Lead (Pb) pollution on the Pangandaran coast, West Java Province, Indonesia

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Abstract. Pangandaran coast is one of many marine tourism locations in Indonesia with a great potential. Some of the most frequent marine tourism activities that occured here are aquatic sports and traditional ferry. Numerous water transportation activities, for both tourism and fishing, have the potential to increase lead (Pb) pollution derived by the residual combustion gases and boat paint. Monitoring Pb concentration on coastal area is necessary to promote sustainable marine tourism. The aim of this research was to determine the levels and the feasibility of Pb concentration in water, sediments, and organisms caused by the tourism activities. Survey research methods were used at four sites which are the West coast (Site 1), East coast (Site 2), Sunset Pangandaran Beach (Site 3), and Madasari Beach (Site 4). Sample collection and laboratory analysis were carried out during the dry and rainy seasons, and data were analyzed using a comparative and descriptive analysis method. The results showed that the coast of Pangandaran was polluted with Pb during the dry season with a concentration ranging from 2.55 to 3.56 mg L^{-1} in water, 5.33 to 76.07 mg kg^{-1} in sediment, 1.58 to 2.01 mg kg^{-1} in fish, and 0.52 to 4.11 mg kg^{-1} in crustaceans. Meanwhile, during the rainy season, Pb levels ranged from 0.28 to 1.18 mg L^{-1} in water, from 0.001 to 9.844 mg kg^{-1} in sediments, from 0.001 to 72.248 mg kg^{-1} in fish, and from 0.001 mg kg^{-1} in crustaceans. The feasibility test results showed that in all research sites water was polluted, while sediment was not. Water quality in the dry season was heavily polluted, while in the rainy season it was moderately polluted. Average dry season bioconcentration of Pb in fish and in crustaceans was 0.6 and 0.8 mg kg^{-1}, respectively, while the average bioconcentration during the rainy season was 102.6 in fish and in 0 in crustaceans. Average dry season bioaccumulation in fish was 0.05 mg kg^{-1} and in crustaceans 0.3 mg kg^{-1}, while the average rainy season bioaccumulation in fish was 10.4 mg kg^{-1} and in crustacean it was 0 mg L^{-1}, which confirmed that anthropogenic activities related to marine tourism are causing significant Pb pollution in Pangadaran coast ecosystem.

Key Words: accumulation, coastal area, concentration, index, polluted, transportation activity.

Introduction. Pangandaran Regency, which has a great tourism potential, especially marine tourism (Komariah et al 2017), is located at 108°8'0" to 108°50'0" east longitude and 7°24'0" to 7°54'20" south latitude, on the island of Java, Indonesia, at the borders of the Indian Ocean. Geographically, it is bordered by Tasikmalaya and Ciamis to the north, Cilacap to the east, the Indian Ocean to the south, and Tasikmalaya to the west (BPS Statistic of Ciamis Regency 2021). Heavy metal contamination in coastal areas varies greatly depending on the socio-economic conditions of the surrounding community, the presence of sources of pollution, and the geographical conditions (Pan & Wang 2012). Heavy metal contamination in water enviroment came from industrial waste, traffic activities, domestic waste, and atmospheric deposition (Elfidasari et al 2020; Rahim & Soeprobowati 2018; Santoso et al 2021).

Heavy metals which contaminated the aquatic environment will cause a degradation in water quality (Hasibuan et al 2020). The high content of heavy metals in an aquatic environment, specifically in water and sediment, can contaminate the existing food chain and will affect the livelihood of organisms (Paundanan et al 2015). Heavy metals that enter the waters will settle on the bottom of the waters and bound to the sediment particles, eventually contaminating benthic marine biota (shrimp, clams, and crabs). If the contaminated marine biota is consumed, it will damage the human biochemical system and can threaten human health (Setiawan 2015; Suyatna 2017). Pb pollution in the coastal environment can be caused by various human activities both on land and in sea. Pb originating from land usually comes from residual industrial, agricultural and household activities, specifically from building construction, furniture trade, peeling paint, vehicle maintenance, and oil spills (Liu et al 2018; Santosa 2013; Elyazar et al 2012). Besides that, Pb contamination originating from the sea mostly comes from portuary activities, marine tourism, and industrial activities (Ramlia et al 2018; Warni et al 2017). Marine tourism activities using sea transportation can trigger Pb pollution from fuel, paint, cables, water pipes, and batteries (Tamele & Loureiro 2020). Most of the Pb pollution on the coast occurs as a result of waste from the use of motorized boats in the form of combustion gas and paint (Warni et al 2017). Sea transportation maintenance activities such as painting, cleaning and welding can cause Pb pollution (Rizkiana et al 2017). The use of anti-corrosion paint used in sea transportation is also a product that contains Pb (Anisyah et al 2016).

Lead levels in Segara Anakan Waters (Cilacap), which are geographically adjacent to Pangandaran Beach, are in a range of 0.12–0.24 mg L^{-1} in water and 3.959–21.995 mg kg^{-1} in sediment. These results indicate that Pb levels in water have passed the threshold while the sediment content is still within the threshold (Hidayati et al 2014). It is suspected that the heavy metals found in Segara Anakan Waters were originated from human activities such as fishing activities, agriculture and industrial activities (the oil, cement, lime and coal production), as well as from natural sources (Hidayati et al 2014).

