Omni-Akuatika, 13 (2): 25–38, 2017
ISSN: 1858-3873 print / 2476-9347 online

Research Article

Lead (Pb) Distribution on Soil, Water and Mangrove Vegetation Matrices in Eastern Part of Segara Anakan Lagoon, Cilacap

Endang Hilmi[1,2*)], Asrul Sahri Siregar[1], Agung Dhamar Syakti[3,4]

[1] Fisheries and Marine Sciences Faculty-Jenderal Soedirman University, Kampus Perikanan Unsoed Karangwangkal, Jl dr. Suparno, Purwokerto, 53123, Indonesia
[2] Center for Disaster Mitigation – Jenderal Soedirman University, Indonesia
[3.] Fisheries and Marine Sciences Faculty and Center for Maritime Biosciences studies - Jenderal Soedirman University, Jl. HR. Boenyamin 708 Purwokerto 53122, Indonesia
[4.]Marine Science and Fisheries Faculty - Raja Ali Haji Maritime University, Jl. Politeknik Senggarang-Tanjungpinang, Riau Islands Province, 29100, Indonesia

**Corresponding author: dr.endanghilmi@gmail.com*

Received 1 February 2017; Accepted 14 August 2017; Available online 27 November 2017

ABSTRACT

Eastern part of Segara Anakan Lagoon (E-SAL) is an estuarine ecosystem to dispose industrial waste i.e. lead (Pb) containing waste. The study aims to analysis the distribution of Pb in soil, water and mangrove vegetation matrices. Several parameters including bioaccumulation factor (BAF), translocation factor (TF), leaf morphometric (the effect of Pb for mangrove vegetation) were used to estimate their impact. We developed a pre-design of mangrove zone as a model in reducing Pb cntaminantion in E-SAL. The results showed the distribution of Pb in E-SAL was 0.177 – 0.233 mg/L (water), 0.320 – 0.780 mg/kg (soil), 4.80–8.67 mg/kg (mangrove root), 2.48–6.96 mg/kg (mangrove stem), and 1.48–4.76 mg/kg (mangrove leaf). The scoring of BAF in mangrove vegetation had value between 22.2–40.1 and TF between 0.9–1.3. The distribution of Pb in soil depths were 8.89 mg/kg (0-50 cm) to 0.56 mg/kg (150-200 cm). The impact of Pb was 2-60 % of leaf damage on surface leafs. The mangrove zone to reduce impact of Pb in E-SAL was *Rhizophora apiculata, Bruguiera sexangula, Aegiceras corniculatum* and *Sonneratia caseolaris* as mangrove species in the first zone.

Keywords: *Pb accumulation; mangrove capacity; bioaccumulation factor; translocation factor; the effect of Pb*

1. Introduction

The Eastern part of Segara Anakan Lagoon (E-SAL) is a specific estuarine which is influenced by settlement, agriculture or industry as a resource of heavy metal contaminant (Qiu et al., 2014; Cuong et al., 2005) including of the contaminant of Pb. Pb is a heavy metal in IV A group of periodic system which has atomic number 82 and atomic weight 207.19 (Palar, 2004). Pb is used by oil industry, ship industry, port (Buwono et al., 2005; Maslukah, 2006), water waste of shape balsat (Agustriani et al, 2016). and as active matter for electron transfer used in the battery industry. Pb also is used to increase metallurgic properties for electric cables, active matters of premium, chemical industry and to protect corrosion (Palar, 2004). Pb has characteristics are toxicity less than cadmium (Cd) and Mercury (Hg), give chronic effect for organism (Herman, 2006; Maslukah, 2006), difficult to degrade, to accumulate, insoluble (Susanti, 2010; Lestari, 2014), can be distributed in water ecosystem, soil, vegetation and organism (Ahmed, et al., 2011), and give forward effect for organism in coastal ecosystem (Hartis and Santos, 2000).

Mangrove vegetation's in E-SAL are a predominant vegetation in coastal ecosystem (Ardii, 2008; UNEP, 2006; Brander et al., 2012; Hilmi et al., 2015) with lowest trees, sapling and seedling association (Hilmi et al, 2015) have

http://dx.doi.org/10.20884/1.oa.2017.13.2.83

ability to interface ecosystem (Kathiresan and Bingham, 2001; Parvarest et al., 2010), high litter productivity (Sharma et al., 2012) and have capacity to accumulate Pb contaminant (Lestari, 2014). Mangrove vegetation's have ability to reduce heavy metal pollution (Arisandy et al., 2012), to occupy heavy metal pollutants area (Abohassan, 2003; Cuong et al., 2005), to receive a large amount of waste from related drainage and rivers and to absorb heavy metal contaminant (Abohassan, 2003; Cuong et al., 2005; Lestari, 2014).

The distribution and accumulation of Pb in mangrove vegetation show a mangrove activity to reduce disposal of Pb from coastal ecosystem. The activity to release contaminant of Pb can be conducted by absorption and accumulation of Pb in mangrove vegetation. The metabolism process to reduce Pb contaminant from environment can be done by the accumulation, absorption and secretion activity in the gland of mangrove (Arisandy, et al., 2012; Qiu et al., 2014). The activity to absorb Pb can be done by mangrove vegetations (Abohassan, 2003; Cuong et al., 2005; Lestari, 2014) which will be accumulated in stem, roots, leaves and fruits, so can be measured in stem, leaf and root. The accumulation of Pb in mangrove vegetation can be reached until 5,890 ppm (Arisandy et al., 2012).

The analysis of accumulation as indicator's of Pb accumulation can be measured by score of *Bioaccumulation Factor* (BAF) and *Translocation Factor* (TF). The score of BAF and TF in vegetation, water and sediment show the pollution of Pb in the E-SAL. This data's can be used to develop plantation pattern of mangrove vegetation in disposal area.

This paper aims to determine the accumulation of Pb in mangrove vegetation, water and soil; to analysis BAF and TF; to observe effect of Pb accumulation and to develop mangrove zone based on accumulation of Pb in E-SAL.

2. Material and Methods

Study area

E-SAL is located in 7°44'40"- 7°37'20" South longitude and 108°52'40" – 109°01'00" East latitude consist several ecosystem such as mangrove, estuarine, sea grass and river ecosystem. Mangrove ecosystem in E-SAL is dominated by *Rhizophora* spp, *Bruguiera* spp, *Avicennia* spp., *Sonneratia* spp., *Aegiceras* spp., *Xylocarpus* pp., etc. (Ardii, 2008; Lestari, 2014; Hilmi et al., 2015). The site research in E-SAL was focused in Donan River (Station 1 is 7°42'30" South longitude – 108°59'40" East latitude, Station 2 is 7°42'10" South longitude – 108°59'10" East latitude, Station 3 is 7°41'30" South longitude – 108°59'50" East latitude and station 4 is 7°40'30" South longitude – 109°00'40" East latitude) can be seen on **Fig. 1**.

