BIODIVERSITAS
Volume 23, Number 12, December 2022
Pages: 6471-6479

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d231246

Occurrence of heavy metals Cu, Pb, and Cd in *Rhizophora apiculata* and *Sonneratia caseolaris* in the coastal area of Subang, West Java, Indonesia

YUNI TRI HEWINDATI[1,♥], DEDDY AHMAD SUHARDI[2], FAWZI RAHMADIYAN ZUHAIRI[1], DIKI[1], ERNIK YULIANA[3]

[1]Program of Biology, Department of Mathematics and Natural Sciences, Faculty of Science and Technology, Universitas Terbuka. Jl. Cabe Raya, Pamulang, South Tangerang 15418, Banten, Indonesia. Tel./fax.: +62-21-7434290, ♥email: hewindati@ecampus.ut.ac.id
[2]Program of Statistics, Faculty of Science and Technology, Universitas Terbuka. Jl. Cabe Raya, Pamulang, South Tangerang 15418, Banten, Indonesia
[3]Program of Agribusiness, Faculty of Science and Technology, Universitas Terbuka. Jl. Cabe Raya, Pamulang, South Tangerang 15418, Banten, Indonesia

Manuscript received: 6 October 2022. Revision accepted: 14 December 2022.

Abstract. *Hewindati YT, Suhardi DA, Zuhairi FR, Diki, Yuliana E. 2022. Occurrence of heavy metals Cu, Pb, and Cd in* Rhizophora apiculata *and* Sonneratia caseolaris *in the coastal area of Subang, West Java, Indonesia. Biodiversitas 23: 6471-6479.* The high urbanization in coastal areas is one of the causes of mangrove ecosystems experiencing pressure due to water pollution by anthropogenic activities, especially through heavy metals pollution. As vegetation grows in transitional areas, mangroves have a different structure and physiology from plants in the land area, so they have a high resistance to the pressure of heavy metal pollution. The measurement was carried out on the content of heavy metals Cadmium (Cd), Cuprum (Cu), and Plumbum (Pb) in Subang, West Java. Our study aimed to evaluate the characteristics of heavy metal found in the roots, leaves, and trunks of species *Rhizophora apiculata* Blume and *Sonneratia caseolaris* (L.) Engler. Sampling was conducted in the rivers at three locations: Langensari, Blanakan, and the estuary area. The concentration of heavy metals in each organ was measured using Atomic Absorption Spectrophotometry (AAS). The Multiple Factor Analysis (MFA) technique was used to obtain a more detailed description of the accumulation pattern of heavy metals. The mapping was carried out using a two-dimensional plot containing 18 observation samples, nine variable combinations of heavy metal content in three organs, and the location of observations and plant species. Both plant species had a high accumulation absorption of heavy metals but with different characteristics. *S. caseolaris* determined the accumulation characteristics of Cu and Cd in the three observation areas with a total contribution of 60.3%. Meanwhile, *R. apiculata* significantly contributed to determining the characteristics of the accumulation of Cu and Pb in the entire observation area, with its contribution of 15.5%. However, the highest average accumulation of Pb was found in the *R. apiculata* leaves in Blanakan and the estuary area, which was 16.054 mg/kg and 12.769 mg/kg, respectively.

Keywords: Heavy metals accumulation, mangroves roles, multiple factor analysis

INTRODUCTION

Blanakan is a sub-district located in Subang District, West Java. Geographically, Subang Regency is located at 1070 31' - 1070 54' East Longitude and 60 11' - 60 49' Latitude. The area covering 131.37 hectares consists of nine villages, and seven directly border the northern coastal area. The community activities depend on the existing resources in the coastal area (Hartanti et al. 2018). Out of the seven villages bordering the sea, only Blanakan Village relies on fishing in the sea. Meanwhile, other villages, such as Langensari, rely more on fish farming. Therefore, the river's main function is for fishing boats that transport fish caught from the sea. According to data from the Blanakan Sub-district in 2021, land use in Blanakan and Langensari Village consists of 4 zones, respectively upstream to the sea area (estuarine): (i) rice fields, (ii) densely populated settlements, (iii) aquaculture area and (iv) a mangrove forest area directly adjacent to the beach. Both villages are traversed by rivers that flow through densely populated settlements. The river that runs through Blanakan (Mambu River) and Langensari (Bayong River) Village originates from Subang and Purwakarta Districts, respectively, passes through rice fields, densely populated residential areas, and the fish auction market in each village. Mambu and Bayong Rivers meet at the end of Blanakan Village and then flow towards the estuary. The busy community and agricultural activities in the upstream areas of the two villages have resulted in pollution along the river, including heavy metal pollution.

Metal transport is a natural phenomenon within a dynamic environmental system, and it usually occurs due to natural activities such as volcanoes (Mandon et al. 2019) and erosion (Fang et al. 2016). Such transport carries heavy metal substances that can affect terrestrial and aquatic ecosystems. However, human activities have a more significant impact than natural metal transport, for example, industrial activities (Kisku et al. 2000), such as agrochemicals, oils, and paints (Umar et al. 2020); agricultural activities, such as insecticides, pesticides or chemical fertilizer pollution (Seiler and Berendonk 2012); and household waste (Aprilia et al. 2013), thus causing a massive increase of toxic heavy metal waste dispersed into the surrounding ecosystem. Aquatic ecosystems are the most vulnerable to pollution since their rate and accumulation occur faster than terrestrial ecosystems (Liu et al. 2014). The presence of heavy metals in aquatic ecosystems will be dispersed into the ecological system containing living organisms, such as aquatic animals and plants, as well as non-living components like sediment (Rahman et al. 2014). Mangroves can accumulate heavy metals in the root sediment, mangrove structure, or organs (Parvaresh et al. 2011). Heavy metals deposited in the mangrove roots enter the plant organs through the xylem. They are carried to the leaves with water and other particles following photosynthesis and then enter the organ system. Non-biodegradable properties and long biological half-life of heavy metals lead to accumulation when entering the food chain, and the concentration can increase through biomagnification (Thakur et al. 2016).

