Research Article

Health Risk Assessment and Levels of Heavy Metals in Farmed Nile Tilapia (*Oreochromis niloticus*) from the Volta Basin of Ghana

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Heavy metals (Pb, Cd, As, Mn, Fe, Zn, Cu, Ni, and Cr) are some of the most toxic elements that can bioaccumulate from sources linked to human activities, such as industry and agriculture. This study quantifies the concentrations of several heavy metals in caged tilapia found in Ghana's Volta Basin and assesses the associated health risks. The levels of heavy metals in the tissues of *Oreochromis niloticus* from three cage farms ($N=52$) were determined using Atomic Absorption Spectrometry (AAS). The implication for human health was assessed using several risk assessment techniques. Fe (50.11 ± 10.22 mg/kg) and Cr (0.31 ± 0.07 mg/kg) had the highest and lowest accumulated metal concentrations, respectively. Heavy metal concentrations in tilapia tissue from fish farms were ordered as follows: Fe > Mn > Zn > Ni > Cr (farm A), Fe > Zn > Ni > Mn (farm B), and Fe > Mn > Zn > Ni > Cr (farm C). All metals had an estimated daily intake (EDI) below the threshold, and mean differences between sample farms were not statistically significant. Similarly, the values of target hazard quotients (HQs) and hazard indices (HIs) were less than one. According to the risk assessment results, eating tilapia from farms posed no risk to human health. The presence of Mn, Fe, and Ni concentrations above the maximum level in the fish, on the other hand, suggests that they may affect fish health.

1. Introduction

Global fish consumption has increased in recent years, owing to the growing awareness of fish's nutritional and therapeutic benefits. Fish is low in cholesterol and contains all essential amino acids and is estimated to provide roughly 60% of the world's protein requirements, with 60% of the developing world obtaining more than 30% of their animal protein from fish [1]. In addition to being a good source of protein, fish is high in vitamins, unsaturated fatty acids, and essential minerals [2]. The American Heart Association recommends eating fish at least twice a week to meet the daily omega-3 fatty acid requirement [3]. Regrettably, some forms of human activity have posed a significant threat to fish habitats and aquatic ecology in recent years [1, 4, 5]. Due

to the rapid population growth and industrial development, increased waste discharge into aquatic ecosystems has resulted in a significant increase in metal contamination. These metals are persistent and nonbiodegradable in the ecosystem, which results in metal bioaccumulation in aquatic biota, including fish [6].

Heavy metals enter the aquatic food chain in two ways: directly through the gastrointestinal tract when food and water are consumed and indirectly through nondietary pathways, such as gills and muscles [2]. As a result, the concentrations of heavy metals found in fish tend to correlate with those found in the water and sediment of the aquatic habitat from which they are drawn, as well as the duration of exposure [7]. Nonessential metals such as lead, cadmium, arsenic, and mercury are considered highly toxic,

even in trace amounts. There are histopathological and physiological consequences when an organism's metabolic, storage, and detoxifying processes cannot balance absorption [8]. Apart from being persistent and toxic, nonessential metals are bioaccumulated and metabolically regulated via various mechanisms, including active excretion and storage [9]. Heavy metals can build up in fish and proliferate throughout the food web, causing health problems in humans, such as cardiovascular, renal, and neurological disorders [10, 11]. Environmental pollution and fish vulnerability to heavy metal contaminants are primarily due to exposure to anthropogenic sources, such as agricultural and domestic pesticides, fertilisers, incinerator emissions, municipal or local waste emissions, and smelting and mining operations [12].

The demand for seafood products increases as the world's population grows at an accelerating pace in the twenty-first century [13]. Aquaculture production continues to grow year after year. Larsen and Roney [14] conducted a global analysis of animal protein consumption and discovered that in 2011, global cultured fish productivity surpassed beef production. If farmed fish are raised in metal-contaminated waters, they may accumulate metals from the sediment, water, and fish feeds, posing a greater health risk to humans who inadvertently consume a lot of fish.

Cage culture systems account for over 90% of farmed fish in Ghana, while ponds account for 10% [15]. Cage aquaculture is the dominant commercial activity in the Volta Basin, growing at a rate of 73% per year between 2010 and 2016. Aquaculture contributes between 3% and 5% of the country's GDP and provides employment opportunities for the populace [16]. The vast majority of cage farmers in the Volta Basin, where this study was conducted, feed their fish with more expensive imported commercial floating feed. These feeds are fortified with anticaking agents, minerals, vitamins, and supplements, all of which can be sources of heavy metals in animal feeds [17]. The contaminated feed may transfer these nonbiodegradable heavy metals toxins to farmed fish, which humans then consume.

