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Research paper

Determination of Some Heavy Metals in The Sediment Samples Collected from Selected Dams in Katsina State, Nigeria

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Abstract

Heavy metal contamination in aquatic environments is a major ecological and public health concern due to the toxic, non-biodegradable, and bioaccumulative nature of these elements. In particular, sediments serve as both sinks and potential sources of heavy metals in aquatic systems, playing a crucial role in regulating their distribution and bioavailability. Elevated concentrations of heavy metals in sediments can impair benthic communities, disrupt food web dynamics, and pose long-term risks to ecosystem stability and human health through trophic transfer.This study assessed levels of cadmium (Cd), nickel (Ni), lead (Pb), and zinc (Zn) in sediment samples from three multipurpose dams in Katsina State—Gwaigwaye, Maska, and Zobe important for water supply, irrigation, fishing, and livestock use. Sampling was conducted during both dry and wet seasons using composite methods. Metal concentrations, determined via MP-AES after acid digestion, were all below USEPA and NOAA limits, indicating good sediment quality. One-way ANOVA showed no significant seasonal variation ($p > 0.05$). Pollution Load Index (PLI) and Geoaccumulation Index (I_geo) values were below critical thresholds, indicating no contamination across both seasons.

Keywords: *Contamination Factor; Heavy Metals; Geo-Accumulation and Pollution Indices; Sediment.*

1. Introduction

Heavy Metals are defined as metallic elements that have a density greater than 5g/cm$^{3.}$ Heavy metals may find their way into the aquatic environment through natural processes and Human activities[1].
The use of phosphate-based fertilizers and certain pesticides in surrounding farmlands contributes trace metals like cadmium (Cd) and zinc (Zn), which are subsequently introduced into the dams through leaching and surface runoff, especially from fields situated on slopes and unprotected catchment areas[2]. Livestock grazing near the dams and the use of the water bodies for animal watering further contribute to sediment contamination through fecal matter deposition and soil erosion[3]. Domestic wastewater discharges from nearby communities, including laundry activities, bathing, and direct wastewater disposal, also introduce trace levels of metals into the aquatic system. The use of detergents and soaps containing metal compounds may lead to accumulation over time [4]. Additionally, unregulated sand dredging or minor excavation activities near the dams disturb bottom sediments and may resuspend previously buried contaminants[5].
The Global concern surrounding the aquatic environments by heavy metals, including their persistence and bioaccumulative nature, has intensified, as these metals continue to threaten the health of aquatic life [6]. Human activities such as mining, smelting, agricultural, and industrial processes have been identified as the primary sources of heavy metal contamination of various environmental components, including soil, air, and water [7]. The presence of heavy metals in organisms can stimulate the production of reactive oxygen species (ROS), which cause oxidative stress and result in DNA damage and cell death, ultimately leading to harmful effects on organisms [8]. Sediment refers to minerals or organic materials that are found below the water's surface. It is an essential and inextricable part of aquatic ecosystems, as it helps in assessing the levels of heavy metals present in the water and their potential impact on aquatic life and the overall health of the ecosystem [9]. Sediment serves as both a significant habitat and a primary source of nutrients for aquatic organisms [10].
Aquatic environments often accumulate trace toxic metals in bottom sediments through processes like adsorption and coagulation, posing a significant threat to the ecosystem [11].
Aquatic organisms that live in and feed on metal-contaminated sediments are at increased risk of bioaccumulating toxic heavy metals, which can then be indirectly transferred to humans through consumption of their tissues[12]. Gwaigwaye, Maska, and Zobe dams were considered for this research because of their contributions to the well-being of the neighbouring communities, supplying water for consumption, irrigation, fishing, and other agricultural activities [13]. Although the three dams serve multipurposes including domestic, industrial, and agricultural activities, they also receive untreated effluent from industrial sources, anthropogenic inputs from cleaning, washing, and remnants of agrochemicals from nearby farmlands. These various inputs can lead to increased concentrations of heavy metals in the water and sediment, which can pose a significant threat to the health of the environment and organisms that inhabit it.This study

aimed to quantify the concentrations of Cadmium, Nickel, Lead and Zinc in the sediment samples from three dams(Gwaigwaye, Maska and Zobe) in both dry and wet seasons, and to evaluate the level of pollution in these dams using both pollution and Geoaccumulation indices, as this information has not been extensively covered in the previous literatures.
All the chemicals used met the analytical grade standard for purity. Distilled water was utilized as a diluent for all solution preparation. Analytical grade reagents and deionized water were used throughout the study.
Before use, all glassware and plastic containers used were washed, cleaned, and oven-dried at
105°C. All weighing was carried out on an analytical weighing balance[14].