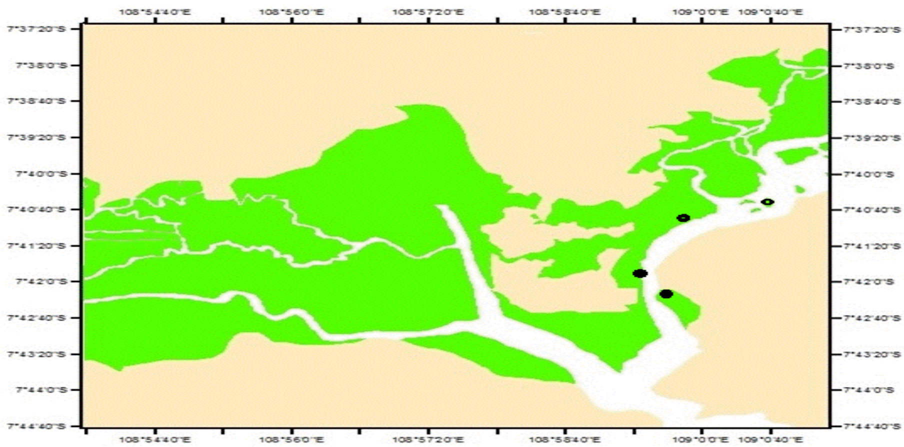


Figure.1. Site research in E-SAL

A global positioning system (GPS, Garmin GPS Map 62s, US) and geographic information system (ArcView GIS 3.3 "Environmental System Research Institute, Inc., HCI Technologies Ltd, India") were used to select the different sites in this research. The sampling technique to collect Pb data's used stratified sampling (Cochran 1997) for 4 stations with 3 replications.

Chemicals/Reagents, extraction and separation

Chemicals/regents used to determine Pb were Nitric acid (HNO_3) (Sigma Aldric, United States, SWN). And extraction and preparing Pb analysis are done by dry ash oxidation procedure. Dry ash oxidation procedures are (1) Weight 1.000 g dried, ground plant material (<0.8 mm) previously dried at, 65°C for 2 hours into a clean acid-washed crucible and place in a muffle furnace (2). Ash analyzed at 480°C overnight (16 hours). Remove the crucible from the muffle furnace, (3). When cool, add 10 drops of de-ionized water, and then carefully add 2 mL50% (v/v) HNO_3. (4) Evaporate to dryness on a hot plate (100°C), (5) Return the crucible to the muffle furnace (cooled to <200°C) and ash at 450°C for 30 min. Remove the crucible from the muffle furnace. (6.) When cool, dissolve the ash in 2 ml 20% (vlv) HNO_3 by heating one hotplate at approximately 100°C (7). Transfer the digest quantitatively to a 10 ml volumetric flask and dilute to volume with de-ionized water. If necessary, filter contents through a Whatman No. 42 filter and collect the filtrate in a plastic vial taking care to discard the first 2 ml (approximately) of filtrate. (8). Store samples at or below 10°C and analyze within a week. Loss of solution by evaporation is minimized by the low temperature

Atomic Absorption Spectrometry (AAS)

Equipments were used to determine Pb accumulation were tall-form glazed porcelain crucibles, 30-ml capacity, analytical balance (accurate to 1.0 mg), volumetric flasks with capacity 10 ml, electric hot plate, dispensers, muffle furnace and atomic absorption spectrophotometer or inductively coupled plasma emission spectrophotometer (Perkin Elmer 3110). Plant tissues normally contain, on a dry mass basis, 3 to 20 mg Pb/kg. As a general guide, if all five elements are required to be analyzed, the analyst should prepare multi element standards in 0.5 M HNO_3. The exact ratio will vary with the source and nature of the plant material and the chemistry of the soil or growing medium. Further adjustments in the ratio may be made with experience gained from analyzing particular types of samples. The normal recommended wave lengths (in nm) and detection limit (in parentheses) is Pb, 220.3 (1.5 pg/L). For laboratories that do not have access to an ICP-AES spectrometer, it is often possible to quantitatively determine Pb by air-acetylene flame AAS by using a 1.0 g sample in a final volume of 10 ml with the use of slotted or concentrator tubes.

Quality control and quality assurance

The preferred method of analysis is ICP-AES because of its sensitivity, relative freedom from interferences, and simultaneous multi elemental capability.

Bioaccumulation Factor and Translocations Factor

Bioaccumulation Factor and Translocation Factor were analyzed by the equation (Madejon et al.,2006; Ang et al.,2010; Ashraf et al.,2011; Madjid et al.,2011; Maldonado-Magna, 2011) that were Bioaccumulation factor is $\frac{\text{heavy metal trees}}{\text{heavy metal in soil}}$, and translocation factor is $\frac{\text{heavy metal in stem and leaves}}{\text{heavy metal in root}}$

Morphometric of mangrove vegetation

The analysis of morphometric was done by calculating of length, width, thickness and percentage of leaf damage. *Vernier Caliper* with precision 0, 05 mm was used to measure length, width and thickness of leaf. The leaf damage was analyzed by percentage of leaf damage and degradation of leaf coloring

Environmental factor

Analysis of pyrite, nitrate, and phosphate

The analysis of pyrite and nitrate used soil testing and plant analysis and phosphate which used Bray Method (Burt, 2004).

Analysis of salinity, pH and soil texture

The analysis of soil and water salinity used Handrefractometer (Atago. Japan); the analysis of soil and water pH used pH meter method (Rayment and Higginson, 1992) and soil texture was analyzed by hydrometer method Bouyoucos (1962).

Data Analysis

The analysis of data's used descriptive analysis with the data tabulation and the drawing of mangrove zone based on data of Pb accumulation

3. Results and Discussion

Pb Contaminant in east Segara Anakan Lagoon

Pb contaminant in the water and soil

Pb contaminant of water and soil in Segara Anakan Lagoon (E-SAL) was between 0.177 – 0.233 mg/L (water) and between 0.320 – 0.780 mg/kg (soil) (Fig.2). Fig.2, showed that potency of Pb in station 1 contained 0.177 mg/L (water) and 0.780 mg/kg (soil), the station 2 contained 0.212 mg/L (water) and 0.525 mg/kg (soil), the station 3 contained 0.180 mg/L (water) and 0.419 mg/kg (soil) and the station 4 contained 0.223 mg/l (water) and 0.320 mg/kg (soil). Potency of Pb in water and soil in E-SAL was higher than Research of Lestari and Edward (2004) which noted that average of contaminant of Pb in Teluk Jakarta had ranged 0.001-0.0027 mg/L, but did not differ with Arisandy et al., (2012) and Qiu et al., (2014). Based on the Indonesian Ministry for Life Environment (2004) which wrote that the standard of Pb contaminant in water must be lower than 0.008 mg/L give indication that contaminant of Pb in soil and water in E-SAL is very high. Hidayati et al., (2014) and Susanto et al., (2014) noted that the accumulation of heavy metal is largely dependent on soluble heavy metal present in pore waters and may also depend upon the chemical forms of solid phases of heavy metal.

The contaminant of Pb in soil and water had significant correlation with the source of contamination of Pb in lagoon ecosystem (Fernandes and Nayak, 2012; Cuong etal., 2005; Rochyatun, et al., 2006). The contaminant of Pb on soil **(**Fig 2) showed that in station 1 > station 2 > station 3 > station. Stasion 1 had highest contaminant of Pb because the station 1 had area near Pb source.

