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Bioaccumulation of Iron (Fe) in the Sea Catfish (*Arius sagor*) from the Coastal Swamp of Kuala Tambangan, South Kalimantan, Indonesia

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ABSTRACT

Iron is a vital element for numerous physiological processes in various organisms, but when present in excessive amounts, it can lead to hazardous effects. The present study aimed to examine the levels of iron (Fe) in the coastal swamp ecosystem of Kuala Tambangan in South Kalimantan. The sea catfish (*Arius sagor*) was employed as an indicator species to assess the extent of heavy metal pollution in the area. Insights into the effects of Fe levels on both environmental and human health was obtained by the analysis of Fe levels in water bodies and fish tissues. The Fe levels in the coastal swamp environment of Kuala Tambangan were assessed using atomic absorption spectroscopy. The results revealed a significant and positive correlation between the levels of Fe in both water and fish tissues. Both natural and anthropogenic causes contribute to the accumulation of Fe, with anthropogenic pollution being the primary factor. The research findings indicated elevated levels of Fe throughout the coastal swamp ecosystem of Kuala Tambangan, prompting worries over potential ramifications for both ecological and human health. The results of this study would provide valuable insights that can enhance our comprehension of more effective approaches to managing coastal swamp wetland ecosystems. Continuous biomonitoring, identification of pollutant sources, public awareness, regulatory enforcement, and remediation are essential to address heavy metal pollution and its ecological impacts.

INTRODUCTION

Estuary and coastal swamp ecosystems experience a significant anthropogenic stress and are exposed to a diverse range of pollutants, including heavy metals. High quantities of heavy metals can persist in estuary sediments for extended periods; however, they can eventually seep into the overlying waters, posing a hazardous threat to the local fish population **(Gabriel *et al.*, 2020; Hashempour-baltork *et al.* 2023)**. This observation aligns with the environmental characteristics found within the coastal swamp habitat of Kuala Tambangan in the Tanah Laut district, located in the South Kalimantan region of Indonesia. The Kuala Tambangan coastal swamp is situated along the shoreline of the Java Sea, an area characterized by a significant anthropogenic activity. This activity encompasses various human interventions, such as the mooring of fishing vessels, residential settlements, transit of fishing boats, and coal transportation. Anthropogenic activities have a significant impact on the environment, leading to the production of pollutants that can adversely affect the water quality of estuaries. Consequently, it is imperative to implement a biomonitoring program to mitigate the detrimental effects of heavy metal contamination effectively. The assessment of heavy metal pollution in commercially consumed fish holds significance not only for the evaluation of coastal ecosystem health but also for the biosurveillance of food safety within the coastal communities. The bioaccumulation of heavy metals through fish intake not only offers qualitative and quantitative insights into the ecological health of water bodies but also poses risks to public health **(Ahmed *et al*., 2019; Amadi *et al*., 2020; Yang *et al.*, 2021; Zaynab *et al*., 2022; Barani *et al*., 2023)**.

The sea catfish (*Arius sagor*), also known as the otek fish in the local vernacular, has gained an economic importance as a sought-after species for eating among the population of South Kalimantan. This fish is commonly found in river estuaries and coastal waters in the tropical and subtropical areas. Sea catfish primarily inhabit two distinct habitats, specifically freshwater environments, followed by a migration to estuary waters for reproduction, ultimately extending their journey to the open ocean. *Arius sagor* has the potential to attain a significant size and serve as a valuable resource for commercial fishing purposes due to its suitability for food. This particular kind of fish can be classified within the category of large demersal fish. The captured specimens of this certain fish species are typically observed within the range of 250- 700mm in length, with the potential to attain a maximum size of 1,500mm. Sea catfish exhibit carnivorous and predatory feeding behaviors, mostly consuming mollusks, gastropods, and crustaceans. The sea catfish exhibits a wide distribution in the coastal seas of Indonesia, with a particular affinity for regions characterized by the presence of estuaries. This species inhabits the benthic areas in the estuarine waters, namely inside the transitional zone between the river and the sea, at depths ranging from 20 to 100 meters. The sea catfish exhibits notable features, including the presence of an adipose fin situated on its dorsal fin. Additionally, its head is distinguished by rigid plates that bear a resemblance to the form of a butterfly (sagor) **(Burhanuddin *et al*., 1987)**. Due to the presence of heavy metal contaminants in the coastal swamp waters where it resides, it is imperative to conduct monitoring and assessment of heavy metal bioaccumulation in specific body tissues that are commonly consumed by humans, including meat/muscle, liver, and skin. Currently, there is a lack of available knowledge or empirical evidence regarding the phenomenon of heavy metal bioaccumulation in the sea catfish species inhabiting the coastal regions of South Kalimantan.

