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ABSTRACT

Dams and their environment, interrelate with a degree of complexity that often affects the availability of potable water. In Nigeria, dams are an important source of drinking water in many communities but are vulnerable to contamination from different sources. This study assessed the possible elemental (Cd, Cr, Cu, Fe, Ni, Pb, Mn, and Zn) contamination sources of selected dams in a total of 126 samples comprising 54 surface water, and 72 sediment samples collected from six main dams in Osun State using multivariate analyses like Principal Component Analysis (PCA) and Cluster Analysis (CA). Generally, the average elemental concentration was in the decreasing order of Cr > Ni > Cd > Pb > Cu > Fe > Zn > Mn and Pb > Cr > Ni > Cd > Zn > Mn > Fe > Cu for surface water and sediment samples respectively. Furthermore, statistical analysis showed that the average concentrations of the potentially toxic elements (PTEs) did not differ significantly ($p < 0.05$) across the sampling sites, indicating similar PTEs profiles. The PCA and CA revealed possible sources of elemental contamination to the dam quality as weathering of bedrocks, uncontrolled farming activities, abandoned equipment, boat fueling, maintenance, and repairs. Although only 13.9% of the hazard quotients (HQ) were higher than one for all the studied heavy metals in surface water, 91.7% of the hazard index (HI) were higher than one. This suggests an unacceptable risk of non-carcinogenic effects from the direct consumption of dam water. Furthermore, the oral target cancer risk, TCR_{oral} in children > adults and $> 1 \times 10^{-4}$ for cancer risk set by USEPA, however, the % contribution of Cr to $\sum TCR_{oral}$ in adults which is $> 1 \times 10^{-4}$ ranged between 98.9 to 99.5%, indicating that Cr is the most dominant carcinogens in the overall cancer risk in adults.

KEYWORDS
Trace metals; health risk assessments; sediment contamination; dams; correlation analysis; multivariate statistical technique

1. Introduction

Although the recent report of the WHO/UNICEF Joint Monitoring Programme (JMP) for water supply, sanitation, and hygiene showed that 107 million people gained access to safely managed drinking water at home between 2015 to 2020. However, approximately 2 billion people still lack access to potable and uninterrupted water supplies (WHO/UNICEF, 2021). Therefore, the provision of clean water as one of the sustainable development Goals (SDGs) of the United Nations General Assembly (UNGA) is still a serious environmental concern especially in Sub-Saharan African countries like Nigeria with high records of waterborne diseases due to lack of clean water (Ayandiran, Fawole, and Dahunsi 2018).

In Nigeria, dams are an important source of domestic water supply for many homes nevertheless are prone to contamination from the natural flow of water bodies due to contributions from natural and anthropogenic sources (Astatkie, Ambelu, and Beyene 2021). Naturally, dams tend to concentrate contaminants into a one-point collection reservoir with significant contribution from non-point sources along the pathways of the dammed water body (Ahmed *et al.* 2009; Gómez-Hortigüela *et al.* 2013). Consequently, contaminants monitoring to establish their concentrations in raw water is a significant step toward their removal to ensure the provision of clean water to citizens.

Among the most important contaminants known to be present in the aquatic ecosystem globally, heavy

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metals represent a significant group due to their non-biodegradability, persistence, and toxicity in the environment (Ali and Khan 2018, 2019). Consequently, their presence leads to the accumulation and pollution of aquatic components such as water and sediment (Zeng, Xin, and Chen 2013; Akele *et al*. 2016). Major anthropogenic sources of heavy metals in dammed water reservoir includes municipal wastes, untreated wastes (solids and liquid) from various industries, and agrochemical wastes from farms near dammed reservoirs. Other anthropogenic sources include the combustion of fossil fuel, especially from fishing vessels' movement. However, natural sources of heavy metals comprise mainly bedrock weathering.

Multivariate statistical techniques can be employed to extract information from an environmental dataset for the possible environmental factors influencing water quality and to also identify common groupings within a set of data. This is achieved by finding interrelationships in a dataset and extracting the important factors influencing the quality, which are then used to infer the possible sources of contamination (Sheikhy Narany *et al*. 2014). The application of multivariate statistical tools such as PCA and CA on data collected from diverse complex environmental matrices aids in decoding the effect different factors have on water quality and the overall ecological status of the studied systems (Varol *et al*. 2012).

So far, previous studies on heavy metal contamination and pollution in dams in Nigeria mainly focused on heavy metal concentration monitoring. However, this study investigated sources of heavy metal contamination in six major dams in Osun State and their associated human health risk due to the consumption of water from these dams across the three Federal Constituencies in Osun State, Nigeria.

2. Materials and Methods

2.1. Description of the Study Area

Samples for this study were obtained from six preselected Dams in Osun State, Nigeria. Osun State with a land area of approximately 14, 875 km^2 is one of six southwestern States in Nigeria (Awomeso, Ahmad, and Taiwo 2020). It was formed on the 27th of August 1991 and takes its name from River Osun, a revered natural spring. Its capital city is called Osogbo, and it is home to thirty (30) Local Government Areas (LGAs) (Ojurongbe *et al*. 2015). As an Inland state, it lies between latitude 7° 30′ 0″ N and longitude 4° 30′ 0″ E and is bounded by Ogun State (from the South), Kwara State (from the North), Oyo State (from the West), and Ondo and Ekiti States (from the East) (Awomeso, Ahmad, and Taiwo 2020). Osun State is the nineteenth (19th) most populous among the 36 States in Nigeria. Based on the most recent Nigeria population census of 2006, the population of the State is about 3,416,959 (NPC (National Population Commission) 2006), however, the population has since continued to rise and the Bureau of Statistics projected the human population in the state to be 4,237,396 in 2019 (NBS (National Bureau of Statistics) 2020; Adeyemi and Ayinde 2022).

Osun State is divided between the lowland forests in most parts of the state and the drier Guinean forest-savanna mosaic in the North. The temperature fluctuates on average from 32 °C to 34 °C during the dry season, while it ranges from 22 °C to 24 °C during the wet season. Other major geographical features are the Erinle, Oba, and Osun rivers. The river Osun flows through the state's interior before forming much of the state's Southwestern border with Oyo State and then flowing South. The Erinle and Oba Rivers are both Osun tributaries that flow from the North before meeting the Osun along the Southwestern border. Osun State Water Corporation is responsible for supplying potable water within the State and the major raw water resources are the Dam waters from these major rivers. The operating parameters for the studied dams are summarized in Table S1.

A total of six dams were used for this study, two each from the three Federal Constituencies in Osun State namely: Eko-Ende and Iba dams (Osun Central), Ilesa and Esa-Odo dams (Osun East), Ede and Ikire-Asejire dams (Osun West). The sampling points are shown and described in Figure 1 and Table S1 respectively.

2.2. Sample Collection

2.2.1. Water Sample Collection

A total of 54 surface water samples from the six selected dams in Osun State were randomly collected with the aid of a Van Dorn water sampler from a total of nine (9) sampling locations from each dam. Water samples were collected in a 1 L container, transported, and kept at 4 °C before analysis.

