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Analyses of Heavy Metals Bioaccumulation in the Organs of *Clarias gariepinus* Following Exposure to Sub-Lethal Concentrations of Waste Burnt Tire Residues

Sulaiman Yusuf [a]*, Audu Bala Sambo [b]
and Wade John Wokton [b]

[a] Department of Zoology, Nasarawa State University Keffi, Nasarawa State, Nigeria.
[b] Department of Zoology, Faculty of Natural Sciences, University of Jos, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study evaluated the bioaccumulation of certain heavy metals of waste burnt tire residues (WBTRs) in certain organs (viz-gills, liver, kidney and muscles) of *Clarias gariepinus* following exposure to sublethal concentrations (SLCs) of water-soluble fractions (WSFs) of WBTRs. *Clarias gariepinus* (average weight of 47.95±0.34g and length of 15.54±0.36cm) were exposed to SLCs at different concentrations (0.00, 0.23, 0.47, 0.94, 1.87, and3.74 ppm) of WSFs of WBTRs for a period

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**Corresponding author: Email: ysulaiman371@gmail.com;*

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of fifty-eight days. Heavy metal concentrations in WBTRs and in the organs of the experimental fish were measured using a handheld X-Ray Fluorescence Analyzer (NitonXL3T). Results showed that strontium, lead, zinc, cobalt, bismuth, rubidium, gold, tungsten, iron, thorium, arsenic, copper, and niobium were detected in WBTRs although the maximum level of zinc was perceived however, no significant difference (P>0.05) was observed as compared to the control group regarding heavy metal accumulation in muscles, 53.10±12.78; liver, 56.30±76.96; kidney, 164.54±12.78; and gills, 241.36±146.87 of the exposed fish. The high levels of heavy metals present in WBTRs are of great concern as potential detrimentl pollutants to the aquatic ecosystem. These allochthonous inputs get into the aquatic ecosystem through sewage flow and runoffs effluents. Resident non-target communities particularly fishes from such polluted aquatic systems with WBTRs become vunerable and incriminated with attendant high levels of heavy metals that could be detrimental to human consumers.

Keywords: Bioaccumulation; Burnt tire ashes; Catfish, Heavy metals; Pollution.

1. INTRODUCTION

The fact that there are around 1.5 billion trash tires produced annually globally poses a serious threat to the environment, as evaluated by (Amir & Thomas, 2016). Waste tires are non-biodegradable and despite recycling efforts, the majority of these tires get disposed off as landfills or are discarded without concern to the potential harm to the environment (Amir & Thomas, 2016). Lulu et al. (2020) observed that the majority of such tires end up in landfills or other garbage dumps. In Nigeria such, waste tires are burnt to recover materials like iron and steel, which are then used for a variety of purposes. But when tires are burnt outside, harmful substances including carbon black, zinc oxide, wax, sulfur, and heavy metals like cadmium, Cronium, iron, lead, and zinc are released (Aya & Nwite, 2016). These substances spread throughout the atmosphere and other habitats before entering the aquatic ecosystems. (Aya & Nwite, 2016). Undoubtedly, studies have demonstrated that burning tires release a range of air pollutants, the majority of which are well-known carcinogens, as well as particulate matter and volatile organic compounds (Francis et al., 2018).

These heavy metals may bioaccumulate in aquatic species upon entry into aquatic systems, causing physiological dysfunction in the aquatic biota and possibly decrease fish populations (Luo et al., 2014). Invariably, major heavy metals accumulation in fishes occurs in the organs including the gills, liver, kidney, and muscles, This may apparently become extremely harmful to both aquatic faunal species and fish consumers (Graciela et al., 2014). Extensive research have documented elevated concentrations of heavy metals, including cadmium (Cd), nickel (Ni), cobalt (Co), and zinc (Zn), in the vicinity of waste tire burning sites. These levels are frequently greater than the highest permissible threshold values established by global health organizations (Anaf & Emad, 2014; Beetseh & Onum, 2013). Both fish and humans who consume such fishes may be negatively impacted by these metals when they build up to hazardous levels in the exposed fish (Olaniyi et al., 2019). Excessive consumption of African catfish, (*Clarias gariepinus*,) has been linked to heavy metals contamination in other fish species in Nigeria (Olaniyi et al., 2019). This species is considered crucial for ecological monitoring.