2.1. Study areas

Gwaigwaye Dam was constructed in the year 2003 by the former president, Chief Olusegun Obasanjo, in Funtua, Katsina state, to provide water for irrigation to the surrounding communities and drinking water for the local government areas, namely Funtua, Faskari, and Bakori Local Government. The reservoir is formed by an embankment over the Gwaigwaye River on a Latitude (11° 58'N) and a longitude (7° 20' E)(Figure 1). Funtua, Katsina state. The size of the reservoir is above 450 m while the depth is about 130m. It has a storage capacity of 130 million cubic meters. The climate of the area is typical savannah type with wet season (May- October) and dry season (November-April. [15]
Maska Dam Was Built in the year 1996, during the administration of the Former military Head of State, late Gen Sani Abacha, in Maska Village, Funtua Local Government, Katsina State, to provide water for irrigation to the surrounding Communities and drinking water for some Local government areas, namely, Funtua, Dandume, and Sabua. It is located on a Geographical Coordinate of Latitude 11^0 19' 0"North of the Equator and Longitude 7^0 20'0"East of Greenwich meridian(fig1).
The Climate of the area is typical savannah type with wet season (May-October and dry season (November-April)[12].
Zobe Dam was established in the late 1970s during the Administration of former Military Head of State General Olusegun Obasanjo. It was planned to supply 50% of the drinking water for Katsina state while also supporting the irrigation farming in Dutsinma Area. The dam was completed and commissioned in 1983 by then-President Alhaji Shehu Shagari. It is located on a Geographical coordinate of latitude 12°23'18" North of the equator and longitude 7°28'29"East of the Greenwich Meridian(Fig.). It has a height of 19 meters and a length of 2,750 meters. The Dam has a storage capacity of 170 million cubic meters, covering 800 Hectares of land. The climate of the areas is typical savannah type with wet season (May-October) and dry season (November-April) [16].

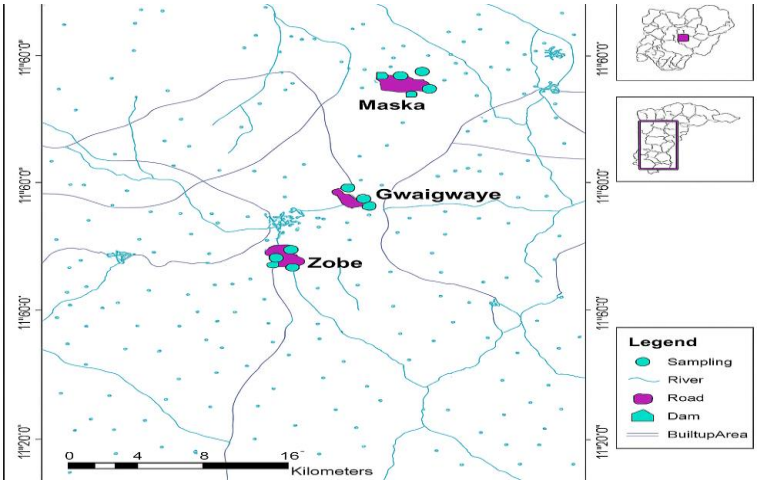

Fig. 1: Map Showing Maska, Gwaigwaye, and Zobe Dams.

2.2. Sediment samples collection

Each Dam was sampled at five distinct locations, 50 metres apart, for sediment analysis. 5 bottomed sediment samples were collected with a soil auger. Sediment samples weighing approximately 200g were collected from each site. The individual samples were combined and thoroughly mixed to form composite samples and allowed to dry in the laboratory. The samples were ground with a porcelain pestle and mortar, then sieved through a 2 mm brass sieve and stored till ready for the analysis [17].

2.3. Digestion of sediment samples

The sample (3 g) of the dried, ground, and sieved sediment samples was placed in a clean 250 cm^3 beaker. Nitric acid and Hydrochloric acid in the ratio 3:1 were added to each sample. The mixture was left to stabilize, then the beakers covered with watch glasses were placed on a hot plate and heated at 120°C until a yellow-brown coloration was observed. The Solution was cooled before filtration using Whatman No. 1 Filter paper to obtain a clear filtrate. It was transferred into a pre-cleaned sample bottle and topped up to the mark with distilled water [13].
After digestion, three (3) replicate concentration measurements of all metals in the various samples were carried out using an Agilent Microwave Plasma Atomic Emission Spectrometer (MP-AES) equipped with an inert nebulizer and a double-pass glass cyclonic spray chamber.