The dissolved oxygen (DO), electrical conductivity (EC), temperature (Temp), total dissolved solids (TDS), total suspended solids, and pH were measured onsite using a a pre-calibrated portable multi-meter. However, samples for alkalinity (Alk.), biological oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO_3^-), phosphate (PO_4^{3-}), sulphate (SO_4^{2-}),

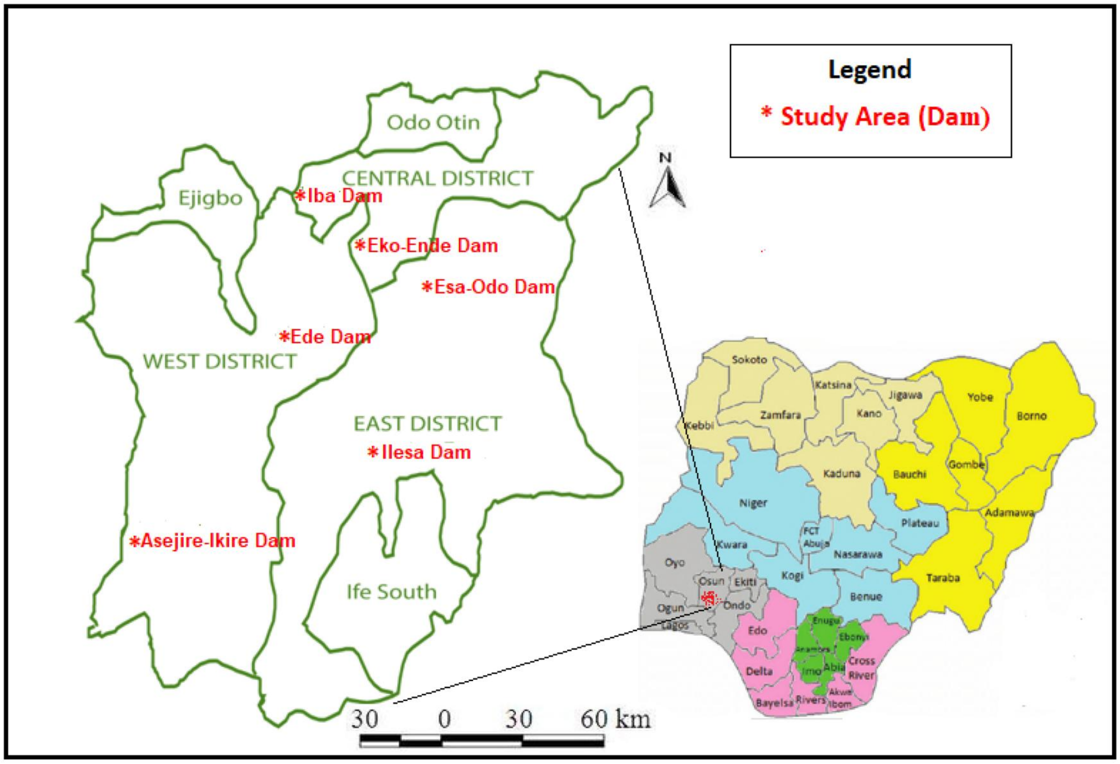

Figure 1. Map showing the district where sampling sites are located.

total hardness (TH), and Turbidity (Turb.) were transported, and measured afterward in the laboratory using standard methods as described by Jonnalagadda and Mhere (2001).

Alkalinity was determined by Acid-Base titration by titrating 100 mL of water sample with 0.10 M HCl and Alk. expressed as mg L^{-1}. Biological oxygen demand (BOD) samples were collected in DO bottles and the BOD of the water samples was subsequently determined after 5 days of incubation in tightly stoppered DO bottles in the dark at 20 °C by determining the oxygen consumed *via* DO evaluation. For the COD determination, excess dichromate ions were added to 100 mL of water sample in the presence of H_2SO4, $AgSO_4$ and $HgSO_4$. Subsequently, the excess amount of dichromate was measured by titration with ferrous ammonium sulphate. COD was expressed as mg L^{-1} (APHA (American Public Health Association) 2006).

Nitrate, PO_4^{3-}, SO_4^{2-} and Turb. were determined by the spectrophotometric method. For NO_3^-, 50 mL of water sample was evaporated to dryness and then 2 mL of phenol disulphonic acid was added to dissolve the residue by constant stirring. Later, Conc. NaOH and distilled H_2O were then added with constant stirring. The resultant alkaline solution was filtered into a Nessler's tube and made up to 50 mL with distilled water. The absorbance was read at 410 nm using a spectrophotometer after the development of colour. The value of nitrate was found by comparing the absorbance of the sample with the standard curve and expressed in mg/L. (APHA/AWWA, WEF, 1995). PO_4^{3-} was determined by the phosphomolybdate method after the conversion of orthophosphates by digestion with persulfate respectively (APHA (American Public Health Association) 1992)

Total hardness was determined by titration of buffered (pH10) 50 mL water sample with 0.01 M EDTA with Eriochrome black -T as the indicator (APHA/AWWA/WEF. 1995).

2.2.2. Sediment Sample Collection

Likewise, a total of 72 sediment samples from the dams were collected at a depth of 0 - 5 cm with a stainless-steel grab sampler from twelve (12) separate spots per dam. Thereafter, loose particles and plant debris were manually removed, and the leftover deposited into a black polyethylene bag labeled and transported to the laboratory.

2.3. Reagents, Analytical Quality Assurance and Standards

All chemicals used were supplied by Sigma Aldrich (St. Louis, USA) and Merck (Kenilworth, USA) chemical companies. Analytical reagent grade chemicals were used for samples and spectroscopic grade was used for standards. A multi-elemental calibration standard was prepared from spectroscopic grade stock standard solutions of 1000 mg L^{-1}. Glassware and other equipment were cleaned with 6 M HNO_3 and rinsed off with deionized water to prevent contamination before usage. All plastic containers were washed with deionized water and then soaked overnight in 1 M HNO_3. All analyzes including blanks were carried out in triplicates.

2.4. Samples Preparation and Digestion

2.4.1. Preparations and Digestion of Water Samples

Water samples for elemental analysis were preserved with the addition of 5 mL of conc. HNO_3 at the point of collection (Ghaderpoori *et al.* 2018). The acid-preserved water sample (50 mL) was digested in a 125 mL conical flask with the addition of 10 mL HNO_3 (70%). The mixture was covered with a watch glass and allowed to evaporate to near-dryness while keeping the beaker's bottom from drying out. After washing with 1 mL HNO_3, distilled water, and filtering through Whatman No. 42 filter paper into a 25 mL volumetric flask, the residue in the beaker was diluted with deionized water to the mark and kept in a polyethylene bottle at a temperature of 4 °C before elemental analysis (Olubanjo and Adeleke 2020).

2.4.2. Preparations and Digestion of Sediment Samples

Approximately 2 kg of the sediment sample was taken per dam, placed in an oven for almost three days at a temperature of 60 °C, and dried to a constant weight (Doamekpor *et al.* 2018). It was later crushed into small particles with the aid of an agate mortar. Open vessel digestion was used to digest the sediment samples, 1 g dried sediment samples were digested with 5 mL of conc. HNO_3 acid (Merck, 99.99%). The sample and conc. HNO_3 mixture was then heated to 80 °C until it was nearly dry. Two more times, the acid was added and the heating process was repeated. To the leftover substance, a small amount of water was added. The suspension was filtered (0.45 m Whatman filter Merck) and the filtrate was diluted to a final volume of 50 mL with deionized water (Nkinda *et al.* 2021; Bubu, Ononugbo, and Avwiri 2017).

