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Evaluation of heavy metals contamination in Rabbit Fish (*Signus Sutor*) from selected landing sites in Zanzibar, Tanzania

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ABSTRACT

The increase of heavy metals concentrations in aquatic and terrestrial environments and their toxicity is of global concern. The bioaccumulation of toxic metals in fish poses a serious risk to human health when consumed. This study assessed the quality of Rabbit fish (*Signus Sutor*) and their associated health risks from four landing sites (namely Malindi, Mazizini, Kizimkazi and Matemwe) in Zanzibar. The concentrations of toxic metals, including Lead (Pb), Cadmium (Cd), Copper (Cu), Chromium (Cr), Nickel (Ni), and Arsenic (As), in the fish muscle were scrutinized using inductively coupled plasma optical emission spectrometry (ICP-OES). The detected mean concentration (mg/kg) of Pb, As, Cr, Cd, Cu, and Ni at Malindi were 0.25±0.14, 2.22±0.44, 0.02±0.02, 0.01±0.00, 0.02±0.02 and 0.00±0.00 respectively; at Kizimkazi were 0.39±0.39, 2.30±0.44, 0.11±0.01, 0.07±0.04, 0.17±0.13 and 0.15±0.04 respectively: at Matemwe were 0.38±0.12, 0.52±0.14, 0.04±0.02, 0.05±0.01, 0.65±0.21 and 0.09±0.03 respectively; and Mazizini were 0.21±0.12, 5.56±1.37, 0.02±0.02, 0.03±0.01, 0.05±0.02 and 0.15±0.05 respectively. The mean concentration levels detected for all the elements in the fish gathered from all four landing sites were below international and local maximum (FAO/WHO) permissible limits for human consumption, except for Arsenic (As) and lead (Pb). The study also investigated the relationship between fish size and metal concentration which shows a positive correlation for Cu and Ni. However, it was negative for the remaining metals, possibly due to ecological and metabolic differences. The study emphasizes the necessity for regular monitoring of the marine environment and enforcement of hygienic regulations, as well as the treatment of land-based pollutants before they are discharged into the marine environment to protect fish quality.

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1. Introduction

Fisheries involve the harvesting of fish or any aquatic bio-products from the wild (capture fisheries) or raising them in confinement (culture fisheries), small-scale fisheries (SSF) for sustenance, or large-scale fisheries for economic gain (3). While freshwater fisheries in Tanzania contribute to about 2.7% of the GDP (4), marine water fisheries are mostly artisanal but important activities to the majority of the coastal

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communities in Tanzania. Marine fish and other seafood are the main sources of protein for the coastal human population (1).These marine bio-products are fundamental in the human diet and economy to a large proportion of people living along the coastlines, coastal cities, towns, and villages (2). Fish is low in cholesterol, calories, sodium, and saturated fats and have a high quality of protein, and essential minerals such as calcium, potassium, iodine, iron, zinc, and selenium and are rich in essential omega-3 fatty acids (2). The American Heart Association recommends the consumption of fish at least twice a week to reach the daily intake of omega-3 fatty acids (5). Globally, fish consumption has progressively increased (6), however, this increase is accompanied by a growing concern about the discharge of chemical waste directly into rivers and seas (7).Heavy metals, metallic elements that occur naturally with high relative density and atomic weight greater than 4 g/cm^3, or 5 times or greater than water (6), are considered toxic or poisonous even at low concentrations (5). Essential metals such as Copper, Chromium, Zinc, Iron, Nickel, and Selenium are naturally occurring elements with biological functions in living organisms and are toxic at elevated levels. Whereas, non-essential metals such as Lead, Cadmium, and Mercury are considered toxic even at low concentrations (8). Heavy metals are common pollutants that occur naturally in aquatic environments in deficient concentrations, however, due to the increase of anthropogenic activities over time their concentration levels have profoundly increased (5). Often, fish are ideal indicators of heavy metal contamination in aquatic systems, due to their constant exposure to polluted waters at different trophic levels, and represented as carriers of heavy metals to humans (1). Heavy metals are released into the marine environment through atmospheric deposition, geological weathering, shipping, harbor activities, poor waste management, agriculture, industrial, domestic, and other anthropogenic activities along the coastal area (9). The released metals deposit in marine organisms via bioaccumulation and bio-concentration through the food chain and they become toxic when the accumulation surpasses the desirable levels (9). In the last 50 years, the extent of contamination of heavy metals in marine environments has drastically increased due to technological developments but also increasing consumption of materials containing heavy metals (10,11). Accumulation of heavy metals in the fish depends on the fish growth rate, fish metabolism, feeding pattern, and ecological requirement of a given fish species (12). Other factors that can influence metal uptake in fish include sex, age, size, reproductive cycle, swimming pattern, feeding behavior, and geographical location (13). Heavy metals enter a fish by either direct absorption from water through their gills and or skin, or through ingestion of contaminated food or nonfood particles (14). The metal then enters the fish's bloodstream and accumulates in their tissues, mainly the liver. The metal is then bio-transformed and taken up into the food chain to consumers such as human beings. When the metal is up taken by a human being, it can cause either acute or chronic diseases or even fatal cases (2). Heavy metals are ecotoxic due to their long persistence in the environment (2). Thus, high concentration of heavy metals in the environment has the potential to cause devastating effects on the recipient environment and organisms, the ecosystem