Additionally, the Volta Basin is under intensive and extensive farming and has some irrigation facilities for nonseasonal crop and vegetable cultivation. Farmers have applied pesticides widely and unregulated throughout the basin catchment to improve crop yield to increase profit margins. These practices release pesticides containing heavy metals into the basin during runoff, polluting the ecosystem and contaminating aquatic organisms.

Along the Volta Basin, there has been an increase in rural metal fabrication, textile factories, pottery enterprises, and livestock and poultry farms [18]. These industries are situated closer to the fish farms. Wastewater effluents from these industrial activities are released, without any treatment, into the open environment. The effluents are discharged into the basin column during runoff after rainfall, polluting the entire aquatic ecosystem. Although some of these metals discharged into the water are necessary micronutrients, their high proportion in the food web can induce toxicity and environmental effects, putting aquatic habitats and their users at risk. Few studies have been performed on heavy

metals in the sediment from the caged aquaculture farms [19] in the Volta Basin. Other studies have focused on the impact of cage culture on the lake's water quality [20–22]. However, these studies have been limited to water and sediment quality in the vicinity of the cages. The heavy metals' content of the tilapia cultured in the cages has not received any attention. The research aims to determine the amounts of heavy metals in caged tilapia and estimate the potential health risks connected with the dietary ingestion of the fish.

2. Materials and Methods

2.1. Study Area and Sampling. The study area includes Ghana's Asuogyaman District in the eastern region and the Greater Accra region's Shai-Osudoku District. Figure 1 shows the locations of the fish farms from which samples were taken. The districts are located between 6° 34'N and 6° 10'N latitudes and 0° 1'W and 0° 14'E longitudes. Regarding employment and rural income creation, rain-fed agriculture and irrigated agriculture are the most important economic activities in these districts. Farmers use agrochemicals extensively on their farms to increase crop productivity. As a result, the use of pesticides that are restricted or banned cannot be ruled out. The area has a two-season rainfall pattern, with the major season falling between September and November and the minor season falling between May and July.

The study used 52 cage tilapias fish (*Oreochromis niloticus*) purchased from three cage fish farms in the Volta Basin: A = 19, B = 16, and C = 17. Two tilapia fish were combined into a composite working sample. The two fishes shared similar morphometric characteristics. Additionally, ten wild *Oreochromis niloticus* samples were collected as controls from areas upstream of the study area that does not have aquaculture. All fish samples were stored at 4°C in an airtight bag and transported to the Ghana Atomic Energy Laboratory for further examination.

2.2. Consideration of Ethical Issues. This study's purpose was explained to the fish farmers, who consented to their fish sampling. All scientific experiments used in the cage aquaculture tilapia (*Oreochromis niloticus*) studies were approved by the Institute for Environment and Sanitation Studies management and the University of Ghana's Research Ethical Committee.

2.3. Digestion of Fish Samples for Heavy Metals. In the laboratory, the fillets of the tilapia were removed using a stainless-steel knife. The samples were then washed with deionised water, wrapped in a precleaned aluminium foil, and stored at -20 °C until extraction. After one week, the samples were taken out of the freezer and defrosted. The fish muscle samples were homogenised and lyophilised for 72 hours (LMC-1, Martin Christ Gefriertrocknungsanlagen GmbH, Germany). The samples were dried in the oven at 150°C for 20 minutes. The samples were pounded into powder using a mortar and pestle. Then, 6 mL of HNO₃ and

FIGURE 1: Map of the study area of the Volta Basin, Ghana.

1 mL of H_2O_2 were added to 0.5 g of dried powdered sample in a Teflon beaker. The Teflon beakers were inserted inside the bomb and carefully capped. The bomb was situated in the centre of a microwave oven (Sineo Jupiter-A microwave) and digested at maximum power for 26 minutes. The fully digested samples were left to cool down at room temperature before being diluted with deionised water to a level of 20 mL. The Varian AA 240FS Atomic Absorption Spectrometer was used to analyse the digested samples in triplicate. The quantitative analysis included the measurement of final concentrations from the initial concentrations of the specified elements and their conversion into final concentrations using the following equation:

$$\text{final concentration} = \frac{\text{initial conc (D.F.)} \times \text{nominal vol}}{\text{sample weight in grams}} \quad (1)$$

Nominal volume was given as 20 mL, and the sample weight for fish was 0.5 g. Each result was expressed in mg/kg.

2.4. Quality Control and Quality Assurance (QC/QA) of the Heavy Metal Analyses. All reagents used were of analytical grade, and distilled water was also used in all the preparations. Glass materials were soaked and rinsed in 10% HNO_3 for 24 h and distilled water, respectively. Analyses of solvent blanks, procedural matrix blanks, and samples were carried out in triplicate for quality assurance. The functioning of equipment was established using a serial dilution

to verify their reliability. Precision and accuracy of procedure were verified by using standard reference materials, such as CRM 320. Recovery percentages of analytical results were within the range of 94–115% for all the metals studied.

