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HEALTH RISK ASSESSMENT AND POTENTIAL ECOLOGICAL RISK OF TRACE METALS OF OGUNPA RIVER, OYO STATE, NIGERIA

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ABSTRACT

Background: Heavy metals have been continuously deposited and assimilated into water, biota, and sediments as a result of human activity's contamination of aquatic ecosystems.
Objectives: This study aims to assess the trace metals (Fe, Pb, Co, Zn, Cb, Cu, Mn, Ni) contamination and evaluate the status of pollution in Ogunpa River.
Methods: Water samples were taken monthly to analyze the heavy metal concentration, while several pollution indexes, including the human health risk analysis, degree of contamination (Cd), heavy metal evaluation index (HEI), comprehensive pollution index (CPI), water quality index (WQI), heavy metal pollution load index (HPLI), and single factor pollution index were employed to ascertain the contamination status of the River.
Results: The concentrations mean of the nine heavy metals respectively for dry and wet seasons were; Pb (ND), Cr (ND), Cd (0.12±0.25), Co (0.30±0.65), Zn (29.90±70), Cu (14.45±23.06), Ni (0.21±0.59), Mn (83.42±36.64), Fe (34.40±76.87) and Pb (0.01±0.01), Cr (0.01±0.01), Cd (0.14±0.25), Co (0.01±0.01), Zn (11.15±24.00), Cu (9.33±20.50), Ni (0.14±0.47), Mn (29.31±27.64), Fe (58.71±48.35). Single factor pollution index were in this order; Pb < Cr < Cd < Co < Zn < Cu < Ni < Mn < Fe. HPLI results showed that Cu, Zn, Ni, Mn, and Fe had a significant impact on the pollution level in both seasons, while WQI results during the dry and wet seasons were determined to be 2384.3 and 1144.2 respectively. CPI had a mean of 203.8 ranging from 4.4 to 923.4 and 101.2 ranging from 2.9 to 191.2 during the dry and rainy seasons respectively. HEI values ranged from 13.0 to 4211.7 during dry seasons and from 3.0 to 648.0 during wet seasons. The average wet season (290.6) and dry season (882.0) degrees of contamination were recorded during the sampling period. The metal hazard index (ingestion) varied from 0.00 (Cr) to 14.83 (Cu), while the values of the hazard index (dermal) varied from 0.00 (Cr) to 0.27 (Cu).
Conclusion: The substantial risk of heavy metal pollution in Ogunpa River implicated an indiscriminate discharge of agricultural, domestic and industrial waste along the Stream.

Keywords: Industrial waste, Ingestion, Dermal, Agricultural, Domestic

INTRODUCTION

The best way to measure the effects of manmade and natural contaminants on the ecosystem is through the use of rivers. Globally, the state of river waters in and around towns and communities has gotten worse geometrically. Due to the extraordinary population development in the towns along the rivers, there is severe river quality depletion and overexploitation (Khan et al 2020). As a result, the structure of the river's fauna and flora has been impacted by the consequent shift in the aquatic ecology and river processes, which has reduced biodiversity (Ugochukwu et al, 2019). As a consequence of man's careless use of resources, heavy metals are toxic, persistent, and readily available, which poses a danger to the biodiversity of aquatic creatures. Heavy metals have been continuously deposited and assimilated into water, biota, and sediments as a result of human activity's contamination of aquatic ecosystems (Iordache et al., 2021). Pollutant changes in the water and sediments are caused by a variety of environmental factors, including pH, organic matter, discharges, temperature, and so forth.

Metal pollutants in rivers are known for their tenacity, toxicity to the ecosystem and bioaccumulation (Jose et al., 2023). According to Zhang et al. (2012), they can enter the human body directly through drinking water or indirectly through the food chain. Metal pollution in water bodies can come from both natural and artificial sources, including fertilizer and pesticide use, mining, metal processing, industrial wastewater, weathering, and precipitation (Zeng *et al*., 2019). Additionally, sediments are a source of metals since metals can be discharged into surrounding water after desorption and then re-suspended in surface water (Liang et al., 2019).

Certain metal elements, including Cu, Zn, Fe, and Mn, are required for human metabolism but are poisonous when their concentration rises above a particular point. The United State Environmental Protection Agency (USEPA) has classified certain metal substances (As, Cd, Hg, and Pb) as environmental endocrine disruptors because they harm human endocrine systems even if they have no physiological activity (Bhattacharya et al., 2016). Numerous investigations have demonstrated the mutagenic, carcinogenic, and teratogenic properties of several trace metals. Investigating and evaluating the health risks, and the toxicity of metals in surface water and overlaying water is therefore practically important.