Current research focused on examining the bioaccumulation of iron (Fe) in *Arius Sagor* since the South Kalimantan region operates a lot of coal mining industry along with transportation and loading and unloading through estuaries or coastal swamps before heading to the Java Sea. According to **Kasmiarti *et al*. (2021)**, waste from the coal mining process and coal avalanches during loading and unloading/transportation enter water bodies, which, if they last long and accumulate, have the potential to cause pollution in the estuary. The waste generated from these processes is composed of several heavy metals, including Mn, Fe, Hg, Cd, Cr, Pb, and Cu. There is a suspicion that inadequate treatment and discharge of this material into water bodies may present an adverse risk to both aquatic ecosystems and human health. Consequently, it is imperative to implement biomonitoring initiatives in order to identify and assess any detrimental effects resulting from pollution promptly. Moreover, Fe is a plentiful transition metal present in the Earth's crust **(Jaishankar *et al.*, 2014)**. Iron (Fe) is present in aquatic environments, either in a dissolved or suspended state inside the water column or it can be found at the sediment-water interface. Investigations conducted on water bodies and the body tissues of fish play a crucial role in assessing the condition and extent of pollution. Hence, the assessment of the concentration of Fe in water bodies and fish tissues holds a significant importance in the evaluation of the ecological well-being of aquatic ecosystems. The study aimed to achieve two objectives: [1] To assess the quality of coastal swamp waters using the pollution index method; [2] To examine the concentration of Fe in the liver, skin, and muscles of the sea catfish (*Arius sagor*), which is frequently consumed by the local population. The assessment of Fe monitoring outcomes holds a significant importance in the evaluation of the likelihood of Fe bioaccumulation in fish intake, therefore serving as a crucial component in the management of coastal swamp ecosystems. The findings of our study can serve as a conceptual framework for stakeholders to assess the impacts of human activities on the environment in subsequent periods.

MATERIALS AND METHODS

1. Study area

The study site is situated within the Kuala Tambangan's coastal swamp, which is located in South Kalimantan, Indonesia (Fig. 1). The estuary of Kuala Tambangan, located in the Takisung District of Tanah Laut, South Kalimantan, Indonesia, is a location characterized by its proximity to the Java Sea. Kuala Tambangan encompasses an administrative territory spanning 5.92km^2, with a shoreline extending for a length of 6.95km **(Central Agency on Statistics, 2021)**. Kuala Tambangan is situated within the geographical coordinates of 114°30'20" E to 155°23'3" E and 3°30'33" S to 4°11'38" S. The estuarine region of Kuala Tambangan serves as a reservoir for the Kuala Tambangan watershed, with an area of 1,315.9km^2 and a width of 50 meters **(Hidayat, 2018)**. The sampling sites are situated at coordinates 3°56'56.14836" S, 114°38'9.39912" E (referred to as Location 1, representing a river estuary) and 3°58'6.81996" S, 114°37'46.49664" E (referred to as Location 2, representing a coastal area) (Fig. 1). Additionally, Fig. (2) depicts the anthropogenic activity linked to the Kuala Tambangan coastal swamp.