Numerous studies have documented the bioaccumulation of heavy metals in various fish organs; with some of these metals, such as chromium and mercury, above WHO/FAO acceptable limits (Graciela et al., 2014). Indeed, it has been established that XRF analysis is the fastest, non- destructive method for determining if different biological samples, soils, and sediments contain heavy metals pollution (Jacqueline et al., 2014). The technique has been used in research works to evaluate eavy metals in fish muscles that come from coastal areas where high concentrations of metals like iron, zinc, lead, and copper have been found (Yusuf & Othman 2014). Similar methods were applied to the analyze heavy metals from dried fish samples in Bangladesh, where the concentration of metals were reported in the order Fe > Zn > Hg > Cu> Cr (Refat et al., 2022). This result demonstrates the frequency of metal pollution in fish and emphasized the necessity of routine monitoring, particularly in areas where used tires are burn or used as fuel.

Thus, the X-Ray fluorescence technique was adopted to measure heavy metals bioaccumulation in the organs of *C. gariepinus* juvenile after exposure to sub-lethal amounts of waste burnt tire residues. The assessment of the environmental impacts resulting from waste tire burning and potential threats to human and ecological health will be improved by knowing the extent of heavy metals buildup particularly in versatile travelled aquatic species.

2. MATERIALS AND METHODS

2.1 Collection of Waste Burnt Tire Residues

Tire waste was collected from Ring Road in Jos North Local Government Area, Plateau State, Nigeria, where an inconceivably large quantity of tires is used every day to tenderize rocks. Remaining (black rubber) and steel components were isolated from waste tire fragments. The latter was ground into a powder using a mortar and pestle, and the resulting 40µm-sized particles were filtered through an ASTM D40µm mesh screen. For 48 hours, the 500g of sieved particles were macerated in 5 L of distilled water while being constantly stirred with a magnetic stirrer. The mixture was passed through a non-absorbent cotton wool-lined plastic funnel,for collecting the WSF filtrate in a plastic container for later use (Bala & Malachy, 2020).

2.2 Collection and Acclimation of Experimental Fish (*Clarias gariepinus*)

Exactly, one hundred and twenty live, apparently healthy mixed-sex juveniles of *C. gariepinus*, with a mean weight of 46.9±0.3.44g and a total length of 14.54±0.36cm, were acquired from Catfish Expert Global Venture Farm in Zarmaganda, Jos, Plateau State, Nigeria. They were then brought to the Department of Zoology, Aquaculture Laboratory of Hydrobiology and Fisheries Unit, at the University of Jos, Nigeria. A week was spent acclimating fish to laboratory conditions in six (6) 35L plastic tanks that were filled with 20L of borehole water each. Daily around 8:00 a.m., the water in the holding tanks was replaced. Commercial feed (Coppens®) was supplied twice a day, at 8:00 AM and 5:00 PM, until the fish were fully satisfied. To remove feces and leftover feed, three-quarters of the water in the tank was drained off each day and replaced with fresh water.

2.3 Sublethal Exposure to Water-Soluble Fractions of Burnt Tire Residues: Test Procedure

The LC_{50} (11.22 g/L) value of WSF of WBTRs on *C. gariepinus* juveniles reported by Bala and Malachy, (2020) was serially diluted to produce successive SLCs of 11.22 g/L at the 1/3rd, 1/6th, 1/12th, 1/24th, and 1/48th levels (Bala et al., 2014). Five sublethal test concentrations were used (3.74, 1.87, 0.93, 0.47, and 0.23g/L), as well as a control (0.00g/L). Renewable bioassays lasted 58 days, or two months. The test fish were fed commercial feed (Coppens®) twice a day at 8:00 AM and 5:00 PM until they were satisfied. Photoperiod was normal (12 hours of light and 12 hours of darkness).

