Heavy metal (Pb, Hg, Cu) contamination level in sediment and water in Segara Anakan Lagoon, Cilacap, Indonesia

G Prayoga1,*, S Hariyadi2, Sulistiono2 and H Effendi1,2

1 Environmental Research Center, IPB University, Dramaga, Bogor 16680, Indonesia
2 Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, IPB University, Dramaga, Bogor 16680, Indonesia

*Corresponding author: gatotprayoga16@gmail.com

Abstract. Segara Anakan lagoon in Indonesia receives a variety of contaminants from numerous and various human activities. One of these was heavy metals, which were dangerous pollutants and will accumulate in the environment. This study aimed to determine the heavy metals content in sediment and water in the Segara Anakan lagoon. Those data were then scrutinized, whether they were toxic to the aquatic biota. Sampling was conducted at six observation stations every month. The heavy metals content was compared to the quality standard (set out by CCME and ANZECC & ARMCANZ for sediment, and the Decree of the Minister of Environment Number 51 of 2004 for water). The heavy metals in sediments were below the minimum limit (Pb (30.2; 50.0), Hg (0.13; 0.15), Cu (18.7; 65.0), all in mg.kg\(^{-1}\) units), except Cu showing higher value than quality standard at one observation. Other results, Pb and Cu in water, showed exceeding the quality standard (both were 0.008 mg/l). However, it was still within safe limits for most types of aquatic biotas. Overall, the three types of heavy metals in sediment were safe for aquatic biota, while in water, only Hg can be clearly stated that it was safe.

Keywords: contamination; heavy metals; sediment; water

1. Introduction
The Segara Anakan lagoon was located on the southern coast of Java Island, in Cilacap Regency, Central Java, Indonesia. Astronomical position of this area was between 7°35’–7°46’ S, and 108°45’–109° 01’ E. Segara Anakan was located in the north of Nusa Kambangan Island, starting from the Citanduy River estuary in the west to the Donan River estuary or Cilacap City in the east. The Segara Anakan lagoon was divided into three parts, namely the western, central, and eastern [1, 2]. Western water body receives substantial freshwater input from the Citanduy, Cikonde, and Cibeureum Rivers. Eastern water body includes the Donan and Sapuregel Rivers, which provide much less freshwater input than the rivers in the western part. The central part is the water channels that connect the western and eastern water bodies. The western and eastern parts were directly connected to the ocean through the channels called West Plawangan and East Plawangan [2, 3].

Segara Anakan is rich water [4], making this area a place for spawning, feeding, and nursery grounds of aquatic biota living there. Segara Anakan has a high biodiversity level, including a mangrove ecosystem with 26 species of living mangrove, 85 species of birds, monkeys, banded linsang, more than 45 species of fish and 18 species of mud crab, and other various aquatic biotas [1, 4]. The lagoon was necessary for research and education activities because it was an estuary with the largest mangrove area.
along the southern coast of Java Island [5]. The result of Paryono's study shows that the economic value of the mangrove ecosystem in the Segara Anakan lagoon was worth a total of IDR 140,880,427,700/year or IDR 8,188,980/Ha/year [6]. The Segara Anakan lagoon has several problems that potentially threaten the sustainability of its ecosystem. One example was water pollution originating from agricultural, domestic, and industrial activities around the watershed where the river disembogues into the lagoon. Agricultural activities produce residual use of pesticides that cannot be degraded by living organisms (non-biodegradable). Domestic waste comes from settlements around the lagoon and watershed, either directly or indirectly. Industrial waste mainly comes from the Donan River watershed, which has many industrial activities. Based on several result studies, this area was widely used for various human activities [7-9]. There are port activities at Sleko Ports for the crossings and Tanjung Intan Ports for industrial shipping, petroleum processing conducted by PT Pertamina RU IV, cement industry (PT Holcim), fertilizer industry (PT Pupuk Sriwijaya), and other various industrial activities in the Cilacap Industrial Area (KIC).

Waste inputs from these various activities lead to pollution in the waters, including heavy metal contamination. Heavy metal pollution can cause problems ecologically, economically, and socially. Heavy metal contamination in waters causes health problems both for aquatic biota and humans, leading to the problem in the nervous system, respiratory system, liver function, kidney, and expected growth of bones [10]. Heavy metals were classified as hazardous pollutants because they are toxic, non-biodegradable, and accumulate in the environment [11].

Heavy metals can bond with organic materials to form complex compounds that eventually settle to the bottom of the water (accumulate in sediments) [12]. On the other hand, sediments were an inseparable part of aquatic ecosystems that can provide habitat, feeding grounds, spawning grounds, and nurseries for various aquatic organisms. Contaminated sediments can reduce or eliminate the organisms with essential values for ecology, commercial, or recreational uses [13].

