Iron bioaccumulation and ecological implications in the coastal swamp wetlands ecosystem of South Kalimantan: Insights from giant mudskipper fish as bioindicators

by H.B. Santoso

Journal of Degraded and Mining Lands Management
Volume 11, Number 3 (April 2024):5539-5550, doi:10.15243/jdmlm.2024.113.5539
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Iron bioaccumulation and ecological implications in the coastal swamp wetlands ecosystem of South Kalimantan: Insights from giant mudskipper fish as bioindicators

Heri Budi Santoso[1*], Krisdianto[1], Rizmi Yunita[2]

[1] Department of Biology, Faculty of Mathematics and Natural Sciences, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia
[2] Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Lambung Mangkurat University, Banjarbaru, South Kalimantan, Indonesia

[*]corresponding author: heribudisantoso@ulm.ac.id

Article history:
Received 27 September 2023
Revised 15 November 2023
Accepted 3 January 2024

Keywords:
aquatic ecosystem
environmental impact
estuarine fish
iron accumulation

Abstract

This study investigated iron (Fe) accumulation in South Kalimantan's coastal swamp wetlands ecosystem, utilizing giant mudskipper fish as indicators of heavy metal pollution. By analyzing Fe levels in water, sediment, and fish organs over time, insights into its effects on the environment and human health were gained. Furthermore, through Atomic Absorption Spectrometry, Fe concentrations in Kuala Lupak's coastal wetland were measured, revealing significant correlations between Fe levels in water, sediment, and fish tissues. These results enhance our understanding and inform better management strategies. Anthropogenic and natural sources contribute to the accumulation of heavy metals, particularly Fe, with anthropogenic pollution being the most dominant. This study presented the escalating concentrations of Fe within the Kuala Lupak estuary and raised concerns regarding the ecological and human health implications. Continuous monitoring, source identification, public awareness, regulations, remediation, and long-term exploration are essential for addressing heavy metal pollution and its ecological impact. Therefore, valuable insights are provided for environmental management and conservation efforts.

To cite this article: Santoso, H.B., Krisdianto, and Yunita, R. 2024. Iron bioaccumulation and ecological implications in the coastal swamp wetlands ecosystem of South Kalimantan: Insights from giant mudskipper fish as bioindicators. Journal of Degraded and Mining Lands Management 11(3):5539-5550, doi:10.15243/jdmlm.2024.113.5539.

Introduction

Heavy metals are a significant threat to the health of estuarine ecosystems, affecting the biodiversity of aquatic organisms at both individual and community levels (Sarah et al., 2019; Tabrez et al., 2021; Zaoui et al., 2023). This negative impact is attributed to the bioaccumulation of heavy metals in aquatic biota, resulting from the discharge of industrial and domestic waste into the estuarine environment. Yogeshwaran et al. (2020) reported that the bioaccumulation of the metals in estuarine aquatic biota is directly linked to water contamination. The presence of heavy metals in aquatic biota is due to their availability in water bodies and sediment, as well as the food consumed by the fish (Moniruzzaman and Saha, 2020). These trace elements exist in sediments in various forms, including dissolved, bound to suspended particulate matter, or accumulated, enhancing their incorporation into biological processes (Soltani et al., 2021).

Iron, as the fourth most dominant metal on Earth, possesses the capacity to change valence and form complexes with oxygen. Furthermore, it plays a crucial role in respiration in nearly all aerobic organisms. However, unless suitably sequestered, Fe can catalyze the formation of radicals capable of damaging biological molecules, cells, tissues, and entire organisms (Tenenbein and Huang, 2022). Certain trace

Metals such as Fe, Cu, Mn, and Zn are essential to biological systems but can become toxic at high concentrations. Metals, including Zn, Fe, Cu, and Mo, are integral components of metal-protein complexes in enzymes, contributing to enzymatic activities. Fe is a constituent of oxygen transport within living organisms, while it also plays a vital role in oxidative metabolism, serving as a cofactor for proteins and enzymes, DNA synthesis, and electron transport (Zafar and Khan, 2020).

Other heavy metals such as Cd, Cr, Pb, and Hg have adverse effects even at deficient concentrations (Akinsanya et al., 2020). Despite its physiological functions in fish, environmental pollution can render Fe toxic due to excessive accumulation (Garg and Gauns, 2023). The continuous and substantial discharge of trace metal pollutants into the sea poses a significant threat to estuarine and coastal ecosystems due to their chronic toxicity, non-biodegradability, and bioaccumulation in biota (Zaynab et al., 2022). The metals can be transferred and biomagnified through food chains, presenting significant risks to human health. Metal contamination in estuarine ecosystems can induce toxic effects in fish and humans, primarily by consuming contaminated food (Franco-Fuentes et al., 2023; Prasad et al., 2023). Therefore, evaluating the occurrence of Fe content in the estuarine ecosystem of South Kalimantan is essential.

Analyzing the levels of Fe in the water body, sediments, and its bioaccumulation in wild fish, particularly those that inhabit estuaries for a significant portion of their life, such as the giant mudskipper fish (*Periophthalmodon schlosseri*), is of great importance. This fish species holds potential as a bioindicator for monitoring heavy metal pollution in estuarine waters, aiming to mitigate the adverse impacts of Fe on biodiversity conservation and environmental health. Evaluating the presence of Fe in the ecosystem serves as a valuable environmental indicator to understand anthropogenic influences and associated risks to the estuary environment.

Iron is an abundant transition metal in Earth's crust (Jaishankar et al., 2014), and it can exist in aquatic environments in dissolved or suspended forms in water or sediment. Investigating Fe in water, sediment, and fish tissues aids in determining contamination status and loads. Therefore, quantifying the presence of this metal is pivotal in analyzing the health of aquatic ecosystems. Valuable information about the impacts of environmental changes and anthropogenic activities over time is obtained through long-term bioaccumulation of heavy metals. As a result, biomonitoring studies are essential in tracking trends in the concentrations of these metals, enabling scientists to identify changes in estuarine health (Muhammad and Ahmad, 2020). Contamination of aquatic ecosystems by trace metals has garnered global attention from environmental and biological experts, leading to numerous studies on their accumulation in estuarine and marine biota (La Colla et al., 2017).

There is a pressing need for comprehensive information on the evaluation of Fe presence, toxicity, and effects on giant mudskipper fish in the South Kalimantan estuary. Therefore, effective monitoring and evaluation of the availability of this metal in the estuarine environment (water, sediment, biota) are crucial. The giant mudskipper fish has potential as a bioindicator species for heavy metal pollution biomonitoring programs in the estuarine ecosystem of South Kalimantan because it meets the requirements, including natural abundance (Hidayaturrahmah et al., 2019), easy to obtain in large quantities, wide tolerance to polluted environmental conditions, benthic living habits, high trophic level in the aquatic food chain, and capability to accumulate heavy metals (Santoso et al., 2020). Fish, renowned for their capacity to accumulate heavy metals, are well-suited to serve as bioindicator species in pollution biomonitoring, enabling the assessment of estuarine ecological health (Alizada et al., 2020). The giant mudskipper fish, in particular, possesses unique biological characteristics, namely having amphibian-like characters, which distinguish them from other species. Additionally, they are often called "fish walking on land" or "fishes out of water"(Kumaraguru et al., 2020).

Kuala Lupak in the Barito River estuary is a coastal swamp wetland area characterized by extensive transportation activities, loading and unloading of coal, and coal mining waste disposal. The continuous input of waste from the coal mining process and coal-related activities into the water body has the potential to cause estuary pollution when prolonged and accumulated. These waste materials contain heavy metals such as Mn, Fe, Hg, Cd, Cr, Pb, and Cu (Kasmiarti et al., 2021). Furthermore, Kuala Lupak has witnessed the conversion of mangrove land to ponds, a place for ship transportation traffic and settlements. Several industries along the riverbank, such as wood/plywood processing factories, rubber, fisheries, and oil palm plantations, pollute estuary waters through waste discharge (Sofarini et al., 2012). It is hypothesized that the unchecked release of these wastes into water bodies poses a significant risk to both aquatic ecosystems and human health. Therefore, urgent biomonitoring efforts are warranted for early detection of the negative impacts of pollution. In light of these considerations, it is important to investigate the presence and occurrence of Fe in the Kuala Lupak estuary ecosystem during the period from 2020 to 2022.

