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Transfer Factor of Heavy Metals from Sediments to Organs of Mud Crabs (*Scylla serrata*) of Mida-Creek, Kilifi Kenya

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ABSTRACT

Heavy metal accumulation and transfer from sediments to edible mud crab organs (*Scylla serrata*) pose major ecological and health risks to consumers. The bioaccumulation of these metals are detrimental if they are extremely toxic. The objectives of this study were to analyze heavy metal concentrations in sediments and crab organs and determine the transfer of heavy metals in Scylla serrata from sediments in Mida Creek, Kilifi. The crab samples were collected by simple random sampling whereas sediment samples were collected by purposive sampling. The transfer factor of heavy metals from sediments to the organs of edible mud crabs (Scylla serrata) was evaluated in both the wet and dry seasons. The measurements and examinations of heavy metals, samples of crab organs, and sediments were obtained from three sampled sites. The concentration of metals in the samples was determined using an X-ray fluorescence (XRF) spectrometer. The results showed that the majority of the components are accumulated by the crabs from sediments. The order in which the metal transfer factor to crabs from station 1 sediments increased was Fe > Zn > Ni > Cu > Cd > Hg. In station 2, the transfer factor increased in the following order: Fe > Zn> Cu>Ni>Cd> Hg, while in station 3, it increased in the following order: Fe > Ni> Zn>Hg>Cd>Cu. The study concluded that mud crabs in Mida Creek actively absorb most of the elements from the sediments. The study recommends a routine monitoring of heavy-metal levels in other crustacean marine biota, and fish is necessary.

INTRODUCTION

The mercury emissions risk the sustainability of seafood, as it is a significant health hazard to humans globally (Sundseth et al., 2017). There are short-term and long-term health effects of mercury. Adverse effects on cardiovascular health, embryonic development, and neurotoxicity of methylmercury are some highlights, thus endorsing the consumption of fish from less contaminated sources, which requires extensive surveys to be undertaken to inform the nation on the exposure risk from mercury in shellfish (Saadati et al., 2020). The relatively less expensive basket and the bush kilns are significant sources of inorganic Hg emissions to the atmosphere (Brocza et al., 2024). Additionally, mercury emissions contribute to the risk of Hg methylation in the sediments (Al-Sulaiti et al., 2023). Mud crabs and bivalves of Mida Creek are known to contain low levels of mercury, but other heavy metals may have accumulated in them through their prolonged exposure and continued interaction with the creek sediment (Zhang et al., 2022). The challenging issue is the transfer factor from contaminated sediments to the edible soft shell-covered portion of the bivalves and mud crabs. The present study fills the gap in our understanding of bioaccumulation and the effects of heavy metals on aspects related to the kinetics of the transfer process (Ramos & Leite, 2022).

Africa is rich in mineral deposits, and some African countries are large producers and consumers of products derived from these minerals, such as coal and iron, while the potential for uranium and other metal production is limited (Ali et al., 2021). In general, the presence of heavy metals in the environment occurs through natural geomorphological processes, but in many cases, the cause is anthropogenic (Idoine et al., 2022). Many organic and inorganic chemicals, including many heavy metals, do not readily degrade, or cannot be degraded, by environmental microorganisms and can potentially accumulate to levels that may cause damage to the organisms that depend on these systems for one or more functions that are beneficial to human beings (Ali et al., 2019; Briffa et al., 2020; Zhang et al., 2023). The environment in Africa is getting increasingly contaminated with heavy metals, elements, and compounds. Areas of serious heavy metal pollution include river systems that flow through or are alongside mining and industrial towns, coastal environments, and agricultural areas that receive irrigation water from polluted sources (Addo-Bediako et al., 2021; Jafarabadi et al., 2017; Singh et al., 2024). In these types of areas, it is not only the inorganic compounds that generate concern; organic chemicals, depending on use and production, can also have serious environmental impacts.

