Global J. Environ. Sci. Manage. 9(3): 497-514, Summer 2023, Serial #35

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

ORIGINAL RESEARCH ARTICLE

Cadmium and lead uptake by wild swamp eel in the populous river

N. Nurhasanah[1,*], L. Sulistyowati[1], E. Riani[2], M.R. Cordova[3]

[1] Environmental Studies Graduate Program, Universitas Terbuka, Jl. Cabe Raya, Pondok Cabe, Pamulang Tangerang Selatan, Indonesia

[2] Department of Aquatic Resources Management, Faculty of Fishery and Marine Science, Bogor Agricultural University, Bogor, Indonesia

[3] Research Center for Oceanography, National Research and Innovation Agency Republic of Indonesia, Jakarta, Indonesia

ARTICLE INFO

Article History:
Received 20 October 2022
Revised 25 November 2022
Accepted 02 December 2022

Keywords:
Asian swamp eel (Monopterus albus)
Cadmium (Cd)
Ciliwung River
Lead (Pb)
Indonesia
Sediment

DOI: 10.22035/gjesm.2023.03.09

ABSTRACT

BACKGROUND AND OBJECTIVES: For enhanced environmental management of the Ciliwung River, toxic pollutions such as cadmium dan lead data are required. Cadmium and lead have widespread industrial applications. However, cadmium and lead are poisonous and classified as cancer-causing non-essential elements. Moreover, cadmium and lead accumulation in Ciliwung River-caught eels has not yet been examined. Consequently, it is essential to acquire the gathered data from this study. The primary objective of this study was to explore the accumulation of cadmium and lead in sediments and eel organs along the Ciliwung River and to estimate the weekly cadmium and lead intake from eel consumed by the people.

METHODS: Sediment and eel samples were collected at six sampling locations ranging from the upstream, midstream, and downstream regions. Method of 3051a of the United States Environmental Protection Agency was applied to analyze the metal yield from the sediment samples and targeted eel organs (gills, digestive tract, and flesh). In addition, quality control and quality assurance standards were employed, and Certified Reference Materials were used to ensure the quality of data and instruments.

FINDINGS: The average concentrations of cadmium (0.7825±0.3768 milligram per kilogram) and lead (36.9333±14.9040 milligram per kilogram) were greater than their natural levels. The average cadmium concentration in riverine sediment was below the interim sediment quality guidelines. However, the lead concentration exceeded the guidelines. The cadmium and lead accumulation patterns in the sediment and eels were found to be lowest in the upstream and found increased in the downstream are. In this case, the gills acquired the most concentration of cadmium (1.4571±0.3433 microgram per gram) and lead (43.2489±18.6775 microgram per gram). The fact that eel gills accumulated the highest cadmium and lead indicates the presence of heavy metals in their environment. The accumulation of cadmium and lead in the eel surpassed the permitted levels. According to the Provisional Tolerable Weekly Intake estimation, this research showed 0.0328 milligram/week for the cadmium and 1.2826 milligram/week for the lead.

CONCLUSION: The prevalence of cadmium and lead in riverine sediments and eels in the Ciliwung River is believed to be predominantly the result of inefficient wastewater management. However, cadmium and lead pollution must be handled with extreme caution because it interferes with the physiological processes of the biota, hence decreasing the population of eels and posing a health risk if consumed. In general, Asian swamp eels from the Ciliwung River are still edible. As a result, it is hoped that enhanced management will reduce the number of pollutants entering the riverine ecosystem.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
96	5	1

*Corresponding Author:
Email: *nenganah@ecampus.ut.ac.id*
Phone: +622 1749 0941
ORCID: 0000-0001-7234-9111

Note: Discussion period for this manuscript open until October 1, 2023 on GJESM website at the "Show Article".

INTRODUCTION

The river ecosystem is one of the most interactive ecosystems considering that it is affected by natural and human factors. As the commercial hub of an area developed, river is recognized as one of the earliest establishments of civilization. Rivers provide basic needs such as drinking and agricultural water sources, transportation, trade, recreational purposes, energy sources (hydroelectric), and other ecosystem service providers (Sulistyowati *et al.,* 2022). However, the proliferation of improperly managed human activities produces ecological stresses that surpass the river ecosystem's capacity for assimilation (Wijesiri *et al.,* 2018). In Indonesia, more than 50 percent (%) of the pollution status of rivers are polluted and heavily polluted (Statistic Indonesia, 2021). This motivates stakeholders to work toward a better river ecosystem management and ecological restoration. This compels stakeholders to enhance the river's environment in order to maintain and restore its ecological function (Riani *et al.,* 2018). The rehabilitation of the Ciliwung River, whose middle and downstream regions are in Jakarta, the Indonesian capital, is one of the government's top priorities (Pambudi, 2020). It is estimated that over 71,000 families and 350,000 individuals reside in the Ciliwung banks zone. Environmental management is not available to all residents of this region. For improved environmental management of the Ciliwung River, data pertaining to environmental contamination are required, particularly pertaining to heavy metals in riverine sediments and their accumulation in creatures inhabiting this ecosystem (Koesmawati *et al.,* 2018; Lestari *et al.,* 2018; Riani *et al.,* 2018). Heavy metal contamination is a type of water pollution that receives special consideration alarm (Islam *et al.,* 2015). Essential and non-essential types of heavy metals are distinguished (Riani *et al.,* 2014, 2018; Rosado *et al.,* 2016). In this case, iron (Fe) and zinc (Zn) are essential heavy metals that play a role in biological systems despite their harmful effects in high quantities (Mohammed *et al.,* 2011). On the other hand, non-essential heavy metals that are hazardous in low doses, such as cadmium (Cd) and lead (Pb), have no known biological role (Ali and Khan, 2019). In addition, the Agency for Toxic Substances and Disease Registry (ATSDR, 2012) considers both of these metals hazardous heavy metals in its classification system. Heavy metals have the potential to bioaccumulate in the body, and their levels have the potential to rise (biomagnify) as a result of the feeding process that occurs along the food chain (Saher and Siddiqui, 2019). To comprehend this, it is crucial to examine the accumulation and deposition of heavy metals in the geochemical phase in order to determine the possibility of bioavailable compounds linked to ecotoxicity threats (Dixit *et al.,* 2015). In addition, the degree of heavy metal pollutant pollution can be quantified more precisely by examining the accumulation of heavy metals in riverine sediment (Kaewtubtim *et al.,* 2016). Sediments play a crucial role in the transportation of contaminants, such as heavy metals (Miranda *et al.,* 2021). When the current pattern diminishes, the transport mechanism for redistributing polluted material frequently involves the transient adsorption of suspended particles, followed by releasing the polluting material to the surrounding environment (Custodio *et al.,* 2020). After sediment analysis, biomonitoring is essential to undertake additional environmental assessments about heavy metal pollution. Fish are frequently employed for biomonitoring and are one of the most informative aspects when studying pollution in aquatic environments (Yin *et al.,* 2012). Additionally, fish are also the most preferred biota for human consumption. The presence of contaminants, specifically heavy metals in fish, that people afterwards consume disrupts the metabolism or, in the worst case, is one of the causes of cancer (Riani, 2017). The Asian swamp eel (*Monopterus albus*) is a species of eel that inhabits Asian wetlands and riverbanks. Its organisms interacting directly with silt and murky water may accumulate heavy metals (Yin *et al.,* 2012). This kind of eel is highly popular in Indonesia as both a farmed and wild fish, notably those captured in the Ciliwung River. The Ciliwung River is contaminated with heavy metals, which increases the likelihood of heavy metal buildup in creatures that come into contact directly with the mud, such as eels. Sadly, this has not been investigated. Aksari *et al*. (2015), who examined the content of heavy metals (Cd, Hg, and Pb) in amazon sailfin catfish, are among the researchers who have conducted heavy metal accumulation investigations in Ciliwung (*Pterygoplichthys pardalis*). Furthermore, Ismi *et al*. (2019a) researched the ten types of heavy metals contained in the flesh of broom fish (*Pterygoplichthys pardalis*). Elfidasari *et al*. (2019)

investigated the pollution of Ciliwung water with heavy metals. Elfidasari *et al*. (2020) further also examined the concentration of heavy metals in water, sediment, and *Pterygoplichthys pardalis*. Meanwhile, Elfidasari *et al*. (2018) examined the connection between heavy metal concentration and nutritional content in Plecostomus (*Pterygoplichthys pardalis*). Ismi *et al*. (2019b) analyzed the heavy metal concentration of Plecostomus (Loricariidae). Putri *et al*. (2022) investigated the dangers of heavy metal (Cd, Hg, Pb) presence in processed *Pterygoplichthys pardalis* products to human health. In addition, Mulyaningsih *et al*. (2020) examined the heavy metals contamination in sediment, whereas Cadmium and lead uptake by wild swamp eel in the densely populated Ciliwung River that have never been evaluated. In this study, Cd and Pb were chosen because Riani *et al*. (2018) found significant amounts of Cd and Pb in Jakarta Bay, where the Ciliwung River drains, and it has been demonstrated to induce abnormalities in green mussels. In addition, operations in the Ciliwung watershed, such as the battery and electroplating industries and the use of natural phosphate rock-based fertilizers in agricultural activities upstream to the middle of the Ciliwung River, can produce Cd-containing trash. Transportation in the middle and downstream portions of the Ciliwung watershed is likewise classified as high to very high, even though transportation activities and various types of industries in the middle and downstream regions have the potential to generate relatively high levels of pollutants. Therefore, Cd and Pb were chosen for this investigation due to their significant potential for contamination of the Ciliwung River. Based on this information, it is essential to investigate the uptake of Cd and Pb heavy metals in riverine sediments and wild Asian swamp eels inhabiting the Ciliwung River. The findings of this study will be necessary for the environmental management, particularly in determining the fate of Cd and Pb in the riverine ecosystem. The aims of this primary was to investigate the accumulation of Cd and Pb in the river sediments and eel organs from upstream to downstream of the Ciliwung River and to estimate the weekly intake of Cd and Pb from eel consumed by the local community. Therefore, this study was undertaken on the Ciliwung River in Indonesia during the dry season of 2022.