Heavy metals deposited in sediments can cause water quality changes and transfer of toxic chemicals to aquatic organisms [14]. Sediment functions as a metal container could release the metal into the water through natural and anthropogenic processes [15]. Currents, winds, and waves are several natural processes that can release the heavy metals in sediment and then accumulate in plankton, macrobenthos, marine mammals, fish, birds, and other terrestrial animals, even humans [16]. Heavy metals accumulation, coupled with biomagnification, was hazardous and lethal for aquatic biota and humans.

Concerning the above, determining the heavy metals content in the Segara Anakan lagoon becomes important. Several previous studies related to heavy metal pollution in the Segara Anakan had been reported by Sudaryanto [17], Tumisem and Puspawiningtyas [18], Hidayati et al. [7], and Kasari [9], but all of these studies were carried out in the eastern part of Segara Anakan lagoon. Therefore, this study wants to reveal the condition of heavy metals in sediment and water for the western and central parts of the Segara Anakan lagoon that have never been reported. This study was expected to complement the information on heavy metal contamination in the entire Segara Anakan lagoon area and form a good basis for future waters management.

2. Methodology

2.1. Location and time

This study was conducted in the western and central parts of Segara Anakan lagoon, Indonesia, from May to October 2017. A sampling of sediment and water were conducted at 6 (six) station, i.e., Station 1 (the central lagoon, main water body of the western part), Station 2 (water channels near Klaces Village), Station 3 (water channels near Ujung Alang Village), Station 4 (water channels in Kalibayi area), Station 5 (water channels in Kali Potong or Tambakreja area), and Station 6 (Kembang Kuning River estuary or western of Sapuregel River estuary). Station 1 and 2 represent the western part of Segara Anakan lagoon, while the Station 3-6 represents the central part. The study location map equipped with sampling station, and some related information is presented in figure 1.
2.2. Research data and method

The primary data were the heavy metal (Pb, Hg, and Cu) contents in sediment and water, taken at six sampling stations in the study location. The sediment sample was grabbed using an Ekman grab at the bottom of the water from each station. Water samples were taken from the water's surface at the same station as the sediment sampling, then preserved according to the APHA standards method [19]. The Atomic Absorption Spectrometry (AAS) method was used to measure the heavy metal concentration in sediment and water refer to the APHA standards method [19]. Laboratory analysis was conducted at the Aquatic Environmental Laboratory, Department of Aquaculture, Faculty of Fisheries and Marine Sciences, IPB University and Testing Laboratory, Department of Agriculture Industrial Technology, Faculty of Agricultural Technology, IPB University.

2.3. Data analysis

The heavy metal contents in sediment and water were compared to the quality standard. The guidelines used to assess the sediment quality were the Canadian Sediment Quality Guidelines for the Protection of Aquatic Life on Marine set out by the Canadian Council of Ministry of Environment (CCME) in 2001 [20] and Australian and New Zealand Guidelines for Fresh and Marine Water Quality set out by the Australian and New Zealand Environment and Conservation Council & Agriculture and Resources Management Council of Australia and New Zealand (ANZECC & ARMCANZ) in 2000 [21]. In water, the heavy metals were compared to seawater quality standard for marine biota from Decree of the State Minister for the Environment Number 51 of 2004 (Appendix III) [22]. According to those guidelines or standards, the reference value for heavy metal quality standards in sediment and water are presented in table 1.
Table 1. The reference value for heavy metal quality standards in sediment and water.

| Heavy Metal | Sediment | | Water |
|-------------|----------|-----------------|--------|
|             | CCME     | ANZECC & ARMCANZ| Decree of the State Minister for the Environment 51/2004, Appendix |
|             | (mg.kg\(^{-1}\) dry wt.)| (mg.kg\(^{-1}\) dry wt.)| Appendix III (mg.L\(^{-1}\)) |
| Pb          | ISQG\(^{a}\) | PEL\(^{b}\) | ISQG-low\(^{c}\) | ISQG-high\(^{d}\) | 0.008 |
| Hg          | 0.13     | 0.7          | 0.15           | 1            | 0.001 |
| Cu          | 18.70    | 108.0        | 65.00          | 270          | 0.008 |

\(^{a}\) Interim Sediment Quality Guidelines (ISQG) is the minimum limit value, i.e., the limit of metal concentrations that has a low possibility to cause an adverse biological effect.

\(^{b}\) Probable Effect Level (PEL) is the maximum limit value, i.e., the limit of metal concentrations that has a high possibility to cause an adverse biological effect.

\(^{c}\) ISQG-low is the minimum limit value, i.e., the limit of metal concentrations with a low risk of biological disturbance to organisms. If the concentration below that, then it does not require any mitigation. If this limit exceeded, either management (including remedial) action or additional site-specific studies concerning the factors behind must be taken.

\(^{d}\) ISQG-high is the maximum limit value, i.e., the limit of metal concentrations with a high risk of biological disturbance to organisms. Concentrations above that value illustrate a high possibility of causing an adverse biological effect, and it is necessary to conduct a thorough study of the control factors for contaminant bioavailability.