(15). Arguably, marine organisms such as fish can hold toxic materials in small to high concentrations in their body without harming themselves, however, such toxicity can severely affect humans who feed on them (6).

The increasing trend of fish consumption, ever-increasing pollution of the marine environment and the bioaccumulation capacity of fish heavy metal have increased the necessity to assess the quality and safety of the commonly consumed fish. Rabbitfish (*Signus Sutor*) is among the commonly consumed fish in Zanzibar; however, its potential bioaccumulation of heavy metal has been overlooked. Thus, this study aimed to assess the concentration of heavy metal in rabbit fish (*Signus Sutor*) from selected landing sites in Zanzibar by using inductively coupled plasma optical emission spectrometry (ICP-OES) and to assess their possible health risks to fish consumers. This study intends to raise public knowledge of the possible health concerns linked with fish consumption to ensure public health safety.

2. Materials and Methods

2.1. Study area

Zanzibar is an archipelagic semi-autonomous country that is part of the United Republic of Tanzania. Zanzibar is composed of two major sister islands (Unguja and Pemba) and over 50 small islets. Zanzibar has a total population of about 1.9 million inhabitants, a majority (over 60%) live in Unguja. Zanzibar has a total of 235 formal landing sites of which 109 (49%) are in Unguja and 126 (57%) in Pemba (16).

This study was carried out in Unguja Island. Administratively, Unguja is structured into three Regions and seven Districts. The data was collected from four landing sites located in four Districts. The landing sites are – Matemwe from North A, Malindi Beach from Urban, Mazizini from West B, and Kizimkazi Mkunguni from South. The data was collected between February and March 2023. These selected landing sites are the very common and busiest landing sites in each district. Locations of the landing sites are shown in the map below (in Fig. 1).

Figure 1. Map of Unguja showing the sampling sites.

2.2. Research design

A cross-sectional study design was used. The study allows data to be collected at a single point without repetition.

2.3. Materials and reagents

The material used was inductively coupled plasma optical emission spectrometry (ICP-OES) Agilent model 5900, analytical balance (0.0001 g), microwave digester, Teflon rank, Teflon tubes 50 ml and 12 ml, measuring cylinder 100 ml, volumetric flask 1000 ml, wash bottle, vortex mixer, micropipette tits (100 -1000 µl) and high purity of (99%) of argon was used as plasma, auxiliary and nebulizer gas. All the reagents used, such as Concentrated Nitric acid 69% A.R, concentrated hydrogen peroxide 30 weight % solution A.R, deionized water were used for the dilution process and standard preparation and standard solution of 1000 ppm.

2.4. Sample collection and preparation

A total of 48 fish samples of the same fish species (Signus surtor) from 4 landing sites were collected to evaluate heavy metal contamination levels in the fish. 12 fish samples were collected from each landing site. The samples were placed in plastic bags immediately preserved in a cool icebox and transported to be kept in the freezer (-18°C). The fish samples were thawed at room temperature and then their physical parameters (weight and length) were measured before the dissection of their body muscle with stainless steel scalpels into small pieces and ground well thoroughly to achieve homogeneity.