The riverbanks of Blanakan and Langensari are overgrown by mangroves, a unique, highly productive ecosystem that grows in the intertidal area between sea and land (Ardhana et al. 2018). Besides having ecological functions, mangroves also function physiologically to absorb various industrial and household pollutants in rivers and estuaries. In addition, mangroves have a better ability to absorb and store Carbon, which is approximately three times higher than tropical forests (Donato et al. 2011). According to Wang et al. (2019), mangroves have the potential for the deposition of toxic heavy metals, thus enabling them to play an important role in restoring water quality. The mangrove's ability to absorb pollutants and heavy metals have been studied extensively. Mangroves can absorb heavy metals in large quantities; therefore, they can be utilized as biofilters (Heriyanto et al. 2011). In addition, the accumulation of heavy metal sediments around the mangrove roots could even exceed the heavy metal threshold around it, demonstrating that the roots can act as a pollutant filter by depositing heavy metals. That was supported by Kuswandono (2017), who stated that one of the characteristics of the mangrove root is its ability to bind sediments as its substrate. Each mangrove species responds differently to the accumulation of heavy metals as pollutants. Research on heavy metal translocation in mangrove plants has been widely studied, such as in the *Avicennia marina*. Studies showed a high ability to absorb heavy metals Cd and Pb in the mangrove ecosystem of South Gujarat Coast, India (Arumugam et al. 2018) and Cd, Cu, and Pb in the red sea (Adel et al. 2013). Analuddin et al. (2017) reported that the translocation and bioaccumulation ability of heavy metals by mangroves in Southeast Sulawesi is different for each species: *Lumnitzera racemosa* can absorb Cu and Hg metals with high concentrations in tissues, whereas large quantities of Cd and Pb are found in *Bruguiera gymnorrhiza.* It also has been reported that among the 27 mangrove species in Muara Angke National Park, the *Sonneratia* sp. has very high resilience to environmental pollution pressure, which is believed suspected to potentially contain heavy metals (Hewindati and Utomo 2017).

The content of heavy metals in organisms is important to understand as a reflection of the ability of mangrove plants to accumulate pollutants, especially heavy metals. We evaluate the accumulation of heavy metals between organs, species, and locations. This study aims to map the characteristics of heavy metal content in the roots, leaves, and trunks of the *Rhizophora apiculata* Blume and *Sonneratia caseolaris* (L.) Engler species are found in Langensari, Blanakan, and estuary areas. Our study focused on the two species since both are abundant in the coastal area of Subang. Mapping analysis in this study can be used to make decisions in developing the potential of the Blanakan area, such as assisting local governments' policy in environmental management.

MATERIALS AND METHODS

Study area

This research was conducted from April to July 2019. The research locations were Langensari Village and Blanakan Village, Blanakan District, Subang Regency, West Java (Figure 1). Measurements of heavy metal content in the mangrove plants were carried out at three observation stations, namely: Station 1 (St1) in the Mambu River area, Langensari Village; Station 2 (St2) in the Bayong River area, Blanakan Village; and Station 3 (St3) in the estuary area in Blanakan. Station 1 is a residential area for the people of Langensari Village, and there is a fish auction here for fish farmers. Station 2 is a residential area of Blanakan Village people; there is a fish auction for the fish caught by fishermen and crocodile farm ecotourism. Station 3 is the estuary area in Blanakan, the confluence of the Mambu River from Langensari Village and the Bayong River from Blanakan Village.

Procedures

At the observation stations, three trees each, samples for heavy metal content were taken from the roots, trunks, and leaves of *R. apiculata* and *S. caseolaris*. Three types of heavy metals, copper (Cu), lead (Pb), and cadmium (Cd), were measured in the roots, trunks, and leaves of mangrove plants using AA-7000, Shimadzu® atomic absorption spectrophotometer (AAS) at the Cibinong National Research and Innovation Agency (*Badan Riset dan Inovasi Nasional*/BRIN) laboratory, Bogor. The plant samples and their measurement results were each coded according to the station, plant species and organs, and the type of heavy metal observed, as shown in Table 1 (code column).

Data analysis

The data from the heavy metal measurements were then analyzed using the Multiple Factor Analysis (MFA) technique to obtain an overview of the heavy metal content accumulation pattern in the plant sample observed at the three stations. MFA is a multivariate statistical technique to analyze the correlation structure between groups of variables (Abdi et al. 2013; Pagès 2014). This analysis used the FactoMineR application package (Pagès 2014; Husson et al. 2017).

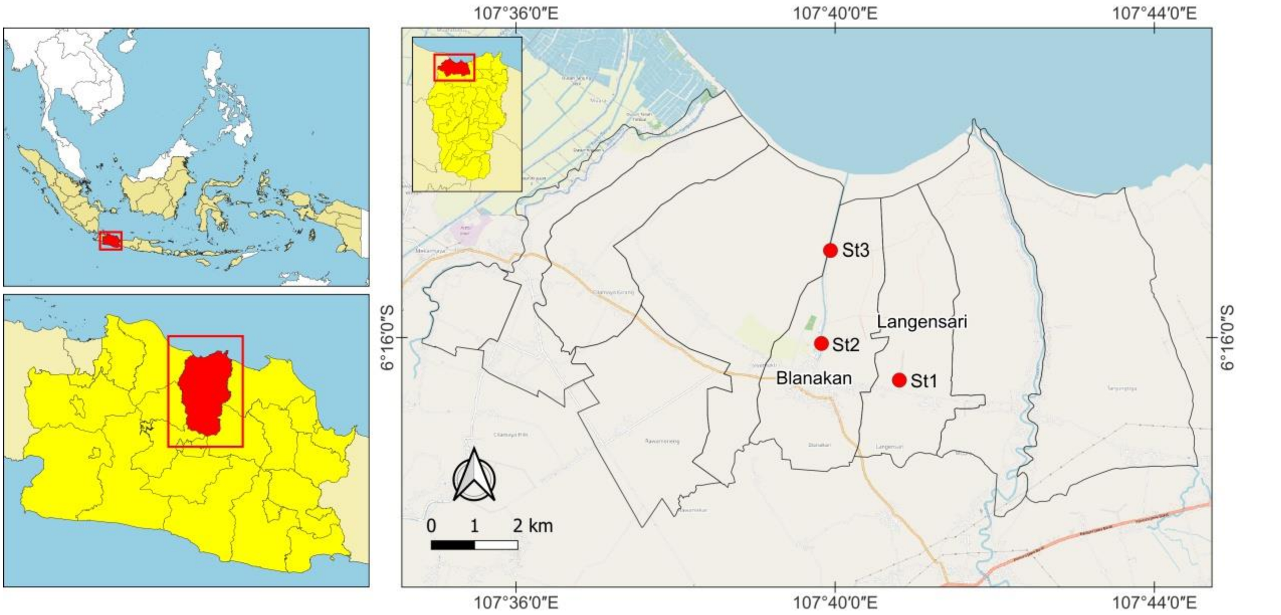

Figure 1. Sampling Locations in Blanakan and Langenssari Village consist of three stations: Station 1 (St1) in Bayong River, Langensari (6°16'32.10"S, 107°40'48.27"E); Station 2 (St2) in Mambu River, Blanakan (6°16'4.51"S, 107°39'49.71"E); and Station 3 (St3) is the estuary area in Blanakan (6°14'54.46"S, 107°39'56.50"E)

