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The distribution of heavy metals in Jakarta and Semarang bay during the period of 2016-2019

Yudi Nurul Ihsan[1,*], Phobe Nadine Alfa Zefa Silitonga[2], Kalysta Fellatami[3], Mega Laksmini Syamsuddin[1], Sheila Zallesa[1]

[1]*Marine Department, Faculty of Fisheries and Marine Sciences, UniversitasPadjadjaran.*
[2]*Marine Science Study Program, Faculty of Fisheries and Marine Science, UniversitasPadjadjaran.*
[3]*College of Fisheries, Ocean University of China, Qingdao, China.*

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ABSTRACT

Coastal areas have an important role and have high natural resources that can be utilized for human life. Over time, the increase in population is directly proportional to the activities and utilization of coastal areas, which puts great pressure on coastal areas. One of the pressures that occur in coastal areas is heavy pollution. This research aims to see the distribution of heavy metals especially Cd, Cu and Pb in the coastal areas of Jakarta Bay and Semarang Bay and to see the differences in heavy metal content from the two gulfs. The data used in this study is secondary data, which consists of data on heavy metals, current velocity, pH and water temperature. The period of data used in this research are from 2016 to 2019, The method used in this study is the GIS method with descriptive analysis. The comparison of concentrations from two bays shows a higher mean of concentration value of heavy metals cadmium (Cd) in Semarang Bay (2016, 2017, 2019) and heavy metals of copper (Cu) in Jakarta Bay (2016 and 2018). Meanwhile, the concentration value of heavy metal lead (Pb) was higher in Jakarta Bay (2016, 2017, 2018), yet in 2019, the two locations have the same concentration value of heavy metal lead (Pb)

Introduction

The coastal area has a pivotal role and high natural resources that can be utilized for human life (Dewi *et al.*, 2021). Over time, the population increases directly proportional with the activities and utilization of coastal areas that pressure it greatly. Pollution is one of the pressures that commonly occur in the coastal areas and the sources of pollution can come from both land and sea activities (Neumann *et al.*, 2015; Effendi *et al.*, 2018; Febrita *et al.*, 2020; Ihsan *et al.*, 2020). Several factors cause high pollution in coastal areas particularly dominated by antrophogenic sources, such as industrial, domestic effluents, agricultural runoff, water ballast etc. (Johansson *et al.*, 1995; Ansari *et al.*, 2004; Gregg *et al.*, 2009; Echegoyen *et al.*, 2014; Sharifuzzaman *et al.*, 2016; Meirikayanti *et al.*, 2018; Khakpoor *et al.*, 2020). In addition, the ocean is a place for litter disposal and waste generated from human activities; therefore, in the ocean, there is various type of litter and pollutants, especially heavy metals. Heavy metal in water will settle and cause sedimentation and contaminate humans (Elfidasari *et al.*, 2019). Heavy metals such as lead (Pb), cadmium (Cd), arsenic (Ag), mercury (Hg), general exist at low concentrations, which can bring huge pollution and damage to environment when their accumulations exceed certain levels (Zhang *et al.*, 2018).

Jakarta Bay is one of the coastal environments with a high level of pollution due to recreational areas (Ancol), the high of population reclamation, industries as well as large ports such as Tanjung Priok Port and Timber Port (Arifin, 2004; Riani *et al.*, 2018). In addition, Jakarta Bay has become the biggest waste disposal site for people in Jakarta and becomes the

* Corresponding author.
Email address: yudi.ihsan@unpad.ac.id

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final disposal site for 14 rivers in Jakarta with high population live on the riverbanks (Koropitan & Cordova, 2017; Surya *et al.*, 2019; Nizardo *et al.*, 2021). According to Elfidasari *et al.*, (2020) and Rumanta (2014), the concentration of heavy metal in water, sediment in river around Jakarta Bay is quite high. Because of that the water quality can decreasing (Septiono *et al.*, 2016). In the western of Jakarta Bay, the levels of heavy metals in sediments ranged from 8.9-31.22 ppm for Pb, <0.001-0.47 ppm for Cd and 13.81-193.75 ppm for Cu metal, in the central of Jakarta Bay contained 2.21-69.22 ppm for Pb, <0.001-0.28 ppm for Cd and 3.36-50.65 ppm for Cu and in Eastern of Jakarta Bay contained 0.25-77.42 ppm for Pb, <0.001-0.42 ppm for Cd and 0.79-44.94 ppm for Cu (Kusuma *et al.*, 2015).

Apart from Jakarta Bay, Semarang Bay is located in the capital city of Central Java Province and is the largest bay on the North Coast of Central Java. In addition, Semarang Bay has a large port, namely Tanjung Emas Port and has also become a final disposal site for 29 rivers in Semarang (Hakim *et al.* 2015). The existence of Tanjung Emas Port and final disposal site increases human activities, so the pollution that occurs will be higher (Puspitasari & Purbonegoro, 2016). Semarang is a strategic economic area such as the Tugu industrial area, Terboyo industrial are, Ahmad Yani airport (Directorate General of Marine Coastal and Small Islands, 2013). According to Suprapto *et al.*, (2021), heavy metals concentration in Semarang Bay respectively ranging from 1.1 to 51.9 mg/L. Other study also explained that one of the banks of the Semarang Bay River has experienced moderate pollution (Harahap *et al.*, 2020). Being the capital, both cities certainly have high human activities that can affect the quality of waters, in addition there's no domestic waste water treatment in Semarang, so the solid and liquid waste directly into the sea and it can affect the contained heavy metal. Furthermore, this study aims to: (1) determine the distribution of heavy metals in Jakarta Bay and Semarang Bay; and (2) determine the comparison of heavy metal concentrations in Jakarta Bay and Semarang Bay. In this paper, researcher wants to show the concentration of heavy metals in Jakarta and Semarang Bay and their correlation with pH, temperature and current velocity.

Materials and Methods

Location and time of research

The research study areas are located on Jakarta Bay and Semarang Bay with sampling stations along the coast (Figure 1). The data used in this study is secondary data obtained from the Ministry of Environment and Forestry. The data was collected by direct sampling with 20 sampling points for Jakarta Bay and 14 for Semarang Bay. Sampling in Jakarta Bay was carried out on July 25th 2016, May 8th 2017, July 13th 2018 and July 14th 2019. Meanwhile, sampling in Semarang Bay was carried out on May 17th 2016, May 16th 2017, May 8th 2018 and May 8th 2019. The primary data are the concentration of heavy metals Cadmium (Cd), Copper (Cu) and Lead (Pb) in units of mg/L. Sea surface temperature and pH support data from Ministry of Environment and Forestry, also current data is obtained from EU's Copernicus. The number of sampling points for surface temperature and pH is the same as the number of sampling points for heavy metal.

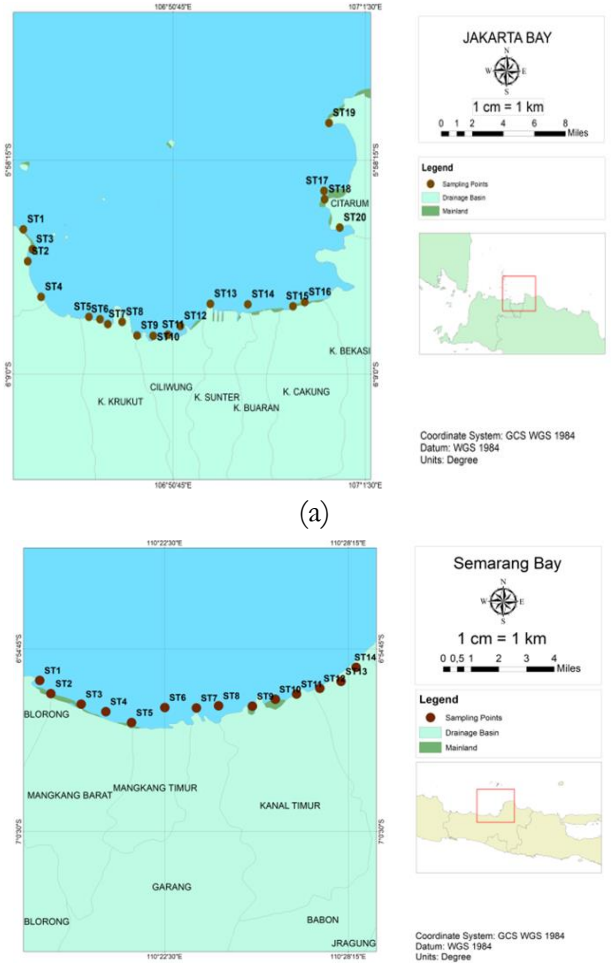


Figure 1. Maps showing the sampling station in (a) Jakarta Bay and (b) Semarang Bay.