2.5. Sample analysis

The samples (0.5 g of each) were placed in a microwave digestion tube followed by the addition of digestion acid. The mixture of 6 ml of concentrated nitric acid (Conc. HNO_3) and 1 ml of concentrated hydrogen peroxide (Conc. H_2O_2) both analytical reagent grades was used for digestion in the high-performance microwave digestion system (Milestone ETHOS UP) according to the US EPA method 3015. The sealed digestion tube was placed in a microwave digester and digested according to the digestion program. After digestion, the mixture was cooled to room temperature and then transferred onto 50 ml Teflon tubes followed by the addition of distilled water to the mark and mixed well using a vortex mixture. From 50 ml of mixture 5 ml was drawn and transferred onto a 10 ml Teflon tube, the mixture was diluted with 5 ml of distilled water to make 10 ml of analytical sample and vortexes by using a vortex mixer. The analytical sample was placed on an autosampler rack and analyzed by ICP-OES (Agilent model 5900), the blank sample was prepared and treated in the same manner as the other samples. 00Calibration standard solutions of concentrations 0.05 mg/kg, 0.1000 mg/kg, 0.3500 mg/kg, 0.5000 mg/kg, 0.7500 mg/kg, and 1.000 mg/kg of the multi-element ,standard were prepared for calibration of the machine and calibration curve for each element was established. Each element (arsenic, cadmium, chromium, copper, nickel and lead) was analyzed as per their specific wavelength. After completion of the analyses, the machine results were quantified.

Table 1. The LOD and LOQ (in g/kg) of trace elements in fish

	As	Cr	Cd	Cu	Ni	Pb
LOD	1.71	0.68	0.99	1.41	0.36	0.6
LOQ	5.69	2.27	3.30	4.71	1.20	2.02

LOD: Limit of Detection, LOQ: Limit of Quantification

2.6. Statistical analysis

Mean concentrations ± standard deviations (SD) in mg/kg for all the elements were determined using One-way analysis of variance (ANOVA). Statistical analysis of data was carried out using IBM Statistical Package for Social Sciences (SPSS) version 25 statistical package programs. ANOVA was used to assess whether the average of elemental concentrations varied significantly among sites. A p-value less than 0.05 ($p < 0.05$) was considered statistically significant. The relations between fish size and concentrations of trace elements in fish muscles were evaluated using the Pearson correlation matrix.

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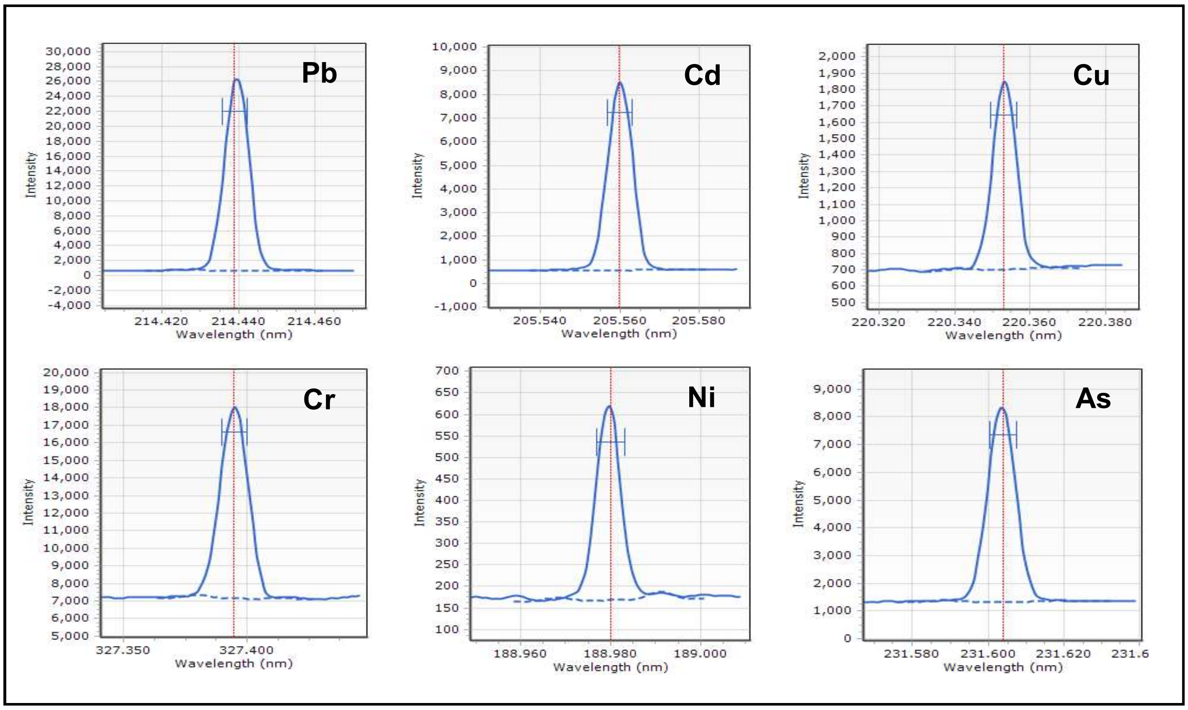

Figure 2. Standard curves for Lead (Pb), Cadmium (Cd), Copper (Cu), Chromium (Cr), Nickel (Ni), and Arsenic (As)

Results

The study analyzed data from four landing sites to understand heavy metal concentrations in fish muscle samples, focusing on lead, arsenic, chromium, cadmium, copper, and nickel in (mg/kg) in Table 1.