Currently, no research has been recorded on Pb levels and waters feasibility for marine tourism activities on the coast of Pangandaran. Therefore, it is necessary to determine the concentration of Pb in this ecosystem, as it can be used as baseline data for marine tourism management. This research was conducted to determine the level of Pb pollution from marine tourism activities using sea transportation, to determine the feasibility of the Pangandaran Coastal tourism area.

Material and Method

Description of the study sites. The research was conducted from July to December 2022 using a survey method, sampling using a random purposive sampling method, data were analyzed using a comparative descriptive method. Determination of research locations was based on marine tourism transportation activities, namely the number of operating boats obtained through interviews. Samples were taken at 4 sites (Figure 1) with 5 repetitions, carried out in the dry and rainy seasons. Coordinate of the site are as listed here:
Site 1 At coordinates 108°39'21.42" S, 07°42'17.48" E (high activity)
Site 2 At coordinates 108°39'31.59" S, 07°42'16.50" E (moderate activity)
Site 3 At coordinates 108°39'12.41" S, 07°42'18.40" E (no activity)
Site 4 at coordinates 108°29'47.09" S, 07°47'34.25" E (no activity)

Figure 1b represents the West Coast (Site 1), where the beach is entirely covered with sand and have calm waves, and Pb contamination can come from tourism activities, namely ferries, trash from tourists and business actors such as traders, restaurants and hotels, and from fishing activities. Figure 1c is the East Coast (Site 2), where the beach are mostly covered by wave crusher rocks to tackle large waves and Pb contamination can come from tourism activities in the form of watersports, trash from tourists, business actors such as traders, restaurants and hotels, fishing activities, under the influence of waves and tides. Figure 1c is Pangandaran Sunset Beach (Site 3), which is part of the West Beach, located at the northern end and directly adjacent to the Pamugaran Tourism Area, which has clean sand and large waves with many rip currents and where swimming is prohibited and the Pb contamination comes from tourist waste, under the influence of waves and tides, and from the West Coast (Site 1). Figure 1d is the Madasari Beach, located at the western tip of Pangandaran Regency, having very large waves and lots of naturally forming large towering rocks, where Pb contamination can come from tourist waste and trash from the high seas under the influence of waves and currents.