2.4 Experimental Design

The sub-lethal toxicity experiment was done in six rectangular glass tanks, employing a randomized complete block design (40x25x23cm) with 120 mixed-sex *C. gariepinus* juveniles average 47.95±3.44g and 15.54±0.36 cm in length. Each of the six glass tanks was filled with 10L of borehole water, and five of the tanks were infected with varying concentrations of WSFs and WBTRs, followed by the introduction of ten mixed sex *C. gariepinus* juveniles (Bala and Malachy, 2020). The remaining two control tanks (0.00g/L) each held ten juveniles and were not injected with the test substance. The experimental setting was replicated.

2.5 Heavy Metals Loads Determination

Using an X-ray fluorescence analyzer, the NitonXL3T, waste burned tire residues were collected along Ring Road in the Jos North Local Government Area of the Plateau and analyzed for heavy metals. An X-Ray Fluorescence Analyser NitonXL3T was therefore used to study the bioaccumulation of heavy metals in the gills, liver, kidney, and muscles of *C. gariepinus* juveniles exposed to 58-day SLCs of WSFs or WBTRs.

2.5.1 Heavy metals loads in waste burnt tyre residues

Heavy metals such Mo, Zr, Sr, U, Rb, Th, Pb, Au, Se, As, Hg, Zn, W, Cu, Ni, Co, Fe, Mn, Sb, Sn, Cd, Pd, Ag, Nb, Bi, Pt, Re, Ta, Hf, Cr, V, and Ti were evaluated in WBTRs using the X-Ray Fluorescence Analyzer NitonXL3T. WBTRs were subjected to XRF analysis in an XRF thin film (Rinklebe et al., 2021).

2.5.2 Heavy Metal Accumulation in *Clarias gariepinus* Organs Exposed to Sublethal Levels of Burnt Tyre Residue

Blood traces were removed from *C. gariepinus* organs treated with SLCs or WSFs or WBTRs after 58 days of inoculation with distilled water. An air-dry method and a laboratory mortar and pestle were used to pulverize the excised organs. X-ray fluorescence (XRF) thin film mounting of dried organs was done, and the organs were reviewed using XRF (Basco et al., 2010).

Precisely, three locations on each of the ground-up fish samples received the radiation beam directed from the instrument aperture. Subsequently, it was controlled via a soft-touch, intuitive screen interface, and the outcomes were shown on the connected PC for printing. The instrument software computed the quantitative results. The results given for each sample are the average of the three measurements that were made, with the principal elements being identified and expressed in parts per million (ppm).

3. RESULTS

Heavy Metals Loads: Heavy metals load in WBTRs recovered from Ring Jos, Plateau State;Nigeria revealed the bioaccumulation of heavy metals in the organs of *C. gariepinus* juveniles on 58-day exposure of the WSFs of WBTRs.

Waste Burnt Tire Residues obtained from Ring Road, Jos Plateau State, Nigeria included the following, Sr, Pb, Zn, Co, Bi, Rb, Au, W, Fe, Th, As, Cu, and Nb. The highest and lowest mean Zn and Nb levels were 92540.31±1439.69 and 5.76±3.05 ppm, respectively. Th, Sr, As, Bi, Au, and Pb showed less than 100 ppm values; the respective values are 16.52±5.69, 17.99±2.66, 18.50±11.41, 72.62±12.19, 83.59±13.07 and 98.12 ± 11. 51 ppm, whereas those of Cu, W, Fe, Co, and Zn were above 100 to 201.52±30.54, 931.03±190.19, 2079.23±93.83, 2858.17±125.09, and 92540.31 ± 1439.69, respectively. The increasing order of the number of heavy metals in the test material is given as: Nb < Th < Sr < As < Bi < Au < Pb < Cu < W < Fe < Co < Zn.