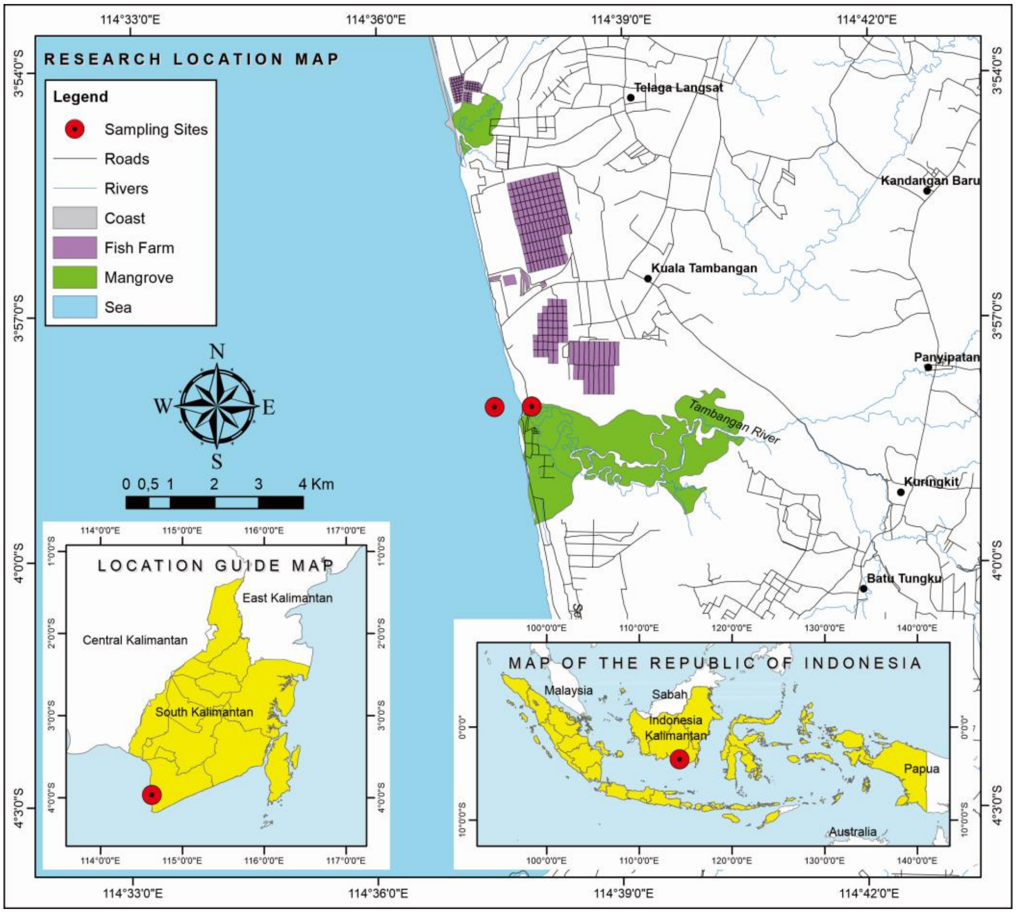

Fig. 1. Research location map within the coastal swamp of Kuala Tambangan

2. Sample collection

The technique utilized for the sampling of fish and water is known as "purposive sampling", wherein samples are chosen based on predetermined study criteria. The sampling approach employed for river water adheres to the prescribed standards specified in the Indonesian National Standard (SNI) 6964.8:2015. In July 2023, a maximum of 15 sea catfish (*A.sagor*) were captured per station by proficient fishermen. The average weight of the fish caught was 378.0± 1.29 g, with an average length of 48.8± 5.68cm (Fig. 3a). The cranial region of this particular fish species exhibits a distinctive rigid plate that displays a bilateral pattern like a pair of butterflies, known as sagor, positioned on both the left and right sides of the skull (Fig. 3b). The specimens were promptly placed in an ice box containing dry ice cubes to prevent any degradation of their properties. Next, the specimens were delivered to the laboratory for investigation and carefully preserved at a frozen condition of -20°C. Following the initial washing of the selected samples with distilled water, the samples were allowed to thaw at room temperature. In conjunction with the fish collection, water samples of 2L were obtained at each site to assess physical and chemical water characteristics. Additionally, 2mL of concentrated solution of nitric acid (HNO_3) was added to each sample (1L) directly in the field subsequent to the filtration process in order to facilitate further examination. The water samples were transferred to the laboratory at a temperature of 4ºC using clean plastic bottles.

Subsequently, the samples were examined in accordance with the standard methods as outlined by the SNI.