These days, the various contaminants that pollute rivers and sediment constitute a complex, long-term environmental concern, especially in locations where anthropogenic pressure is high. Heavy metals rank among the most dangerous environmental contaminants due to their many and persistent nature, as well as their poisonous effects, which can accumulate in aquatic settings. The most dangerous heavy metals, lead, cadmium, and arsenic, can have detrimental effects on health and cause cancer even at very low amounts. According to Nagajyoti et al. (2010), high quantities of some heavy metals can be hazardous, even though they are essential micronutrients for both plants and animals. These metals include Fe, Mn, Co, Cu, and Zn.
Accordingly, the high concentration of heavy metals may have a major effect on the survival, reproduction, and health of species that live in rivers (Moore et al. 2009). Polluted runoff from urban and agricultural regions, as well as discharges of industrial and municipal waste, immediately releases heavy metals (USEPA, 1999). Generally, various pollution indicators are used to evaluate the metal contamination in rivers, including the human health risk assessment, contamination factor (CF), degree of contamination (Cd), heavy metal evaluation index (HEI), comprehensive pollution index (CPI), heavy metal pollution load index (HPLI), water quality index (WQI) and single factor pollution index (Ideriah et al. 2012; Li et al. 2010). Since many of these pollution indicators are widely used worldwide to evaluate the threat that heavy metal contamination poses to water quality, we aim to offer; the first comprehensive report on the application of these indicators for the Ogunpa River, which other researchers can utilize as a reference, determine the levels and distribution of toxic heavy metals in the Ogunpa River; explore the degree of contamination and pollution impacts; and establish baseline data on the current status of the rivers that can be used by relevant authorities.

The human health risk assessment, contamination factor (CF), degree of contamination (Cd), heavy metal evaluation index (HEI), comprehensive pollution index (CPI), heavy metal pollution load index (HPLI), water quality index (WQI), single factor pollution index, and comprehensive pollution index are some of the pollution indicators that are typically used to assess the metal contamination in rivers (Li et al. 2010). Since many of these pollution indicators are widely used worldwide to evaluate the threat that heavy metal contamination poses to water quality. We aim to offer the first comprehensive report, investigate the extent of pollution and its effects, and compile baseline data on the rivers' current condition that the appropriate authorities can use.

MATERIALS AND METHODS

Study Area: The study was done along Ogunpa Rivers in Ibadan (7º23' N, 3º5' E), Oyo State, Nigeria. Draining the heavily populated eastern region of Ibadan. The Ogunpa River system, a third-order stream having a drainage basin that is 73.3 km^2 in size and a channel length of 21.5 km. The city sits between 508 and 510 meters above sea level. The monthly average temperature is in the region of 15 to 25 °C. Ibadan is the largest city in West Africa and has a long history of indiscriminate waste disposal. It is one of Nigeria's most significant industrial cities.

Water sampling: Water samples were taken monthly from January to December 2019 using

1.5-liter Van Dorn plastic bottles, which were collected in compliance with ISO 5667-1 (2006) standard procedure. After collection, samples were immediately brought to the lab in an ice chest and stored there at 4 °C until analysis.

Determination of Heavy Metals: The water samples were preserved using one milliliter of concentrated nitric acid (HNO3) once they arrived at the laboratory. They were then filtered, stored at room temperature in the dark, and microwave acid digested using USEPA procedure 3015 (1994). 50 mL was digested using a combination of 4-5 mL HNO3 65% and 1 mL HCl 35%. After being digested, the whole metal samples were filtered using 0.45-µm nylon filters. The concentrations of Cd, Co, Cr, Cu, Fe, Mn, Ni, Zn, and Pb were measured using inductively coupled plasma–optical emission spectrometry (ICP–OES, Optima 2100 DV) following USEPA standard method US 6010C (2007).

Statistical Analysis and Estimation of Pollution Indicators: Descriptive statistics were applied to the data using the Statistical Package for Social Sciences (SPSS 20.0) to calculate means and standard deviations. The World Health Organization (WHO) and Federal Environmental Protection Agency (FEPA) guidelines were compared with the means, and the reservoir's pollution status was assessed using the following indices:

The single-factor pollution index:

$$P_i = \frac{C_i}{S_i}$$

Where: Ci is the pollutant concentration in milligrams per liter (mg/l), Si is the maximum amount of the pollutant that is allowed in the water, and Pi is the pollution index of pollutant i (Yan *et al.,* 2015). The single-factor pollution index (Pi) is divided into five grades as follows; *Pi* : < 0.4 (Non-polluted), *Pi* : 0.4 -1.0 (Slightly polluted), *Pi* : 1.0 – 2.0 (Medium pollution), *Pi* : 2.0 - 5.0 (Heavily polluted), *Pi* : > 5.0 (Serious pollution) as reported in Li et al. (2010).