Heavy Metal Load in *Clarias gariepinus* Exposed to Sublethal Burnt Tyre Residue Fractions: After the juvenile *C. gariepinus* fish were exposed to the WSFs of WSBTRs for 58 days, the heavy metal burden in their muscles, liver, kidney, and gills were determined using an XRF machine. Heavy metals such as Sr, Rb, Pb, As, Zn, Fe, and Nb were found in the gills of the *C. gariepinus* juveniles that were exposed for 58 days to SLCs of WSFs of WBTRs (Table 2). Rb, Pb, As, and Zn had the maximum values at 1.87g/L, with values of 29.01±20.36, 75.79±5.79, 18.74±8.74, and 314±95.57 ppm, respectively. Sr and Nb had maximum values of 21.09±1.74 and 19.32±2.00 at maximum concentrations, respectively, whereas Fe levels were highest at 9.40 and lowest at control concentrations of 229.56±29.56 and 0.00±0.00, respectively, at minimum concentrations. All of the heavy metals with a P-value of >0.05 showed no discernible change when compared to the control.

Table 1. Mean Heavy Metals Loads in Waste Burnt Tires Residues obtained from Sites of Tenderizing Rock at the Ring Road of Jos North, Plateau State, Nigeria

Heavy Metals	Mean Conc. Of HM (ppm)	Percentage (%) of HM	WHO Permissible Level (mg/L)	US EPA Permissible Level (mg/L)
Nb	5.76±3.05	0.01	No specific limit	No specific limit
Th	16.25±5.69	0.02	No specific limit	No specific limit
Sr	17.99±2.68	0.02	No specific limit	No specific limit
As	18.50±11.41	0.02	0.01	0.01
Bi	72.62±12.19	0.07	No specific limit	No specific limit
Au	83.58±13.07	0.09	No specific limits	No specific limits
Pb	98.12±11.51	0.10	0.01	0.015
Cu	201.52±30.54	0.20	2.0	1.3
W	931.03±190.19	0.94	No specific limits	No specific limits
Fe	2079.23±93.83	2.10	Up to 0.3	0.3 (secondary standard)
Co	2858.17±125.09	2.89	<0.05	No specific limit
Zn	92540.31±1439.7	93.54	Up to 5.0	5.0

(Sr=Strontium, Pb = Lead, Zn = Zinc, CO = Cobalt, Bi = Bismuth, Rb = Rubidium, Au = Gold, W = Tungsten, Fe = Iron, Th = Thorium, As = Arsenic, Cu = Copper, Nb = Niobium, ± = Mean standard error and WBTRS = Waste burnt tyre residues) No specific limit indicates that there are no specific recommended limits for those metals by the WHO or US EPA.

Table 2. Heavy Metals Loads in the Gills of *Clarias gariepinus* Juveniles

Conc (g/L)	Heavy metals in Gills (ppm)							
	Sr	**Rb**	**Pb**	**As**	**Zn**	**Fe**	**Nb**	**Total**
0.00	20.85±1.1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	18.21±3.7	39.06±4.87
0.23	21.05±1.8	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	18.49±0.8	39.54±2.63
0.47	19.71±2.8	11.5±11.5	44.31±44.3	6.82±6.82	208.16±208.2	31.18±31.2	14.78±2.4	336.48±307.2
0.94	21.33±2.6	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	229.56±9.6	18.52±1.1	269.41±13.3
1.87	17.95±3.9	29.1±20.4	75.79±0.8	18.74±0.7	314.40±95.8	50.47±0.47	14.65±0.4	521.01±122.4
3.74	21.02±1.7	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	19.32±2.0	40.34±3.74
P values	0.92	0.31	0.57	0.55	0.54	0.60	0.46	

Values with asterisks () in the same column indicate significant difference (P<0.05) compared with the control (Conc.=Concentrations, Sr=Strontium, Pb=Lead, Zn=Zinc. Rb=Rubidium, Fe=Iron, As=Arsenic Nb=Niobium and ±= Mean standard error)