The MFA on the data of 18 mangrove plants and nine measurement variables in Table 1 yielded: (i) dimension scores of the organs and types of heavy metals factors for each sample; and (ii) a correlation of each variable with the dimension scores. The number of MFA dimensions produced was as many as the variables used; in this case, nine variables were used, producing nine dimensions. However, analysis was generally carried out on only the first two-dimension scores of MFA (Dim 1 and Dim 2), representing the greatest data variability. Furthermore, the position of the 18 observation samples and nine variables of heavy metal content and plant organs was made in the form of biplots, an x-y plane plot between Dim 1 (x-axis) and Dim 2 (y-axis). The occurrence of heavy metal accumulation between organs, plants, and locations was observed from mapping the biplots.

RESULTS AND DISCUSSION

Heavy metal content level

Our observations showed various heavy metal distributions among different organs of both species *S. caseolaris* and *R. apiculata*. The overall and average heavy metal content at each observation station and species are presented in Table 1. The distribution of data for the heavy metal content level is presented in Figure 2.

Based on the data in Table 1, an accumulation of heavy metals Cu, Cd, and Pb occurred in each plant organ (roots, trunks, and leaves). These data indicate the mangroves' ability to accumulate heavy metals in their structure or organs (Parvaresh et al. 2010). In Figure 2, it can be seen that the heavy metal content level accumulation varied in each metal type and plant organ. In this case, Cu accumulated more in the trunks, Cd in the roots, and Pb in the leaves.

In Table 2, for station 1 (Langensari) observations, the average accumulation of Cu in the roots, trunks, and leaves of *R. apiculata* was 4.272 mg/kg, 8.898 mg/kg, and 1.932 mg/kg, respectively. Meanwhile, the average accumulation of Cu in the roots, trunks, and leaves of *S. caseolaris* was 4.340 mg/kg, 7.566 mg/kg, and 3.238 mg/kg, respectively. Therefore, the accumulation of Cu in *R. apiculata* and *S. caseolaris* was different, especially in the trunks and leaves. The accumulation of Cd was also different in both species; the accumulation in roots and trunks of *R. apiculata* was lower than that of *S. caseolaris*. The average accumulation of Cd content in the roots, trunks, and leaves of *R. apiculata* was 0.075 mg/kg, 0.013 mg/kg, and 0.136 mg/kg, respectively, while for *S. caseolaris* was 0.638 mg/kg, 0.283 mg/kg, and 0.086 mg/kg. The most obvious difference was that the accumulation of Pb in the roots, trunks, and leaves of *R. apiculata* was higher than that of *S. caseolaris*. The average accumulation of Pb content in the roots, trunks, and leaves of *R. apiculata* was 5.786, 4.799, and 8.918 mg/kg, while that of *S. caseolaris* was 3.614, 2.232, and 4.337 mg/kg.

A similar pattern also occurred at station 2 and station 3, with differences as indicated in Figure 2 above, namely the accumulation of Cu in trunks, Cd in roots, and Pb in leaves. The highest average accumulation of Cu was in the trunks of *R. apiculata* (8.898 mg/kg) at station 1, while the lowest average was in the trunks of *S. caseolaris* (4.095 mg/kg) at station 3. The highest average accumulation of Cd was in the roots of *S. caseolaris* (0.745 mg/kg) at station 3, while the lowest was in the roots of *R. apiculata* (0.059 mg/kg), also at station 3. The highest average accumulation of Pb was in the leaves of *R. apiculata* (16.054 mg/kg) at station 2, while the lowest was in the roots of *S. caseolaris* (4.337 mg/kg) at station 1.

Table 1. Cu, Cd, and Pb heavy metal content in mangrove plants (mg/kg)

Location	Species	Sample code	Cu			Cd			Pb		
			Root	**Trunk**	**Leaf**	**Root**	**Trunk**	**Leaf**	**Root**	**Trunk**	**Leaf**
Station 1 (St1)	*R. apiculata*	LR1	4.415	8.105	1.986	0.065	0.014	0.094	5.299	5.187	8.832
		LR2	4.578	8.758	2.176	0.095	0.013	0.136	5.983	4.410	8.720
		LR3	3.823	9.831	1.633	0.065	0.013	0.179	6.076	4.799	9.201
		Mean	4.272	8.898	1.932	0.075	0.013	0.136	5.786	4.799	8.918
		StDev	0.397	0.871	0.276	0.017	0.001	0.043	0.424	0.389	0.252
	S. caseolaris	LS1	4.441	8.045	2.817	0.533	0.249	0.079	3.799	1.952	4.152
		LS2	4.289	7.721	3.478	0.570	0.373	0.065	3.836	2.491	5.068
		LS3	4.290	6.932	3.419	0.810	0.226	0.113	3.206	2.252	3.791
		Mean	4.340	7.566	3.238	0.638	0.283	0.086	3.614	2.232	4.337
		StDev	0.088	0.572	0.366	0.150	0.079	0.025	0.354	0.270	0.658
Station 2 (St2)	*R. apiculata*	BR1	1.844	4.817	2.013	0.100	0.017	0.067	5.602	4.035	15.277
		BR2	3.293	6.711	1.388	0.075	0.016	0.062	5.126	4.092	16.247
		BR3	3.231	6.064	1.497	0.081	0.021	0.095	7.519	4.005	16.639
		Mean	2.789	5.864	1.633	0.085	0.018	0.075	6.082	4.044	16.054
		StDev	0.819	0.963	0.334	0.013	0.003	0.018	1.267	0.044	0.701
	S. caseolaris	BS1	3.864	4.297	3.701	0.602	0.104	0.126	4.502	1.244	10.923
		BS2	4.864	4.044	4.280	0.433	0.089	0.126	4.206	1.059	11.623
		BS3	4.129	5.701	3.448	0.449	0.095	0.111	4.206	1.429	11.400
		Mean	4.286	4.681	3.810	0.495	0.096	0.121	4.305	1.244	11.315
		StDev	0.518	0.893	0.427	0.093	0.008	0.009	0.171	0.185	0.358
Station 3 (St3)	*R. apiculata*	ER1	3.693	5.946	1.974	0.049	0.230	0.382	6.799	5.509	12.079
		ER2	5.186	5.742	2.774	0.054	0.145	0.345	7.315	5.604	12.879
		ER3	3.652	6.190	2.231	0.075	0.219	0.295	7.687	5.555	13.348
		Mean	4.177	5.959	2.326	0.059	0.198	0.341	7.267	5.556	12.769
		StDev	0.874	0.224	0.408	0.014	0.046	0.044	0.446	0.048	0.642
	S. caseolaris	ES1	2.022	4.323	3.193	0.734	0.986	0.322	2.429	2.429	7.295
		ES2	2.112	3.844	2.542	0.795	0.533	0.285	2.133	2.133	6.780
		ES3	2.318	4.119	3.082	0.707	0.441	0.255	3.318	3.318	8.023
		Mean	2.151	4.095	2.939	0.745	0.653	0.287	2.627	2.627	7.366
		StDev	0.152	0.240	0.348	0.045	0.292	0.034	0.617	0.617	0.625