Pollution Index (*PI*): The pollution index is divided into five classes, based on calculations for specific metals and is calculated using the following formula:

$$PI = \frac{\sqrt{\left[\left(\frac{Ci}{Si}\right)^2_{max} + \left(\frac{Ci}{Si}\right)^2_{min}\right]}}{2}$$

Where; *Si* is the standard value and *Ci* is the concentration of each element according to WHO (2003) and FEPA (2003). The five categories are as follows; Class 1 (PI < 1 = No effect), Class 2 (PI 1-2 = Slightly affected), Class 3 (PI 2-3 = Moderately affected), Class 4 (PI 3-5 = Strongly affected), Class 5 (PI > 5 = Seriously affected) (Caeiro *et al*., 2005).

Water Quality Index (WQI)

The water quality index (WQI) was calculated as:

$$WQI = \sum_{i=1}^{n} SI_i$$

Where $SI_i = RW \times Q_i$

Relative Weight of each parameter (RW) is:

$$RW = \frac{AW_i}{\sum_{i=1}^{n} AW_i}$$

Where; *AW* = the assigned weight of each parameter which ranges from 1 - 5, n = the number of parameters (Table 3).

Quality rating for each parameter (*Qi*) is:

$$Qi = \left[\frac{Ci}{Si}\right] \times 100$$

Where; *Si* = the recommended water quality parameter obtained from WHO (2003) and FEPA (2003), *Ci* = value of the water quality parameter obtained from the laboratory analysis. The computed *WQI* values were classified as follows; WQI < 50 (Excellent), WQI 50 - 100 (Good), WQI 101 - 200 (Poor), WQI 201 – 300 (Very Poor), WQI > 300 (Bad, Unsuitable for life) (Shetaia et al., 2020).

Comprehensive pollution index (CPI):

$$CPI = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i}{S_i}$$

Where; n is the number of pollutants evaluated, Ci is the pollutant i concentration (mg/l), Si is the legal limit for the pollutant i in water, and CPI is the comprehensive pollution index. Tao et al. (2011) divided the CPI into five water quality levels as thus; CPI < 0.2 (Cleanness),

Table 1: *RW* (relative weight) and *AW* (assigned weight) of each heavy metals

Parameter	Standard (WHO, 1997, 2003; FEPA, 2003)	Assigned weight (*AW*)	Relative weight (*RW*)
Cd	0.5	3	0.12
Co	0.05	2.5	0.1
Cr	0.05	2	0.08
Cu	2	2	0.08
Fe	0.3	3	0.12
Mn	0.5	3	0.12
Ni	0.02	2.5	0.1
Pb	0.1	5	0.2
Zn	5	2	0.08
Total		25	

CPI 0.21 – 0.4 (Sub-cleanness), CPI 0.41 - 1.0 (Slight pollution), CPI 1.01 – 2.0 (Moderate Pollution), CPI > 2.01 (Severe Pollution).

Heavy Metal Pollution Index (*HPI*): represents the total heavy metals water quality. The HPI was calculated as:

$$HPI = \frac{\sum_{i=1}^{n} WiQi}{\sum_{i=1}^{n} Wi}$$

Where; n is the number of parameters taken into consideration, Wi is the ith parameter's unit weightage, and Qi is the ith parameter's sub-index (Sheykhi and Moore, 2012).
Qi (sub-index) is calculated as:

$$Qi = \sum_{i=1}^{n} \frac{|M_i - I_i|}{S_i - I_i} \times 100$$

Where; Si is the standard value of the ith parameter, Ii is the ideal value, and Mi is the monitored value of the heavy metal of the ith parameter.
The critical pollution index of the HPI value for drinking water is 100. For drinking water, Prasad and Bose (2001) gave the critical pollution index of HPI a value of 100. The HPI for this investigation was determined using the following factors: Zn, Pb, Mn, Ni, Cu, Cd, Co, Cr, and Pb. The weightage (Wi) was determined as the inverse of MAC (MAC adapted from Siegel, 2002), with Si serving as the WHO standard for drinking water and Ii as the recommendation value for the chosen element (Edet and Offiong, 2002) shown in table 2.

Table 2: Standard values used for the Heavy metals Pollution index

Parameters	W	MAC (ppm)	I (ppm)	S (ppm)
Co	0.02	0.05	0.01	0.05
Cd	0.3	0.003	0.003	0.005
Cu	0.001	1	2	1
Zn	0.0002	5	3	5
Fe	0.005	0.2	0.2	0.3
Cr	0.02	0.05	0.05	0.05
Ni	0.05	0.02	0.02	0.02
Pb	0.7	0.0015	0.01	0.1
Mn	0.02	0.05	0.5	0.1

Heavy Metal Evaluation Index (HEI): is the overall heavy metals water surface quality and is calculated as follows;

$$HEI = \sum_{i=1}^{n} \frac{M_i}{MAC_i}$$

Where; MACi is the maximum permissible concentration of each metal, and Mi is the value of the metal derived from the laboratory analysis. According to Shetaia et al. (2020), the computed HEI values were divided into three categories: <10 for low pollution, 10 - 20 for moderate pollution, and >20 for excessive pollution.