2.4. Analysis of some heavy metals using microwave plasma atomic emission spectroscopy (MPAES)

After sample digestion, the resulting solution from the digestion was transferred into a sample cup. The sample cup was placed in the microwave plasma atomic emission spectrometer and was sealed. The instrument was turned on and allowed to warm up for a while. The sample was injected into the plasma torch, where it was atomized and excited by microwave radiation. The excited atoms emitted characteristic wavelengths of light, which are then measured by a microwave plasma atomic emission spectrometer. The microwave plasma

atomic spectrometer analyzed the wavelength and determined the concentrations of Cd, Pb, Ni, and Zn in the sample simultaneously. The results were displayed on the computer screen [18].

2.5. Statistical analysis

The Data obtained from sediment samples were processed statistically and presented as mean ± standard error. Statistical significance of the comparison of data was analyzed using one-way Analysis of variance (ANOVA) using the software Statistical Package for Social Sciences (SPSS). The result of the analysis indicated no significant difference between sediment samples collected from Maska, Gwaigwaye, and Zobe dams in both dry and wet seasons.3.0 Results

Table 1: Concentrations of some heavy metals (mg/Kg) in Sediment Samples Collected from Maska, Gwaigwaye, and Zobe Dams in the Dry Season

Metals(mg/kg)	Cd	Ni	Pb	Zn
Maska Dam	0.0196±0.02	0.166±0.04	0.00	0.26±0.01
Gwaigwaye Dam	0.020±0.00	0.190±0.01	0.01±0.00	0.29±0.03
Zobe Dam	0.01±0.00	0.15±0.01	0.016±0.03	0.023±0.01

Table 2: Concentrations of Some Heavy Metals (mg/Kg) in Sediment Samples Collected from Maska, Gwaigwaye, and Zobe Dams in Wet Season

Metals(mg/kg)	Cd	Ni	Pb	Zn
Maska Dam	0.019±0.01	0.160±0.01	0.00±0.00	0.201±0.03
Gwaigwaye Dam	0.020±0.02	0.190±0.01	0.00±0.00	0.26±0.03
Zobe Dam	0.019±0.01	1.037±0.01	0.00±0.00	0.023±0.01

Table 3: Contamination Factors of Some Heavy Metals of Maska, Gwaigwaye, and Zobe Dams in Dry Season.

	Cd	Ni	Pb	Zn
Maska Dam	0.049	0.415	0.00	0.65
Gwaigwaye Dam	0.05	0.475	0.02	0.725
Zobe Dam	0.025	0.375	0.04	0.075

Table 4: Contamination Factors of some Heavy Metals of Gwaigwaye and Zobe Dams in Wet Season

Metals	Cd	Ni	Pb	Zn
Maska Dam	0.0475	0.40	0.00	0.5026
Gwaigwaye	0.05	0.475	0.00	0.65
Zobe Dam	0.0475	0.323	0.00	0.0575

Table 5: Geoaccumulation and Pollution Load Indices of some Heavy Metals in Maska, Gwaigwaye, and Zobe Dams in Dry Season

Metals	Cd	Ni	Pb	Zn	Pollution load indices (PLI)
Maska Dam	-1.18	-0.25	0.00	-0.062	0.00
Gwaigwaye Dam	-1.17	-0.199	-1.574	-0.015	0.14
Zobe Dam	-1.19	-0.301	-1.369	-1.12	0.07

Table 6: Geoaccumulation and Pollution Load Indices of some Heavy metals in Maska, Gwaigwaye, and Zobe Dams in Wet Season

Metals	Cd	Ni	Pb	Zn	pollution load indices (PLI)
Maska Dam	-1.19	-0.097	0.00	-0.174	0.00
Gwaigwaye Dam	-1.18	-0.022	0.00	-0.062	0.00
Zobe Dam	-1.19	-0.364	0.00	-1.12	0.00

2. Discussions

Tables 1 and 2 present the seasonal variations in the concentrations of cadmium (Cd), nickel (Ni), lead (Pb), and zinc (Zn) in sediment samples from Maska, Gwaigwaye, and Zobe dams. The data demonstrate generally low concentrations of all analyzed metals, remaining below NOAA and USEPA permissible limits, suggesting minimal contamination levels across both dry and wet seasons.

