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Heavy Metal Contamination in Aquatic and Terrestrial Animals Resulted from Anthropogenic Activities in Indonesia: A Review

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Abstract: Hazardous metal pollution has raised a global concern to its increasing trend in response to industrial growth. As an emerging economy, Indonesia starts to receive a backlash of increasing anthropogenic activities resulting in higher emission of heavy metal pollutants. Heavy metals are non-biodegradable pollutants and toxic to humans and other living organisms. Herein, we have reviewed published investigations on the contamination of heavy metals (Pb, Cu, Hg, Ni, Cd, Zn and As) in aquatic and terrestrial animals, attributed to anthropogenic activities in Indonesia. Some reports found the contamination levels have surpassed the tolerable limits of international standards. Most of the research was conducted in the industrial area, indicating that the heavy metal released into the environment can reach the human body through the food chain. A report in a non-industrial area suspected the contamination to be originated from the chain of anthropogenic activities (fertiliser industry—agriculture—livestock industry).

Key words: Heavy metal, health, contamination, animal, industry, wastewater.

Introduction

Indonesia suffers from heavy metal pollution owing to the increase in industrial activities. Studies on the sediment and beach vegetation at Dasun Estuary, reveal the heavy metal pollution from the textile industries (Harmesa & Cordova, 2021). A major river in Jawa Barat, the Cimanuk River, was reported to be heavily

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polluted by Mn, Fe, Ba, Co, Zn, Cu, Pb, and Cr with high concentrations reaching 609, 3.965, 33.1, 3.6, 469.1, 21.4, 14 and 1.6 μg/L, respectively (Wulan et al., 2020). Not only big industries, but artisanal small-scale gold mining may also contribute to a significant amount of heavy metal release (Gafur et al., 2018), especially mercury (Hg) that is used in the gold extraction via amalgamation (Veiga et al., 2009). Improper handling of domestic waste may also contribute to the heavy metal released from the landfill, especially in the case of electronic waste (Pandebesie et al., 2019).

Heavy metals are non-biodegradable and bioaccumulative, making them the most challenging toxic and hazardous waste to handle. Their exposure to the human body may cause a wide spectrum of abnormalities (Rai et al., 2019). Clinical manifestations occur differently in each heavy metal poisoning. Arsenic (As) targets the skin and pulmonary nervous system resulting in skin lesions and bronchiectasis (Mazumder et al., 2005). Cadmium causes damage to the kidney, reproductive system, and bone (Godt et al., 2006). The carcinogenic pathway is the famous route of toxicity of Cr, Ni, V, Co, and As in the human body by inducing oxidative stress (Rehman et al., 2018). Additionally, the most abundant pollutant in the environment, lead (Pb), may cause impaired growth in children below 5 years old (Zeng et al., 2019). Heavy metals are the contributing factors to the increase in the burden of cancer (Qing et al., 2020) and cardiovascular disease (Sevim et al., 2020). Recently, the intertwined between SARS-CoV-2 infection and heavy metal exposure on the severity of respiratory system damage has been reported (Skalny et al., 2020).

Review literature pertaining to heavy metal contamination in animals have scarcely reported on this issue, especially in the context of Indonesia. A similar review has been published for aquatic biota from Mediterranean Sea (Yılmaz et al., 2017), giving useful information. Review on heavy metal contamination in milk, meat, and egg through the circulation from domesticated animals in general settings have been reported as well (Rajaganapathy et al., 2011). Herein, we discussed the reports on heavy metal contamination in aquatic and land animals, followed by the analysis of the source of contamination.

Heavy Metal Contamination in Aquatic Animal

Aquatic animals that have been investigated include daily consumed shrimps, *Penaeus merguiensis* (Komalasari et al., 2019) and *Litopenaeusvannamei* (Syahrir et al., 2019), crabs (*Scylla serrata*) (Zaini et al., 2016), clams (*Anadaragranosa*, *Anadaraantiquata*) (Rahayu et al., 2016), *Anadara inflataa* (Saragih, 2003), and *Pernaviridis* (Maharani et al., 2019). Crustaceans, such as crabs and shrimps, as well as mussels are famous for their ability in bioaccumulating heavy metals indicated by their high intake of heavy metal contents (Table 1).