MATERIALS AND METHODS

Study area description

The Ciliwung River drains an area of more than 476-kilometer square (km^2) with length of the river of 119 kilometer (km). This river flows through the administrative territory of three provinces: West Java Province (Bogor Regency, Bogor City, Depok City), DKI Jakarta Province (South Jakarta City, East Jakarta City, Central Jakarta City, West Jakarta City, and North Jakarta City), and Banten Province (Tangerang City and Tangerang Regency). The Ciliwung River serves as a source of water for fisheries, agricultural, and industrial activities in the upstream region and a source of potable water in the upstream and midstream areas. Mount Pangrango, at an elevation of 3,020 meters (m) above sea level, is the origin of the river. The annual precipitation range for the Ciliwung watershed is between 1,500- and 3,500-millimeter (mm). The province of DKI Jakarta has the greatest portion of the Ciliwung Watershed, including 40% of its total area. Land use features in a river's upstream, midstream, and downstream are incredibly distinct. In the upstream land use, there is a mixture of primary forest, agricultural land, and settlements; however, in the midstream and downstream, practically all of the area is built-up land. In the Ciliwung watershed, there has been a considerable shift in land cover, particularly the replacement of agricultural and forest areas with built-up land, which has increased by more than 100% annually since 1990 (Abighail *et al.,* 2022). So that the hypothesis in this study are the concentrations of Cd and Pb in the river sediment is higher than their natural levels, Cd and Pb accumulation at riverine sediments and target organ eels increase from upstream to downstream, and the accumulation of Cd and Pb in the eel is greater than in the sediment.

Field sampling

The sampling technique was applied at six locations (Fig. 1). The two stations represent the upstream area (CL01-CL02), midstream area (CL03-CL04), and downstream area (CL05-CL06), respectively. Three sediment samples were collected at each sampling location using a sediment grab from the river's middle and from each embankment (van Veen grab sampler). On the surface of the sample in the

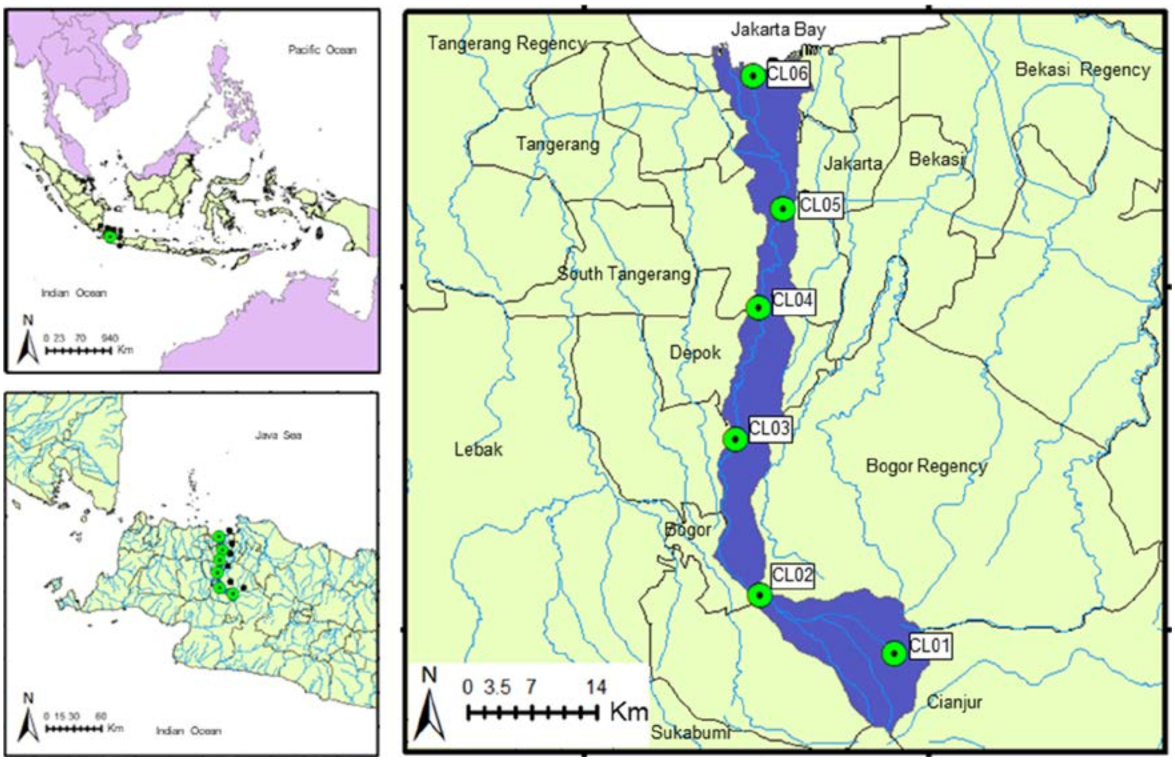

Fig. 1: Geographic location of the study area along with the sampling locations at Ciliwung River, Indonesia

sediment grab (about 10 to 15 centimeters (cm)), a composite sample was obtained by homogenizing the sample using a plastic spoon. The sample was then placed in a 300-milliliter (mL) glass container. Specimens of the Asian swamp eel were collected with the assistance of local fishermen by fishing for the eel in its nest on the bank of the Ciliwung River. The length and weight of the eels captured were determined. The length of eels varied from 11.86 to 42.02 centimeter (cm), with a mean of 27.06 cm. The average weight of the obtained eels was 13.46 gram (g), with a range of 4.2 to 25 g. Asian swamp eel samples were further put in a glass container like sediment samples. For the analysis, all sediment samples and Asian swamp eels were placed in a cooler at a temperature of 4±2 degrees Celsius (°C).

Heavy metals analysis

Method 3051a of the United States Environmental Protection Agency (USEPA, 2007) was used to analyze the metal yield from the sediment and eel samples. In this case, surgical equipment was used to dissect each individual eel. On separate sheets of sterile aluminum foil, the eel's gills, digestive tract, and flesh, as well as the sediment, were placed. Samples of sediment and eels were then dried for 24 hours at 105°C to eliminate water content (Cordova *et al.,* 2017). After the drying, the sample was finely powdered in a mortar. In test tubes containing samples, 3 mL of hydrochloric acid (HCl) and 9 mL of nitric acid (HNO_3) were added to transform organometallic into inorganic form (Riani *et al.,* 2018). The sample was then placed in the Microwave Accelerated Reaction System (MARS) microwave digestive oven (CEM MARS5 Xpress) for 15 minutes at 185°C. The sample was let to rest for 30 minutes before being diluted with 25 mL of ultrapure water. All samples were further evaluated using the Thermo Scientific iCAP 7400 Inductively Coupled Plasma – Optical Emission Spectrometry (ICP-OES) for Cd and Pb levels. This research also employed quality control and quality assurance (QC/QA) to guarantee that all processes were adequate and well-managed (Harmesa and

Cordova, 2020). As samples, the National Research Council of Canada Certified Reference Materials (CRM) DOLT-5 (for trace metals) and PACS-3 (for sediments) were utilized. All CRM test results fall within the certificate's specified range (NRCC, 2013; NRCC, 2014).

Data analysis

For the Cd and Pb content in sediments, data analysis in this study is reported in milligram per kilogram (mg/kg), whereas the level of Cd and Pb in eels is shown in microgram per gram (µg/g). The initial analysis compared the Cd and Pb concentrations in riverine sediment to the Canadian Council of Ministers of the Environment (CCME, 2001) sediment quality guidelines and natural concentrations. In contrast, eels' Cd and Pb concentrations were compared to the Food and Agriculture Organization/World Health Organization of the United Nations (FAO/WHO 2019) permissible levels. This study's statistical analysis, which comprised descriptive statistics (mean and standard deviation of Cd and Pb) and a significant difference test utilizing a non-parametric test (the Kruskal-Wallis test followed by the Mann-Whitney post hoc test), was conducted using PAST Software Version 4.03.

RESULTS AND DISCUSSION

Cd and Pb concentrations in sediments and eels from Ciliwung river

Ciliwung River is a river that receives a significant amount of waste runoff from human activities. Industrial, residential, agricultural, urban, and other anthropogenic activities exist near the river and dump their waste into the waterway. On the other hand, anthropogenic activities such as wastewater disposal from industrial and domestic activities, smelting in mining activities, burning fossil fuels, and use of fertilizers and pesticides in agricultural activities are anthropogenic sources of heavy metals such as Cd and Pb (Yousif *et al*., 2021), which enter the water and eventually settle and become trapped in the sediment (Fretes *et al*., 2020, Riba *et al*., 2004). In contrast, eels as infauna in the Ciliwung River that inhabit sediments contaminated with Cd and Pb will get contaminated with Cd and Pb. Fig. 2 demonstrates the typical Cd and Pb concentrations in the sediments and eel target organs. The average Cd concentration (0.7825±0.3768 mg/kg, in riverine sediment (Fig. 2a) in Ciliwung was relatively lower than the interim sediment quality guidelines of CCME (2001). However, the Pb concentration (36.9333±14.9040 mg/kg) was higher (Fig. 2b). Furthermore, the average levels of Cd and Pb were higher than in natural concentrations which were 0.102 mg/kg (Cd) and 17 mg/kg (Pb), respectively (Wedepohl 1994). The average content of Cd and Pb in Ciliwung River sediments was slightly less than the XRF results of Elfidasari *et al*. (2020). The concentrations of Cd and Pb in the Ciliwung river were lower than rivers in China (Li W *et al.,* 2022; Li X *et al.,* 2022; Fang *et al.,* 2022), India (Saikia *et al.,* 2022), Pakistan (Hossain *et al.,* 2021), and Mexico (Vargas-Solano *et al.,* 2022), comparable to those in Argentina (Magni *et al.,* 2021), Poland (Jaskuła and Sojka, 2022), and Thailand (Ta and Babel, 2020), as well as greater than those in Zambia (Nakayama *et al.,* 2010) and Iran (Jafarzadeh *et al.,* 2020). Compared to FAO/WHO (2019) permissible levels (2 µg/g for Cd and Pb), the accumulation of Cd (0.7808±0.5339 microgram per gram (µg/g) in eels is comparatively moderate (Fig. 2c). However, the accumulation of Pb (30.5384±15.3307 µg/g) in eels greatly surpassed these levels (Fig. 2d). The amount of Cd and Pb in eels was much higher than in the flesh of *Pterygoplichthys pardalis* caught in the Ciliwung River and analyzed by XRF with concentrations of Cd 0.2-0.4 µg/g and Pb 1.9-2.88 µg/g (Elfidasari *et al*., 2020) and much higher than the amount of Cd and Pb allowed in fish flesh by several permissible standard limit (BPOM, 2018; FAO/WHO, 2011; SNI, 2009; CFDA, 2017; European Commission, 2006; Canada Guidelines, 2018; ANZFS, 2016) (Table 1). The much higher bioaccumulation in eels was considered to be because eels are aquatic biota that lives in mud, which is rich in organic matter, so it will accumulate (or "trap") heavy metals much more than biota that lives in the water column and sand and rock sediments (Riani *et al*., 2017). This fits with what Fretes *et al*. (2020) said about sediment being a place where heavy metals can be absorbed. Heavy metals in the water column will go through a deposition process and build up in sediments, and then they will build up in the bodies of benthic organisms. Pb presented in greater amount in sediments and eels than Cd in each sampling station. The gill was the organ that accumulated the

