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The Mangrove Strengthen and Ecological Risk Assessment of Mercury Contamination in the Segara Anakan Cilacap Lagoon, Indonesia

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Abstract:
Ecological risk assessment of mercury contaminant has a means to analyze the ecological risk aspect of ecosystem using the potential impact of mercury pollution in soil, water and organism. The ecological risk assessment in a coastal area can be shown by mangrove zonation, clustering and interpolation of mercury accumulation. This research aims to analyze ecological risk assessment of potential mercury (including bioaccumulation and translocation) using indicators of species distribution, clustering, zonation and interpolation of mercury accumulation. The results showed that the Segara Anakan had a high risk of mercury pollution, using indicators like as the potential of mercury contaminant in water body was 0137±0.0137 ppm, substrate and sediment were 0.0134±0.0212 ppm. To reduce the impact of mercury pollution could be conducted by mangrove planting, following the ability of mercury accumulation in stem and bark between 0.011 and 0.064 ppm, in mangrove roots between 0.0260 and 0.0690 ppm and in mangrove leaves between 0.0020 and 0.0120 ppm,. The second indicator of mangrove ability to reduce the impact of mercury contaminant used the indicator of bioaccumulation factors, which had a range between 0.021 and 0.4751, and the translocation factors were between 0.0459 and 1.0547. The results also showed that: *Avicennia marina, Sonneratia alba, Rhizophora apiculate, Rhizophora mucronata* and *Nypa frutican* had a good ability to accumulate and reduce the impact of mercury contamination.

Keywords: Bioaccumulation factor, C and mangrove zoning, Ecological risk assessment, Mercury contamination, Translocation factor.

Introduction:

The ecological risk assessment of mercury contaminants is described through the measurement of biotic responses, including mangrove ecosystems that have bioavailability to reduce the impact of metals contaminant and their influence on the aquatic and terrestrial ecosystem [1,2]. Basically, the mangrove vegetation has the ability to reduce mercury pollution with absorption, filtering, binding and trapping activities [3,4]. The potential mercury contaminants comes from the oil and cement industry, garbage, and household [3,5]. The mangrove stand has a specific metabolism system, specific nutrient absorption and specific root activity [3,5,6]. In Eastern Segara Anakan, the mangrove stand has a specific freshwater supply from Sapuregel, Donan and Kembang Kuning Rivers [4, 7-10] and seawater from Samundra, Indian Ocean.

The mangrove ecosystem can be used as a suitable area to support the activity of mercury disposal from industry, transportation and anthropogenic activities [3,4,11]. These activities support mercury contaminant in coastal ecosystem and estuary ecosystem [3, 12-14]. The mercury contaminants including (CH_3)-Hg (methyl mercury) waste disposal from the oil refinery petroleum industry, cement industry and laboratories that are characterized as a liquid substance at room temperature 25°C, boils at 365, 68°C and a freezing point of -39°C [15,16,17], which has the nondegradable properties and easily accumulation in water and sediments. Mercury also has high toxicity level [18], very hazardous properties, and very strong binding properties [16, 17, 19- 21]. Mercury also has a negative impact on aquatic organisms, causing the organism to be genetically altered, have stunted growth, organ damage and cause death [17,20,22,23]. Mercury contaminants also have high risks in fishponds, due to human community activity and coastal stabilization [24].

The ecological risk assessment of mercury contaminant is developed by the distribution, clustering, and interpolation of accumulation activity and translocation activity and are used as an index of ecological risk assessment in the mangrove ecosystem [3,17,18,25]. The ecological risk assessment of mercury contaminant can be analyzed by mercury potency in mangrove stem, mangrove roots, and mangrove leaves [22,26,27]. ***The bioaccumulation of mercury contaminant*** is an indicator of ecological risk assessment can be analyzed by absorption process, accumulation process, and utilization activity of mercury in a mangrove root and surface area of vegetation [17,28,29]. This activity aims to reduce the impact of mercury toxic effect with dilution activity and mercury translocation to dead organs [26,30] and organic absorption [31,32]. The second indicator is a ***translocation of mercury contaminants*** as an activity to transfer contaminants to other organs stem, branches and leaves through cells and the vascular tissue. The translocation process is a passive transport system following the activity of distribution and nutrient absorption [26,32,33].

The ecological risk assessment of the mangrove ecosystem using bioaccumulation and translocation of mercury contaminant give information and data on the adaptation of mangrove vegetation in mercury pollution area. Mangrove vegetations must have the ability to reduce the effect of mercury contaminant [4,19,20]. The ecological risk assessment of mercury contaminant also describe the relationship and adaptation of mangrove vegetation in pollution area using the mangrove landscaping, zonation, clustering and association [4,5,9,34]. This research aims to analyze the ecological risk assessment of mercury contaminants (including bioaccumulation and translocation) using indicators of distribution, clustering, zonation and interpolation

Materials and Methods:

Research area

The research of ecological risk assessment of mercury contaminants was conducted in a waste disposal area in Eastern Segara Anakan (E-SAL) on June -July 2021 and January-March 2022 [8,35]. The research area could be shown in Fig.1 and Table. **1**. The area of waste disposal in the mangrove ecosystem was dominated by Rhizophora apiculata, Rhizophora mucronata, Rhizophora styllosa, Bruguiera gymnorrhiza, Sonneratia caseolaris and Avicennia marina [8,10,34,36]. The sampling of mercury contaminants in the mangrove ecosystem can be conducted in Kalipanas River (Station 1), the Sleko Port (Station 2), Pertamina /oil refinery Area (Station 3), the Cement Plant (Station 4), and East Pelawangan/estuary. (Station 5).