The method used in this study is a descriptive method using spatial analysis of the Geographic Information System (GIS). The descriptive method is a method that is suitable for research that using correlations and is suitable for use in comparative research. In addition, descriptive methods are also

used more in research that focuses on facts that have occurred and not hypothetical scenarios (Lambert & Lambert, 2012; De Jong and Van Der Voordt, 2002). This method is carried out by processing secondary data. Then, the data is processed using ArcGIS software to derive an output map of heavy metal content in Jakarta Bay and Semarang Bay.

Results

The distribution of heavy metals (Cd, Cu, Pb) in Jakarta Bay

Cadmium (Cd)

The Cadmium (Cd) concentration in 2016 – 2019 was in the range of 0.0005 mg/L – 0.02 mg/L with the lowest concentration at station 20 in 2016; meanwhile, the highest concentration is in station 12 in 2017 (Figure 2).

Based on research, in 2016, the highest cadmium concentration was at station 9 (Figure 2). Along the coast of Jakarta Bay in 2016, the concentration of heavy metal Cd ranged from ≤0.001 mg/L to 0.006 mg/L. The average value of cadmium concentration in 2016 was 0.0011 mg/L (Figure 3).

In 2017, the concentration of Cd ranged from 0.0011 mg/L - 0.02 mg/L and station 12 became the station with the highest concentration in 2017. The average value of cadmium (Cd) concentration in 2017 was 0.002 mg/L and this value has increased from 2016 (Figure 3). The concentration of Cd from all stations in 2017 exceeded the quality standard threshold for biota according to the Decree of the state minister for Environment No. 51 of 2004 concerning in Seawater Quality Standards

In 2018 the concentration of Cd ranged from ≤ 0.051 mg/L - 0.0092 mg/L and station 7 became the station with the highest concentration of Cd in 2018. The average value of Cd concentration in 2018 was 0.0068 mg/L and this value has increased from 2017 (Figure 3). Meanwhile, in 2019 the concentration of Cd ranged from ≤ 0.0071 mg/L - 0.0078 mg/L and station 9 became the station with the highest Cd concentration in 2019. The average value of Cd concentration in 2019 was 0.0069 mg/L and this value has increased from 2018 (Figure 3). The concentration values of all stations in and 2018 and 2019 have exceeded the water quality standard threshold for biota based on Kepmen LH No 51 of 2004.

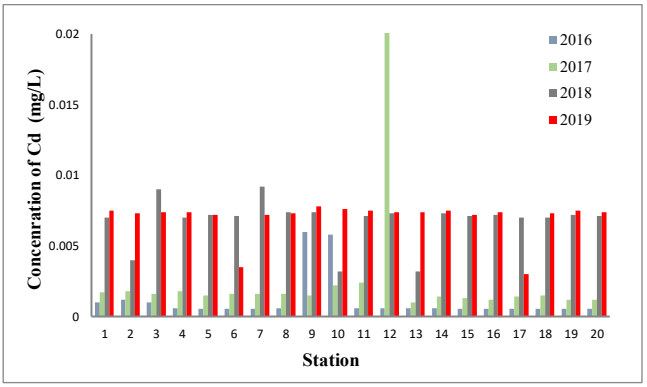
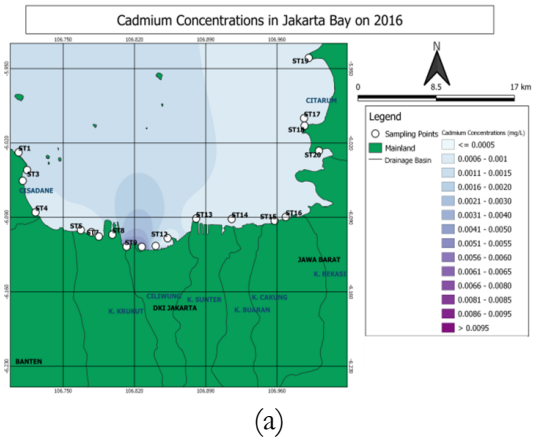


Figure 2. The graph of means value heavy metal Cd in Jakarta Bay from 2016 – 2019.



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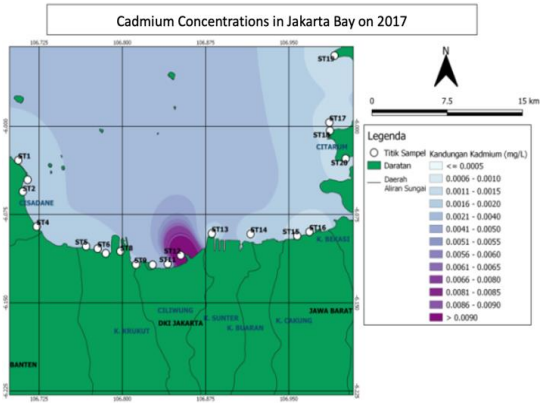

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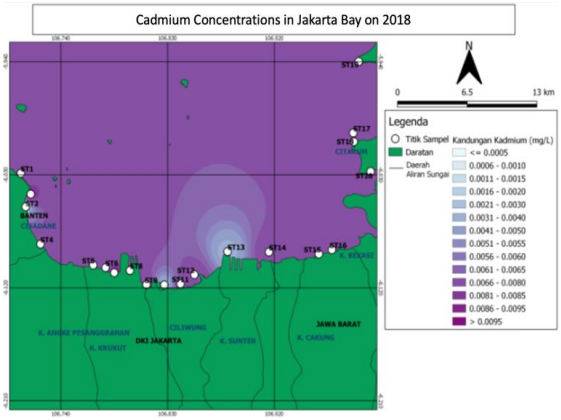

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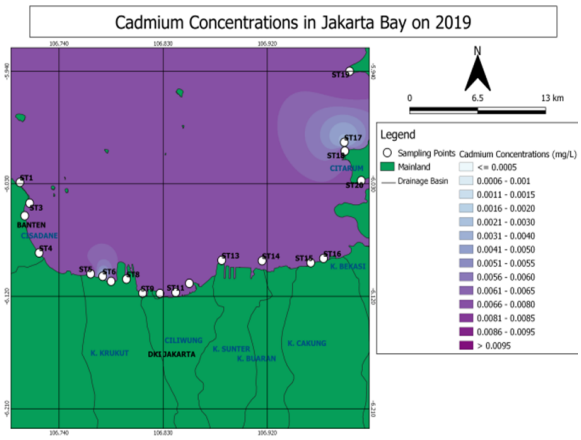

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Figure 3. Cd Distribution in Jakarta Bay (a) 2016, (b) 2017, (c) 2018 (d) 2019.