A. Fishing boat traffic **B.** Densely populated settlements

C. Garbage pile **D.** Shipping dock

Fig. 2. Utilization of Kuala Tambangan estuary: **(A)** Fishing boat traffic, **(B)** Densely populated settlements, **(C)** Domestic waste, and **(D)** Shipping dock

3. Physical and chemical examination

Water quality assessments were conducted to evaluate the levels of water pollution based on various metrics. These parameters encompass both physical factors, such as temperature and total suspended solid, as well as chemical factors, including dissolved oxygen, pH, salinity, biological oxygen demand, and chemical oxygen demand. The measurement of water quality parameters adheres to the requirements specified by SNI and digital instruments, as depicted in Table (1).

Fig. 3a. Sea catfish (*Arius sagor*) morphology

Fig. 3b. The head of the sea catfish (*Arius sagor*) showcases a distinctive hard plate that exhibits a bilateral pattern like a pair of butterflies (sagor) situated on both the left and right sides of the head

Table 1. Water quality parameter analysis

No.	Parameter	Unit	Method specification
		Field	
1.	Temperature	°C	Thermometer
2.	pH	-	pH indicator
		Laboratory	
3.	BOD	mg/L	SNI 6989.72:2009
4.	TSS	mg/L	SNI 06-6989.3:2004
5.	COD	mg/L	SNI 6989.73:2009
6.	DO	mg/L	digital DO meter

4. Water quality analysis

The water quality readings were compared to the Water Quality Standards specified in Government Regulation Number 22 of 2021, which applies to the Implementation of Environmental Protection and Management in relation to water quality. Furthermore, the examination was carried out employing the pollution index (PI) technique as outlined in the State Ministry of Environment No. 115 of 2003, which was published by the State Minister of Environment of the Republic of Indonesia. Determination of pollution index (PI) was performed using the equation:

$$IP_j = \sqrt{\frac{(\frac{Ci}{Lij})_M^2 + (\frac{Ci}{Lij})_R^2}{2}}$$

IP_j	: Pollution index for designation j
C_i	: Concentration of parameter test results
L_{ij}	: Concentration of the parameter according to the quality standard of the water designation j
$(C_i/L_{ij})_M$	: Maximum Ci/Lij value
$(C_i/L_{ij})_R$	: Mean Ci/Lij value

The parameters used for the calculation of pollution index values and the methods used are shown in Table (1). While, the quality standards for water designation for class II are shown in Table (2). Class II water quality criteria are water whose designation can be used for water recreation infrastructure/facilities, fish farming, animal husbandry, water for irrigating crops, and/or other designations that require the same water quality as these uses.

The classification of water quality is determined based on the pollution index (PI) value. Water is considered to be in good condition if the PI value falls between the range of $0 \leq Pij \leq 1.0$. If the PI value is between $1.0 < Pij \leq 5.0$, the water is classified as slightly polluted. A PI value between $5.0 < Pij \leq 10$ indicates that the water is fairly polluted. Lastly, water is categorized as heavily polluted if the PI value exceeds 10 ($Pij > 10$).

5. Analysis of Fe concentration

The concentration level of iron (Fe) in water and fish tissue samples was determined using atomic absorption spectroscopy (AAS Thermo Scientific ICE 3500 series Germany). The samples for metal determination were prepared according to method described by **Jayaprakash *et al*. (2015)**.

5.1. Water

Surface water samples were obtained from two stations distributed across the study region utilizing the aqua trap water sampler. In the field, following filtration, a volume of 2mL of concentrated nitric acid (HNO_3) was introduced to each sample with a volume of 1L in order to facilitate further analysis. The present work employed the liquid- liquid extraction **(Jayaprakash *et al.,* 2015)** to determine the concentration levels of dissolved trace elements, specifically iron (Fe). A 100mL of unfiltered sample was collected in a separating funnel, which was afterward combined with 2mL of a 2% solution of ammonium pyrrolidine dithiocarbamate (APDC). Consequently, the specimens were extracted using a 10mL volume of iso-butyl methyl ketone (IBMK) following vigorous agitation. The aqueous phase that was obtained was subjected to back extraction using concentrated HNO_3 and high-purity water. The organic solvents present in the solutes were evaporated using a low-temperature hot plate, and the resulting solution was subsequently analyzed using AAS. The concentrations of iron (Fe) in water were quantified and expressed in milligrams per liter (mg/ L).