The mean concentrations of Lead (Pb), Cadmium (Cd), and Nickel (Ni) at landing sites showed no statistically significant differences ($p > 0.05$). However, significant variations were observed for Arsenic (As), Copper (Cu), and Chromium (Cr) ($p < 0.05$), with p-values of 0.01, 0.023, and 0.027, respectively. Post hoc Tukey tests revealed that the Arsenic concentration was significantly different between Matemwe and Mazizini ($p = 0.007$). Although a trend of probability toward significance was observed for Arsenic between Mazizini and Malindi ($p = 0.057$) and between Mazizini and Kizimkazi ($p = 0.063$), these differences did not reach statistical significance. On the contrary, copper showed significant differences between Malindi and Matemwe ($p = 0.029$), and Matemwe and Mazizini ($p = 0.035$). Furthermore, chromium showed a significant difference between Malindi and Kizimkazi, and Kizimkazi and Mazizini ($p = 0.032$, $p = 0.045$, respectively). In conclusion, the results indicated significant variations in the mean concentrations of these six heavy metals across the different landing sites.

3.1. The mean concentrations of heavy metals

The mean concentrations of these heavy metals show distinct patterns across the sites within the fish muscle.

In particular, lead (Pb) concentrations vary between 0.39±0.39 and 0.21±0.12, with Kizimkazi exhibiting the highest mean concentrations and Mazizini the lowest, respectively. Similarly, arsenic (As) concentrations revealed significant differences, with Mazizini showing the highest mean concentration of 5.56±1.37, contrasting the Matemwe concentration of 0.52±0.14. Chromium (Cr) differ, with Kizimkazi standing out at 0.11±0.01, while Mazizini and Malindi share lower mean concentrations of 0.02±0.02. Cadmium (Cd) concentrations vary between 0.07±0.04 and 0.01±0.00, with Kizimkazi exhibiting the highest and Malindi the lowest mean concentration, respectively. Copper (Cu) concentrations are most noticeable in Matemwe, where the mean was 0.65±0.21, as opposed to Malindi lowest was 0.02±0.02. Nickel (Ni) remains consistently low across sites, with Kizimkazi revealing the highest mean of 0.15±0.04, followed by Mazizini at 0.15±0.04 and Malindi at 0.00±0.00. In summary, Kizimkazi and Mazizini exhibited generally elevated heavy metal concentrations compared to Malindi and Matemwe. Mazizini showcases elevated levels of arsenic (As), while Matemwe boasts a higher level of copper (Cu) concentrations. Cadmium (Cd) concentrations remain relatively stable across sites, with nickel (Ni) showing consistently low presence.

Also, the data was analyzed in descending order within each site, with heavy metal concentrations. In Malindi, the sequence was led by arsenic (As) > lead (Pb) > copper (Cu) > chromium (Cr) > cadmium (Cd) > nickel (Ni). Similarly, in Kizimkazi, arsenic (As) > lead (Pb) > copper (Cu) > chromium (Cr) > nickel (Ni) > cadmium (Cd). Conversely, Matemwe showcased a unique trend where, Copper (Cu) held the highest concentration, distinguishing it from other sites. Arsenic (As) followed by > lead (Pb) > nickel (Ni) > cadmium (Cd) > chromium (Cr). Lastly, in Mazzini, was arsenic (As) > lead (Pb) > nickel (Ni) > copper (Cu) > cadmium (Cd) > chromium (Cr). This variation may be attributed to local factors influencing metal uptake and distribution.