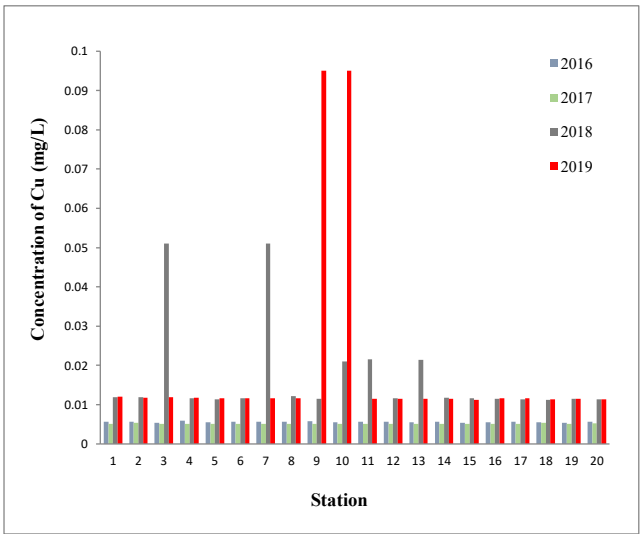


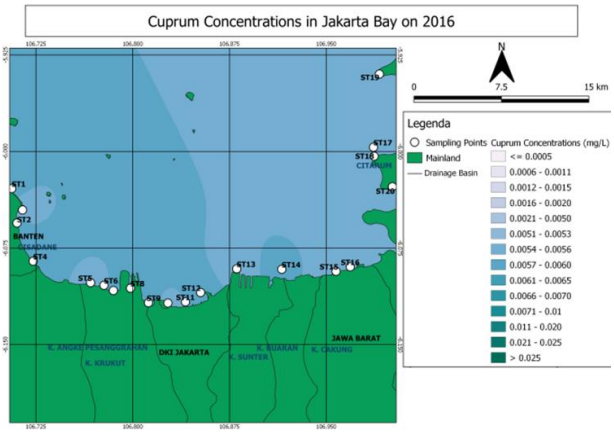
Figure 4. The graph of means value heavy metal Cu in Jakarta Bay from 2016 – 2019.

Copper (Cu)

Copper (Cu) concentrations in 2016 – 2019 were in the range of 0.005 mg/L - 0.095 mg/L, with the lowest concentration being at station 19 in 2017 and the highest concentration being at stations 9 and 10 in 2019 (Figure 4).

Based on research, along the coast of Jakarta Bay in 2016, the Cu concentrations ranged from 0.0054 mg/L - 0.0059 mg/L with the highest Cu concentration at station 4. Cu concentrations in 2017 ranged from ≤0.0051 mg /L - 0.0054 mg /L, with Station 2 as the station with the highest concentration (Figure 5). The average value of Cu concentration was the same in 2016 and 2017 (0.005 mg/L). All stations in 2016 and 2017 had Cu concentrations that were still below the water quality standard for marine biota. According to the Decree of the state minister for Environment No. 51 of 2004, the water quality standard for Cu for marine biota is 0.008 mg/L.

In 2018, Cu concentrations ranged from ≤ 0.02 mg/L - 0.0051 mg/L with Station 3 as the station with the highest concentration (Figure 5). All stations in 2018 experienced an increase in engagement compared to 2016 and 2017. The average Cu concentration in 2018 was 0.017 mg/L. This value has increased from 2017. Whereas Cu concentrations in 2019 ranged from ≤0.01 mg / L - 0.095 mg/L, with stations 9 and 10 being the stations with the highest Cu concentration (Figure 5). The average value of copper concentration in 2019 was 0.019 mg/L, this value has increased from 2018. All stations in both 2018 and 2019 had Cu concentrations that were already exceeded the water quality standard threshold for biota.



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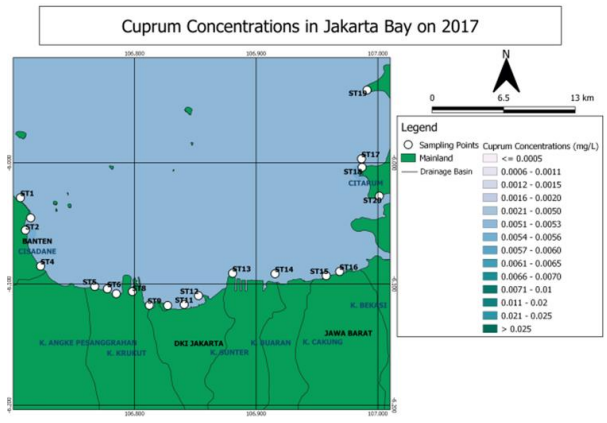

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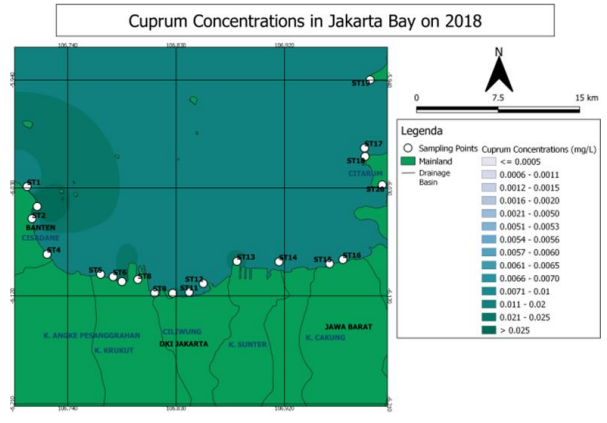

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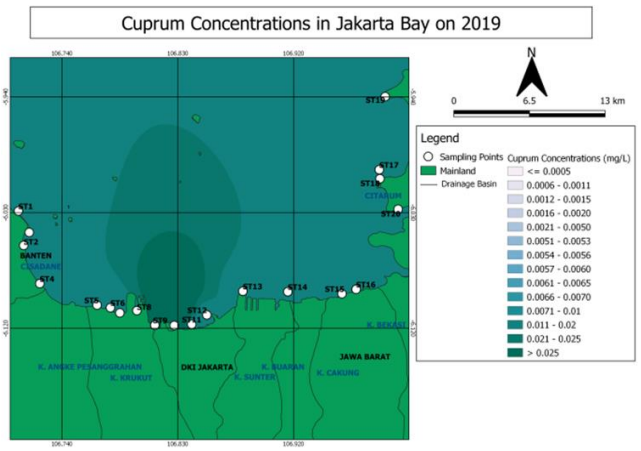


(d)

Figure 5. Cu Distribution in Jakarta Bay a) 2016, (b) 2017, (c) 2018 (d) 2019.

Lead (Pb)

Pb concentrations in 2016 – 2019 were in the range of 0.052 mg/L - 0.6 mg/L, with the lowest concentrations being at station 1 in 2016 and the highest concentrations at stations 15 and 16 in 2019 (Figure 6).

The concentration of Pb along the coast of Jakarta Bay in 2016 is ranged from ≤0.052 mg/L - 0.059 mg/L (Figure 7). In 2016, the highest Pb concentrations were at stations 8 and 9. Despite being the highest Pb concentration station, the concentration value is still below the water quality standard for biota (0.008 mg/L) based on Kepmen LH No 51 of 2004. The average value of Pb concentration in 2016 is 0.055 mg/L.

Based on data, all stations have an increasing concentration. The stations with the highest Pb concentration in 2017 were Stations 9 and 10. All stations in 2017 have concentration values that exceed the water quality standard threshold for biota based on Kepmen LH No 51 of 2004. The average value of lead concentration in 2017 is 0.15 mg/L, this average value has increased from 2016.

In 2018 the Pb concentration ranged from ≤ 0.51 mg / L - 0.059 mg / L (Figure 7) with station 12 being the highest concentration because the station was near the Ciliwung River. All existing stations have concentration values that have exceeded the water quality standard threshold for biota based on Kepmen LH No 51 of 2004. This average value has increased from 2017. In 2019, Pb concentrations ranged from 0.52 mg / L - 0.059 mg / L (Figure 7) with station 19 as the station with the highest concentration. The average value of Pb concentration in 2019 is 0.5 mg/L. This average value tends to be stable and does not experience a decrease or increase from 2018.