Note: St1, Observation station at Langensari; St2, Observation station in Blanakan; St3, Observation stations in the estuary area; LR(.), LS(.), BR(.), BS(.), ER(.), ES(.), Sample code in Langensari, Blanakan, and Estuary area, for each of *R. apiculata* and *S. caseolaris*, respectively; (.), Plant sample numbers for each of sampling location and species, accordingly. For example, LR1 belongs to sample number 1 from Langensari of *R. apiculata*

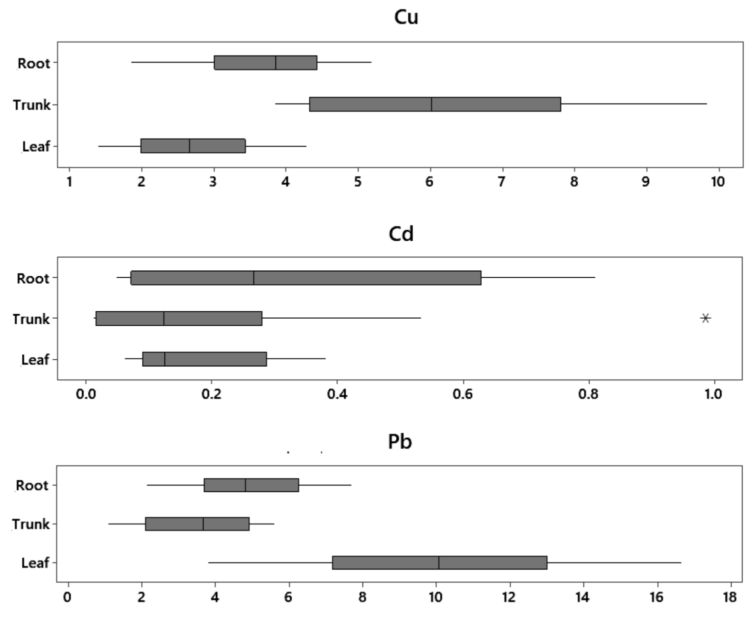

Figure 2. Boxplot distribution of Cu, Cd, and Pb heavy metal content (mg/kg) in the mangrove plants' roots, trunks, and leaves (N = 18 samples)

These figures indicate that the concentration of each heavy metal accumulates specifically in certain organs, species, and regions. Furthermore, the variations indicate differences in responses between organs and plant species (Hewindati and Utomo 2017) and environmental factors in their growth locations (Kuswandono 2017).

Discussion

Further examination of the characteristics of different accumulation levels of Cu, Cd, and Pb in each organ, species, and location of mangrove plants was conducted using the following MFA technique.

Mapping the characteristics of the heavy metal content

The differences between organs, species, and observation areas to consider an MFA analysis was conducted on the data in Table 2 to map the effect of these differences. The two MFA scores with the greatest variability for mapping analysis are presented in Table 2. The data variability from Dim 1 and Dim 2 reached 69.89% (46.95% from Dim 1 and 22.93% from Dim 2). The percentage of data variability by Dim 1 and Dim 2 was sufficient to represent the diversity of the data in Table 2 because it exceeded the minimum value required to represent the structure of the data diversity of nine variables and 18 observation samples. This minimum value refers to Husson et al. (2017), which is 30.2% for Dim 1, and the total variability is 50.8% for Dim 1 and Dim 2.

Table 2 also presents each organ's MFA Dim 1 and Dim 2 scores. In this table, each row represents a plant code, and each column is a dimension score. For example, the Dim 1 score in the table appears to be negative for the *Soneratia* plant code (LS, BS, and ES), while *R. apiculata* has a positive value (LR, BR, and ER). That means that the first dimension distinguishes the position of heavy metal content between *S. caseolaris* and *R. apiculata*. In other words, the Dim 1 score in Table 2 shows the characteristics of the plant species (*R. apiculata* and *S. caseolaris*) ability to accumulate the heavy metals Cu, Cd, and Pb.

To be able to find out in more detail the position of the heavy metal content in each organ, the dimension scores in Table 2 were projected on biplots (Dim 1 and Dim 2) so that the position of the heavy metal content in each plant sample could be obtained, as can be seen in Figure 3. In Figure 3.A, it can be seen that the level of the heavy metal content of *S. caseolaris* located on the left side is different from that of *R. apiculata* located on the right side of Dim 1. Therefore, Dim 1 separates the level of heavy metal content between *S. caseolaris* and *R. apiculata*. Furthermore, this pattern showed the different abilities of mangroves to accumulate certain heavy metals between both species. Therefore, the level of heavy metal accumulation in *S. caseolaris* appears to be lower than that in *R. apiculata*. The plots in Figures 3.B-D show that the roots, trunks, and leaves of *R. apiculata* accumulated more Pb with some Cu in the roots and trunks, while *S. caseolaris* plants accumulated more Cd in their roots and trunks, and Cu in the leaves.

Meanwhile, the second dimension appears to separate the plants of *S. caseolaris* at station 3 (St3) from the other two stations. However, this separation characteristic is less clear for *R. apiculata.* Some of the *R. apiculata* plants observed in the area of Station 1 Langensari (LR3) or Station 2 Blanakan (BR1-BR3) had Pb absorption characteristics that were almost the same as those in the estuary area of Blanakan.