The objectives of this study were to evaluate the presence of Fe levels in water bodies, sediments, and giant mudskipper fish, assess the bioaccumulation of Fe in various tissues of giant mudskipper fish (liver, kidney, muscle, skin, and gills), evaluate the relationship or correlation between Fe content in water bodies and sediments as well as the concentrations in the liver, kidney, skin, muscle, and gill tissues of giant mudskipper fish, and validate the potential of giant mudskipper fish as a bioindicator of Fe contamination in the Kuala Lupak estuary. The trends and intricacies of iron (Fe) contamination are investigated into by this research, especially within estuarine environments. The accessibility of this metal was primarily evaluated, and its annual fluctuations were also monitored. The knowledge acquired from this study provides significant insights, especially for comprehending the possible consequences of future environmental changes. The results of this multi-year trace metal monitoring are of paramount importance in understanding the bioaccumulation potential of trace metals and constitute a crucial step in the management of estuarine and coastal ecosystems. These outcomes serve as a foundational framework for stakeholders to assess and address anthropogenic effects in the future.

Materials and Methods

Study area

The study was conducted in the coastal wetland of Kuala Lupak, situated in the Barito Kuala Regency. This region is approximately 8 km west of the mouth of the Barito River, the largest and longest river in South Kalimantan Province, Indonesia. The coastal wetland area of Kuala Lupak directly merges with the Java Sea coastline to the south. A comprehensive review of each study station/site is presented in Table 1, while the precise sampling locations are visually shown in Figure 1.

Sample collections and analysis

The process of collecting water, sediment, and giant mudskipper fish samples was conducted during August in 2020, 2021, and 2022. The sampling was carried out using the purposive sampling method, where sample selection was based on specific criteria, such as the potential sources of pollution. To accurately identify these sources, various activities that contribute to contamination were taken into consideration. Figure 1 shows the collection of fish, water, and sediment samples at the study location.

Water

Using an Aqua trap water sampler, surface water samples were collected from two stations scattered throughout the study region. In preparation for further analysis, approximately 2 mL of concentrated HNO_3 was added to each 1 L sample after filtration. The study adopted the liquid-liquid extraction technique (Jayaprakash et al., 2015) to determine the concentration level of dissolved Fe. A 100 mL unfiltered sample was placed in a separating funnel and mixed with 2 mL of 2% ammonium pyrrolidine dithiocarbamate (APDC). Subsequently, 10 mL of iso-butyl methyl ketone (IBMK) was used for extraction after severe agitation. The extracted aqueous phase was subjected to further extraction using concentrated HNO_3 and high-purity water. Any remaining traces of organic solvents in the solutes were evaporated on a low-temperature hot plate, and the final solution was analyzed using Atomic Absorption Spectrometry (AAS Thermo Scientific ICE 3500 series Germany). This instrument was used to measure the concentration level of Fe in water, sediments, and fish samples. For water, the concentration was expressed in mg L^{-1}. Finally, samples for metal determination were conditioned following Jayaprakash et al. (2015).

Sediment

Sediment samples were procured from two estuary stations using a Van Veen grab sampler. Furthermore, they were dried at 40°C and powdered in an agate mortar for the digestion procedures. Approximately 1 g of the dried sediment sample was digested with an acid mixture containing $HClO_4$+HF+HCl, and the residue was dissolved with concentrated HCl, then diluted to 25 mL. The solution was analyzed using flame AAS to estimate the Fe concentrations which were expressed in mg kg^{-1} for sediment.

Fish sampling and analysis

Fish samples were obtained from the estuarine area by local fishermen. A total of 15 giant mudskipper fish with identical dimensions, ranging between 19 and 20 cm in length and weighing from 160 to 170 g, were collected from each sampling station to ensure representativeness. The obtained samples were transported to the laboratory in ice boxes to maintain their preservation and appropriate conditions for further analysis. Furthermore, the dissection of the fish was conducted using surgical stainless-steel instruments, facilitating the extraction of organs, including the liver, kidneys, gills, muscles, and skin. A digestion tube, pre-loaded with 5 mL of HNO_3 and H_2SO_4, was utilized for each organ sample to initiate the reaction. The samples were subjected to digestion using a hot block digestion apparatus, maintained at 60°C for 30 minutes. Following the cooling of the samples, 10 mL of HNO_3 was added, and the mixture was further heated at temperatures ranging from 120 to 150 °C until a discernibly dark coloration of the solution was achieved. For facilitating the subsequent filtration process, 1 mL of H_2O_2 was introduced to yield a clear solution. Those filtered samples were then analyzed using Atomic Absorption Spectrometry (AAS) to quantify the concentration of Fe in the fish tissues, expressed mg kg^{-1}.

Statistical analysis

Data processing and analysis were executed employing GraphPad Prism software, specifically the 5.9.0 series from Dotmatics. The statistical evaluations comprised the determination of mean, standard deviations (SD), minimum and maximum values, the creation of graphical representations showing the interrelationship among variables, and the calculation of Pearson correlations. The analyses were conducted using GraphPad Prism 7.02, developed by the company of GraphPad Software Inc., San Diego.

Table 1. Study station description.

Location	Stations/sites	Description
Kuala Lupak	Estuarine	The estuarine water of Kuala Lupak is a coastal wetland area with the status of Margasatwa Wildlife Sanctuary, specifically a mangrove swamp ecosystem. The mouth of the Kuala Lupak River is surrounded by human settlements, and it flows into the Java Sea. The samples were collected from the coordinates 3°27'28.223"S 114°22'04.780" E in the estuarine waters.
	Coastal	The coastal waters of Kuala Lupak are located approximately 8 km west of the mouth of the Barito River and border the Java Sea to the south, with a coastline of 30 km. Furthermore, they are characterized by mangrove swamps. At the coordinates 3°28'02.383"S 114°21'31.282" E samples were collected in the coastal waters where the Kuala Lupak River flows into the sea.

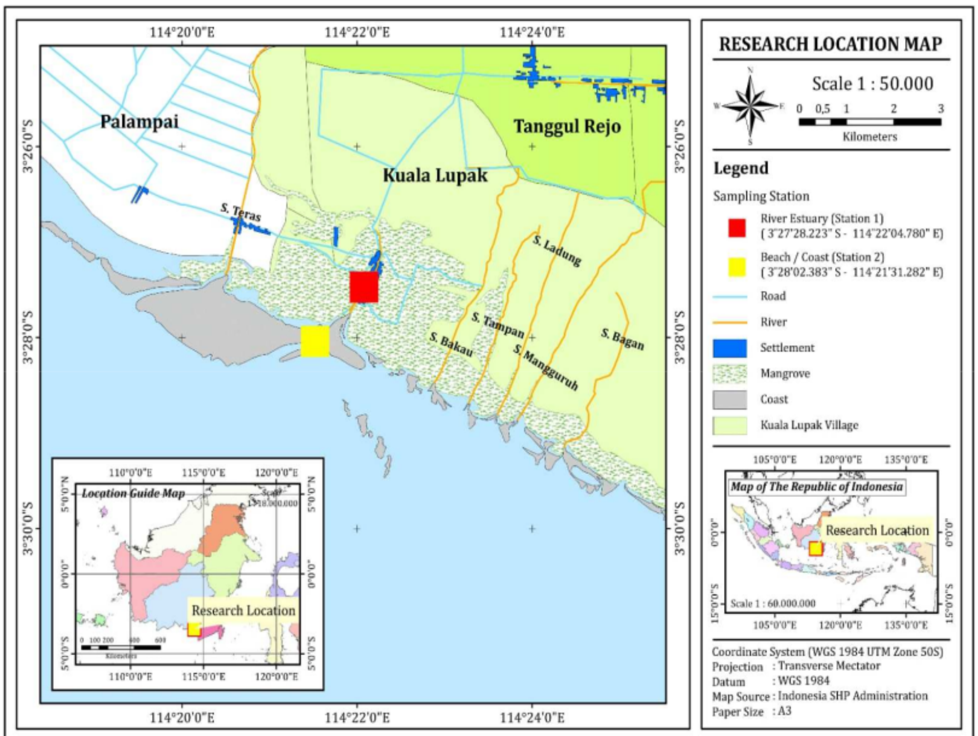

Figure 1. Study area map and sampling locations in the estuary Kuala Lupak South Kalimantan.

Results

Occurrence of Fe concentrations in water and sediment

The average concentrations of Fe in the water column from 2020 to 2022 ranged from 2.55 to 11.61 mg L^{-1}. This showed a significant trend of increase over each successive year. The highest average concentration of Fe was recorded in 2022 to the 11.61 mg L^{-1}, as presented in Table 2. The Maximum Permissible Limits (MPLs) for heavy metals in estuary water were not regulated by International Guideline values. The Fe in Kuala Lupak estuary water exceeded the threshold value set by Government Regulation of Indonesia number 22 of 2021 concerning the Implementation of Environmental Protection and Management. Furthermore, the seawater quality standard for marine biota was set at 0.30 mg L^{-1}. In parallel, the average concentrations of Fe within the sediment, serving as the habitat of the giant mudskipper fish, was in the range of 1,245.92 to 48,911.78 mg kg^{-1}.