The comparison between the measured heavy metal content and the quality standard was visualized in a graph, using data processing software, namely Microsoft Excel. For some data, the graph was not informative enough for the reader, so a slight modification was made using the CorelDraw software.

After analyzing the data, the condition of heavy metals in sediment and water for the western and central parts of the Segara Anakan lagoon can be seen. Furthermore, this paper also attempts to summarize information about heavy metal contamination in the entire Segara Anakan lagoon area so that a comparison between the results of this study and the results of previous studies in the eastern part is also discussed.

3. Results and discussion

3.1. Lead (Pb) in sediment and water

The lead was a non-essential metal that was very dangerous and poisonous for living things [23]. The Pb metal in sediments shows a low concentration range of <0.050–2.525 mg.kg\(^{-1}\). The spatial analysis (figure 2) shows that most Pb concentrations were below the determination method's detection limit (<0.050 mg.kg\(^{-1}\)), especially at Stations 4 and 5. The Pb metal was never to exceed the minimum limits value of the two references [20,21]. This condition indicates that lead in the sediment was still safe and has a low possibility of causing an adverse biological effect on aquatic biota.

Some of the Pb concentrations in water have exceeded the seawater quality standards for marine biota in a range of <0.002–0.053 mg.L\(^{-1}\) [22]. Concentrations above the quality standard were obtained at all sampling stations, significantly higher at Station 1 (figure 3). In Station 1, the Pb concentration has reached more than six times from the seawater quality standard [22]. This result was worrying because it means the lagoon water has been polluted by Pb metal and has become a dangerous place for aquatic biota that lives in the water column.
Figure 2. Pb concentration in sediments in the western and central parts of the Segara Anakan lagoon.

Figure 3. Pb concentration in water in the western and central parts of the Segara Anakan lagoon.
Previous studies have revealed the lethal limit of Pb metal in water for various aquatic biota, which will compare with study results. Two genera of phytoplankton began to experience growth inhibition in waters containing dissolved Pb of 0.05 mg.L\(^{-1}\) (Chlorella) and dissolved Pb of 0.15 mg.L\(^{-1}\) (Dunaliella) [24]. The dissolved Pb of 0.020–0.465 mg.L\(^{-1}\) could eliminate the half population of *Synechococcus* and nanoplankton in the ocean [25]. Referring to Palar's book in 2012, crustaceans will experience mortality after 245 hours of exposure to a dissolved Pb range of 2.75–49.00 mg.L\(^{-1}\), while the aquatic insect group will experience the same thing within 168–336 hours with a Pb concentration of 3.5–64.0 mg.L\(^{-1}\) [23]. A higher concentration of 188 ppm can kill fishes [23]. Based on these lethal limits, the lead concentration in water bodies in the western and central parts of the Segara Anakan lagoon has threatened several types of plankton, but it was still safe for crustaceans, aquatic insects, and fishes.

Both in sediment and water, the lead metal tended to be relatively higher in the western part of the lagoon. Pb in sediment was higher at Stations 1-3, while in water was higher at Station 1. The entry of Pb metal into the lagoon was thought to be influenced mainly by the discharge of domestic and agricultural waste that enters through river flow. The three stations are adjacent to residential areas, agricultural activities, and large rivers in the western lagoon that contributes much freshwater input. Household waste, urban water flow, and the utilization of phosphate (PO\(_4\)) fertilizers significantly contribute the Pb metal into the waters [16, 26]. The lead can also be derived from corrosion of solder and plumbing in residential areas, mixed in the water flow, and then wasted into the environment [27]. Shipping and port activities also have the potential to increase Pb content. For example, at Station 6, a high Pb content was detected even though it was not the highest. Station 6 was the closest location for these activities. Much lead enters the waters through ballast water effluents from ships, where the ballast water contains very high lead and positively correlates with lead pollution at the ports [28, 29].

The lead concentration in sediment was found to be related to the type of sediment. Sediment from the sampling stations in the western part of the lagoon was dominated by mud while the central part was dominated by sand (large grains). The lead concentration in the sediment was relatively higher in the western part than the central part. The heavy metals content in sediments were influenced by the sediment particles [30, 31], that was, the smaller the particle size, the greater the metal content. Sediments with small particles have a larger surface area with a more stable ion density for binding heavy metals.