Essential metals are preferentially absorbed due to their crucial functions in metabolism, whereas non-essential metals such as cadmium are absorbed passively or through non-specific pathways (Leal et al., 2023). With heavy metals, organic pollutants can produce toxic effects at relatively low concentration levels (Hembrom et al., 2020). Even in low quantities, heavy metals like arsenic, cadmium, chromium, lead, and mercury are known to be harmful (Gezahegn et al., 2024a). These metals can change transcription and DNA replication, damage DNA, and cause chromosome abnormalities (Das et al., 2023). African estuaries are affected primarily by a high input of organic matter from the land, and marine sediments store organic compounds and heavy metals. Because estuaries are used for housing, food, and industrial activities, there is always sewage discharge and industrial waste that end up in these ecosystems (Gelaye & Musie, 2023). Forest and agricultural lands are also threatened by industrial, urban, and military waste, and mines containing various metalloids, as well as by other elements that are used to obtain benefits from some areas.

Heavy metal contamination of aquatic products is one of the problems leading to the rejection of some consignments in the international market (Manas, 2021). This has caused a significant economic loss to Kenya. Decapods are good bio-monitors of aquatic ecosystems as they accumulate heavy metals from the surrounding environment (Demirbas et al., 2021). The concentration of heavy metals in the organs becomes harmful to the decapods themselves and to humans who consume the decapods. The ability of decapods to transfer these harmful heavy metals from a contaminated environment to edible parts and the predation of decapods are key concerns (Ighariemu et al., 2023). This research intends to observe the transfer factor of heavy metals from the sediments to the organs of mud crabs from three different sites in Mida Creek, Kilifi County, Kenya. Heavy metal contamination of the aquatic ecosystem is a global problem, especially in the developing world where economic development is partly reliant on a healthy environment (Wechuli et al., 2023). These heavy metals are considered to be dangerous for both aquatic organisms and the animals that consume the aquatic products, as they are harmful to the target organs, such as the liver and kidneys (Gezahegn et al., 2024b). High levels of cadmium are harmful to humans and may lead to kidney failure (Balali-Mood et al., 2021). It has also been shown that more than 3 mg of cadmium a day is dangerous; thus, marine food should contain as low cadmium levels as possible.

Human activity in coastal ecosystems, especially in creeks, exposes the marine environment to heavy metals (Okbah et al., 2018). The primary routes by which heavy metal pollution of aquatic life impacts humans are through industrial, agricultural, municipal, and urban waste (El-Sharkawy et al., 2025). Heavy metals bioaccumulate in organisms that are part of the food chain when they are frequently released into the marine environment. (Venkateswarlu & Venkatrayulu, 2020). A variety of mechanisms, including the direct release of contaminated effluents, the release of contaminated wet depositions into water through rainwater, runoff, sediments, and weathering of rocks and the earth's crust, allow the metals to enter aquatic life (Olowookere et al., 2018). Humans that utilize marine life as a food source may also be negatively impacted by metal pollution (Zhuzzhassarova et al., 2024). Therefore, it is crucial to have a solid understanding of the quantity and type of these heavy metals in non-targeted ecosystems as well as how they are transferred. Although just a small portion of the sediments are consumed by the crabs, they serve as a storehouse for a variety of materials that enter the stream. As a major sink, the sediments take up a variety of contaminants, including heavy metals, herbicides, and hydrocarbons (Ramos & Leite, 2022; Rinehart et al., 2023). The study aims to analyze heavy metal concentrations in sediments and crab organs and determine the transfer of heavy metals in *Scylla serrata* from sediments in Mida Creek, Kilifi.