The concentration of Pb contamination in *Palaemonetespaludosus* from the port industrial area in Jawa Timur (Jailani & Kristiani, 2018) and that in *Penaeus merguiensis* from the tin sand mining areas (Komalasari et al., 2019) exceeded the safe limit for food (0.5 mg/kg) (Li et al., 2020). Investigation of green mussels (*P. viridis*) acquired from Semarang (Yulianto et al., 2020) and Banten (Noviani et al., 2020) reveal the concentrations of 2.26 and 1.02 mg/kg, respectively, which are above the maximum threshold. Cd contamination levels in *P. viridis* (Maharani et al., 2019) and *A. inflataa* (Saragih, 2003) were 4.8 and 7.2 times higher than the maximum threshold (0.05 mg/kg), obtained from different sampling locations.

Mangrove crab (*S. serrata*) acquired around the coal mining area was detected to contain Cu and Hg ranging from 12.54–22.66 and 0.69–0.72 mg/kg, respectively. However, only Hg concentration exceeded the maximum threshold for foods (0.5 mg/kg) (Li et al., 2020). For fish, the conducted studies mostly collected the samples from the area surrounded by artisanal gold mining installations (Amqam et al., 2020; Castilhos et al., 2006). The main pollutant released from this activity is mercury, due to its use in the gold separation process. As expected, fish samples collected from that area were contaminated with Hg with a concerning level above the safe limit.

Heavy Metal Contamination in Terrestrial Animal

Heavy metal contaminations were also reported in tissues of land domestic animals, viz., duck (Susanti et al., 2020; Widayanti & Widwiastuti, 2018), chicken (Ismail et al., 2018; Widayanti & Widwiastuti, 2018), and cattle (Ako et al., 2019; Widayanti & Widwiastuti, 2018). A study of duck samples in Semarang, Central Java, revealed the Hg and Cd levels were 4.42 and 0.074 mg/kg, respectively, exceeding the maximum threshold (Susanti et al., 2020). The maximum limit for Hg and Cd in foods based on the international standard are 0.5 and 0.05 mg/kg, respectively (Li et

Table 1: Heavy metal contaminated aquatic animals reported from studies across Indonesia

Ref.	Year	Method	Location		Industry	Animal	Heavy metal (mg/kg)						
			Province	City/ regency			*Pb*	*Cu*	*Hg*	*Ni*	*Cd*	*Zn*	*As*
(Komalasari et al., 2019)	2019	AAS	Kepulauan Bangka Belitung	Pulau Bangka	Tin sand mining	*Penaeus merguiensis*	1.54*	4.5×10^{-4}	NA	NA	NA	NA	NA
(Jailani & Kristiani, 2018)	2018	AAS	Jawa Timur	Bangkalan	Port industry	*Palaemonetespaludosus*	1.32*	NA	NA	NA	NA	NA	NA
(Syahrir et al., 2019)	2018	AAS	Sulawesi Tenggara	Kolaka	Mining and nickel processing	*Litopenaeusvannamei*	NA	NA	1.04*	18.16	NA	NA	NA
(Hidayati et al., 2020)	2018	ICP-AES	Jawa Barat	Brebes	Port industry	*Litopenaeusvannamei*	0.88 –0.13	2.6 – 8.72	NA	NA	NA	0.18 – 0.02	NA
				Tegal	Port industry	*Litopenaeusvannamei*	0.86 –0.01	2.6 – 6.9	NA	NA	NA	0.11 – 0.07	NA
				Pekalongan	Port industry	*Litopenaeusvannamei*	1.51 –0.29	4.8 – 5.05	NA	NA	NA	0.51 – 0.15	NA
				Pemalang	Port industry	*Litopenaeusvannamei*	1.39 –0.23	5.3 – 6.5	NA	NA	NA	0.49 – 0.15	NA
(Maharani et al., 2019)	2018	AAS	Lampung	Pasaran Island	Coal mining	*Pernaviridis* Linn	NA	NA	NA	NA	0.24*	NA	NA
(SARAGIH, 2003)	2019	AAS	Sumatra Utara	Medan	Port industry	*AnadaraInflataa*	NA	NA	NA	NA	0.36*	NA	NA
(Yulianto et al., 2020)	2017	AAS	Jawa Tengah	Semarang	Port industry	*Pernaviridis*	2.26*	2.29	NA	NA	0.03	14.38	NA
(Rahayu et al., 2016)	2016	AAS	Nusa Tenggara Barat	Lombok Barat	Artisanal gold mining	*Anadaragranosa*	NA	NA	0.02 – 0.049	NA	NA	NA	NA
						Anadaraantiquata	NA	NA	0.03 – 0.075	NA	NA	NA	NA
(Putri et al., 2017)	2017	ICP	Jakarta	Jakarta	Port industry	*Pernaviridis*	0.004	NA	NA	NA	0.004	NA	ND
(Noviani et al., 2020)	2020	AAS	Banten	Banten	Port industry	*Pernaviridis*	1.02*	NA	0.40	NA	NA	NA	NA
(Zaini et al., 2016)	2015	ICP	Kalimantan Selatan	Tanah Laut	Coal mining	*Scylla serrata*	ND	12.54 – 22.66	0.69 – 0.72*	NA	NA	ND	NA