3.2. *Mercury (Hg) in sediment and water*

Mercury was a very toxic element, and its presence that exceeding the safe limits can directly or indirectly endanger organisms [23, 32]. The result showed that Hg metal in sediment was very low (below the determination method's detection limit) that was <0.005 mg.kg\(^{-1}\). These concentrations were found at each station throughout the observation period (table 2). The same condition also occurs for Hg in water. The mercury was very low (below the determination method's detection limit) in all station sampling throughout the observation period, which was <0.0002 mg.L\(^{-1}\) (table 3). Compared with the quality standard [20-22], the mercury concentrations in sediment and water were far below it. This result indicates that there has not been found any mercury contamination in sediment and water in the western and central parts of the Segara Anakan lagoon.

| Month  | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 |
|--------|-------|-------|-------|-------|-------|-------|
| May    | <0.005| <0.005| <0.005| <0.005| <0.005| <0.005|
| June   | <0.005| <0.005| <0.005| <0.005| <0.005| <0.005|
| July   | <0.005| <0.005| <0.005| <0.005| <0.005| <0.005|
| August | <0.005| <0.005| <0.005| <0.005| <0.005| <0.005|
| September | <0.005| <0.005| <0.005| <0.005| <0.005| <0.005|
| October | <0.005| <0.005| <0.005| <0.005| <0.005| <0.005|

Table 2. Hg concentration in sediments in the western and central parts of the Segara Anakan lagoon.
Table 3. Hg concentration in water in the western and central parts of the Segara Anakan lagoon.

| Month       | St. 1 | St. 2 | St. 3 | St. 4 | St. 5 | St. 6 |
|-------------|-------|-------|-------|-------|-------|-------|
| May         | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 |
| June        | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 |
| July        | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 |
| August      | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 |
| September   | -     | -     | -     | -     | -     | -     |
| October     | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 | <0.0002 |

There was some information regarding the lethal limits of mercury. The lethal toxicity tests show that a concentration of ≥0.16 ppm was able to reduce the survival rate and growth rate of Nile tilapia (Oreochromis niloticus) caused by the increase of stress and organ damage, whereas a concentration of ≥3 ppm can cause mass death in common carp (Cyprinus carpio) [33, 34]. In 96 hours, nilem carp (Osteochilus hasselti) can experience 50% of deaths in the dissolved Hg of 0.396 ppm [35]. Milkfish (Chanos chanos) that live in dissolved mercury of 0.06–0.09 ppm experience necrosis, cell degeneration, and cariolysis in their gills. In groups of microorganisms, the addition of Hg of 0.005 mg.L\(^{-1}\) to water can inhibit the growth of bacteria and phytoplankton and increase the mortality of copepods [36]. A study in Jakarta Bay explained that sediment contained mercury of 1.9–2.3 ppm associated with malformations on the green mussels (Perna viridis) body but did not cause mass death (still chronic effects) [37]. It can be concluded that the mercury levels in the western and central parts of the Segara Anakan lagoon (both in sediment and water) were still safe for various aquatic biotas, such as plankton, bacteria, fishes, and mollusks.

3.3. Copper (Cu) in Sediment and Water

Copper was a very toxic and dangerous element [23, 31, 38] and an essential metal for living things [23, 39]. Cu concentrations in the sediments show a range from <0.050 to 21.875 mg.kg\(^{-1}\). The spatial analysis (figure 4) shows that almost all sampling stations have low Cu content, below the minimum limits of the two references [20, 21]. A different case was found at Station 5, where the Cu concentration exceeds the minimum limit (ISOG) [20]. If exceeding the minimum limit, then Cu in the sediment has an intermediate possibility of causing an adverse biological effect on aquatic biota.

One condition in Station 5 was a warning for the users and managers to care for and managed the lagoon better, especially for Cu issues. ANZECC & ARMCANZ, in their guidelines, suggest taking management (including remedial) action or additional site-specific studies concerning the factors behind [21]. Although the Cu in the sediment has not exceeded the minimum limit set out by ANZECC & ARMCANZ (ISOG-low), this suggestion can still be considered.

Copper in water mostly exceeded the seawater quality standards for marine biota in a range of <0.002–0.052 mg.L\(^{-1}\) [22]. Concentrations above the quality standard were obtained at all sampling stations (figure 5). The Cu metal in water was relatively higher at Station 6, even reaching more than six times from the seawater quality standard [22]. This result was worrying because it means the lagoon water has been polluted by Cu metal and has become a dangerous place for aquatic biota that lives in the water column.

Aquatic biota was very sensitive to excess of Cu in the water bodies where it lives. Referring to Palar's book in 2012, Cu concentrations reaching 0.01 ppm will cause a phytoplankton death [23]. In 96 hours, crustaceans will experience mortality in the dissolved Cu range of 0.17–100 ppm, while mollusks will experience the same thing in a range of 0.16–0.50 ppm [23]. For fishes, the dissolved Cu in a range of 2.5–3.0 ppm was deadly [23]. Based on these lethal limits, the copper contamination levels in water in the western and central parts of the Segara Anakan lagoon was very lethal to phytoplankton, but it was still safe for crustaceans, mollusks, and fishes.
Figure 4. Cu concentration in sediments in the western and central parts of the Segara Anakan lagoon.