METHODS

Descriptions of the Study Area

According to Gajdzik et al. (2014), the Mida Creek (3°19'-3°23'S/39°40'-39°51'E) is home to a variety of freshwater, semi-terrestrial, and marine species. It is made up of intertidal mudflats (580 ha) and mangrove forests (1600 ha). The mangrove ecosystem, which offers a variety of marine ecosystem services like carbon sequestration, nursery grounds, and habitat for marine organisms, is one of the important marine habitats found in Mida Creek (Newton et al., 2020; Yount, 2021). It is open to the Indian Ocean and is mainly fed by the Sabaki River. It is located in the Watamu Marine National Reserve (Alemayehu, 2015). In Watamu, considerable activity in agriculture, tourism, and hospitality businesses are ascribed to rapid likely sources of petrochemicals released into the environment, notably the local sea (Owuor et al., 2019). The confluence of modern industrial and historically coexisting lives is bound to result in a distinct blend of pollutants in the catchment area and hence in the sediments (Halabowski & Lewin, 2021). Mangrove swamps in Mida Creek are home to agricultural, industrial, and urban waste products, and they function similarly to a heavy metal reservoir (Alemayehu, 2015). From this perspective, it is critical to better understand the creek ecology and monitor it regularly so that any changes may be incorporated into Kenya's integrated Coastal Zone Management Plan.

Research Design

Heavy metal analysis was conducted on sediment samples from three different locations along Mida Creek including mud crabs (Scylla serrata). The mud crabs were collected using simple random sampling, which involved selecting crabs at random from three designated sites in Mida Creek: Uyombo (Station 1), Temple Point (Station 2), and Dabaso (Station 3) during the dry season (September to December 2022) and the rainy season (March to June 2023). Heavy metals were analyzed from crab organs such as the gills, gut, hepatopancreas, and muscle tissues, and the results were interpreted and assessed. The sediment samples were collected along transects (Hall et al., 2001). Transect lines were drawn through each sampling site. Four sediment samples were collected along each transect line. Each of the three sites collected sediment samples from a depth of 15 cm. Sediments were also collected twice a month for six months from three different locations using an 'Ekman grab' sampler and stored in a plastic container that had been treated with 10% nitric acid for 24 hours and rinsed with de-ionized water.

Heavy Metals Analysis in Sediments

In the lab, samples were stored at 20°C until they were processed and analyzed with (XPXRF). Sediment samples were oven-dried at 70°C for 4 hours, crushed to break down aggregates, and sieved using a 2mm sieve. To analyze mercury, a separate fraction was dried at ambient temperature (65 ºC) to avoid volatilization. The sample was homogenized, and a representative portion was ground with a mortar and pestle before passing through a 60-mesh sieve. Acid digestion was carried out by accurately weighing 0.5 g of the material into a dry, clean conical flask and adding 2 ml of deionized water. Concentrated nitric acid (7.5 mL) was added to the mixture, which was covered with a watch glass and heated on a hot plate for 15 minutes. Two (2) milliliters of deionized water were added first, followed by 3 milliliters of 30% hydrogen peroxide. The sample was covered with a watch glass and cooked in the acid peroxide digestate until it was reduced to approximately 1 ml. Five (5) milliliters of strong hydrochloric acid were added to the sample digestate, which was then covered with a watch glass and heated on a hotplate for 25 minutes. The resulting mixture was filtered using Whatman 41 paper into a 50ml volumetric flask, which was then filled to the desired level with deionized water. The metal concentration was evaluated using a (FPXRF) spectrometer. IAEA-433 Standard reference materials were used to conduct accuracy and performance checks on sediment. All procedures followed the IAEA's standard method for heavy metal sampling and analysis (Gray & Cunningham, 2019). The results were presented in milligrams per kilogram (mg/kg) of dry materials.

Evaluation of Heavy Metal Contamination using Mud crabs

To evaluate heavy metal contamination for biological and human health issues, mud crabs can be utilized for creating a sensitive bio-indicator (Venkateswarlu & Venkatrayulu, 2023). To study heavy metal bioaccumulation, researchers have looked at aquatic organisms with high food value, such as fish, crabs, bivalves, and mollusks (Noman et al., 2022). These organisms are employed to continuously measure the degree of contamination in the environment. The ability of crabs and other benthos to absorb heavy metals is influenced by the length of time spent in their living environment, which invariably means that top predators would have accumulated higher levels of heavy metals due to their dietary feed. Health risk studies have associated a high intake of marine organisms with a high accumulation of heavy metals with various diseases.