Analogous to the pattern observed in the water column, the concentrations of Fe in the sediment also displayed a significant upward trend over each year, as shown in Figure 2. The highest average level of Fe (48,911.78 mg kg^{-1}) in the sediment was observed in 2022 (Table 2). The concentration of this metal in Kuala Lupak estuary sediments exceeded the maximum limit of 20,000 mg kg^{-1} set by the International Guideline value, CBSQG 2003: Consensus-Based Sediment Quality Guidelines (Wisconsin Department of Natural Resources). The mean plot of Fe level in water and sediment from 2020 to 2022 demonstrated a significant interrelationship between variables, with a confidence level of 95%, as indicated by the statistical analysis ($p<0.05$, $R^2 = 0.649$).

Table 2. Mean values of Fe concentration in water, sediment, and some tissues of giant mudskipper fish from the Kuala Lupak estuary between the period of 2020 to 2022.

Sampling Period	Water (mg L^{-1})	Sediment (mg kg^{-1})	Liver (mg kg^{-1})	Kidney (mg kg^{-1})	Muscle (mg kg^{-1})	Skin (mg kg^{-1})	Gill (mg kg^{-1})
2020	2.55	1,245.92	5.52	7.98	40.44	4.42	1.23
2021	5.54	47,348.42	8.43	11.99	51.56	6.70	3.32
2022	11.61	48,911.78	12.84	15.44	69.74	8.80	6.22

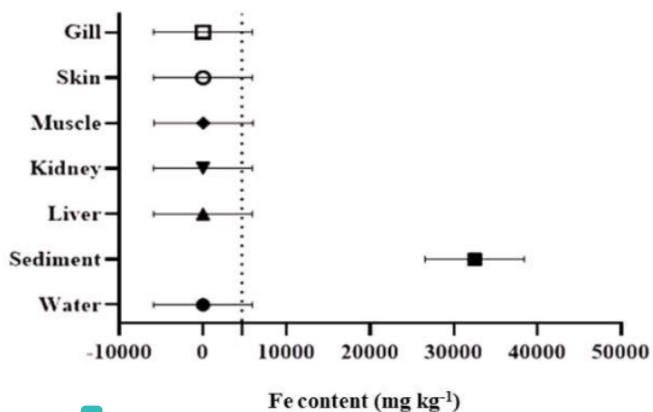

Figure 2. The mean plot of Fe concentration in water, sediment, and some tissue of giant mudskipper fish from 2020 to 2022.

Temporal variations in Fe concentrations in giant mudskipper fish

The mean Fe concentrations in the liver, kidney, muscle, skin, and gills of giant mudskipper for the years 2020-2022 ranged from 5.52 to 12.84 mg kg^{-1}, 7.98 to 15.44 mg kg^{-1}, 40.44 to 69.74 mg kg^{-1}, 4.42 to 8.80 mg kg^{-1}, and 1.23 to 6.22 mg kg^{-1}, as presented in Table 2. The average level of this metal in several fish tissues exhibited a significant upward trend annually, with the highest value being recorded in 2022, as specified in Figures 2 and 3. Based on the results in Table 2, muscle had the highest accumulation among the tested fish tissues, followed by kidney, liver, skin, and gills. The Maximum Permissible Limit (MPL) for Fe in fish meat was not regulated by international guideline values but was regulated by national guideline values. The Fe in giant mudskipper fish organs exceeds the threshold value of 1 mg kg^{-1}, as regulated by the Indonesian National Standard (SNI 7387:2009) regarding the maximum limit of heavy metal contamination. When comparing the content of this metal among the tested samples in the Kuala Lupak estuarine ecosystem, the average concentration in sediment was the highest.

The relationship between Fe contents in water, sediment, and giant mudskipper fish tissues

The interrelationships among heavy metal concentrations in water, sediment, and the tissues of giant mudskipper fish from 2020 to 2022 were evaluated and presented in Figure 3. The graphical representation shows a substantial positive correlation between the concentration of Fe in the water and the levels identified in the liver, muscle, and gills, with a correlation coefficient of 1. This implied that elevated levels of this metal in the water correspond with its heightened concentrations in the liver, muscles, and gills. Furthermore, a robust positive correlation was observed between waterborne Fe concentrations and the levels of the metal in the kidney and skin, with correlation coefficients of 0.97 and 0.98, respectively.

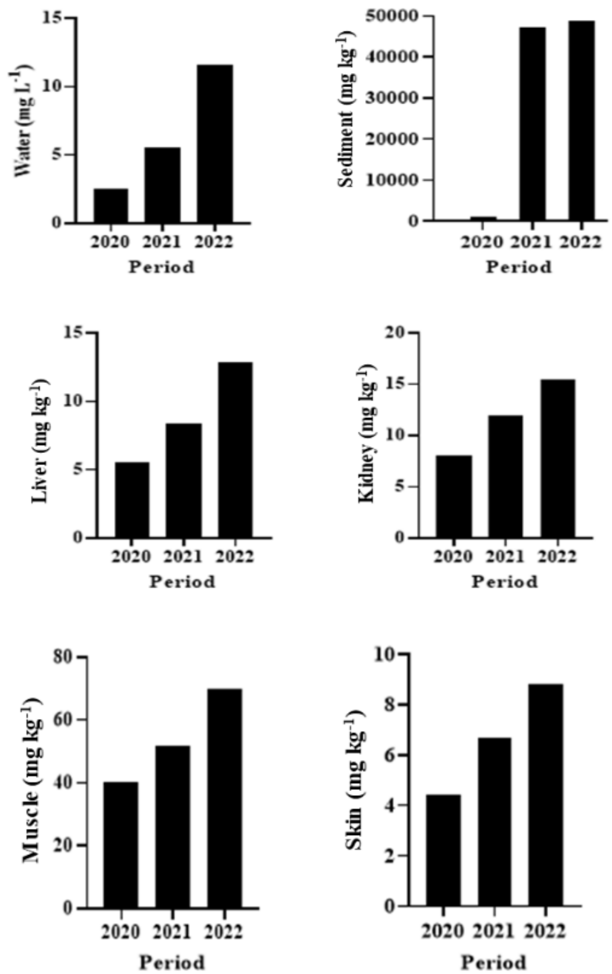

Figure 3. Fe content trend in some tissue of giant mudskipper fish period 2020-2022.

The correlation coefficient between Fe levels in the water and sediment was 0.77. A highly significant positive correlation among the concentrations present in the water, sediment, and tissues of the giant mudskipper fish, as indicated by the outcomes of this investigation. Based on these observations, the accumulation in water and sediment has augmented Fe levels within the tissues of the fish. This correlation was in line with the consistently high concentrations in water and sediment. Figure 3 further shows a robust positive correlation between sediment-bound Fe concentrations and those in the kidney, skin, gills, liver, and muscle tissues, with correlation coefficients of 0.90, 0.89, 0.83, 0.82, and 0.81, respectively. These results underscored the effect of sediment-bound Fe accumulation on the corresponding values within the tissues of the fish. This correlation was in line with the consistent elevation of sediment-bound Fe concentrations over 3 years, exhibiting an annual increment, as presented in Figure 1. The study also underscored a significant positive correlation across various organs of the giant mudskipper fish. This indicated a uniform distribution across diverse organs after Fe uptake into the body of the fish. In Figure 3, a close positive correlation is evident between the Fe concentration in the skin, serving as an entry point for Fe uptake. In the kidney, gills, muscle, and liver, the level of this metal exhibited correlation coefficients of 1.00, 0.99, 0.99, and 0.99, respectively. Similarly, a positive, strong correlation existed among the concentration in the gills, another site of Fe entry, and the Fe levels in the liver, muscle, skin, and kidney.

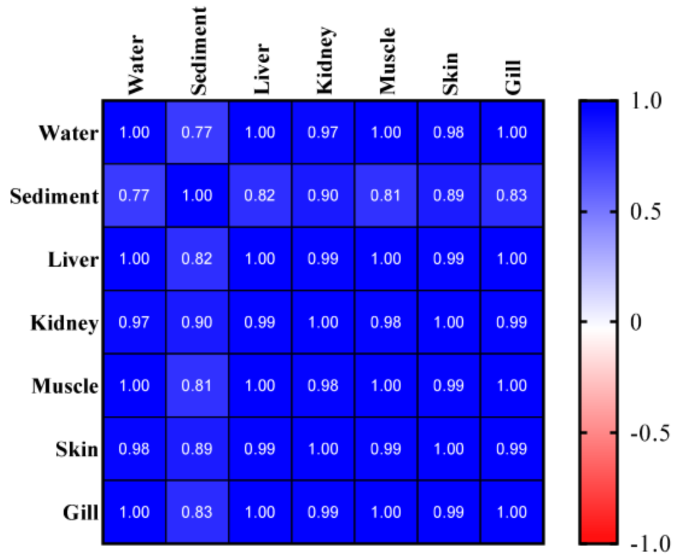

Figure 4. Pearson correlation of Fe content in some tissue of mudskipper fish period 2020-2022.