3.2. Comparison of the mean concentrations of toxic metals in fish muscles with the maximum permissible limits.The result compared with international permissible limits as recommended by the Food Agriculture Organization (FAO), the World Health Organization (WHO), and East Africa Standard for heavy metals in seafood. The toxic metals detected ranged as follows;

The mean concentration of lead (Pb) reveals that kizimkazi and Matemwe (0.39±0.39 and 0.38±0.12 mg/kg), exceed the recommended permitted limit of 0.3 mg/kg for fish established by FAO/WHO (17) and East Africa Standard (EAS). As for Arsenic (As), the mean concentrations were found to range from (0.52±0.14 to 5.56±1.37 mg/kg), it showed that all landing sites exceeded the recommended limit of 0.1 mg/kg by both EAS and FAO/WHO (2010). The mean concentration of chromium (Cr) ranged between (0.02±0.02 and 0.11±0.01 mg/kg), staying within the maximum tolerable range of 0.1-1.0 mg/kg for fish as established by Food Agriculture Organization (FAO) (1983) and World Health Organization (WHO) (2004). Meanwhile, cadmium (Cd) mean concentration ranged between (0.01±0.00 and 0.07±0.04 mg/kg). According to East Africa Standard (EAS), the maximum allowed concentrations are 0.3 mg/kg. However, the mean concentration remained below these thresholds.

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Table 2. Metal concentration (mg/kg) in fish muscle tissue collected from four landing sites (Mean ± SD)

Landing sites	Lead (Pb) (mg/kg)	Arsenic (As) (mg/kg)	Chromium (Cr) (mg/kg)	Cadmium (Cd) (mg/kg)	Copper (Cu) (mg/kg)	Nickel (Ni) (mg/kg)
Malindi	0.25±0.14[a]	2.22±0.44[abc]	0.02±0.02[ac]	0.01±0.00[a]	0.02±0.02[ac]	0.00±0.00[a]
Kizimkazi	0.39±0.39[a]	2.30±0.44[abc]	0.11±0.01[b]	0.07±0.04[a]	0.17±0.13[abc]	0.15±0.04[a]
Matemwe	0.38±0.12[a]	0.52±0.14[b]	0.04±0.02[abc]	0.05±0.01[a]	0.65±0.21[b]	0.09±0.03[a]
Mazizini	0.21±0.12[a]	5.56±1.37[c]	0.02±0.02[a]	0.03±0.01[a]	0.05±0.02[c]	0.15±0.05[a]

Mean values bearing different letters within the same column show statistically significant differences ($p<0.05$) among the landing sites.
SD - standard deviation

The mean concentration of copper (Cu) ranged (0.02±0.02 and 0.65±0.21 mg/kg), which did not exceed the acceptable limits of 30 mg/kg established by international organizations, including FAO/WHO (1993). Lastly, nickel (Ni) concentrations were recorded between (0.00±0.00 and 0.15±0.04 mg/kg). Although there is a lack of established permissible levels of nickel in seafood, the WHO has introduced the Provisional tolerable weekly Intake (PTWI), fixed at 2.45 mg/person/week per kg of body weight. The existing standards set by organizations like the European Commission (EC), the Food and Agriculture Organization (FAO), and the US Food and Drug Administration (USFDA) do not provide specific insights into acceptable Ni levels in fish tissues. The scarcity of individual fish consumption data in Tanzania contributes to the complexity of determining a weekly nickel intake, as outlined in research conducted by (18). Another relevant study, conducted by (19), these studies lacks precise descriptions of Ni toxicity to fish.

Table 3. Maximum allowable limits of heavy metals in fish

Metals	Maximum limit (mg/kg)	Source
Pb	0.3	DEAS (20) - EAS 827:2021 FAO/WHO (17)
As	0.1	FAO/WHO (17)
Cr	1	FAO (21) and WHO (22)
Cd	0.3	DEAS (20) - EAS 827:2021
Cu	30	FAO (23)
Ni	-	-

3.3. Correlation analysis of fish size and heavy metal concentrations in fish

The Pearson correlation coefficient (R) and significance levels (P) provide a view of the strength and direction of the relationships between fish size (length and weight) and heavy metal concentration as shown in Table 3.

The analysis revealed a positive correlation between the length of fish and the concentration of copper (Cu) (R=0.74, P=0.01*), as well as a moderate positive correlation between fish length and nickel (Ni) (R = 0.60, P = 0.04*) and association was statistically significant ($p<0.05$) as shown in Table 3 below. Also, there was a significant positive correlation between the weight of fish and concentration of copper (Cu) (R=0.77, $p<0.05$). Fish size exhibited a strong positive correlation with copper (Cu), suggesting its influence on (Cu) accumulation, weak correlations were observed for other metals such as lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), and nickel (Ni). Notably, nickel showed a moderate positive correlation with both fish length and weight. The correlation between Copper and Nickel in fish is variable, with larger bodies showing a significant positive correlation.

