

## Fate of Heavy Metals Pb and Zn in the West Season at Jeneberang Estuary, Makassar

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### Abstract

*The pollutant quantity of heavy metals entering water environment does not give complete answer toward the generated effect and risk, however it needs thoroughly study related to the pollutant dynamic. The aim of this research was to investigate the fate of Pb and Zn in water, such as: distribution, behavior, and reactivity (case study: Jeneberang Estuary, Makassar). Pb and Zn concentrations were determined using Atomic Absorption Spectrophotometry (AAS). The distribution of dissolved Pb and Zn showed a pattern that the lowest concentration was in the fresh water (the river zone), whereas the highest concentration was in the salt water (the marine zone). The distribution pattern of particulate Pb and Zn showed that the highest concentration was in the fresh water (the river zone) and the salt water (the marine zone), whereas the lowest concentration was in the estuary zone. The behavior of dissolved Pb and Zn tended to increase the concentration (desorption) along the increased salinity gradient. The residual fraction was the dominant component of geochemical fractions in the sediment that indicated the sources of Pb and Zn mainly derived from a natural process and the reactivity was low in the water.*

**Keywords:** *distribution, behavior, reactivity, lead, zinc, pollution*

### Introduction

Recent studies of heavy metals are dominantly focused on the quantity analysis of dissolved elements and in the sediments of waters bottom. Several studies have been published, such as: from around coastal waters of Makassar (Samawi, 2007; Rastina, 2012), around coastal of Java (Hamzah and Setiawan, 2010; Lestari, 2011; Suryono and Rochaddi, 2013), Maluku (Rumahlatu, 2012), around of Sumatera (Arifin, 2011; Ahmad 2013; Purwiyanto, 2015), and Kalimantan (Arifin 2008).

The complexity of environmental problems could not sufficiently be answered only toward the information of the dissolved element concentration and in the sediment. However, it needs further investigation related to the dynamics of elements in water environment. Martin and Whifield (1983) proposed that the existence and effects of elements in the water system should be associated with four main factors, such as: 1) the quantity of metals in the waters, 2) the composition of dissolved fraction and particulate

in the waters, 3) the fate of elements in the mixing zone, and 4) the quantity and amount of heavy metals transferred from estuary to marine waters.

Occurrence of elements in the waters is in two forms: dissolved and particulate forms. The dissolved metals are constantly in the water column and spread toward the pattern of water flow, while the particulate matter will be soon deposited and part of it will spread to water column, particularly the very small particles, and afterwards settle in the slow water movement. Both the metal forms play a role in the geochemical cycle of water environment. The dissolved and particulate elements took a role in the mechanism of adsorption-desorption, deposition-resuspension, and dispersion, thus determined the fate of the chemical element of heavy metals in the estuary (Sanusi, 2006; Kontas, 2012).

In addition, the studies of heavy metals in the environment were also found limited, particularly on the geochemical fractionation of elements of sediment. The geochemical fractionation will characterize the chemical bond

and reactivity. The type of chemical bond and reactivity in the sediment will determine the bioavailability of elements to be absorbed by the organisms (uptake). Tessier *et al.* (1979) indicated that the geochemical fractionation of metals in the sediment was fundamental due related to its mobility, bioavailability, and toxicity.

Estuary is of special character as the waters are mixed of fresh and saline waters that lead the chemical and physical process occurred are dynamic and contrast to the coastal region and open sea (Dyer, 1986). Therefore, the dynamic and existence of pollutant in the estuary are greatly influenced by the ocean tide and the flow of rivers. Evolving dynamics in the estuary thus stimulates the fate alteration of chemical element in it.

Jeneberang is the biggest water river basin in Makassar City stretching from Gowa district to Makassar City. The stream flow of Jeneberang River laid on urban region leads the estuary to be a potential intake of various metals that influences the environmental problems. In addition, based on RTRW of Makassar, the region nearby the Jeneberang Estuary was declared as a strategic region for integrated business area (local government regulation of Makassar 2010). Consequently, the development of Makassar City in the future, particularly the region nearby the estuary, will endure the threat as the potential of waste disposal become increasing that pose the quality of waters environment.