Table 3. Bioaccumulation of Heavy Metals in Liver of *Clarias gariepinus* Juveniles

Conc.(g/L)	Heavy metals (ppm)			
	Sr	**Fe**	**Nb**	**Total**
0.00	22.77±0.07	0.00±0.00	17.29±2.32	40.06±2.39
0.23	22.66±1.22	72.79±0.40	16.33±0.61	111.78±2.23
0.47	23.57±0.03	0.00±0.00	17.24±1.32	40.81±1.35
0.94	24.74±1.85	0.00±0.00	16.20±0.45	40.94±2.30
1.87	22.55±1.24	0.00±0.00	15.99±0.52	38.54±1.76
3.74	24.34±0.63	7.99±7.99	17.09±0.18	49.42±8.80

Conc.=Concentrations ±= Mean standard error, Sr= Strontium, Fe = Iron, Nb= Niobium

Table 4. Heavy Metals Load in the Kidney of *Clarias gariepinus* Juveniles

	Heavy Metals (ppm)								
Conc (g/L)	**Sr**	**Rb**	**Pb**	**As**	**Zn**	**Cu**	**Fe**	**Nb**	**Total**
0.00	22.55±0.05	0.00±0.0	0.00±0.00	0.00±0.00	0.00±0.0	0.00±0.00	7.40±0.40	4.78±2.42	34.73±2.87
0.23	23.98±1.00	0.00±00	0.00±0.00	0.00±0.00	0.00±0.0	0.00±0.00	0.00±0.00	17.19±0.00	41.17±1.00
0.47	24.49±1.93	0.00±0.0	0.00±0.00	0.00±0.00	0.00±0.0	224.64±0.6	0.00±0.00	16.20±0.84	265.33±3.4
0.94	21.67±0.32	9.08±0.9	17.67±11.2	19.71±10.3	4.68±0.7	0.00±0.00	89.16±33.7	14.76±0.18	276.7±57.3
1.87	24.97±0.55	0.00±0.0	0.00±0.00	0.00±0.00	0.00±0.0	0.00±0.00	0.00±0.00	16.05±0.89	41.02±1.44
3.74	22.33±1.91	4.54±4.5	108.07±8.1	23.49±0.49	5.01±0.0	0.00±0.00	22.72±0.72	13.73±0.045	199.9±15.8

Where: ±= Mean standard error, Conc.= Concentrations, Sr = Strontium, Pb = Lead, Zn = Zinc, Rb = Rubidium, Fe = Iron, As = Arsenic, Cu = Copper, and Nb = Niobium

Table 5. Bioaccumulation of Heavy Metals in Muscles in *Clarias gariepinus* Juveniles

Conc. (g/L)	Heavy metal in muscle (ppm)			
	Sr	**Fe**	**Nb**	**Total**
0.00	23.78±3.53	0.00±0.00	15.97±0.29	39.75±3.82
0.23	22.62±0.97	0.00±0.00	15.75±1.96	38.37±2.93
0.47	23.81±1.22	70.01±0.01	15.13±0.01	108.95±1.24
0.94	26.38±2.16	0.00±0.00	15.97±1.57	42.35±3.73
1.87	21.38±0.61	0.00±0.00	17.07±0.46	38.45±1.07
3.74	20.12±1.06	0.00±0.00	17.28±0.14	37.40±1.20

Note: ± = Mean standard error, Conc.= Concentrations, Sr = Strontium, Fe = Iron, Nb = Niobium

Table 6. Heavy Metals Loads in Gills, Liver, Kidney and Muscles of *Clarias gariepinus* Juveniles