Degree of Contamination (*Cd*): For every water sample that is evaluated, the *Cd* is calculated independently and is the total of the contamination factors of each component that exceeds the maximum allowable value:

$$Cd = \sum_{i=1}^{n} Cf_i$$

$$Cf_i = \frac{C_{Ai}}{C_{Ni}} - 1$$

The contamination factor for the i-th component is represented by Cfi, the analytical value is by CAi, the upper permitted concentration of the i-th component is by CNi (where N stands for the "normative value"), and CNi is considered the maximum allowable concentration.
Three categories might be applied to the estimated *Cd* values: low (*Cd* < 1), medium (*Cd* = 1-3), and high (*Cd* > 3) (Edet and Offiong, 2002).

Human Health Risk Assessments: Risk assessment is defined as the process of estimating the probability that any given possible magnitude of detrimental health effects will occur during a specific period. It is a function of exposure and hazard. Three main pathways exist for human exposure to trace metals: direct ingestion, inhalation, and dermal absorption through exposed skin (Wu et al., 2009; Meng et al., 2016). The native people use river water for washing, fishing, and swimming more frequently. As a result, the exposure dose for dermal absorption through exposed skin was calculated using the formula below:

$$CD_d = \frac{C_w \times SA \times Kp \times ET \times EF \times ED \times CF}{BW \times AT}$$

Where; Cw is the concentration of heavy metal in water, mg/l, and CDd is the dermal absorption (μg/kg/day); The study's exposed skin area, or SA, is 18,000 cm^2, and the skin permeability coefficient in water (Kp) is measured in cm/h. ET (exposure time) during showering and bathing is 0.6 hours per day; Exposure frequency (EF) is 350 days per year, assuming that the locals spend 15 days annually away from the place; The variables that represent the exposure duration (ED) and unit conversion factor (CF) are 54 years and 1/1000 cm^3 respectively, and the average body weight (BW) is 60 kg (Tripathee et al. 2016), AT is the average time (in days), ED × EF (350 days).

$$HQ_s = \frac{CD_d}{RfD}$$

$$\text{HI} = \sum HQ$$

Reference Dose (Dermal) was Ni (0.005), Cu (0.012), Pb (0.42), Cr (0.003), Co (0.005), Fe (0.045), Zn (0.06), Mn (0.8) and Cd (0.005) while Reference Dose (Oral) was 0.020, 0.04, 0.300, 0.700, 1.5, 0.02, 0.14, 0.004 and 0.001, for Ni, Cu, Zn, Fe, Cr, Co, Mn, Pb and Cd respectively (USEPA, 2006; Olawusi-Peters *et al.*, 2019).

RESULTS AND DISCUSSION

Heavy Metals in Water: Understanding the distribution of heavy metal pollution in a river is crucial for regulators and environmental scientists. According to Xia et al. (2020), heavy metals damage aquatic life and may cause ecosystems to collapse. Therefore, it is essential to compare the mean concentrations of heavy metals in water samples to relevant water quality requirements to pinpoint specific pollution exceedances and confirm the extent of the exceedances (Chen et al., 2019). Table 3 shows the WHO (2006) drinking water standards and Food and Agricultural Organisations minimum standards, in conjunction with the monthly and seasonal mean content of heavy metals in this study. The investigation determined that the nine heavy metal concentrations focused in this study were in the following order: Mn > Fe > Zn > Cu > Ni > Cd > Co > Cr > Pb. The highest standard deviation was found for the heavy metals Mn and Fe, suggesting that their concentrations were widely distributed during the observation period. For Pb and Cr, a slight standard deviation was recorded, but for Zn and Cu, a moderate one; demonstrating that there was less variation in these metals' concentrations throughout the sampling process. Both seasons recorded high levels of Fe and Mn, which were found to be above WHO and FAO norms. Similarly, Zn and Ni were discovered to be higher than the FAO and WHO recommended limits for both seasons. On the other hand, Pb, Co, and Cr concentrations were found to be lower than those recommended by the WHO and FAO. High concentrations of Cd and Cu can harm domestic animals, wildlife, and humans (mostly through DNA damage, oxidative stress, cytotoxic effects, and protein degradation) when these aquatic resources are used for transport (Ayenimo et al. 2010). Hossen and Mostafa, (2023) and Atangana and Oberholster (2021) reported similar findings. Zinc and nickel were also found to be above the recommended values of WHO and FAO. Akinbile and Omoniyi (2018) and Ayodele and Percy (2011) made similar observations, suggesting that the higher concentrations of these metals recorded in the dry season than in the wet season could be attributed to the leaching of industry-based effluents within the city.