(*Contd.*)

Table 1: (*Contd.*)

Ref.	*Year*	*Method*	*Location*		*Industry*	*Animal*	*Heavy metal (mg/kg)*						
			Province	*City/ regency*			*Pb*	*Cu*	*Hg*	*Ni*	*Cd*	*Zn*	*As*
(Castilhos et al., 2006)	2003	AAS	Sulawesi Utara	Tatelu	Artisanal gold mining	Fish	NA	NA	0.03 ± 0-.02 - 0.85 ± 0.41*	NA	NA	NA	NA
			Kalimantan Tengah	Katingan	Artisanal gold mining	Fish	NA	NA	0.05 ± 0.05 - 1.24 ± 0.39*	NA	NA	NA	NA
(Amqam et al., 2020)	2020	MP-AES and AAS	Maluku Utara	Dum-Dum, Kao bay	Artisanal gold mining	*Lutjanus griseus*	NA	NA	0.108 ± 0.006*	NA	NA	NA	0.235
						Caranxsexfasciatus:	NA	NA	0.205 ± 0.093*	NA	NA	NA	0.484
						Siganussp:	NA	NA	0.097	NA	NA	NA	ND
				Tabobo, Kao bay	Artisanal gold mining	*Lutjanus griseus*	NA	NA	0.350± 0.311*	NA	NA	NA	0.611
						Caranxsexfasciatus	NA	NA	0.228± 0.024*	NA	NA	NA	0.458
(Salami et al., 2008)	2007	AAS	Jawa Barat	NA	Domestic and industrial wastes	Big Fish	0.04 – 0.06	5.51 – 7.54	NA	NA	NA	NA	NA
						Small Fish	0.05-0.06	6.62 – 9.24	NA	NA	NA	NA	NA

AAS =Atomic Absorption Spectroscopy; ICP =Inductively Coupled Plasma; MP = Microwave Plasma; AES =Atomic Emission Spectroscopy
NA = Not Applicable; ND = Not Detected
*Exceeding the safe limit for foods based on the multiple international standards (Li et al., 2020).

Table 2: Heavy metal contaminated land animal reported by studies across Indonesia

Ref.	*Year*	*Method*	*Location*		*Industry*	*Animal*		*Heavy Metal (mg/kg)*					
			Province	*City/ Regency*		*Species*	*Speci-men*	*Pb*	*Cu*	*Hg*	*Ni*	*Cd*	*Zn*
(Susanti et al., 2020)	2020	ICP-OES	Jawa Tengah	Semarang, Temanggung, Magelang, Pati, Salatiga	Electric Power Industry and Shipyards	Duck	Meat	0.062	0.86	4.42*	0.06	0.074*	1.40
(Widayanti & Widwiastuti, 2018)	2018	AAS.	Jawa Timur	Malang	Home Industry Ceramics	Cattle	Meat	NA	NA	NA	NA	0.1*	NA
						Chicken Boiler	Meat	NA	NA	NA	NA	0.27*	NA
						Free-Range Chicken	Meat	NA	NA	NA	NA	0.1*	NA
						Duck	Meat	NA	NA	NA	NA	0.42*	NA
(Ismail et al., 2018)	2018	AAS	Sulawesi Selatan	Sidrap district	NA	Chicken	Muscle	NA	NA	NA	NA	0.461*	NA
							Liver	NA	NA	NA	NA	0.493*	NA
				Pinrang district	NA	Chicken	Muscle	NA	NA	NA	NA	0.48*	NA
							Liver	NA	NA	NA	NA	0.523*	NA
(Ako et al., 2019)	2019	AAS	Sulawesi Selatan	Makassar	Landfill	Cattle(2 YGP)	Blood	2.05	NA	NA	NA	0.04	NA
							Feces	2.03	NA	NA	NA	0.03	NA
							Meat	2.00	NA	NA	NA	0.04	NA
							Liver	2.01	NA	NA	NA	0.03	NA
						Cattle (5 YGP)	Blood	3.05	NA	NA	NA	0.15*	NA
							Feces	2.06	NA	NA	NA	0.06*	NA
							Meat	2.00	NA	NA	NA	0.08*	NA
							Liver	3.04	NA	NA	NA	0.23*	NA

YGP = Year-Grazing Period
NA = Not applicable
*Exceeding the safe limit for foods based on multiple international standards (Li et al., 2020).

al., 2020). Concerning levels of Cd contamination were also observed in chicken, chicken boiler, free-range chicken, and duck reaching 0.1, 0.27, 0.1, and 0.42 mg/kg, respectively (Widayanti & Widwiastuti, 2018).