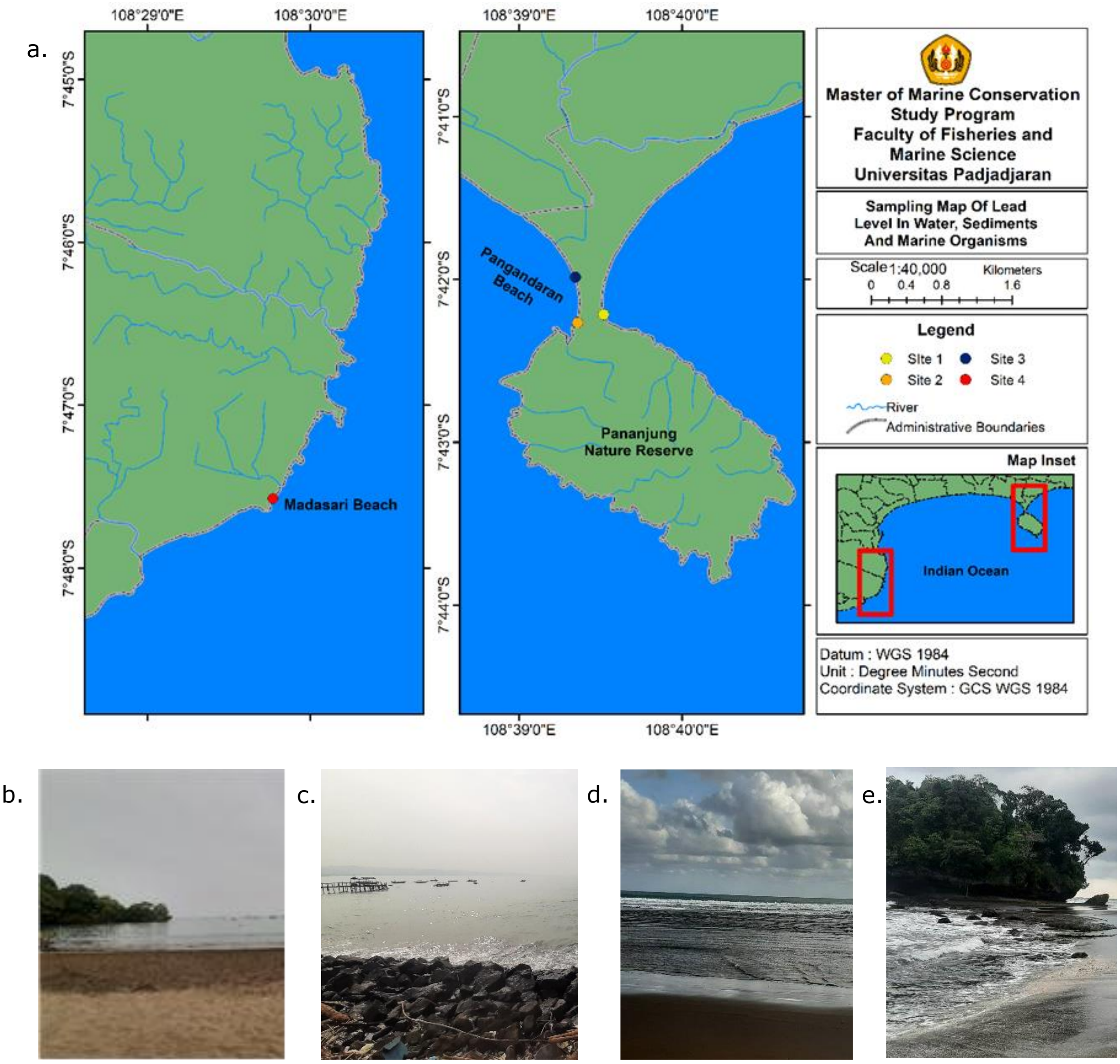


Figure 1. The research map (a), West Coast (Site 1) (b), East Coast (Site 2) (c), Sunset Pangandaran Beach (Site 3) (d), and Madasari Beach (Site 4) (e).

Sampling method. Water and sediment samples were collected in the afternoon between 15.00 and 18.00 at low tide in the intertidal zone. Sampling was carried out in the intertidal zone to look at seasonal variation linked to the tidal cycles between dry season and rainy season (David & Saucède 2015). Samples of fish and crustaceans were purchased directly from fishermen who caught them at the research location. Water and sediment samples were collected according to Harmesa et al (2020) and U.S. Environmental Protection Agency (2021), as well as to Maslukah (2013) and U.S. Environmental Protection Agency (2020), respectively. Sample analysis was carried out at the Central Laboratory of Universitas Padjadjaran. Destruction of water samples was carried out using HNO_3 (wet digestion), sediments with HNO_3+$HCLO_4$, and marine organisms with HNO_3+HCl (dry digestion). The destructed samples were analyzed for their concentration using Atomic Absorption Spectrophotometry (AAS). The temperature, dissolved oxygen (DO), pH and salinity were measured in situ using a DO meter, pH meter, and a refractometer. Measurment was done to determine the seawater characteristics that can be affected by human activity in coastal and estuary areas such as waste disposal, shipping, and cultivation activities (Riter et al 2018; Nurhayati 2006). Data on water transportation activities for marine tourism activities was collected at 2 sites, specifically on the West Coast and the East Coast, through interviews. The interviews were conducted at these 2 sites because marine tourism activities were absent at site 3 (Sunset Pangandaran Beach) and site 4 (Madasari Beach). The number of respondents on the West Coast was of 30 traditonal ferry operators and on the East Coast there were 6 water sport operators. Interviews were conducted to find out transportation activities in tourist areas by looking at daily data on usage time, distance traveled, fuel consumption, type of fuel, and the number of fleets used.

Data analysis*.* The concentration of Pb in water, sediments and organisms, as well as the boat activities, were tabulated and compiled using Microsoft Excel. To determine the feasibility of water and sediment quality in relation to marine tourism activities, the measured data was compared to the threshold values for environmental quality standards (as in the government regulation of the Republic of Indonesia number 22 of 2021 appendix viii (Indonesian Government 2021), concerning implementation of environmental protection and management, as well as the regulations ANZECC & ARMCANZ (2000), Australian and New Zealand guidelines for fresh and marine water quality), presented in Table 1. Furthermore, to determine the effect of tourism transportation activities on Pb concentrations, an analysis of concentration differences was carried out between sites that have and did not have water transportation activities.

Table 1

Threshold value of lead

Pb threshold	*Indonesian Goverment (2021)*	*ANZECC & ARMCANZ (2000)*
Sea water (mg L^{-1})	0.005	0.005
Sediment (mg kg^{-1})	-	50[a]; 220[b]
Aquatic organism (mg kg^{-1})	0.08	0.007

[a]ISQG Low Value; [b]ISQG High Value.

The Index Pollution (IP) of Pb in water and sediment was determined using the method from the Decree of the Minister of the Environment No. 113, according to the Ministry of Environment (2003). The Consensus Based Sediment Quality (CSBQ) was calculated using formula from Sahli et al (2012). The Bioconcentration Factor (BCF) and the Bioaccumulation Factor (BAF) were calculated using formulas from Olawusi-Peters et al (2017), Wang (2016) and Alagic et al (2013).

$$IP_j=\sqrt{\frac{(C_i/L_{ij})_M^2+(C_i/L_{ij})_R^2}{2}}$$

Where:
IP_j - pollution index for threshold j;
$(C_i/L_{ij})_M$ - maximum value of C_i/L_{ij};
$(C_i/L_{ij})_R$ - average of C_i/L_{ij};
C_i - measurement value;
L_{ij} - threshold value.

$$Q_m=\frac{\sum\left(\frac{C_x}{PEC}\right)}{n}$$

Where:
Q_m - sediment quality value;
C_x - parameter concentration on sediment;
PEC - probable effect concentration (highest threshold value);
n - data amount.

$$BCF=\frac{C}{C_w}$$

$$BAF=\frac{C}{C_s}$$

Where:
BCF - bioconcentration factor;
BAF - bioaccumulation factor;
C - heavy metal concentration on organism;
C_w - heavy metal concentration on water;
C_s - heavy metal concentration on sediment.