2.5. Statistical Analysis. The Kolmogorov–Smirnov (K-S) analysis was used to determine the normality of the data, and findings were considered statistically significant when the p -value obtained was less than 0.05. The levels of heavy metals in the fish muscle were described using statistics, such as means and standard deviation (SD). ANOVA was used to determine the differences in contaminants between the fish farms and controls from which samples were taken. Where statistically significant, a post hoc Tukey's HSD test was performed.

2.6. Estimation of Potential Health Risks for Human. The adverse health effects of heavy metal exposure in fish on humans were investigated using the USEPA's analytical method [23]. The risk assessment is calculated using the ingestion rate reported by [24], as shown in Table 1.

2.6.1. Exposure Assessment. Heavy metals exposure estimations were obtained using caged tilapia (*Oreochromis niloticus*) as the model organism. Using USEPA-proposed methods, the concentrations of contaminants in the examined fish were employed to calculate the estimated daily

TABLE 1: Parameters for the health risk estimations of heavy metals.

Parameters	Units	Children	Adults
Bodyweight (BW)	kg	15	70
Exposure frequency (EF)	Days/year	365	365
Exposure duration (ED)	Years	6	30
Ingestion rate (IR)	mg/day	200	100
Average time (AT)	Days/year		
For carcinogenic		365 × 70	366 × 70
For noncarcinogenic		365 × ED	365 × ED

intake (EDI) (mg/kg/day) from ingestion of fish in this study. The equation below was used to produce separate exposure estimates for children and adults:

$$EDI \text{ (mg/kg}^{-1}\text{day}^{-1}\text{)} = \frac{(C \times IR \times EF \times ED)}{(BW \times AT)}, \quad (2)$$

where BW denotes body weight in kilograms and AT denotes the average exposure duration in years (life expectancy), C is the concentration of the examined heavy metals in the fish, EF is the exposure frequency (days/year), ED is the exposure duration (years), and IR is the ingestion rate of tilapia. Thus, the Estimated Daily Intakes (EDIs) for the pollutants were compared with the Reference Dose values (RfDs). The pollutant will present a relatively high risk if $EDI > Rfd$. Using the reference dosage and Cancer Slope Factor (CSF) of various pollutants, the health risk can be estimated [23].

2.6.2. Noncarcinogenic Effects of Contaminants in Fish. The hazard quotient (HQ) is a commonly used method of risk characterisation, which is the ratio of the predicted exposure to the chemical above the level at which no detrimental effects are expected. The hazard quotient is mathematically expressed as follows:

$$HQ = \frac{EDI}{Rfd \text{ (mg kg}^{-1}\text{day}^{-1}\text{)}}, \quad (3)$$

$$HQ = \frac{C \times IR \times EF \times ED}{BW \times AT \times Rfd},$$

where IR is the ingestion rate (kg/day) for normal adults (≥ 12 years) and children (< 12 years), BW is the body weight, and C is the average chemical level in fish tissues (mg/kg). The frequency of exposure (EF) (365 days/year) is the number of days per year that one is exposed to the contaminant through the consumption of contaminated fish. The exposure duration (ED) is the number of days per year that one is exposed to the contaminant through the consumption of contaminated fish (equivalent to an average of 30 years for adults and 6 for children for USEPA standard). The average lifespan of chemical exposure is denoted by AT (365/366 days $\times$ ED for noncarcinogenic or carcinogenic). Hazard quotient ($HQ > 1$) indicates a noncarcinogenic effect on health, while $HQ \leq 1$ shows no harmful influence on health. According to [24], the exposure thresholds used for health hazard calculations are shown in Table 1.

The oral RfDs of the heavy metals were as follows: As = 0.003 mg/kg/day, Zn = 0.3 mg/kg/day, Fe = 0.36 mg/kg/day,

Ni = 0.2 mg/kg/day, Pb = 0.000035 mg/kg/day, Cr = 0.003 mg/kg/day, and Mn = 0.014 mg/kg/day [25, 26].

The Hazard Index (HI) adapted from [27] is the cumulative toxicity risk of metals on human health. It was obtained to measure the noncarcinogenic threats to humans using the relation in the following equation:

$$HI = \sum_{i=1}^n HQ_i, \quad (4)$$

where HQ_i represents the hazard quotient for the i th metal. Hazard Index ($HI > 1$) indicates a noncarcinogenic effect on health, while $HI \leq 1$ shows no harmful effect.