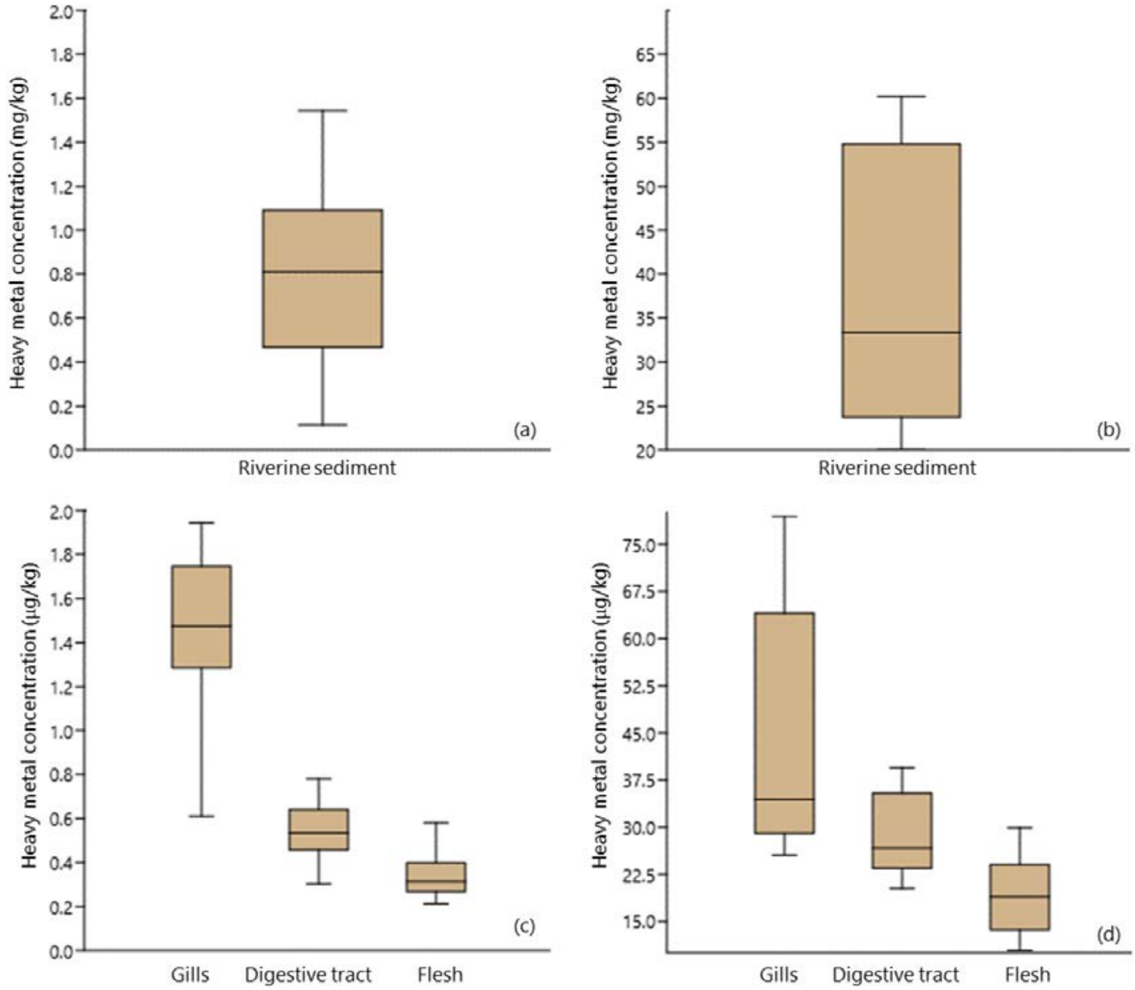

Fig. 2: The concentrations of Cd in the sediments (a), Pb in the sediments (b), Cd in the eels targeted organ (c), and Pb in the eels targeted organ (d)

Table 1: Concentrations of Cd and Pb in Ciliwung River eels compared to several permissible standard limit

Heavy metals	Concentration in eels from Ciliwung River (µg/g)	BPOM, 2018	FAO/WHO, 2011	SNI, 2009	CFDA, 2017	European Commission, 2006	Canada Guidelines, 2018	ANZFS, 2016
Pb	30.5384±15.3307	0.2	0.03	0.3	0.2	0.3	0.5	0.5
Cd	0.7808±0.5339	0.1	0.01	0.1	0.05	0.05	-	-

most Cd and Pb in eels, followed by the digestive tract. Compared to the other two organs, the flesh had the least amount of Cd and Pb. The gills of eels accumulated the most Cd and Pb, indicating the heavy metal content in their environment (water and sediment). Asian swamp eels inhabit shallow, murky waters with a mud-to-water ratio of 80:20 (Nhan *et al.,* 2019). Gill is the first organ in contact with the environment and serves as a site for ion absorption from the surrounding environment (Heath, 2018).

Heavy metals that exist in the environment and enter the gills are bound, transported, and stored by gill cells (Luo *et al.,* 2014). Then, the gill cells control the balance between oxidation and reduction to control the stress response to heavy metals (Luo *et al.,* 2014). In accordance with several earlier studies on the same or similar fish species, this investigation discovered distinct heavy metal accumulations in different organs. Similar to studies conducted in Turkey (Karadede *et al.,* 2004), Malaysia (Yin *et al.,* 2012), and France (Oliveira Ribeiro *et al.,* 2005), heavy metal accumulation in benthic fish was the highest in the gills and lowest in other organs. Meanwhile, the flesh acquired the lowest accumulation of heavy metals because it is a relatively inert organ in the process of interacting with the environment (Roméo *et al.,* 1999).

Heavy metals originate from both natural and anthropogenic sources, including rock weathering, volcanic activity, and atmospheric deposition, as well as residential, agricultural, and industrial activities (Fang *et al.,* 2016a; Harmesa *et al.,* 2020; Suresh *et al.,* 2012). In this research, the influence of human-made sources was greater than that of natural sources. According to Hosono *et al.* (2011), heavy metals started to accumulate in Jakarta Bay, the estuary of the Ciliwung River, from the 1920s to the 1990s (due to the industrialization) and then commenced to decrease in the 2000s (owing to the increased stringency of environmental restrictions). The two heavy metals examined in this study are believed to originate from human activity. Cd is utilized as a raw material in the battery and electroplating industries (Harmesa and Cordova, 2020). In addition, Cd is a heavy metal present in natural phosphate rock-based fertilizers that are bonded to Cd (Ayangbenro and Babalola, 2017; Liu *et al.,* 2016; Tang *et al.,* 2010). Consequently, Cd is typically observed in agricultural areas. The Ciliwung watershed region, particularly upstream, remains an agricultural region. Based on what this study found, more research projects should be done on the amount of heavy metals in agricultural fertilizers in the Ciliwung watershed. The relationship between Pb accumulation and transport activity is strong (Burton *et al.,* 2005). It is associated with heavy land, sea, and air transportation activities that lead-containing fuel enters the combustion engine system and is expelled in the exhaust (Hossain *et al.,* 2019; Sakawi *et al.,* 2013). In addition, Pb is also produced through industrial processes. The amount of Pb in the environment goes up as the number of industrial operations goes up (Liu *et al.,* 2016; Tepanosyan *et al.,* 2017).