Results and Discussion. Table 2 shows the collected physico-chemical data measured in seawater off the Pangandaran Coast. It shows that all seawater parameters meet the environmental quality standard criteria for marine tourism and organism life, except for oxygen saturation in the rainy season.

Table 2

Average physical and chemical parameters of seawater

Season	*Site*	*Temp (°C)*	*Oxygen saturation (%)*	*Salinity (‰)*	*pH*	*DO (mg L^{-1})*
Dry season	1	29.53±0.25	113-123	32±0.7	7.99±0.19	7.4±0.4
	2	29.70±0.5	114-120	32±1.5	7.92±0.24	7.39±0.18
	3	29.96±0.1	108-124	31±0.6	7.97±0.24	7.42±0.5
	4	28.34±0.56	111-119	34±1.9	7.93±0.17	7.4±0.24
Rainy season	1	28.15±1.6	76-101	31.5±2.1	7.29±1.1	5.7±1.3
	2	28.4±0.7	76-140	30.0±7.1	6.76±1.7	7.1±3.3
	3	28.0±1.4	78-101	33.5±0.7	7.28±1.1	5.75±1.2
	4	26.65±2.3	78-95	32.5±3.5	7.16±1.5	5.6±0.8
Threshold value		15–35	>80	30–40	7.0–8.5	>5.0
Reference		ANZECC & ARMCANZ (2000)			Indonesian Goverment (2021)	

During the rainy season, oxygen saturation was ranging from 76 to 78% at all sites, which is below the quality standard for oxygen saturation, established by ANZECC & ARMCANZ (2000). However, the minimal value of average dissolved oxygen (DO) in seawater was 5.6 mg L^{-1}, which is an acceptable value. At DO below 5 mg L^{-1}, most fish species cannot survive long and mass mortality will occur when the DO value reaches 3 mg L^{-1} (Giri et al 2022; Bozorg-Haddad et al 2021). The average pH at site 2 during the rainy season is also below the quality standard, namely 6.755±1.7 pH value, less than the standard threshold, which is an indication of ocean acidification, a phenomenon of increasing atmospheric carbon dioxide (CO_2) concentration, which will lead to a decrease in seawater pH. A decrease in pH can interfere with the ability of marine biota in communication, homing ability, habitat selection, detection of predators and prey, breeding processes, species recognition, and symbiotic relationships (Clements & Hunt 2017; Noone et al 2013; Vallero 2014).

In the dry season, the temperature, oxygen saturation, DO and pH, were relatively higher than in the rainy season, but the salinity tends to be the same in every season. According to Surbakti et al (2021), the seawater physical and chemical parameters can affect the level of Pb contamination. High temperatures will accelerate the accumulation of Pb in sediments. High dissolved oxygen levels cause Pb content of water to dissolve more easily. High DO cause a higher accumulation rate of Pb in water, while a low DO causes accumulation of Pb in sediments (Sugiyanto et al 2016; Li et al 2013). A low pH value will cause a decrease of the Pb content in water solubility and increases heavy metal levels in sediments, while a high pH can increase heavy metal levels in water (Sugiyanto et al 2016; Riba et al 2004). Salinity can inhibit the process of heavy metal deposition and reduce heavy metal levels in water (Suryono 2016; Acosta et al 2011; Riba et al 2004).

The accumulation of heavy metals in marine biota is also influenced by water parameters such as temperature, which can affect the metabolic rate of fish, the level of food consumption, and the ability of organisms to accumulate Pb and other chemicals (Volkoff & Rønnestad 2020; Hutagalung 1984). A study of Somero et al (1977) showed an increase of up to 19 times of lead content in Gillichthys mirabilis fish which lives at high temperatures (20-25°C) compared to those living at a lower temperature (10°C). Table 3 shows the average Pb concentration in seawater, sediment, fish and crustaceans on the coast of Pangandaran. Overall, the concentration of Pb are as follows: in the seawater it ranges from 0.278 to 3.555 mg L^{-1}, precipitated in thesediment between 0.001 to 76.07 mg kg^{-1}, accumulated in fish between 0.001 and 72.2478 mg kg^{-1}, and in crustaceans between 0.001 and 4.109 mg kg^{-1}.

Table 3

Average Pb concentration in seawater, sediment, fish and crustacean at Coastal Pangandaran, Indonesia

Sample	*Site*	*Dry season average*	*Rainy season average*	*Thresholds value*	
				Indonesian Goverment (2021)	*ANZECC & ARMCANZ (2000)*
Sea water (mg L^{-1})	1	2.945±0.34	0.335±0.02	0.005	0.005
	2	2.807±0.5	0.334±0.05		
	3	3.133±0.39	0.755±0.6		
	4	3.208±0.31	0.293±0.02		
Sediment (mg kg^{-1})	1	12.709±8.04	4.92±6.9	-	50
	2	34.728±36.43	2.04±2.89		
	3	9.675±1.44	ND*		
	4	6.669±1.97	ND*		
Fish (mg kg^{-1})	1	-	44.65±5.19	0.08	0.007
	2	1.793±0.308	24.08±41.71		
	3	-	-		
	4	-	-		
Crustacean (mg kg^{-1})	1	-	-	0.08	0.007
	2	0.873±0.5	ND*		
	3	-	-		
	4	4.109	-		

*ND: Not Detected (Pb value ≤0.001 ppm).