The contaminant of Pb in the soil and water will significant effect for mangrove life and other organisms e.g marine invertebrate communities (McKinley et al., 2011).. The effects of Pb contaminant for mangrove vegetation's are yellow coloring of leaf, mangrove stunted, and mangrove dying. Mangrove vegetation needs nutrient supply enough from environment to reduce effect of Pb. The nutrient is used to reduce Pb effect and to support mangrove life as soil characteristics are nitrate, phosphate, and pyrite. The nutrient supply are shown in station 1 are nitrate 0.090 mg/l, phosphate 3.20 mg/l and pyrite 2.55 %. The station 2 has nitrate 0.084 mg/l, phosphate 3.60 mg/l and pyrite 3.62%. The station 3 has nitrate 0.274 mg/l, phosphate 4.30 mg/l and pyrite 2.06 %, and the station 4 has nitrate 0.388 mg/l, phosphate 6.34 mg/l and pyrite 4.91 %. These soil factors on Fig 2 show that the station 1 is the lowest soil fertility. According MacFarlane et al., (2003) noted that the anaerobic sulphide, phosphate and nitrate of soil are used to increase vegetation adaptation (Charles et al., 2016) and to support mangrove vegetation to life in contaminant area.

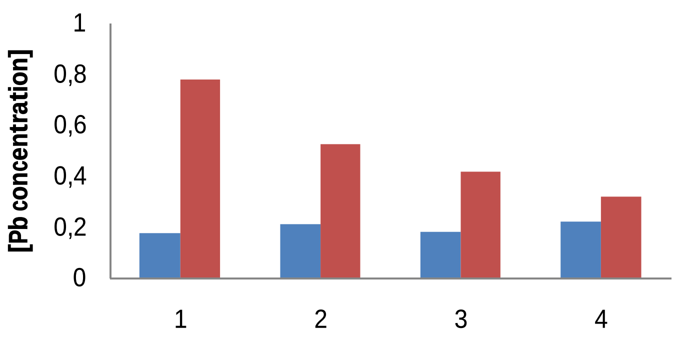


Fig. 2. Pb concentration in water(mg/L) and sediment (mg/kg) in difference stations (1-4) of Segara Anakan Lagoon. Blue = water; red = sediment

The other factor is the soil texture as a main factor will influence mangrove vegetation to life in pollution area (Thomas and Fernandes, 1997; Krauss and Alen, 2003). The soil texture in Segara Anakan is dominated by mud clay which is not different with Arisandi et al., (2012) which give best effect to accumulate Pb in environment, because Pb will be accumulated in clay > sandy clay> sand. The pore of soil in soil texture will influence transport of heavy metal to ecosystem (Alhashmi et al, 2015). SAL ecosystem is dominated by fine texture (clay) which has the best ability to increase heavy metals absorption. This condition shows that E-SAL has Pb contaminant higher than other ecosystems, because fine texture in SAL will easily absorb Pb than coarse texture (Parvaresh et al., 2011; Marchand et al., 2006).

The existence of Pb in the soil has important role to asses' metal contaminant of aquatic systems (Nemr et al., 2006; Wardas, 1996; Fernandes and Nayak, 2012). The potency of Pb in aquatic ecosystem gives worst effect for organism. The reports of the toxic effects from heavy metal (Pb) give impact for sudden mortalities of organism in the contaminant area (Davidson et al., 2009; Liu et al., 2014), because Pb give high toxicity level for the environment. Pb concentration between 0.1 – 0.2 ppm gives impact to the poisoning of fish. Pb concentration until 188 ppm causes mortality of fish, and crustacean (Lestari and Edward, 2004; Tarigan et al., 2003), crabs (Sabu et al, 2006) and micro benthic (Ahmad et al., 2011; Liu et al., 2014).

The vertical distribution of Pb accumulation in the soil

The vertical distribution of Pb accumulation in the soil can be seen on Table 1. The Table 1 showed that decreasing trend of Pb accumulation in the depth level of soil. The vertical distribution of Pb accumulation following of soil depth stratification showed that Pb accumulation (1) among 0 cm - 50 cm had 5.11 mg/kg – 8.89 mg/kg, (2) among 50 cm – 100 had 3.98 mg/kg – 5.35 mg/kg, (3) among 50 cm - 100 had 2.08 mg/kg – 3.13 mg/kg, (4) among 100 cm – 150 cm had 0.92 mg/kg – 1.15 mg/kg and (5) among 150 cm – 200 cm had 0.56 mg/kg – 0.73 mg/kg. This condition gave synthesis that Pb accumulation in top soil is bigger than other deep of soil.

Table 1. The vertical structure of Pb accumulation in the soil based on soil depth in E-SAL

Station	Vertical depth structure (cm)	Pb Accumulation of sediment (mg/kg)
1	0	8.8905
	50	4.7710
	100	2.2172
	150	0.9218
	200	0.7320
2	0	8.0267
	50	5.2780
	100	2.7326
	150	1.0237
	200	0.7328
3	0	5.1167
	50	3.9780
	100	2.0755
	150	1.1450
	200	0.7320
4	0	7.8825
	50	5.3470
	100	3.1256
	150	0.9870
	200	0.5614

This research showed that the accumulation of Pb in top soil (0-50 cm) is biggest accumulation and would give bigger negative effect for mangrove growth than other soil segment. Hilmi et al., (2015) reported that mangrove vegetation in E-SAL (Pb contaminant area) had bad performance for diameter, height or leaf of mangrove vegetation. Mangrove vegetation in E-SAL was stunted, damage and dying. Agoramoorthy et al., (2008) and Thomas and Fernandes (1997) also noted that the mangrove had worst growth in area would be influence by pollution.

The distribution of Pb accumulation on mangrove species in E-SAL

The accumulation of Pb on stem, root and leaf.

The chemical wastes such heavy metals in seawater ecosystems from anthrophogenic activities input such as industrial effluent, urban runoff, domestic activities etc were serious probleme for mangrove ecosystems, including Pb waste (Yudhistira et al, 2015). The accumulation of Pb as process of absorption and accumulation in mangrove vegetation will be accumulated in stem, leaf, fruit and root (Munawar dan Rina, 2004; MacFarlane et al., 2003; Machado et al., 2002). Wang et al., (2012) noted that beside in sediment, Pb also was accumulated in fine roots, thick roots, branches, and leaves. The accumulations of Pb in mangrove vegetation's were shown in Fig.3.

The root of mangrove had accumulation of Pb higher than the stem and the leaf. The accumulation of Pb in mangrove root ranged from 4.80 mg/kg to 8.67 mg/kg while the extent on stem and leaf ranged from 2.48 mg/kg – 6.96 mg/kg, and 1.48 mg/kg – 4.76 mg/kg respectively. The accumulation of Pb in *Sonneratia* spp root ranged from 5.34 – 8.13 mg/kg. For other mangrove species show that Pb in roots system has been found within a range 5.10 – 8.27 mg/kg in *Rhizophora apiculata*, 4.40 – 6.96 mg/kg in *Rhizophora mucronata*, 4.80 – 5.72 mg/kg in *Avicennia* spp, 5.55 – 8.67 mg/kg in *Bruguiera* spp, and 6.96 – 7.37 mg/kg for *Aegiceras corniculatum*.