Several previous studies conducted around the coastal waters of Makassar city and also Jeneberang Estuary that related to the heavy metal pollution were Samawi (2007), Taufieq (2010), and Werorilangi *et al.* (2013), however, the reports were only on the concentration of sediment and the quantity of dissolved elements. Although the report of Werorilangi *et al.* (2013) described the analysis of geochemical fractionation, it was limited on the labile fraction and there were lack results of the particulate form. Therefore, analyzing the fate of Pb and Zn in this study involved the distribution, behavior, and reactivity. The distribution of elements was analyzed spatially based on the waters zone or region classified as: fresh water (river), estuary, and salt water (coast/marine). The behavior of elements was analyzed by conservative mixing graph (conceptual approach) and the reactivity was studied based on the geochemical fractionation of the sediment.

### Materials and Methods

The study location was conducted at Jeneberang River estuary, Makassar, South Sulawesi. The geographical location are 5°08' 40" - 5°12'40"S and 119°21'00" - 119°24'10"E. Data was undertaken during the west season started from December 2014 to February 2015. The data was collected from 17 sampling points classified as three waters zone, such as:

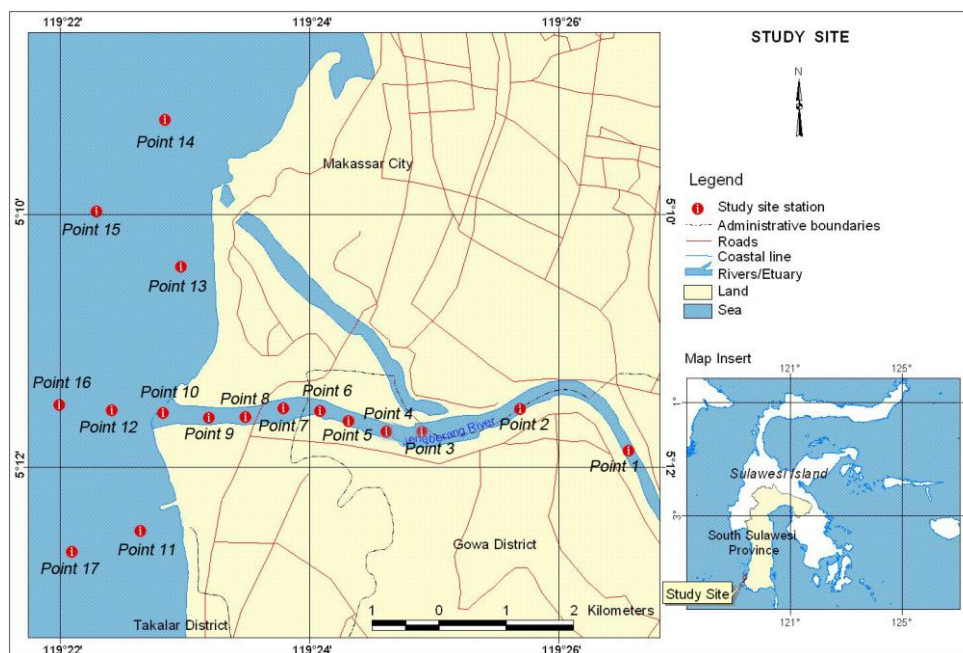


Figure 1. Study location and sampling points of Jeneberang River estuary, South Sulawesi

fresh water (point 1-3), estuary (point 4-10), and coast-marine waters (point 11-17) as described at Figure 1.

The water sample was the surface layer as the estuary type was completely mixed and water mass was not stratified vertically. The water samples were taken using 2 liter Van Dorn Water Sampler and placed in 1 liter polyethylene bottles that were previously soaked with 2N HCl for 24 hour and rinsed with distilled water. 500 g sediment samples were taken at the layer surface using Ekman Grab Sampler. The samples were placed in polyethylene bottles that were previously soaked with 6 N HNO<sub>3</sub> and rinsed with distilled water. The samples were placed and stored in the medium transport under cool temperature (4°C). Soon arrived at laboratory, the sediment samples were freeze dried at -12°C for further analyses. The particle samples were obtained by filtering approximately 50 L water through 0.45 µm Millipore with vacuum pump. The Millipore papers used were previously soaked with 2N HCl for 1 week and rinsed with aquades. The samples were then stored in the ice box.

The metal concentration was determined using Atomic Absorption Spectrophotometer (AAS) based on APHA, AWWA, WEF (2005) and the heavy metals geochemical fractionations of the sediments were determined using extraction simultaneously (*Sequential Extraction Procedure*) based on Tessier *et al.* (1979).

## Results and Discussion

### *Distribution of Pb and Zn in the waters*

The heavy metals of water column are composed of two forms - dissolved (liquid phase) and particulate (solid phase). In addition to metal characteristics, element distribution in the column is also influenced by the chemical-physical waters, tidal cycle, and season. While, the metal quantity is determined by the input from the mainland through rivers flow, and tidal currents.