5.2. Fish

The various tissues, including the edible muscles, liver, and skin, of the fish were dissected using a stainless steel scalpel. In the context of surgical procedures, fish were administered with ice cubes externally as a means to alleviate pain, in accordance with animal welfare. Approximately 5mL of HNO_3 and sulfuric acid (H_2SO_4) were introduced into individual digestive tubes containing dissected organs. The mixture was then allowed to undergo a chemical reaction. Afterward, the samples were subjected to digestion using a hot block digestion device, maintaining a temperature of 60°C for 30 minutes. Following the cooling of the sample, a volume of 10ml of HNO_3 was introduced, and subsequent heating was conducted within the temperature range of 120- 150°C until the solution exhibited a darkened hue. A volume of 1mL of hydrogen peroxide (H_2O_2) was subsequently introduced in order to achieve a transparent solution suitable for the filtration procedure. The samples that underwent filtration were subjected to analysis using AAS in order to determine the amounts of Fe. The concentrations of Fe were quantified and represented in milligrams per kilogram (mg/ kg).

6. Bioaccumulation factor (BF)

Bioaccumulation factor (BF) was calculated to measure the degree of metal accumulation in the organism tissues as follows: Bio-water accumulation factor (BWAF) = metals' concentration in fish tissues (mg/ kg dry weight)/ metals' concentration in water (mg/ L) **(Abdel Gawad, 2018)**.

7. Statistical analysis

The mean ± SD was used to express the presence of iron (Fe) in water bodies and tissues of sea catfish. An independent t-test was used to determine the statistical significance between different sites. A significance level of $P< 0.05$ was deemed to indicate a statistically significant difference. The study employed the Pearson correlation test to ascertain the association between heavy metal concentrations in aquatic environments and heavy metal concentrations in the tissues of *Arius sagor*. The statistical analysis was conducted using the IBM SPSS version 21. The graph was created using Microsoft Office Excel 2010 (Microsoft Corporation, Redmond, WA).

RESULTS

1. Physical and chemical analysis

Table (2) displays the physical and chemical attributes of water throughout the surveyed region of the Kuala Tambangan coastal swamp. The sampling was conducted in July 2023 at two sites, namely site 1 (estuary) and site 2 (coastal). According to Table (2), it is evident that the measured values of BOD_5, COD, DO, and TSS surpass the quality criteria established by the Government Regulation of the Republic of Indonesia Number 22 of 2021, which pertains to the Execution of Environmental Protection and Management. These standards specifically pertain to the quality of seawater with regard to sustaining marine life.

Table 2. Water quality measurement results

Parameter	Unit	Average[1)]		Class II seawater quality standard according to Gov. Regulation No 22 of 2021[2)]
		S1	S2	
pH	-	8±0.03	8±0.07	7−8.5
Temperature	℃	29±0.2	30±0.4	28 – 30
BOD_5	mg/L	20±0.03	21±0.05	20
COD	mg/L	46±0.06	45±0.002	40
DO	mg/L	4.5±0.01	4.7±0.05	>5
TSS	mg/L	110±0.5	100±0.8	100
Salinity	‰	8±0.06	28±0.02	30 – 33

Description: [1)] S1 (estuary) & S2 (coastal).
[2)] Government regulation No. 22 of 2021 concerning the implementation of environmental protection and management of seawater quality standards for marine biota.

2. Pollution index analysis

Table (3) presents the outcomes of the water quality study based on the pollution index in the surveyed regions of Kuala Tambangan coastal swamp in July 2023. The objective of this study was to assess the pollution index of the coastal swamp waters in Kuala Tambangan in accordance with the guidelines outlined in the Decree of the Minister of Environment No. 115 of 2003. This decree provides a framework for determining the status of water quality. Based on the obtained findings, it is evident that the coastal swamp waters situated in Kuala Tambangan within the Tanah Laut district exhibit a fairly polluted. This is supported by the pollution index values of 7.04 and 7.02 recorded for the estuary stations and coastal stations, respectively.

Table 3. Water quality analysis by pollution index

Site[1)]	Pollution index value	Range[2)]	Category
S1	7.04	5.0 < Pij ≤ 10.0	fairly polluted
S2	7.02	5.0 < Pij ≤ 10.0	fairly polluted

Note: [1)] S1 = estuary; S2 = coastal.
[2)] State Ministry of Environment No. 115 of 2003.