The concentrations of Pb in fish and crustaceans were only analyzed at sites 1 and 2; at site 3 there was no fishing activity, while at site 4 fishing activities was only traditional and seasonal lobster catchingperformed when waves are calmer. The results showed that the coast of Pangandaran was polluted with Pb. The levels of Pb in seawater, fish and crustaceans have exceeded the quality standards set by the Indonesian Goverment (2021) and ANZECC & ARMCANZ (2000). However, the concentration of Pb in sediment meets the requirements of ANZECC & ARMCANZ (2000).

There was a difference in the concentrations of Pb between the dry season and the rainy season. During the dry season the concentration of Pb in seawater, sediment, and crustaceans was high and the concentration of Pb was low during the rainy season. Additionally, during the rainy season the concentration of Pb in fish was high. These results is similar to those found by Ebah et al (2016) which stated that heavy metals tend to have high concentrations during the dry season and low concentrations during the rainy season. This tendency can occur due to an increase in the lixiviation process (dissolving of substances in water) which occurs as a result of high rainfall resulting in dilution which can reduce heavy metal concentrations (Rajeshkumar et al 2018). Besides that, it shows that the tourism activities dominantly contribute toward high concentration of Pb during the dry season. The level of tourism on the beach is high during the dry season, this is because most of the tourism activities carried out on the beach such as watersport and boating are more often carried out when conditions are sunny and tend to stop or slow down during the rainy season. In Table 3, the levels of Pb in sediments and marine biota are higher than in water, this is due to the nature of heavy metals that are difficult to dissolve in water and have a higher density than water. Therefore, they are deposited on sediments in large and consistent quantities, and bioaccumulation & biomagnification occur in biota (Anandkumar et al 2018; Haeruddin et al 2020; Kahlon et al 2018). Upon entry on aquatic ecosystems, heavy metals can be found dissolved in water or suspended in sediments, but due to the nature of heavy metals that are difficult to dissolve in water, over time heavy metal particles will accumulate in sediments through the process of absorption, precipitation and ion exchange. or accumulated by marine biota (bioaccumulation) (Baguma et al 2022; Nur-E-alam et al 2022; Algül & Beyhan 2020; Wojciechowska et al 2019).

Water and sediment quality index. Based on the IP value, the water quality status at all sites during the dry season is heavily polluted while in the rainy season it is moderately polluted (Table 4). Meanwhile, based on the CSBQ value sediment was not polluted by Pb (Table 4). Pb levels are the most determining factor in water quality status in this study, more specifically Pb level was 10 times higher in the dry season compared to wet season. The different water quality values between the rainy and dry seasons can be caused by differences in anthropogenic activities such as fishing, tourism and industrial activities and the physical, chemical and biological characteristics of the waters.

Table 4

Seawater quality and sediment status

Season	*Site*	*Water quality*		*Sediment quality*	
		IP Value	*Status*	*CBSQ value*	*Status*
Dry season	West Coast (Site 1)	10.68	Heavily polluted	0.06	Not polluted
	East Coast (Site 2)	10.60	Heavily polluted	0.16	Not polluted
	Sunset Pangandaran Beach (Site 3)	10.78	Heavily polluted	0.04	Not polluted
	Madasari Beach (Site 4)	10.8	Heavily polluted	0.03	Not polluted
Rainy season	West Coast (Site 1)	7.3	Moderately polluted	0.02	Not polluted
	East Coast (Site 2)	7.29	Moderately polluted	0.01	Not polluted
	Sunset Pangandaran Beach (Site 3)	8.56	Moderately polluted	0	Not polluted
	Madasari Beach (Site 4)	7.08	Moderately polluted	0	Not polluted

Biota accumulation. The BAF and BCF values of more than 1 indicate heavy metals that have concentrated and accumulated in marine biota (Alagic et al 2013). Tables 5 shows that the levels of BAF and BCF in fish were high in the rainy season and low in the dry season, while in crustaceans they were high in the rainy season and low in the dry season. The accumulation rate of heavy metals in biota is influenced by age, feeding habitat, sex, swimming behavior, absorption of metals in the digestive system, properties of heavy metals, and physical-chemical conditions of the ecosystem (Akila et al 2022; Ali et al 2019; Jonathan et al 2015). High concentrations of Pb in fish can occur due to the influence of other organisms that are consumed containing Pb (trophic transfer), so that it accumulates in fish, which are a higher level of the trophic chain (Anandkumar et al 2018). High Pb concentrations in crustaceans can be caused by their feeding habit, as scavengers, and their habitat at the bottom of the waters (benthos): they can accumulate Pb from garbage and from dead biota (Liu et al 2018).