Dissolved Pb concentration in the location study ranged <0.002-0.075 mg.L<sup>-1</sup> with the mean 0.022 mg.L<sup>-1</sup>, while Zn ranged <0.002-0.020 mg.L<sup>-1</sup> with the mean 0.005 mg.L<sup>-1</sup>. In addition, the particulate concentration of Pb ranged 0.360-2.569 µg.g<sup>-1</sup> with the mean 1.408 µg.g<sup>-1</sup>, while Zn ranged 28.536-90.942 µg.g<sup>-1</sup> with the mean 57.902 µg.g<sup>-1</sup>. Compared to the results in Tallo estuary found by Rastina (2012), the distribution of dissolved metal concentration of Pb and Zn

were 0.002–0.492 mg.L<sup>-1</sup> and 0.010–0.087 mg.L<sup>-1</sup>, respectively. Dissolved concentration of Pb and Zn in this study was higher than that in Tallo estuary as the location was very close to the industrial area (urban area).

The spatially distribution of dissolved Pb concentration showed that the point 14 (coast-marine water) was the higher concentration (0.075 mg.L<sup>-1</sup>), and the point 1-3 (fresh water) was the lower concentration (<0.002 mg.L<sup>-1</sup>). The distribution pattern of dissolved Zn was also under similar pattern to that dissolved Pb, where the zone of high or low concentration was similar to Pb. However, the concentration of dissolved Zn was lower compared to dissolved Pb. Higher Zn concentration were 0.020 mg.L<sup>-1</sup>, whereas lower Zn concentration were less than 0.002 mg.L<sup>-1</sup> (Figure 2.).

Spatially distribution pattern of the dissolved metal forms indicated that the input of the dissolved Pb and Zn was mainly derived from anthropogenic sources in the coast/marine, while the input from the mainland was undetected (below the detection limit). Higher concentration of Pb and Zn in the point 14 was supposedly derived from various activities, such as: Makassar seaport and domestic activities around the coastal waters of Losari (hospital, restaurant, hotels, and residence). The potential source came from waste of exhaust of car and boat/ship, the dust from road and residence, waste of hospital, hotels, restaurant, and beach. This result was also in accordance with Werorilangi *et al.* (2013) that higher dissolved Pb concentration, found around the Losari coast, was derived from anthropogenic sources.

Lower dissolved concentration of Pb and Zn found in this study indicated that there were small amount of pollutants originated from the mainland to increase the concentration in the waters. However, the dissolved concentration of Pb and Zn also indicated that the characteristics of Pb and Zn were low solubility. Low solubility characteristics then influenced the higher particulate formation of elements that settled and accumulated in the sediment of waters bottom. This was in accordance with Sanusi (2006) that the solubility of Pb and Zn in the waters was relatively low.

The higher suspended particle concentration in the water column also affected the suspended particles to adsorb the dissolved metals so that there were a reduced dissolved

concentration and an increased particulate concentration (Najamuddin *et al.*, 2016b). This assumption was supported by Kontas (2012), and Sanusi (2006) that, in the water column, the suspended particles have the ability to adsorbed the dissolved particle in surface hydrophobic adsorption through the chemical and physical process. The adsorption process will reduce the concentration of the dissolved chemical compound in the water column and increase the concentration of the particulate in sediment.

The spatially distribution of particulate Pb concentration showed different pattern with that the distribution of dissolved metal form. The highest concentration of particulate Pb in the water column was in the point 1 (fresh water zone) which are  $2.569 \mu\text{g.g}^{-1}$ , while the lowest concentration was in the point 4 (estuary zone) which are  $0.360 \mu\text{g.g}^{-1}$ . Likewise, the distribution pattern of particulate Zn, the highest concentration of particulate matter was in the point 3 (fresh water zone) which are  $90.942 \mu\text{g.g}^{-1}$  while the lowest concentration was in the point 4 which are  $28.536 \mu\text{g.g}^{-1}$ . The pattern difference of spatially concentration distribution of the dissolved and particulate forms was attributed with the input or pollutant source, transport mechanism, and flushing time (Turekian, 2010).

Distribution pattern of particulate metal matter showed that the main source of particulate Pb and Zn was dominantly derived from the mainland as result of rock weathering and from various human activities along the water river basin of Jeneberang, such as: agriculture, settlement, and transportation. This assumption was supported by the evidence that the sampling was performed during the peak of rainy season so that there an increase erosion in the downstream, although there were a Bili-Bili dam at upstream area and dam of rubber near to estuary. Higher total concentration of suspended particles of water column also supported the assumption. This was in accordance with Al-Najjar *et al.* (2008) that the rainy season influenced the distribution of element concentration. The result comparisons of dissolved and particulate element concentration in this study with other studies are shown in Table 1.