While the accumulation of Pb in stems of *Sonneratia* spp, *R. apiculata, R. mucronata*, *Avicennia* spp, *Bruguiera* spp, *Aegiceras corniculatum* and *Acrosticum aureum* had range 3.61 – 7.67 mg/kg, 3.47 – 6.96 mg/kg 2.48 - 4.55 mg/kg, 2.96 – 3.85 mg/kg, 3.59 -5.12 mg/kg, 3.54 – 5.72 mg/kg and 1.24 mg/kg respectively, And Qiu et al., (2014) estimated the average accumulation of Pb on standing stock of *Rhizophora apiculata* in leaf, branch and root were 0.50 mg/kg, 7.04 mg/kg, 3.13 mg/kg. These results were not different with Arisandi et al., (2012) which noted that Pb accumulation of stem *Avicennia marina* had scored 5.89 mg/kg.

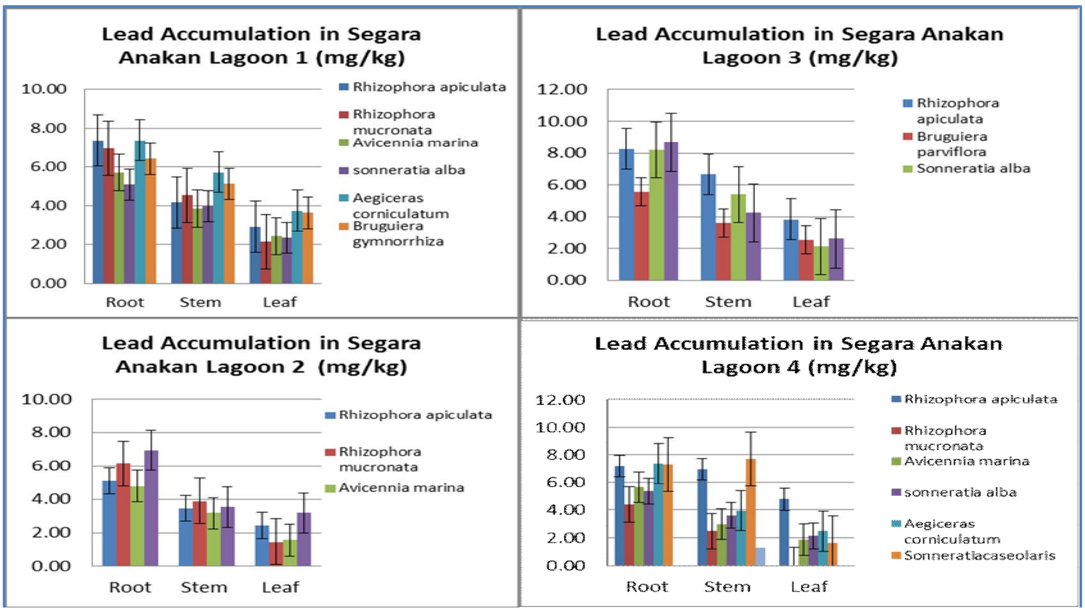


Fig 3. The accumulation of Pb at the part of mangrove tress.

The Fig 3 showed that the accumulation of Pb in root > stem > leaf. Arisandy et al., (2012) and MacFarlane et al., (2003) noted that the heavy metal (i.e. Pb) concentrations in roots were significantly higher than those found in the other plant parts is caused by time to accumulate heavy metal of stem is longer than other trees dimension and root as the first contact with Pb metal pollution thus is translocate to other parts of the vegetation (Munawar dan Rina, 2004). The other reason is the roots have been known as good absorptive sponge to heavy metal in soil and water. Metals absorbed or adsorbed by roots are often bound with the cell wall material or other macro molecules to prevent them from translocation to the sensitive plant parts.

The accumulation of Pb in mangrove vegetation's were high, because Pb waste from industry and domestic activities were often disposed in coastal areas, both by petroleum refinery, cement and power plants. E-SAL is the ecosystem of estuary is used to dispose industry waste. The potency of Pb in E-SAL had ranged 0.18 – 0.22 ppm (in water) and 0.32 – 0.78 ppm (in sediment). The potency of Pb in the environment influences accumulation of Pb in mangrove vegetation. The accumulation of Pb in mangrove vegetation show that mangrove has capacity to retain heavy metals (Machado et al., 2002; Alongi et al., 2004), has highly depend on the chemical (Guangqiu et al., 2007), biological and/or physical processes, and the entire soil-plant-water system in mangrove ecosystem (Munawar dan Rina, 2004). Based on data of this accumulation showed mangrove vegetation had good tolerance of Pb contaminant similar with Parvaresh et al., (2011) reported the potency of Pb in the sediments and leaves of grey mangrove (*A.marina*), and high tolerance of mangrove vegetation in pollution area (Marchand et al., 2006).

However, the accumulation of Pb shows the effectiveness of mangrove ecosystem to remove input pollutants from water and sediment (MacFarlane et al., 2003). Mangrove still needs salinity, nitrate, phosphate, and pyrite to life. Based research showed that potency salinity, nitrate, phosphate, and pyrite in locations are 0.090 - 0.388 ppm (nitrate), 3.20 - 7.34 ppm (phosphate), 1.89 - 4.91 % (pyrite) and 15- 23 ppt (salinity) (Lestari, 2014; Hilmi et al., 2015) were good categorize to support mangrove growth (Krasuss and Alen, 2003; Chebo, 2009;)

The analysis of Pb for each species can be seen on Fig.4 which showed the capacity and tolerance of mangrove vegetations to absorb Pb (Buwono et al., 2005; Machado et al., 2002) that were *Acrosticum aureum* < *Avicennia marina* < *Rhizophora mucronata* < *Bruguiera parviflora* < *Sonneratia alba* < *Aegiceras corniculatum* < *Bruguiera gymnorrhiza* < *Bruguiera sexangula* < *Rhizophora apiculata* < *Sonneratia caseolaris.*

The data showed that *Sonneratia caseolaris* absorbs Pb higher than other species and can be lived in the first zone of pollution area in E-SAL. The result of this research is not different with Arisandy et al., (2012) which note that Pb in mangrove species range from 25 to 225 µg g^{-1}dry wt which are distributed that are *A. officinalis* has range 75 to 225µg/g dry wt, *Acanthus ilicifolius* and *Sonneratia caseolaris* has range 25 to 125 µg/g dry wt, and *Bruguiera gymnorrhiza* has range 50 to 75µg/g dry wt. The data showed that mangrove species have different abilities to accumulate Pb contaminant (Thomas and Fernandez, 1997). The accumulation of Pb on mangrove species are influenced by mangrove adaptation, length of expose, temperature, pH, and salinity (Rudiyanti, 2007), mangrove zone (Hilmi, et.al., 2015), mangrove capacity (Machado et al., 2002), the expose of species, and condition of site habitat as freshwater, estuarine and marine ecosystem