Table 1. Research area and stations

No	Research stations	The coordinates	
		Latitude (South)	Longitude (East)
1.	Kalipanas River	07°42'36,60"	108°59'43,91"
2.	The Sleko Port	07°43'17,11"	108°59'31,00"
3.	Pertamina Area/oil refinery	07°41'48,64"	108°59'34,98"
4.	Cement Plant	07°40'59,81"	109°00'40,35"
5.	East Pelawangan/estuary	07°43'40.87"	108°59'03,31"

The number of sampling plots to analyze mercury contaminant in sediment and water was 15 sampling plots (3 sampling plots/stations). Whereas the number of sampling for mangroves (collecting roots, barks, stems, and leaves) from 15 sampling plots were 75 individual samples (5 samples of vegetation/mangrove species) [37,38.] The samples total from part of mangrove tree to analysis heavy metal accumulation were 225 samples

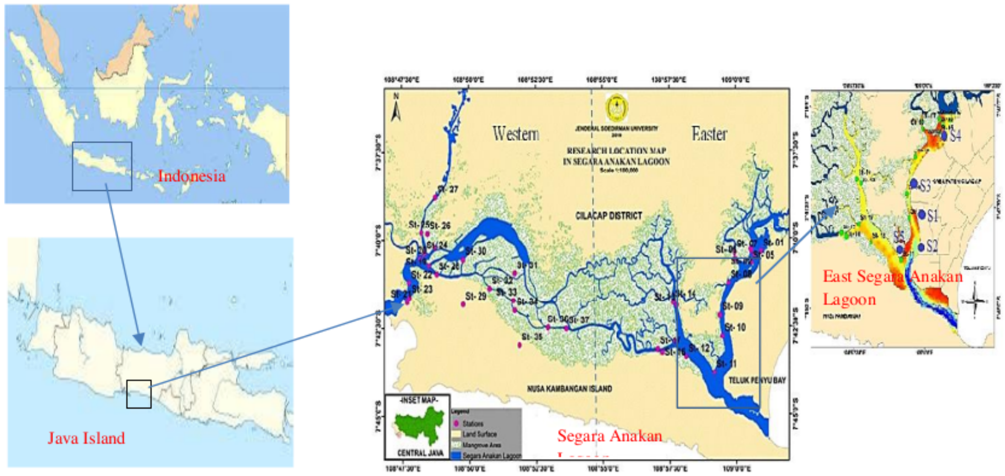

Figure 1. Research area

The sampling of mercury contaminant

a. The sampling in the water body and substrate's

The sampling in water bodies and substrates could be conducted by the collection of 600 mL of water samples and be placed and labeled into a bottle. The water samples be added by 0.75 mL concentrated HNO_3 until the pH until two [3,21,39]. Substrate samples were collected 250 g using Eckman grab until 50-100 cm form the bottom. The substrate samples were placed and labeled into the plastic bag [3,11,21].

The sampling of mangrove vegetation

Mangrove vegetation was collected by sampling 150 – 350 g. The samples (bark, stem, leaves and roots) were collected by destructive methods and then materials were extracted. Specifically the mangrove roots were collected from actual roots beneath the sediment including the respiratory roots. The mangrove samples were collected, labeled and placed into plastic bags and the plastic bags were put into an icebox [3,26].

Mercury analysis

The mercury accumulation from mangrove leaves, stems and roots were analyzed by a spectrophotometric method using Shimatsu® the accuracy level is 2). x10^{-4} pmBefore the analysis of mercury accumulation using the spectrophotometric, the mangrove samples were extracted by a filtrate system using the mixed system of 10 ml H_2SO_4, 2 ml $KMnO_4$ 2%, 1 ml K_2S $2O_8$, and 1 ml stannous chloride $SnCl_2$, 10% were extracted system using tetra dithizone liquid. Hg was measured by mercury analyzer (SP-3D) method with a wavelength of 480 ηm. This method uses: $Hg^{2+} + SnCl_2 \rightarrow HgO$ and then uses the Hg Detector analyzer [40].

The bioaccumulation factor (BAF) of mercury contaminant

The Bioaccumulation factor (BAF) of mercury contaminant was analyzed by the equation of [3,4,41].

$$\mathrm{BAF} = \frac{mercury\ \text{accumulation of mangrove leaves, roots and stem (mg}\ kg^{-1})}{\text{mercury accumulation of mangrove substrates (mg}\ kg^{-1})}$$

Bioaccumulation Factor (BAF) had categories were [3,24,42].

BAF ≤1 describe low or unable activity to accumulate mercury pollution

BAF >1 describe high ability to accumulate mercury pollution.

The Translocation factor (TF) of mercury contaminant

The translocation factor (TF) was analyzed by the equation of [3,4,41].

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$$TF = \frac{\text{mercury accumulation of mangrove leaves, roots and stem (mg } kg^{-1})}{\text{mercury accumulation of mangrove roots (mg } kg^{-1})}$$

Translocation *Factor* (TF) had categories were [3,24,42]
TF ≤ 1 describe low or unable activity of translocate mercury pollution to other organs
TF > 1 describe to good activity to translocate mercury pollution to other organs

The clustering of mangrove vegetation using indicator mercury contaminant accumulation

The clustering of mangrove vegetation using indicator mercury contaminant accumulation used Euclidian distance analysis based on dissimilarity accumulation [8,43,44].

Stage 1.

$$\text{Euidian distance}_{jk} = \sqrt{\sum_{i=1}^{s}(xij - xik)^2}$$

Stage 2.

$$D\,(j,k)h = \propto_1 D(j,h) + \propto_2 D(k,h) + \beta\, D(j,k)$$

Stations	2	3	4	...	22
1	$EuDi_{12}$	EuDi13	EuDi14		
2		EuDi23	EuDi24		
3			EuDi34		
			...		
22			EuDi22		

Notes [44, 8]:
EuDi*jk* : Euclidean Distance of mercury accumulation
i : species
X*ij* : mercury accumulation of species- *j*
X*ik* : mercury accumulation of species - *k*
D : Distance between potency of mercury accumulation
α1 : 0.625
α2 : 0.625
β : - 0.25 [44, 8]:

The interpolation analysis of mercury accumulation

The interpolation analysis of mercury contaminant accumulation was conducted by mapping analysis. The mapping analysis used the combined approach among sampling data, Landsat data, NDVI and NDWI method, and interpolation tool in ArcGIS software [45,46].

The landscaping of mangrove vegetation

The landscaping of mangrove vegetation using the data of mercury contaminant accumulation based on BAF and TF scores. The landscape of mangrove vegetation showed the zonation of mangrove species following the score of mercury accumulation [13,19].