Single-Factor Pollution Index: The study of the single-factor pollution index was conducted in the Ogunpa River. The results of this method, which evaluated the heavy metal concentrations of the sampling water's single-factor pollution index, are displayed in Table 4. During the sample months, cadmium levels ranged from non-polluted to slightly polluted, but Cr and Pb stayed unpolluted. The levels

Table 3: Heavy Metals in Water of Ogunpa River

Season	Cd(mg/kg)	Co(mg/kg)	Cr(mg/kg)	Cu(mg/kg)	Fe(mg/kg)	Mn(mg/kg)	Ni(mg/kg)	Pb(mg/kg)	Zn(mg/kg)
Jan	0.03±0.04	0.74±1.28	0.00±0.00	21.28±17.50	3.92±3.57	0.67±0.95	0.00±0.00	0.00±0.00	2.00±0.96
Feb	0.21±0.21	0.00±0.00	0.00±0.00	31.22±49.88	113.00±57.57	412.58±76.17	0.00±0.00	0.00±0.00	134.52±117.53
Mar	0.20±0.18	0.00±0.00	0.00±0.00	0.95±0.22	30.83±11.10	0.17±0.14	0.90±1.08	0.00±0.00	10.50±6.90
April	0.00±0.00	0.00±0.00	0.00±0.00	0.66±0.04	16.25±3.19	1.83±0.63	0.00±0.00	0.00±0.00	0.39±0.68
May	0.42±0.52	0.03±0.03	0.03±0.00	18.13±28.17	254.25±82.59	195.83±38.11	0.00±0.00	0.03±0.00	43.27±62.17
June	0.26±0.21	0.00±0.00	0.03±0.00	4.56±4.54	57.50±11.21	4.67±6.14	0.00±0.00	0.03±0.00	14.74±14.34
July	0.00±0.00	0.00±0.00	0.00±0.00	0.23±0.40	0.04±0.08	0.01±0.01	0.07±0.08	0.00±0.00	0.02±0.02
Aug	0.36±0.49	0.01±0.01	0.00±0.00	11.55±9.76	55.08±40.89	2.42±0.88	0.31±0.51	0.00±0.00	7.16±3.37
Sept	0.10±0.17	0.00±0.00	0.00±0.00	35.93±42.23	52.08±42.50	2.08±.52	0.00±0.00	0.00±0.00	5.66±2.85
Oct	0.00±0.00	0.00±0.00	0.00±0.00	4.85±4.64	0.00±0.00	0.58±0.38	0.00±0.00	0.00±0.00	3.50±1.80
Nov	0.00±0.00	0.04±0.04	0.00±0.00	3.11±1.17	0.00±0.00	1.25±1.25	0.73±1.26	0.00±0.00	2.56±2.22
Dec	0.00±0.00	0.70±0.62	0.00±0.00	5.11±1.66	0.00±0.00	0.17±0.29	0.00±0.00	0.00±0.00	3.28±0.11
Dry Season	0.12±0.25	0.30±0.65	0.00±0.00	14.45±23.06	34.40±76.87	83.42±36.64	0.21±0.59	0.00±0.00	29.90±70.08
Wet Season	0.14±0.25	0.00±0.01	0.01±0.01	9.33±20.50	58.71±48.35	29.31±27.64	0.14±0.47	0.01±0.01	11.15±24.88
WHO	0.003	0.01	0.05	2.00	0.50	0.40	0.02	0.01	3.00
FAO	0.003		0.05	2.00	0.5	0.5	0.02	0.01	5.00

Table 4: Single-Factor Pollution Index of Ogunpa River

SFPI	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
JAN	0.01	0.20	0.00	14.51	2.00	1.20	0.00	0.00	0.41
FEB	0.66	1.16	0.00	4.26	557.00	318.70	18.75	0.00	22.91
MAR	0.59	1.79	0.00	2.59	158.33	13.36	46.00	0.00	10.65
APRIL	0.00	0.00	0.00	0.33	39.00	1.40	0.00	0.00	0.02
MAY	0.81	0.10	0.30	1.12	112.50	0.90	72.50	0.15	2.80
JUNE	1.27	9.00	0.50	0.96	100.17	1.30	28.00	0.25	1.02
JULY	0.00	0.00	0.00	0.00	0.15	0.01	2.75	0.00	0.00
AU-GUST	0.05	0.40	0.00	12.47	48.33	3.79	0.75	0.00	2.37
SEPT	0.29	0.50	0.00	4.10	42.17	3.20	29.75	0.00	1.97
OCT	0.00	8.80	0.00	2.12	4.83	0.70	0.00	0.00	1.28
NOV	0.00	0.20	0.00	3.75	0.00	0.10	0.00	0.00	0.41
DEC	0.05	0.20	0.00	3.40	0.00	0.10	0.00	0.00	0.60
DRY	0.15	0.43	0.00	7.68	121.47	64.78	3.90	0.00	5.34
WET	0.42	2.88	0.11	1.60	65.31	2.98	25.57	0.06	2.53