Figure 5. Cu concentration in water in the western and central parts of the Segara Anakan lagoon.
The copper metal, both in sediment and water, has the highest concentration than the other metals studied (Pb and Hg). It was a strong reason why Cu in the sediment can reach an intermediate level while in other metals was low. The characteristics and sources that more diverse were thought to be the reason for the high Cu content (both in sediment and water). The Cu metal characteristic was tightly bonded with organic material, making it more easily settle and accumulate in sediment than the other two metals [40]. Copper input into the lagoon was diverse, namely, comes from ports and industrial activities around the Donan River Estuary, settlements, and agricultural activities. The Cu metal was commonly used in port activities, anti-fouling paints, insecticides, fungicides, brass alloys for household appliances, machine parts, water purification, and a food additive [23]. Household waste in the form of metabolic waste and corrosion of pipes in residential areas usually contains Cu metal [26]. The Cu metal was also widely used in the electroplating, textile, and metal (alloy) industries [41].

3.4. Comparison of Heavy Metal in Sediment and Water
The heavy metal contents in sediments are generally higher than in water. The results also showed that the average concentration of Pb, Hg, and Cu metal in the sediment was higher than in water (figure 6-8). Lead in water showed a low value in a range of 0.005–0.018 ppm, while in the sediment was more than 0.100 ppm at four observation stations. The Hg metal content in sediment and water was not detected or below the determination method's detection limit. However, the determination method's detection limit for the mercury content in the sediment and water was different, which was <0.0050 ppm for sediment and <0.0002 ppm for water. Due to the heavy metal characteristics, which are generally higher in sediments, there was a chance that the mercury was higher in the sediment. For visualization and review purposes, it was assumed that the concentration obtained was at the detection limit (figure 7), although it was very likely to be below that in reality. The average concentration of Cu in water shows a low value in a range of 0.016–0.024 ppm. Most of the Cu content in sediments were found above 1.000 ppm, even reaching 3.793 ppm at Station 5.

The three heavy metal elements studied were always higher in sediment than in water during the observation (figure 6-8). The three metal elements in sediment were higher about 9-198 times than in water, with Cu metal has the highest comparison percentage (table 4). The concentration of metals in sediments typically reaches 3-5 times higher than in water [42]. It is because the sediment acts as a final reservoir for various contaminants [43], as well as due to the presence of fine-grain particles in the sediment which act as a carrier for heavy metals from the water column to the sediment [44]. Similar conditions were also found in the eastern part of the lagoon, even with a much higher accumulation in sediments, Pb metal was about 33-91 times [7] and 680-1820 times higher than in water [9], whereas for Hg was about 653-1068 times higher than in water [9]. These results indicate an excessively high accumulation of heavy metals in the sediments for the entire Segara Anakan lagoon.

Figure 6. Comparison of Pb concentration in sediment and water.
Although the heavy metal contents were much more significant in the sediment, this does not mean that the water's value was safe. Referring to the seawater quality standard [22], the Pb and Cu content in the water had passed the limits. Meanwhile, even though it was many times higher than water, the content of heavy metals in sediment was still below the quality standard with a low-intermediate possibility of causing an adverse biological effect on aquatic biota [20, 21]. This condition could be happening because related to a greater assimilative capacity on sediment.

Due to the high content of heavy metals in water (exceeding the quality standard), the previous discussion has answered that these three heavy metal elements were still safe from lethal limits for most types of aquatic biotas, such as planktons, aquatic insects, crustaceans, mollusks, and fishes. However, if this continues without any treatment, then the content in water and even the sediment will increase and eventually exceed the quality standard. Another threat that may need attention is Cu metal in sediment, which had exceeded the quality standard. If the heavy metals in sediment were released, then...
the heavy metals will be higher in water and more harmful for aquatic biota and humans who may consume them.

3.5. Heavy Metal Contamination Level in All Areas of Segara Anakan Lagoon
The three metal contamination levels in sediment in the western and central parts of the lagoon tend to be lower than the eastern part. In western and central parts of the lagoon, the concentration of Pb, Hg, and Cu in sediment was <0.050–2.525 mg.kg\(^{-1}\), <0.005 mg.kg\(^{-1}\), and <0.050–21.875 mg.kg\(^{-1}\), respectively. These results were predominantly below the minimum limit of the two references [20, 21]. The previous study in the eastern part of the lagoon shows something different. The Pb in sediment was measured in the range of 2.46–26.40 mg.kg\(^{-1}\) [17], 3.96–21.99 mg.kg\(^{-1}\) [7], and <0.23–53.13 mg.kg\(^{-1}\) [9]. In 2016, the mercury in sediments was found to have exceeded the maximum limits value of the two references (0.67–1.51 mg.kg\(^{-1}\)) [9]. The study in 2011 revealed that crustaceans in the Pertamina Cilacap tailings disposal area had accumulated high amounts of copper in their bodies [18]. A recent study in 2018 showed that the residue of Pb, Hg, and Cu in mud clams (Geloina erosa) from the western and eastern part of the lagoon was still below the threshold [45]. However, it does not mean that the consumption of mud clams in large quantities will be harmless.