2.6.3. Carcinogenic Risk Assessment. Individuals may be exposed to cancer through the consumption of fish contaminated with pollutants. To examine this, a carcinogenic risk evaluation, which predicts the likelihood of a person developing cancer over a lifespan, resulting from exposure to possible carcinogens [27], was estimated. The main assessment parameter, called the cancer slope factor (CSF), was obtained from the USEPA carcinogenic risk assessment. The CSF represents the probable upper-bound estimate of the likelihood that a person will develop cancer if exposed to a chemical (cancer-causing agent) for a lifetime of 70 years. Therefore, the target risk of cancer was estimated using the following equation:

$$TCR = EDI \times CSF, \quad (5)$$

where CSF is the cancer slope factor of the individual pollutant and TCR is the target cancer risk. The CSF values used for the carcinogenic estimation for the heavy metals Ni, As, Pb, Cr, and Cd were as follows: Ni = 0.91 mg/kg/day, Cd = 0.38 mg/kg/day, Pb = 0.0085 mg/kg/day, Cr = 0.5 mg/kg/day, and As = 1.5 mg/kg/day [28, 29].

3. Result and Discussion

Six heavy metals (Zn, Fe, Mn, Ni, As, and Cr) were detected in the muscle tissues of tilapia at a 100% frequency of occurrence. Table 2 summarises the findings. Other heavy metals such as copper, cadmium, and lead were below the detection limit. The concentrations of heavy metals at the various sampling points did not differ significantly ($p < 0.05$). The mean concentration of heavy metals ranged from 0.31 mg/kg to 50.11 mg/kg. Fe concentrations of up to 50 mg/kg were detected in the muscle tissues of tilapia at fish farm B (Table 2). In contrast, Cr concentrations were the lowest in tilapia from fish farm A. Only the control samples contained arsenic. Heavy metal concentrations in tilapia tissue from fish farms were classified as follows: Fe > Mn > Zn > Ni > Cr (for fish farm A), Fe > Zn > Ni > Mn (for fish farm B), and Fe > Mn > Zn > Ni > Cr (for fish farm C). Ni, Mn, and Fe had concentrations in the muscles of *O. niloticus* exceeding the USEPA/WHO legal limit for human consumption, implying that fish from the farms could potentially cause Ni-, Fe-, and Mn-related health problems over time.

TABLE 2: Levels of heavy metals concentrations (mg/kg) in caged tilapia from fish farms.

Metals	Fish farm A		Fish farm B		Fish farm C		Controls	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
Zn	2.07 $\pm$ 0.140	1.80–2.28	2.13 $\pm$ 0.33	1.92–2.80	1.82 $\pm$ 0.29	1.80–2.28	0.97 $\pm$ 0.20	0.58–1.11
Fe	37.28 $\pm$ 10.84	21.60–54.80	50.11 $\pm$ 10.22	38.92–62.6	39.58 $\pm$ 9.14	21.6–54.80	11.09 $\pm$ 2.03	8.21–14.21
Mn	3.41 $\pm$ 2.03	1.64–8.80	1.76 $\pm$ 0.69	1.04–3.08	2.46 $\pm$ 0.60	1.64–8.80	0.77 $\pm$ 0.15	0.52–0.96
Ni	1.62 $\pm$ 0.03	1.58–1.64	2.74 $\pm$ 1.87	0.03–5.04	2.00 $\pm$ 0.14	1.58–1.64	0.65 $\pm$ 0.11	0.52–0.81
Cr	0.31 $\pm$ 0.07	0.20–4.00	—	—	0.33 $\pm$ 0.07	0.20–0.40	0.10 $\pm$ 0.02	0.07–0.12
As	—	—	—	—	—	—	0.23 $\pm$ 0.07	0.15–0.32