2.5. Samples Analysis

All digested water and sediment samples were analyzed for Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn by Atomic Absorption Spectrophotometer (Shimadzu model 2380). The accuracy of analytical procedures was checked by analyzing certified reference materials (CRMs) (Table S2).

2.6. Sediment Quality Guidelines (SQGs)

The ecological risk of the studied heavy metal contents in sediment samples from the selected dams was evaluated by comparing the heavy metal concentrations in sediments with Sediment quality guidelines (SQGs) indices (Varol et al., 2022). This assessment was based on two categories of indices, including threshold effect concentration (TEC) and probable effect concentration (PEC). The TEC expresses the concentration of a contaminant in sediment below which harmful effects are not expected to occur on benthic-dwelling biota, but when the concentration exceeds the PEC, harmful effects are expected to frequently occur (Varol, 2020).

2.7. Sediment Pollution and Ecological Risk Assessment Indices

Likewise, level of heavy metal contamination in the sediments was assessed *via* sediment contamination indices such as the enrichment factor (EF), Contamination Factor (CF), and Geo-accumulation Index (Igeo).

2.7.1. Contamination Factor (Cf) C_{Fe}

The assessment of the degree of heavy metal contamination in the sediments was evaluated using the Contamination Factor (CF) as expressed equation 1.

$$Cf = C^i / C^i{}_n \qquad \text{Equation 1}$$

Where $C^i{}_n$ is pre-industrial value of metal (i); C^i is the concentration of heavy metal (i)

2.7.2. Enrichment Factor (EF)

The Enrichment Factor (EF) is the relative abundance of a chemical element in sediment compared to the bedrock. The EF was computed by comparing the concentrations of the element and the reference element in the sample to the average shale values using equation 1.

$$EF = \left[\frac{Ci}{CFe}\right] sample / \left[\frac{Ci}{CFe}\right] background \qquad \text{Equation 2}$$

Where C^i is the concentration of heavy metal in the sample; CFe sample is the concentration of the reference element in the sample; C^i (background) is the average shale value of the element; and Fe (background) is the average shale value of the reference element.

2.8. Statistical Analysis

The results of the studied parameters were subjected to a student's t-test to determine whether the results varied significantly across the sampling sites (dams), with values less than 0.05 ($p < 0.05$) considered statistically significant. Furthermore, bivariate (Pearson's correlation) and multivariate statistical analyzes were used to investigate the association between studied variables, and hence the possible sources. Therefore, multivariate statistical analysis was done using principal component analysis (PCA) and hierarchical cluster analysis (CA) to establish the relationship between metals (Loska and Wiechuła 2003). PCA with varimax normalized rotation was used to reduce the dimensionality of the original data and the most significant principal components with Eigenvalues > 1 were retained. Kaiser-Meyer-Olkin (KMO) and Barlett's Sphericity tests were conducted to check the adequacy of data for structure detection and validation of results from PCA. All statistical analyzes were performed using the Statistical Package for the Social Sciences (PASW version 26, IBM Corporation, Cornell, NY, USA).

2.9. Health risk Assessments

2.9.1. Non-Carcinogenic Risk Assessments

The human health risk associated with the direct consumption of water from the selected dams was evaluated using the daily human exposure assessment. This was measured *via* the ingestion pathway using the lifetime average daily dose (LADD) as described by USEPA (2005). The daily human exposure assessment of each heavy metal based on the quantification of their risk level was estimated in terms of a non-carcinogenic health risk.

The chronic risk was determined using chronic daily intake (CDI) and hazard quotient (HQ) index (USEPA (United States Environmental Protection Agency) 1992; Chrowtoski 1994), based on the modified equation by Kavcar, Sofuoglu, and Sofuoglu (2009) and Belkhiri *et al.* (2017).

$$\mathrm{CDI} = (\mathrm{C} \times \mathrm{DI})/(\mathrm{BW}) \quad (1)$$

where CDI is the human exposure risk through the drinking water pathway (mg/kg/day), C is the concentration of heavy metal in the dam water in mg L^{-1}, DI is the average daily intake rate (2.0 L/day/person), and BW is the body weight (USEPA, 2005).

The non-carcinogenic hazard was evaluated through the hazard quotient (HQ) *via* equation 2 (USEPA, 1999).

$$\mathrm{HQ} = \mathrm{CDI}/\mathrm{RfD} \quad (2)$$

Where RfD is the oral reference dose (mg/kg/day) for individual heavy metals that humans can be exposed to and presented in Table S3 (USEPA IRIS, 2011). The cumulative HQ was calculated as the hazard index (HI) for all the heavy metals studied and it indicates concern about potential toxicity (USEPA, 1999). If the value of HQ is less than 1, it is considered safe for human health, while if the value of HQ exceeds 1, there is an unacceptable risk of adverse non-carcinogenic effects on human health (USEPA (United States Environmental Protection Agency) 2001). To evaluate the cumulative potential risk of all the studied heavy metals in the dams, the hazard index (HI) was evaluated. HI > 1 depicts the mixture of heavy metals to have an unacceptable risk of non-carcinogenic effects while HI < 1 illustrates an acceptable level of risk to human health (ECETOC 2001).

2.9.2. Carcinogenic Risk (CR)

The lifetime exposure to the incremental risk of an individual developing cancer was evaluated using the life-time target carcinogenic risk (TCR) and computed by the excess lifetime cancer risk equation

$$\mathrm{TCR} = \mathrm{CDI} \times \mathrm{CSF} \quad (3)$$

Where CSF is the cancer slope factor (Table S3) and converts the CDI of the studied heavy metals in the body over a lifetime of exposure directly to the incremental risk of an individual developing cancer. if the computed TCR $> 1.0 \times 10^{-4}$, then it is considered unacceptable and intolerable.

3. Results and Discussion

3.1. Physico-Chemical Parameters of Dams

Table 1 summarized the physicochemical (Alk., BOD, COD, DO, EC, NO_3^-, pH, PO_4^{3-}, SO_4^{2-}, Temp, TDS, TH, TSS, and Turb) results of water samples collected from six (6) dams in Osun State. The highest temperature of 23.3 °C was recorded at Ede Dam while Ilesa Dam recorded the lowest temperature of 19.1 °C. This result is consistent with the findings reported in the literature (Chiromawa, Adamu, and Shitu 2019). The pH of the surface water samples ranged from 6.45 to 6.84 (slightly acidic) and was similar to those

Table 1. Physico-chemical parameters of surface water from six selected dams.