Moreover, there was also an input from coast/marine, but the quantity was lower than that come from the mainland. The source of particulate elements derived from coast/marine supposedly originated from dust particles of loading and discharging activity of the port and domestic activities around the Losari coast. Heavy traffic activity from both mainland and ocean around the

area of port and urban to be the source of Pb pollutant, particularly from fume exhaust, as tetra ethyl lead (TEL) has been used as octane number enhancer of fuel so that the fume disposal of combustion engine increased the amount of Pb to the environment. This was supported by Syakti *et al.* (2012) that the concentration of dissolved Pb of the aquatic environment associated with human activities was mainly derived from TEL that is used as octane number enhancer of fuel.

The different and interesting case in this study was the establishment of dam of rubber that to be a boundary between the fresh water (river) and the estuary. The dam was utilized by the local water company as raw material source. The dam influenced that the amount of fresh water and particles entering the estuary became limited as it only flows through the surface of the dam, thus influences the pattern of water mass and the pollutant transport to the estuary.

The dam building also influenced that water mass movement to become slow so that the particle deposition would be high. This will take an effect that the pollutant flux of particulate metals will be reduced to the estuary since part of it has been deposited with particles. This indication could be seen in the data that the concentration of particulate Pb and Zn in both the sediment and particle was high (Figure 2).

The distribution change showed that there a decreased concentration significantly of particulate matter in the sediment, but an increased concentration of dissolved form. This was in accordance with Chester (1990) reporting that the behavior of elements in the waters was greatly influenced by the interaction of dissolved phase, particulate (solid), and pollutant input.

The dam in the location study influenced the transport and distribution of the pollutant in the waters, particularly the particulate metals, by reducing the pollutant transport rate from the rivers to the estuary, as a consequence of deposition to the waters bottom. Therefore, higher particulate and lower dissolved forms of Pb and Zn concentration affected that the mobility of Pb and Zn were low that reduced the generated environmental risks.

This is supported by the report of Turekian (2010) that the spatial and temporal distribution of dissolved elements were greatly determined by: 1) local hydrodynamics acting in the pollutant dispersion and 2) interaction of particles and water determined by the metal partition of particulate phase and dissolved phase, as the