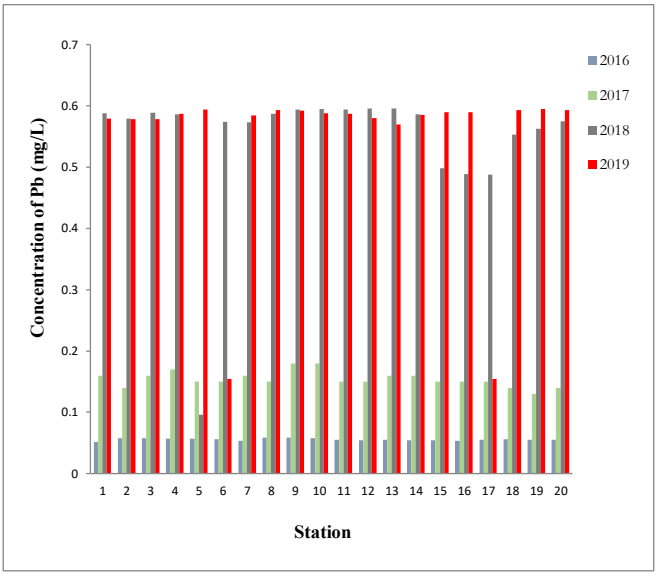
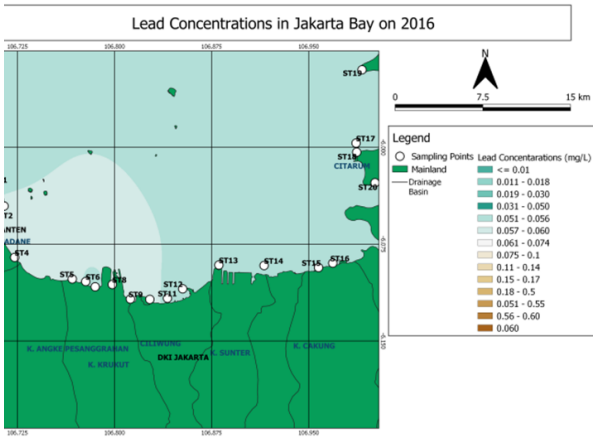


Figure 6. The graph of means value heavy metal Pb in Jakarta Bay from 2016 – 2019.



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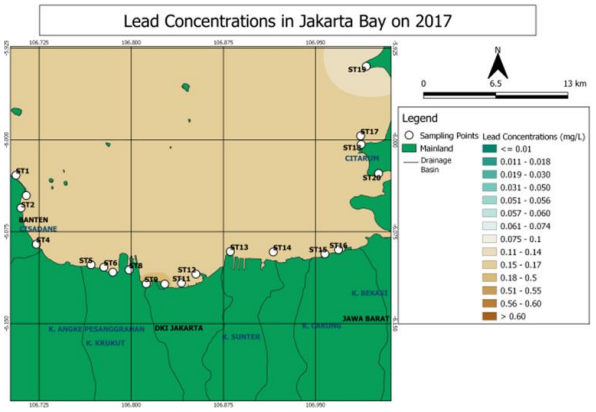

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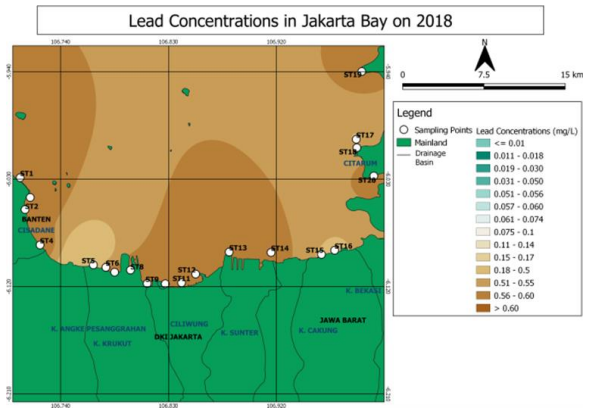

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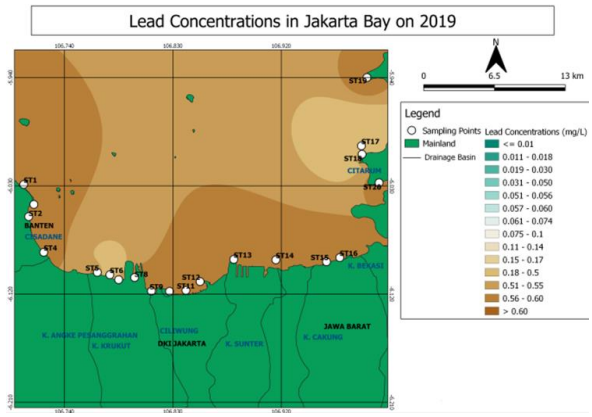


(d)

Figure 7. Pb Distribution in Jakarta Bay a) 2016, (b) 2017, (c) 2018 (d) 2019.

The distribution of heavy metals (Cd, Cu, Pb) in Semarang Bay

Cadmium (Cd)

The concentration of Cd in 2016 – 2019 was in the range of 0.0019 mg/L - 0.0094 mg/L with the lowest concentration being at station 13 in 2016 and the highest concentration being at Station 1 in 2019 (Figure 8).

In 2016, the concentration of Cd in Semarang Bay ranged from 0.00193 mg/L –0.002 mg/L (Figure 9) and station 5 was the station with the highest concentration. The average value of Cd concentration in Semarang Bay in 2016 was 0.00195 mg/L. Whereas in 2017, the concentration of Cd ranged from 0.0052 mg/L - 0.0058 mg/L (Figure 9) and station 5 became the station with the highest concentration of Cd. The average value of Cd concentration in Semarang Bay in 2017 increased from 2016 to 0.0054 mg/L. Based on the data, all stations in 2016 and 2017 had a Cd concentration value that was above the water quality standard for biota. According to the Decree of the state minister for Environment No. 51 of 2004, the water quality standard for heavy metal cadmium for marine biota is 0.001 mg/L.

In 2018 the concentration of Cd ranged from ≤0.0061 mg / L - 0.0068 mg/L (Figure 9) and stations 10 and 11 were the stations with the highest concentrations. The average value of Cd concentration in Semarang Bay in 2018 was 0.0064 mg/L. This value has increased from 2017. In 2019 the concentration of Cd ranged from ≤0.0081 mg/L - 0.0094 mg/L (Figure 9) and station 1 was the station with the highest concentration of Cd. This was due to the station's location, which was close to the pier. The average value of Cd concentration in Semarang Bay in 2019 was 0.0085 mg/L, this value has increased from 2018. All stations in Semarang Bay both in 2018 and 2019 have exceeded the water standard threshold for biota (0.001 mg/L) based on Kepmen LH No 51 of 2004.