of pollution for iron, Mn, Ni, Zn, and Cu varied from mild to extreme. The following nine heavy metals had average concentrations observed in the two seasons: Pb < Cr < Cd < Co < Zn < Cu < Ni < Mn < Fe. In this study, Pb, Cd, and Cr generally have "No Pollution" single factor pollution, but Fe, Mn, Ni, Zn, and Cu have "Severely Polluted" single factor pollution.

Heavy Metal Pollution Load Index (HPLI): Pollution Index (PI) is used to ascertain the quality of the sampled river. Table 5 presents the results of the calculation of the PI values for the water samples from Ogunpa. During the sampling seasons, the PI results indicate no influence of contamination of the following heavy metals: Cd, Co, Cr, and Pb. Meanwhile, Cu, Zn, Ni, Mn, and Fe, had a significant impact on the pollution level in both seasons. The indiscriminate discharge of domestic and industrial garbage in and around the Ogunpa market may have contributed to the leaching of heavy metals, which could be the cause of the high pollution index values. It should be made very clear that Fe, Mn, and Ni were the possible heavy metals that could contribute to a high

Table 5: Pollution Index (PI) of Ogunpa River

PI	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
DRY	0.33	0.92	0.00	7.31	280.50	159.36	23.50	0.00	11.46
WET	0.69	4.52	0.38	2.51	56.26	1.90	40.75	0.17	1.40

Table 6: Contamination Index, Heavy Metal Evaluation Index and Water Quality Index (WQI) of Ogunpa River

Month/ Season	WQI value	CPI value	HEI value	*Cd* value	HPI value
JAN	159.9	18.3	51.1	42.1	5.9
FEB	10932.8	923.4	4211.7	4202.7	4478.1
MAR	2651.2	233.3	576.1	567.1	4088.5
APRIL	487.6	40.7	73.2	64.2	57.5
MAY	2133.3	191.2	403.1	394.1	5532.5
JUNE	1627.7	142.5	648.0	639.0	8613.2
JULY	29.4	2.9	3.0	-6.0	5.3
AUG	756.3	68.2	156.8	147.8	331.5
SEPT	898.9	82.0	196.0	187.0	1938.7
OCT	181.6	17.7	239.8	230.8	11.7
NOV	36.5	4.5	13.9	4.9	5.4
DEC	35.8	4.4	21.7	12.7	274.2
DRY	**2384.3**	**203.8**	**891.0**	**882.0**	**966.2**
WET	**1144.2**	**101.5**	**305.6**	**296.6**	**2904.5**

pollution index value out of all the others.

Water Quality Index (WQI): Applying the proper allocated weight and relative weight, the WQI of Ogunpa River was assessed using the Shetaia et al., (2020) technique. WQI results were determined to be 2384.3 during the dry season and 1144.2 during the wet season (Table 6). These results were consistent with the WQI classification class of "Bad," which denotes unsuitability for aquatic life. This finding suggests that water from the Ogunpa River at the studied location, which is used for potable as well as other industrial and commercial purposes, needs to be treated before being used for these purposes because using it untreated in both the dry and wet seasons poses a serious risk to human health and way of life. This study shows the highest level of pollution compared to those of Akinbile and Omoniyi (2018), who reported a Bad WQI of the river Ogbese in Ondo State, Southwest Nigeria, and Iwar et al. (2021), who reported a Bad WQI of the river Benue in Makurdi, North Central Nigeria. These findings suggest that Nigerian rivers are becoming more and more polluted due to a variety of factors, including urbanization and anthropogenic activities. As a result, it is imperative to support ongoing surface water body monitoring to prevent the risks that come with consuming heavily polluted water.