Results and Discussion

The ecological risk assessment of the mangrove ecosystem based on the potential for mercury contaminant

The ecological risk assessment of Segara Anakan Lagoon is influenced by mercury contaminants in water and sediments coming from sea water treatment of oil refinery industry, aquaculture pesticides, domestic pollution, charcoal industry and cement industry [31]. The potential for mercury contaminations gives a negative impact on the environment, organisms and the local human community [12,18,47] (Fig.2).

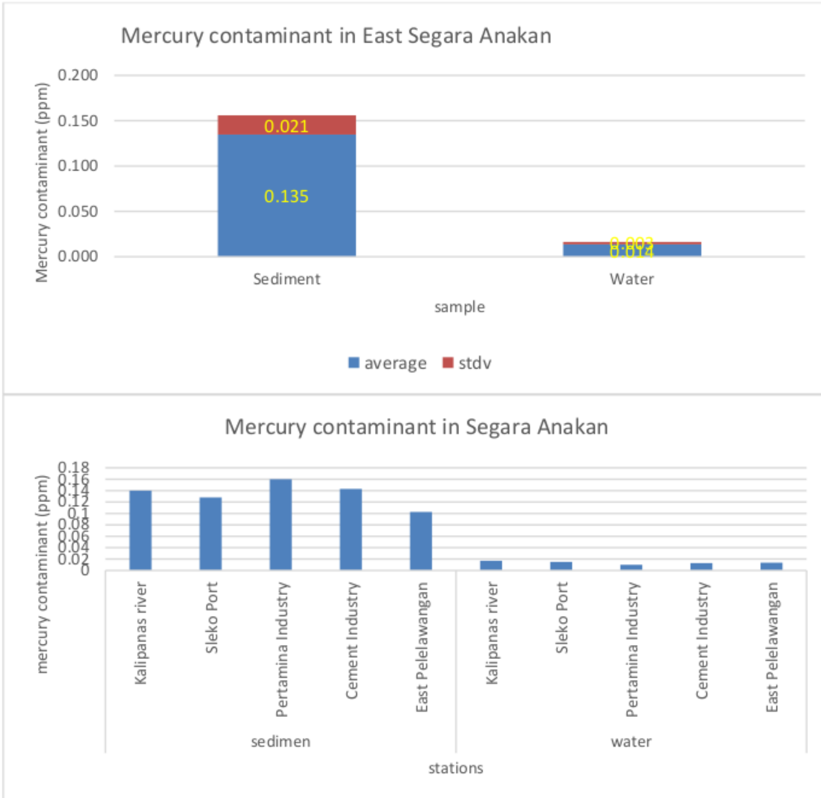

Figure 2. The potential of mercury contaminant on sediment and water body in Segara Anakan Lagoon.

Fig. 2 shows the potential of mercury contaminant in sediment 0.135±0.0021 ppm > potential in water 0.014±0.003 ppm. Based on the Government Regulation of the Indonesia Republic, Number 101/2014 and Number 82/2001 and the data potential mercury in sediment and water noted that Segara Anakan lagoon was polluted.[48] indicated that mercury concentration in the coastal sediment in Buyat Bay had potential up to 7 mg kg^{-1} , and [33] also indicated that mercury contaminant in sediments of the mangroves ecosystem have ranges SJM 414.50 ng g^{-1} > XXM 272.30 ng g^{-1}, FTM 216.47 ng g^{-1} > BGM 80.91 ng g^{-1}; SJM 356.25 ng g^{-1} > XXM 234.57 ng g^{-1}, FTM 197.23 ng g^{-1} > BGM 65.35 ng g^{-1}.

Basically[14], also indicated 90% of mercury contaminants are deposited in sediments because the heavy metal contaminant was easy to bond and deposited in sediments [49,50]. Whereas based on the distribution in sediments from every station showed that the mercury contaminant in oil refinery station (pertamina stations) > cement industry > Kalipanas River > Sleko port > east of Pelawangan (estuary station), then the mercury contaminant of water body in Kalipana Rivers > Sleko Port > oil refinery Industry, cement industry and East of Pelawangan. The pollution category of Government Regulation of the Indonesia Republic, Number 82 (2001) explains that the Segara Anakan Lagoon was polluted with mercury contaminant. Otherwise, [31] only found that Zn, Cd and Pb contaminated the Red Sea coast of Egypt are 14.94 – 134.22 □g/g (Zn), 3.17-40.25 □g/g (Pb) and 0.12-1.25 □g/g (Cd)[26]. also reported the potential contamination in sediments show that potential Cd between 0.15-1.62 mg/g < Pb 1.36-6.28 mg/g < Ni 17.9-24.3 mg/g < Cu 9.27-36.47 mg/g < Cr 27.68 -84.62 mg/g. According to [51] reports that Busan city has the potential for contaminant Zn ≤ Pb <Cu < Cr ≤ As < Ni ≤ Cd < Hg. This data is not different from [52] in China's Hainan and Zhoushan coastal areas. [18] using the PCA analysis show that potential for contamination by Ni, Cr, Cu, As, Hg and Zn from natural sources and Cd and Pb from anthropogenic source.

The accumulation of mercury contaminants in water and sediments also is influenced by the following environmental factors: dissolved oxygen (DO); chemical oxygen demand (COD); biological oxygen demand (BOD); total suspended solids (TSS); pH; conductivity; ammonium (NH_4^+-N); nitrate (NO_3^--N); Kjeldahl nitrogen; and total phosphorus [13,53]. The data also showed that salinity was 16 PSU – 25.7 PSU, pH 5.7 – 7.1, COD 22.9 ppm – 41.5 ppm, sediment salinity was 19.7 – 23.7 PSU and sediment pH was 5.3 – 5.8 (Table. 2). Based on data COD showed that Pertamina industry is designated as a polluted area (COD > 25 ppm)

Table 2. Environmental factors affecting mercury contamination in the area of Segara Anakan Cilacap