These featured coefficients of 1.00, 1.00, 0.99, and 0.99, respectively. The results showed that elevated Fe concentrations in the skin and gills precipitate were directly proportional to the liver, kidney, and muscle tissues.

Discussion

Fe contamination in estuarine waters: Sources and implications

The heightened prevalence of Fe within the Kuala Lupak estuary in 2022 was attributed to the effects of extreme rainfall and substantial flooding in the region of Kalimantan Selatan from December 2020 to February 2021. This event led to the dissolution of heavy metal deposits from upstream areas, resulting in their transport into the estuarine environment and eventual deposition within the estuary. This result was in line with the study conducted by (Čmelík et al., 2019), which identified a substantial increase in heavy metal concentrations in both water and sediment along the course of the Bílina River in the Czech Republic, directly attributed to extreme rainfall events. However, it is important to note that floods had a comparatively shorter-lived influence on the quality of water and sediment compared to the cumulative impacts of anthropogenic activities.

A study by Supriyantini and Endrawati (2015) also reported elevated concentrations within water bodies, sediment, and tissues of the green mussel (*Perna viridis*) in the coastal rivers of Tanjung Emas Semarang. In this investigation, the elevated Fe content in the estuary stemmed from various sources, including soil and anthropogenic activities occurring on land. These activities comprise household waste containing Fe, water reservoirs sourced from Fe, industrial waste deposits, and corrosion from Fe-containing pipes transported into the estuary by river flow. According to Haeruddin et al. (2020), the highest heavy metal concentrations within sediment were proximal to contamination sources.

Fe contamination within estuarine waters emanates from natural processes, such as geological weathering, rock decomposition, and anthropogenic activities. These anthropogenic sources include Fe release from ore materials and volcanic eruptions that discharge Fe-rich materials into water bodies through runoff, erosion, and flooding. Human activities such as coal transportation and mining operations contribute significantly to this pollution (Dalu et al., 2020). Anthropogenic Fe sources also include land-based activities, such as the discharge of household waste containing Fe, Fe-laden water reservoirs, industrial waste deposits, and the corrosion of Fe-containing pipes, releasing Fe^{2+} and sulfuric acid due to the oxidation of Fe pyrite (FeS_2) present in coal layers (Jaishankar et al., 2014).

The escalating temporal increase in Fe concentrations in both water bodies and sediments, as observed in this study, was supported by an investigation conducted by Weber et al. (2020) concerning the contamination in Brazil's Piranga and Doce rivers. Both rivers were contaminated with Fe due to the collapse of the Samarco mine tailings dam in Brazil in 2015. Environmental catastrophes such as dam failures that release tailings profoundly impacted the landscape and aquatic environments, progressively deteriorating the water quality of the Doce and Piranga rivers over time. Another source of this contamination stems from mineral weathering/erosion and elevated Fe content in soil. The contamination of these rivers has led to the bioaccumulation of Fe in *Hoplias intermedius* and *Hypostomus affini* fish. This caused histopathological lesions in the liver, including vacuolization, hepatocyte hypertrophy, and elevated necrotic areas compared to fish from non-tailings-contaminated rivers. This study strengthens the notion that fish living in heavy metal-contaminated waters experience declining aquatic health quality, leading to heavy metal bioaccumulation and histopathological lesions.

Accumulation of iron in sediments: Multifaceted sources and ecological implications

In this study, sediments in the Kuala Lupak estuary accumulate higher levels of heavy metals than the water column. This has rendered the sediments a significant potential source and a primary repository for all pollutants (Weber et al., 2013). These particles can store diverse heavy metals in substantial and consistent quantities, hence, they become valuable indicators for assessing water pollution status (Haeruddin et al., 2020). Liline et al. (2022) reported that sediments in the Rutong, Waai, and Poka mangrove areas in Maluku function as a medium for transferring heavy metals such as chromium (Cr) and Fe to mudskipper fish. The heavy metals in estuarine sediments result from sedimentation processes that retain significant amounts of adsorbed metal particles, leading to their deposition at the bottom. Wastes containing these metallic elements were deposited in sediments upon entering estuaries. This was facilitated by reduced environmental conditions, low dissolved oxygen, and elevated pH, causing metal concentration or enrichment (Carvalho Neta et al., 2019). The result was in line with the study by Dalu et al. (2020), stating that heavy metal content in sediment was significantly higher than in the water column, as suspended particles were absorbing it. High Fe content in sediment can lead to contamination of water bodies, which can have negative impacts on the health of aquatic biota and the overall ecological balance of aquatic ecosystems.

Sediments serve as indicators of land-based pollution by acting as "sinks" for pollutants. The rise in heavy metal levels in sediments suggests that heavy metals in the water column are deposited along with suspended solids, posing a potential threat to estuarine and coastal ecosystems. These sediments, serving as sinks for various human activities, may also act as sources of heavy metals, underscoring the ongoing necessity for monitoring to evaluate their role as pollution sources. Heavy metals are prone to accumulating in sediments, resulting in consistently higher concentrations than those in the water column. Suspended sediment particles quickly transport these metals into water through the movement of water masses (Weber et al., 2013). The high volume of merchant and coal transport vessels contributes to water mass movement in the Barito River estuary.

The accumulation of heavy metal in sediments was attributed to a variety of sources, including leaded gasoline emissions, chemical manufacturing industries, motorized transportation, underground pipe corrosion, coal-based thermal power plants, and urban waste. The results of this study were in line with the report of Jayaprakash et al. (2015), indicating that heavy metal concentrations in water were consistently lower than in sediment within contaminated water bodies. This is because sediment particles tend to absorb metals from the water. In sediment-rich environments, organisms such as the giant mudskipper fish accumulated heavy metals from their food and water through gills, mouth, and skin mucus, further underscoring the potential for metal bioaccumulation. The intricate interplay between suspended sediment particles and their propensity to absorb heavy metals from the aqueous phase was a crucial mechanism underlying the contrasting concentrations of these metals in water and sediment. This phenomenon accentuated the role of sediments as repositories for heavy metals, specifically in aquatic environments subject to anthropogenic influences and diverse pollutant sources.

The congruence between the report of Jayaprakash et al. (2015) and this study underscores the broader ecological implications of metal accumulation in sediments. The distinct levels of heavy metals within water and sediment reflect the differential interactions between these metals and particulate matter suspended in water. Consequently, sedimentary environments act as crucial hubs for storing heavy metals, providing a pertinent context for comprehending the potential ecological ramifications of anthropogenic pollution in aquatic ecosystems. High Fe content in sediment can alter the physical and chemical properties, such as color, texture, and pH. This could also affect the habitat of benthic organisms and the overall ecological balance of aquatic ecosystems (Viana et al., 2021). These results elaborate on the necessity for robust monitoring practices to assess the extent and impacts of contamination within sediment systems.

Direct observations during this study, as well as interviews with residents, led to the identification of sources of coastal swamp water pollution in Kuala Lupak. These sources include residential waste and the waste products of factories situated along the banks of the Barito River estuary. Factories, such as plywood processing plants perform wood washing activities as well as generate solid waste such as wood fragments, bark, sawdust, and sanding residues. Other sources of contamination were believed to arise from gold mining activities in the Barito River basin, the use of paint in shipyards, agricultural activities including the application of pesticides and fungicides, converting mangrove areas to fish ponds, and the application of explosives for fishing. Fuel companies discharging waste were also suspected sources of pollution. These companies distributed diesel fuel through water transport routes that traverse the Barito River estuary. Additionally, the high density of commercial and coal transport ships, alongside coal spillage and debris entering the river, contributed to the degraded water quality of the river. According to the National Transportation Safety Committee, approximately 7.101 units of coal barges navigate the Barito River (Mitra et al., 2023).

In addition to anthropogenic activities, Fe is sourced from natural processes comprising regular biogeochemical cycles, volcanic activities, soil erosion, continental runoff, shelf inputs, as well as atmospheric deposition from volcanic events and wildfires (Soltani et al., 2021). Furthermore, as the most dominant transition metal in the Earth's crust, it undergoes multiple natural cycles (Jaishankar et al., 2014). Anthropogenic pollution of trace metals, including Fe, in estuarine waters has deteriorated water quality and negatively impacted fish health (Inayat et al., 2023).

Bioaccumulation potential and ecological impact of iron in giant mudskipper fish

Many studies have documented that indicator species accumulate contaminants in their tissues at higher levels than the surrounding habitat, such as water and sediment. This characteristic makes them valuable as potential bioindicators within ecosystem health biomonitoring programs. According to Table 2, the concentrations of Fe in the muscle, kidney, liver, and skin of giant mudskipper fish exceeded those in the surrounding aquatic environment. The elevated concentrations within fish tissues were attributed to the increased levels present in both sediment and water. These results corroborate with those of Gawad (2018), who posited that high concentrations of heavy metals in sediment and water allow aquatic organisms to accumulate metals biologically and transport them through the food chain. The ability of giant mudskipper fish to accumulate heavy metals in tissues stems from their position at the pinnacle of the food chain. These organisms reside benthically in mud within the intertidal coastal zone and mangrove forest floor; hence, they are susceptible to direct exposure to pollutants within the estuarine environment. According to Ferreira et al. (2019), estuaries represent habitats with continuous and direct exposure to heavy metal pollutants.