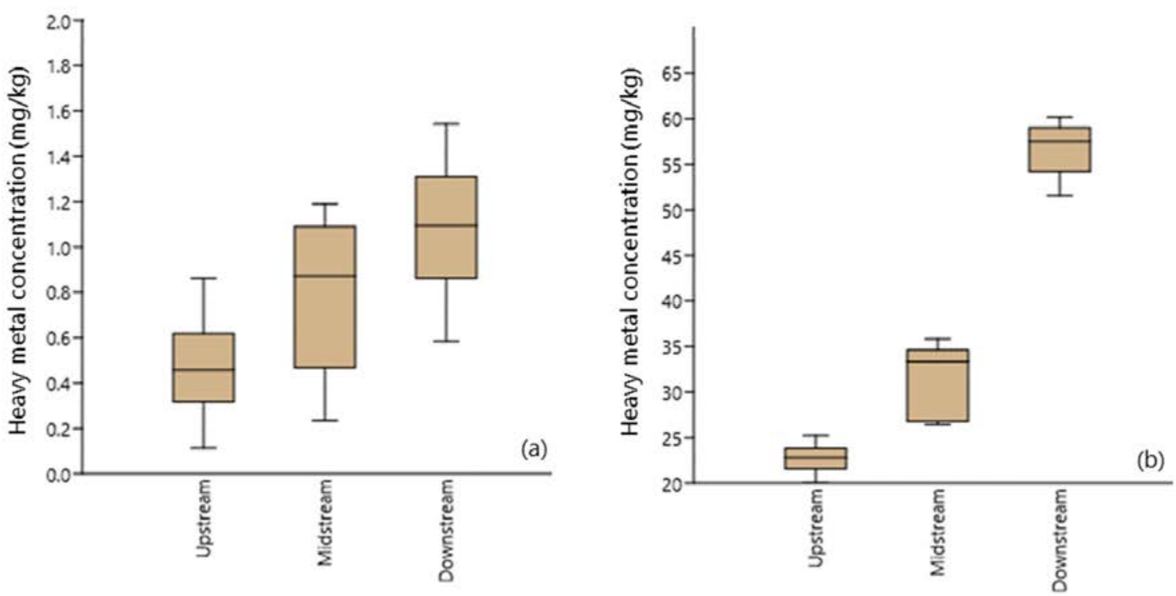

Fig. 3: Spatial distribution of Cd (a) and Pb (b) in riverine sediment from Ciliwung River

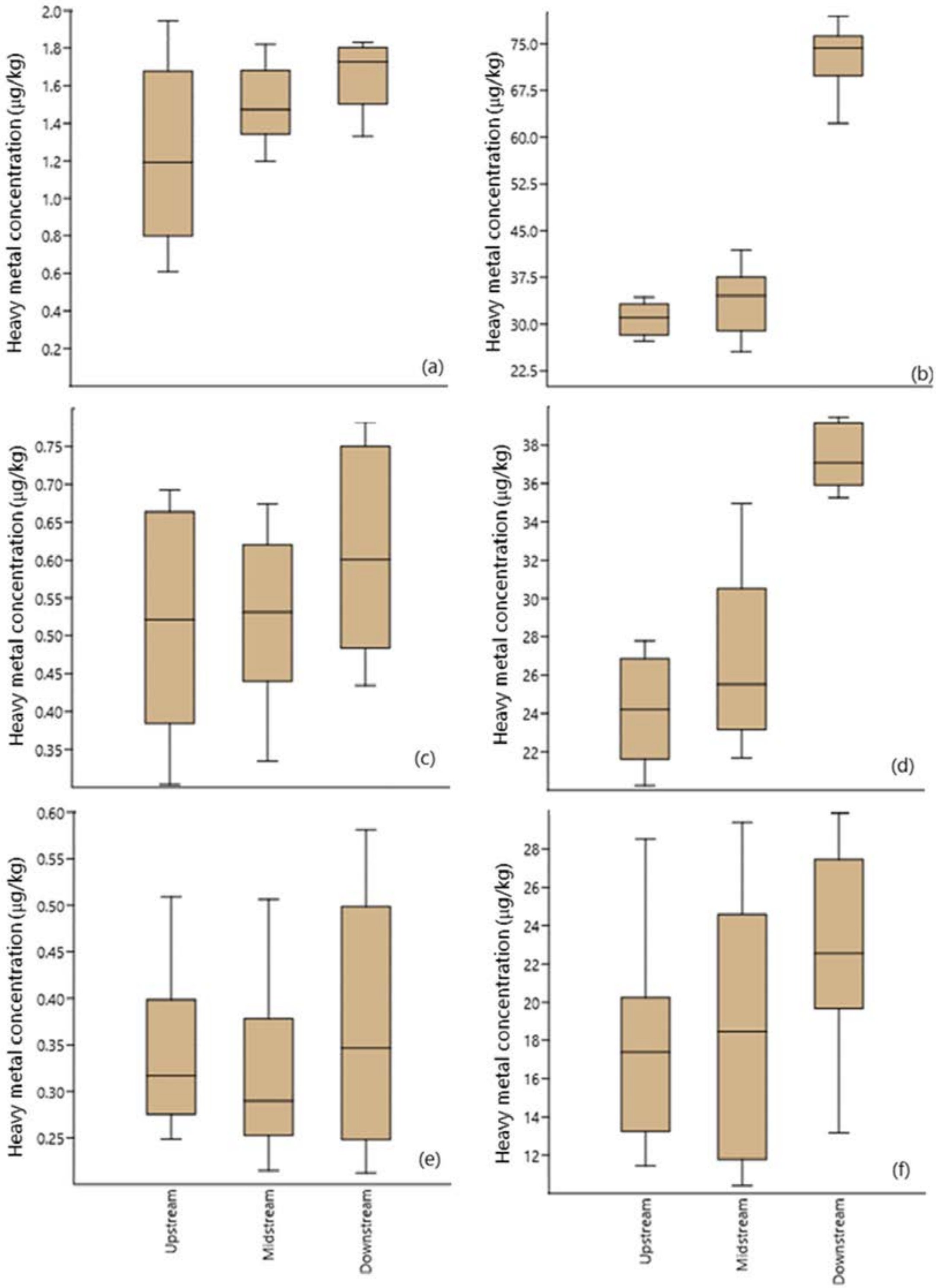

Fig. 4: Spatial distribution of Cd in gill (a), digestive tract (c) and flesh (e) and Pb in gill (b), digestive tract (d) and flesh (f) from Ciliwung River.

Spatial distribution of Cd and Pb in sediment and target organ eels from Ciliwung River

The findings of the study of Cd and Pb in sediments and eels from the upstream, midstream, and downstream regions of the Ciliwung River are presented in Fig. 3 and Fig. 4. The Cd and Pb accumulation pattern in the two research objects were found to be lowest in the upstream area and continue to increase in the downstream area. There were significant differences in sediments ($p<0.05$) for Pb accumulation in the upstream, midstream, and downstream regions (Fig. 3a), whereas only in the downstream and upstream regions for Cd accumulation (Fig. 3b). Variations in the accumulation of Cd and Pb in target organs of the eel were induced by differences in the accumulation of Cd and Pb in upstream, midstream, and downstream sediments. This study demonstrated substantial variance in the accumulation of Cd in the gills (Fig. 4a) and digestive system (Fig. 4c) of upstream eels. However, variation in the accumulation of Cd in the flesh was higher in the downstream region (Fig. 4e). Different things were discovered in the variation of Pb accumulation that was not readily apparent in the gill (Fig. 4b) and digestive tract (Fig. 4d). However, there was a significant variation of Pb accumulation in the flesh in the midstream region (Fig. 4f).

On the rationale of additional analysis, there were significant differences ($p<0.05$) between the upstream and midstream regions and the downstream regions for Pb accumulation solely in the gill and digestive organs. At the same time, there were no significant differences in the target organs for Cd accumulation. Heavy metals arising from natural processes and human waste that are not effectively managed will enter water bodies and be transported by freshwater flows (Fang *et al.,* 2016b). The water flow in the upstream region of the Ciliwung River originates from Mount Gede Pangrango, a volcano with an active status but at a normal level. The accumulation of heavy metals in riverine sediments, which will eventually accumulate in the eel, is a natural consequence of rock weathering, erosion, and volcanic activity (Hussein *et al.,* 2021; Wuana and Okieimen, 2011). In addition, the source of heavy metals in upstream regions is the result of human activities, particularly agriculture and domestic activities with inefficient wastewater treatment. This study's findings show that the concentration of Cd and Pb tends to grow in the likely midstream result of domestic and industrial activities. These human-based activities happened more often in the upstream area, which made the pattern of Cd and Pb buildup more prominent (Harmesa and Cordova, 2020; Thongyuan *et al.,* 2021). On the other hand, Cd and Pb are heavy metals that can induce toxic effects that can affect biota in aquatic environments (Sanchez, 2014). In addition to being hazardous, heavy metals also harm the ecosystem due to their toxicity, solubility, and ability to accumulate in organisms (Demkova *et al.*, 2017). Cd and Pb that have settled in the sediment will be acquired by creatures (particularly benthic organisms) by diffusion through the skin, digestion, and osmoregulation (Riani, 2017). In addition, metals that cannot be detoxified and expelled will bind to enzymes, causing them to accumulate and disturb numerous systems and physiological organisms of the organism (Riani *et al.*, 2017). Therefore, heavy metals, particularly Cd and Pb, can have a significant effect even in small amounts (Wuana and Okieimen, 2011); thus, it is essential to consider this condition. Cd and Pb can be transported from upstream to downstream and into estuaries and marine ecosystems by water currents (Fernández-Cadena *et al.,* 2014), transporting Cd and Pb adsorbed by suspended solids (González-Ortegón *et al.,* 2019). Heavy metals contained in river sediments will undergo an anaerobic decomposition process that promotes movement between locations and is highly prone to enter the organs of biota (Demirbilek *et al.,* 2013), such as eels whose nests are located in river mud. The higher organic content and comparatively low oxygen level of river mud (Hussein *et al.,* 2021) generate methanogenic conditions (Ishchenko, 2019) that make it easier for reductive metals to be released (Thongyuan *et al.,* 2021) and enter the eel's organ (Li *et al.,* 2009). The gill is the organ with the highest concentration of heavy metals, particularly in the downstream region. This is because the gill interacts directly with the mud and suspended particulates and the greater concentrations of Cd and Pb in the downstream region. In addition, the bioavailability of Cd and Pb will multiply in mud and suspended particles (Bergamaschi *et al.,* 2012). This study was conducted during the dry season when there is substantially less natural water compared to greywater from human activities. As a result,