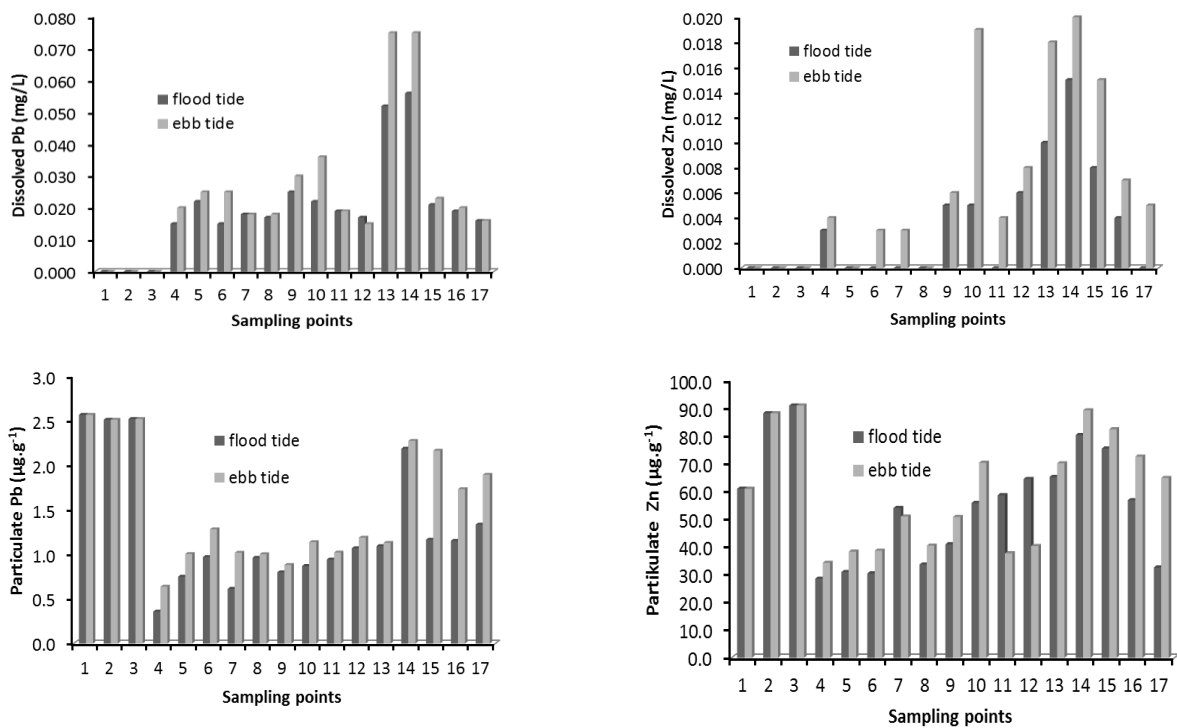


Figure 2. Concentration Distribution of Particulate and Dissolved Forms of Pb and Zn In Jeneberang River Estuary

Table 1. Comparison of dissolved (mg.L<sup>-1</sup>) and particulate (µg.g<sup>-1</sup>) of Pb and Zn concentration from several locations of Indonesian waters.

References	Location	Dissolved		Particulate	
		Pb	Zn	Pb	Zn
This study	Jeneberang River Estuary	<0.002-0.221	<0.002-0.092	0.465-2.569	16.998-90.942
Samawi, 2007	Coastal of Makassar	0.158-0.167	-	-	-
Rastina, 2012	Tallo Estuary of Makassar	<0.002-0.492	0.009-0.087	-	-
Sagala <i>et al.</i> , 2014	Natuna Island waters	<0.005	-	-	-
Arifin, 2011	Kelabat Bay, Bangka Island	0.001-0.0026	0.001-0.004	-	-
Sanusi <i>et al.</i> , 2005	Jakarta Bay	0,0024-0.0121	-	0.0002-0.007	-
Mokoagouw, 2000	Coastal of Bitung	<0.0001-0.0025	<0.0001-0.0240	-	-

transport mechanisms of particle and dissolved substance are different. Therefore, the concentration of suspended particle and its characteristic were instrumental to control particle metal fraction. Zinc (Zn) has a high partition coefficient ( $K_D$ ) as it tends to form a complex bond with hydroxyl and carboxyl groups that are dominant in natural particle surface, thus the concentration of its particulate matter is high. However, Lead (Pb) has a mild partition coefficient ( $K_D$ ) due to its ability to form a complex with chloride in the water

**Distribution of Pb and Zn in the sediment**

The highest Pb concentration in the sediment was in the point 1 (4.330 µg.g<sup>-1</sup>) that

was the fresh water zone (river). High Pb concentration was also found in the point 14 and 15 that was coast/marine waters zone located in the north of Jeneberang Estuary. The Pb distribution in the sediment has a pattern that is similar to that of the particulate form. This implied that the heavy metals were the result of deposition or particulate sedimentation accumulated so that the metal concentration in the sediment was higher than that in particulate (Figure 3).

The lowest Pb concentration was in the point 4 (0.237 µg.g<sup>-1</sup>) that was the estuary zone. This was presumably due to mixing process or water mass turbulence, thus metal desorption process occurred from the sediment to water

column as a consequence of sediment re-suspension. Compared to the fresh water zone, the situation affected an increased concentration of dissolved metals in the estuary (Najamuddin *et al.*, 2016a). The assumption was in accordance with Lenzi (2010) that the sediment re-suspension led to a desorption metals and nutrient release, an increased carbonate, and an increased oxygen consumption, as a consequence, there an interaction pattern change of particulate and dissolved metals in the water column. The mechanism described the occurrence in the estuary waters that the behavior of heavy metals in the estuary waters was specific and dynamic.

However, the re-suspension effects depended upon season and water bottom condition. For example, the re-suspension effects was an abruptly increased nitrogen as result of trapped water mixing in the sediment (interstitial water) with water column, however the amount released was influenced by its diffusion gradient under long term period. Sediment re-suspension with soft surface character increased the oxidation in the sediment that there were an increased Eh value and increased organic matter, but did not show an increased nutrient and oxygen consumption significantly in the water column (Lenzi, 2010).

The highest Zn concentration in the sediment was in the point 3 (113.190  $\mu\text{g.g}^{-1}$ ) that was the fresh water zone (river). High Zn concentration found in this study was presumably associated with that the particulate carried on the stream was trapped in the dam, settled, and accumulated highly in the sediment.