Table 4. Pearson correlation coefficient (R) and levels of significance (P) for the relationships between heavy metal concentrations and fish size (length and weight)

Factor	Metal	R	P
Length	Lead (Pb)	0.13	0.69
	Copper (Cu)	0.74	0.01*
	Arsenic (As)	-0.19	0.55
	Cadmium (Cd)	0.40	0.20
	Chromium (Cr)	0.19	0.56
	Nickel (Ni)	0.60	0.04*
weight	Lead (Pb)	0.06	0.86
	Copper (Cu)	0.77	0.00*
	Arsenic (As)	-0.23	0.47
	Cadmium (Cd)	0.47	0.12
	Chromium (Cr)	0.04	0.91
	Nickel (Ni)	0.54	0.07

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4. Discussion

Heavy metal concentration in aquatic ecosystems beyond acceptable limits pose a direct risk within the food chain and, ultimately, to human well-being. In this context, the study focuses on assessing the concentrations of selected heavy metals lead (Pb), arsenic (As), chromium (Cr), cadmium (Cd), copper (Cu), and nickel (Ni) in *Signus surtor* fish, the common fish in the diet of a large proportion of the Zanzibar population.

The annual per capita fish consumption in Zanzibar is about 22 kg/year, as reported by (24). The population's extensive fish intake raises concerns about health problems to the public due to the presence of harmful heavy metals in commonly consumed fish. This study focuses on determining heavy metals in fish muscle and comparing them against established limits to estimate their suitability for human consumption.

The results from this study reveal significant insights into the heavy metal concentrations within landing sites, revealing potential environmental variations and their impact on fish quality. The heavy metal concentrations were analyzed across four landing sites and, the mean values represented with associated standard deviations, indicated distinct trends in heavy metal accumulation among these sites. The overall average concentrations of metals were found to be below the maximum permissible limit for human consumption recommended by the Food and Agriculture Organization (FAO), World Health Organization (WHO), and East Africa Standard (EAS), except for Arsenic (As) and lead (Pb).

The mean concentrations of arsenic (As) in this study ranged between 0.52±0.14 to 5.56±1.37 mg/kg. These findings reveal the presence of heavy metal contamination in the examined fish, which raises concerns about their unsuitability for consumption due to the elevated levels of these metals. The contamination level, about arsenic (As), exhibited a significant difference between the two landing sites, Mazizini and Matemwe. Mazizini has the highest mean concentration, exceeding the permissible levels across all landing sites. Both sites exceeded the recommended level of 0.1 mg/kg established by FAO/WHO (17). Whereas the other heavy metals did not show significant differences.

This finding is congruent with the research conducted by Zhang, and Chen (25), which focused on the biotransformation of inorganic arsenic in the marine herbivorous fish *Siganus fuscescens,* which shares similarities with *Signus surtor* from the *Siganidae* family. Their study indicated that marine herbivorous fish at lower trophic levels tend to accumulate higher levels of arsenic (As). Similarly, a study by Islam, Ahmed (26) reported the highest arsenic concentration in *H. fossilis* (5.95 mg/kg), followed by *A. testudineus* (4.37 mg/kg), and showed a significant difference compared to other fish species, possibly due to their enhanced capacity to accumulate arsenic from the aquatic environment. The study conducted by Ngoc, and Chuyen (27) revealed consistent results with our study, showing that arsenic (As) levels in fish tissues were higher than lead (Pb) levels, where mean concentrations of 1.59 mg/kg for As and 1.13 mg/kg for lead (Pb) in summer, and 1.81 mg/kg for arsenic (As) and 1.45 mg/kg for lead (Pb) in winter, respectively. The research conducted by (2), observed elevated levels of arsenic (As) in fish from the Kunduchi fish market in Dar es Salaam, exceed the recommended level. Furthermore, notable levels of arsenic (As) contamination were detected in mackerel fish collected from both Dar es Salaam (3.34 mg/kg) and Tanga (3.4 mg/kg), exceeding the limits established in the study by Shilla and Sawe (18), and Mania, Rebeniak (28), reported mean concentration of Arsenic (As) was 0.46 mg/kg. These findings are consistent with studies conducted by Rakocevic, and Sukovic (29), who similarly observed varying metal concentrations among different regions.