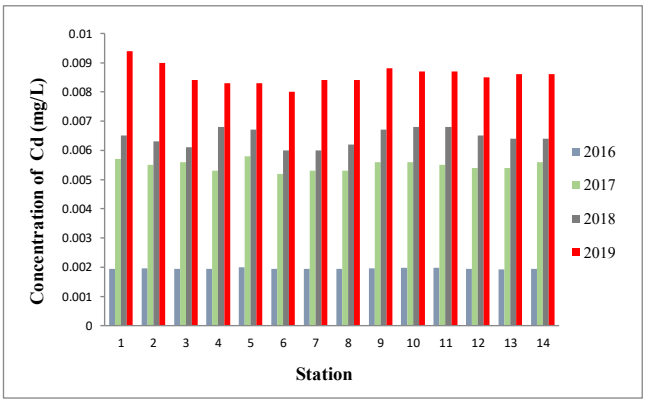
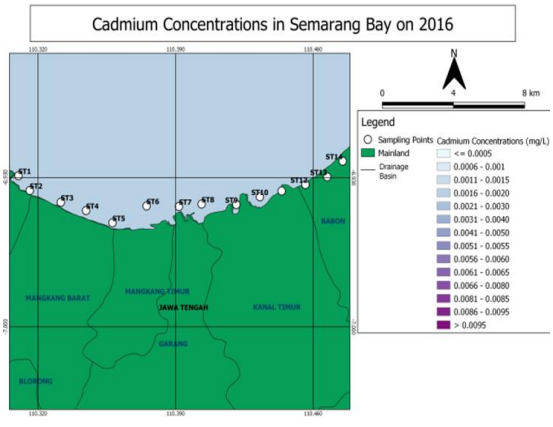


Figure 8. The graph of means value heavy metal Cd in Semarang Bay from 2016 – 2019.



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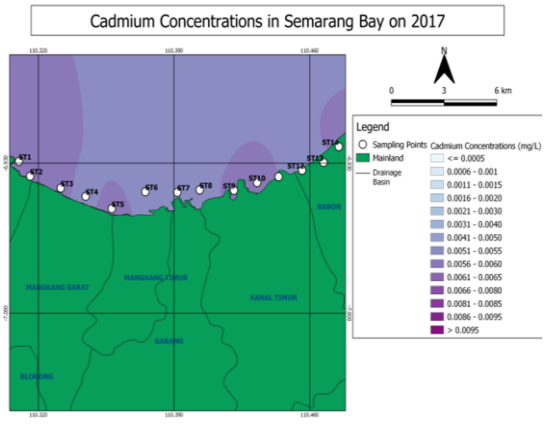

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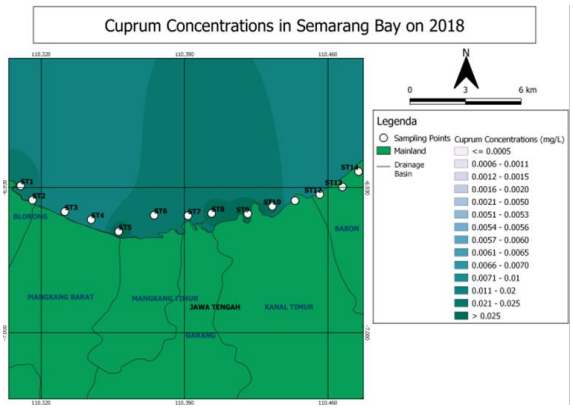

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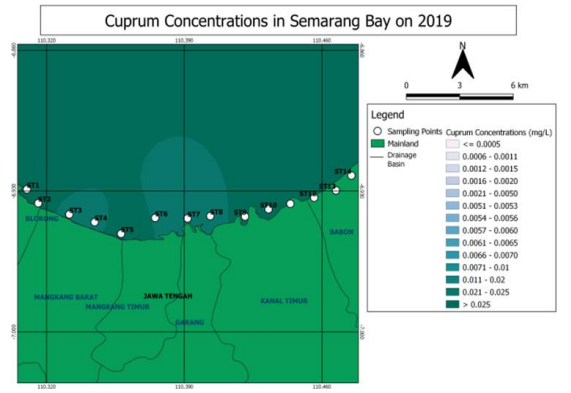


(d)

Figure 9. Cd Distribution in Semarang Bay a) 2016, (b) 2017, (c) 2018 (d) 2019.

Copper (Cu)

The Cu concentration in 2016 – 2019 was in the range of 0.001 mg/L - 0.028 mg/L, with the lowest concentration being at station 13 in 2016 and the highest concentration being at station 5 in 2018 (Figure 10).

In 2016, Cu concentrations ranged from 0.001 mg /L - 0.0018 mg /L (Figure 11) with the highest concentrations is in stations 5 and 9. The average value of Cu concentration in Semarang Bay in 2016 was 0.0014 mg/L. Meanwhile, in 2017, Cu concentrations ranged from 0.0051 mg/L to 0.007 mg/L (Figure 11), with Station 9 as the highest Cu concentration. All stations in Semarang Bay (2016 – 2017) had Cu concentrations which were still below the water quality standard. According to the Decree of the state minister for Environment No. 51 of 2004, the water quality standard for Cu heavy metal for marine biota is 0.008 mg/L.

In 2018, Cu concentrations ranged from 0.01 mg/L - 0.028 mg/L (Figure 11) and station 5 was the station with the highest concentration. All stations in Semarang Bay in 2018 have concentration values that are above the water quality standard threshold for biota. The average Cu concentration in Jakarta Bay in 2018 was 0.0028 mg/L. This value has increased from 2017. Whereas in 2019, Cu concentrations ranged from 0.0025 mg /L - 0.0259 mg/L (Figure 11) and station 3 became the station with the highest Cu concentration in 2019. The average value of Cu concentration in Semarang Bay in 2019 was 0.026 mg/L and this value has increased from 2018.

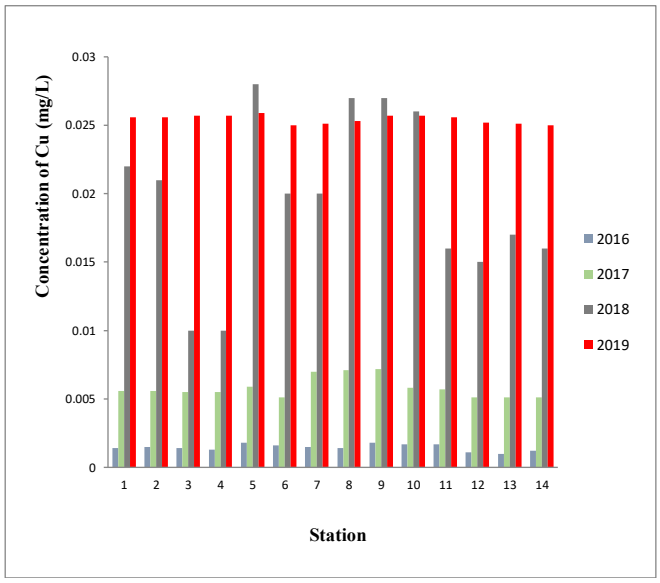
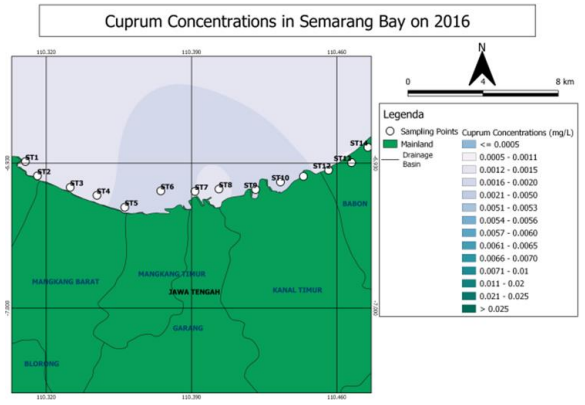


Figure 10. The graph of means value heavy metal Cu in Semarang Bay from 2016 – 2019.