Table 2. MFA score of heavy metal content in mangrove plants

Sample code	Root		Trunk		Leaf		Overall	
	Dim 1	Dim 2	Dim 1	Dim 2	Dim 1	Dim 2	Dim 1	Dim 2
LR1	1.218	-0.614	2.269	-1.086	0.595	-1.002	1.360	-0.901
LR2	1.509	-0.715	2.014	-1.707	0.299	-0.516	1.274	-0.979
LR3	1.492	-0.030	2.574	-2.138	1.076	0.466	1.714	-0.567
LS1	-0.995	-0.790	-0.415	-1.365	-1.545	-2.378	-0.985	-1.511
LS2	-1.123	-0.655	-0.594	-0.570	-2.168	-2.791	-1.295	-1.339
LS3	-2.189	-0.724	-0.506	-0.752	-2.420	-2.265	-1.705	-1.247
BR1	0.729	1.704	0.566	0.258	2.076	-0.417	1.124	0.515
BR2	0.865	0.377	1.186	-0.726	3.103	-0.007	1.718	-0.119
BR3	2.057	0.599	0.920	-0.397	3.033	0.470	2.003	0.224
BS1	-0.970	-0.231	-1.522	-0.141	-1.131	-1.134	-1.208	-0.502
BS2	-0.389	-1.129	-1.661	-0.124	-1.708	-1.335	-1.253	-0.863
BS3	-0.591	-0.473	-0.951	-0.849	-0.687	-1.142	-0.743	-0.822
ER1	1.885	0.139	1.101	0.925	1.178	3.647	1.388	1.570
ER2	2.444	-1.162	1.367	0.768	0.366	2.811	1.393	0.806
ER3	2.250	0.235	1.239	0.774	1.201	2.452	1.563	1.154
ES1	-2.824	1.259	-3.643	3.353	-1.452	1.400	-2.640	2.004
ES2	-3.145	1.151	-2.512	1.914	-0.716	1.136	-2.125	1.400
ES3	-2.223	1.059	-1.432	1.862	-1.098	0.607	-1.585	1.176

Note: *) The MFA score was produced using the FactoMinerR application package (Husson et al. 2017); **) The Dim 1 and Dim 2 variance was 2.450 dan 1.196, respectively, with the percentages of the total variance of all the dimensions produced by the MFA for the raw data in Table 1 were 46.95% and 22.93%

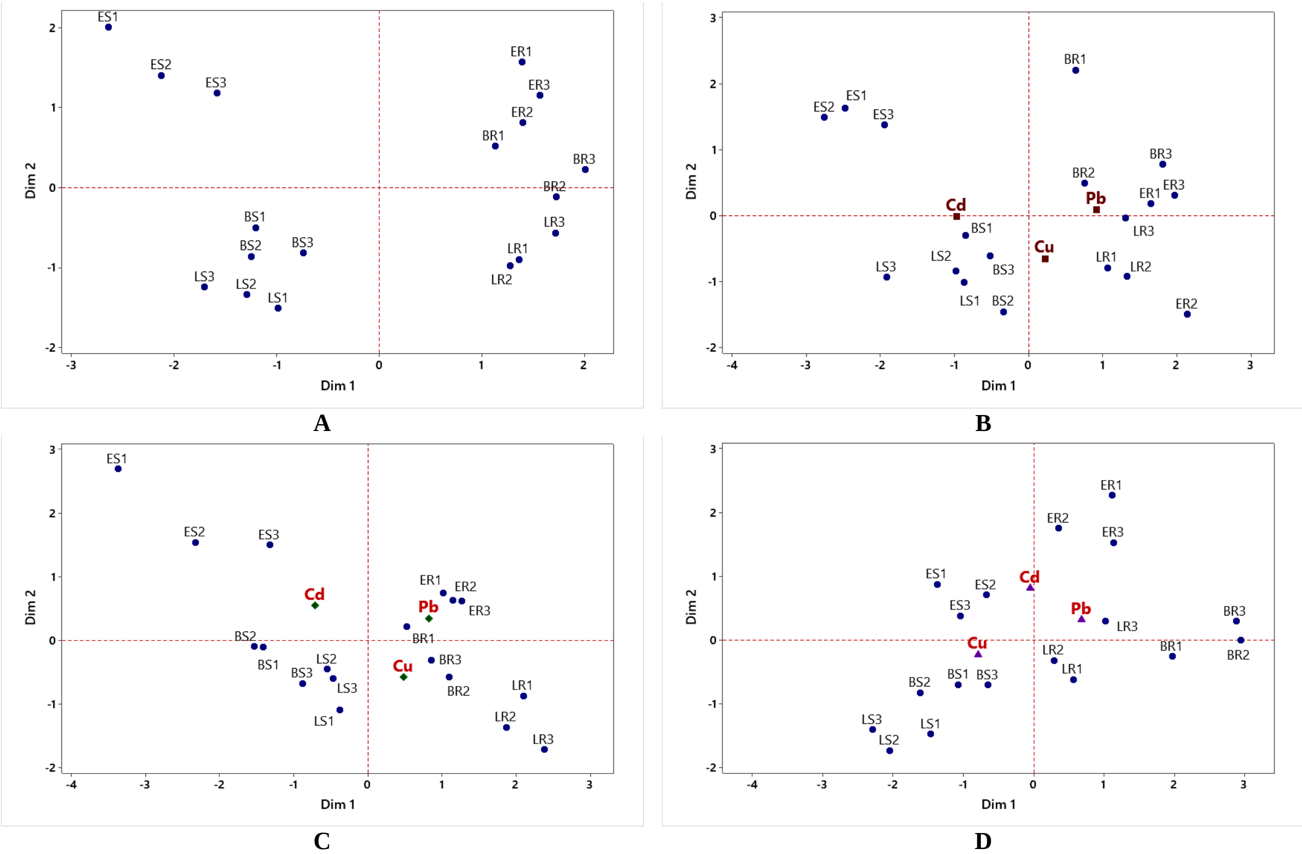

Figure 3. Projection of the heavy metal content observations on the MFA biplots: A. Overall, B. Root, C. Trunk, D. Leaf. Note: Dim 1 (46.95% variance) and Dim 2 (22.93% variance)

Table 3. Contribution of plant samples (A) and variable (B) to Dim 1 and Dim 2 Content of Cu, Cd, and Pb in mangrove plant organs