3. Fe concentration in water bodies and the tissues of *Arius sagor*

The data shown in Table (4) indicate that the average concentration of Fe in the coastal swamp waters of Kuala Tambangan falls within the range of 0.372 to 0.475mg/ L. Furthermore, there is a significant difference (P< 0.05) in Fe concentration between the estuary and coastal stations. The concentration of iron (Fe) in water bodies surpasses the established national quality criteria, as outlined in the Government Regulation of the Republic of Indonesia No. 22 of 2021, which specifies a maximum permissible limit of 0.300mg/ L. In contrast, the levels of Fe in the tissue of *A. sagor* follow a progressive pattern, with the liver exhibiting the highest average of Fe concentration, followed by the skin and then the muscle. There is a significant disparity in the Fe concentration found in the liver and skin tissue of fish inhabiting estuary and coastal environments. Additionally, a notable difference in the Fe concentration is observed in the muscles of these fish, as indicated in Table (4). The concentration of Fe in the sea catfish tissues surpasses the national quality standard value, as defined by SNI 7387:2009, by 1mg/ kg. The standard SNI 7387:2009 establishes guidelines for the permissible threshold of heavy metal presence in fish-derived food products.

Table 4. Mean ± SD levels of Fe in water bodies and body tissues of sea catfish (*Arius sagor*)

Fe	Estuary	Coastal	*P-value*[1]	Description[2]
Water bodies (mg/L)	0.475 ±0.0015	0.372 ±0.0005	0.000	statistically significant
Skin (mg/kg)	25.49±0.106	23.49±0.118	0.000	statistically significant
Muscle (mg/kg)	25.24±0.046	25.19±0.053	0.284	statistically non-significant
Liver (mg/kg)	29.73±0.622	26.43±0.0058	0.001	statistically significant

[1] $P< 0.05$ was considered as a statistically significant difference.
[2] Results of statistical analysis with independent t-test.

The bio-water accumulation factor (BWAF) is a metric that describes the accumulation of certain heavy metals from water bodies, into ecological receptor networks **(Jayaprakash *et al*., 2015)**. Table (5) displays the calculated BWAF. Table (5) shows that the bioaccumulation factor value is greater in the liver tissue of *Arius sagor* fish from coastal locations (71.05). The value of the bioaccumulation factor indicates the relationship between the heavy metal concentrations in the water and the heavy metal concentrations in the fish organs.

Table 5. Bio-water accumulation factor (BWAF) of Fe concentration values in skin, muscles and skin of *Arius sagor*

Tissue	Location	Bio-water accumulation factor (BWAF)
Skin	Estuary	53.66
	Coastal	63.15
Muscles	Estuary	53.66
	Coastal	67.72
Liver	Estuary	62.59
	Coastal	71.05

4. The relationship between metal concentration in water bodies and the tissues of sea catfish (*Arius sagor*)

Table (6) illustrates the association between Fe concentrations found in aquatic environments and the corresponding Fe concentrations inside the bodily tissues of sea catfish. A significant and positive correlation was observed between the concentrations of Fe in water bodies and the concentrations of Fe in both the liver and skin tissues. There is a positive correlation between the concentration of Fe in a body of water and the concentration of Fe in liver tissue (0.977) and skin (0.996). In general, this study found a positive correlation between variables, indicating that the availability of Fe in water bodies influenced the levels of Fe in the fish body tissues examined. However, it is worth noting that, there was a statistically non-significant rise in Fe levels in the muscle tissues.

Table 6. Correlations between the metal concentrations in water and those in the liver, muscles, and skin of sea catfish (*A. sagor*)

	Water	Liver	Muscle	Skin
Water	1	0.977**	0.525	0.996**
Liver	0.977**	1	0.405	0.986**
Muscles	0.525	0.405	1	0.463
Skin	0.996**	0.986**	0.463	1

**Correlation is significant at the 0.01 level (2-tailed).

DISCUSSION

Water quality is negatively impacted on a global scale by pollution resulting from human activities, sometimes known as anthropogenic activities. The presence of heavy metal contamination is a significant factor in the disruption and potential harm inflicted upon the aquatic ecosystems. The presence of heavy metal pollution in estuaries poses a substantial danger to the conservation of biodiversity and the well-being of human populations **(Adani *et al*., 2022; Albuquerque *et al*., 2023)**. Consequently, the investigation of heavy metal deposition in fish through biomonitoring research is a matter of a great significance for scientists and practitioners dedicated to promoting environmental sustainability.