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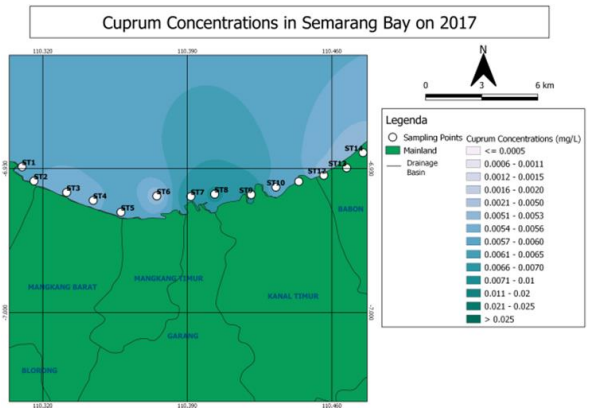

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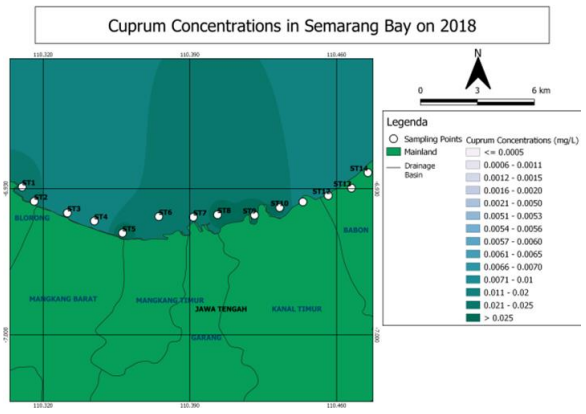

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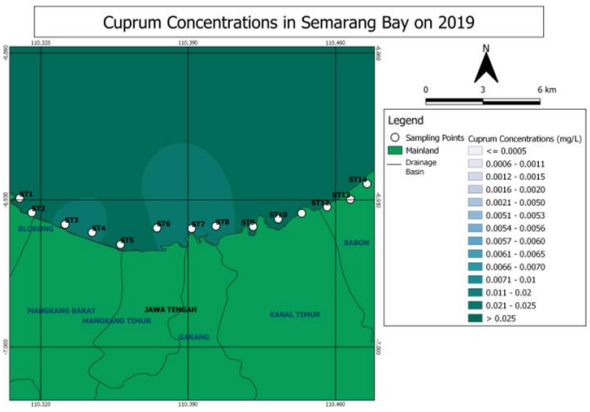


(d)

Figure 11. Cu Distribution in Semarang Bay a) 2016, (b) 2017, (c) 2018 (d) 2019.

Lead (Pb)

Lead (Pb) concentrations in 2016 – 2019 were 0.018 mg/L - 0.76 mg/L (Figure 12) with the lowest concentrations being at stations 12 and 14 in 2016 and the highest concentrations being at Stations 9 in 2019.

In 2016, Pb concentrations ranged from 0.018 mg/L - 0.0189 mg/L (Figure 13) with station 5 as a station with the highest concentration. There are only two stations that have concentrations below the water quality standard for biota, namely station 7 and station 13. The average value of Pb concentration in Semarang Bay in 2016 was 0.016 mg/L. Besides that, in 2017, Pb concentrations ranged from 0.03 mg/L - 0.18 mg/L (Figure 13) and station 12 was the station with the highest concentration. All stations in 2017 had concentrations that exceeded the water quality standard threshold for biota based on Kepmen LH No 51 of 2004 . The average Pb concentration in Semarang Bay in 2016 was 0.09 mg/L. This value has increased from the average value in 2016.

In 2018, Pb concentrations ranged from ≤0.02 mg/L to 0.33 mg/L (Figure 13), and station 5 had the highest concentration. The average Pb concentration in Semarang Bay in 2018 was 0.15 mg/L. This value has increased from 2017. In 2019, Pb concentrations ranged from 0.29 mg/L - 0.076 mg/L (Figure 13) and Station 9 was the station with the highest concentration. The average Pb concentration in Semarang Bay in 2019 was 0.5 mg/L. This value has increased from 2018. All stations in 2018 and 2019 have concentrations that have exceeded the water quality standard threshold for biota (0.008 mg/L) based on Kepmen LH No 51 of 2004.

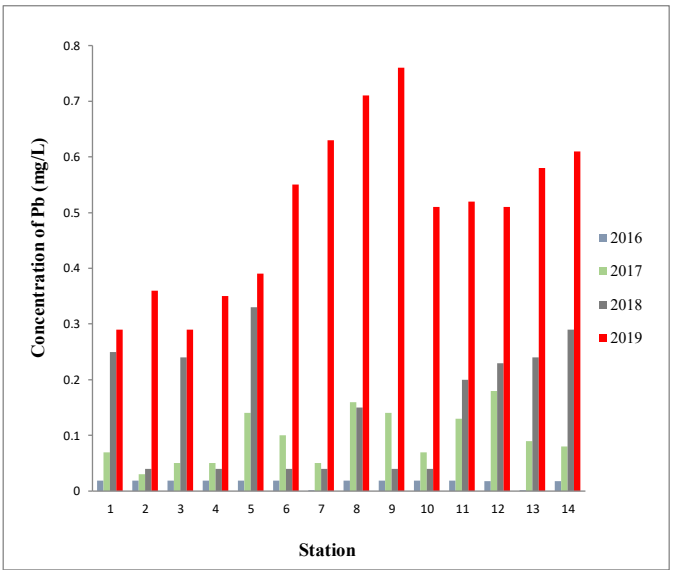
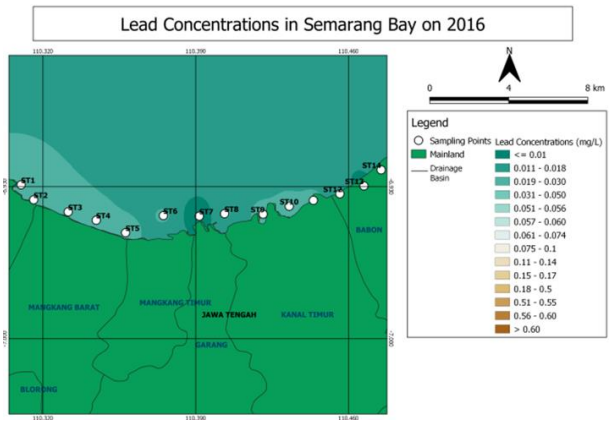
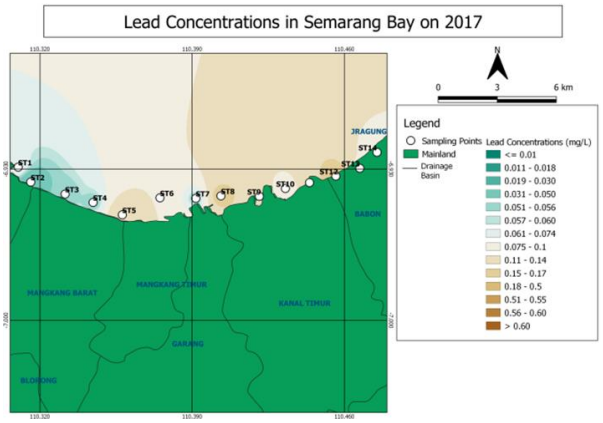


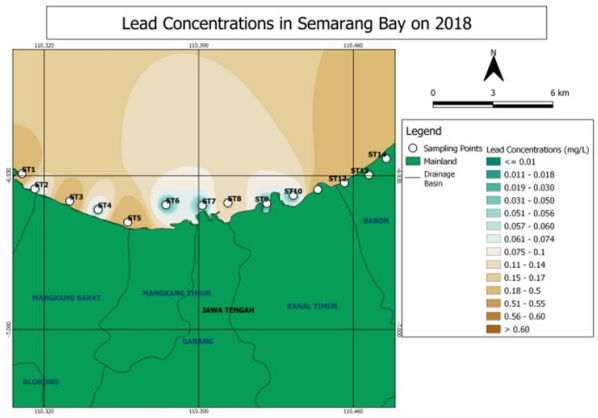
Figure 12. The graph of means value heavy metal Pb in Semarang Bay from 2016 – 2019.