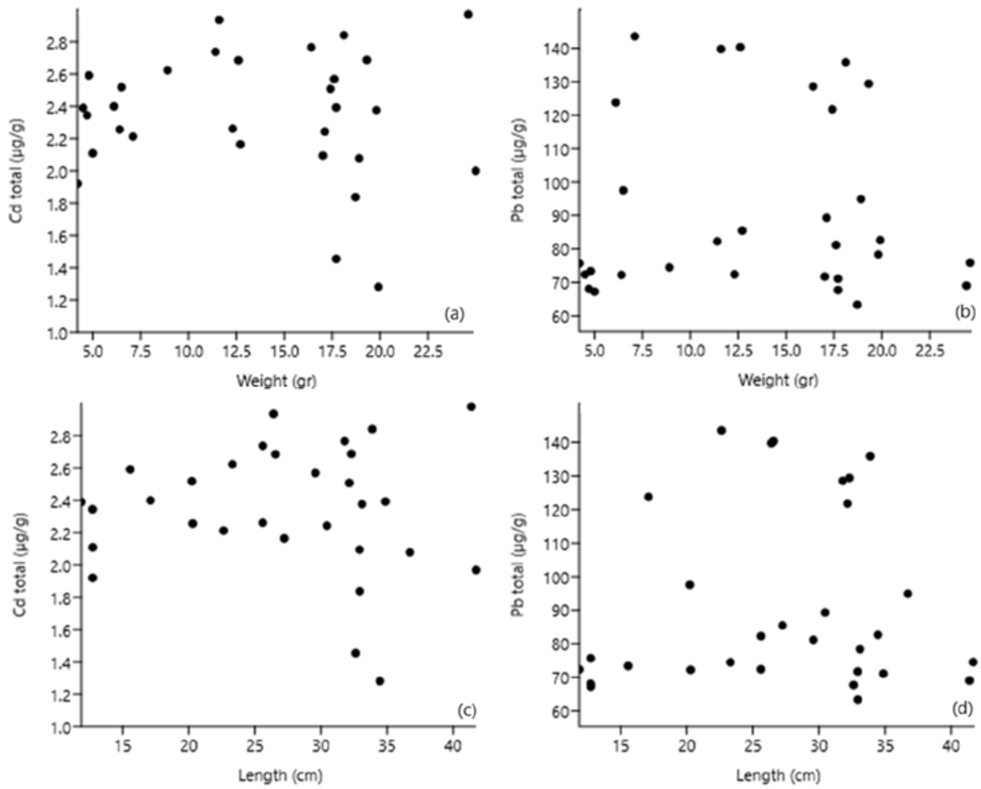

Fig. 5: Correlation between eel weight and total Cd (a), eel weight and total Pb (b), eel length and total Cd (c), and total eel and Pb length (d)

heavy metal transport mechanisms can increase and tend to be deposited more in river sediments (Wijesiri *et al.,* 2018). The increasing concentrations of Cd and Pb from upstream to downstream, both in sediments and those accumulated in the body of the eel, are considered to be linked to the vastly different land uses in the upstream, middle, and downstream rivers. In the upstream area, the land is dominated by primary forest, agricultural land, and a small number of settlements, whereas further downstream, almost the entire area is built-up land (Abighail *et al*., 2022). Aside from this, field observations reveal that there are significantly fewer upstream activities, with only a few domestic and agricultural activities, but downstream activities are more diverse and numerous and even more dominated by industrial, transportation, and urban activities. Consequently, the concentration of lead is rising downstream. Cd and Pb created in the upstream area will also be carried downstream by river currents (Fernández-Cadena *et al*., 2014).

This study found a correlation between the length and weight of an eel's body and the overall accumulation of Cd and Pb in the gill, digestive tract, and flesh. The correlation results are displayed in Fig. 5. All relationships between eel weight and total Cd (Fig. 5a), total eel weight and Pb (Fig. 5b), total eel length and Cd (Fig. 5c), and total eel length and Pb (Fig. 5d) follow the same pattern. R-squared (R^2) is the proportion of the variation of a dependent variable that an independent variable or variables can explain in a regression model. The investigation revealed a very modest connection ($R^2<0.1$) between the body size of wild eels and the accumulation of Cd and Pb. This result showed that a connection between metal uptake from contaminated ecosystems might vary. It might be due to ecological demands, metabolism, contamination gradients in water, food, and sediment, as well as other parameters such as salinity, temperature, and interacting agents (Pagenkopf,

Table 2: The estimated weekly intake of Cd and Pb from eel flesh and whole eel

Eel body part	Region area	Estimated weekly intake (mg/week)	
		Cd	Pb
Eel flesh	All region	0.0143	0.8191
	Upstream	0.0144	0.7326
	Midstream	0.0136	0.7956
	Downstream	0.0156	0.9547
Whole eel	All region	0.0328	1.2826
	Upstream	0.0291	1.0108
	Midstream	0.0329	1.1151
	Downstream	0.0368	1.8606
Maximum weekly intake (MWI) mg/week		0.39-0.43	1.41-1.54

1983; Custodio *et al.,* 2020; Yin *et al.,* 2012).

Eels are one of the most popular types of fish and are even sought after by Indonesians; for example, in 2010, Jakarta alone required 20 tons of eels per day, Yogyakarta required 30 tons of eels per day, and various other cities required the same amount (Warta Pasar Ikan, 2010), thus eels have even become a commodity. The strong demand for eels from within the country is due to the low-fat content and the presence of the essential unsaturated fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The results of a survey of residents of the Ciliwung watershed indicate that a significant number of people are searching for eels in the Ciliwung River for consumption by their families. Given that eels from the Ciliwung River are contaminated with high levels of Cd and Pb, their intake must be restricted so as not to put consumers at risk. The estimated weekly intake of Cd and Pb from eel flesh and whole eel is presented in Table 2. According to the findings of the analysis, the estimated average accumulation of Cd and Pb in eel flesh was 0.0143 mg/week and 0.8191 mg/week, respectively, while the corresponding values for whole eels were 0.0328 mg/week (Cd) and 1.2826 mg/week (Pb). As with sediment accumulation and the eel's targeted organ, the estimated weekly intake of Cd and Pb tends to increase from upstream to downstream as the distance increases. The estimation results were then compared to the Maximum Weekly Intake (MWI) derived from the average weight of Indonesian women (56.2 kg) and men (61.4 kg) and the Provisional Tolerable Weekly Intake (PTWI) from FAO/WHO (2019) of 7 g/ kg and 25 g/ kg for Cd and Pb, respectively. The estimated weekly intake of Cd and Pb was lower than the MWI, except for the estimated weekly intake of Pb from entire eels in the downstream area (1.8606 mg/ week). In general, eel from upstream, midstream, and downstream is still acceptable for consumption; nevertheless, consumers must continue to monitor the eel's Pb intake, particularly in the downstream area. An excessive Pb dosage can interfere with metabolism, limit growth, and diminish survival rates (Burton *et al.,* 2005; Tepanosyan *et al.,* 2017). Heavy metals will negatively affect numerous body organs, causing cellular disruptions at the molecular level and influencing the glycolysis, Krebs cycle, and lipid metabolism in organism cells (Strydom *et al*., 2007). Even non-essential heavy metals such as Cd and Pb exhibit substantial toxicity at low concentrations (Okoro *et al*., 2012). Their bioaccumulative qualities cause heavy metal concentrations in live creatures to increase with time (Naser, 2013), increasing Cd and Pb pollution. Particular consideration should be given to the population's regularly consumed eels. Long-term exposure to Cd and Pb increases the chance of developing high blood pressure, renal illness, cardiovascular disease, and impaired fertility in the reproductive organs (David and Isangedighi, 2019). In addition, heavy metals Cd and Pb that accumulate in fish can also damage the health of humans who consume them due to the toxicity of Cd and Pb, which can lead to kidney, hypertension, liver, and pulmonary illnesses, among others (Sonone *et al*., 2020; Abu-Qdais *et al.,* 2020). The buildup of Cd and Pb in fish can have cytotoxic, genotoxic, and mutagenic consequences (Matos *et al*., 2017), therefore if humans ingest eels polluted with high levels of Cd and Pb, they may experience the same side effects. Even though the Cd concentration in the Ciliwung River sediment was still below the sediment quality guidelines from CCME (2001), the average concentration of Cd and Pb is higher than the natural concentration. It has accumulated in the eel, causing ecosystem damage and physiological disturbances in the eels and danger to humans who consume them. Therefore, comprehensive management must be conducted following the nature of the Indonesian people, namely management based on zero waste technology, blue economy, and law enforcement, in order to minimize the input of Cd and Pb into rivers and bring economic benefits, while also combining monitoring and evaluation with strict law enforcement on the ground.

CONCLUSIONS

This study studies the deposition of Cd and Pb in the sediments and eels of the Ciliwung River from upstream to downstream. Based on the analysis results, it was determined that the concentrations of Cd and Pb in the river silt are higher than their natural levels. Cd and Pb concentrations in the Ciliwung River sediments are higher than their natural values relative to the interim sediment guidelines, although only Pb concentrations are above the threshold. Cd and Pb are bioaccumulated by eels, whose habitat is sediments. The buildup of Cd and Pb increase from upstream to downstream, both in the sediment and in the internal organs of the eel. Cd and Pb concentrations are higher in the eel than in the sediment. The amounts of mercury and lead are also higher in the gills compared to the digestive system and the flesh. The eel exceeds FAO/WHO permitted values for Cd and Pb accumulation. The correlation analysis between the body of the eels in terms of length and weight to be connected with the accumulation of lead and cadmium in the gill, digestive system, and flesh yielded data indicate a very weak correlation between the three variables. This research demonstrates the disparities in ecological requirements, metabolic rates, and contamination gradients that each organism of eel encounters in its water, food, and sediment environments. Nevertheless, according to the estimation of the Provisional Tolerable Weekly Intake, eels from the Ciliwung River can be consumed within strict limitations and in small quantities, hence preventing exposure to Cd and Pb accumulated by eels. It is believed that the presence of Cd and Pb in riverine sediments and eels in the Ciliwung River is primarily due to improper wastewater disposal from human activities. Consequently, it is anticipated that improved management will decrease the number of pollutants entering the riverine ecosystem based on zero-waste technologies, blue economy principal, and stringent law enforcement.

AUTHOR CONTRIBUTIONS

N. Nurhasanah, the corresponding author, has contributed in interpreted the results, and preparing the manuscript. L. Sulistyowati designed the field sampling and performed data analysis. E. Riani contributed to the data analysis and interpretation of the results. M.R. Cordova contributed to supervision, study design, laboratory analysis, data analysis, and writing with the assistance of the other authors. M. R. Cordova is the main contributor to this manuscript.