In addition, the lowest Zn concentration was in the point 4 (57.84  $\mu\text{g.g}^{-1}$ ) that was the estuary zone (Figure 3.). Higher number of Zn found in this study was the results of deposition and particle metal accumulation originated from

material decay and rock erosion as the Zn concentration in the earth's crust were naturally under large number. Moreover, sampling time was undertaken during the peak of rainy season, therefore, the erosion rate was high and it increased the amount of particulate elements entering the water body.

The concentration of Pb and Zn in this study was lower than that reported by Rastina (2012) (Tallo River), however it was higher than that reported by Werorilangi *et al.*, 2013. Compared to several reported results of other locations of Indonesian waters, Pb concentration was under lower number, but Zn concentration was under high number, except for Lestari and Budiyanto (2013) (Table 2.).

**Behavior of Pb and Zn in the waters**

Dissolved heavy metals in the waters are conservative and non-conservative elements. The characteristic and behavior are determined by physicochemical process and estuary type. The non conservative elements occurred because of a removal process (adsorption) or addition (desorption) as a result of physicochemical process in the estuary, but not the degradation process of microorganisms activity, photolysis, and radioactive (Chester, 1990). The elements undergoing removal are indicated with low concentration below the value of theoretical dilution line (TDL), and, conversely, the elements will undergo addition if the concentrations are above the TDL value.

Common behavior of heavy metals in the estuary showed a tendency where the TDL value was decreased along salinity gradient. The concentration condition showed that the elements dissolved in the estuary were mainly derived from the rivers, as reported by Chester (1990) on Cu, Fe, Zn, and Mn, the concentration

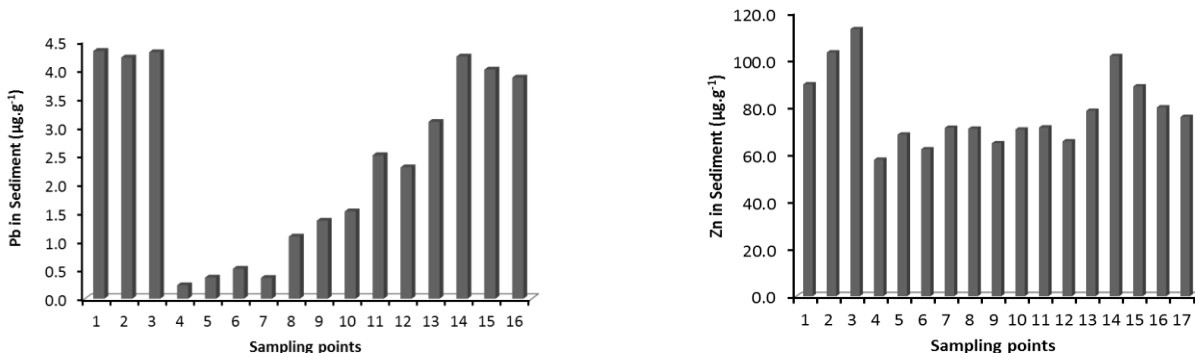


Figure 3. Concentration distribution of Pb and Zn in the sediment of Jeneberang River Estuary

**Table 2.** Comparison of Pb and Zn concentration in the Sediment ( $\mu\text{g.g}^{-1}$ ) from several locations of Indonesian waters.

References	Location	Pb	Zn
This study	Jeneberang Estuary	0.24-4.33	57.84-113.19
Werorilangi <i>et al.</i> 2013	Coastal of Makassar City	0.38-2.58	0-107.49
Rastina, 2012	Tallo Estuary	14.55-83.01	53.57-294.76
Hamzah and Setiawan, 2010	Angke Estuary, Jakarta	18.64-29.57	56.58-69.30
Arifin, 2011	Kelabat Bay, Bangka Island	11.46	13.64
Arifin, 2008	Delta of Berau, Kalimantan	12.2	6.1
Ahmad, 2013	Bangka Island	5.794	16.706
Lestari and Budiyanto, 2013	Coastal of Gresik	1.74-12.70	77.3-405.0
Lestari, 2011	Coastal of Semarang	10.9-17.3	13.6-16.3

decreased as the salinity increased particularly with the salinity 5-25 %. It could be implied that adsorption process in the estuary waters greatly occurs characterized with a decreased dissolved concentration in the water due to particle adsorption.

This results showed that there a deviation of dissolved Pb and Zn from commonly found in the estuary, as reported by Chester (1990). The relationship pattern of dissolved Pb and Zn in this study was tended to increase as the salinity increased (Figure 4.). In this study, the deviation of dissolved Pb and Zn from commonly found in the estuary could be attributed by a low pollutant input of dissolved elements entering the estuary that originated from the mainland, on the contrary, the dissolved elements of the estuary were mainly originated from the coast/marine zone.