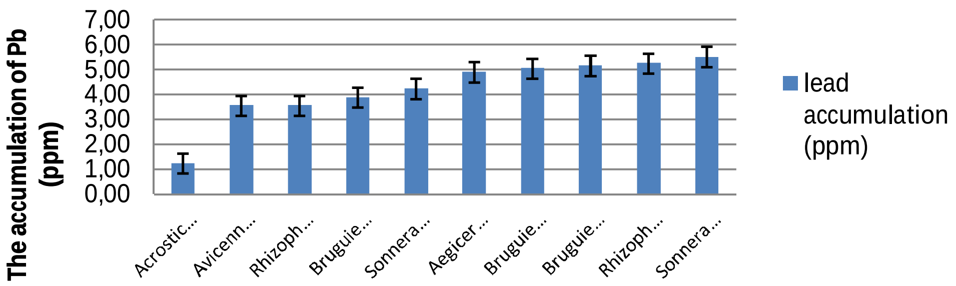


Fig 4. The accumulation of Pb for each mangrove species

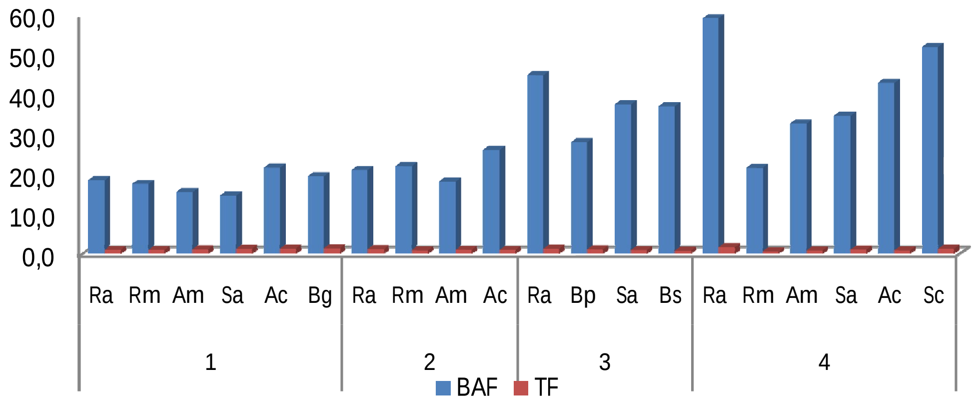
Bioaccumulation factor and translocation factor of Pb

The bioaccumulation factor and translocation factor of Pb can be seen on **Fig. 5**. The capacity, performance and ability of vegetation to accumulate Pb for root, leaf and stem of mangrove vegetation's are determined as Bioaccumulation Factor of Pb (BAF) of Pb (Yoon et al., 2006; Ahmadpour, 2012; Buwono et al., 2005; Madejon et al.,2006; Ang et al.,2010; Ashraf et al.,2011; Madjid et al.,2011; Maldonado-Magna, 2011). BAF is determined by ratio between Pb accumulation of mangrove vegetation with sediment. The score of BAF has range between 0 until more than 1 (Madejon et al.,2006; Ang et al.,2010; Ashraf et al.,2011; Madjid et al.,2011; Maldonado-Magna, 2011). If BAF > 1 this gives indication that mangrove species has best ability to accumulate Pb. The high score of BAF shows high capacity of vegetation to accumulate Pb from environment (Yoon et al., 2006; Branzini and Zubillaga, 2013).

Figure 5 showed that the average of BAF from *Rhizophora apiculata* (35.8), *Rhizophora mucronata* (22.2), *Avicennia marina* (25.9), *Sonneratia alba* (28.1), *Aegiceras corniculatum* (42.1), *Bruguiera gymnorrhiza* (30.2), *Bruguiera praviflora* (30.4), *Bruguiera sexangula* (31.2), *Sonneratia caseolaris* (40.1). Fig 5 also showed that the score of BAF in mangrove species gave the indication the ability of Pb accumulation by mangrove vegetation's in Segara Anakan Lagoon (E-SAL) (Yoon et al., 2006; Branzini and Zubillaga, 2013).

Thus, translocation factor (TF) gives viewing of capacity to absorb and translocate Pb contaminant from root (below ground) until leaf (above ground) (Ahmadpour et al., 2012). TF is formulated by comparison between the accumulation of Pb of leaf and stem with root. If TF score > 1 gave indication that vegetation has high ability to absorb and translocate Pb contaminant (Maldonado-Magaña, 2011; Ahmadpour et al., 2012; Arifin et al., 2012; Branzini and Zubillaga, 2013; Madejon et al.,2006; Ang et al.,2010; Ashraf et al.,2011; Madjid et al.,2011; Maldonado-Magna, 2011).

Fig. 5 explained that the average of TF from *Rhizophora apiculata* (1.3), *Rhizophora mucronata* (0.9), *Avicennia marina* (1.0), *Sonneratia alba* (1.0), *Aegiceras corniculatum* (1.3), *Bruguiera gymnorrhiza* (1.1), *Bruguiera praviflora* (1.0), *Bruguiera sexangula* (0.9), *Sonneratia caseolaris* (1.2). The score of TF in Fig 5 gave indication that mangrove vegetation had high capacity to absorb and translocate Pb contaminant in root, leaf and stem. The accumulation of Pb has indication Pb absorption and translocation in root, stem and leaf. Abohassan (2003) give note that translocation of the accumulation of Pb s in Shuaiba Mangrove System are 5.01 μg/ g^{-}(Fine root), 0.38 μg/g(stem), 0.68 μg/g (branch) and 0,57 μg/g (leaves).



Note : *Ra = Rhizophora apiculata, Rm = Rhizophora mucronata, Am = Avicennia marina, Sa = Sonneratia alba, Ac = Aegiceras corniculatum, Bg = Bruguiera gymnorrhiza, Bp = Bruguiera parviflora, Bs = Bruguiera sexangula, sc = Sonneratia caseolaris*

Fig 5. The distribution of BAF dan TF for each mangrove species

The accumulation of Pb in mangrove vegetation's also showed the positive correlation between the tolerance of mangrove vegetation with capacity to reduce impact of Pb pollution with precipitation, membrane filtration, electrolyte or liquid extraction, electro dialysis and reversed osmosis activity (Oo, et al., 2009). Arisadi et al., (2012) explained that mangrove has good adaptation to reduce impact pollution with best adaptation for xylem and phloem of root and stem but not good adaptation for bark and fruit tissue, but pollution still give impact of bark and fruit damage, deformation of leaf tissue and fruit tissue. The accumulation of Pb in mangrove root and leaf can be defined as indicators of metal translocation and protect the sensitive parts of the plant from metal contamination (Tam and Wong, 1997)

Leaf morphometric as an indicator of pb contaminant effect

The effect of heavy metal pollution is showed by high mortality, leaf damage, and also matured leaves gradually whitered to be yellow and defoliated and induced changes in the chemical compounds (Rivero, 2001; Booker et al., 1996). Leaf morphometric is an indicator of Pb contaminant impact give viewing degradation of leaf. The leaf degradation is leaf size, leaf color or leaf damage. Leaf morphometric can be seen on Table 2. Table 2 showed that in station 1 gave viewing of leaf damage between 10 % - 60 %, station 2 had scored 20 % - 55 %, and station 3 had scored 2 % - 40 % and station 4 between 2 – 20 %. The grade of leaf damage shows as the respective stations based on mangrove ecosystem distance from contaminant source. The location of first station is near to a Pb resource (high Pb contaminant) which gives the highest Pb impact to leaf size, leaf coloring and leaf damage.