	EKO-ENDE	IBA	ILESA	ESA-ODO	EDE	IKIRE	WHO (World Health Organization) (2022)
Temp	20.4 ± 0.06^a	19.50 ± 0.23^a	19.07 ± 0.57^a	20.63 ± 1.90^a	23.30 ± 0.22^b	21.33 ± 0.12^{ab}	20-30
EC	195 ± 0.02^a	225 ± 0.04^b	232 ± 0.03^b	208 ± 0.01^a	210 ± 0.06^{ab}	225 ± 0.00^b	1000
TDS	92.5 ± 2.20^a	112.5 ± 3.60^b	166.00 ± 4.33^d	86.20 ± 2.27^a	114.00 ± 3.38^b	125.00 ± 0.02^c	500
Alk	26.5 ± 0.2^a	29.20 ± 0.1^b	26.50 ± 0.2^a	29.20 ± 0.1^b	26.50 ± 0.2^a	29.20 ± 0.1^b	500
TH	32.2 ± 0.1^a	30.01 ± 0.3^a	32.20 ± 0.1^a	30.01 ± 0.3^a	32.20 ± 0.1^a	30.01 ± 0.3^a	500
Turb	$\mathbf{6.00 \pm 0.01^b}$	$\mathbf{10.0 \pm 0.02^c}$	$\mathbf{30.55 \pm 0.00^e}$	$\mathbf{21.0 \pm 0.01^d}$	$\mathbf{6.00 \pm 0.02^b}$	1.00 ± 0.00^a	5.0
TSS	16 ± 0.04^b	$17 \pm .04^b$	172 ± 0.04^d	125 ± 0.01^c	15 ± 0.01^b	3.0 ± 0.06^a	<1500
pH	6.45 ± 0.24^a	6.64 ± 0.25^a	6.60 ± 0.25^a	6.66 ± 0.22^a	6.67 ± 0.26^a	6.84 ± 0.07^a	6.5-8.5
DO	5.80 ± 0.0^b	4.60 ± 0.01^a	4.10 ± 0.02^a	4.20 ± 0.00^a	4.92 ± 0.02^{ab}	4.80 ± 0.01^{ab}	>4.0
BOD	$\mathbf{14.00 \pm 6.00^a}$	$\mathbf{18.00 \pm 10^b}$	$\mathbf{24 \pm 12.00^c}$	$\mathbf{20 \pm 2.00^b}$	$\mathbf{22 \pm 2.01^{bc}}$	$\mathbf{28 \pm 1.20^d}$	10
COD	$\mathbf{10.30 \pm 4.02^c}$	$\mathbf{7.10 \pm 1.00^b}$	$\mathbf{7.60 \pm 5.01^b}$	$\mathbf{7.30 \pm 3.00^b}$	$\mathbf{12.40 \pm 4.03^c}$	$\mathbf{5.10 \pm 1.02^a}$	4
NO_3^-	2.3 ± 0.04^a	5.7 ± 0.03^d	3.8 ± 0.02^b	3.0 ± 0.04^b	4.7 ± 0.01^c	4.81 ± 0.03^c	10
SO_4^{2-}	5.0 ± 0.1^a	6.0 ± 0.2^{ab}	7.0 ± 2.0^c	8.0 ± 0.9^c	5.0 ± 0.9^a	6.0 ± 2.03^{ab}	250
PO_4^{3-}	0.06 ± 0.01^a	$\mathbf{0.86 \pm 0.02^c}$	0.09 ± 0.01^a	0.11 ± 0.00^{ab}	$\mathbf{0.75 \pm 0.02^c}$	0.04 ± 0.01^a	0.5

Values are in mg L^{-1} (mean ± SD). EC: Electrical conductivity (µs cm^{-1}), Alk: Alkalinity, TH: Total hardness, Turb: Turbidity (NTU), DO: Dissolves Oxygen, BOD: Biological Oxygen Demand, COD: Chemical Oxygen Demand. In each row, different letters indicate a significant difference ($p < 0.05$) for each element. Different superscript letters within rows indicate mean separations by Tukey's post-hoc tests at the 5% level.

Table 2. Comparison Of concentrations of selected heavy metals in surface water in this study with international guidelines.

	Fe	Cu	Zn	Mn	Ni	Cr	Cd	Pb	Reference
EKO-ENDE	$0.47\ (0.02)^b$	$0.92\ (0.01)^b$	$1.34\ (0.01)^c$	$0.06\ (0.01)^{ab}$	$0.02\ (0.01)^a$	$0.03\ (0.01)^a$	$0.001\ (0.01)^a$	<LOD	This study
IBA	$0.66\ (0.01)^c$	$1.16\ (0.02)^c$	$1.46\ (0.00)^c$	*0.08* $(0.02)^b$	$0.02\ (0.02)^a$	$0.04\ (0.02)^a$	$0.006\ (0.02)^b$	<LOD	This study
ILESA	$0.35\ (0.02)^{ab}$	$1.11\ (0.01)^c$	$0.42\ (0.00)^a$	*0.08* $(0.02)^b$	$0.03\ (0.03)^a$	$0.04\ (0.01)^a$	$0.001\ (0.00)^a$	<LOD	This study
ESA ODO	$0.12\ (0.03)^a$	$0.16\ (0.03)^a$	$0.32\ (0.01)^a$	$0.04\ (0.01)^a$	$0.03\ (0.01)^a$	$0.03\ (0.01)^a$	$0.002\ (0.01)^a$	<LOD	This study
EDE	$0.24\ (0.02)^a$	$0.82\ (0.02)^b$	$0.71\ (0.01)^b$	$0.13\ (0.11)^b$	$0.03\ (0.00)^a$	$0.02\ (0.01)^a$	$0.003\ (0.01)^a$	<LOD	This study
IKIRE	$0.22\ (0.00)^a$	$0.94\ (0.04)^b$	$0.60\ (0.00)^b$	$0.16\ (0.01)^c$	$0.04\ (0.02)^a$	$0.03\ (0.01)^a$	$0.002\ (0.01)^a$	<LOD	This study
WHO	0.3	2	0.05	0.08	0.07	0.05	0.003	0.01	WHO (2022)
Freshwater quality criteria for protection of aquatic life									USEPA. (2021a)
USEPA CMC_{acute}	1.0*	0.013*	0.12	–	0.47	0.016	0.0018	0.082	
USEPA $CCC_{chronic}$	–	–	0.12	–	0.052	0.011	0.00072	0.0032	
Drinking water quality criteria									USEPA. (2021b)
$USEPA_{MCL}$	–	1.3	–	–	–	0.1	0.005	0.015	
$USEPA_{MCLG}$	–	1.3	–	–	–	0.1	0.005	0	
Other Studies									
Keban Dam	1.24×10^{-1}	2.40×10^{-3}	6.80×10^{-3}	2.55×10^{-2}	2.00×10^{-3}	1.00×10^{-3}	ND	2.00×10^{-4}	Canpolat *et al.* (2020)
Kralkızı Dam	1.89×10^{-1}	9.18×10^{-3}	1.96×10^{-2}	–	5.21×10^{-2}	9.01×10^{-2}	2.50×10^{-4}	2.65×10^{-2}	Varol (2013)
Dicle Dam	2.52×10^{-1}	9.63×10^{-3}	1.93×10^{-2}	–	5.42×10^{-2}	4.66×10^{-2}	3.22×10^{-4}	1.47×10^{-2}	Varol (2013)

Values are in mg L^{-1} [Mean (SD)]. In each column, different letters indicate significant differences ($p < 0.05$) for each element. *- USEPA. (2006).
CMC, criterion maximum concentration; CCC, criterion continuous concentration; MCL, maximum contaminant level; MCLG, maximum contaminant level goal.

reported for other rivers and dams in Nigeria (Wyasu 2020; Onah, Ajanwachukwu, and Ubachukwu 2022; Opaluwa *et al.* 2022). This slightly acidic pH might be due to natural phenomena, as well as anthropogenic sources such as industrial effluent contamination and fertilizers leakages. Ikire Dam had the highest pH value of 6.84, while Eko-Ende Dam had the lowest pH value of 6.45. The pH values recorded in this study are sufficient to support aquatic life including fish.