Stations	Tools	Water			Sediments	
		Salinity (PSU)	pH	COD (ppm)	Salinity (PSU)	pH
Kalipanas rivers	Average	25.0	6.6	22.9	23.7	5.8
	Standard deviation	0.1	0.1	1.6	0.6	0.1
Sleko port	Average	24.3	7.1	26.5	20.3	5.6
	Standard deviation	0.6	0.2	0.7	0.6	0.1
Pertamina area	Average	21.3	5.7	41.5	22.0	5.8
	Standard deviation	0.6	0.1	7.2	1.0	0.1
Cement industry	Average	16.3	6.6	32.9	22.7	5.6
	Standard deviation	0.6	0.2	4.4	0.6	0.1
East Pelalawang	Average	25.7	6.8	27.1	19.7	5.3
	Standard deviation	0.6	0.1	1.6	0.6	0.2

Based on COD, salinity and pH mangrove have sensitive characteristics since they can be influenced by the potential for mercury contamination and other pollutants [19,26]. To reduce the impact of contamination, salinity, pH and potential COD, mangroves must have highly adaptative using activities of the excretion gland, exclusion gland and accumulation gland [3,54,55]. Waste disposal from the cement industry and oil refinery are the major source of mercury contamination and mercury easily accumulates through a binding and deposition process of organic matter [6,38]. However, the mercury accumulation within the East Segara Anakan Lagoon sediments is still lower than the US EPA standard (< 0.2 mg/Kg). But based the Government Decree No. 82 (2001) and the Decision of the State Minister of the Environment No. 51 (2004) showed that mercury contamination in this lagoon was polluted since the potential for mercury contamination > the mercury standards for aquatic organisms mercury > 0.001 mg/L. The mercury accumulation in this lagoon also is distributed by tidal currents and water inundation [13,19,56]. In rivers, mangrove stands and lagoon ecosystems in Segara Anakan as semiclsoed estuary give a specific distribution of mercury accumulation.

The ecological risk assessment of mangrove stands base on potential for mercury contaminantion

Potential of mercury accumulation in mangrove stands

The ecological risk assessment of mangrove stands using the distribution of mercury accumulation in Segara Anakan Lagoon was shown in Table. 3 and Fig.3. Table. 3, describes that potential accumulation of mercury contamination in the mangrove stem had a range of 0.0110 – 00640 ppm, mangrove leaves ranged 0.0020-0.0120 ppm, and mangrove roots ranged 0.0160-0.0690 ppm. Based on the species distribution Avicennia marina, Sonneratia alba, Rhizophora apiculate, Rhizophora mucronata and Nypa frutican, had a high ability to accumulate mercury contaminants. According to 1 Aviccenia marina had a good ability to accumulate Fe (2892.83 -2902,83 ppm), Mn (2.53-127.3 ppm), Cu (27.84 -60.81 ppm), and Ni (15.55-78.85 ppm). The potential mercury accumulation of mangrove stands in Segara Anakan is relatively different than [18] and [19], which reported that the potential mercury contaminant in Lumnitzera racemose was

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approximately 0.52 µg g−1, and [26] also indicated that Avicennia marina had the ability to accumulate Cr > Cu > Ni > Pb > Cd [19,57].

The accumulation of mercury contaminants in mangrove roots, stems, and leaves had higher potency than in water but was still smaller than the mercury accumulation in sediments. The potential of mercury accumulation has a correlation with the ability to absorption, accumulation and extract of mercury from water and sediments. These activities are following the activity of nutrient absorption and metabolic process to support mangrove growth [19, 29]. The absorption, transferring and translocating activity of mangrove roots to other parts of the tree influence the rate of mangrove growth [26, 32]. The highest potential of mercury accumulation was influenced by root activity as direct contact and nutrient absorption from water column and sediment [19, 31], which are translocated to other parts [3,26,33]. Similarly [58], reported that potential concentration ion of roots still is higher than stem, branches and leaves. Mangrove roots have to metabolize to avoid excessive mercury input and have the ability to reduce mercury contamination to support mangrove growth. The mercury absorption by the roots is influenced by the mangrove roots system and potential of lentic size [21,28], because the mangrove roots have the function as a direct contact and nutrient absorber, which is followed by mercury absorption from sediment and water column [19,31] and then translocated to other parts [3,26,33].

Table 3. The mercury accumulation distribution of mangrove species

mangrove species	Hg accumaltion (ppm)		
	Mangrove stem	Mangrove leaves	Mangrove roots
Aegiceras corniculatum	0.0200-0.0260	0.0040-0.0060	0.0468-0.0500
Aegiceras floridum	0.0201-0.0210	0.0060-0.0080	0.0468-0.0501
Avicennia marina	0.0220-0.0520	0.0090-0.0160	0.0270-0.0670
Bruguiera gymnorrhiza	0.0300-0.0370	0.0030-0.0040	0.0436-0.0502
Bruguiera sexanggula.	0.0180-0.0187	0.0020-0.0030	0.0436-0.0500
Ceriops tagal	0.0130-0.0150	0.0021-0.0030	0.0438-0.0505
Excoecaria agallocha	0.0118-0.0120	0.0040-0.0050	0.0451-0.0507
Hibistus tiliaceus	0.0110-0.0118	0.0030-0.0050	0.0436-0.0501
Melaluca leucadendron	0.0170-0.0172	0.0070-0.0090	0.0436-0.0505
Nypa frutican.	0.0405-0.0450	0.0070-0.0090	0.0427-0.0440
Rhizophora apiculata	0.0120-0.0240	0.0080-0-0090	0.0260-0.0590
Rhizophora mucronata	0.0150-0.2300	0.0030-0.0040	0.0460-0.0690
Rhizophora stylosa	0.0150-0.0180	0.0020-0.0040	0.0436-0.0500
Sonneratia alba	0.0250-0.0640	0.0090-0.0120	0.0427-0.0440
Xylocarpus granatum	0.0200-0.0260	0.0030-0.0040	0.0418-0.0422

In other conditions, mangrove species still must have the ability to reduce the impact of mercury pollution, mangroves must have a toxic mechanism for mercury alleviation, mercury dilution and mercury translocation mechanism and must have the ability to increase absorption of organic matter [31,32]. Mercury contamination will have an increasing proline and malonaldehyde contents, glutathione, non-protein thiols, inhibit the photosynthetic pigment and phytochelatins [20,54].