A small amount of Mn is required for normal human development and growth. The US EPA has established an Rfd of 140 g/kg/day for Mn, which becomes harmful when consumed above this level [30]. The lowest and highest Mn concentrations were found in *Oreochromis niloticus* from the wild and farm A, respectively, at 0.77 mg/kg and 3.41 mg/kg. Aquatic organisms are known to absorb pollutants from the water and store them at much higher concentrations than the rest of their ecosystem; thus, elevated heavy metal concentrations in aquatic organisms' tissues suggest cumulative exposure to Mn-contaminated water [31]. For this study, there were elevated levels of Mn in the analysed fish feed than the maximum residue levels required in the fish diet by FAO (see Table 3). There was also a significant positive correlation of Fe-Mn ($r=0.852$, $p<0.01$) and Mn-Mn ($r=0.852$, $p<0.01$) in fish and fish feed as in Table 4, indicating that the high level of manganese in the caged fish was probably due to the uptake from the fish feed. In this study, the Mn content of tilapia muscle tissues ranged between 0.77 and 3.41 mg/kg (ww). In literature, 0.49–0.84 mg/kg manganese concentrations in *O. niloticus* from Burullus Lake, Egypt, was reported [32], 0.05–4.64 mg/kg dry weight in commercially valuable fish species from Iskenderun Bay, North East Mediterranean Sea, Turkey [33], and 0.22–1.84 mg/kg in freshwater fish from central and eastern Norway has also been reported [34]. Additionally, Mn concentrations in muscle tissue of fish from the Mediterranean and Marmara Seas, Black Sea, and Aegean Sea varied between 0.07–3.62 mg/kg (ww) and 0.03–1.72 mg/kg (ww), respectively [35]. For this study, the Mn content of muscle tissues was within the range previously reported [35] but was lower than the 21.1–33.0 mg/kg (ww) found in Egyptian fish species by [36]. According to WHO standards, the maximum allowable concentration of Mn is 1.00 mg/kg [37]. Mn contents in tilapia muscles tissues from the farms were far beyond the WHO threshold.

Fe is a necessary element for the proper functioning of cells in organisms. Consumption of iron above 700 g/kg/day has been linked to type 2 diabetes and Alzheimer's disease [35]. The lowest and highest Fe concentrations were observed in *Oreochromis niloticus* from the wild and farm B, respectively, at 11.09 mg/kg and 50.11 mg/kg. The levels of Fe in the studied tilapia were far higher than the controls. In addition, the analysed fish feeds in the fish farms, mainly from farms A and C, showed higher levels of Fe beyond the WHO/FAO levels (see Table 3). The Pearson correlation matrix for heavy metal concentrations in fish and fish feed revealed significant correlations between Fe-Fe ($r=0.958$,

$p<0.01$) and Fe-Mn ($r=0.852$, $p<0.01$) in fish feed and tilapia muscles as in Table 2, indicating their similar origins or comparable chemical properties [38]. In line with these, the elevated Fe levels in the farmed fish may be due to the uptake of iron-fortified fish feed during the investigation period. The mean Fe concentrations in this study ranged between 11.09 and 50.11 mg/kg (ww). Fe levels in the study were within the range 5.15–135.00 mg/kg (ww) for fishes from the Turkish Sea [39] but were greater than 0.21–3.59 mg/kg for fishes from the Mediterranean Sea [40]. The highest concentration of Fe was detected in the flesh of tilapia in Egypt's El-Fayoum Province, ranging from 63.6 to 120 mg/kg [36]. El-Batrawy et al. [32] reported Fe concentrations in Burullus Lake fish ranging from 8.42 to 13.18 mg/kg wet weight. Both of these studies found concentrations higher than those obtained in the current study.

Chromium is a critical trace metal required for the biologically useful state of glucose metabolism [41]. Farm C (0.33 ± 0.07 mg/kg) had the highest Cr content (average value) in the consumable portion (tilapia flesh), while farm A (0.31 ± 0.07 mg/kg) had the lowest. There was no significant correlation between the levels of Cr in fish and that of the fish feed (see Table 4). Therefore, the sources of Cr in the tilapia could not be attributed to the fish feed. However, the pottery, clothing, and dyeing factories activities along the Volta Basin likely explain the elevated Cr concentrations in the fish's muscles studied from farms A and C. This local factory uses chromium salts in its dyeing operations [42]. As a result, the Volta Basin may become severely chromium polluted without proper and efficient waste management.

The Cr concentration (0.07 – 4.00 mg/kg) in this study matched the range observed by [33] in fish species from Iskenderun Bay. Taweel et al. [43] determined that *O. niloticus* farmed in Malaysia had Cr concentrations of 5.70 – 6.21 mg/kg (ww), and [44] determined that *T. nilotica* cultivated in Chittagong, Bangladesh's south-eastern region, had Cr concentrations of 0.590 ± 0.052 mg/kg. Both investigations found slightly higher Cr concentrations than this study. Hasan et al. [45] determined a Cr concentration of 0.75 ± 0.02 mg/kg (ww) in market fish from Dhaka, [46] determined a Cr concentration of 0.524 ± 0.053 mg/kg (ww) in cultured fish *Pangasianodon hypophthalmus* in India, and [47] determined a Cr concentration of 0.54 – 2.46 mg/kg in cultured tilapia on Taiwan's southwest coast. Cr levels in all of these regions exceeded those found in our study. On the other hand, the present study Cr concentrations were higher than the 0.15 mg/kg observed by [48] in farmed grass carp in the Pearl River, China. Except for farm B and controls, mean

TABLE 3: Levels of heavy metals concentrations (mg/kg) in the fish feed from fish farms.