Generally, the physicochemical results for Alk., DO, EC, NO_3^-, pH, PO_4^{3-}, SO_4^{2-}, Temp, TDS, TH, and TSS from all the sampled dam water were below the WHO permissible limit (Table 1). However, the BOD, COD, and Turb of the sampled water which ranged between $14.0 - 28.0$, $12.40 - 5.10$, and $30.55 - 1.00$ respectively, were above the WHO permitted limit (10, 4, and 5 mg L^{-1}). Similarly, although the TDS, TSS, and NO_3^- of the surface water samples were below the WHO permissible limits across all the sampling sites, concentrations varied significantly ($p < 0.05$), suggesting the influence of different factors at each site. The non-significance difference in the pH, DO, Temp, EC, and TH values among the six (6) selected dams also corroborated the impact of similar activities at these sites. Although the PO_4^{3-} values ranged from 0.04 to 0.86 mg L^{-1} and 66.66% of the sites were within the WHO permissible limits of 0.5 mg L^{-1}, values at Iba and Ede dams were higher and significantly different compared to others (Table 1).

3.2. Heavy Metal Concentrations in Surface Water

The accuracy of the analytical procedure was validated by recovery experiments, and % recoveries ranged from 99.5 to 100% (Table S2). Table 2 summarized the elemental concentrations in the surface water

Table 3. Comparison Of heavy metal concentration in sediment samples in this study with other studies.

	Fe	Cu	Zn	Mn	Ni	Cr	Cd	Pb	Reference
EKO-ENDE	42.6 (11.5)^{a}	38.3 (10.7)^{a}	138 (0.65)^{ab}	78.2 (0.21)^{a}	31.6 (6.4)^{a}	36.3 (7.1)^{a}	14.0 (5.2)^{a}	61.9 (7.2)^{a}	This study
IBA	88.8 (10.6)^{b}	64.5 (13.1)^{b}	138 (0.65)^{ab}	78.2 (0.21)^{a}	70.7 (14.2)^{b}	79.3 (7.6)^{b}	39.0 (10.3)^{b}	92.3 (9.9)^{b}	This study
ILESA	81.0 (12.4)^{b}	52.0 (33.6)^{b}	173 (0.23)^{c}	123 (1.02)^{b}	67.9 (19.8)^{b}	77.1 (4.6)^{b}	38.7 (15.5)^{b}	90.9 (4.7)^{b}	This study
ESA ODO	50.4 (50.9)^{a}	63.3 (7.8)^{b}	119 (0.23)^{a}	147 (0.60)^{c}	67.8 (11.1)^{b}	79.4 (6.6)^{b}	41.0 (15.1)^{b}	112 (46.6)^{c}	This study
EDE	41.3 (16.8)^{a}	41.7 (9.7)^{a}	128 (0.45)^{a}	75.3 (0.41)^{a}	32.4 (3.1)^{a}	32.7 (7.3)^{a}	13.9 (2.2)^{a}	59.1 (10.1)^{a}	This study
IKIRE	71.9 (44.6)^{b}	69.1 (12.4)^{bc}	212 (0.23)^{d}	137 (0.43)^{c}	77.6 (14.6)^{b}	84.4 (9.3)^{b}	45.0 (10.9)^{bc}	97.1 (11.7)^{b}	This study
TEC	–	31.6	121	–	22.7	43.4	0.99	35.8	
PEC	–	149	459	–	48.6	111	4.98	128	
WASVs	47,200	45	95	850	68	90	0.3		
Other studies									
Yedikir Dam, TR	15483	13	25	332	23	40	0.17	11	Varol et al., 2022
Ladik Dam, TR	14892	16	28	495	14	23	0.17	10	Varol et al., 2022
Değirmendere Dam, TR	16161	16	26	387	22	41	0.11	9	Varol et al., 2022
Khiav River, IR	ND	57	103.41	ND	31.41	59.71	ND	13.35	Shakeri *et al.* 2020
Oluwa River, NGA	ND	12.205	71.76	35.91	15.465	22.835	8.4	13.005	Ayandiran, Fawole, and Dahunsi (2018)
Molopo river, SA	16456.93	53.27	110.90	ND	35.40	92.73	0.16	17.76	Mohajane and Manjoro (2022)
Houguan Lake, CH	37700	38.6	90.7	580	ND	76.3	2.68	39.3	Rao *et al.* (2021)

Values are in mg kg^{-1} [Mean (SD)]. In each row, different letters indicate significant differences ($p < 0.05$) for each element. ND- Not determined; TR-Turkey; IR-Iran; NGR-Nigeria; SA-South Africa; CH-China. WASVs (mg/kg): world average shale values as reported by Turekian and Wedepohl (1961).

samples collected from the dams in Osun State. Generally, the average concentration of the studied micro-element was in the decreasing order of Cu > Fe > Zn > Mn. The average concentrations of Mn, Fe and Zn in 33.3, 50 and 100% of the total surface water samples were above the WHO permissible limit of 0.08, 0.3 and 0.05 mg L^{-1} respectively. The average concentrations of Cu, Zn, Cr, and Cd in all surface water samples from the studied dams were above the criterion maximum concentrations (CMC) and criterion continuous concentrations (CCC) set for the protection of aquatic life in freshwater by USEPA except for Cd at EKO-ENDE and ILESA (USEPA. 2021a). However, the average concentrations of Ni in all dams were below the CMC (0.47 mg L^{-1}) and CCC (0.052 mg L^{-1}) established by USEPA and similar to those reported by Canpolat *et al.* (2020) and Tokatlı and Varol (2021). Likewise, the average concentrations of Cu, Cr, Cd and Pb in all the dams were below the WHO-permitted limits (2.0, 0.05, 0.003 and 0.01 mg L^{-1}) and USEPA maximum contaminant level (MCL) quality criteria set for drinking (1.3, 0.1, 0.005 and 0.015 mg L^{-1}) respectively (WHO, 2022; USEPA. 2021b) (Table 2). These elemental concentrations (Cu, Cr, Cd and Pb) were also below the maximum contaminant level goal (MCLG) set by USEPA for quality drinking water (USEPA. 2021b). Conversely, Cd average concentration at IBA dam exceeded the MCL and MCLG values set by USEPA of 0.005 mg L^{-1} (Table 2).