In western and central parts of the lagoon, the concentration of Pb, Hg, and Cu in water was the amount of <0.002–0.535 mg.L\(^{-1}\), <0.0002 mg.L\(^{-1}\), and <0.002–0.052 mg.L\(^{-1}\), respectively. Some of these results have exceeded the seawater quality standard for marine biota [22], except for Hg metal. In a previous study on the eastern part of the lagoon, Pb, and Hg metal in water was high and exceeded the seawater quality standard [22]. The lead metal was found to be high in the range of 0.12–0.24 mg.L\(^{-1}\) [7] and <0.006–0.047 mg.L\(^{-1}\) [9], while Hg metal was an amount of <0.0001–0.0089 mg.L\(^{-1}\) [9]. A study in 2017 showed that the Cu metal content in mullet fish (Chelon subviridis) had exceeded the threshold [46]. Another study informs that the whiting fish (Silago shama) was no longer safe for consumption because there had been an accumulation of Pb, Hg, and Cu on the flesh [8]. A study about heavy metals in fish has also been carried out in the western and central parts of the lagoon. The Pb, Hg, and Cu content in the flesh of tank goby (Glossogobius giuris) was still below the threshold limit [47].

Comparing the study results with these previous studies makes it possible to conclude and obtain a fact. The sedimentary layers in the western and central parts of the lagoon have relatively low contamination levels of Pb and Cu metal, even without contamination from mercury, but the eastern part has the opposite condition. Meanwhile, for the water, all areas of the Segara Anakan lagoon has been polluted by Pb, Hg, and Cu metal, except Hg metal in western and central parts of the lagoon. The contamination of these three metal elements has not yet reached the accumulation level on several types of fish and mollusks bodies in the western and central parts of the lagoon, while it has occurred in the eastern part.

Regarding fisheries management in a lagoon, if the water managers plan to make this lagoon a fishery cultivation area, then it needs to be rethought. Although the heavy metal was still far from the lethal limit for most types of aquatic biotas, and the accumulation level has not yet reached the fish bodies, but the Pb and Cu metal levels that have exceeded the seawater quality standards have a very high risk of contaminating fish commodities to be unsafe for human consumption. The cultivation of benthic biota was likely to be safer from the threat of heavy metal contamination. Previous studies explained that mud clams caught from the western part of the lagoon still safe from heavy metal residues [45], and there was ±326 ha area which was quite suitable for the cultivation of mud clams in West Plawangan and west of the central lagoon [48]. However, this needs to be considered with the principle of caution because benthic biota generally has a narrow (sessile) movement, so it has more potential to be exposed to and accumulate heavy metals continuously. Thus, it is necessary to pay attention in detail to the safety level for consumption of mud clam or other benthic biotas (usually in g/week).

4. Conclusions
The western and central parts of the Segara Anakan lagoon have low to intermediate contamination levels on Pb and Cu metal in the sediments, and the water has been polluted by both of them. Even
though these two metal elements have exceeded the seawater quality standards, they were still within safe limits for most types of aquatic biota, referring to the lethal limit from the previous result studies. However, this statement must be treated with caution, as the potential for its concentration to increase continuously was enormous. In this area, there has not been found any mercury contamination in the sediment and water. This study has succeeded in complementing the information on heavy metal contamination in the entire Segara Anakan lagoon area and reveals that the three metal contamination levels in the western and central parts of the lagoon were lower than the eastern part.

Acknowledgments
This research gets financial support from Prof. Dr. Ir. Sulistiono, M.Sc. and the authors would like to express the gratitude for that. Big thanks also presented to the research team, laboratory assistant, and all parties who supported this research.