Heavy metals	Fish farm A	Fish farm B	Fish farm C	FAO /EU MRL
Fe	109.20	96.14	115.42	100.00
Ni	0.76	0.22	—	8.00
Mn	11.40	11.60	11.90	7.70
Zn	0.26	0.43	0.23	150.00
Cr	—	—	0.44	1.00

Cr levels in tilapia fish species were less than the [49] standard limit of 12–13 mg/kg, but all fish on farms A and C exceeded the FAO [50] approved threshold of 0.15 mg/kg. When Cr is consumed, it plays a critical role in glucose and lipid metabolism. Cr deficiency can impede progress and result in protein, glucose, and lipid metabolism [50]. However, excessive Cr consumption can result in acute respiratory diseases [10] and damage the lungs, liver, and kidneys [51]. When Cr(III) is present in high concentrations in body cells, it has the potential to destroy DNA [44].

Zn is required for the proper functioning of the human metabolic pathways, and thus its deficiency may result in loss of appetite, stunted growth, skin changes, and immune system dysfunction [52]. Additionally, zinc is required for cell division, normal protein synthesis, the immune system, and collagen formation [53]. On the other hand, a higher concentration of Zn becomes harmful to human health [54]. Among the *O. niloticus* under investigation, the highest concentration of Zn was found in fish from farm B. Zn concentrations in the farmed fish followed the following order: farm B (2.13 ± 0.330 mg/kg wet weight) > farm A (2.07 ± 0.140 mg/kg wet weight) > farm C (1.82 ± 0.29 mg/kg wet weight) > controls (0.97 ± 0.20 mg/kg wet weight), which were significantly less than the FAO and WHO permissible limits for Zn in fish of 30 mg/kg and 40 mg/kg, respectively [55]. The Zn metal concentrations in the studied tilapia from fish farms were below the permissible limit for human consumption established by studies in some countries, for example, England (i.e., 50 mg/kg) [55]; El-Fayoum Province, Egypt (49.2–66.3 mg/kg) [36]; and Bangladesh (16.25–0.303 mg/kg) [36]. Others are Taiwan (9.06–26.2 mg/kg) for tilapia [47]; China's Pearl River Delta (25.2 mg/kg) for farmed grass carp [48]; and Malaysia (29–45 mg/kg) for *O. niloticus* [43]. Such elevated Zn levels may result from contamination in the aquatic environment in which the fish are raised.

Humans obtain nickel primarily through natural food sources and food production. The mean Ni concentrations in the *O. niloticus* concentrations in farms A, B, C, and controls were 1.62 ± 0.03 mg/kg, 2.74 ± 1.87 mg/kg, 2.00 ± 0.14 mg/kg, and 0.65 ± 0.11 mg/kg, respectively. Ni concentrations in the entire sampled *O. niloticus* range between 0.65 and 2.74 mg/kg (ww). Ni concentration (2.74 mg/kg) in farm B was consistent with that found in [43, 56], which determined Ni levels in *Tilapia zillii* (2.760 mg/kg) and *Oreochromis niloticus* (2.70 mg/kg) from illegal fish farms near the Sabal Drainage Canal and fish from one of the farm ponds in Malaysia, respectively. Nickel

concentrations in Taiwanese tilapia fish species [47] ranged between 0.27 and 2.28 mg/kg dry weight and 2.7 and 3.2 mg/kg (ww) in *O. niloticus*, native to Malaysia [47]. The range of average Ni levels observed in muscle tissues for this study was consistent with that of previous researches, though it was higher than the range 0.46–0.58 mg/kg (ww) reported by [32] in fish species from Burullus Lake in Egypt and 0.24 mg/kg in farmed Grass carp in China's Pearl River Delta [48]. *O. niloticus* from an unauthorised fish farm in the Sabal drainage canal had a Ni content of 4.611 mg/kg, which was higher than our findings in all the farms [57]. Increased metal concentrations in drainage water discharged into the Sabal Drainage Canal could explain the higher Ni value in the illegally farmed *O. niloticus* muscles than those examined in this study. The Sabal Drainage Canal water is contaminated by fertilisers, agricultural chemicals (pesticides and metals), excess nutrients, and other contaminants from industrial discharge [58]. All tilapia fish samples had Ni levels greater than the WHO-recommended permissible level of 0.5–0.6 mg/kg [59]. A high Ni intake can result in lung and nasal cavity cancer. Ni poisoning symptoms include skin rashes, chest pain, vomiting, nausea, headache, dizziness, diarrhoea, coughing, and body weakness. Prolonged exposure to Ni vapour can enlarge the brain, liver deterioration, eye discomfort, and a variety of cancers [60].