Similarly, the average concentration of the potentially toxic elements (PTEs) in surface water samples was in the decreasing order of Cr > Ni > Cd > Pb with the concentration of Ni, Cr and Cd, ranging from 0.02 to 0.04, 0.02 to 0.04 and 0.001 to 0.006 mg L^{-1} respectively. However, Pb was below the limit of detection across all the sampling locations. The concentrations of all the PTEs were below the WHO permissible limit for drinking water except for Cd at Iba (0.006 mg L^{-1}) dam. The Ni result is consistent with the previous study (Flefel, Nokhrin, and Donnik 2020). Nickel (Ni) is thought to play a role in physiological processes such as iron absorption from the intestine as a co-factor. Furthermore, statistical analysis showed that the average concentrations of Mn, Ni, Cr and Cd did not differ significantly ($p < 0.05$) across the sampling sites, indicating similar elemental profile and origin.

3.3. Heavy Metal Concentrations in Sediment Samples

Table 3 summarized the concentrations of micro and potentially toxic elements in sediment samples. The concentration of essential micro-elements was in the decreasing order of Zn > Mn > Fe > Cu. The average concentrations of Fe, Cu, Zn, and Mn in sediment samples from the six selected dams ranged from 41.3 to 88.8, 38.3 to 69.1, 119 to 212, and 75.3 to 147 mg kg^{-1} respectively.

All the concentrations of the essential micro-elements in sediment samples were significantly above the WHO permissible limit of 5.0, 50.0, and 50 mg L^{-1} for Fe, Zn, and Mn respectively except for Cu. This elevated concentration is consistent with several studies that have shown that sediment can behave as a sink for heavy metals (Adesanya *et al.* 2020; Gupta and Singh 2011; Kang *et al.* 2019; Pandey and Singh 2017). The average concentrations of Fe in sediment samples were not significantly different ($p < 0.05$) across all the dams, suggesting similarity in the factors responsible for Fe and indicating a common source. Likewise, the concentration of PTEs was in the decreasing order of Pb > Cr > Ni > Cd (Table 3). The average concentration of Cd at all locations was above the WHO permissible limit of 0.8 mg kg^{-1}. Similarly, approximately 67% of the sediment samples had Ni and Pb concentrations above the WHO permissible limit of 35 and 85 mg kg^{-1} respectively. However, the average Cr concentration was below the WHO permissible limit of 100 mg kg^{-1} across the studied dams. The high concentrations of Pb, Cr, and Ni in sediment samples may be attributed to deposition unto the sediments. Generally, the average concentrations of the studied PTEs were not significantly different ($p < 0.05$) across all the study sites (Table 3), indicating similarity in the PTEs profile and origin.

3.4. Sediment Quality Guidelines

Similarly, Table 3 shows the comparison of heavy metal concentrations in the current study with TEC and PEC values. The concentrations of Cu and Zn in 100% of the sediment samples were above the TEC values but below the PEC values. These contents (Cu and Zn) were significantly lower than the PEC values, suggesting that there were no harmful biological effects of Cu and Zn in the sediments of all the dams on freshwater benthic-dwelling organisms. The Cr content was below the TEC values in 33.3% of the sediment samples, while Cd, Ni and Pb concentrations in 100% of the samples were above the TEC values. Although, Ni, Cr and Pb contents in 33.3%, 66.7% and 100% of the samples were within their TEC and PEC values, Cd contents in 100% of the samples exceeded the PEC value. Consequently, these studied PTEs can accumulate in the tissue of benthic-dwelling organisms in these dams (Varol and Sünbül 2018).

3.5. Sediment Pollution and Ecological Risk Assessment

The contamination factor of Fe, Cu, Zn, Mn, Ni, Cr and Cd for all the sediment samples collected from the dams ranged between 0.001- 0.002, 0.85- 1.54, 1.25 – 2.23, 0.09- 0.17, 0.46- 1.14, 0.36- 0.94 and 46.3 - 150 respectively (Table S4). The contamination factor in terms of Fe < 1, indicating low contamination of the sediments, while the Cf in terms Cd > 6, indicating very high contamination.

3.6. Bivariate Statistical Analysis

3.6.1. Correlation Matrix for Physico-Chemical Parameters in the Surface Water Samples

For surface water samples, the physico-chemical parameters' correlation matrix had positive significant ($p < 0.05$) correlations ranging from 0.6 to 0.9 while negative significant correlations ranged from −0.6 to −1.0. Positive significant correlations between BOD and TDS ($r = 0.6$), TH and COD ($r = 0.8$), TSS and SO_4^{2-} ($r = 0.8$), PO_4^{3-} and NO_3^- ($r = 0.7$) were observed. A positive three-way synergy between NO_3^-, pH, and EC and SO_4^{2-}, Turb, and TSS with significant correlations of $r = 0.6$ and 0.7 and 0.8 respectively were observed (Table S5). Equally, a four-way synergy between BOD, pH, EC and TDS corresponding to $r = 0.9$, 0.7 and 0.6 respectively was also observed. Likewise, a positive five-way synergy between pH, EC, Alk, BOD and NO_3^- was also observed for surface water samples. These positive significant correlations indicate similarity in the sources of studied parameters.

Likewise, negative significant correlations between pH and TH (r = −0.6), Turb and DO (r = −0.7), TSS and DO (r = −0.7), DO and SO_4^{2-} (r = −0.8) and COD and SO_4^{2-} (r = −0.6) were observed. There were also negative two-way and three-way synergies between studied physicochemical parameters. Conversely, these negative significant correlations indicate the influence of different sources.

3.62. Correlation Matrix for Heavy Metals in Surface Water Samples

Table S6 summarized The results of the correlation statistical analysis for the studied heavy metals in surface water samples from the six selected dams in Osun State. The results showed both positive and negative correlation matrices ranging from -0.1 to -0.8 and 0.2 to 1.0 for negative and positive correlation matrices respectively, with some significant ($p < 0.05$) associations: Mg and Ni ($r = 0.7$) and Zn and Ni (r = -0.8). a negative significant ($p < 0.05$) correlation (r = -0.8) was also observed between Fe and Ni (Table S6) indicating a different source. Likewise, there was a positive five-way synergy between Fe, Cu, Zn, Cr and Cd with the correlation matrix ranging from 0.6 to 0.9. The surface water Fe strongly correlated with Zn (0.9) and Ni (-0.8) and moderately with Cu (0.7), Cr

(0.06) and Cd (0.6). this positive five-way synergy indicates similarity in the sources of the associated heavy metals and suggests a common source of contamination for the surface water samples and hence, the selected six dams in Osun State. However, surface water Fe correlated weakly with Mn (-0.2) while Cd weakly correlate with Cu (0.3), Zn (0.5), Mn (0.1), Ni (-0.4) and Cr (0.2).

3.6.3. Correlation Matrix for Heavy Metals in the Sediment Samples

Similarly, Table S7 summarized the results of the correlation matrix for the studied heavy metals in sediment samples from the six selected dams in Osun State. Table S7 shows a more significant correlation relative to Table S6 suggesting that the concentrations of the studied heavy metals were more enhanced in the sediment samples corroborating that sediments are sinks for heavy metals. Previously, we also reported a similar enhancement of heavy metals in sediment samples relative to surface water (Adesanya *et al.* 2020). The sediment Fe strongly correlated with Ni (0.8) and Cr (0.8), moderately with Cd (0.7), Cu (0.6), Zn (0.5) and Pb (0.5) and weakly with Mn (0.2).