ACKNOWLEDGEMENT

The authors would like to thank waste picker and fishers who have voluntary supported this study. This study is supported by the Universitas Terbuka funding scheme 2022 [Grant No. B/284/UN31.LPPM/PT.01.03/2022 and B/410/UN31.LPPM/PT.01.03/2022] for Nurhasanah, L. Sulistyowati, and M.R. Cordova. All authors discussed the results and provided input and comments on the manuscript. The authors would like to express gratitude to the anonymous reviewers for their insightful and constructive comments, which resulted in a significant improvement of the manuscript. The editor's constructive comments on earlier drafts of the manuscript are greatly appreciated.

CONFLICT OF INTEREST

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/

or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

OPEN ACCESS

PUBLISHER'S NOTE

ABBREVIATIONS

ANZFS	Australia New Zealand Food Standards Code
ATSDR	Agency for Toxic Substances and Disease Registry
BPOM	Badan Pengawas Obat dan Makanan – Republik Indonesia (The National Agency of Drug and Food Control – Republic of Indonesia)
°C	degree Celsius
CCME	Canadian Council of Ministers of the Environment
CFDA	China Food and Drug Administration
Cd	Cadmium
Cm	Centimeter
CRM	Certified reference material
HCl	Hydrogen chloride (Hydrochloric acid)
HNO_3	Nitric acid
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectrometry
FAO/WHO	Food and Agriculture Organization/ World Health Organization of the United Nations
Fe	Iron
g	gram
ISQG	Interim sediment quality guidelines
kg	Kilogram
km	Kilometer
km^2	Kilometer square
m	Meter
MARS	Microwave accelerated reaction system
µg/g	microgram per gram
mg/kg	milligram per kilogram
mm	Millimeter
mL	milliliter
MWI	Maximum weekly intake
Pb	Lead
PTWI	Provisional tolerable weekly intake
R^2	R-squared
SNI	Standar Nasional Indonesia (Indonesian National Standard)
USEPA	United States Environmental Protection Agency
QC/QA	Quality control and quality assurance
Zn	Zinc

REFERENCES

Abighail, S.H.; Kridasantausa, I.; Farid, M.; Moe I.R., (2022). Pemodelan banjir akibat perubahan tata guna lahan di daerah aliran sungai Ciliwung. J. Tek. Sipil, 29(1): 61-68 **(8 pages)**.

Abu-Qdais, H.A.; Al-Ghazo, M.A.; Al-Ghazo, E.M., (2020). Statistical analysis and characteristics of hospital medical waste under novel Coronavirus outbreak. Global J. Environ. Sci. Manage., 6(SI): 21-30 **(10 pages)**.

Ali, H.; Khan, E., (2019). Trophic transfer, bioaccumulation, and biomagnification of non-essential hazardous heavy metals and metalloids in food chains/webs—Concepts and implications for wildlife and human health. Hum.

Ecol. Risk Assess., 25(6): 1353–1376 **(24 pages)**.

Aksari, Y.; Perwitasari, D.; Butet, N. (2015). Concentration of heavy metals (Cd, Hg, and Pb) of amazon sailfin catfish, Pterygoplichthys pardalis (Castelnau, 1855) in Ciliwung River West Java. J. Iktiol. Indonesia, 15(3), 257-266 **(10 pages)**.

Ayangbenro, A.S.; Babalola, O.O., (2017). A new strategy for heavy metal polluted environments: A review of microbial biosorbents. Int. J. Environ. Health Res., 14(1): 94 **(16 pages)**.

ATSDR, (2012). Toxicity profile for heavy metals. Agency for Toxic Substances and Disease Registry.

Bergamaschi, B.A.; Krabbenhoft, D.P.; Aiken, G.R.; Patino, E.; Rumbold, D.G.; Orem, W.H., (2012). Tidally driven export of dissolved organic carbon, total mercury, and methylmercury from a mangrove-dominated estuary. Environ. Sci. Technol., 46(3): 1371–1378 **(8 pages)**.

Burton, E.D.; Phillips, I.R.; Hawker, D.W., (2005). Geochemical partitioning of copper, lead, and zinc in benthic, estuarine sediment profiles. J. Environ. Qual., 34(1): 263–273 **(11 pages)**.

BPOM (2018). Peraturan Badan Pengawas Obat dan Makanan Nomor 5 Tahun 2018 tentang Batas Maksimum Cemaran Logam Berat dalam Pangan Olahan, Jakarta.

Canadian Guidelines (2018). Canadian Guidelines for Chemical Contaminants and Toxins in Fish and Fish Products.

CCME (2001). Canadian sediment quality guidelines for the protection of aquatic life. in canadian environmental quality guidelines. Canadian Council of Minister of the Environment, Winnipeg.

CFDA (2017). National Health and Family Planning Commission of the People's Republic of China.; China Food and Drug Administration. National food safety standard. Maximum levels of contaminants in foods GB2762–2017.

Cordova, M.R.; Eftiah, F.D.M.; Zamani, N.P., (2017). Ability of mangrove apple as mercury bioindicator. Omni-Akuatika, 13(2): 137–143 **(7 pages).**

Custodio, M.; Orellana-Mendoza, E.; Peñaloza, R.; De la Cruz-Solano, H.; Bulege-Gutiérrez, W.; Quispe-Mendoza, R., (2020). Heavy metal accumulation in sediment and removal efficiency in the stabilization ponds with the hydrocotyle ranunculoides filter. J. Ecol. Eng., 21(5): 72–79 **(8 pages)**.

David, G.S.; Isangedighi, I.A., (2019). Heavy metals contamination in fish: effects on human health. *J. Aquat. Sci. Mar. Biol*., 2(4):7–12 **(6 pages)**.

Demirbilek, D.; Öztüfekçi Önal, A.; Demir, V.; Uslu, G.; Arslanoglu-Isık, H., (2013). Characterization and pollution potential assessment of Tunceli, Turkey municipal solid waste open dumping site leachates. Environ. Monit. Assess., 185(11): 9435–9449 **(15 pages)**.

Demková, L.; Jezný. T.; Bobuľská, L., (2017). Assessment of soil heavy metal pollution in a former mining area–before and after the end of mining activities. *Soil Water Res*., 12(4): 229-236 **(6 pages)**.

Dixit, R.; Wasiullah, Malaviya, D.; Pandiyan, K.; Singh, U. B.; Sahu, A.; Shukla, R.; Singh, B.P.; Rai, J.P.; Sharma, P.K.; Lade, H.; Paul, D., (2015). Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria of fundamental processes. Sustainability. 7(2): 2189–2212 **(24 pages)**.

Elfidasari, D.; Ismi, L.N.; Shabira, A.P.; Sugoro, I., (2018). The correlation between heavy metal and nutrient content in Plecostomus (Pterygoplichthys pardalis) from Ciliwung River in Jakarta. Biosaintifika, 10(3): 597-604, **(8 pages)**.

Elfidasari, D.; Ismi, L.N.; Sugoro, I., (2019). Heavy metal contamination of Ciliwung River, indonesia. J. Inter. Sci. Pub., 13: 106-111, **(6 pages).**

Elfidasari, D.; Ismi, L.N.; Sugoro, I., (2020). Heavy metal concentration in water.; sediment.; and Pterygoplichthys pardalis in the Ciliwung River.; Indonesia. AACL Bioflux, 13(3): 1764- 1778 **(15 pages).**

European Commission (2006). European Commission Regulation No 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs.

Fang, T.; Wang, H.; Liang, Y.; Cui, K.; Yang, K.; Lu, W.; Li, J.; Zhao, X.; Gao, N.; Yu, Q.; Li, H.; Jiang, H. (2022). Source tracing with cadmium isotope and risk assessment of heavy metals in sediment of an urban river, China. Environ. Pollut., 305: 119325 **(8 pages)**.

Fang, W.; Wei, Y.; Liu, J., (2016a). Comparative characterization of sewage sludge compost and soil: Heavy metal leaching characteristics. J. Hazard. Mater., 310: 1–10 **(10 pages)**.

Fang, W.; Wei, Y.; Liu, J.; Kosson, D.S.; van der Sloot, H.A.; Zhang, P., (2016b). Effects of aerobic and anaerobic biological processes on leaching of heavy metals from soil amended with sewage sludge compost. Waste Manage., 58: 324–334 **(11 pages)**.

FAO/WHO, (2019). General standard for contaminants and toxins in food and feed. CXS 193-1995. **(66 pages)**.

FAO/WHO (2011). Joint FAO/WHO Food Standards Programme Codex Committee on Contaminants in Foods Fifth Session.; Rome.

Fernández-Cadena, J.C.; Andrade, S.; Silva-Coello, C.L.; De la Iglesia, R., (2014). Heavy metal concentration in mangrove surface sediments from the north-west coast of South America. Mar. Pollut. Bull., 82(1–2): 221–226 **(6 pages)**.

Fretes, C.C.; Kakisina, P.; Rumahlatu, D., (2020).

Concentration of heavy metal Hg, Au, and Fe in sediments, water, and tissue damage of golden sea cucumber Stichopus herrmanni (Semper, 1868) (Holothuroidea; Stichopodidae) in Kayeli Bay, Indonesia. Acta Aquatica Turcica. 16(1):113-123, **(11 pages).**

González-Ortegón, E.; Laiz, I.; Sánchez-Quiles, D.; Cobelo-Garcia, A.; Tovar-Sánchez, A., (2019). Trace metal characterization and fluxes from the Guadiana, Tinto-Odiel and Guadalquivir estuaries to the Gulf of Cadiz. Sci. Total Environ., 650: 2454–2466 **(13 pages)**.

Harmesa, H.; Cordova, M.R., (2020). A preliminary study on heavy metal pollutants chrome (Cr): cadmium (Cd): and lead (Pb) in sediments and beach morning glory vegetation (Ipomoea pes-caprae) from Dasun Estuary, Rembang, Indonesia. Mar. Pollut. Bull., 111819 **(6 pages)**.