Arsenic has been classified as a human carcinogen by the International Agency for Research on Cancer [61]. Arsenic is found in both organic and inorganic components in nature. Arsenic in its inorganic form is much more toxic than arsenic in its organic form. Arsenic poisoning can result in bladder, lung, kidney, and skin cancers [44]. Arsenic in the wild fish was most likely derived from natural geological sources as well as pollution caused by industrial activities prevailing in the study area. Arsenic level in wild tilapia (control samples) was 0.23 mg/kg (ww), below the tolerable limit of 1 mg/kg proposed by FAO/WHO. The current study's reported level was higher than 0.096 mg/kg reported by [62] in cultured cyprinid fish species from Northeast China, 0.023 mg/kg in Bangladeshi fish [44], 0.002 mg/kg in Taiwanese tilapia [47], and 0.04 mg/kg in Pearl River Delta Grass [48]. However, the study As level was less than the average value of 0.332 mg/kg determined in Bangladesh by [63].

When the values from this investigation were compared to those of other local investigations, the values from this study were higher than those in [41, 64], except Zn in River Densu, which was approximately 14 times greater than the values from this study. Ansah et al. [65] determined that the levels of heavy metals in the Weiija reservoir were significantly higher than those in cage tilapia from the Volta Basin.

3.1. Heavy Metals Carcinogenic and Noncarcinogenic Risk Assessment. The average daily intake of Cr, Mn, Zn, Ni, and Fe in children and adults who consumed tilapia from the Volta Basin's various cage aquaculture facilities is shown in Table 5. The EDI for heavy metals in fish was significantly less than the Rfd set by the USEPA (2012). For the metals examined, farms B and C had the highest Fe values in the

TABLE 4: Pearson's correlation for heavy metal concentrations in fish and fish feed.

Metals	Zn	Fe	Mn	Ni	Cr
Zn	0.321	0.215	0.411	0.310	0.247
Fe	0.215	0.958**	0.852**	0.472	0.311
Mn	0.411	0.852**	0.745**	0.222	0.363
Ni	0.310	0.472	0.222	0.267	0.136
Cr	0.247	0.311	0.363	0.136	0.481

**Correlation is significant at $p < 0.01$ level (two-tailed).

TABLE 5: Estimates of average daily dose (mg/kg/day) of heavy metals in tilapia for children and adults for noncarcinogenic risk.

Metal	Fish farm A		Fish farm B		Fish farm C		Control	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Zn	$2.76E-05$	$2.96E-06$	$2.84E-05$	$3.05E-06$	$2.43E-05$	$2.60E-06$	$1.29E-05$	$1.39E-06$
Fe	$7.72E-09$	$5.33E-05$	$6.68E-04$	$7.17E-05$	$5.27E-04$	$5.66E-05$	$1.48E-04$	$1.58E-05$
Mn	$4.55E-05$	$4.88E-06$	$2.34E-05$	$2.52E-06$	$3.28E-05$	$3.52E-06$	$1.03E-05$	$1.10E-06$
Ni	$2.16E-05$	$2.32E-06$	$3.65E-05$	$3.92E-06$	$2.67E-05$	$2.86E-06$	$8.67E-06$	$9.29E-07$
Cr	$4.13E-06$	$4.43E-07$	—	—	$4.39E-06$	$4.72E-07$	$1.33E-06$	$1.43E-07$
As	—	—	—	—	—	—	$3.07E-06$	$3.29E-07$

TABLE 6: Noncarcinogenic HQ of heavy metals in cage tilapia for children and adults.

Metal	Fish farm A		Fish farm B		Fish farm C		Control	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Zn	$9.20E-05$	$9.87E-06$	$9.47E-05$	$1.02E-05$	$8.10E-05$	$8.67E-06$	$4.30E-05$	$4.63E-06$
Fe	$2.14E-08$	$1.48E-04$	$1.86E-03$	$1.99E-04$	$1.46E-03$	$1.57E-04$	$4.11E-04$	$4.39E-05$
Mn	$3.25E-03$	$3.49E-04$	$1.67E-03$	$1.80E-04$	$2.34E-03$	$2.51E-04$	$7.36E-04$	$7.86E-05$
Ni	$1.08E-04$	$1.16E-05$	$1.83E-04$	$1.96E-05$	$1.34E-04$	$1.43E-05$	$4.34E-05$	$4.65E-06$
Cr	$1.38E-03$	$1.48E-04$	—	—	$1.47E-03$	$1.58E-04$	$4.43E-04$	$4.77E-05$
As	—	—	—	—	—	—	$1.02E-02$	$1.10E-03$
HI	$4.83E-03$	$6.66E-04$	$3.81E-03$	$4.08E-04$	$5.48E-03$	$5.88E-04$	$2.04E-02$	$1.09E-03$

TABLE 7: EDI of heavy metals in tilapia for children and adults for carcinogenic risk.