A. Plant contribution (%)							B. Variable Contribution (%)		
Code	Dim 1	Dim 2	No	Code	Dim 1	Dim 2	Variable code	Dim 1	Dim 2
LR1	4.20	3.77	10	BS1	3.31	1.17	Cd_Root	18.78	0.02
LR2	3.68	4.46	11	BS2	3.56	3.46	Cu_Root	0.96	17.66
LR3	6.67	1.49	12	BS3	1.25	3.14	Pb_ Root	16.58	0.31
LS1	2.20	10.60	13	ER1	4.37	11.45	Cd_Trunk	11.75	14.04
LS2	3.80	8.32	14	ER2	4.40	3.02	Cu_Trunk	5.52	16.27
LS3	6.60	7.22	15	ER3	5.54	6.18	Pb_Trunk	15.88	5.59
BR1	2.86	1.23	16	ES1	15.81	18.65	Cd_Leaf	0.08	37.45
BR2	6.70	0.07	17	ES2	10.24	9.11	Cu_Leaf	17.59	3.06
BR3	9.11	0.23	18	ES3	5.70	6.42	Pb_Leaf	12.86	5.60

The ability level of each organ to accumulate heavy metals can be shown from the magnitude of the difference in the contribution of each organ to the average value of the dimension scores (Dim 1 and Dim 2). The greater the contribution of an organ to a dimension, the more important the organ is in determining the value of that dimension. Table 3 presents each plant sample's contribution level and the variable content of heavy metals Cu, Cd, and Pb in each plant organ (roots, trunks, and leaves). For example, in Table 3.B, the roots contributed more to Dim 1 (36.32%); in this case, it contributed to the difference in the ability to accumulate Cd and Pb between *S. caseolaris* and R. *apiculata*.

Table 3.B shows that the trunks contributed 33.15% to Dim 1 and 35.90% to Dim 2, while leaves contributed 30.53 to Dim 1 and 46.11% to Dim 2. Therefore, leaves had a greater contribution to Dim 2, which means it was more instrumental in determining the difference between the level of Cu accumulation by mangroves in estuaries and the levels of Cu accumulation by *S. caseolaris* or Pb by *R. apiculata* in upstream/settlement areas (Langensari or Blanakan). Meanwhile, the trunks contributed to differences in the two species of mangrove plants' (*S. caseolaris* and *R. apiculata*) general ability to accumulate heavy metals (Cu, Cd, Pb). Therefore, the overall characteristics of mangrove plant organs in accumulating

heavy metal content were examined further according to the species and the location where the mangrove plants were observed. An examination of these characteristics is presented in Figure 4.

Moreover, Figure 4 shows that dimension 1 refers to a factor that distinguishes *S. caseolaris* (Sc) and *R. apiculata* (Ra), while dimension 2 distinguishes the location of *station 3* (estuarine area) and two other observation locations (*station 1* in Langensari and *station 2* in Blanakan). Therefore, the mapping of the accumulation characteristics of heavy metal content could be divided into four quadrants according to species and location as follows: (I) *Sc*-Estuary (left-top); (II) *Sc*-Langensari and Blanakan (bottom-left); and (III) *Ra*-Langensari (bottom right); and (IV) Ra-Estuaria and Blanakan (top right).

Quadrant I (top-left) has the characteristics of the estuary area with Cd accumulation in the trunk of *S. caseolaris*. Figure 4 shows that as many as three *S. caseolaris* plants in the estuary in quadrant I (ES1, ES2, and ES3) contributed 31.75% to Dim 1 and 34.19% to Dim 2 (Table 3). Quadrant II (left-bottom) has the characteristics of Balanakan and Langensari areas with an accumulation of Cd in the roots and Cu in the leaves of *S. caseolaris*. A total of six plants in quadrant II (LS1, LS2, and LS3) contributed 20.72% to Dim 1 and 33.91% to Dim 2. As a whole, the total contribution of quadrants I and II was that of *S. caseolaris* to Dim 1, and Dim 2 were 52.47% and 68.10%, respectively. That means that *S. caseolaris* greatly determines the characteristics of differences in the accumulation of heavy metals Cu and Cd in the three observed regions. The overall contribution of Cu and Cd (in Table 3) was 88.5% to Dim 2, so *S. caseolaris* to the difference in the accumulation of Cu and Cd in the three observed regions was 68.10% x 88.5% = 60.3%.

In the same way, based on quadrant III and quadrant IV, the contribution of *R. apiculata* was 47.53% to Dim 1 and 31.90% to Dim 2. That means that *R. apiculata* played a role in determining the characteristics of differences in Cu and Pb accumulation in the three observation areas, with a contribution of 31.9% x 48.5% = 15.5%. Meanwhile, the total contribution of the estuary area was 46.06% for Dim 1 and 54.84% for Dim 2. That means that the estuary area determined the characteristics of differences in the accumulation of high heavy metal content between regions. The contribution from the Blanakan and Langensari areas to Dim 1 was 53.94%, and to Dim 2 at 45.16%. That means that the two regions determined the characteristics of differences in the accumulation of heavy metal content between species, in this case, the high Cu and Cd accumulation in *S. caseolaris* and high Cu and Pb in *R. apiculata*.

Characteristics of Cu content

Table 3.B calculations showed that the total contribution of Cu is 24.1% to Dim 1 and 37.0% to Dim 2. The mapping results above show that Cu accumulates in *S. caseolaris* leaves in Blanakan and Langensari (Quadrant II). The total contribution of Cu accumulation in mangrove leaves to Dim 1, and Dim 2 was 17.59% and 3.06%, respectively. In this case, Cu accumulation indicates more of the characteristic of heavy metal accumulation differences between species (between *S. caseolaris* and *R. apiculata*). In addition, a high accumulation of Cu also occurred in the roots and trunks of *R. apiculata* in the Langensari area (Quadrant III). The total contribution of Cu accumulation in mangrove roots and trunks to Dim1 and Dim 2 was 0.96% and 17.66% for roots and 5.52% and 16.27% for leaves, respectively. That means that Cu accumulation in mangrove roots and trunks generally determines the characteristics of differences in heavy metal accumulation between areas (between Langensari versus Blanakan and the estuary).