Based on the pollution index calculation, it can be determined that the coastal swamp waters of Kuala Tambangan exhibit a fairly polluted level. The assessment of water quality parameters that contribute to pollution includes the examination of biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), dissolved oxygen (DO), and total suspended solids (TSS) levels that surpass the established national standards for water quality. The reduction in water quality in coastal swamp waters is hypothesized to be attributed to the pollution of contaminants originating from anthropogenic activities. The elevated levels of COD, BOD, and TSS, as well as the diminished levels of DO, observed in estuarine waters, can be attributed to a multitude of variables, including [1] Industrial pollution; industries that release untreated or inadequately treated wastewater into estuarine environments can make substantial contributions to the levels of COD, BOD, and TSS. This is in line with **Kasmiarti *et al.* (2021)**, which stated that the coal mining sector operating in South Sumatra has been responsible for the release of waste materials containing Mn, Fe, Hg, Cd, Cr, Pb, and Cu. Consequently, this has resulted in the contamination of water sources in the region. [2] Waste disposal; the improper disposal of untreated or inadequately treated waste has the potential to introduce significant quantities of organic matter and suspended particles into estuarine environments. This phenomenon may lead to an elevation in the concentrations of chemical COD, BOD, and TSS; [3] Organic waste; elevated concentrations of organic matter, including industrial and domestic waste, have the potential to result in augmented levels of COD, BOD, and TSS in coastal aquatic environments. During the process of decomposition, organic matter consumes oxygen, resulting in a decrease in the DO value. The DO value is an indicator of the quantity of oxygen necessary for the decomposition of organic compounds. Moreover, the presence of organic matter might potentially lead to elevated TSS levels, as suspended particles may be present in the water; [4] Agricultural runoff; the overutilization of fertilizers and pesticides in agricultural activities has the potential to result in the discharge of nutrients and sediment into estuarine environments. This phenomenon has the potential to result in an elevation of organic matter and suspended solids concentrations, consequently impacting the values of DO, COD, BOD, and TSS; [5] Urban runoff; estuarine waters may experience elevated levels of COD, BOD, and TSS as a result of insufficient waste management in urban regions. The disposal of domestic garbage has the potential to introduce several contaminants, including oil, heavy metals, and sludge, into aquatic ecosystems, exerting a detrimental influence on the overall water quality **(Obed *et al.*, 2013)**.

The results of the examination indicated that the concentrations of iron (Fe) in the liver, skin, and muscle tissues of sea catfish (*A.sagor*) were found to be greater compared to the concentrations of Fe seen in the surrounding water bodies. The elevated presence of Fe in fish tissues can be attributed to the heightened concentration of iron in aquatic environments. The findings of this study align with the research conducted by **Abdel Gawad (2018)**, which posited that elevated levels of heavy metals in sediment and water create favorable conditions for some aquatic creatures to bioaccumulate metals and subsequently transfer them through the food chain. Sea catfish possess the capacity to amass heavy metals within their tissues due to their position as apex predators in the food chain.

The bioaccumulation of heavy metals in fish tissue has a negative impact on the ecosystem, being one of the pollution entry points. Bioaccumulation in fish tissues is generally influenced by heavy metal concentrations in water and sediment, diet, fish species, excretion and metabolism. According to **Mustafa (2020)**, the elevated BWAF concentration of all metals in the studied organs indicated that these metals underwent bioaccumulation and biomagnification. These results are in accordance with the findings of **Jayaprakash *et al.* (2015)**, which stated that the heavy metals Ni, Pb, Mn, Co, Cd, Fe and Cu had the highest BWAF concentrations in liver tissue. The presence of elevated concentrations of Fe in coastal swamp ecosystems can lead to detrimental consequences for both fish and human populations, manifesting in toxicological impacts that may contribute to the development of carcinogenic ailments. This phenomenon occurs due to the consumption of fish by humans that are contaminated with heavy metals **(Prasad *et al.*, 2023)**.