Transfer Factor Ratio

It is a ratio of the efficiency with which a metal moves from one environmental medium to another. TF was computed using the following equation.

$$TF = \frac{\text{Metal Concentration in Organs}}{\text{Metal concentration in C}}$$

Where **TF** = Transfer Factor; [**C**] = Concentration of Metal in Sediments. Where if the transfer factor is greater than 1, then bioaccumulation occurs.

Sampling and analysis of heavy metals in organs of crabs

A total of 180 Mud crabs (*Scylla serrata*) were collected for the study. The samples were handled with care to avoid external damage and contamination. The organs were retrieved through dissection. The sample was pre-concentrated at 65 °C using oven drying. The samples were ground after drying to confirm their uniformity. (Kebbekus, 2003) the protocol was followed for triplicate digestions. The gills, muscles, hepatopancreas, and gut were all wet digested, and 1g of the organ was accurately weighed using an electronic balance. Each sample (2.0g) was weighed into a 200ml Kjeldahl digestion flask, and 10ml of concentrated HNO3 was added first, then 2ml of 62% HCLO4 and H2SO4. Following the formation of white thick vapors, the flask was heated on an electric heating mantle until nearly dry (Soegianto et al., 2022; Vince Cruz et al., 2015).

The flask was allowed to cool before the contents were diluted with distilled water, filtered into a 50ml volumetric flask, and marked with distilled water. Eighteen (18) milliliters of concentrated. HNO3 was placed in a Kjeldahl flask and gradually heated over a hot mantle until dense brown fumes formed. Hydrogen peroxide was added in drops to eliminate the black fumes and facilitate nitric acid solubility (Vince Cruz et al., 2015). The organ digestion was allowed to evaporate, resulting in roughly 5 mL. This was filtered (with Whatman No 42-filter paper) into a 25 ml clean and dry volumetric flask, which was then diluted to the mark using distilled water. The digested samples were labeled and stored for analysis (Kebbekus, 2003) To adjust for background, six blanks were digested as pre-test samples and examined using an X-ray fluorescence (XRF) spectrometer.

RESULTS AND DISCUSSION

Heavy Metals Transfer Factor (TF) in Sediments During the Dry and Wet Seasons (Station 1)