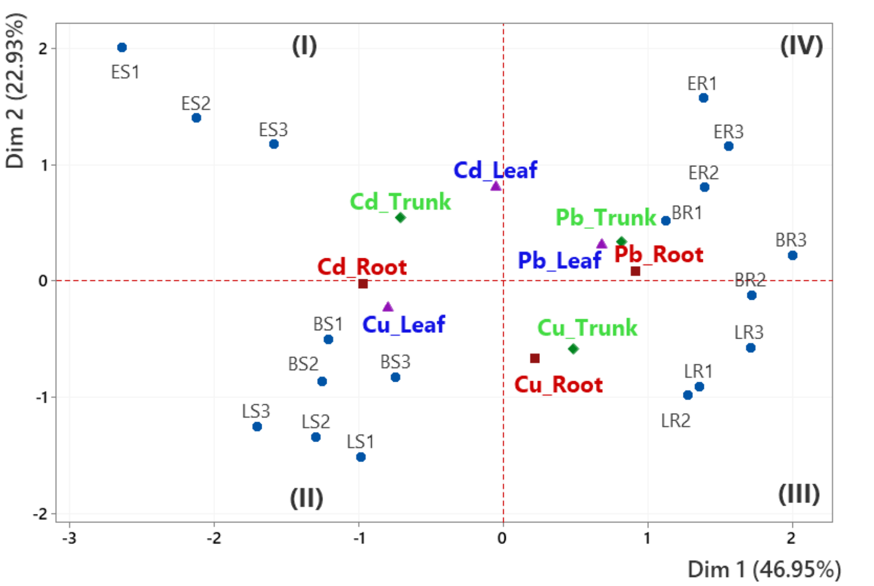

Figure 4. Map of heavy metal accumulation characteristics according to the mangrove species and plant location

In both areas (Langensari or Blanakan), there are fish auctions and agricultural activities in the upstream areas. Using agricultural facilities such as pesticides, insecticides, and chemical fertilizers tends to produce Cu. Similarly, chemical cleaning agents used to clean fish auction markets produce Cu. The continuous presence of Cu in the waters can cause accumulation in mangrove roots. This build-up can occur because of the strong bond between Cu and organic matter, making it easy to form sediments on the riverbed (Supriyantini 2016). Accumulation in trunks is part of physiological processes, especially transporting substances along with minerals and other substances from the roots to various plant organs.

The characteristics of Cd content

Calculated from Table 3.B, the total contribution of Cd as a whole was 30.6% to Dim 1 and 51.5% to Dim 2, most of which is characterized by the contribution of Cu accumulation in mangrove leaves to Dim 2 (37.45%). A larger contribution to Dim 2 indicated that the accumulation of Cd in mangrove leaves determined the characteristics of differences in heavy metal content between regions. However, the mapping results also showed that Cd accumulated much in the roots and trunks of *S. caseolaris* (quadrants I and II). In general, the contribution of Cd content in mangrove roots and trunks was the largest for Dim 1 (30.54%), which means that it was more decisive for the differences in accumulation between mangrove species.

Cd is a dangerous heavy metal; even in low concentrations, it can cause health problems for humans and other organisms. It is stated in Government Regulation Number 18 of 1999 concerning the Management of Hazardous and Toxic Waste that Cd is classified as a Hazardous and Toxic Waste (*Bahan Berbahaya dan Beracun*/B3). The high accumulation of Cd in mangroves also indicates a tendency for a high accumulation of other organisms in the ecosystem. There is no standard limit for Cd content in mangroves. Silva et al. (2006) stated that high concentrations of heavy metals do not affect the mangroves' health; therefore, mangroves function as a biofilter for coastal communities and organisms in the mangrove ecosystem. However, the continuous presence of Cd in waters can cause accumulation in organisms. According to the Indonesian National Standard (Standar Nasional Indonesia/SNI 7387:2009), the maximum limit of heavy metal contamination in fish ranges from 0.1 to 0.5 mg/kg.

The characteristics of Pb content

Significant heavy metal accumulation characteristics were also demonstrated by the accumulation of Pb in *R. apiculata* in all areas. The highest average accumulation was found in leaves in the Blanakan and estuary areas, with 16.054 mg/kg and 12.769 mg/kg, respectively, in *R. apiculata* leaves (Table 2). Overall, the total contribution of Pb to Dim 1 and Dim 2 was 45.3% and 11.5%, respectively (Table 3.B). A larger contribution to Dim 1 indicated that the Pb accumulation was more dominant in characterizing differences in the ability of mangrove species to accumulate heavy metals. In this case, *R. apiculata* accumulated more Pb than *S. caseolaris* in Blanakan and the estuary.

Pb accumulation is the highest compared to Cd and Cu. The high accumulation of Pb is suspected to be due to the activities of motorized fishing vessels in river waters in Blanakan that use fuel and pollute the river. Furthermore, industrial activities, mining, and using Pb-containing products such as agrochemicals, oils, and paints can cause Pb contamination in the environment (Kumar et al. 2020). It is also reported by Hasyim (2016) that lubricating oil and gasoline containing Pb can pollute waters. In addition to petrol, pesticides used by agricultural activities also strongly impact the waters (Hartini 2011). The Pb content is also carried away by currents and accumulated in the estuary, causing a high accumulation of *R. apiculata* in the area. Agricultural activities in the upstream part of Blanakan are also suspected of causing Pb exposure, specifically from fertilizer and pesticide use. That was also stated by Supriyantini and Soenardjo (2016), who reported that Pb results from the use of pesticides in agricultural activities. The standard amount of Pb accumulation in plant organs is undetermined. However, a study by Widyaningrum et al. (2007) stated that an accumulation of 0.5 - 3 mg/kg of Pb in vegetables is considered normal.

Based on our multiple-factor statistical analysis, there are three main conclusions that we would like to emphasize. First, the characteristics of Cu accumulation differ between areas: Blanakan and Langensari accumulate Cu more than estuary. Second, each mangrove species has a different response to the accumulation of heavy metals. For example, heavy metal accumulation of Cd and Pb differs between the two species: *R. apiculata* accumulate more Pb than *S. caseolaris*. Third, *R. apiculata* and *S. caseolaris* have the ability to absorb and accumulate heavy metals, as supported by the studies of Wang et al. (2019) and Heriyanto et al. (2011). Therefore, these mangroves have the potential to be utilized as biofilters for the polluted environment.

ACKNOWLEDGEMENTS

The authors would like to thank the Institute for Research and Community Service (*Lembaga Penelitian dan Pengabdian kepada Masyarakat*), Universitas Terbuka, Indonesia, for research funding (contract number: 2738/UN31.LPPM/PM/2019).

REFERENCES

Abdi H, Williams LJ, Valentin D. 2013. Multiple factor analysis: principal component analysis for multi-table and multiblock data sets. Wiley Interdiscip Rev: Comput Stat 5 (2): 149-179. DOI:10.1002/wics.1246.