Table 5

Bioconcentration factor (BCF) and bioaccumulation factor (BAF) in fish and crustacean

Season	*Site*	*Fish*		*Crustacean*	
		BCF	*BAF*	*BCF*	*BAF*
Dry season	West Coast (Site 1)	-	-	-	-
	East Coast (Site 2)	0.6	0.05	0.3	0.03
	Sunset Pangandaran Beach (Site 3)	-	-	-	-
	Madasari Beach (Site 4)	-	-	1.3	0.6
	Average	0.6	0.05	0.8	0.3
Rainy season	West Coast (Site 1)	133.2	9.1	-	-
	East Coast (Site 2)	72.1	11.7	0	0
	Sunset Pangandaran Beach (Site 3)	-	-	-	-
	Madasari Beach (Site 4)	-	-	-	-
	Average	102.6	10.4	0	0

Marine tourism activities. In general, marine tourism transportation activities on the Pangandaran Coast occur at 2 sites, specifically the West Coast (Site 1) and the East Coast (Site 2). On the West Coast, marine tourism transportation activities (Figure 2) are in the form of ferries for tourists to visit the area around Pangandaran Beach. One of the popular destinations usually taken by these traditional ferries is Pasir Putih Beach, which has the closest distance of approximately 300 m and the farthest distance of approximately 3km. Apart from going to Pasir Putih, boats can also be rented with routes chosen by the tourists, such as going around the Pananjung Nature Reserve or going around the entire Pangandaran Beach area. The Pangandaran Tourism Office stated that a total of 143 boats that can be rented are divided into 7 groups according to the operation/landing location. On the East Coast, marine tourism transportation activities are in the form of watersport activities with the help of boats or speedboats. There are 6 watersport service providers on the East Coast. The results of interviews with 30 tourists on the west coast and 6 people on the east coast are presented in Figure 2. The impact of Covid-19 on marine tourism transportation activities can be seen in Figure 3.

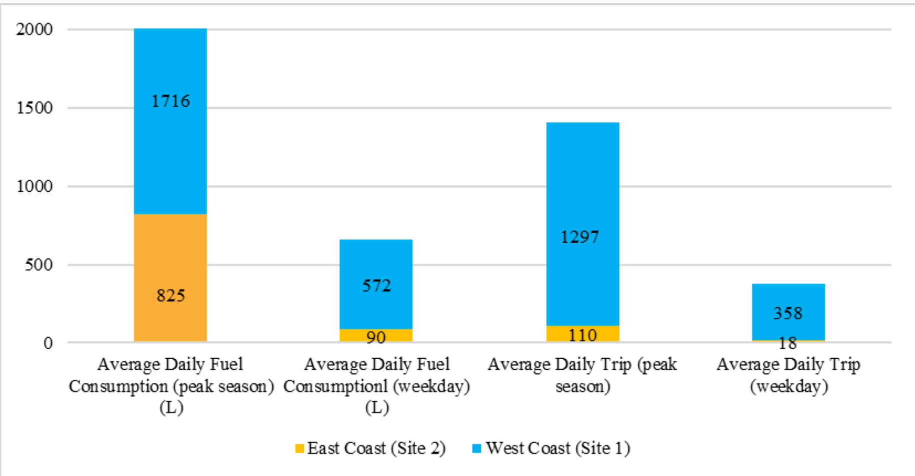
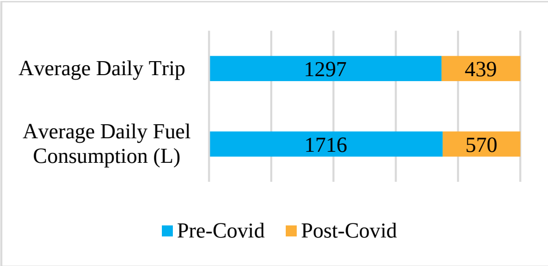


Figure 2. Average marine tourism transportation activities comparison pre-Covid 19 event.

Figure 2 shows that the highest maritime tourism transportation activity is on the west coast, with a stronger potential to pollute the waters as compared to other areas. The high activity of sea transportation on the coast has the potential to increase heavy metal levels in the waters (Xie et al 2023). The use of sea transportation can cause Pb pollution originating from leftover paint, iron frames, and fuel which accidentally dissolve into the waters (Rizkiana et al 2017; Warni et al 2017; Anisyah et al 2016). Maritime tourism transportation activity is high on the West Coast, indicating that the highest Pb pollution occurs in that area.

a)



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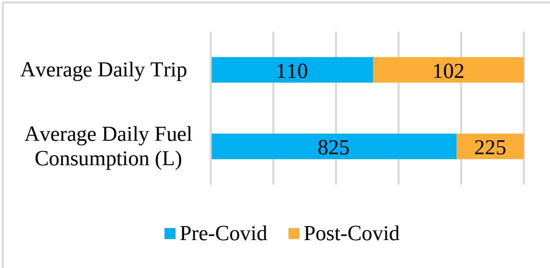


Figure 3. Covid 19 effect on the average marine tourism transportation activities (peak season) at West Coast (a) and East Coast (b).