Comprehensive Pollution Index (CPI): Throughout the sampling months, the Ogunpa River's CPI, which measures the overall level of water pollution, was always more than two (2), indicating severe or heavy pollution. Table 6 shows the monthly CPI of heavy metal for the river under study for both seasons. During the dry season, it was noted that the CPI had a mean of 203.8 and varied from 4.4 to 923.4. It was found that contributions from February and December were, respectively, the highest and lowest. CPI ranged from 2.9 to 191.2 (mean = 101.5) during the rainy season. July was shown to have the lowest contribution to the mean CPI during the wet season and the highest contribution was recorded in May. Overall, it was noted that Ogunpa River's CPI values were significantly higher than the threshold value throughout both the wet and dry times. The city's surrounding industrial and agricultural operations are the cause of both diffuse and point-source pollution, which accounts for the high CPI levels in the river. Since the Ogunpa River serves as the primary sink for all of the region's pollution sources, it is reasonable to assume that the high concentrations of hazardous pollutants in the river are a result of the city's, growing population and industrial activity. These results are in complete agreement with the WQI results, which demonstrated that the Ogunpa River is of the kind that qualifies as "Severely Polluted."

As anticipated, the CPI values for surface water reported in this study are greater than those previously reported by Zakhem and Hafez (2015) and that of Sharma et al., (2020). This was due to the expectation that surface water would be more contaminated than groundwater due to the contributions of both diffuse and point source pollutants to surface water bodies. Additionally, this figure is higher than the CPI on the Yellow River Wetland Reserve in China reported by Chen et al. (2023). Moreover, the regular habit of disposing of trash close to the riverbank in the Ogunpa River region is associated with elevated CPI levels. The wastewater from the Ogunpa market, is one of the other potential sources of these metals. Other likely sources of heavy metal contamination in the city may be the use of fertilizers and pesticides, as well as the effluents from mechanics' workshops and nearby factories.

Heavy metal Evaluation Index (HEI): According to Table 6, the heavy metal evaluation index ranged between 3.0 and 648.0 (mean = 305.6) in the wet season and from 13.0 to 4211.7 (mean = 891.0) in the dry season. The Ogunpa River's HEI value is more than 50 in all sampling months throughout both the wet and dry seasons, according to Shetaia et al. (2020) values evaluation results of the HEI model. According to this, the study area is "highly polluted."

Degree of contamination: Table 6 displays the findings of the degree of contamination for this investigation. According to Håkanson (1980), the Cd values range in the rainy season from -6.0 to 639.0 with an average of 290.6, and in the dry season from 4.9 to 4202.7 with a mean value of 882.0. This suggests that the Ogunpa River was highly contaminated during the test months.

Heavy metal pollution index (HPI): Table 6 summarizes different pollution indices and the monthly/seasonal change of HPI. In the Ogunpa River, 5.3 was the lowest reported heavy metal pollution index level, while 8613.2 was the highest. The current study has adopted a modified three-class scale following Edet and Offiong's (2002) research. Water quality can be categorized using the HPI into three groups: low HM pollution, threshold risk, and high risk (>100, 100, <100), in that order. The health of people who drink the water may be at risk if the HPI rises above 100. Therefore, it is important to conclude that there is a substantial risk of heavy metal pollution in the Ogunpa River. The likelihood of runoff contaminating the river water is increased by the existence of anthropogenic (industrial and agricultural) activity in the area surrounding the location. This pattern raises concerns since it may indicate that the Ogunpa River will become more contaminated in the future.

Human Health Risk Assessment Analysis: The health risk assessment of metals in drinking water sources has drawn a lot of attention, despite the fact that the well-being of the impacted population is greatly impacted by the quality of the drinking water (Belew et al., 2024). Tables 7 and 8, respectively, show the hazard index (HI) and hazard quotient (HQ) values of each metal for ingestion and dermal in the Ogunpa River. The metal hazard index (ingestion) varied from 0.00 (Cr) to 14.83 (Cu), while the values of the hazard index (dermal) varied from 0.00 (Cr) to 0.27 (Cu). Given that all calculated values for HQ and HI are less than 1, this result suggests that there is no non-carcinogenic risk associated with cutaneous contact (Table 8). However, the results for Cd, Cu, Fe, Mn, and Zn indicate high HQ values (> 1) for ingestion, which further contributes to an overall HI value of more than 1 (Table 7). In other words, there exists a possibility that human exposure to these heavy metals poses a non-carcinogenic risk. This outcome is consistent with surface water studies conducted by Jiao et al. (2023) at the site of an abandoned multi-year pyrite mine in China. The health risk is contingent on the heavy metal and changes greatly depending on the manner of consumption (i.e., cutaneous absorption versus

Table 7: The hazard index (HI) and hazard quotient (HQ) ingestion values of each metal Human Health Risk Assessment