Adel RA, Usman RS, Alkredaa MI, Al-Wabel. 2013. Heavy metal contamination in sediments and mangroves from the coast of Red Sea: *Avicennia marina* as potential metal bioaccumulator. Ecotoxicol Environ Saf 97: 263-270. DOI: 10.1016/j.ecoenv.2013.08.009.

Analuddin K, Sharma S, Jamili, Septiana A, Sahidin I, Rianse U, Nadaoka K. 2017. Heavy metal bioaccumulation in mangrove ecosystem at the coral triangle ecoregion, Southeast Sulawesi, Indonesia. Mar Pollut Bull 125 (1-2): 472-480. DOI: 10.1016/j.marpolbul.2017.07.065.

Aprilia A, Tezuka T, Spaargaren G. 2013. Inorganic and hazardous solid waste management: Current status and challenges for Indonesia, Proc Environ Sci 17: 640-647. 10.1016/j.proenv.2013.02.080.

Ardhana IPG, Rimbawan IMGS, Pujo NC, Yuyun F, Siska R. 2018. The distribution of vertical leaves and leaves biomass on ten mangrove spesies at Ngurah Rai Forest Park Denpasar, Bali, Indonesia. Biodiversitas 19 (3): 918-926. DOI: 10.13057/biodiv/d190322.

Arumugam G, Rajendran R, Ganesan A, Sethu R. 2018. Bioaccumulation and translocation of heavy metals in mangrove rhizosphere sediments to tissues of *Avicenia marina* - A field study from tropical mangrove forest. Environ Nanotechnol Monit Manag 10: 272-279. 10.1016/j.enmm.2018.07.005.

Brander LM, Wagtendonk AJ, Hussain SS, McVittie A, Verburg PH, de Groot RS, van der Ploeg S. 2012. Ecosystem service values for mangroves in Southeast Asia: A meta-analysis and value transfer application, Ecosystem Services 1 (1): 62-69.

Donato DC, Kauffman JB, Murdiyarso D, Kurnianto S, Stidham M, Kanninen M. 2011. Mangroves among the most carbon-rich forests in the tropics. Nat Geosci 4: 293-297.

Fang H, Huang L, Wang J, He G, Reible D. 2016. Environmental assessment of heavy metal transport and transformation in the Hangzhou Bay, China. J. Hazard Mater 302: 447-457.

Hartanti U, Patria MP, Utomo SW. 2018. The physical carrying capacity of mangrove ecotourism in Blanakan, Subang Regency, West Java, Indonesia. In E3S Web of Conferences.

Hartini E. 2011. Plumbum (Pb) content in shallot bulbs in Kersana District, Brebes Regency. J Visikes 10 (1): 69-75. [Indonesian]

Hasyim UH. 2016. Study of metal adsorption in used lubricants and prospects of its utilization as fuel. Jurnal Konversi 5 (1): 11-16. DOI: 10.24853/konversi.5. [Indonesian]

Heriyanto NM, Subiandono E. 2011 Absorption of heavy metal pollutants (Hg, Pb, and Cu) by mangrove species. Jurnal Penelitian Hutan dan Konservasi Alam 8: 177-188. [Indonesian]

Hewindati YT, Utomo SW. 2017. Mangrove ecosystem viability of Muara Angke Wildlife Reserve (SMMA) towards the pollution pressure. Austr J Basic Appl Sci 11: 91-96.

Husson, F, Lê S, Pagès J. 2017. Exploratory Multivariate Analysis by Example Using R. CRC Press, Boca Raton.

Kisku, GC, Barman SC, Bhargava SK. 2000. Contamination of soil and plants with potentially toxic elements irrigated with mixed industrial effluent and its impact on the environment. Water Air Soil Pollut 120: 121-137.

Kumar A, Kumar AM, MMS Cabral-Pinto, Chaturvedi AK, Shabnam AA, Subrahmanyam G, Mondal R, Gupta DK, Malyan SK, Kumar SS, Khan SA, Yadav KK. 2020. Lead toxicity: Health hazards, influence on food chain, and sustainable remediation approaches. Intl J Environ Res Public Health 17 (7): 2179. DOI: /10.3390/ijerph17072179.

Kuswandono A. 2017. Role of coordinating ministry of maritime affairs in sustainable management of Indonesian mangrove and its ecosystem. Proceeding of International Conference on Mangrove Ecosystems. 18 April 2017. Bali, Indonesia.

Liu J, Wu 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.

Mandon CL, Christenson BW, Schipper CI, Seward TM, Garaebiti E. 2019. Metal transport in volcanic plumes: A case study at White Island and Yasur volcanoes. J Volcanol Geotherm Res 369: 155-171.

Pagès J. 2014. Multiple Factor Analysis by Example using R. CRC Press, Boca Raton, IL.

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. Biol Trace Elem Res 143 (2): 1121-1130.

Rahman MS, Saha N, Molla AH, Al-Reza SM. 2014. Assessment of anthropogenic influence on heavy metals contamination in the aquatic ecosystem components: water, sediment, and fish. Soil Sediment Contam Intl J 23: 353-373.

Seiler C, Berendonk TU. 2012. Heavy metal-driven co-selection of antibiotic resistance in soil and water bodies impacted by agriculture and aquaculture. Front Microbiol 3: 399.

Silva CAR, Silva AP, Oliveira SR. 2006. Concentration, stock and transport rate of heavy metal in a tropical red mangrove, Natal, Brazil. Mar Chem J 99 (1-4): 2-11.

Standar Nasional Indonesia [SNI]: 7387:2009. 2009. The Maximum Limit of Heavy Metal Contamination in Food.

Supriyantini E, Soenardjo N. 2016. Kandungan logam berat timbal (Pb) dan tembaga (Cu) pada akar dan buah mangrove *Avicennia marina* di Perairan Tanjung Emas Semarang. Jurnal Kelautan Tropis 18 (2): 98-106. [Indonesian]

Thakur S, Singh L, Wahid ZA, Siddiqui MF, Atnaw SM, Din FM. 2016. Plant-driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives. Environ Monit Assess 188: 206. DOI: /10.1007/s10661-016-5211-9.

Wang Q, Mei D, Chen J, Lin Y, Liu J, Lu H, Yan C. 2019. Sequestration of heavy metal by glomalin-related soil protein: Implication for water quality improvement in mangrove wetlands. Water Res 148: 142-152.

Widyaningrum M. 2007. Bahaya kontaminasi logam berat dalam sayuran dan alternatif pencegahan cemarannya. Buletin Teknologi Pascapanen Pertanian 3: 1-12. [Indonesian]