Harmesa, H.; Lestari, L.; Budiyanto, F., (2020). Distribusi logam berat dalam air laut dan sedimen di perairan Cimanuk, Jawa Barat, Indonesia. Oseanologi Dan Limnologi Di Indonesia (OLDI). 5(1): 19-32 **(14 pages)**.

Heath, A.G. (2018). Water pollution and fish physiology, second edition. In Water Pollution and Fish Physiology, Second Edition. CRC Press **(384 pages)**.

Hosono, T.; Su, C.C.; Delinom, R.; Umezawa, Y.; Toyota, T.; Kaneko, S.; Taniguchi, M. (2011). Decline in heavy metal contamination in marine sediments in Jakarta Bay, Indonesia due to increasing environmental regulations. Estuar. Coast. Shelf Sci., 92(2): 297–306 **(10 pages)**.

Hossain, M.B.; Shanta, T.B.; Ahmed, A.S.S.; Hossain, M.K.; Semme, S.A., (2019). Baseline study of heavy metal contamination in the Sangu River estuary, Chattogram, Bangladesh. Mar. Pollut. Bull., 140: 255–261 **(7 pages)**.

Hossain, Z.; Hossain, M.S.; Ema, N.S.; Omri, A. (2021). Heavy metal toxicity in Buriganga river alters the immunology of Nile tilapia (Oreochromis niloticus L). Heliyon. 7(11) **(11 pages)**.

Hussein, M.; Yoneda, K.; Mohd-Zaki, Z.; Amir, A.; Othman, N., (2021). Heavy metals in leachate, impacted soils and natural soils of different landfills in Malaysia: An alarming threat. Chemosphere, 267 **(19 pages).**

Ishchenko, V., (2019). Heavy metals in municipal waste: the content and leaching ability by waste fraction. J. Environ. Sci. Health A., 54(14): 1448–1456 **(9 pages)**.

Islam, M.S.; Ahmed, M.K.; Raknuzzaman, M.; Habibullah -Al- Mamun, M.; Islam, M.K., (2015). Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country. Ecol. Indic., 48: 282–291 **(10 pages)**.

Ismi, L.N.; Elfidasari, D.; Puspitasari, R.L.; Sugoro, I., (2019a). Kandungan 10 jenis logam berat pada daging ikan sapu-sapu (Pterygoplichthys pardalis) asal Sungai Ciliwung wilayah Jakarta. J. Al-Azhar Indonesia: Sains Teknol.; 5(2): 56-59 **(4 pages)**.

Ismi, L.N.; Elfidasari, D.; Puspitasari, R.L.; Sugoro, I.; Sabira, A.P., (2019b). The contents of heavy metals in Plecostomus (Loricariidae) from the Ciliwung River Jakarta, Indonesia. BioEco2019- International Biodiversity & Ecology Sciences Symposium, 164-168 **(5 pages)**.

Jaskuła, J.; Sojka, M., (2022). Assessment of spatial distribution of sediment contamination with heavy metals in the two biggest rivers in Poland. CATENA, 211: 105959 **(13 pages)**.

Jafarzadeh, S.; Fard, R.F.; Ghorbani, E.; Saghafipour, A.; Moradi-Asl, E.; Ghafuri, Y. (2020). Potential risk assessment of heavy metals in the Aharchai River in northwestern Iran. Phys. Chem. Earth. 115 **(7 pages)**.

Kaewtubtim, P.; Meeinkuirt, W.; Seepom, S.; Pichtel, J., (2016). Heavy metal phytoremediation potential of plant species in a mangrove ecosystem in Pattani Bay, Thailand. Appl. Ecol. Environ. Res., 14(1): 367–382 **(16 pages)**.

Karadede, H., Oymak, S. A., Ünlü, E. (2004). Heavy metals in mullet, Liza abu, and catfish, Silurus triostegus, from the Atatürk Dam Lake (Euphrates), Turkey. Environment International, 30(2): 183–188 **(6 pages)**.

Koesmawati, T.A.; Suratno, S.; Cordova, M.R., (2018). Preliminary assessment of mercury, arsenic and selenium content in fish from Batam Island Indonesia. AIP Conference Proceedings, 2024 **(10 pages)**.

Lestari, L.; Budiyanto, F.; Puspitasari, R.; Purbonegoro, T.; Cordova, M.R.; Hindarti, D., (2018). Fractionation of metal in surface sediment from Cirebon coastal waters, West Java, Indonesia. AIP Conference Proceedings, **(10 pages)**.

Li, W.; Qian, H.; Xu, P.; Zhang, Q.; Chen, J.; Hou, K.; Ren, W.; Qu, W.; Chen, Y. (2022). Distribution characteristics, source identification and risk assessment of heavy metals in surface sediments of the Yellow River, China. Catena, 216: 106376 **(10 pages)**.

Li, X.; Bing, J.; Zhang, J.; Guo, L.; Deng, Z.; Wang, D.; Liu, L. (2022). Ecological risk assessment and sources identification of heavy metals in surface sediments of a river–reservoir system. Sci. Total Environ., 842: 156683 **(13 pages)**.

Li, Y.; Richardson, J.B.; Mark Bricka, R.; Niu, X.; Yang, H.; Li, L.; Jimenez, A., (2009). Leaching of heavy metals from E-waste in simulated landfill columns. Waste Manage., 29(7): 2147–2150 **(4 pages)**.

Liu, J.; Yin, P.; Chen, B.; Gao, F.; Song, H.; Li, M., (2016). Distribution and contamination assessment of heavy metals in surface sediments of the Luanhe River Estuary, northwest of the Bohai Sea. Mar. Pollut. Bull., 109(1): 633–639 **(7 pages)**.

Luo, L.; Ke, C.; Guo, X.; Shi, B.; Huang, M. (2014). Metal accumulation and differentially expressed proteins in gill of oyster (Crassostrea hongkongensis) exposed to long-term heavy metal-contaminated estuary. Fish Shellfish Immunol., 38(2), 318–329 **(12 pages)**.

Magni, L.F.; Castro, L.N.; Rendina, A.E. (2021). Evaluation of heavy metal contamination levels in river sediments and their risk to human health in urban areas: A case study in the Matanza-Riachuelo Basin, Argentina. Environ. Res., 197 **(13 pages)**.

Matos, L.A.; Cunha, A.C.S.; Sousa, A.A.; Maranhão, J.P.R.; Santos, N.R.S.; Gonçalves, M.de M.C.; Dantas, S.M.M.d.M.; Sousa, J.M.d.C.e.; Peron, A.P.; Silva, F.C.C.da, Alencar, M.V.O.B.d.; Islam, M.T.; Aguiar, R.P.S.de, Melo-Cavalcante, A.A.d.C.; Bonecker, C.C.; Junior, H.F.J., (2017). The influence of heavy metals on toxicogenetic damage in a Brazilian tropical river. Chemosphere, 185, 852–859 **(8 pages)**.

Miranda, L.S.; Wijesiri, B.; Ayoko, G.A.; Egodawatta, P.; Goonetilleke, A., (2021). Water-sediment interactions and mobility of heavy metals in aquatic environments. Water Res., 202 **(9 pages)**.

Mohammed, A.S.; Kapri, A.; Goel, R., (2011). Heavy metal pollution: Source, impact, and remedies. 1–28 **(28 pages)**.

Mulyaningsih, T.R.; Irmawati, M.; Istanto.; Alfian., (2020). Assessment of heavy metals pollution in the sediment of Ciliwung River. J. Physics: Conf. Series, 1436 (2020) 012038: 1-8 **(8 pages)**.

Nakayama, S.M.M.; Ikenaka, Y.; Muzandu, K.; Choongo, K.; Oroszlany, B.; Teraoka, H.; Mizuno, N.; Ishizuka, M. (2010). Heavy metal accumulation in lake sediments, fish (Oreochromis niloticus and Serranochromis thumbergi), and crayfish (Cherax quadricarinatus) in lake itezhi-tezhi and lake Kariba, Zambia. Arch. Environ. Contamin. Toxicol., 59(2): 291–300 **(10 pages)**.

Naser, H.A., (2013). Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review. Mar. Pollut. Bull., 72(1): 6–13 **(8 pages)**.

NRCC, (2013). Certificate of analysis PACS-3 Marine Sediment Certified Reference Material for total and extractable metal content. National Research Council Canada **(8 pages)**.

NNRC, (2014). Certificate of analysis DOLT-5 Dogfish Liver Certified Reference Material for Trace Metals and other Constituents. Certificate of analysis. National Research Council Canada **(7 pages)**.

Nhan, H. T.; Tai, N. T.; Liem, P. T.; Ut, V. N.; Ako, H. (2019). Effects of different stocking densities on growth performance of Asian swamp eel Monopterus albus, water quality and plant growth of watercress Nasturtium officinale in an aquaponic recirculating system. Aquaculture, 503, 96–104 **(9 pages)**.

Okoro, H.K.; Fatoki, O.S.; Adekola, F.A.; Ximba, B.J.; Snyman, R.G., (2012). A review of sequential extraction procedures for heavy metals speciation in soil and sediments. J. Environ. Anal. Toxicol., 01(S1): 1–9 **(9 pages)**.

Oliveira Ribeiro, C. A., Vollaire, Y., Sanchez-Chardi, A., Roche, H. (2005). Bioaccumulation and the effects of organochlorine pesticides, PAH and heavy metals in the Eel (Anguilla anguilla) at the Camargue Nature Reserve, France. Aquatic Toxicology, 74(1): 53–69 **(17 pages).** Pagenkopf, G.K., (1983). Gill surface interaction model for trace-metal toxicity to fishes: Role of complexation, pH, and water hardness. Environmental Science & Technology. 17(6):342–347 **(6 pages)**.

Pambudi, A.S. (2020). System dynamics modelling of deforestation rate and forest rehabilitation in the upstream of Ciliwung Watershed, Bogor Regency. Indonesian J. Dev. Plan., 4(3): 327-346 **(20 pages).**

Putri HD.; Elfidasari D.; Haninah; Sugoro, I., (2022). Hazards of heavy metal content (Cd, Hg, Pb) in processed products of *Pterygoplichthys pardalis* origin in Jakarta Ciliwung River for human health. J. Pengolahan Pangan, 7 (1): 7-13 **(7 pages)**.