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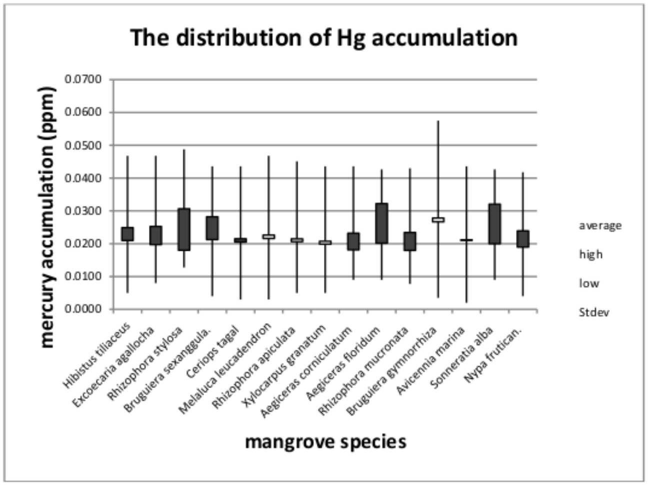


Figure 3. Distribution of mangrove species to accumulate mercury contaminant

The distribution of mangrove species to accumulate mercury contaminant in Fig. 4 explained that the average mercury accumulation > Stdev. The data showed that mercury accumulation of mangrove species had ranges 0.020 – 0.032 mg/L with an average accumulation 0.025 mg/L and study accumulation 0.045 mg/L. The ability of Avicennia marina, Sonneratia alba, Nypa frutican and Rhizophora apiculata, to accumulate mercury contaminants without harm, support these species as the best to rehabilitate in Segara Anakan Lagoon [3,8,9,59], due to their good respiratory system and spreading root systems [34] to grow in mercury contamination area [60,61].

The Bioaccumulation factor (BAF) and the Translocation Factor (TF) of mercury contaminant in a mangrove stand

The bioaccumulation factor and the translocation factor of mercury accumulation were shown in Table. 4 and Fig. 4. The data shows that the BAF of mercury concentrations in the mangrove stem was Sonneratia alba > Nypa frutican > Bruguiera gymnorrhiza > Melaluca leucadendron > Avicennia marina > other mangrove species. BAF of mercury concentrations in the mangrove leaves shows that Avicennia marina > Sonneratia alba > Nypa frutican > Aegiceras floridum > other mangrove species. And BAF of mercury concentrations in the mangrove roots shows that Ceriops tagal > Rhizophora mucronate > Hibiscus tiliaceus > other mangrove species. The potential BAF of mercury concentrations in mangrove stem had ranged between 0.1259 and 0.3262 BAF of mercury concentrations leaves between 0.0156-0.0904 and BAF of mercury concentrations in roots ranges between 0.2984 and 0.4338. This data is different from [26] that reported a BAF of mercury concentrations in mangrove leaves for Cr (0.43), Cu (0.88),Ni (0.47), Pb (1.57), and Cd (0.39). And BAF of areal roots were Cr (0.47), Cu (0.59), Ni (0,49), Pb (1.60) and Cd (0.23)

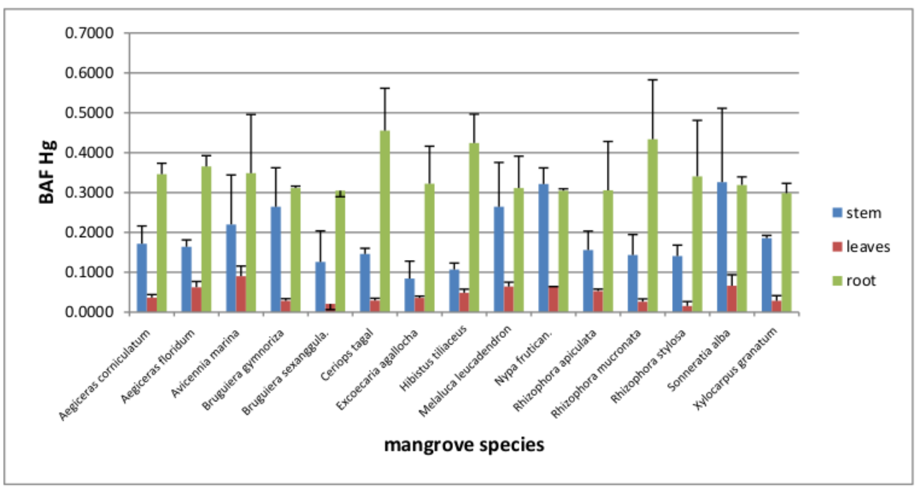
Table 4. The Bioaccumalation factor (BAF) and The Translocation Factors (TF) of mercury contaminant in mangrove stands

mangrove species	BAF						TF			
	stem	stdev	leaves	stdev	root	stdev	stem	stdev	leaves	stdev
Aegiceras corniculatum	0.1715	0.0447	0.0366	0.0076	0.3463	0.0271	0.8240	0.2163	0.5993	0.2124
Aegiceras floridum	0.1641	0.0171	0.0625	0.0145	0.3654	0.0271	0.7856	0.0810	0.5826	0.0944
Avicennia marina	0.2199	0.1243	0.0904	0.0253	0.3486	0.1471	0.7804	0.0496	0.5211	0.1378
Bruguiera gymnoriza	0.2643	0.0979	0.0286	0.0054	0.3114	0.0046	0.7511	0.0876	0.4645	0.1215
Bruguiera sexanggula.	0.1259	0.0779	0.0210	0.0146	0.3049	0.0154	0.8750	0.0856	0.6363	0.1195