The deviation of dissolved Pb and Zn found in this study could also be associated with a smaller adsorption process of dissolved elements by the particles compared to the desorption process in the estuary and coast/ marine zones. High dissolved element addition of coast/marine zone compared to the river zone inflicted that the behavior of dissolved elements in this study was different with other estuary waters.

In addition, the dam building near the downstream also influence the pattern of dissolved elements as the supply of fresh water entering to the estuary became decreased, therefore, the water mass was dominant in the estuary. This condition inflicted that the mixing pattern of fresh water mass with salt water mass was completed, therefore, Jeneberang was a well-mixed estuary. This opinion was supported by Chester (1990) that the behavior of elements in the estuary was influenced by the characteristic or estuary type. Other results showed that the element removal process of dissolved Pb and Zn in Gota estuary, Sweden, ineffectively occurred, as the estuary type were salt wedge and unpolluted.

Lim *et al.* (2012) who studied the Langat River, Malaysia, found that Pb concentration in the sediment was tended to be higher than in the water column. The phenomena showed that Pb has a larger adsorption capacity. However, Hamad *et al.* (2012) who studied the Tigris River, Iraq, reported that Pb has a balance concentration under dissolved and particulate forms. There is a different characteristic of element in Langat River and Tigris River. This could be associated with the suspended particle (composition, size, and concentration) which act on adsorption and desorption mechanisms, and the physicochemical characteristic of the waters.

Other studies reported that there conservative and non-conservative nature from different estuary waters. Duinker and Notling (1978) reported that Cu, Zn, and Cd of Rhine estuary which was polluted underwent removal process (adsorption). However, Li *et al.* (1984) reported that Cd and Zn originated from river entering the estuary underwent desorption.

**Geochemical fractionation of Pb and Zn**

Geochemical fractionation of elements in the sediment is important aspect since the condition of geochemical sediment will describe the process occurred in the water column. The process could comprise the reactivity and mobility of elements in the water that are related to bioavailability and toxicity aspects. Element fractionation could be used as a base to identify the potential source of element in the waters. Geochemical fractionation of element in the sediment can be classified as: the labile/non-resistant fraction (exchangeable, carbonate, Mn-Fe oxides, and organic), and the non-labile/resistant fraction (residual). Results showed that the labile/non-resistant fraction was the dominant fraction in sediment for both Pb and Zn.

Percentage mean of the non-labile fraction of Pb were 80.41%, while percentage mean of the labile fraction of organic, carbonate, Mn-Fe

oxides, and exchangeable were 13.48%, 2.19%, 3.92% and 0.00%, respectively. In addition, percentage mean of the non-labile fraction of Zn were 74.96%, while percentage mean of the labile fraction of organic, Mn-Fe oxides, exchangeable, carbonate were 21.98%, 3.05%, 0.00% and 0.00%, respectively (Figure 5.). The dominant resistant fraction of Pb and Zn found in this study indicated that the main source of element pollutant was derived from natural process which was stone decay or land erosion in the mainland entering the waters. Resistant components are the non-labile fraction that was destructed only by strong acid. The highest non-resistant fraction was organic fraction indicating that human activity (anthropogenic source) contributed to Pb and Zn in the waters, particularly in coast/marine waters. This was in accordance with Teixeira *et al.*, (2003), Rodrigues and Formoso (2006) that the sediment-associating labile fraction was derived from anthropogenic source, while the sediment-associating non-labile fraction was derived from natural process.

The dominant geochemical fraction of sediment was resistant fraction describing that the Pb and Zn were bound to rock minerals. Chemical bonds between minerals and elements are strong chemical bond that the reactivity and mobility were low, therefore, the bioavailability and

availability of adsorbable element in the waters for the organisms were low. The occurrence of elements bound to the sediment was considered safe to the organism as the element bonds could only be released if the decomposition occurred. Moreover, re-suspension did not release the element bonds (desorption) in the sediment surface.

The non resistant fraction of exchangeable is a very weak bond fraction and the bond can be simply released through ion exchange, therefore, the reactivity and mobility are high leading to high bioavailability. However, exchangeable fraction in the sediment was not found this study. Organic fraction is a fraction with medium to high mobility. Carbonate and Mn-Fe oxides fractions are a fraction with medium mobility that the chemical bonds could be released by redox change and decomposition. If the fraction in the sediment is high, the pollutant source should be derived from anthropogenic activity (Najamuddin *et al.*, 2016a).