Cadmium (Cd):

Cadmium concentrations in sediment samples remained relatively consistent across Maska and Gwaigwaye dams, ranging from 0.0196 ± 0.002 to 0.02 ± 0.003 mg/kg during the dry season, and 0.019 ± 0.01 mg/kg for both sites during the wet season. However, in the Zobe dam, cadmium increased from 0.010 ± 0.00 mg/kg (dry) to 0.019 ± 0.00 mg/kg (wet). Despite these changes, all recorded values were significantly lower than the NOAA/USEPA threshold of 22.7 mg/kg. The observed concentrations align with the findings of [19], who reported 0.03 ± 0.01 mg/kg for Cd in sediments from Ujere Dam. Comparable or slightly higher values have been reported in other Nigerian and international studies, such as 0.06 mg/kg in Al-Nasiriyya City, Iraq [20] 0.4265 ± 0.03 mg/kg in Dannakolo Dam, Nigeria [21] and 0.08 ± 0.10 mg/kg in Koramar Wanke Dam [22] 0.5±0.09 mg/Kg for Cd from Parnai river in Brazil, by[23], 0.80±0.88 mg/Kg for Cd in sediment from Ciujung water shed Baten province in Indonesia by[24], Much higher levels, such as 2.44 ± 2.12 mg/kg in Erlu Reservoir [25] and 1.82 ± 0.03 mg/kg in the Estuary Porong Sidoarjo, East Java [26] and 0.02 mg/Kg for Ni was also reported by [21] from Awe dam in Nassarawa state, Nigeria. Industrial and agricultural activities contribute significantly to cadmium (Cd) accumulation in sediments in many regions [27]. The low cadmium levels observed in the present study could be attributed to limited point-source pollution and the relatively low intensity of nearby anthropogenic activities [28]

Nickel (Ni):

Nickel concentrations ranged from 0.13 ± 0.01 to 0.19 ± 0.01 mg/kg across all sites and seasons, well below the permissible limit of 35.8 mg/kg. This finding is consistent with the report of [17], who obtained 0.15 ± 0.01 mg/kg in River Bunsuru, Zamfara State, and [29] who reported 0.407 mkg/Kg for Ni in sediment, Mangla Lake dam district of Mirpur. In contrast, significantly higher levels have been recorded in Algeria River Basin (16.80 ± 2.6 mg/kg) [30] Zungeru Fishing Settlement (1.67 ± 0.07 mg/kg) [31] 0.791 mg/Kg for Nickel from Balu river bangaledash reported by [32] and Nairobi Dam (5.94 ± 0.12 mg/kg) [33]. The elevated nickel (Ni) levels in those areas are likely linked to extensive urbanization, industrial discharge, and agricultural runoff [34]. The relatively low Ni levels in the current study area may reflect less intensive industrial and agricultural practices or effective sediment trapping [35].

Lead (Pb):

In the dry season, lead was detected at 0.00 ± 0.00 mg/kg in Maska, 0.010 ± 0.00 mg/kg in Gwaigwaye, and 0.0160 ± 0.003 mg/kg in Zobe. However, Pb was not detectable in any of the dams during the wet season, possibly due to dilution effects caused by increased water volumes, as also suggested by [36]. The concentrations remained well below the NOAA/USEPA limit of 120 mg/kg. Some higher values for Pb levels have been reported by [37] in Songkhla lake in southern Thailand (3.5±0.6 mg/Kg) and [38] in Rumbia River, Indonesia (1.34 mg/kg), while higher values such as 17.45 mg/kg in Mara River [39], 46 mg/Kg for Pb in sediment from Balu river sediment of Bangaledash reported by [40] and 7.547 ± 1.234 mg/kg in Baleh River, Malaysia. [41] also reported a range of 0-33 mg/Kg from Kuwait bay by [42] 6.95±21.3 mg/Kg for Pb from Parnai river Brazil by [23] and 4.37±0.28 mg/Kg for Pb in sediment of mara rivers tributaries in Tanzania reported by [43] Elevated lead concentrations are indicative of higher anthropogenic inputs, including industrial discharges and vehicular emissions [44].

Zinc (Zn):

Zinc concentrations showed a declining trend from dry to wet seasons in Maska (0.26 ± 0.01 to 0.201 ± 0.03 mg/kg) and Gwaigwaye (0.29 ± 0.01 to 0.26 ± 0.03 mg/kg), while remaining unchanged at 0.023 ± 0.00 mg/kg in Zobe. The observed stability in Zn concentrations may be due to sedimentation dynamics and low variability in anthropogenic input during the study period [12]. All values were significantly below the NOAA/USEPA threshold of 4.9 mg/kg. Higher values reported in other studies, such as 0.7376 ± 0.0004 mg/kg in Ajiwa Dam, Katsina [21] and 0.2 mg/kg in Bonny-New Calabar Estuary [45] Likewise, higher values were also reported such as a range of 2.33-4.81 mg/Kg for Zn in sediment from Vedaranya coast southern india by [46], 65.1±0.00 mg/Kg for Zinc in sediment of coastal marine area of Tanzania by [47] and 120 mg/Kg for Zn in coast sediment from nile delta Egypt by [48]. Agricultural activities significantly contribute to zinc enrichment in dam sediments through the use of zinc-rich fertilizers and manure, as well as pesticide application [49].