The prevalence of elevated levels of Fe can be linked to iron being the most commonly utilized metal **(Bat & Arici, 2018)**, therefore making it readily available in the environment; Fe is a prevalent constituent found in industrial and mining waste, frequently released into aquatic ecosystems, hence exhibiting a strong association with aquatic organisms, particularly fish. The accumulation of iron in fish organs is facilitated by greater concentrations of Fe in both water and substrate. The toxicity of iron to fish is greater when it is present in the form of Fe^{2+} as compared to Fe^{3+}. The toxicity of Fe^{2+} to fish arises from its ability to bind to the surfaces of gills and undergo oxidation to form insoluble Fe^{3+}. This process leads to the deposition of Fe^{3+} on the gill surfaces, causing cellular damage and ultimately resulting in respiratory failure **(Singh *et al.*, 2019)**. The present study observed the highest concentration of iron (Fe) in the liver of *Arius sagor*. This finding aligns with the research conducted by **Omar *et al.* (2014)**, which shows that the liver of fish is susceptible to Fe poisoning. It is postulated that the presence of elevated levels of Fe in the liver may give rise to various pathological alterations in the examined fish species. The findings of this study provide a potential foundation for future investigations in the field of histopathology pertaining to the effects of elevated Fe exposure.

The introduction of iron into estuary waters can be attributed to natural phenomena, including weathering and the decomposition of rocks, ore materials, and volcanic eruptions. These processes result in the release of iron into water bodies through mechanisms, including runoff, erosion, and flooding. Furthermore, it is derived through human-induced activities, like the transportation and mining of coal **(Dalu *et al*., 2020)**. The origin of Fe also includes anthropogenic activities taking place in terrestrial environments, including the discharge of domestic waste containing Fe, the presence of Fe in water reservoirs, the deposition of industrial waste, and the corrosion of water pipes holding Fe. These activities result in the transportation of Fe through river flows to estuaries. The origin of Fe can also be attributed to the generation of sulfuric acid, which leads to the liberation of Fe^{2+}. This process happens as a result of the oxidation of iron pyrite (FeS_2) found in coal seams **(Jaishankar *et al*., 2014).**

Estuaries, or coastal swamps, are recognized as significant repositories for heavy metals, such as Fe, due to the rapid settling of Fe ions in these environments **(Crerar *et al*., 1981)**. Rivers transport significant quantities of dissolved iron (Fe) and particulate matter into the marine environment, with a substantial portion being captured and deposited in estuarine sediments **(Daneshvar, 2015)**. This accumulation occurs due to the sediment's exceptional capacity to serve as a final trap and adsorptive sink for heavy metals in aquatic ecosystems **(Shafie *et al*., 2015)**. Iron colloids undergo immobilization in the sediments of the estuary, followed by mobilization through their interaction with organic matter and reduction agents. The accumulation of iron (Fe) beyond a certain threshold value has negative consequences for aquatic ecosystems, as it results in harmful effects on fish. The persistence, non-biodegradability, accumulation, and toxicity of heavy metals, coupled with their large and diversified sources, contribute to this phenomenon **(Shafie *et al*., 2015).**

CONCLUSION

Kuala Tambangan coastal swamp water quality is classified as fairly polluted, with elevated levels of Fe that surpass the national quality guideline. The sea catfish (*A. sagor*), a species of economic significance, is abundantly distributed and frequently consumed by coastal people. Notably, the liver, skin, and muscles of this fish contain iron levels that surpass the national quality standards. The findings of the study revealed a significant and positive correlation between the concentrations of Fe in water bodies and the concentrations of Fe in the liver and skin tissues of fish.

This study aimed to address the lack of available data regarding the bioaccumulation of iron (Fe) in commercially consumed fish, which is of significant importance in assessing the potential impact of heavy metal contaminants on fish populations. The findings of this study have potential implications for both ecosystem health and human well-being. Hence, future studies must adopt a comprehensive approach that encompasses scientific inquiry, policy development, public consciousness, and collaborative endeavors among relevant parties. This multifaceted approach is crucial in safeguarding the welfare of aquatic ecosystems and human communities.

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