Estuaries have gained wide recognition as net sinks for trace metals, including Fe, which precipitate rapidly within the environment (Crerar et al., 1982). While rivers transport substantial amounts of dissolved and particulate Fe into the sea, a significant portion is retained and accumulated within sediments (Daneshvar et al., 2015; Zhu et al., 2018). This phenomenon is attributed to the exceptional capacity of the sediments as a final trap and adsorptive reservoir for heavy metals in aquatic environments. Fe colloids are immobilized within surface estuarine sediments and can become mobilized by organic matter and reduction agents. When these values exceed a certain threshold, the mobility and deposition of Fe lead to pollution, thereby posing toxicity risks to fish. This risk arose primarily because of the persistent, non-biodegradable, accumulative, and diverse sources of trace metals (Shafie et al., 2015). Continued and significant discharges of trace metal pollutants into the sea can damage estuarine and coastal ecosystems, given their chronic toxicity, non-biodegradability, and bioaccumulation in biota, including fish. Trace metals can transfer and biomagnify through food chains, posing severe threats to ecosystem health and human well-being. Furthermore, the contamination of metal within estuarine ecosystems can engender toxic effects in fish and humans, primarily by consuming contaminated food sources (Prasad et al., 2023).

The investigation into the toxic effects of Fe on fish inhabiting estuarine ecosystems proved a compelling inquiry for biologists in South Kalimantan, attributable to the robust positive correlation between Fe levels in the water, sediment, and fish organs. The heightened concentrations of this metal were suspected to be a consequence of its extensive usage (Bat and Arici, 2018). Furthermore, Fe is a prevalent component of industrial and mining waste, frequently discharged into aquatic environments, hence, exhibiting a pronounced correlation with aquatic biota, including fish. Its elevated contents in water and sediment facilitated a more pronounced accumulation within fish organs. Fe in its ferrous form (Fe^{2+}) had heightened toxicity towards fish compared to when it was ferric (Fe^{3+}). Fe^{2+} exhibited toxic effects by binding to gill surfaces and undergoing oxidation to form insoluble Fe^{3+}, thereby inciting cellular damage, ultimately culminating in respiratory dysfunction (Singh et al., 2019).

The bioconcentration of Fe within fish tissues attained its zenith within the liver and gonads, subsequently diminishing in the brain, muscles, and heart (Authman, 2015). The study conducted by Omar et al. (2014) substantiated the liver as a prime target organ for Fe-induced toxicity in fish. Furthermore, the toxicity of this metal within gills disrupts respiration due to the physical obstruction of the surfaces (Dalzell et al., 1999). The alkaline nature of the gill surfaces promoted the facile oxidation of soluble Fe, forming insoluble Fe compounds that cloak gill lamellae, impeding respiratory function.

Excessive Fe absorption led to poisoning in *Labeo rohita*, catalyzing the generation of ROS via Fenton reactions, which damaged biomolecules, cells, and tissues through oxidative stress mechanisms (Singh et al., 2019). This metal also potentiates the toxicity of other chemical agents, such as paraquat or 2,3,7,8-tetrachlorodibenzo-p-dioxin (Sevcikova et al., 2011). In a study by Kaloyianni et al. (2020), the toxicity of magnetite nanoparticles (Fe_3O_4) was reported in *Danio rerio* and *Carassius gibelio* fish, evoking oxidative, proteolytic, genotoxic, and apoptotic effects, accompanied by elevated malondialdehyde and carbonyl protein levels.

Conclusion

In conclusion, the study elucidated substantial positive associations in Fe levels across water, sediment, and tissues of the giant mudskipper fish (*Periophthalmodon schlosseri*) during the 2020-2022 period. These associations underscored the dynamic interplay between environmental Fe buildup and its assimilation within fish tissues. The graphical representation accentuated a strong positive correlation (correlation coefficient 1) between waterborne concentrations and those in the liver, muscle, and gills. This indicated that higher Fe levels in water correspond to elevated levels in these fish tissues. Similarly, noteworthy positive correlations were observed between Fe levels in water as well as kidney and skin tissues, with correlation coefficients of 0.97 and 0.98, respectively.

Sediment-bound Fe also correlated positively with kidney, skin, gills, liver, and muscle tissues, with sequential correlation coefficients of 0.90, 0.89, 0.83, 0.82, and 0.81. The strong positive correlation within the various fish organs implied uniform Fe dispersion post-uptake. The skin and gills, primary entry points for this metal, exhibited robust positive correlations with kidney, gills, muscle, liver, and skin tissues. This inquiry into the detrimental impacts of Fe on estuarine fish in South Kalimantan assumed significance due to the strong positive correlations between the concentrations of this metal in water, sediment, and fish organs. The widespread dispersion of Fe from industrial and mining activities underscored its prevalence in aquatic ecosystems, often resulting from industrial and mining by-products infiltrating water bodies.

The intricate associations between Fe concentrations in water, sediment, and fish tissues illuminated the intricate relationship between environmental Fe accumulation and biological assimilation in estuarine ecosystems. The study underscored the importance of comprehending the impact of heavy metal contaminants, such as Fe, on aquatic organisms and habitats, with potential implications for ecosystem health and human well-being. Therefore, future studies should comprise a multifaceted approach, including scientific investigations, policy formulation, public awareness, and collaborative endeavors among stakeholders to safeguard the well-being of aquatic ecosystems and human populations.

Acknowledgments

This research was funded by a Research Lecturer Grant (PDWM) of Lambung Mangkurat University Banjarmasin, Indonesia.

References

Akinsanya, B., Ayanda, I. O., Fadipe, A. O., Onwuka, B. and Saliu, J.K. 2020. Heavy metals, parasitologic and oxidative stress biomarker investigations in *Heterotis niloticus* from Lekki Lagoon, Lagos, Nigeria. *Toxicology Reports* 7:1075-1082, doi:10.1016/j.toxrep.2020.08.010.

Alizada, N., Malik, S. and Bin, S. 2020. Bioaccumulation of heavy metals in tissues of Indian anchovy (*Stolephorus indicus*) from the UAE coast, Arabian Gulf. *Marine Pollution Bulletin* 154(October 2019), doi:10.1016/j.marpolbul.2020.111033.

Authman, M.M. 2015. Use of fish as bio-indicator of the effects of heavy metals pollution. *Journal of Aquaculture Research and Development* 06(04), doi:10.4172/2155-9546.1000328.

Bat, L. and Arici, E. 2018. Heavy Metal Levels in Fish, Molluscs, and Crustacea From Turkish Seas and Potential Risk of Human Health. In: food quality: balancing health and disease. Elsevier Inc, doi:10.1016/B978-0-12-811442-1/00005-5.

Carvalho Neta, R.N F., Mota Andrade, T. de S. de O., de Oliveira, S.R.S., Torres Junior, A.R., da Silva Cardoso, W., Santos, D.M.S., dos Santos Batista, W., de Sousa Serra, I.M.R. and Brito, N.M. 2019. Biochemical and morphological responses in *Ucides cordatus* (Crustacea, Decapoda) as indicators of contamination status in mangroves and port areas from northern Brazil. *Environmental Science and Pollution Research* 26(16):15884-15893, doi:10.1007/s11356-019-04849-0.

Čmelík, J., Brovdyová, T., Trögl, J., Neruda, M., Kadlečík, M., Pacina, J., Popelka, J. and Sirotkin, A.S. 2019. Changes in the content of heavy metals in Bílina river during 2012-2017: Effects of flood and industrial inputs. *Water (Switzerland)* 11(3), doi:10.3390/w11030481.

Crerar, D., Means, J., Yuretich, R., Borcsik, M., Amster, J. and Hasting, D. 1981 Transport and deposition of iron, aluminum, dissolved organic matter, and selected trace elements in stream, ground- and estuary water. *Chemical Geology* 33(1-4):23-44, doi:10.1016/0009-2541(81)90083-8.

Dalu, T., Tshivhase, R., Cuthbert, R., Murungweni, F. and Wasserman, R. 2020. Metal distribution and sediment quality variation across sediment depths of a Subtropical Ramsar declared wetland. *Water* 12(10):12779, doi:10.3390/w12102779.