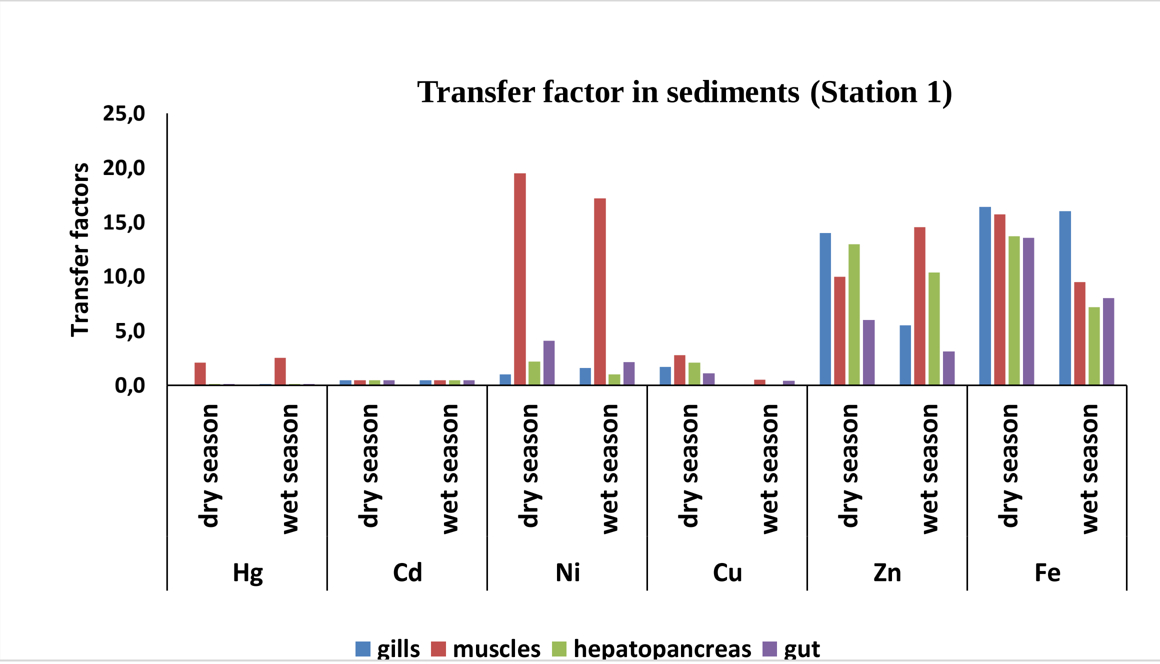

Figure 1. A graph showing the transfer factor of heavy metals from sediments in station 1 during wet and dry seasons

Except for muscle tissues, the transfer factor of Hg at station 1 was less than one. All of the organs had Cd transfer factors less than one. Cadmium TF was the least during both seasons. Unlike critical metals, cadmium plays no biological role in crabs or other organisms (Banaee et al., 2024; Ivanina et al., 2010; Waqas et al., 2024). As a result, crabs lack particular mechanisms for actively absorbing and storing cadmium. Cadmium can create insoluble cadmium (Charkiewicz et al., 2023). Cd in sediments was less than one in all organs, although Fe was larger than one in all organs. (Lee et al., 2021) reported higher concentrations of cadmium from the sediments in a study assessing heavy metals in Santubong estuary Malaysia. Ni and Zn transfer factors were greater than one in all organs and seasons. Fe had transfer factors greater than 1 during both seasons. The TF of Cu was less than one during the wet season. The metal transfer factor to crabs from station 1 sediments increased in the following order: Fe > Zn > Ni > Cu > Cd > Hg.

Heavy Metals Transfer Factor (TF) in Sediments During the Dry and Wet Seasons (Station 2)