The research conducted by Bravo, and Cannicci (30) on the ecological health of coral reefs in Zanzibar and the impact of trace metal contamination revealed the bioaccumulation of trace metals, particularly arsenic (As) and cadmium (Cd), across various coral reef sites. These findings point to the influence of human activities such as industrial discharges, domestic waste, agricultural runoff, and natural sources as contributors to ecosystem disruption and variation Rumisha, Leermakers (31). These findings align with the current study focuses on assessing the herbivore fish species *Signus surtor* to elevated trace metals levels, and reveals the significant difference in arsenic accumulation level, as shown by the mean level which exceeded the required limit. This finding raises concerns regarding the larger implications for both the fish species and the ecosystem at large. The noticeable arsenic accumulation within *Signus surtor,* a herbivore occupying a vital ecological role within coral reef habitats, draws attention to the persistent issue of metal contamination in the coral reef environment.

Prolonged exposure to arsenic (As) has been associated with various adverse health effects, including skin diseases, vascular issues, renal disorders, neurological impacts, cardiovascular diseases, chronic lung conditions, cerebrovascular ailments, reproductive complications, and development of skin, lung, liver, kidney, and bladder cancers. Additionally, arsenic exposure has been connected to non-insulin-dependent diabetes mellitus and visual impairments, particularly among children Agbugui and Abe (32). The element is also considered possibly carcinogenic, and elevated levels of exposure can even lead to death (2).

The mean concentrations of lead (Pb) in this study ranged between 0.38±0.12 and 0.39±0.39 mg/kg. These findings indicate the presence of heavy metal contamination in the examined fish, raising concerns about their suitability for consumption due to elevated metal levels. The contamination levels for lead (Pb) exceeded the recommended permissible limit of 0.3 mg/kg for fish established by FAO/WHO (17) and East Africa Standard 827:2021 at Matemwe and Kizimkazi. This result aligns with the other studies, such as those conducted by Leonard, and Mahenge (4), which showed lead (Pb) concentrations ranging from 1.09 mg/kg to 2.95 mg/kg, surpassing World Health Organization (WHO) food safety guidelines. Hasan, Satter (33) also found lead (Pb) concentrations in fish exceeding the Food and Agriculture Organization (FAO) and World Health Organization (WHO) recommended limit of 0.5 µg/g, ranging from 1.07 to 5.78 µg/g across different sampling sites. Moreover, Koleleni and Haji (6) found higher lead (Pb) levels (1.7 µg/g) in sardines, indicating lead (Pb) exceeding acceptable limits. Additionally, a study conducted by Elnabris, and Muzyed (34) reported that lead (Pb) concentrations in *M. furnieri fish* exceeded the permissible limits in fish proposed by the European

Commission (EC). These findings emphasize the potential health risks of lead (Pb) exposure at all life stages, with minimal exposure impacting newborns and young children's physical health, behavior, and cognition. In adults, the lead (Pb) can lead to elevated blood pressure and an increased risk of cardiovascular disease (33,35). Lead (Pb) exposure occurs through food consumption and inhalation, accumulating in various bodily tissues and causing damage to organs, nerves, and reproductive systems, as well as heart disease, anemia, and high blood pressure. Notably, even slight lead (Pb) exposure can lead to reduced IQ and learning deficits in fetuses and young children due to damage to their nerves and brain (32).

As evident from prior studies, heavy metal bioaccumulation within fish is particularly species-dependent, which involves interactions between ecological factors shaping accumulation dynamics. Notably, feeding habits and habitat characteristics assume essential roles in determining heavy metal concentrations (36). In this regard, it is well-established that certain fish species tend to accumulate distinct heavy metal profiles based on their feeding behavior and specific habitats, particularly those influenced by pollutants.

4.1. Comparison of metals within the landing sites

The variations in metal concentration patterns within the landing site are a result of local environmental factors, contamination sources, and possibly the feeding habits of the species. The study found that arsenic (As) contamination was notably high across almost four sites, with Matemwe showing elevated copper (Cu) contamination followed by arsenic (As). These findings highlight anthropogenic activities in these locations, such as shipping, which likely released elements like copper into surface water and reflected in fish samples. This could be attributed to the use of copper-based antifouling paint on boats, particularly evident in areas with intense fishing and tourism (37). Zanzibar's marine ecosystem has suffered degradation due to factors like population growth which causes coastline erosion, urban runoff, sewage disposal, uncontrolled tourism development, overfishing, destructive fishing practices, and waste discharge which are contaminated by various pollutants such as industrial and agricultural chemicals (38).

4.2. Relationship between heavy metal concentrations and body sizes

Multi-layered dynamics driving heavy metal accumulation extend beyond feeding habit and habitat location. Intraspecific attributes, encompassing variables such as body size, age, growth rates, and tissue composition, are involved in linking the heavy metal load in fish. Our findings highlight that fish size plays an essential role in influencing the accumulation of specific metals such as copper (Cu) and nickel (Ni), while demonstrating weaker or non-significant correlations for other metals.