Conc. (g/L)	HMLG (ppm)	HMLL (ppm)	HMLK (ppm)	HMLM (ppm)	MTCHMC (ppm)
0.00	39.06±4.87	40.06±2.39	34.73±2.87	39.75±3.82	38.40±3.48
0.23	39.54±2.63	111.78±2.23	41.17±1.00	38.37±2.93	57.72±2.20
0.46	336.48±307.17	40.81±1.35	265.33±3.41	108.95±1.24	187.89±78.30
0.94	269.41±13.28	40.94±2.30	276.73±57.30	42.35±3.76	157.36±19.16
1.87	521.01±122.35	38.54±1.76	39.58±0.00	38.45±1.07	159.40±31.30
3.740	40.34±3.74	49.42±8.80	199.89±15.79	37.40±1.20	81.7625±7.38
MHLO	241.36±146.87	56.30±76.96	164.54±12.78	53.10±12.78	123.13±63.52
P value	0.17	0.00	0.01	0.00	0.02

HMLS=Heavy Metals load in skin HMG= Heavy Metals load in gills
HMLL= Heavy Metals load in liver HMTM= Heavy Metals load in kidney
HMLM=Heavy Metals load in muscles MHLO=Mean heavy load in organs
MTCHO=Mean Total Concentrations of Heavy Metals (ppm) in each Concentration

Heavy Metals Load in Liver of *Clarias gariepinus* Juveniles: Heavy metals such as Sr, Fe, and Nb were found in the livers of *C. gariepinus* juveniles exposed to WSF or WBTR SLCs for 58 days. The maximum Sr and Nb values were 24.74±1.85 and 17.29±2.32ppm at 0.94 and 0.00 g/L, respectively. Table 3 shows that the minimum Sr and Nb values were 22.77±1.24 and 15.99±0.52ppm in 1.87 g/L, respectively. There was no significant difference in the identified heavy metals compared to the control

Heavy Metals Load in Kidney of *Clarias gariepinus* Juveniles: Among the detectable heavy metals in the kidney of the exposed fish were Sr, Rb, Pb, As, Zn, Fe, Cu, and Nb (Table 4). In the control tank (0.00g/L), only Sr, Fe, and Nb were detected in the kidneys. Maximum values of Rb as 9.08±0.92ppm, Pb as 117.67±11.29ppm, and Fe as 89.16±33.67ppm were recorded at 0.94g/L. The maximum value for Cu as 224.64±0.64ppm was recorded at 0.47g/L. Maximum quantity of As and Zn were 23.49±0.49ppm and 5.01±0.01 ppm, respectively, at 3.74g/L with no significant difference of P value >0.05 between the identified heavy metals and the control.

Heavy Metals Load in Muscles of *Clarias gariepinus* Juveniles: After *C. gariepinus* was exposed to SLCs of WSFs of WBTRs, three heavy metals—Sr, Fe, and Nb—were found in its muscles (Table 5). The highest result for Sr, 26.38±2.16ppm, was found in the muscles of the experimental fish subjected to 0.94g/L of WSFs or WBTRs. Recorded at 3.74g/L, the maximum Nb value was 17.28±0.14ppm. 20.12±1.06 and 15.13±0.01 ppm, at 3.74 and 0.47 g/L, respectively, were the lowest values for Sr and Nb. In the muscles of all fish exposed to SLC, as well as in the controls, Fe was not found.

Comparative Heavy Metals Loads in Gills, Liver, Kidney and Muscles of *Clarias gariepinus* Juveniles Exposed: After 58 days of exposure to SLCs of WSFs of WBTRs, *C. gariepinus* juveniles had mean heavy metal levels of 53.10±12.78, 56.30±7.69, 164.54±12.78, and 241.36±146.87ppm in their muscles, liver, kidney, and gills (Table 6). Heavy metal loads in *C. gariepinus* juveniles exposed to WSFs of WBTRs were measured in the following order: muscles, liver, kidney, and gills. Heavy metal concentrations of 1.87 and 0.00g/L resulted in the greatest (187.89±78.30) and lowest (38.40±3.48) mean values, respectively

(Table 6). There was no significant difference ($P>0.05$) in heavy metal levels in all organs tested in *C. gariepinus* juveniles exposed to 58-day SLCs of both W.