References
[1] Yuwono, E, Jennerjahn TC, Nordhaus I, Riyanto EA, Sastranegara MH and Pribadi R 2007 Ecological status of Segara Anakan, Indonesia: a mangrove-fringed lagoon affected by human activities Asian Journal of Water, Environment and Pollution 4 61–70
[2] Holtermann P, Hans B and Jennerjahn T 2009 Hydrodynamics of the Segara Anakan Lagoon Regional Environmental Change 9 245–58
[3] Saputra SW 2007 Condition of Segara Anakan waters Cilacap based on salinity and turbidity variable) Seminar Nasional Perikanan dan Kelautan (Semarang) pp 1–19 (Indonesian)
[4] Sukardi Y 2010 Problematica of the Segara Anakan Areas 2nd ed [Internet] (downloaded 2018 Jan 16) Available in: http://docplayerinfo/37952712-Permasalahan-kawasan-segara-anakan-yuliarko-sukardi-abstrakhtml (Indonesian)
[5] Setyawan W 2010 Conservation for the Segara Anakan Estuary Pros Seminar Nasional Biodiversitas dan Bioteknologi Sumberdaya Akuatik ed Prabowo RE, Ardli ER, Sastranegara MH, Lestari W and Wijayanti G (Purwokerto) pp 733–741 (Indonesian)
[6] Paryono TJ 1999 Economic studies of ponds management in mangrove areas of Segara Anakan, Cilacap Regency, Central Jawa Pesisir & Lautan 2 8–16
[7] Hidayati NV, Siregar AS, Sari LK, Putra GL, Hartono, Nugraha IP and Syakti AD 2014 Estimating of contamination level of heavy metal Pb, Cd and Cr on water and sediment in Segara Anakan waters, Cilacap Omni-Akuatika 13 30–9 (Indonesian)
[8] Cahyani N, Batu DTFL and Sulistiono 2016 Heavy metal contain Pb, Hg, Cd, and Cu in flesh of whiting fish (Sillago sihama) in Donan River Estuary, Cilacap, Central Java JPHPI 19 267–76 (Indonesian)
[9] Kasari AF 2016 Pollution status based on heavy metal Pb, Hg, Cd, and Ag in water and sediment at Donan River Estuary, Eastern Segara Anakan [Undergraduated Thesis] (Bogor: IPB University) pp 1–15 (Indonesian)
[10] Sanusi HS 1985 Accumulation of heavy metals Hg and Cd in milkfish (Chanos chanos Forsk) bodies [Dissertation] (Bogor: IPB University) pp 17–8 (Indonesian)
[11] Roehyatun E and Rozak A 2007 Monitorig of heavy metal content in sediment on Jakarta Bay Makara Sains 11 28–36 (Indonesian)
[12] Marchand C, Lallier-Verges E, Baltzer F, Alberic P, Cossa D and Baillif P 2006 Heavy metals distribution in mangrove sediments along the mobile coastline of French Guiana Marine Chemistry 98 1–17
[13] [US EPA] US Environmental Protection Agency 2001 Methods for Collection, Storage and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual, EPA 823-B-01-002 (Washington DC: US EPA, Office of Water) p 1-1
[14] Permanawati Y, Zuraida R and Ibrahim A 2013 Heavy metal content (Cu, Pb, Zn, Cd, and Cr) in water and sediment in Jakarta Bay waters Jurnal Geologi Kelautan 11 (1) 9-16 (Indonesian)
[15] Fatoki OS and Mathabatha S 2001 An assessment of heavy metal pollution in the East London
and Port Elizabeth harbours *Water SA* 27 233–40

[16] Harteman E 2011 The impact of heavy metal contents against the occurrence of badukang fish (*Arius maculatus*, Fis & Bian) and Sembilang fish (*Plotosus canius*, Web & Bia) on the Mouth of Kahayan River and Katingan, Central Kalimantan [Dissertation] (Bogor: IPB University) pp 12–101 (Indonesian)

[17] Sudaryanto A 2001 Community structure of macrozoobenthos and physico chemical condition of sediment in Donan waters, Cilacap-Central Java *Jurnal Teknologi Lingkungan* 2 119–23 (Indonesian)

[18] Tumisem and Puspawiningtyias E 2011 Metal content analysis and easily recognize for shrimps that accumulates of metal: case study about shrimps in Donan River Cilacap, Central Java *Jurnal Manusia dan Lingkungan* 18 114–26 (Indonesian)

[19] [APHA] American Public Health Association 2005 *Standard Methods for the Examination of Water and Wastewater* 21st ed (Washington DC: APHA) pp 1–1368

[20] [CCME] Canadian Council of Ministers of the Environment 2001 *Canadian Sediment Quality Guidelines for the Protection of Aquatic Life: Summary Tables* Updated In: Canadian Environmental Quality Guidelines 1999 (Winnipeg: CCME) pp 1–4

[21] [ANZECC & ARMCANZ] Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand 2000 *Australian and New Zealand Guidelines for Fresh and Marine Water Quality: The Guidelines* vol 1 (Canberra) pp 3.5–4–7

[22] [ME Decree] Minister of Environment 2004 Decree of the State Minister of the Environment No 51 Year 2004 about Seawater Quality Standard (Jakarta: Minister of the Environment) pp 1497–8 (Indonesian)

[23] Palar H 2012 *Heavy Metal Pollution and Toxicology* 4th ed (Jakarta: Rineka Cipta) pp 1–152 (Indonesian)

[24] Muhaemin M 2004 Toxicity and bioaccumulation of lead in *Chlorella* and *Dunaliella* *Journal of Coastal Development* 8 27–33

[25] Echeveste P, Agustí S and Tovar-Sánchez A 2012 Toxic thresholds of cadmium and lead to oceanic phytoplankton: cell size and ocean basin–dependent effects *Environ. Toxicol. Chem.* 31 1887–94 https://doi.org/10.1002/etc.1893

[26] Connell DW and Miller GJ 2006 *Chemistry and Ecotoxicology of Pollution* ed Koestoer Y, translator (Jakarta: UI Press) p 346 (Indonesian)

[27] Weiner ER 2008 *Applications of Environmental Aquatic Chemistry: a Practical Guide* 2nd ed (Boca Raton: CRC Press) p 392

[28] Apriani P, Amin B and Thamrin 2015 The concentrations of heavy metals Pb, Cu and Zn in sea water and sediment in Enam River of Bintan Island, Riau Islands Province *Jurnal Online Mahasiswa Unri* 3 1–9 (Indonesian)