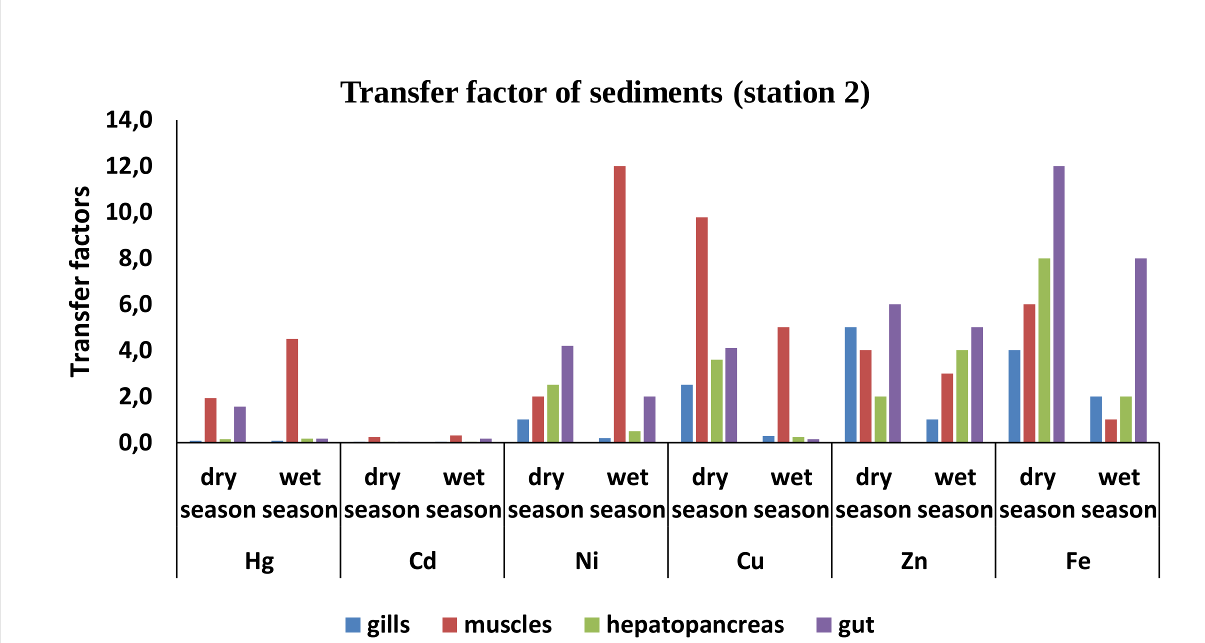

Figure 2. A graph showing the heavy metal transfer factor from sediments in station 2 during wet and dry seasons

The transfer factor of Hg was less than one in all the organs except in muscle tissues during both the wet and dry seasons and greater than one in the gut during the dry season. During the wet season, Cu was less than one in the gills, hepatopancreas, and gut. Zn and Fe were greater than one during both seasons. The transfer factor of the metals to crabs from sediments in station 2 increased in the order of Fe > Zn> Cu>Ni>Hg>Cd. In crabs, the concentration of Fe was the highest of any metal analyzed. A study with similar findings was conducted by Okorondu et al., (2021) in South Atlantic coast of Nigeria. The study reported that Fe had the highest concentration in the sediments. Similar studies where the TF of Zinc was greater than one were conducted by Mehanna & Abd El-Azim, (2018) in the Suez Gulf, where researchers examined the accumulation of heavy metals in fish organs. They observed that the TF of zinc (Zn) in fish liver from both water and sediment was larger than one, indicating considerable bioaccumulation of these metals in liver tissue. This is due to their important participation in biological processes, active absorption, and retention mechanisms (YH, 2021). Fe is required for hemocyanin production and enzyme activity, including oxidative metabolism. In contrast, Zn is essential for enzymatic activity, cell division, and protein synthesis. Its involvement in multiple zinc-dependent enzymes results in excellent bioavailability (Costa et al., 2023; Khan Mohammad Beigi et al., 2015).

Heavy Metals Transfer Factor (TF) in Sediments During the Dry and Wet Seasons (Station 3)