A four-way synergy between Ni and Cr (0.9), Cd (1.0) and Pb (0.9), a three-way synergy between Cr and Cd (1.0), and Pb (0.9), as well as a two-way synergy between Cd and Pb (0.9), were observed, indicating very strong associations. These high correlation coefficients signify a strong association among the related heavy metals, and hence the common origin of contributions. The typical source of heavy metal contamination includes runoffs from anthropogenic activities such as the uncontrolled application of fertilizers, herbicides, and pesticides for farming activities around the dams. Other contributing factors might be due to leaching from abandoned parts of major pumping machines and equipment littering most of the dams' environs at the time of this study. Apart from V, Ni is an indicator of oil pollution, the main source of Ni contamination in this study area is the activities of fishing boats such as fueling, maintenance and repairs. However, Zn did not correlate significantly ($p < 0.05$) with the other studied heavy metals (Table S7).

3.7. Multivariate Statistics

3.7.1. Principal Component Analysis (PCA)

Several reports have shown that sediments are a good indicator of contamination in the aquatic system because they often act as sinks for these contaminants (Kang *et al.* 2019; Pandey and Singh 2017). Sediments are estimated to accumulate up to 98% of the heavy metal load associated with the aquatic environment (Thuong *et al.* 2013), consequently, sediments can serve as a good tool for source identification of contaminants and pollutants in the aquatic environments. Hence, the results of the PCA for the metal concentrations in sediment samples are summarised and illustrated in Table 4 and Figure 2 respectively. Before the PCA was conducted, the raw data were normalized to avoid misclassifications due to the different order of magnitude and range of variation of the concentration parameters (Tabachnick *et al.*, 2007). The preliminary results of the Kaiser-Meyer-Olkin KMO test (> 0.7) and Bartlett's Test of Sphericity ($p < 0.001$) further validated the results of the PCA, showing that concentration data were adequate for structure detection.

The sediment PCA result was dominated by two principal components, accounting for over 80% of the total variability, which described the overall elemental pattern based on the investigated heavy metals thus, signifying varying sources. A 3-D plot of the PCA loadings is shown in Figure 2A, and the interactions between the 8 metals are evidently seen. Component 1 was dominated by Cr, Pb, Cu, Ni, Cd, Zn and Mn which explained over 60% of the total variance.

The significantly high loadings observed for Pb (0.89), Cd (0.87), and Mn (0.86) indicate a very strong association (Figure 2A) between these three studied heavy metals and strongly suggest common anthropogenic sources. Their likely source is fossil fuel combustion from vehicles and fishing vessels (Rao *et al.* 2021). Previously, we reported a similar association between Cd, Cr, Pb and Mn in petroleum-polluted sites (Ogunlaja *et al.* 2019; Adesanya *et al.* 2020). The distances in Figure 2 also revealed the influence of other anthropogenic sources such as fertilizers and industrial wastewater as reported by Rao *et al.* (2021).

Table 4. Rotated component matrix for elemental variables in sediment samples.

Element	Component	
	1	2
Cr	**0.80**	0.47
Pb	**0.89**	−0.06
Cu	**0.81**	0.27
Fe	0.07	**0.97**
Ni	**0.82**	***0.53***
Cd	**0.87**	0.46
Zn	**0.72**	0.38
Mn	**0.86**	0.01
Eigenvalues	5.554	1.068
% Total variance	69.43	13.35
Cumulative %	69.43	82.78

Extraction Method: PCA. Rotation Method: Varimax with Kaiser Normalization. (Bold figures indicate values $\geq$ 0.5)

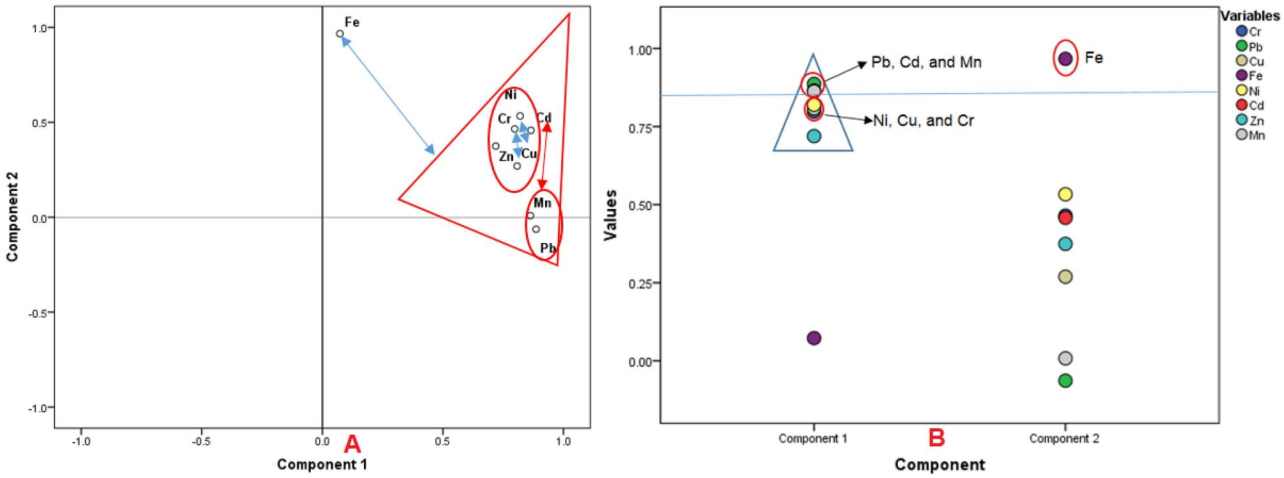

Figure 2. 3-D PCA loading plot (A) and Rotated component matrix dot plot (B) for the studied heavy metals in sediment.

Similarly, component 2, dominated by Fe and Ni, accounted for 13.35% of the total variance indicating another similar origin for these elements. The high loadings of Fe (0.97) may be attributed to both natural geogenic processes (weathering and mineral dissolution) and anthropogenic factors. However, the Ni loading of 0.53 is not as high as that of Fe (0.97) within the group, signifying a quasi-independent behavior within component 2, which is further corroborated by a large distance in the 3-D PCA loading and rotated component matrix dot plots respectively (Figure 2). This weak association in component 2 strongly suggests that Fe and Ni are weakly clustered together, and hence the influence of more than one source for these weakly associated elements.

3.7.2. Hierarchical Cluster Analysis (HCA)

Furthermore, cluster analysis was carried out on the elemental concentrations in the sediment samples. The results are presented in the dendrogram (Fig. S1). The degree of association between the metals is illustrated by the distance between clusters. Fig. S1 shows that the studied elements in the sediment samples were grouped into two main clusters (A and B).

Cluster A contains four mini-clusters, A1 (Cr, Ni, and Cu), and three stand-alone clusters A2 (Cd), A3 (Fe), and A4 (Pb). The short distance and proximity observed in cluster A1 show that Cr, Ni, and Cu were highly correlated signifying a common source. A previous report by Korte (1999) also corroborated this finding and linked elevated concentrations of Ni and Cu to similar origins (parent material). Clusters A2 (Cd), A3 (Fe), and A4 (Pb) were progressively linked to cluster A1 at higher distances showing the influence of other factors and sources of contamination.