Dalzell, D.J., Macfarlane, N.A. 1999. The toxicity of iron to brown trout and effects on the gills: a comparison of two grades of iron sulphate. *Journal of Fish Biology* 55:301-315, doi:10.1111/j.1095-8649.1999.tb00680.x

Daneshvar, E. 2015. Dissolved iron behavior in the Ravenglass estuary waters: An implication on the early diagenesis. *Universal Journal of Geoscience* 3(1):1-12, doi:10.13189/ujg.2015.030101.

Ferreira, C.P., Lima, D., Paiva, R., Vilke, J.M., Mattos, J.J., Almeida, E.A., Grott, S.C., Alves, T.C., Corrêa, J.N., Jorge, M.B., Uczay, M., Vogel, C.I.G., Gomes, C.H.A.M., Bainy, A.C.D. and Lüchmann, K.H. 2019. Metal bioaccumulation, oxidative stress and antioxidant responses in oysters *Crassostrea gasar* transplanted to an estuary in southern Brazil. *Science of The Total Environment* 685:332-344, doi:10.1016/j.scitotenv.2019.05.384.

Franco-Fuentes, E., Moity, N., Ramírez-gonz, J., Andrade-Vera, S., Hardisson, A., Paz, S., Rubio, C. and Gutierrez, A.J. 2023. Mercury in fish tissues from the Galapagos marine reserve: Toxic risk and health implications. *Journal of Food Composition and Analysis* 115(October 2022), doi:10.1016/j.jfca.2022.104969

Garg, S. and Gauns, M. 2023. Marine environmental chemistry and ecotoxicology of heavy metals. In: *Metals in Water*. INC., doi:10.1016/B978-0-323-95919-3.00011-2.

Gawad, S.S.A. 2018. Concentrations of heavy metals in water, sediment and mollusk gastropod, *Lanistes carinatus* from Lake Manzala, Egypt. *Egyptian Journal of Aquatic Research* 44(2):77-82, doi:10.1016/j.ejar.2018.05.001.

Haeruddin, Supriharyono, Rahman, A., Ghofar, A. and Iryanthony, S.B. 2020. Spatial distribution and heavy metal pollution analysis in the sediments of Garang watershed, Semarang, Central Java, Indonesia. *AACL Bioflux* 13(5):2577-2587.

Hidayaturrahmah, Mabrur, Santoso, H.B., Sasmita, R., Rahmy, U.S.A. and Badruzsaufari. 2019. Short communication: Protein profiles of giant mudskipper and its potential use as biomarker candidate for heavy metal contamination in Barito Estuary, Indonesia. *Biodiversitas* 20(3):745-753, doi:10.13057/biodiv/d200319.

Inayat, I., Batool, A., Ur Rehman, M.F., Ahmad, K.R., Kanwal, M.A., Ali, R. and Habib, S.S. 2023. Seasonal variation and association of heavy metals in the vital organs of edible fishes from the River Jhelum in Punjab, Pakistan. *Biological Trace Element Research* June, doi:10.1007/s12011-023-03730-z.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B. and Beeregowda, K.N. 2014. Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology* 7(2):60-72, doi:0.2478/intox-2014-0009.

Jayaprakash, M., Kumar, R.S., Giridharan, L., Sujitha, S.B., Sarkar, S.K. and Jonathan, M.P. 2015. Bioaccumulation of metals in fish species from water and sediments in macro tidal Ennore creek, Chennai, SE coast of India: A metropolitan city effect. *Ecotoxicology and Environmental Safety* 120:243-255, doi:10.1016/j.ecoenv.2015.05.042.

Kaloyianni, M., Dimitriadi, A., Ovezik, M., Stamkopoulou, D., Feidantsis, K., Kastrinaki, G., Gallios, G., Tsiaoussis, I., Koumoundouros, G. and Bobori, D. 2020. Magnetite nanoparticles effects on adverse responses of aquatic and terrestrial animal models. *Journal of Hazardous Materials* 383(August 2019):121204, doi:10.1016/j.jhazmat.2019.121204.

Kasmiarti, G., Sakinah, R.A. and Yudono, B. 2021. The analysis of manganese (Mn) in wastewater treatment (PAL) of coal mine of PT Bukit Asam Indonesia. *Indonesian Journal of Fundamental and Applied Chemistry* 6(2):53-58, doi:10.24845/ijfac.v6.i2.53.

Kumaraguru, A., Mary, R.C. and Saisaraswathi, V. 2020. A review about fish walking on land. *Journal of Threatened Taxa* 12(17):17276-17286, doi:10.11609/5549ot.6243.12.17.17276-17286.

La Colla, N.S., Botte, S.E., Olivia, A. and Marcovecchio, J.E. 2017. Tracing Cr, Pb, Fe and Mn occurrence in the Bahía Blanca estuary through commercial fish species. *Chemosphere* 175:286-293, doi:10.1016/j.chemosphere.2017.02.002.

Liline, S., Rumahlatu, D., Salmanu, S.I.A., Pattipeilohy, M. and Sangur, K. 2022. Bioaccumulation of chromium, iron, and the expression of TNF-α and Caspase-3 in mudskipper (*Periophthalmus* spp .) from Ambon Island waters, Indonesia. *Journal of Ecological Engineering* 23(7):90-104, doi:10.12911/22998993/149583.

Mitra, S.A.J., Tareq, A.M., Emran, T.B., Nainu, F., Khusro, A., Idris, A.M., Khandaker, M.U., Osman, H., Alhumaydhi, F.A. and Simal-Gandara, J. 2023. Corrigendum to impact of heavy metals on the environment and human health: Novel therapeutic insights to counter the toxicity. *Journal of King Saud University – Science* 35(7):102823, doi:10.1016/j.jksus.2022.101865,

Moniruzzaman, M. and Saha, N.C. 2020. Impact of variation in abiotic factors and metal accumulation pattern on the annual rhythmicity of antioxidants and maintenance of oxidative balance in fish gill. *Chemistry and Ecology* 1–15, doi:10.1080/02757540.2020.1843159/

Muhammad, S. and Ahmad, K. 2020. Heavy metal contamination in water and fish of the Hunza River and its tributaries in Gilgit – Baltistan: Evaluation of potential risks and provenance. *Environmental Technology and Innovation* 20:101159, doi:10.1016/j.eti.2020.101159.

Omar, W.A., Saleh, Y.S. and Marie, M.A.S. 2014. Integrating multiple fish biomarkers and risk assessment as indicators of metal pollution along the Red Sea coast of Hodeida, Yemen Republic. *Ecotoxicology and Environmental Safety* 110:221-231, doi:10.1016/j.ecoenv.2014.09.004.

Prasad, B., Kishore, Y., Prasad, S., Pradhan, A., Kumar, T., Patowary, K., Adibah, W., Mahari, W., Shiung, S., Ghfar, A.A., Guerriero, G., Verma, M. and Sarma, H. 2023. Metal pollution in freshwater fish: A key indicator of contamination and carcinogenic risk to public health. *Environmental Pollution* 330(May):121796, doi:10.1016/j.envpol.2023.121796.

Santoso, H.B., Suhartono, E., Yunita, R. and Biyatmoko, D. 2020. Mudskipper fish as a bio-indicator for heavy metals pollution in a coastal wetland. *Egyptian Journal of Aquatic Biology and Fisheries* 24(7):1073-1095, doi:10.21608/ejabf.2020.144402.

Sarah, R., Tabassum, B., Idrees, N., Hashem, A. and Abd_Allah, E.F. 2019. Bioaccumulation of heavy metals in *Channa punctatus* (Bloch) in river Ramganga (U.P.), India. *Saudi Journal of Biological Sciences* 26(5):979-984, doi:10.1016/j.sjbs.2019.02.009.

Sevcikova, M., Modra, H., Slaninova, A. and Svobodová, Z. 2011. Metals as a cause of oxidative stress in fish: a review. *Veterinarni Medicina* 56(11):537-546, doi:10.1016/j.aquatox.2014.06.018.

Shafie, N.A., Aris, A.Z. and Haris, H. 2015. Geoaccumulation and distribution of heavy metals in the urban river sediment. *International Journal of Sediment Research* 29(3):368-377, doi:10.1016/S1001-6279(14)60051-2.

Singh, M., Barman, A.S., Devi, A.L., Devi, A.G. and Pandey, P.K. 2019. Iron mediated hematological, oxidative and histological alterations in freshwater fish *Labeo rohita*. *Ecotoxicology and Environmental Safety* 170:87-97, doi:10.1016/j.ecoenv.2018.11.129.

Sofarini, D., Rahman, A. and Ridwan, I. 2012. Modeling heavy metal testing in water bodies, biota, and sediments in the estuarine waters of the Barito River basin. *Bumi Lestari* 12(1):32-44 (*in Indonesian*).

Soltani, N., Marengo, M., Keshavarzi, B., Moore, F., Hooda, P.S., Reza, M. and Gobert, S. 2021. Occurrence of trace elements (Tes) in seafood from the North Persian Gulf: Implications for human health. *Journal of Food*

Composition and Analysis 97:103754, doi:10.1016/j.jfca.2020.103754.