These findings are aligned with recent research, for instance, a study by Caglar, and Canpolat (39) observed increasing trends in Copper (Cu) values with increasing fish length and weight, supporting our study results. Also, the study conducted by Rakocevic, and Sukovic (29) revealed that significant relationships were primarily observed for essential elements, while non-essential elements did not exhibit clear or significant correlations. This is consistent with our results, where elements like chromium (Cr), arsenic (As), lead (Pb), and cadmium (Cd) demonstrated no significant associations with body size across the fish species analyzed. On the other hand, copper (Cu) and nickel (Ni) revealed notable correlations with body size, both of which were statistically significant ($p<0.05$).

Furthermore, the findings align with Guo (40), who investigated *Branchiostoma belcheri* and found a positive correlation between Copper concentrations and fish length, with statistical significance noted between fish weight and heavy metal concentrations ($p<0.05$). A similar trend was observed by Canpolat and Çalta (41) in their investigation of varying concentrations of copper (Cu), iron (Fe), zinc (Zn), and manganese (Mn) in the tissues and organs of *C. capoeta umbla* based on weight groups, aligning with the increase in fish length. However, it is important to note that the observed correlations are not uniform across all metals. Metals such as lead (Pb), arsenic (As), cadmium (Cd), and chromium (Cr) did not show significant correlations with fish size. These findings align with the study conducted by Nussey and du Preez (42) found that metal levels of chromium (Cr) and lead (Pb) decreased with an increase in the length of fish *Labeo umbratus*, further highlighting the intricate and species-specific nature of the relationship between metal accumulation and fish size. Furthermore, the lack of significant differences in most heavy metal concentrations corresponds to the findings of Al-Yousuf, and El-Shahawi (43), where specific metals demonstrated correlations with fish size but not necessarily with location.

Generally, the accumulation of trace elements in living organisms is influenced by specific mechanisms of uptake, detoxification, and elimination (44). Additionally, the size-specific metabolic rate of organisms plays a crucial role in this process. This phenomenon is well-supported by studies such as (39,45), both of which emphasize the impact of metabolic activity on heavy metal accumulation. Also, a study conducted by Bosch, O'Neill (46) suggests that variations in metabolic activity between younger and older fish can contribute to the negative correlations observed between metal levels and fish size. Higher metabolic rates in younger individuals result in increased metal accumulation in their body tissues. Also, a positive correlation between metal accumulation and fish sizes, such as the observed concentrations of copper (Cu) and nickel (Ni) in our study, may result from prolonged exposure durations or slower excretion rates as suggested by (47). Conversely, a negative correlation observed between fish size and the accumulation of other metals might be due to tissues growing faster than metal intake, leading to rapid weight gain and dilution of metal concentration. This phenomenon of biological dilution has been proven in various other studies (36,48,49). This dynamic suggests that smaller fish exhibit a higher potential for trace metal uptake compared to larger fish, as noted by (50). However, metals such as Chromium (Cr), cadmium (Cd), arsenic (As), and lead (Pb), concentrations exhibited relatively little dependency on fish size, suggesting an equilibrium between uptake and excretion rates.

The study found no significant differences in the impact of length or net weight on tissue metal

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concentrations in fish size. However, length was chosen as the primary measure due to its stability compared to weight, which can be influenced by muscle tissue composition. Positive correlations were found between fish length and Nickel concentrations. These findings highlight the complex interplay between heavy metal accumulation and fish size, reflecting a complex interplay of physiological and ecological factors.

5. Conclusion

In conclusion, this study found high levels of arsenic (As) and lead (Pb) concentration in *Signus surtor* fish from four landing sites in Zanzibar. The concentration level of arsenic (As) exceeded the recommended limits at all landing sites, whereas the level of lead (Pb) exceeded the permissible limit in Kizimkazi and Matemwe only. The relationship between heavy metal concentrations and fish size was complex, influenced by metabolic rates and exposure durations. These findings highlight the need for strict monitoring and management strategies to mitigate heavy metal contamination in fish, which could impact ecosystem health and human well-being. Addressing sources of contamination, including industrial and domestic waste, agricultural runoff, and natural contributors, is crucial for safeguarding aquatic resources and public health in Zanzibar. Ongoing multidisciplinary efforts in research, regulation, and policy are essential to ensure the sustainability of the region's aquatic ecosystems and the safety of its inhabitants.

Conflict of interest

The authors declare no conflict of interest.

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