Ceriops tagal	0.1460	0.0142	0.0292	0.0058	0.4552	0.1063	0.9445	0.0491	0.6313	0.0035
Excoecaria agallocha	0.0843	0.0436	0.0357	0.0046	0.3221	0.0941	0.7090	0.1665	0.4519	0.1269
Hibistus tiliaceus	0.1071	0.0161	0.0487	0.0092	0.4243	0.0723	0.9685	0.1835	0.4942	0.0299
Melaluca leucadendron	0.2643	0.1112	0.0643	0.0110	0.3114	0.0798	1.2339	0.1877	1.0627	0.4019
Nypa frutican.	0.3214	0.0404	0.0643	0.0000	0.3048	0.0047	0.3419	0.6308	0.2358	0.5847
Rhizophora apiculata	0.1559	0.0473	0.0530	0.0048	0.3057	0.1224	0.7525	0.3165	0.5520	0.2514
Rhizophora mucronata	0.1434	0.0513	0.0263	0.0069	0.4338	0.1488	0.8415	0.0314	0.5954	0.0486
Rhizophora stylosa	0.1406	0.0276	0.0156	0.0110	0.3406	0.1403	1.0043	0.1309	0.7836	0.1087
Sonneratia alba	0.3262	0.1851	0.0663	0.0275	0.3190	0.0202	0.5728	0.0481	0.4141	0.0077
Xylocarpus granatum	0.1857	0.0068	0.0286	0.0129	0.2984	0.0247	1.3057	0.4942	1.0716	0.4610

The translocation factor (TF) of mercury contaminant in mangrove vegetation between 0.578-1.3057 (mangrove stem) and 0.2358-1.0716 (mangrove leaves). The species distribution of translocation factor showed that Xylocarpus granatum > Melaluca Leucadendron > Rhizophora stylosa > Hibiscus tiliaceus > ceriops tagal > other mangrove species (Mangrove stem) and Xylocarpus granatum > Melaluca leucadendron > Rhizophora stylosa > other mangrove species (Mangrove leaves). According [26] reports that the translocation factor in aerial roots are Cd (2.72) > Cu (1.74) > Ni (1.42) > Pb (1.29) > Cr (0.90).

The accumulation process of mercury contaminant is influenced by ***phytoextraction process*** as the absorption ability of mercury contaminant from waterbody or substrate through mangrove roots stored in leaves plant [39,62], Phytovolatilization Process as the absorption of mercury contaminant using evaporative process and be transpired by mangrove leaves [29,63,64], phytodegradation or phytotransformation process as they absorb and destroy the activity of mercury contaminant enzymes metabolism or compounds, phytostabilization process as transforming process of mercury contaminant become non-toxic compounds [63,65,66] and rhizofiltration process as the pollutant absorbing process by mangrove root [63,67,68]. Whereas the Translocation Factor (TF) shows the mercury transfer and translocation process from root to leaf and another organ [3, 17, 19, 33]. TF also show transport process and increase in mercury accumulation [19, 26, 3, 46] The data also showed that mangrove had a good ability to accumulate mercury contaminant from substrate or sediment, but must have high adaptation to grow and live in mercury pollution [17, 19, 68]



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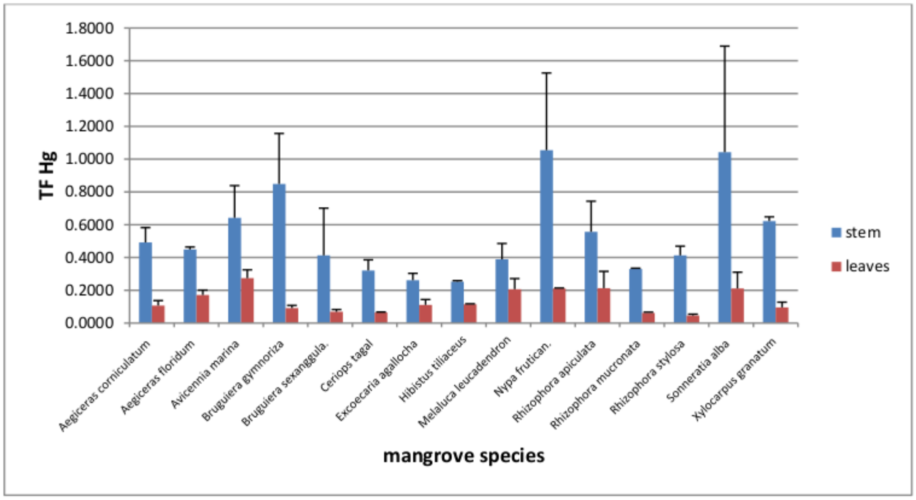

Figure 4. Bioaccumalation factor (BAF) and Translocation Factors (TF) of mangrove vegetation

The mapping interpolation of ecological risk assessment of mercury contaminant in the mangrove ecosystem

The interpolation mapping of mercury contaminants as a model of ecological risk assessment in mangrove ecosystems was developed by the potential mercury accumulation in mangrove stands, sediments and water. The interpolation mapping of ecological risk of mercury contamination could be shown in Fig.5.