Table 2. Leaf morphometric of mangrove vegetation in Pb pollution area

Station	Species	Leaf Morphometric			
		Length	width	Thick	Percentage of damage
1	*Aegiceras corniculatum* (AC)	5.9	4.2	0.67	55%
	Bruguiera gymnorrhiza (BG)	14.1	5.5	1.34	10%
	Rhizophora apiculata (RA)	10.1	4.3	0.23	40%
	Sonneratia caseolaris (SC)	7.6	5.4	0.48	30%
	Avicennia marina (AM)	8.4	3.3	0.30	60%
	Rhizophora mucronata (RM)	10.5	5.0	0.11	45%
2	*A. corniculatum* (AC)	7.8	5.0	0.81	25%
	R. apiculata (RA)	12.7	3.7	1.19	35%
	A. marina (AM)	8.6	3.4	0.35	55%
	S. caseolaris (SC)	6.6	5.2	1.00	20%
	R. mucronata (RM)	9.6	4.5	0.65	30%
3	*B. sexangula* (BS)	14.1	6.3	0.90	20%
	S. alba (SA)	6.4	4.8	1.16	15%
	A. marina (AM)	8.7	3.5	0.79	40%
	B. parviflora (BP)	8.3	3.8	1.36	15%
	A. corniculatum (AC)	11.5	4.0	1.39	15%
	R. apiculata (RA)	13.0	4.5	1.35	10%
	R. mucronata (RM)	14.2	7.8	0.75	2%
4	*S. alba* (SA)	6.5	4.4	0.72	5%
	R. apiculata (RA)	12.3	3.8	1.14	2%
	R. mucronata (RM)	9.9	3.5	0.92	20%
	Acrosticum aureum (Aa)	8.8	1.5	0.24	15%
	A. marina (AM)	9.0	3.5	0.70	15%

Leaf morphometric can be used as a tool of pollution indicator. Leaf morphometric shows effect of Pb contaminant which shows as leaf gets damaged until the plant dies. This research shows that leaf damage had ranged between 10 % - 60 %. The adaptation of mangrove trees to accumulate Pb shows the survival ability of mangrove to reduce Pb effect.

The damage of leaf is an indicator of Pb pollution at leaf besides destruction of root, stem, and other dimension, but leaf damage is easily indicates pollution in the environment than other dimensions. Leaf damage is shown by the yellowing, leaf destruction, size of leaf, etc. The other indicators to see Pb or heavy metal contaminant effect are growth performance of propagules, growth of root including fine root, and stem (El-Nemr et al., 2006; Colt, 2006; Davidson et al.,2009).

Thus, Pb pollutant also gives effect toward the metabolism of mangrove vegetations, mangrove growth and performance of mangrove tissue. Arisandy et al., (2012) noted that the observed result of tissue showed that tissues of stems and roots didn't damage, but only had black spot for epidermis of leaves and deformation of xylem and phloem for fruits. Mangrove trees must build a metabolism mechanism to minimize of Pb effect with the accumulation of Pb mechanism, Pb secretion mechanism and Pb exclusion mechanism. This mechanism aims to reduce Pb impact for mangrove growth both on root, leaf, stem, bark and other.

The zone of mangrove based on ability to accumulate Pb

The zone of mangrove ecosystem representative the mangrove ability to accumulate Pb in mangrove ecosystem which is accumulated in the mangrove leaves, stem and root. The accumulation of Pb on mangrove vegetation's are influenced by the potency of contaminant in soil and water which have significant correlation with the Pb in root, stem and leaf (Seidl,et al., 2012; Shi et al, 2015; Crystal et al., 2014). Davidson et al., (2009). Wang et al., (2012) also noted that soils, water and mangrove vegetation plants of mangrove ecosystem had significant to take Pb contaminant (El-Nemr et al., 2006). Pb contaminant of soil and water influenced plant distribution in mangrove ecosystem which had correlation with plant adaptation and tolerance toward existence of Pb in environment (El-Nemr et al., 2006; Colt, 2006; Cuong etal., 2005; Marchand et al., 2006).

The zone of mangrove is built to show mangrove ability to accumulate Pb can be seen on Table 3. Table 3 explained the zone of mangrove as represtative of accumulation of Pb. The zone of mangrove is divided into three zones. Zone 1 is dominated by *Rhizophora apiculata, Bruguiera sexangula, Aegiceras corniculatum* and *Sonneratia caseolaris,* zone 2 is dominated *Sonneratia alba, Bruguiera gymnorrhiza,* and *Rhizophora mucronata,* zone 3 is dominated by *Acrosticum aureum, Avicennia marina,* and *Bruguiera parviflora*

Table 3. The zone of mangrove base on accumulation of Pb in E-SAL

		The accumulation of Pb		
Zone	Species	root	stem	leaf
3	*Acrosticum aureum*		1.24	
	Avicennia marina	5.38	3.33	1.95
	Bruguiera parviflora	5.55	3.59	2.55
2	*Sonneratia alba*	6.20	4.32	2.19
	Bruguiera gymnorrhiza	6.42	5.12	3.63
	Rhizophora mucronata	5.84	3.64	1.20
1	*Rhizophora apiculata*	6.98	5.31	3.49
	Bruguiera sexangula	8.67	4.23	2.61
	Aegiceras corniculatum	7.22	4.40	3.12
	Sonneratiacaseolaris	7.29	7.67	1.62

The zone of mangrove can be used as criteria of mangrove rehabilitation strategy in coastal area base on ability to reduce contaminant of Pb in coastal ecosystem (Ooa, et al., 2009). *Rhizophora apiculata, Bruguiera sexangula, Aegiceras corniculatum,* and *Sonneratia caseolaris* as major species have biggest ability to accumulate and reduce Pb from water and sediment (the first zone). These species as main species are used to rehabilitate pollution area in coastal ecosystem (Ooa, et al., 2009).

4. Conclusion

Mangrove vegetation's have ability to reduce Pb contaminant through the accumulation activity of at the root, steam, and leaf. Mangrove root is a part of mangrove which best ability to accumulate Pb. *Bruguiera* spp is best of a mangrove species to accumulate Pb which has score of Pb accumulation between 5.55 – 8.67 mg/kg. The mangrove species like as *Bruguiera* spp., *Rhizophora apiculata*, *Sonneratia* spp., *Aegiceras corniculatum*, *Rhizophora mucronata* and *Avicennia* spp., have good adaptation to grow in Pb contaminant area.

BAF dan TF from *Rhizophora apiculata*, *Aegiceras corniculatum*, *and Sonneratia caseolaris* has highest score which indicate that these species have good ability to accumulate Pb contaminant. And the first zone of mangrove ecosystem give indication of best adaptable and best adsorb able of mangrove toward contaminant of Pb. These species are *Rhizophora apiculata, Bruguiera sexangula, Aegiceras corniculatum* and Sonneratia *caseolaris*.

Acklowledgment

This study has been supported by a Competitive Grant from "Dirjen Pendidikan Tinggi Kemendiknas" and Dr. Isdy Sulistyo for re-reading this manuscript. We also acklowledge under-graduated students from Fisheries and Marine Science Faculty for their involvement in this study.