Werorilangi *et al.* (2013) studied the waters of Makassar coast and classified the geochemical fractionation of Pb and Zn into three fractions which were acid soluble (exchangeable and carbonate), reducible (Mn-Fe oxides) and organic fractions. The percentage mean of fraction of Pb and Zn were 0-7% and 0-55% (acid soluble), 64-

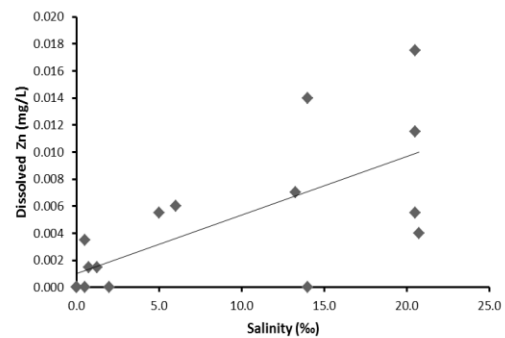
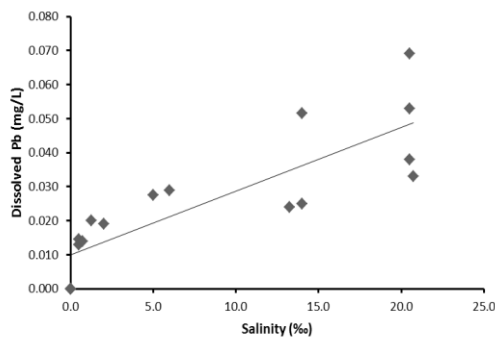


Figure 4. Relationship between dissolved concentration and salinity of Pb and Zn in Jeneberang River estuary

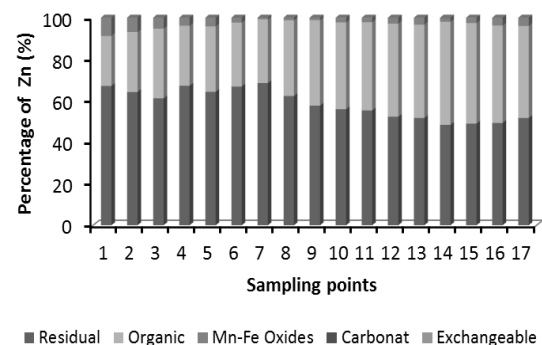
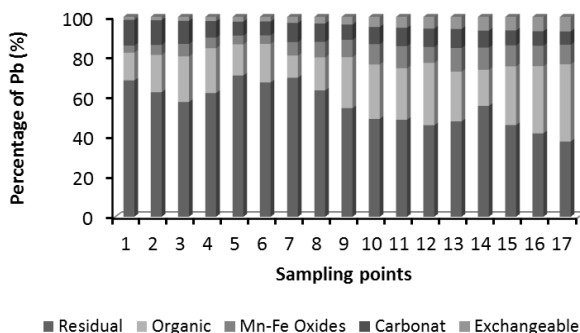


Figure 5. Percentage of geochemical fractionation of Pb and Zn in Jeneberang Estuary



78% and 39-100% (reducible), and 16-33% and 0-25% (organic). However, all of the three fractions was the non-resistant group without the resistant fraction.

Arifin and Fadhlina (2009) studied the Bay of Jakarta and reported that the non-resistant fraction of Pb were 8.55–93.77% (oxidisable organic), 0.17–25.99% (acid reducible), and 0-8.16% (easily, freely, leachable, and exchangeable), and the resistant fraction of Pb were 0-92.66 %. High component of oxidisable organic fraction indicated that the source of Pb pollutant in was derived from human activities (anthropogenic source).

## Conclusion

Based on dissolved form, the highest distribution of Pb and Zn were found in the coastal waters and the lowest distribution was in the fresh water. In addition, the highest distribution of particulate Pb and Zn were found in the fresh water and the lowest distribution of particulate Pb and Zn was in the estuary. Based on the sediment, the highest distribution of Pb and Zn were in the fresh water and the lowest distribution of Pb and Zn was in the estuary. The main source of dissolved heavy metals derived from the coastal waters, while the particulate derived from the river. The behavior of dissolved heavy metals showed an enhanced concentration (desorption) as an increased salinity gradient. Resistant fraction (residual) was a dominant fraction of heavy metals in the sediment. This indicated that the main source in the sediment originated from natural source and it described Pb and Zn were low reactivity in the waters.

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