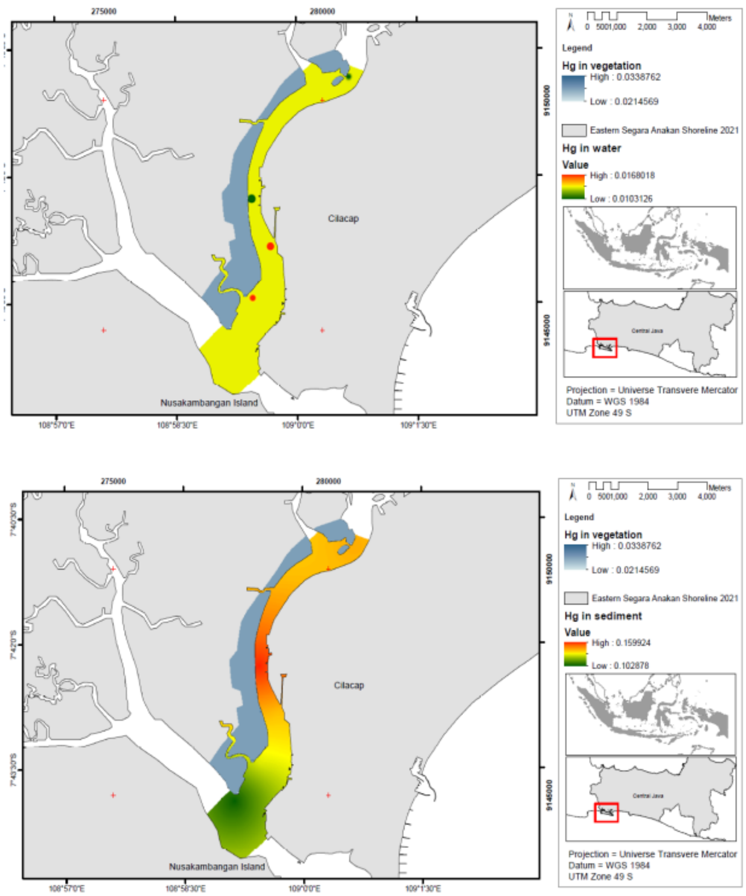

Figure 5. Interpolation of heavy metal contaminant distribution

The interpolation mapping in Fig.5 shows mercury accumulation in stands and water < mercury accumulation in stands and sediment. The potential mercury accumulation can be categorized as moderate to high potential. The interpolation mapping of mercury contamination also shows the critical and toxicity of mercury in vegetation, sediment and water. [47] writes that mangrove stands have a response of phenolic metabolism to reduce the impact of heavy metals in mangroves, including mercury. The mercury contaminant both of a single element or mercury in a compound has high toxicity for many organisms [16,69]. According to [21], the concentration of mercury in the environment must be lower than 0.2 mg/Kg, because if more than the standard accumulation, the mercury will have a high toxicity impact. The mercury toxicity symptoms of trees, in general, are reducing membranes of root cells, growth limitation, chlorophyll damage leading to low photosynthesis, limitation of respiration, can interference with uptake of metabolic of water, disturbance nutrients absorption, and disturbance chlorophyll synthesis [26,29].

The mangrove landscaping to reduce the ecological risk of mercury contaminant

The mangrove landscape was developed to reduce the potential for mercury pollution by zonation of mercury accumulation ability (Fig.6). The ecological risk assessment with the mangrove landscape describes the pattern of mangrove zoning based on the accumulation and reduced ability of mercury contamination and can be used as an adaption pattern and model of mangrove species to grow to live in mercury polluted areas.

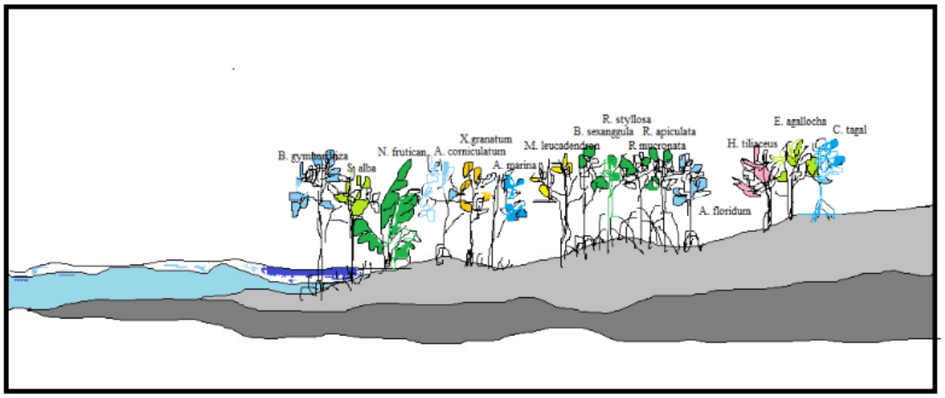

Figure 6. The mangrove landscaping uses the indicator of the mercury accumulation

The mangrove landscape is the model and pattern of ecological risk assessment to reduce mercury contamination showed that the first zone was dominated by Sonneratia alba, Bruguiera gymnorrhiza, Nypa frutican, the second zone was dominated by *Aegiceras* corniculatum, Xylocarpus granatum and Avicennia marina the third zone was dominated by Melaleuca Leucadendron, Bruguiera sexanggula, Aegiceras floridum, Rhizophora mucronata, Rhizophora stylosa and Rhizophora apiculata, the last zone was dominated by Hibiscus tilaceus, Excoecaria agallocha and Ceriops tagal. The mangrove landscape to reduce mercury contaminantion is influenced by the ability to reduce mercury contaminantion with activities of phytostabilization, phytoextraction, phytodegradation or phytotransformation, phytovolatilization, and rhizofiltration [4, 22]. The mangrove landscaping also protects the marine and coastal ecosystems and reduces the impact toxic of mercury with the dilution process and translocation process [3, 19, 69].

The ecological risk assessment uses the clustering of mangrove species to accumulate mercury contamination

The clustering of mangrove species in the contamination area was used to describe the ecological risk of mercury contamination as shown in Fig.7. The mangrove species clustering refers to a grouping of mangrove species following the absorption and accumulation ability of mercury contamination [8, 9] using the Hierarchical and Nonhierarchical Clustering Methods [8, 36, 43, 70]. The clustering of mercury accumulation in mangrove species shows that Sonneratia alba, Nypa frutican and Avicennia marina (Group 1); Bruguiera sexangula, Rhizophora stylosa, Ceriops tagal, Excoecaria agallocha, Hibiscus tiliaceus (Group 2); Aegiceras floridum, Aegiceras corniculatum, Melalauca Leucadendron, Rhizophora apiculata (Group 3); Bruguiera gymnorrhiza and xylocarpus granatum (Group 4) and Rhizophora mucronata as single species (Group 5)