References

Abohassan, R. A. 2013. Heavy metal pollution in *Avicennia marina* mangrove systems on the Red Sea coast of Saudi Arabia. JKAU: Meteorology, Environment and Arid Land Agriculture 24 (1) : 35-53.

Agoramoorthy, G., Chen, F., Hsu, M. 2008. Threat of heavy metal pollution in halophytic and mangrove plants of Tamil Nadu, India. Environmental Pollution 155 : 320–326.

Fitri Agustriani, F., Ida, A.S.P., Suteja, Y. 2016. Penilaian pengkayaan logam Timbal (Pb) dan tingkat kontaminasi air ballast di perairan Tanjung Api-Api, Sumatera Selatan. Omni-Akuatika 12 (3): 114 – 118.

Ahmed, K., Mehedi, Y., Haque. R., Mondol, P. 2011. Heavy metal concentrations in some macrobenthic fauna of the Sundarbans mangrove forest, south west coast of Bangladesh. Environmental Monitoring and Assessment 177: 505–514.

Alhashmi, Z., Blunt, M.J., Bijeljic, B. 2015. Predictions of dynamic changes in reaction rates as a consequence of incomplete mixing using pore scale reactive transport modeling on images of porous media. Journal of Contaminant Hydrology 179: 171–181.

Alongi, D.M, Wattayakorn, G., Boyle, G. 2004. Influence of roots and climate on mineral and trace element storage and flux in tropical mangrove soils. Biogeochemistry 69: 105–123

Ang, L.H., Tang, L.K., Ho, W.M., Hui, T.F., Theseira, G.W. 2010. Phytoremediation of Cd and Pb by four tropical Timber species grown on an ex-tin mine in Peninsular Malaysia. World Academy of Science, Engineering and Technology 62: 244 – 248.

Ardii, E.R. 2008. A trophic flow model of the Segara Anakan lagoon,Cilacap, Indonesia. Dissertation. Faculty of Biology and Chemistry (FB 2) University of Bremen.

Arisandy, K.R., Herawati, E.Y.,Suprayitno, E. 2012. Lead accumulation and histology viewing of *Avicennia marina* (forsk)Vierh tissue in Est Java beach. Jurnal Penelitian Perikanan 1(1), 15-25

Ashraf, M.A., Maah, M.J., Yusoff, I. 2011. Heavy metals accumulation in plants growing in ex tin mining Catchment. International

Journal of Environmental Science Technology 8 (2): 401-416.

Brander, L.M., WagtendonkA.J., Hussain, S., McVittie, A., Verburg, P.H., De Groot, R.S., Ploeg, S.V. 2012. Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application. Ecosystem Services 1: 62–69.

Buwono, D., Lestari, L., Suherman, H. 2005. Reducing effort of Hg, Pb, in Mytilus Viridis Linn. With concentration and retention time of Na2CaEDTA differ. Jurnal Bionatura 7 (3): 192 – 204.

Charles J. Paradis, C.J., Jagadamma, S., Watson, D.B., McKay, L.D., Hazen, T.C., Park, M,. Istok, J.D. 2016. In situ mobility of uranium in the presence of nitrate following sulfate-reducing conditions. Journal of Contaminant Hydrology 187: 55–64

Chebo, A.K. 2009. Monitoring wetlands deterioration in the Cameroon coastal lowlands: implications for management. Procedia Earth and Planetary Science 1: 1010–1015.

Cochran, W.G.,1997. Sampling Techniques (Third edition). John Wiley & sons

Colt, J. 2006. Water quality requirements for reuse systems. Aquaculture Engineering 34: 143–156.

Crystal Ng, G.H., Bekins, B.A., Cozzarelli, I.M., Baedecker, M.J.,Philip C. Bennett, P.C., Amos, R.T., . 2014. A mass balance approach to investigating geochemical controls on secondary water quality impacts at a crude oil spill site near Bemidji, MN. Journal of Contaminant Hydrology 164, 1–15.

Cuong, D.T., Bayen, S., Wurl, O., Subramanian, K., Wong, K.K.S., Sivasothi, N., Obbrad, J.P., 2005. Heavy metal contamination in mangrove habitats of Singapore. Marine Pollution Bulletin 50**:** 1713-44.

Davidson, J., Good, C., Welsh, C., Brazil, B., Summerfelt, S., 2009. Heavy metal and waste metabolite accumulation and their potential effecton rainbow trout performance in a replicated water reuse system operated at low or high system flushing rates. Aquacultural Engineering 41, 136–145

El-Nemr, A., Khaled, A., El-SikailyA. 2006. Distribution and statistical analysis of leachable and total heavy metals in the sediments of the Suez Gulf. Environmental Monitoring and Assessment 118(1–3): 89–112.

Fernandes, L.L., Nayak, G.N. 2012. Heavy metals contamination in mudflat and mangrove sediments (Mumbai, India). Chemistry and Ecology 28 (5): 435–455.

Guangqiu, Q., Chongling, Y., Haoliang, L. 2007. Influence of heavy metals on the carbohydrate and phenolics in mangrove, *Aegiceras corniculatum* L., Seedlings. Bulletin of Environmental Contaminant Toxicology 78, 440–444.

Hartis, R.R., Santos, G.F. 2000. Heavy metal contamination and physiological variability in the the brazilian mangrove crabs *Ucides cordatus* and *Callinectes danae* (Crustacea : Decapoda). Marine Biology 137: 691 – 703.

Herman, D.Z. 2006. Tinjauan terhadap tailing mengandung Unsur Pencemar Arsen (As), Merkuri (Hg), Timbal (Pb), dan Kadmium (Cd) dari Sisa Pengolahan Bijih Logam. Jurnal Geologi Indonesia. Vol. 1 No. 1, 31-36.

Hidayati, N.V., Siregar, A;S., Sari, L.K., Putra, G.L. 2014. Pendugaan tngkat kontaminasi logam berat Pb, Cd dan Cr pada air dan sediment di perairan Segara Anakan, Cilacap. Omni-Akuatika 10 (1) : 30-39.

Hilmi, E., Sahri, A.S., Febryanni, L., Novaliani, R., Amir, S.A., Syakti, A.D. 2015. Struktur komunitas, zonasi dan keanekaragaman hayati vegetasi mangrove di Segara Anakan Cilacap. Omni-Akuatika 11 (2): 20–32, 2015

Kathiresan, K., Bingham, B.L, 2001. Biology of mangroves and mangrove ecosystems. Advance in Marine Biology 40: 81–251

Krauss, K.W.,Alen, J.A. 2003. Factors influencing the regeneration of the mangrove *Bruguiera gymnorrhiza* (L) lamk. on tropical pasific island. Forest Ecology and Management 176: 49 -60.

Lestari, M. 2014. The Bioaccumulation of Lead (Pb) for Rhizophora apiculata di Donan River Segara Anakan Cilacap. Thesis.

Faculty of Fisheries and Marine Science. Jenderal Soedirman University. p. 74

Lestari., Edward. 2004. Heavy metal pollution effect to sea water quality and fisheries resources (Case study fish death in Teluk Jakarta). Makara Sains 8 (2): 52-58.