Metal	Fish farm A		Fish farm B		Fish farm C		Control	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Zn	$2.36E-06$	$1.26E-06$	$2.43E-06$	$1.30E-06$	$2.07E-06$	$1.11E-06$	$1.11E-06$	$5.76E-07$
Fe	$4.25E-05$	$2.28E-05$	$5.71E-05$	$3.06E-05$	$4.51E-05$	$2.42E-05$	$1.27E-05$	$6.60E-06$
Mn	$3.89E-06$	$2.08E-06$	$2.01E-06$	$1.08E-06$	$2.80E-06$	$1.50E-06$	$8.80E-07$	$4.59E-07$
Ni	$1.85E-06$	$9.90E-07$	$3.12E-06$	$1.67E-06$	$2.28E-06$	$1.22E-06$	$7.43E-07$	$3.87E-07$
Cr	$3.53E-07$	$1.89E-07$	—	—	$3.76E-07$	$2.02E-07$	$1.14E-07$	$5.96E-08$
As	—	—	—	—	—	—	$2.63E-07$	$1.37E-07$

TABLE 8: Cancer risk estimations of heavy metals in cage tilapia for children and adults.

Metal	Fish farm A		Fish farm B		Fish farm C		Control	
	Children	Adults	Children	Adults	Children	Adults	Children	Adults
Cr	$1.77E-07$	$9.45E-08$	—	—	$1.88E-07$	$1.01E-07$	$5.70E-08$	$2.98E-08$
Ni	$5.55E-08$	$2.97E-06$	$9.36E-06$	$5.01E-06$	$6.84E-06$	$3.66E-06$	$6.76E-07$	$3.52E-07$
As	—	—	—	—	—	—	$3.95E-07$	$2.06E-07$
HI	$2.33E-07$	$3.06E-06$	$9.36E-06$	$5.01E-06$	$7.03E-06$	$3.76E-06$	$6.77E-07$	$3.54E-06$

entire EDI. Although the Fe and Mn contents of *O. niloticus* muscular tissue tested were above their respective WHO/WPCL/USEPA thresholds, their calculated EDI values were

below the Rfd levels, indicating that these metals pose no risk to humans. However, because heavy metals can accumulate to lethal levels in fish, metal contamination in cage farms

must be monitored regularly. This can assist in ensuring food safety and identifying any potential health risks associated with eating fish from cage farms.

The hazard quotients (HQ) of metals ingested through fish in the Volta Basin are shown in Table 6. In all of the samples examined, the HQ results for heavy metals in fish ingested by adults and children were consistently less than one. As a result, eating fish farmed in cage aquaculture facilities poses no noncarcinogenic threat to the general public's health. It is also critical to consider the additive effect of pollutants on the population regarding noncarcinogenic risks when assessing the potential consequences for people. The hazard indices of the various metals investigated in this work were less than one for all fish from fish farms analysed and controls. This means that consuming heavy metals from any fish studied poses no significant noncarcinogenic risk to humans.

In Table 7, the computed EDI for carcinogenic risk has been presented. The cancer risk was evaluated using the appropriate carcinogenicity factors for each metal, and the results were reported (see Table 8) based on the carcinogenic risk of the observed EDI. The USEPA issued cancer risk regulations ranging from 1.0×10^{-6} to 1.0×10^{-4} (USEPA, 2012). The study findings revealed that the estimated cancer risk for Cr, As, and Ni resulting from consumption of the examined *O. niloticus* from cage aquaculture facilities and the wild was within the USEPA limits. According to the findings of this study, the overall cancer risk of the metals in the fish studied has no impact on the cancer risk for both children and adults who consume fish from the caged farms in the Volta Basin.

4. Conclusions

The results indicate that Zn, Cr, As, Mn, Ni, and Fe were detected in variable concentrations in all samples, with the level of accumulation varying among tilapia fish from different farms. Except for Ni, Mn, and Fe, which exceeded permissible levels in fish tissues for human consumption, all other metals in the *Oreochromis niloticus* muscles were below the USEPA/WHO MRL, implying that fish from the fish farm could potentially cause Ni-, Fe-, and Mn-related health problems over time. According to existing consumption trends, the researchers concluded that the metals of concern provide a negligible noncarcinogenic risk to persons who consume caged tilapia. The cumulative effects of all metals have a hazard index of less than one, effectively eliminating any significant health risk. Furthermore, TCR estimations imply a negligible carcinogenic risk from As, Cr, and Ni if the tested cultured fish are ingested at their current rate.

Data Availability

The datasets generated during the current study are not publicly available due to the University policy on data restriction until PhD thesis is wholly examined. However, data are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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