HQ ingestion	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
JAN	0.16	0.02	0.00	23.19	0.03	0.14	0.00	0.00	0.22
FEB	10.55	0.09	0.00	6.80	7.63	36.38	0.60	0.00	12.21
MAR	9.43	0.14	0.00	4.14	2.17	1.53	1.47	0.00	5.67
APRIL	0.00	0.00	0.00	0.53	0.53	0.16	0.00	0.00	0.01
MAY	12.95	0.01	0.00	1.79	1.54	0.10	2.32	0.12	1.49
JUNE	20.30	0.72	0.00	1.53	1.37	0.15	0.89	0.20	0.54
JULY	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00
AUG	0.80	0.03	0.00	19.93	0.66	0.43	0.02	0.00	1.26
SEPT	4.63	0.04	0.00	6.55	0.58	0.37	0.95	0.00	1.05
OCT	0.00	0.70	0.00	3.39	0.07	0.08	0.00	0.00	0.68
NOV	0.00	0.02	0.00	6.00	0.00	0.01	0.00	0.00	0.22
DEC	0.80	0.02	0.00	5.44	0.00	0.01	0.00	0.00	0.32
DRY	2.46	0.03	0.00	12.27	1.66	7.39	0.12	0.00	2.85
WET	6.76	0.23	0.00	2.56	0.89	0.34	0.82	0.05	1.35
HI	9.22	0.26	0.00	14.83	2.55	7.73	0.94	0.05	4.20

Table 8: The hazard index (HI) and hazard quotient (HQ) dermal values of each metal Human Health Risk Assessment

HQ dermal	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
JAN	0.00	0.00	0.00	0.42	0.00	0.00	0.00	0.00	0.00
FEB	0.01	0.00	0.00	0.12	0.64	0.03	0.00	0.00	0.20
MAR	0.01	0.00	0.00	0.07	0.18	0.00	0.01	0.00	0.09
APRIL	0.00	0.00	0.00	0.01	0.04	0.00	0.00	0.00	0.00
MAY	0.01	0.00	0.00	0.03	0.13	0.00	0.01	0.00	0.02
JUNE	0.02	0.01	0.00	0.03	0.12	0.00	0.00	0.00	0.01
JULY	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AUGUST	0.00	0.00	0.00	0.36	0.06	0.00	0.00	0.00	0.02
SEPT	0.01	0.00	0.00	0.12	0.05	0.00	0.00	0.00	0.02
OCT	0.00	0.01	0.00	0.06	0.01	0.00	0.00	0.00	0.01
NOV	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00
DEC	0.00	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.01
DRY	0.00	0.00	0.00	0.22	0.14	0.01	0.00	0.00	0.05
WET	0.01	0.00	0.00	0.05	0.08	0.00	0.00	0.00	0.02
HI	0.01	0.00	0.00	0.27	0.22	0.01	0.00	0.00	0.07

ingestion). The average HI value of ingestion is 1-3 orders of magnitude larger than that of cutaneous absorption, indicating that ingestion is the primary exposure that results in health risk. Arsenic may have carcinogenic effects on the body, potentially causing lesions on blood vessels, the bladder, etc (Sohrabi et al., 2021); cadmium has negative effects on the renal system, causing immune deficiencies and bone damage (Godt et al., 2006); excessive intracellular zinc content can promote apoptosis, leading to cellular nervous system decline, which may cause the onset of Alzheimer's disease; Parkinson's disease can be caused by manganese in the body (Doroszkiewicz et al., 2023); excessive intracellular zinc content can promote apoptosis, leading to cellular nervous system decline, which may cause the onset of Alzheimer's disease (Ipek et al., 2023).

CONCLUSION

The assessment of heavy metals from the Ogunpa River in the city of one of Nigeria's largest cities is the primary reason for the study's critical importance. The study's nine heavy metal concentrations were concentrated in the following order: Cd > Co > Cr > Pb > Mn > Fe > Zn > Cu > Ni. Pb, Co, and Cr concentrations were under the permissible level, but those of cadmium, cu, Zn, Ni, Mn, and Fe were over the acceptable limit set by the WHO and FAO. Additionally, Pb, Cd, and Cr showed "No Pollution" results on the single factor pollution index in this study, whereas Fe, Mn, Ni, Zn, and Cu showed "Severely Polluted" values. The findings of the pollution load indicated that Cu, Zn, Ni, Mn, and Fe had a major influence. The comprehensive pollution index values were consistently greater than the threshold value during both the wet and dry seasons, indicating the presence of industrial and agricultural activity in the vicinity of the city. The results of the water quality index designate the river as "Bad." According to the heavy metal evaluation index and degree of pollution data, the Ogunpa River is classified as highly contaminated and extremely polluted, respectively. Furthermore, there is a significant risk of heavy metal pollution, according to the heavy metal pollution index. However, a review of the human health risk assessment may conclude that drinking from the river poses a possible non-carcinogenic risk to humans. Therefore, it is advised that swift action be taken to reduce and manage the heavy metal contamination of the Ogunpa River.

Conflict of Interest:

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data availability statement:

Data will be made available on reasonable request.

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