[29] Agustrian F, Purwiyanto AIS and Suteja Y 2016 Enrichment valuation of heavy metal (Pb) and contamination level of ballast water in Tanjung Api-Api waters, Sumatera Selatan *Omni-Akuatika* 12 114–8 (Indonesian)

[30] Sahara E 2009 Distribution of Pb and Cu at various sediment particle size in Benoa Bay *Jurnal Kimia* 3 75–80 (Indonesian)

[31] Syakti AD, Hidayati NV and Siregar AS 2012 *Agen Pencemaran Laut* (Bogor: IPB Press) p 90 (Indonesian)

[32] Garcia-Rico L, Rodríguez MV and Jara-Marini ME 2006 Geochemistry of mercury in sediment of oyster areas in Sonora, Mexico *Marine Pollution Bulletin* 52 453–8

[33] Nirmala K, Hastuti YP and Yuniar V 2012 Toxicity of mercury (Hg) on survival and growth rate, hemato- and histopathological parameters of nile tilapia *Oreochromis niloticus* *Jurnal Akuakultur Indonesia* 11 38–48 (Indonesian)

[34] Tyas NM, Siregar AS and Sulistyow 2013 The lethal and sub-lethal toxicity test of mercury chloride (HgCl2) on common carp *Cyprinus carpio* L *Omni-Akuatika* 12 1–10 (Indonesian)
[35] Prayogo NA, Hidayati A, Siregar AS and Yunasfi 2016 Lethal and sublethal toxicity test of heavy metal mercury (Hg) against nilem carp (*Osteochilus hasselti*) *Omni-Akuatika* **12** 86–94 (Indonesian)

[36] Kuiper J, Brockmann UH, van het Groenewoud H, Hoornsman G and Roele P 1983 Effect of mercury on enclosed plankton communities in the Rosfjord during POSER *Mar. Ecol. Prog. Ser.* **14** 93–105

[37] Cordova MR 2011 Bioaccumulation of heavy metals and malformations of green shellfish (*Perna viridis*) in the waters of Jakarta Bay [Thesis] (Bogor: IPB University) pp 53–77 (Indonesian)

[38] Saeni MS 1997 Determination of the heavy metal contamination level by hair analysis [Scientific Oration] (Bogor: IPB University) pp 1–32 (Indonesian)

[39] Febrita E, Darmiadi and Trisnani T 2011 The heavy metal copper (Cu) content in red snails (*Cerithidea* sp) in the sea waters of Dumai, Riau Province *Jurnal Biogenesis* **8** 36–40 (Indonesian)

[40] Supriyantini E and Soenardjo N 2015 Lead (Pb) and copper (Cu) heavy metal content in root and fruit of mangrove *Avicennia marina* on Tanjung Emas Waters, Semarang *Jurnal Kelautan Tropis* **18** 98–106 (Indonesian)

[41] Fitriyah AW, Utomo Y and Kusumaningrum IK 2013 Analysis of copper (Cu) content in water and sediment in the Surabaya River *Jurnal Online Universitas Negeri Malang* **2** 1–8 (Indonesian)

[42] Bryan GW and Langston WJ 1992 Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review *Environmental Pollution* **76** 89–131

[43] Saeed SM and Shaker IM 2008 Assessment of heavy metals pollution in water and sediment and their effect on *Oreochromis niloticus* in the Northern Delta lakes, Egypt *Proc. of the 8th Int. Symp. on Tilapia in Aquaculture* (Cairo: Central Laboratory for Aquaculture Research) pp 475–90

[44] Chouba L, Kraïem MM, Njimi W, Tissaoui CH, Thompson JR and Flower RJ 2007 Seasonal variation of heavy metals (Cd, Pb and Hg) in sediments and in mullet, *Mugil cephalus* (Mugilidae), from the Ghar El Melh Lagoon (Tunisia) *Transitional Waters Bulletin* **4** 45–52

[45] Irawati, Batu DTFL and Sulistiono 2018 Content of Pb, Hg, Cu, Cd in flesh of mud clams (*Geloina erosa*) on Segara Anakan Waters, Cilacap JPHPI **21** 232–42 (Indonesian)

[46] Prasetyo Y, Batu DTFL and Sulistiono 2017 Heavy metal Cu and Cd content in the mullet fish in the Donan River Estuary, Cilacap, Central Java JPHPI **20** 18–27 (Indonesian)

[47] Sulistiono, Irawati Y and Batu DTFL 2018 Heavy metal content in tank goby (*Glosogobius giuris*) in eastern Segara Anakan Waters, Cilacap, Central Java, Indonesia JPHPI **21** 423–32 (Indonesian)

[48] Herawati VE 2008 Analysis of the suitability of Segara Anakan waters in Cilacap Regency as a cultivation land for mud clams (*Polymesoda erosa*) in terms of productivity aspect using remote sensing [Thesis] (Semarang: Diponegoro University) p 56–107 (Indonesian)