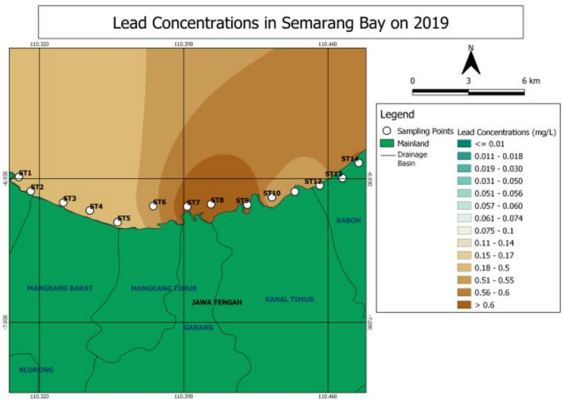
(a)



(b)



(c)

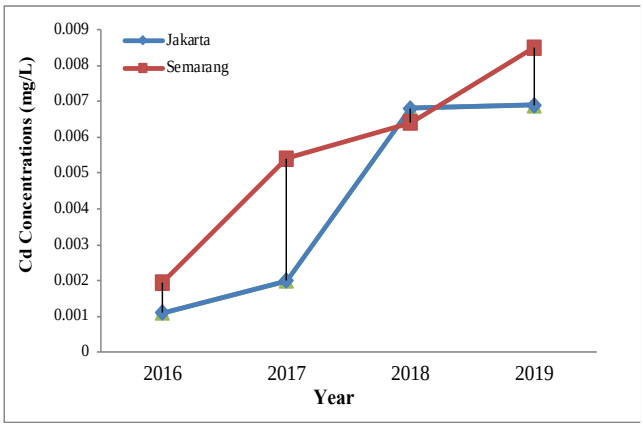


(d)

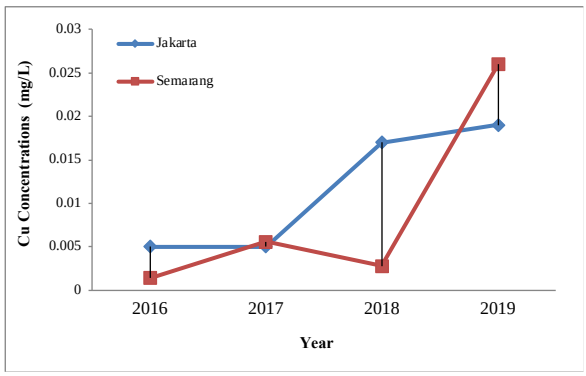
Figure 13. Pb Distribution in Semarang Bay a) 2016, (b) 2017, (c) 2018 (d) 2019.

The comparison of heavy metal concentrations in Jakarta Bay dan Semarang Bay in 2016 – 2019.

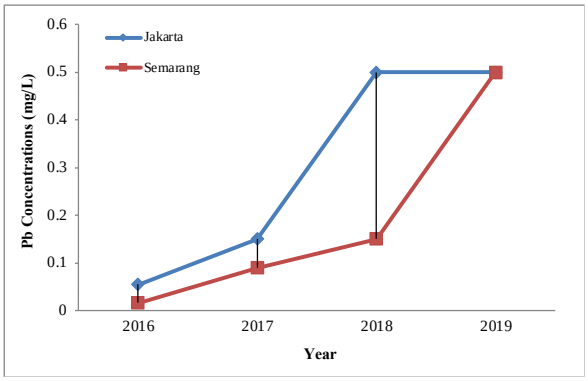
In Figure 14, it can be seen that the average concentration of Cd in Semarang Bay was higher than Jakarta Bay in 2016, 2017, and 2019. The average Cu concentration in Jakarta Bay is higher than in Semarang Bay. This also occurs in the average Pb concentration, in which Jakarta Bay has a higher concentration of Pb than Semarang Bay.



(a)



(b)



(c)

Figure 14. (a) The Comparison of Cd Concentration between Jakarta Bay and Semarang Bay; (b) The Comparison of Cu Concentration between Jakarta Bay and Semarang Bay; and (c) The Comparison of Pb Concentration between Jakarta Bay and Semarang Bay.

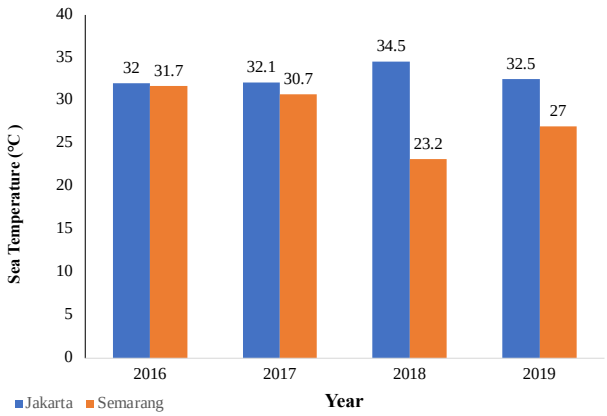


Figure 15. The Average of Temperature in Jakarta and Semarang Bay from 2016-2019.

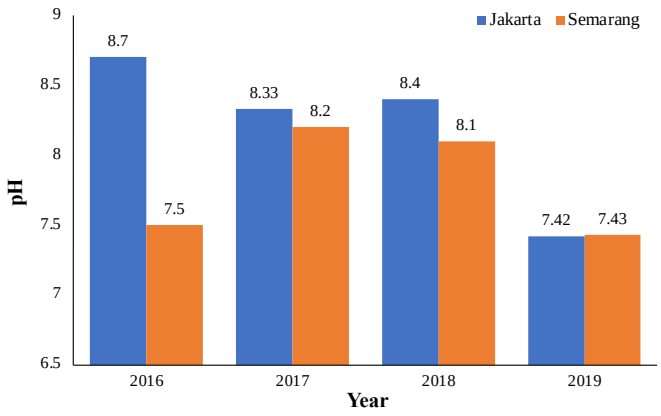


Figure 16. The Average of pH in Jakarta and Semarang Bay from 2016-2019.

Influence of aquatic physical and chemical parameters

Sea temperature

In sampling, the sea surface temperature at each station and year varied between 27°C -34°C in Jakarta Bay and between 23°C -32°C in Semarang Bay (Figure 15).

Based on the research, the results showed that the sea temperature and concentration of heavy metals (Cd, Cu and Pb) had a significant correlation (0.99) (Table 1). A negative correlation was shown between the heavy metal Cd and sea temperature. The negative result showed that the increase in sea temperature was inversely proportional to the increase in the Cd concentration. Meanwhile, Cu and Pb showed positive results.

Table 1. Pearson correlation between temperature and heavy metals concentration in Jakarta and Semarang Bay.

	Temp	Cd	Cu	Pb
Temp	1			
Cd	-0.9971*	1		
Cu	0.9971*	1	1	
Pb	0.9942*			1

**Correlation is significant at the 0,005 level (1-tailed)*

Power of hydrogen(pH)

The pH values in Jakarta Bay and Semarang Bay in 2016-2019 ranged from 6.5 – 8.7 (Figure 16). Heavy metal and pH concentrations in both Jakarta Bay and Semarang Bay showed significant adverse results. Therefore, a negative value indicates the relationship between heavy metal concentration and pH is inversely proportional (Table 2).

Table 2. Pearson correlation between ph and heavy metals concentration in Jakarta and Semarang Bay.

	pH	Cd	Cu	Pb
pH	1			
Cd	-0.9999*	1		
Cu	-0.9999*	-0.9999*	1	
Pb	-0.9999*	0.99952*	0.99968*	1

**Correlation is significant at the 0,005 level (1-tailed)*

Current

Based on research, the surface current velocity in Jakarta Bay is 0.03 m/s – 0.05 m/s, in Semarang Bay the current velocity is 0.03 m/s -0.08 m/s (Figure 17).