Similarly, cluster B consists of Zn and Mn which is however connected at a relatively higher distance to cluster B, implying perhaps a common source.

3.8. Human Health Risk Assessments

3.8.1. Hazard Quotient (HQ)

The computed non-carcinogenic human health risk assessment (HQ) for Cr, Zn, Cu, Mn, Ni and Cd for child and adult age groups is presented in Table 5. The mean child HQ for Cr and Cu were all > 1 for all sites studied except for Cr (0.89) and Cu (0.53) for EDE and ESA-ODO respectively despite being below the WHO-permitted limits. Hence, Cr and Cu presented a non-carcinogenic ingestion risk to children in more than 80% of the sampled surface water from the studied dams. Although the mean child HQ index values for Zn, Mn, Ni, and Cd for 100% of the sites studied were < 1, the cumulative non-carcinogenic risk (hazard index, HI) values were > 1 across all dams, thus signifying a potential adverse human health effect in children. Nevertheless, the estimated non-carcinogenic human health risk assessment HQ values relating to adults were < 1, though the cumulative non-carcinogenic risk (hazard index, HI) values were > 1 across all dams except at ESA-ODO (0.59).

The cumulative non-carcinogenic risk (hazard index, HI) values or Cr, Zn, Cu, Mn, Ni and Cd ranged from 0.59 to 8.16 and 91.7% were higher than 1 for the non-carcinogenic adverse health effects. Overall, the result of the non-carcinogenic human health risk assessment (HQ) and the additive effects (HI) suggest an unacceptable risk of non-carcinogenic effects on human health thus, directly consuming water from these dams without proper treatment can

Table 5. Non-carcinogenic risk (hazard quotient, HQ) and cumulative toxic risk (hazard index, HI) and carcinogenic risk (TCR).

Age group	Site	HQ Cr	Zn	Cu	Mn	Ni	Cd	$\sum$ HQ = Hi	TCR Cr	Cd	Ni	$\sum$ TCR
Child	EKO-ENDE	**1.33**	0.60	**3.07**	0.06	0.16	0.27	**5.48**	**2.0×10^{-3}**	**1.9×10^{-3}**	**2.3×10^{-4}**	**4.1** $\times 10^{-3}$
	IBA	**1.78**	0.65	**3.87**	0.08	0.19	1.60	**8.16**	**2.7×10^{-3}**	**2.3×10^{-3}**	**1.4×10^{-3}**	**6.3** $\times 10^{-3}$
	ILESA	**1.78**	0.19	**3.70**	0.08	0.22	0.27	**6.23**	**2.7×10^{-3}**	**2.6×10^{-3}**	**2.3×10^{-4}**	**5.5** $\times 10^{-3}$
	ESA-ODO	**1.33**	0.14	0.53	0.04	0.26	0.53	**2.84**	**2.0×10^{-3}**	**3.1×10^{-3}**	**4.5×10^{-4}**	**5.6** $\times 10^{-3}$
	EDE	0.89	0.32	**2.73**	0.12	0.24	0.80	**5.10**	**1.3×10^{-3}**	**2.9×10^{-3}**	**6.8×10^{-4}**	**4.9** $\times 10^{-3}$
	IKIRE	**1.33**	0.27	**3.13**	0.15	0.27	0.53	**5.69**	**2.0×10^{-3}**	**3.2×10^{-3}**	**4.5×10^{-4}**	**5.7** $\times 10^{-3}$
Adult	EKO-ENDE	0.28	0.12	0.64	0.01	0.03	0.06	**1.14**	**4.2×10^{-4}**	2.1×10^{-6}	3.7×10^{-9}	**4.2** $\times 10^{-4}$
	IBA	0.37	0.14	0.81	0.02	0.04	0.33	**1.70**	**5.6×10^{-4}**	2.6×10^{-6}	2.2×10^{-8}	**5.6** $\times 10^{-4}$
	ILESA	0.37	0.04	0.77	0.02	0.05	0.06	**1.30**	**5.6×10^{-4}**	2.9×10^{-6}	3.7×10^{-9}	**5.6** $\times 10^{-4}$
	ESA-ODO	0.28	0.03	0.11	0.01	0.05	0.11	0.59	**4.2×10^{-4}**	3.5×10^{-6}	7.4×10^{-9}	**4.2** $\times 10^{-4}$
	EDE	0.19	0.07	0.57	0.03	0.05	0.17	**1.06**	**2.8×10^{-4}**	3.2×10^{-6}	1.1×10^{-8}	**2.8** $\times 10^{-4}$
	IKIRE	0.28	0.06	0.65	0.03	0.06	0.11	**1.18**	**4.2×10^{-4}**	3.6×10^{-6}	7.4×10^{-9}	**4.2** $\times 10^{-4}$

(Bold figures for HQ and HI indicate values ≥ 1, while Bold figures for CR indicate $> 1 \times 10^{-4}$) *Target Carcinogenic Risk = (CDI × SF).

lead to an unacceptable risk of a non-carcinogenic effect on human health in both age groups.

3.8.2. Target Carcinogenic Risk (TCR)

The average TCR_{oral} due to exposure to Cd, Cr and Ni through the consumption of contaminated water in children and adults ranged from 2.3×10^{-4} to 3.2×10^{-3} and 3.7×10^{-9} to 5.6×10^{-4} respectively (Table 5). To evaluate whether or not children and adults were at risk of carcinogenicity, the computed values were compared to the target limit value of 1×10^{-4} for cancer risk set by USEPA (United States Environmental Protection Agency) (2012).

Generally, the TCR_{oral} of Cd, Cr and Ni in children was higher than in adults and the target value of 1×10^{-4}, indicating a high risk of exposure to cancer in children. Although the TCR_{oral} of Cr in adults were $> 1 \times 10^{-4}$, TCR_{oral} of Cr and Ni in adults ranged from 3.7×10^{-9} to 3.6×10^{-6} and were $< 1 \times 10^{-4}$ and hence indicating no cancer risk from Cr and Ni to the adult population. However, the % contribution of Cr to the cumulative carcinogenic risk ($\sum TCR_{oral}$) in adults which is $> 1 \times 10^{-4}$ ranged between 98.9 to 99.5%, indicating that Cr is a major contributor to the overall cancer risk in adults across sampling sites.

4. Conclusion

In conclusion, this study adopted a multidisciplinary scientific approach; multivariate statistical techniques, and health risk assessment to detect the main factors in elemental variables in dam water and assessed the health effect of consuming water from the studied dams. Overall, the concentrations Fe, Zn, Mn, Ni, Cd and Pb in sediments were higher than the permissible limit recommended by WHO. The multivariate statistics revealed that weathering of bedrocks, uncontrolled farming activities, abandoned equipment, boat fueling, maintenance, and repairs as the possible sources of elemental contamination in the studied dams. Data from the human health risk assessment suggest an unacceptable risk of both non-carcinogenic and carcinogenic effects from the direct consumption of dam water.

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No potential conflict of interest was reported by the author(s).

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