Supriyantini, E. and Endrawati, H. 2015. Heavy metal content of iron (Fe) in water, sediments, and green mussels (*Perna viridis*) in Tanjung Emas Semarang waters. *Journal of Tropical Marine* 18(1):38-45, doi:10.1111/j.1600-0404.1962.tb01105.x.

Tabrez, S., Zughaibi, T.A. and Javed, M. 2021. Bioaccumulation of heavy metals and their toxicity assessment in Mystus species. *Saudi Journal of Biological Sciences* 28(2):1459-1464, doi:10.1016/j.sjbs.2020.11.085.

Tenenbein, M. and Huang, X. 2022. Chapter 17 Iron. In: *Handbook on the Toxicology of Metals*: Vol. II (Issue II). Elsevier B.V, doi:10.1016/B978-0-12-822946-0.00016-7.

Viana, L.F, Caroline, J., Sposito, V., Melo, M.P. and De, Barufatti, A. 2021. High iron content in river waters: environmental risks for aquatic biota and human health. *Revista Ambiente & Água* 16(5), doi:10.4136/ambi-agua.2751.

Weber, A.A., Sales, C.F., de Souza Faria, F., Melo, R.M.C., Bazzoli, N. and Rizzo, E. 2020. Effects of metal contamination on liver in two fish species from a highly impacted neotropical river: A case study of the Fundão dam, Brazil. *Ecotoxicology and Environmental Safety* 190(October 2019), doi:10.1016/j.ecoenv.2020.110165.

Weber, P., Behr, E.R., Knorr, C.D.L., Vendruscolo, D.S., Flores, E.M.M., Dressler, V L. and Baldisserotto, B. 2013. Metals in the water, sediment, and tissues of two fish species from different trophic levels in a subtropical Brazilian river. *Microchemical Journal* 106:61-66, doi:10.1016/j.microc.2012.05.004.

Yogeshwaran, A., Gayathiri, K., Muralisankar, T., Gayathri, V., Monica, J.I., Rajaram, R., Marimuthu, K. and Bhavan, P.S. 2020. Bioaccumulation of heavy metals, antioxidants, and metabolic enzymes in the crab Scylla serrata from different regions of Tuticorin, Southeast Coast of India. *Marine Pollution Bulletin* 158(June):111443, doi:10.1016/j.marpolbul.2020.111443.

Zafar, N. and Khan, M.A. 2020. Effects of dietary iron on growth, haematology, oxidative stress and hepatic ascorbic acid concentration of stinging catfish *Heteropneustes fossilis*. *Aquaculture* 516(May):734642, doi:10.1016/j.aquaculture.2019.734642.

Zaoui, N., Bouriga, N., Louiz, I., Bahri, W.R., Saadaoui, N., Quiganrd, J.-P., Trabelsi, M., Ben-Attia, M. and Shahin, A. 2023. Assessment of effects of metal contamination and abiotic factors on fatty acid composition and biochemical biomarkers activity in the liver of Chelon ramada collected from two ecosystems on the Mahdia coast, Tunisia. *Biochemical Systematics and Ecology* 107(January):104608, doi:10.1016/j.bse.2023.104608.

Zaynab, M., Al-yahyai, R., Ameen, A., Sharif, Y., Ali, L., Fatima, M., Ali, K. and Li, S. 2022. Health and environmental effects of heavy metals. *Journal of King Saud University-Science* 34(1):101653, doi:10.1016/j.jksus.2021.101653.

Zhu, X., Zhang, R., Wu, Y., Zhu, J., Bao, D. and Zhang, J. 2018. The remobilization and removal of Fe in estuary - A case study in the Changjiang estuary, China. *Journal of Geophysical Research: Oceans* 123:2359-2553, doi:10.1002/2017JC013671.

Iron bioaccumulation and ecological implications in the coastal swamp wetlands ecosystem of South Kalimantan: Insights from giant mudskipper fish as bioindicators

ORIGINALITY REPORT

17%	6%	16%	2%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Jayaprakash, M., R. Senthil Kumar, L. Giridharan, S.B. Sujitha, S.K. Sarkar, and M.P. Jonathan. "Bioaccumulation of metals in fish species from water and sediments in macrotidal Ennore creek, Chennai, SE coast of India: A metropolitan city effect", Ecotoxicology and Environmental Safety, 2015. Publication	2%
2	Jasper J.A. Obico, R. Sedricke C. Lapuz, Julie F. Barcelona, Pieter B. Pelser. " What explains the high island endemicity of Philippine ? A species distribution modeling analysis of three threatened parasitic plant species and their hosts ", Cold Spring Harbor Laboratory, 2023 Publication	1%
3	Sivakumar Rajeshkumar, Yang Liu, Xiangyang Zhang, Boopalan Ravikumar, Ge Bai, Xiaoyu Li. "Studies on seasonal pollution of heavy	1%

metals in water, sediment, fish and oyster from the Meiliang Bay of Taihu Lake in China", Chemosphere, 2018
Publication

4 Sintje Liline, Dominggus Rumahlatu, Sriyanti Salmanu, Mery Pattipeilohy, Kristin Sangur. "Bioaccumulation of Chromium, Iron, and the Expression of TNF-α and Caspase-3 in Mudskipper (*Periophthalmus* spp.) from Ambon Island Waters, Indonesia", Journal of Ecological Engineering, 2022 1%
Publication

5 Lucilene Finoto Viana, Bruno do Amaral Crispim, Fábio Kummrow, Valter Aragão do Nascimento et al. "Bioaccumulation, genotoxicity, and risks to native fish species from inorganic contaminants in the Pantanal Sul-Mato-Grossense, Brazil", Environmental Pollution, 2022 <1%
Publication

6 proceedings.ums.ac.id <1%
Internet Source

7 Zohra Ben Salem, Habib Ayadi. "Heavy metal accumulation in Diplodus annularis, Liza aurata, and Solea vulgaris relevant to their concentration in water and sediment from the southwestern Mediterranean (coast of <1%

Sfax)", Environmental Science and Pollution Research, 2016
Publication

8 Soad S. Abdel Gawad. "Concentrations of heavy metals in water, sediment and mollusk gastropod, Lanistes carinatus from Lake Manzala, Egypt", The Egyptian Journal of Aquatic Research, 2018
Publication
<1%

9 ejournal.undip.ac.id
Internet Source
<1%

10 Submitted to Higher Education Commission Pakistan
Student Paper
<1%

11 Uraiwan Phoonaploy, Bundit Tengjaroenkul, Lamyai Neeratanaphan. " Effect of heavy metals from an electronic waste open dumping area on the cytotoxicity of climbing perch ( ) ", International Journal of Environmental Studies, 2020
Publication
<1%

12 jurnalsaintek.uinsby.ac.id
Internet Source
<1%

13 epub.ub.uni-greifswald.de
Internet Source
<1%

14 Monica Nordberg. "Toxicology and Biological Monitoring of Metals", General and Applied
<1%

Toxicology, 12/15/2009
Publication

15	e-journal.unair.ac.id Internet Source	<1 %
16	Anang Kadarsah, Dafiuddin Salim, dan Sadang Husain. "Study of Water and Sediment Quality and Heavy Metal Pollution (Pb) at South Kalimantan Mangrove Ecosystem", IOP Conference Series: Earth and Environmental Science, 2020 Publication	<1 %
17	fulir.irb.hr Internet Source	<1 %
18	scholarworks.uaeu.ac.ae Internet Source	<1 %
19	Mauricio Willians de Lima, Wendel Valter da Silveira Pereira, Edna Santos de Souza, Renato Alves Teixeira et al. "Bioaccumulation and human health risks of potentially toxic elements in fish species from the southeastern Carajás Mineral Province, Brazil", Environmental Research, 2022 Publication	<1 %
20	Idris, Nor Shahirul Umirah. "Assessment of Metal Variations in Water, Sediment, and Fish Species (Pangasius Sp. and Hemibagrus Sp.) from Selangor River, Pahang River and	<1 %

Nearby Aquaculture Ponds", University of Malaya (Malaysia), 2023
Publication

21	Rudneva, . "Biomarkers Responses in Fish Embryos and Larvae", Biomarkers for Stress in Fish Embryos and Larvae, 2013. Publication	<1 %
22	ejabf.journals.ekb.eg Internet Source	<1 %
23	Fatemeh Kachoueiyan, Abdolreza Karbassi, Touraj Nasrabadi, Mojtaba Rashidiyan, Gabriel Enrique De-la-Torre. "Speciation characteristics, ecological risk assessment, and source apportionment of heavy metals in the surface sediments of the Gomishan wetland", Marine Pollution Bulletin, 2024 Publication	<1 %
24	Submitted to KTH - The Royal Institute of Technology Student Paper	<1 %
25	Submitted to Verona Area School District Student Paper	<1 %
26	Mrunmayee Manjari Sahoo, Janaki Ballav Swain. "Spatio-temporal distribution and carcinogenic assessment due to potentially toxic elements in aquifer water of Ganga and	<1 %