4. DISCUSSION

One of the main causes of heavy metal pollution in the environment has been shown to be open waste tire burning (Anaf & Emad, 2014). There were variations in the average concentrations of the heavy metals found in WBTRs collected from Ring Road in Jos Plateau State,Nigeria according to the findings of a heavy metal analysis conducted utilizing portable XRF equipment. Nb > Th > Sr > As > Bi > Au > Pb > Cu > W > Fe > Co > Zn was the trend order for heavy metals. Anaf and Emad, (2014) also made a similar discovery and discovered that the scrap tire burning site had rising orders of concentrations of the following heavy metals: Cd, Ni, Co, As, Cr, Mn, Fe, Cu, Pb, and Zn. The waste tires of the passengers also revealed heavy metals like Fe, Zn, Cd, Cr, and Pb in the ashes. The highest number of metals among these was from Pb and Zn (Shakya et al., 2006), in agreement with this study. These results are consistent with a study by Adebola and Peter (2020) that found that the highest Zn concentrations were found in passenger vehicle and motorcycle end-of-life tire ashes, followed by Cu, Cr, Cd, and Pb. Thus, our findings are consistent with those published by Hyeryeong (2022), who found that among tire samples from South Korea, France, and China, Zn had the highest average levels, followed by Cu, Pb, Sn, Sb, Ni, Cr, As, and Cd. The increasing order of concentrations of heavy metals Cd, Pb, Mn, Cu, Co, Ni, Cr, Mg, Fe, and Zn in the emissions from burning particulate matter of discarded vehicle tyres was given as (Jimoda, et al. 2017), which corroborates the trend established in this study.

The XRF results for the collected WBTRs sample reveal a higher level of heavy metals than those reported by Adebola and Peter (2020) and Hyeryeong (2022), who used an atomic spectrometer machine to report that the metal load was relatively low at the scrap tire burning site and, in the end, -of-life tyre ashes from passenger cars and motorcycles. The findings additionally validated that XRF is a reasonably priced, quick, and non-destructive screening method for identifying heavy metals in contaminated soils, sediments, and biological materials (Jacqueline et al., 2014).

In relation to aquatic life, metal buildup in fish organs can therefore be interpreted as a broad indicator of metal contamination (Graciela et al., 2014). When *C. gariepinus* juveniles were exposed to sublethal doses of WSF of WBTRs for 58 days, the heavy metal burden rose in the following order: muscles (53.10 ± 12.78), liver (56.30 ± 76.96), kidneys (164.54 ± 12.78), and gills (241.36 ± 146.87).

The muscles of *C. gariepinus* juveniles treated for 58 days with sublethal dosages of WSF of WBTRs bioaccumulated the fewest heavy metal residues; this observation may be explained by the fact that the muscles do not come into direct contact with the WSF of WBTRs. The reason for this could be because muscle tissue has a higher growth factor, which lowers the amounts of heavy metals. Muscle does not work as actively as the kidney, liver, and gills do in terms of aggregating metals (Jimoda et al., 2017). Inadequate muscle protein binding may be linked to a low propensity for metal aggregation (Squadrone et al., 2013).

The present studies' findings are consistent with those of other earlier research, some of which are included below. Compared to other tissues, the muscle of fish exposed to contaminants, specifically heavy metals, has consistently bioaccumulated a lower heavy load (Mohsen et al., 2016). This is consistent with (Mohsen et al., 2016), who observed that following a six-week sublethal exposure, Zn bioaccumulation in the muscles of *O. niloticus* was less than that in the liver, kidney, and gills.

The results of Abdel-Wahab et al., (2020) after 20 days of exposure to lead nitrate $Pb(NO_3)_2$ in *C. gariepinus* muscles showed reduced bioaccumulation in comparison to gills and liver. According to Francine et al., (2015), muscle of *P. lineatus* juveniles subjected to acute doses of 0.00, 25, 250, and 2500 mg/L for 96 hours showed the least amount of Ni accumulation. These results are consistent with their findings. Within a laboratory setting, yearlings of *Tor putitora* and *Ctenopharyngondon idella* were exposed to varying amounts of lead nitrate for a duration of sixty days. The authors also observe that Pb bioaccumulation happened in the following order after 60 days of exposure: gill, liver, gut, swim bladder, muscle, and skin. Although the Mahseer and Grass carp species under investigation had the greatest and lowest levels of lead found in their gills and epidermis, the results of the study contradict this conclusion.