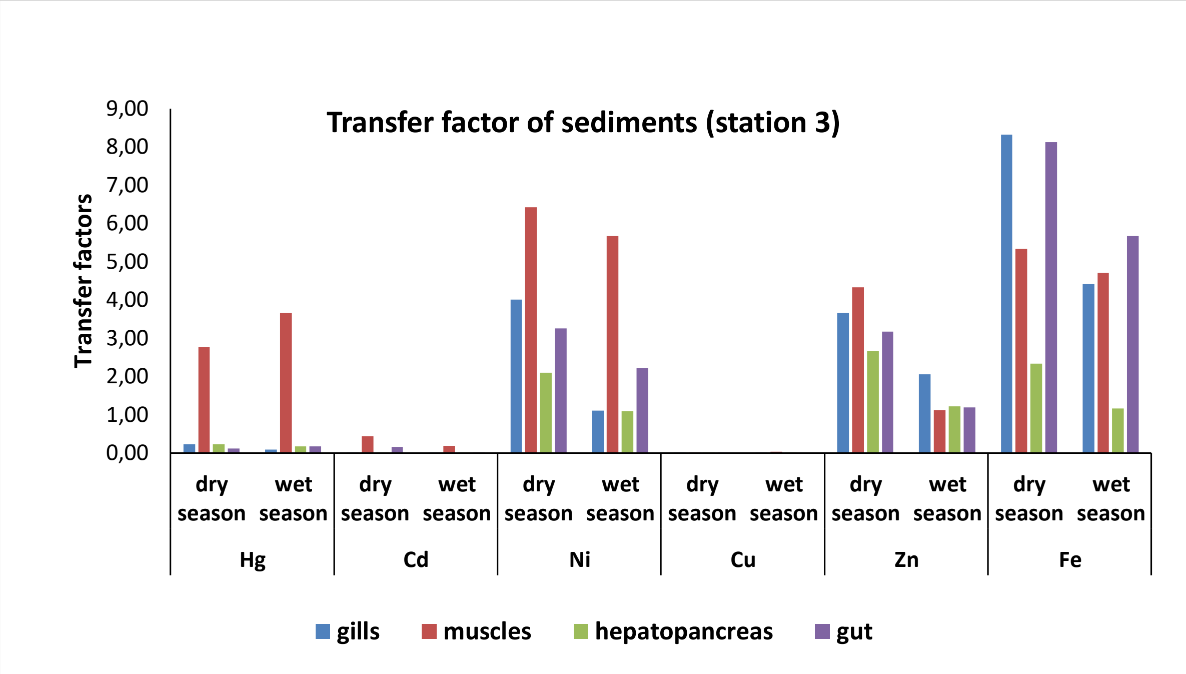

Figure 3. A graph showing the transfer factor of heavy metals from sediments in station 3 during both wet and dry seasons

The transfer factor of Hg was less than 1 in all the organs except in muscle tissues during both seasons. A study by Polak-Juszczak (2018) found that muscle tissue in fish from the southern Baltic Sea had the highest concentrations of total mercury (THg) and methylmercury (CH_3Hg^+) compared to other organs. The liver and heart also accumulated significant amounts of mercury, while the digestive tract, gills, and skin had lower concentrations. The study also found that transfer factors (TFs) for mercury from sediments to fish organs were generally low, indicating that there was little direct accumulation from sediment-bound mercury. Instead, the primary source of mercury in fish tissues was dietary intake, emphasizing the significance of trophic interactions in mercury bioaccumulation. Cd and Cu had a transfer factor of less than one in all the organs during both wet and dry seasons. Calcium sulfides (CdS), which are less accessible to sediment-dwelling species (Rodrigues et al., 2023). Similar results have been reported when heavy metal concentrations were measured in tilapia fish (Oreochromis niloticus) from the Ologe Lagoon in Lagos, Nigeria (Adeyemi et al., 2019). Ni, Zn, and Fe were greater than one in all the organs during both seasons. The transfer factor of the metals to crabs from sediments in station 3 increased in the order of Fe > Ni> Zn>Hg>Cd>Cu.

This suggests that the crabs accumulate these components from sediments (Siddiqui & Saher, 2021; Vilhena et al., 2013). The transfer factors (TFs) for Cd from sediments to fish organs were less than one. This shows that sediment concentrations did not have a substantial effect on Cd accumulation in fish. During both the wet and dry seasons, mercury had the least TF in all organs except the muscles. Organs such as the hepatopancreas, gills, and gut are largely exposed to inorganic mercury, which has limited solubility and bioavailability (Banaee et al., 2024; Suhendrayatna et al., 2019). Methylmercury (MeHg) is highly bioavailable and lipophilic, meaning it can easily cross biological membranes and bind to sulfhydryl groups in muscle proteins (Ajsuvakova et al., 2020; Carrasco et al., 2011; Kalisinska et al., 2019). This leads to increased accumulation in muscular tissues (Dietz et al., 2022).

Conclusion

Mud crabs actively absorb some of the elements from the sediments. Heavy metal accumulation in crabs varies significantly across tissues, seasons, and metal types. Elevated TF values of Fe and Zn in most tissues are due to higher sediment disturbance, increased bioavailability, and runoff contributions. However, poor TF could be ascribed to the organism's low heavy metal uptake and excretion rates and minimal bioavailability of the elements in the ecosystem. Lower TF values in Cd and mercury from sediments and crab organs are likely due to reduced metal mobility and sediment stability. Fe and Zn, are essential for growth, hence high TF of these elements is advantageous while excessive concentrations of others, such as Cd, Pb, Hg, and Ni, which have no biological purpose, can be hazardous to crabs and for human consumption. The study recommends that routine monitoring of heavy metal levels in other marine, crustacean marine biota, and fish is necessary.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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