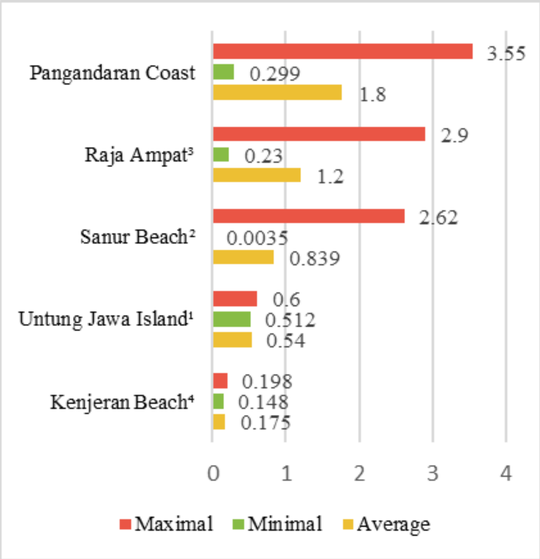
Figure 3 shows the impact of the covid pandemic on marine tourism transportation activities. On the West Coast, the covid pandemic has greatly affected the level of marine tourism transportation activity where the average trip and fuel consumption has drastically reduced to 3 times lower than before the covid. On the East Coast, the number of trips made was not affected by the covid pandemic, however, fuel consumption before covid was higher than after covid, this could be due to differences in activity duration and intensity. Tourism actors on the East Coast also mentioned that post-covid visitors carried out tourism activities for shorter periods.

Table 6

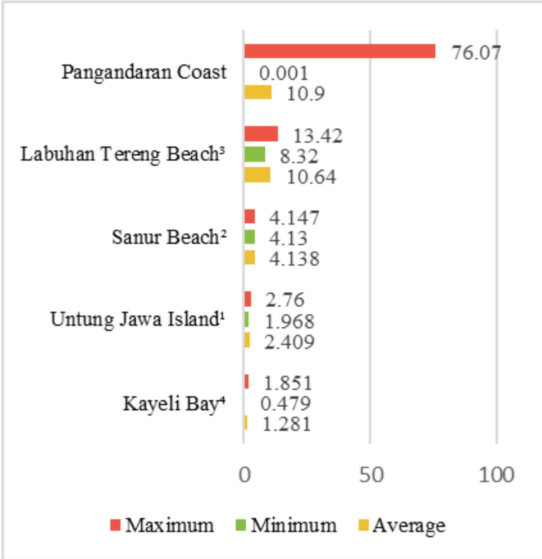
Comparison of peak season pre-Covid on the marine tourism transportation activities with Pb concentrations

Data	*West Coast (Site 1)*	*East Coast (Site 2)*	*Sunset Pangandaran Beach (Site 3)*	*Madasari Beach (Site 4)*
Fleet total	143	16	-	-
Average daily trip	1297	110	-	-
Average daily fuel (L)	1716	825	-	-
Fuel type	RON 90 & 92		-	-
Usage	Exclusive to marine tourism		-	-
Pb concentration on Sea water (mg L^{-1})	1.901±1.44	1.818±1.4	2.182±1.36	2.0419±1.61
Pb concentration on sediment (mg kg^{-1})	9.594±7.91	21.656±31.4	5.805±5.39	4±3.9

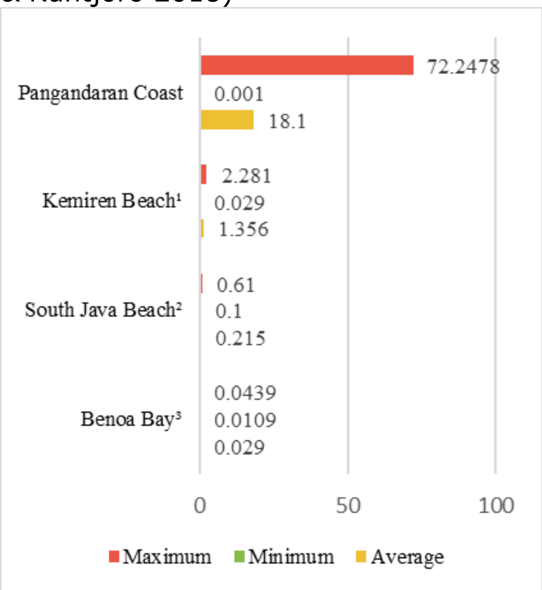
Table 6 shows that Pb levels in water are not affected by marine tourism transportation activities because Pb levels on the East and West coasts are relatively lower compared to Pb concentrations at the Pangandaran beach sunset site (Site 3) and Madasari beach (Site 4). This could be due to the geographical conditions on the West Coast and East Coast which are protected by land jutting into the sea (Pananjung Nature Reserve) while Sunset and Madasari Beaches are directly connected to the open sea. The existence of the Pananjung Nature Reserve as a natural barrier can protect the West Coast area from strong currents and waves originating from the Indian Ocean. The concentration of Pb in the water can be influenced by the sediment transport process so that beaches with high currents and waves have high levels of Pb because the process of sediment accumulation is reduced and Pb dissolves back into the water (Lei et al 2022; Matos et al 2020; Van Loon et al 2017; Khaled et al 2017). Pb levels in sediments are affected by maritime tourism transportation activities because their concentrations are higher on the West and East Coasts. During the rainy season the difference is even more striking. Pb was not detected at all in sediments, on Sunset and Madasari Beaches. The highest sediment content occurs on the East Coast, this can be caused by the use of the East Coast as a fish landing port so that the level of sea transportation activity is high at all times.