When *C. gariepinus* juveniles were exposed to SLCs of WSF or WBTRs for 58 days, there was a greater accumulation of heavy metals in their gills. The results of the current investigations also aligned with a number of previously published papers, including the following few: For sixty days, yearlings of *T. putitora* and *C. idella* were subjected to varying concentrations of lead nitrate in a controlled environment (Latifa et al., 2022). The gills of T. putitora and C. nidella have the greatest Pb content. The same pattern was found by Olaniyi et al., (2019) for large meals that bioaccumulated in the following order: gills > bones > head regions and muscles in tissues removed from *C. gariepinus* in the Asa River. The kidney accumulated the most quantity of Ni in our study, according to the results of Abdel-Wahab (2020), who also found that the liver, gills, and muscles of *P. lineatus* juveniles subjected to acute doses of 0.00, 25, 250, and 2500 mg/L for 96 hours accumulated the most Ni.

This is in contrast to our findings, as per the heavy metal Hg was primarily accumulated in the liver, kidney, muscle, brain, and gills of *C. batrachus* treated to SLCs (0.00, 0.19, 0.09, 0.05, and 0.03 mg/l) of mercuric chloride for 10, 20, and 30 days (Selvanathan et al.,2017). It is contrary to this study that during the 30-day SLCs exposure of lead acetate $Pb(C_2H_3O_2)_2$, the liver, gill, and muscle of *M. cephalus* had the maximum accumulation of heavy metals, as reported by Vardi and Chenji, (2020), in the order of liver > gill > muscle, respectively.

There have been reports of a somewhat high concentration of heavy metals in *C. gariepinus* gills. Several research reported the following explanations, which can be related to the *C. gariepinus* juveniles exposed to SLCs of WSFs of WBTRs for 58 days. Fish bodies are susceptible to heavy metal entry through the gills, digestive system, and body surface (Sehar et al., 2014). Metals can easily pass through the thinnest epithelium seen in gills (Mastan et al., 2014). Because the metal ions are positively charged and these surfaces are negatively charged, there is a strong attraction for bonding between them (Siraj et al., 2016). The following heavy metal concentrations were seen to rise in WBTRS: Nb, Th, Sr, As, Bi, Au, Pb, Cu, W Fe, Co, and Zn. Consequently, exposed *C. gariepinus* has high metal burdens. In juvenile *C. gariepinus*, the organs are arranged as follows: muscles, liver, kidney, and gills. Thus, in Jos North Local Government Area, Plateau State, tire waste incineration could be a source of heavy metal contamination.

5. CONCLUSION

The investigation of the heavy metal loading in WBTRs from Ring Road, Jos, Plateau State, and their bioaccumulation in *Clarias gariepinus* showed concerning pollution levels. Although, no significant mortality of the fish occurred till the experiment (after 58 days of exposure). Excessive deposition of heavy.metals from WBTRs (Zinc, lead, cobalt, copper, and strontium) in the different tissues of *C. gariepinus*made them unsuitable to serve as food. As a result, there may be health risks to aquatic life and organismsup the food chain. Fishes living in natural waters even having low concentration of heavy metals forprolonged periods might accumulate substantial amount of the toxic metal and make themselves unsuitable for human consumption.

The finding of this work reiterate the potential environmental impact of waste management practices with emphases on monitoring, evaluation and mitigation, particularly in metropolitan areas. Long-term exposure to heavy metals and its effects on humans health and the aquatic ecosystem are issues that need investigation. Additionally, it would aid in the development of efficient waste management strategies and remediation approaches.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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