In both bays, the correlation results show that current velocity and heavy metals (Cd, Cu and Pb) have a significant positive correlation. The correlation result can be seen in Table 3.

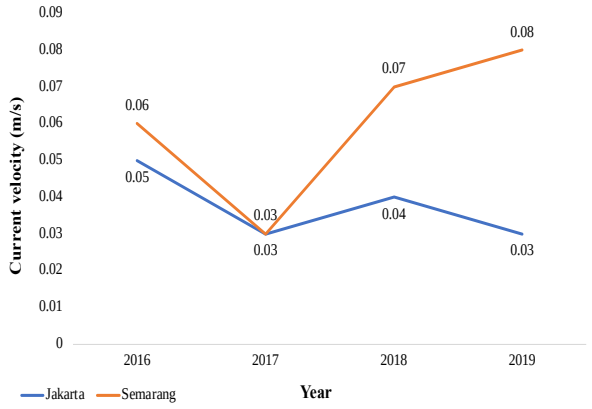


Figure 17. The Average of Current Velocity in Jakarta and Semarang Bay from 2016-2019.

Table 3. Pearson Correlation Between pH and Heavy Metals Concentration in Jakarta and Semarang Bay

	Current Velocity	Cd	Cu	Pb
Current Velocity	1			
Cd	0.9997*	1		
Cu	0.9996*	1	1	
Pb	0.9987*	0.99952*	0.99953*	1

**Correlation is significant at the 0,025 level (1-tailed)*

Discussion

Human activities are the largest contributor of hazardous heavy metals in waters during the industrialization period(Nriagu, 1996). These heavy metals can be distributed into the athmosphere and enter the aquatic environment and eventually go to the sea (Badr *et al.*, 2009). Recreational industries and ports are the sources of coastal environment pollution in Jakarta Bay (Riani *et al.*, 2018). This is in

accordance with this study. In Station 9, the Cd concentration is highest than the other station. This could be due to Station 9, which is close to the Samudera Nizam Zachman fishing port. The high Cadmium concentration in waters can come from fishing boat activities and fishing boat diesel spills (Khakpoor *et al.*, 2020). In 2017, station 12 became the station with the highest concentration. The highest Cd concentration at station 12 was due to the location of station 12 which is at the end of the Ciliwung river basin, which is one of the most polluted rivers in Indonesia (Elfidasari, Ismi and Sugoro, 2019) because it has so many trash such as macro plastics and has many industrial along the rivers (Ciptadi, 2019; Nizardo *et al.*, 2021).

It is related to concentration Cu in Jakarta Bay, in which stations 4, 2 and 3 have high concentration of Cu. The high concentration of Cu at stations 4, 2 and 3 is due to the location of the station which is at the mouth of the Cisadane River because on the banks of the Cisadane river there is a shipbuilding industry that is used Cu as a mixture of preservatives in shipyard construction and the high activity humans around the Cisadane river such as high agricultural activities (Effendi *et al.*, 2018).

Meanwhile, the highest concentration of Pb in Jakarta Bay in 2016 is high in Station 8 and 9. This is due to the station being close to the port. According to Febrita *et al.* (2020), port activities can potentially pollute waters with Pb from oil dumps, shipyard irons, ballast water and engine fuel oil emissions. The highest concentration is also caused by the station near the Ciliwung River. Pb is one of the heavy metals produced from industrial activity (Echegoyen *et al.*, 2014) and along the banks of the Ciliwung river there are many factories (Elfidasari *et al.*, 2019). Moreover, Septiono *et al.* (2016) mentioned that many industries dispose of waste directly into the Citarum River, thus causing a high concentration of Pb in the Citarum River.

In Semarang Bay, the highest concentration of Cd is due to the station adjacent to Tanjung Mas Port. Port activities and sea transportation can be a source of heavy metal pollution because these activities produce waste fuel oil (sludge oil) and ship ballast water (Sharifuzzaman *et al.*, 2016). Cd is used to prevent marine corrosion of iron and steel used on ships so that the risk of Cd contamination from ballast water discharge is quite high (Gregg *et al.*, 2009). In 2018, the highest concentration of Cd is in stations 10 and 11. Both stations are located near East Kanal River, the banks of the East Kanal River were densely populated so that Cd came from the disposal of household waste that lead to Semarang Bay (Harahap *et al.*, 2020). Semarang did not have a domestic wastewater treatment, so the solid or liquid waste from residence enter directly into the sea through the Kanal River (Puspitasari and Purbonegoro, 2016).

A higher concentration of Cu is at station 5 in 2017, The high concentration of Cu at Station 5 can be caused by the location of the adjacent station at Tanjung Mas Port, so that the Cu metal can come from the ship's ballast water. At station 9, which is located at the mouth of the East Kanal River, high Cu concentrations can be caused because along the banks of the East Kanal River there are many residents who are thought to dump household waste into the East Kanal River (Harahap *et al.*, 2020).Then, the location of the station is at the mouth of the Mangkang River which flood-prone point so it is estimated that household waste carried by the water at the time of the flood affects Cu concentrations (Dewi *et al.*, 2021).

The concentration of Pb is high due to the location the Babon River which is located in development area II (industrial area). In 2019, station 9 is the station with the highest concentration due to the location of the station at the mouth of the East Kanal River which is close to residential areas and there are many household wastes carried out by residents around the river such as the workshop, ceramics, aluminium and textile manufacturing (Harahap *et al.*, 2020).

The comparison of heavy metal concentrations in Jakarta Bay dan Semarang Bay in 2016 – 2019.

According to the result, Cd in Semarang Bay was higher than Jakarta Bay, this was due to dense port activity and dense settlements and there's no domestic waste water treatment in Semarang, so the solid and liquid waste directly into the sea through Kanal River (Gregg *et al.*, 2009; Puspitasari & Purbonegoro, 2016; Sharifuzzaman *et al.*, 2016). The concentration of Cu in Jakarta Bay is relatively higher than Semarang Bay because on one of the river basins there is a shipbuilding industry that uses Cu as a mixture of preservatives in its manufacture (Putri et al., 2016). The concentration of Pb in Jakarta Bay tends to be higher than in Semarang Bay (Figure 9), because Jakarta Bay Coast has high activity such as tourism, port activity (Arifin, 2004).

Influence of aquatic physical and chemical parameters

Cd and sea temperature have a negative correlation in this study. A negative correlation between Cd and sea temperature also occurs in the study by Zhang *et al.* (2018). Meanwhile, Cu and Pb showed positive results and accordance with the

statement by Sorensen (1991) *in* Fauziah *et al* (2012), that the increasing water temperature is directly proportional to the increase in accumulation and toxicity of heavy metals in the metabolic system from the air will also increase.

Low pH levels can encourage the solubility of heavy metals. As the level of hydrogen ions increases, metal cations such as Pb, Cuand Cdare released into the water instead of being absorbed into the sediment (Fonderist Environmental. Inc, 2021). As the concentrations of heavy metals increase, their toxicity also increases (Febrita *et al.,* 2020; Johansson *et al.,* 1995; Meirikayanti et al., 2018).

Currents in both bays move to the Northwest, due to the east monsoon winds (Koropitan & Cordova, 2017; Saputra *et al,* 2018). A positive value indicates the higher the current velocity, the higher the concentration of heavy metals in the waters (Febrita *et al*, 2020).

Conclusion

The distribution of heavy metals in Jakarta Bay and Semarang mostly increases every year and most of them have exceeded the water quality standard threshold according to the Decree of the State Minister for the Environment No. 51 of 2004. Sources of heavy metals can come from port activities, domestic and industrial waste carried through rivers. At the concentration of the two bays, the average value of Cd concentration was greater in Semarang Bay and for heavy metals Cu and Pb the average concentration value was greater in Jakarta Bay.

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