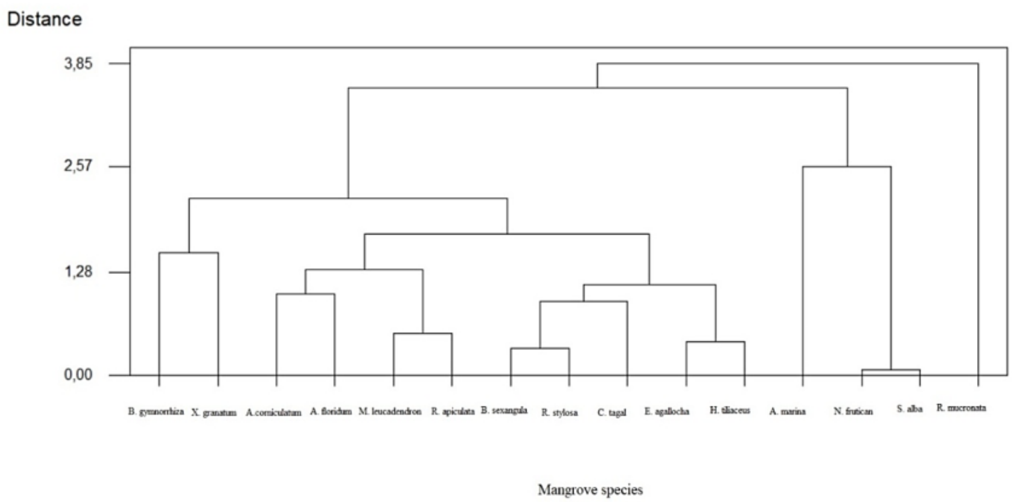

Figure 7. Ecological Risk Assessment using indicator of species mangrove clustering in mercury contaminant area

According to [12, 18, 50, 71] clustering of heavy metals including mercury is influenced by water, water inundation, environmental condition, pollution sources and substrate. The results show that clustering of mangrove stands to reduce mercury contaminantion is relatively different from mangrove zonantion, except Group 1, which is dominated by Sonneratia alba and Sonneratia alba.

Conclusion

The ecological risk assessment of mercury contaminant in the Segara Anakan Lagoon had characteristics are potential contamination in sediments (0.135±0.0021 ppm) and in water (0.014±0.003 ppm). The second indicator is the potential accumulation of mercury contamination are 0.0110 – 00640 ppm (mangrove stem), 0.0020-0.0120 ppm (mangrove leaves), and 0.0260-0.0690 ppm (mangrove roots). The third indicator is Avicennia marina, Sonneratia alba, Rhizophora apiculate, Rhizophora mucronata and Nypa frutican, which had a good ability to accumulate mercury contaminants. The forth indicator is the mangrove landscape that reduces mercury contaminantion with the first zone dominated by Bruguiera gymnorrhiza, Sonneratia alba, Nypa frutican, the second zone dominated by Aegiceras corniculatum, Xylocarpus granatum and Avicennia marina the third zone dominated by Melaleuca Leucadendron, Bruguiera sexanggula, Aegiceras floridum, Rhizophora mucronata, Rhizophora stylos and Rhizophora apiculata, and the last zone was dominated by Hibiscus tilaceus, Excoecaria agallocha and Ceriops tagal. The last conclusion, the author would like thanks to LPPM Unsoed for the Institutional Research Grant 2022 (RISIN 2022) and also thanks for constructive reviews, journal editors for their cooperation in supporting the publication of this journal

Author's declaration:

- Conflicts of Interest: None.
- I hereby confirm that all the Figures and Tables in the manuscript are ours. Besides, the Figures and images, which are not ours, have been given permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee at Jenderal Soedirman University.

Authors' contributions statement

Endang Hilmi made the protocol of the study. Teuku Junaidi, Arif Mahdiana and Rose Dewi supported the study. All authors (Endang Hilmi, Teuku Junaidi, Arif Mahdiana, Rose Dewi) interpreted the data, and read the manuscript carefully and approved the final version of their manuscript.

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تقييم المخاطر البيئية للتلوث بالزئبق في النظام البيئي لأشجار المانغروف في سيجارا أناكان سيلاكاب ، إندونيسيا

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[3].برنامج العلوم البحرية ، كلية المصايد وعلوم البحار ، جامعة جينديرال سوديرمان .جى .دكتور سوبارنو ، بوروكيرتو أوتارا ، بانيوماس 53122 ، جاوة الوسطى ، إندونيسيا.

الخلاصة:
في هذه الدراسة, يعتبر تقييم المخاطر البيئية للتلوث بالزئبق وسيلة لتحليل جانب المخاطر البيئية للنظام البيئي باستخدام التأثير المحتمل للتلوث بالزئبق في التربة والمياه والكائنات الحية. يمكن إظهار تقييم المخاطر البيئية في المنطقة الساحلية من خلال تقسيم مناطق المنغروف ، والتكتل واستيفاء تراكم الزئبق. تهدف هذه الدراسة إلى تحليل تقييم المخاطر البيئية للزئبق المحتمل (بما في ذلك الانتقال و التراكم البيولوجي) باستخدام مؤشر توزيع الأنواع ، والتكتل ، والتقسيم إلى مناطق واستيفاء تراكم الزئبق. أظهرت النتائج أن Segara Anakan كانت معرضة لخطر التلوث بالزئبق ، باستخدام مؤشرات مثل احتمال تلوث الزئبق في الجسم المائي كان (0137 ± 0.0137) جزء في المليون ، الركيزة والرواسب كانت 0.0134 ± 0.0212 جزء في المليون. للحد من تأثير التلوث بالزئبق يمكن إجراؤه عن طريق زراعة المنغروف ، بعد قدرة تراكم الزئبق في الساق واللحاء بين 0.011 و 0.064 جزء في المليون ، في جذور المنغروف بين 0.0260 و 0.0690 جزء في المليون وفي أوراق المنغروف بين 0.0020 و 0.0120 جزء في المليون . استخدم المؤشر الثاني لقدرة المنغروف في تقليل تأثير ملوثات الزئبق في مؤشر عوامل التراكم الأحيائي ، والتي تراوحت بين 0.0210 و 0.4751 ، وكانت عوامل الانتقال بين 0.0459 و 1.0547. . كما أظهرت النتائج أن: Avicennia marina و Sonneratia alba و Rhizophora apiculate و Rhizophora mucronata و Nypa frutican تتمتع بقدرة جيدة على التراكم وتقليل تأثير التلوث بالزئبق.

الكلمات المفتاحية: التلوث بالزئبق، التكتل، تقسيم مناطق المنغروف؛ عامل التراكم الأحيائي؛ عامل الانتقال تقييم المخاطر البيئية.

The Mangrove Strengthen and Ecological Risk Assessment of Mercury Contamination in the Segara Anakan Cilacap Lagoon, Indonesia

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