Riani, E., (2017). Perubahan iklim dan kehidupan biota akuatik (dampak pada bioakumulasi bahan berbahaya dan beracun & reproduksi), **(219 pages)**.

Riani, E.; Cordova, M.R.; Arifin, Z., (2018). Heavy metal pollution and its relation to the malformation of green mussels cultured in Muara Kamal waters, Jakarta Bay, Indonesia. Mar. Pollut. Bull., 133: 664–670 **(7 pages)**.

Riani, E.; Johari, H.S.; Cordova, M.R., (2017). Kontaminasi Pb dan Cd pada ikan bandeng Chanos chanos yang dibudidaya di Kepulauan Seribu, Jakarta. *J Ilmu Teknol. Kelaut. Trop*., 9(1):235–246 **(12 pages)**.

Riani, E.; Sudarso, Y.; Cordova, M.R., (2014). Heavy metals effect on unviable larvae of dicrotendipes simpsoni (diptera: Chironomidae): a case study from Saguling Dam, Indonesia. AACL Bioflux, 7(2): 76–84 **(9 pages)**.

Riba, I.; Delvalls, T.A.; Forja, J.M.; Gómez-Parra, A., (2004). The influence of pH and salinity on the toxicity of heavy metals in sediment to the estuarine clam Ruditapes philippinarum. *Environ. Toxicol. Chem,* 23(5): 1100-1107 **(8 pages).**

Roméo, M., Siau, Y., Sidoumou, Z., Gnassia-Barelli, M. (1999). Heavy metal distribution in different fish species from the Mauritania coast. Science of the Total Environment, 232(3), 169–175 **(6 pages)**.

Rosado, D.; Usero, J.; Morillo, J., (2016). Assessment of heavy metals bioavailability and toxicity toward Vibrio fischeri in sediment of the Huelva estuary. Chemosphere. 153: 10–17 **(8 pages)**.

Saher, N.U.; Siddiqui, A.S., (2019). Occurrence of heavy metals in sediment and their bioaccumulation in sentinel crab (Macrophthalmus depressus) from highly impacted coastal zone. Chemosphere. 221: 89–98 **(10 pages)**.

Saikia, B.J.; Parthasarathy, G.; Borah, R.R. (2022). Geoenvironment and weathering of silicate minerals in sediments of the Brahmaputra River, India: Implications for heavy metal pollution assessment. Geosyst. Geoenviron., 1(3): 100065 **(6 pages)**.

Sakawi, Z.; Rozaimi Ariffin, M.; Mastura, S.S.A.; Jali, M.F.M., (2013). The analysis of heavy metal concentration per distance and depth around the vicinity of open landfill. Res. J. Appl. Sci. Eng. Technol., 5(24): 8619–8625 **(7 pages)**.

Sanchez, J.O., (2014). Coal as a Marine Poluttant. World Maritime University **(116 pages)**.

SNI (2009). Standar Nasional Indonesia 7389:2009. Batas Maksimum Cemaran Logam Berat dalam Pangan. Jakarta.

Sonone, S.S.; Jadhav, S.; Sankhla, M.S.; Kumar, R., (2020). Water contamination by heavy metals and their toxic effect on aquaculture and human health through food chain. Lett. Appl. NanoBioScience. 10(2): 2148-2166 **(19 pages)**.

Statistic Indonesia, (2021). Statistik Lingkungan Hidup Indonesia 2021. Badan Pusat Statistik Indonesia **(318 pages).**

Strydom, C.; Robinson, C.; Pretorius, E.; Whitcutt, J.; Marx, J.; Bornman, M.S., (2007). The effect of selected metals on the central metabolic pathways in biology: a review. *Water SA*. 32(4): 543–554 **(12 pages)**.

Sulistyowati, L.; Nurhasanah, Riani, E.; Cordova, M.R., (2022). The occurrence and abundance of microplastics in surface water of the midstream and downstream of the Cisadane River, Indonesia. Chemosphere. 291: 133071 **(8 pages)**.

Suresh, G.; Sutharsan, P.; Ramasamy, V.; Venkatachalapathy, R., (2012). Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of Veeranam Lake sediments, India. Ecotoxicol. Environ. Saf., 84: 117–124 **(8 pages)**.

Ta, A.T.; Babel, S. (2020). Microplastics pollution with heavy metals in the aquaculture zone of the Chao Phraya River Estuary, Thailand. Mar. Pollut. Bull., 161 **(9 pages)**.

Tang, W.; Shan, B.; Zhang, H.; Mao, Z., (2010). Heavy metal sources and associated risk in response to agricultural intensification in the estuarine sediments of Chaohu Lake Valley, East China. J. Hazard. Mater., 176(1–3): 945–951 **(7 pages)**.

Tepanosyan, G.; Maghakyan, N.; Sahakyan, L.; Saghatelyan, A. (2017). Heavy metals pollution levels and children health risk assessment of Yerevan kindergartens soils. Ecotoxicology and Environmental Safety, Ecotoxicol. Environ. Saf. 142: 257–265 **(9 pages)**.

Thongyuan, S.; Khantamoon, T.; Aendo, P.; Binot, A.; Tulayakul, P., (2021). Ecological and health risk assessment, carcinogenic and non-carcinogenic effects of heavy metals contamination in the soil from municipal solid waste landfill in Central, Thailand. Hum. Ecol. Risk Assess., 27(4): 876–897 **(22 pages)**.

USEPA, (2007). Method 3051A (SW-846): Microwave assisted acid digestion of sediments, sludges, and oils (Revision 1). United States of Environmental Protection Agency.

Vargas-Solano, S.V.; Rodríguez-González, F.; Martínez-Velarde, R.; Morales-García, S.S.; Jonathan, M.P. (2022). Removal of heavy metals present in water from the Yautepec River Morelos México, using Opuntia ficus-indica mucilage. Environ. Adv., 7 **(10 pages)**.

Warta Pasar Ikan (2010). Belut dan Sidat Permintaanya Semakin Meningkat. Direktorat Pemasaran Dalam Negeri. Jakarta. 80 **(1 pages)**.

Wedepohl, K.H., (1994). The Composition of the Continental Crust. Mineralogical Magazine, 58A(2): 959–960 **(2 pages)**.

Wijesiri, B.; Deilami, K.; Goonetilleke, A., (2018). Evaluating the relationship between temporal changes in land use and resulting water quality. Environ. Pollut., 234: 480–486 **(17 pages)**.

Wuana, R.A.; Okieimen, F.E., (2011). Heavy metals in contaminated soils: a review of sources, chemistry, risks and best available strategies for remediation. ISRN Ecology, 2011, 1–20 **(20 pages)**.

Yap C.K.; Ismail A.; Tan S.G. (2004). Concentrations of Cd, Cu and Zn in the fish Tilapia Oreochromis mossambiscus caught from a Kelana Jaya Pond. Asian J. Water Environ. Pollut., 2(1): 65–70 **(6 pages)**.

Yousif, R.; Choudhary, M.I.; Ahmed, S.; Ahmed, Q. (2021). Review: Bioaccumulation of heavy metals in fish and other aquatic organisms from Karachi Coast, Pakistan. *Nusant Biosci*. 13(1):73–84 **(12 pages)**.

Yin, S. A., Ismail, A., Zulkifli, S. Z. (2012). Heavy metals uptake by Asian swamp eel, Monopterus albus from paddy fields of Kelantan, Peninsular Malaysia: Preliminary study. Trop. Life Sci. Res., 23(2): 27–38 **(11 pages)**.

AUTHOR (S) BIOSKETCHES

Nurhasanah, N., Ph.D., Assistant Professor, Environmental Studies Graduate Program, Universitas Terbuka, Jl. Cabe Raya, Pondok Cabe, Pamulang Tangerang Selatan, 15418, Indonesia

- Email: *nenganah@ecampus.ut.ac.id*
- ORCID: 0000-0001-7234-9111
- Web of Science ResearcherID: A-9600-2018
- Scopus Author ID: 57214684688
- Homepage: https://nurhas.staff.ut.ac.id/

Sulistyowati, L., Ph.D., Assistant Professor, Environmental Studies Graduate Program, Universitas Terbuka, Jl. Cabe Raya, Pondok Cabe, Pamulang Tangerang Selatan, 15418, Indonesia

- Email: *liliks@ecampus.ut.ac.id*
- ORCID: 0000-0002-2200-1157
- Web of Science ResearcherID: A-9464-2018
- Scopus Author ID: 57357897800
- Homepage: https://pwk-fst.ut.ac.id/lilik-sulistyowati/

Riani, E., Ph.D., Professor, Department of Aquatic Resources Management, Faculty of Fishery and Marine Science, Bogor Agricultural University, Bogor, Indonesia.

- Email: *etty_riani@apps.ipb.ac.id*
- ORCID: 0000-0003-2080-4236
- Web of Science ResearcherID: AER-8235-2022
- Scopus Author ID: 23398401800
- Homepage: http://psl.ipb.ac.id/teachers/prof-dr-etty-riani-ms/

Cordova, M.R., Ph.D. Senior Researcher, Research Center for Oceanography, National Research and Innovation Agency Republic of Indonesia, Jakarta, Indonesia.

- Email: *muhammad.reza.cordova@brin.go.id*
- ORCID: 0000-0002-4756-9646
- Web of Science ResearcherID: AAL-7273-2020
- Scopus Author ID: 56147418700
- Homepage: https://siin.brin.go.id/smi/7F0D69E8-2A0B-4C8E-8E51-69D3734456E0

HOW TO CITE THIS ARTICLE

Nurhasanah; Sulistyowati, L.; Riani, E.; Cordova, M.R., (2023). Cadmium and lead uptake by wild swamp eel in the populous river. Global J. Environ. Sci. Manage., 9(3): 497-514.

DOI: 10.22035/gjesm.2023.03.09

URL: https://www.gjesm.net/article_696803.html