Liu, J., Wi, H., Feng, J., Li, Z., Lin, G. 2014. Heavy metal contamination and ecological risk assessments in the sediments and zoobenthos of selected mangrove ecosystems,South China. Catena 119: 136–142

MacFarlane, G.R., Pulkownik, A., Burchett, M.D. 2003. Accumulation and distribution of heavy metals in the gray mangrove, Avicennia marina (Forsk.) Vierh: biological indication potential. Environmental Pollution 123: 139-151.

Machado, W., Moscatelli, M., Rezende, L.G. 2002. Mercury, zinc, and copper accumulation in mangrove sediments surrounding a large landfill in southeast Brazil. Environmental Pollution 120:455–461.

Madejón, P., Murillo, J.M., Marañón, T., Cabrera, F. 2006. Bioaccumulation of trace elements in a wild grass three years after the Aznalcólllar mine spill (South Spain). Environmental Monitoring and Assessment 114: 169–189.

Madjid, N. M., Islam, M.M., Justin, V., Abdu, A., Ahmadpour, P. 2011. Evaluation of heavy metal uptake and translocation by *Acacia mangium* as a phytoremediator of copper contaminated soil. African Journal of Biotechnology 10(42): 8373-8379.

Maldonado-Magaña, A., E. Favela-Torres;, E., Rivera-Cabrera, F., Volke-Sepulveda, T.L. 2011. Lead bioaccumulation in *Acacia farnesiana* and its effect on lipid peroxidation and glutathione production. Journal of Plant Soil 339: 377-389.

Marchand, C., Lallier-Vergès, E., Baltzer, F., Albéric, P., Cossa, D., Baillif, P. 2006. Heavy metals distribution in mangrove sediments along the mobile coastline of French Guiana. Marine Chemistry 98: 1–17.

Maslukah, L. 2006. Heavy metal concentration and distribution of Pb, Cd, Cu, Zn in muara Banjir Kanal Barat, Semarang. IPB. Bogor.

McKinley, A.C., Dafforn, K.A., Taylor, M.D., and Johnston, E.L. 2011. High levels of sediment contamination have little influence on estuarine beach Fish. Plos One 6 (10) : e26353.

Munawar, A., Rina. 2004. Mangrove capability to absorb Hg and Pb. Jurnal Ilmiah Teknik Lingkungan 2 (2): 21-30.

Ooa, C.W., Kassima, M.J., Pizzi, A. 2009. Characterization and performance of Rhizophora apiculata mangrove polyflavonoid tannins in the adsorption of copper (II) and lead (II). Industrial Crops and Products 30: 152–161.

Palar, H. 2008. Pollution and heavy metal toxicities. Rineka Cipta, Jakarta. 152 hal.

Parvaresh, H., Abedi, Z., Farshchi, P., Karami, M., Khorasani, N., Karbassi, A. 2011. Bioavailability and Concentration of Heavy Metals in the Sediments and Leaves of Grey Mangrove, Avicennia marina (Forsk.) Vierh, in Sirik Azini Creek, Iran. Biologcal Trace Element Research 143:1121–1130.

Qiu, Y.W., Yu, K.F., Zang, G., Wan, W.X. 2014. Accumulation and partitioning of even trace metals in mangroves and sediment cores from three estuarine wetlands of Hainan Island, China. Journal of Hazardous Materials 190: 631–638

Rivero, R.M., Ruiz, J.M., Garcı´a, P.C., Lo´pez-Lefebre, L.R., Sa´nchez, E., Romero, L. 2001. Resistance to cold and heat stress: accumulation of phenolic compounds in tomato and watermelon plants. Plant Science 160,:315–321

Rochyatun, E., Kaisupy, M.T., Rozak, A. 2006. Heavy metal distribution of water and sediment in Cisadane estuarine. Makara, Sains 10 (1): 35-40.

Rudiyanti, S. 2007. Bioconcentration of *Anadara granosa* Linn toward Cadmium (Cd) in culture media from Kaliwungu area, Kendal. FPIK. UNDIP. Semarang.

Sabu, E.F, Syahrul, M., Hatta, M., Ahyar, A. 2006. Heavy metal analysis of milkfish drying (Chanos Chanosforsskal) by spectofotometric from some area in South Sulawesi. Jurnal Sains & Teknologi 6 (1): 35 – 40.

Seidl, R., Rammer, W.,.Scheller, R.M., Spies, T.A. 2012. An Individual-based process model to simulate landscape-scale forest ecosystem dynamics. Ecological Modelling 231: 87– 100.

Sharma, S., Hoque, A.T.M.R.., Analuddin, K., Hagihara, A. 2012. Litterfall dynamics in an overcrowded mangrove Kandelia obovata (S., L.) Yong stand over five years. Estuarine, Coastal and Shelf Science 98: 31-41.

Shi, Z., Fan, D., Johnson, R.L., Tratnyek, P.G., Nurmi, J.T., Wu. Y., Williams, Y.H. 2015. Methods for characterizing the fate and effects of nano zerovalent iron during groundwater remediation. . Journal of Contaminant Hydrology 18: 17–35.

Susanti, E. 2010. The characteristic of lead transfer in Lotiq water. LIPI Report. Jakarta.

Susanto, F., Hidayati, N.V., Syakti, A.D. 2014. Assessment of cadmium (Cd) contamination in mud crab (Scylla Spp.) and sediment from Segara Anakan Lagoon, Cilacap, Indonesia. Omni-Akuatika 10 (2): 60-70.

Tam, N.F.Y., Wong, Y.S. 1997. Accumulation and distribution of heavy metals in a simulated mangrove system treated with sewage. Hydrobiologia 352: 67–75.

Tarigan Z., Edward And A.Rozak. 2003. Kandungan Logam Berat Lead, Cd, Cu, Zn Dan Ni Dalam Air Laut Dan Sedimen Di Muara Sungai Membramo, Papua Dalam Kaitannya Dengan Kepentingan Budidaya Perikanan. Makara, Sains 7 (3): 119 - 127.

Thomas G., Fernandez, T.V., 1997. Incidence of heavy metals in the mangrove flora and sediments in Kerala, India. Hydrobiologia 352: 77–87, 1997.

UNEP. 2006. Marine and Coastal Ecosystems and Human Well-Being: A Synthesis Report Based on the Findings of the Millennium Ecosystem Assessment. UN Environment Programme, Nairobi.

Wang, Y., Qiu, Q., Xin, G., Yang, Z., Zheng, J., Ye, Z., Li, S. 2012. Heavy metal contamination in a vulnerable mangrove swamp in South China. Environmental Monitoring and Assessment 185 (7): 5775-5787.

Wardas, M., Budek,L., Rybicka, E.H.,1996. Variability of heavy metals content in bottom sediments of theWilga River, a tributary of the Vistula River (Krakow area, Poland). Applied Geochemistry 11: 197–202.

Yoon, J., Xinde, C., Qixing, Z., L.Q. Ma, L.Q. 2006. Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site. Science of the Total Environment 52: 456-464.

Yudhistira, M.A., Gandasasmita, S., Syakti, A.D. 2015. Heavy metals (Ni, Cu, Zn AND Cd) content in serum of rat fed green mussels (Perna Viridis). Omni-Akuatika 11 (2): 1–5.