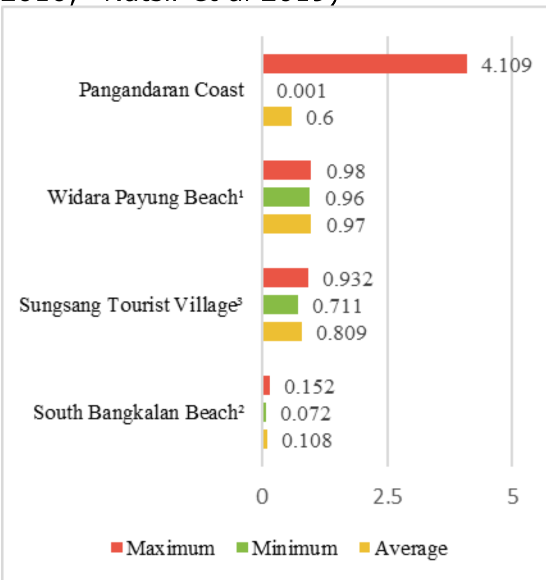
a) Lead concentration on water (mg L^{-1}) comparison ([1]Alisa et al 2020; [2]Aphrodita et al 2022; [3]Taufiq & Lagoa 2018; [4]Wulansari & Kuntjoro 2018)



b) Lead concentration on sediment (mg kg^{-1}) comparison ([1]Alisa et al 2020; [2]Aphrodita et al 2022; [3]Handayani et al 2016; [4]Natsir et al 2019)



c) Lead concentration on fish (mg kg^{-1}) comparison ([1]Fadlilah et al 2023; [2]Hananingtyas 2017; [3]Mardani et al 2018)



d) Lead concentration on crustacean (mg kg^{-1}) comparison ([1]Ketaren et al 2019; [2]Nurhuda et al 2013; [3]Putri et al 2019)

Figure 4. Pb concentration comparison in water (a) sediment (b) fish (c) and crustacean (d).

The comparison graph in Figure 4 shows that the maximum value of Pb concentration in the ecosystem of the Pangandaran Coast is the highest, compared to other marine tourism spots This can be due to differences in the sampling time: while other studies collect samples at one time, in this study samples were taken in two different seasons. Pb concentrations in this study also have a large spread between maximum and minimum values, which could be due to significant geographic and ecosystem differences between each site compared to other studies which have sites that are almost similar to one another.

Overall, the concentration of lead in the Pangandaran Coast is quite high compared to other marine tourism areas, which can be caused by the influence of currents and high waves originating from the Indian Ocean, as well as by the influence of human activities on land (waste flowing into the sea) and on the coast (waste from tourism activities, marine tourism activities and fishing activities).

Conclusions. Based on the results of the study it can be concluded that:
1. The coastal ecosystem of Pangandaran has been polluted with Pb. During the dry season the concentration of Pb in water, sediment and crustaceans is higher, and exceeds a predetermined threshold, compared to the rainy season, and the Pb concentrations in biota crosses the threshold while in sediments it is still within the threshold.
2. High Pb concentrations in coastal ecosystems are caused by anthropogenic activities that occur on land and at sea, one of which is marine tourism transportation. Maritime tourism transportation activities occur on the West Coast in the form of ferries and on the East Coast in the form of water sports,
3. Comparison between the activity level of marine tourism transportation and the concentration of Pb in water and sediment shows that the concentration of Pb in water is not affected by the level of activity of marine tourism transportation, while the concentration of Pb in sediments is directly proportional to the level of activity of marine tourism transportation. A comparison with other coastal areas shows that Pangandaran Coast has the highest concentration of Pb.
4. The feasibility test results show that the waters at all sites, during the dry season, are heavily polluted while in the rainy season it is moderately polluted, whilet the sediment quality at all sites and in all seasons is in good condition. BCF and BAF levels are high during the rainy season and low during the dry season.

Acknowledgements. The authors are grateful to the dean of the Faculty of Fisheries and Marine Science, Universitas Padjadjaran, who has granted research permits and laboratory loans, as well as to the Directorate of Research and Community Service, which has provided funds in accordance with the letter of agreement for implementation of Universitas Padjadjaran Internal grant activities, 2022, number 2203/UN6.3.1/PT.00/2022.

Conflict of interest. The authors declare no conflict of interest.

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Received: 20 April 2023. Accepted: 15 June 2023. Published online: 03 July 2023.
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How to cite this article:
Herawati T., Kusuma U. P., Zahidah, Herawati H., Nurhayati A., Yustiati A., Ghazali A. B., 2023 Lead (Pb) pollution on the Pangandaran coast, West Java Province, Indonesia. AACL Bioflux 16(4):1827-1842.