Yamuna River basins, India", Groundwater for Sustainable Development, 2024
Publication

27	ABDEL-KHALEK, Amr Adel, ELHADDAD, Engy, MAHDOUH, Samar and MARIE, Mohammed-Asem Saed. "Assessment of Metal Pollution around Sabal Drainage in River Nile and its Impacts on Bioaccumulation Level, Metals Correlation and Human Risk Hazard using Oreochromis niloticus as a Bioindicator", TÜBİTAK, 2016. Publication	<1%
28	Baozhu Pan, Yuzhu Wang, Dianbao Li, Taoyi Wang, Lei Du. "Tissue-specific distribution and bioaccumulation pattern of trace metals in fish species from the heavily sediment-laden Yellow River, China", Journal of Hazardous Materials, 2021 Publication	<1%
29	Changchao Li, Quan Quan, Yandong Gan, Junyu Dong, Jiaohui Fang, Lifei Wang, Jian Liu. "Effects of heavy metals on microbial communities in sediments and establishment of bioindicators based on microbial taxa and function for environmental monitoring and management", Science of The Total Environment, 2020 Publication	<1%

30	Deepali Mohanty, Luna Samanta. "Dietary supplementation of Spirulina ameliorates iron-induced oxidative stress in Indian knife fish Notopterus Notopterus", Environmental Toxicology and Pharmacology, 2018 Publication	<1 %
31	Higemengist Astatkie, Embialle Mengistie Beyene, Argaw Ambelu. "Contamination and ecological risk assessment of toxic metals in Awetu watershed stream waters and sediments, Ethiopia", Environmental Monitoring and Assessment, 2022 Publication	<1 %
32	Shriya Garg, Mangesh Gauns. "Marine environmental chemistry and ecotoxicology of heavy metals", Elsevier BV, 2023 Publication	<1 %
33	helda.helsinki.fi Internet Source	<1 %
34	jfrm.ru Internet Source	<1 %
35	www.biorxiv.org Internet Source	<1 %
36	www.msceast.org Internet Source	<1 %

37	"Water Pollution and Remediation: Heavy Metals", Springer Science and Business Media LLC, 2021 Publication	<1 %
38	Bamidele Akinsanya, Isaac O. Ayanda, Adeola O. Fadipe, Benson Onwuka, Joseph K. Saliu. "Heavy metals, parasitologic and oxidative stress biomarker investigations in Heterotis niloticus from Lekki Lagoon, Lagos, Nigeria", Toxicology Reports, 2020 Publication	<1 %
39	Baris Karsli. "Determination of metal content in anchovy (Engraulis encrasicolus) from Turkey, Georgia and Abkhazia coasts of the Black Sea: Evaluation of potential risks associated with human consumption", Marine Pollution Bulletin, 2021 Publication	<1 %
40	M. P. Jonathan, S. Srinivasalu, N. Thangadurai, T. Ayyamperumal, J. S. Armstrong-Altrin, V. Ram-Mohan. "Contamination of Uppanar River and coastal waters off Cuddalore, Southeast coast of India", Environmental Geology, 2007 Publication	<1 %
41	Rachma Puspitasari, Noverita Dian Takarina, Tri Edhi Budhi Soesilo, Haruki Agustina. "Potential risks of heavy metals in green	<1 %

mussels (Perna viridis) harvested from Cilincing and Kamal Muara, Jakarta Bay, Indonesia to human health", Marine Pollution Bulletin, 2023
Publication

---

42 eprints.covenantuniversity.edu.ng
Internet Source
<1%

---

43 "Biosorption for Wastewater Contaminants", Wiley, 2022
Publication
<1%

---

44 Hazzeman Haris, Ahmad Zaharin Aris, Mazlin Bin Mokhtar, Ley Juen Looi. "The accumulation of metals and methylmercury in Nerita lineata and the relation to intertidal surface sediment concentrations", Chemosphere, 2020
Publication
<1%

---

45 Heri B. Santoso, Eko Suhartono, Rizmi Yunita, Danang Biyatmoko. "Mudskipper Fish as a Bio-indicator for Heavy Metals Pollution in a Coastal Wetland", Egyptian Journal of Aquatic Biology and Fisheries, 2020
Publication
<1%

---

46 Naghmeh Soltani, Michel Marengo, Behnam Keshavarzi, Farid Moore, Peter S. Hooda, Mohammad Reza Mahmoudi, Sylvie Gobert. "Occurrence of trace elements (TEs) in seafood from the North Persian Gulf:
<1%

Implications for human health", Journal of Food Composition and Analysis, 2020
Publication

47 Nur Aliaa SHAFIE, Ahmad Zaharin ARIS, Hazzeman HARIS. "Geoaccumulation and distribution of heavy metals in the urban river sediment", International Journal of Sediment Research, 2014 <1%
Publication

48 Simms, Tatum. "Electrochemically Precipitated Struvite Effects on Soil Property and Crop Response", University of Arkansas, 2023 <1%
Publication

49 Tasawar Ali Chandio, Mohammad Nasiruddin Khan, Maria Taj Muhammad, Ozcan Yalcinkaya, Eylem Turan, Ahmet Furkan Kayis. "Health risk assessment of chromium contamination in the nearby population of mining plants, situated at Balochistan, Pakistan", Environmental Science and Pollution Research, 2021 <1%
Publication

50 Wanda Batista de Jesus, Ticianne de Sousa de Oliveira Mota Andrade, Sâmea Heloá Soares, Débora Batista Pinheiro-Sousa et al. "Biomarkers and occurrences of heavy metals in sediment and the bioaccumulation of metals in crabs (Ucides cordatus) in impacted <1%

mangroves on the Amazon coast, Brazil", Chemosphere, 2021
Publication

51	hdl.handle.net Internet Source	<1 %
52	iris.unime.it Internet Source	<1 %
53	mdpi-res.com Internet Source	<1 %
54	portal.uems.br Internet Source	<1 %
55	www.atsdr.cdc.gov Internet Source	<1 %
56	Abhijit Debnath, Prabhat Kumar Singh, Yogesh Chandra Sharma. "Metallic contamination of global river sediments and latest developments for their remediation", Journal of Environmental Management, 2021 Publication	<1 %
57	N. Rubalingeswari, D. Thulasimala, L. Giridharan, V. Gopal, N.S. Magesh, M. Jayaprakash. "Bioaccumulation of heavy metals in water, sediment, and tissues of major fisheries from Adyar estuary, southeast coast of India: An ecotoxicological impact of a	<1 %

metropolitan city", Marine Pollution Bulletin, 2021
Publication

58 Eliane Braga Ribeiro, Katherine Saldanha Noleto, Suelen Rosana Sampaio de Oliveira, Wanda Batista de Jesus et al. "Biomarkers (glutathione S-transferase and catalase) and microorganisms in soft tissues of Crassostrea rhizophorae to assess contamination of seafood in Brazil", Marine Pollution Bulletin, 2020 <1%
Publication

59 Fatma Mohamed, Nahed Gad. "DISTRIBUTION OF SOME HEAVY METALS IN TISSUES OF OREOCHROM1S SILOTICUS* TILAP1A ZJLL11 AND CLARIAS LAZERA FROM ABU ZA'BAAL LAKES AND THEIR IMPACTS ON SOME BIOCHEMICAL PARAMETERS AND ON THE HISTOLOGICAL STRUCTURES OF SOME ORGANS", Egyptian Journal of Aquatic Biology and Fisheries, 2005 <1%
Publication

60 Milton Tenenbein, Xi Huang. "Iron", Elsevier BV, 2022 <1%
Publication

61 P PONKA. "Iron", Handbook on the Toxicology of Metals, 2007 <1%
Publication

62	P. Karthikeyan, S.R. Marigoudar, D. Mohan, A. Nagarjuna, K.V. Sharma. "Ecological risk from heavy metals in Ennore estuary, South East coast of India", Environmental Chemistry and Ecotoxicology, 2020 Publication	<1%
63	Sara Elisa Gallego Ríos, Claudia María Ramírez Botero, Beatriz Estella López Marín, Claudia M. Velásquez Rodríguez. "Evaluation of mercury, lead, and cadmium in the waste material of crevalle jack fish from the Gulf of Urabá, Colombian Caribbean, as a possible raw material in the production of sub-products", Environmental Monitoring and Assessment, 2018 Publication	<1%

Exclude quotes Off
Exclude bibliography On
Exclude matches Off

Iron bioaccumulation and ecological implications in the coastal swamp wetlands ecosystem of South Kalimantan: Insights from giant mudskipper fish as bioindicators

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10

PAGE 11

PAGE 12