Cd contamination was found in higher concentrations in chicken samples collected from Sulawesi Selatan reaching up to 0.523 mg/kg (Ismail et al., 2018). By comparing the contamination level in liver and muscle tissue, they found that the accumulation was higher in the liver. It is understandable since the liver has a detoxification function by mobilizing the toxic substances through excretion (Kar et al., 2018). Similarly, the study conducted using cattle samples from Sulawesi Selatan also found higher Cd levels in the liver tissue (Ako et al., 2019). The summary of reported studies on heavy metal contamination in terrestrial animals in Indonesia has been presented in Table 2.

Source of Contamination

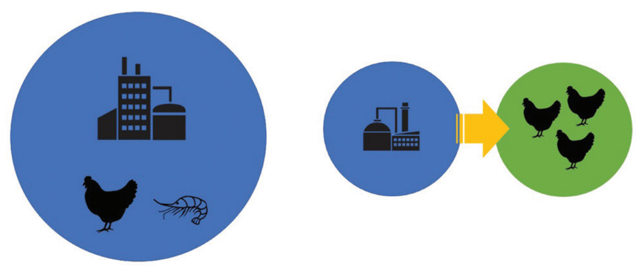
Heavy metals found in aquatic and land animals can be contaminated either from direct or indirect sources (Ako et al., 2019; Krupa et al., 2019). These metals can enter the environment through surface runoff and from natural sources (Dang et al., 2002; Krupa et al., 2019), such as geologic weathering and atmosphere inputs, or they can be derived via effluent discharge from multiple anthropogenic sources, including industrial, agricultural, mining, shrimp farming, and domestic effluents (Vareda et al., 2019).

It has been reported that sediment can be a source of contamination, especially for benthic animals such as shrimp, mussel, and crab (Wu et al., 2017). Similarly in Indonesia, the largest source of Pb and Cu contaminations came from marine sediments (Komalasari et al., 2019). Surface water pollution has been suspected to be the source of Mn and Cd contaminations in a shrimp farm, located in Jawa Tengah (Hidayati et al., 2020). The release of heavy metals from industrial wastewater to the river waters has been associated with the Cd contamination in green mussels collected from traditional markets, Medan, Sumatra Utara (Saragih, 2003).

Sources of heavy metals are also found in food and drinking water from the investigations on duck, chicken, and cattle samples. In Semarang, ducks were contaminated via water and feed consumption (Susanti et al., 2020). Contamination via ingestion was found in cows grazing at landfills in Malang, also coming from their feed (Widayanti & Widwiastuti, 2018), where they also consume organic or inorganic waste containing heavy metals. Farms far away from the landfills have lower contamination in their domesticated animals (Kafiar et al., 2013).

The study conducted above were performed in industrial or landfill areas and suspected to have high pollution of heavy metals. Nevertheless, investigation of different place settings also reported the Cd contamination in chicken tissue. The research did not state the presence of an industrial area, but they investigated the water and feed (Ismail et al., 2018). The study revealed that the feed was the main source of contamination (Ismail et al., 2018), where they further associated their findings with the use of phosphate fertilisers to grow the feed grain (Cheraghi et al., 2012). Phosphate fertilisers are derived from minerals that may contain a high number of cadmium (Roberts, 2014). This suggests that the source of contamination is transported to the distant animals via a chain of anthropogenic activities (i.e. fertiliser industry—agriculture—livestock industry).

Overall, the contamination in animals resulting from the anthropogenic activities may occur in two ways: (1) The presence of the nearby industrial activities, domestic waste discharge, or landfill (Figure 1a); and (2) The source of contamination enters the anthropogenic activities chain (Figure 1b).



(a) (b)

Figure 1: Illustration of anthropogenic activities causing heavy metal contamination (a) in nearby animals and (b) in distant animals via anthropogenic activities chain.

Conclusion

Heavy metal contamination has been found in animal tissues living in the surrounding environment where intense anthropogenic activities are present. Some of the contamination exceeded the safe level standards set by the international bodies. The type of heavy metal can be associated with the industrial activities found nearby. Bioaccumulation of heavy metals by animals can be the main route to entering the human body through the food chain. Interestingly, the anthropogenic activities chain can also be the pathway for heavy metal contamination. Taken altogether, we need the Indonesian government to strengthen its policy in managing heavy metal pollution.

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