Geaoccumulation Index(Igeo) was originally defined by Muller in 1969, in order to determine the levels of the metals contaminated in the sediments by comparing the current concentrations with the Pre-industrial level. It is calculated by the following equation

$$\text{Igeo} = \frac{\text{Log}[\text{Cn}]}{1.5\text{Bn}} \quad (1)$$

Where Cn is the measured concentration in the sediment samples and Bn is the geochemical background content of the same metal. The constant 1.5 is introduced to reduce the effect of possible variations in the background values, which may be attributed to anthropogenic influences. The index of geoaccumulation(I-geo) is grouped according to Müller's seven grades or classes. The value of sediment quality is considered as upolluted(I-geo≤0,class0): from upolluted to moderately polluted(Igeo is 0-1, class1); moderately polluted (Igeo is1-2, class2); from moderately polluted to strongly polluted(Igeo is 2-3, class3); strongly polluted(Igeo is 3-4, class4); from strongly to extremely polluted(Igeo is 4-5, class 5) and extremely polluted(Igeo is >6, class 6).

Contamination Factor(CF) was used to determine the pollution status of the sediments in the present study. CF was calculated using the relation described below.

$$\text{CF} = \frac{\text{MC}}{\text{BC}}$$

Where MC is the measured concentration of the metals and BC is the background concentration of the same metal.

Four contamination categories were recorded based on contamination factor CF<1: Low contamination, 1≤CF≥3 moderate contamination, 3≤CF<6: Considerable contamination, and CF>6: Very high contamination.

Pollution load index(PLI) was used to assess the level of pollution by heavy metals in the dams. The range and class are similar to those of the Geoaccumulation index(Igeo). The pollution load index of each dam is calculated using the relation below.

$$\text{PLI} = (\text{CF}_1 \times \text{CF}_2 \times \text{CF}_3 \times \text{CF}_4 \text{----------CFn})^{1n/} \quad (2)$$

Where n is the number of metals and CF is the contamination factor[17].

The contamination factors (CFs) for cadmium (Cd), nickel (Ni), lead (Pb), and zinc (Zn) in sediments from the three studied dams, as presented in Tables 3 and 4, ranged from 0.025–0.05 for Cd, 0.323–0.475 for Ni, 0.00–0.04 for Pb, and 0.0575–0.725 for Zn. All values were below the threshold value of 1 (CF < 1), indicating low contamination levels and suggesting that the sediments are not significantly impacted by anthropogenic inputs of these metals.

Similarly, the Pollution Load Index (PLI) values, shown in Tables 5 and 6, ranged from 0.00 to 0.14 across all locations and sampling periods. The highest PLI value was recorded in Gwaigwaye Dam during the dry season, followed by Zobe Dam within the same season. However, as all PLI values remained below 1 (PLI < 1), this confirms the absence of significant metal pollution in the sediments. These findings are consistent with those of [50], who reported similar PLI values in the Ahmadu Bello University Dam, Zaria. Conversely, studies by [51]from the Al-Shuaibah coastline in Saudi Arabia,[52] from the coastal area of Chanthaburi Province in the Gulf of Thailand, and [53] from Wadi Al-Wala, Jordan, reported PLI values greater than 1, indicating polluted conditions. In contrast, [54] in the Pearl River Estuary, China[55] in Chongqing, China, and [56] in a riverine system in Pakistan reported PLI values below 1, similar to the current findings.

The Geo-accumulation Index (I-geo) values also support these observations. Across all sampling sites and periods, I-geo values ranged from -1.19 to -1.17 for Cd, -0.364 to -0.097 for Ni, -1.574 to 0.00 for Pb, and -1.12 to -0.062 for Zn. According to Müller's (1979) classification, negative I-geo values (I-geo < 0) indicate unpolluted conditions. These results suggest that the observed metal concentrations are predominantly of natural geogenic origin rather than anthropogenic sources. Similar trends have been reported in the Makassar Strait by [57] and[58] in the Richards Bay Harbour community in South Africa.

However, this study contrasts with findings from Mairua Dam, where positive I-geo values (I-geo > 0) were observed, indicating a higher level of contamination [59]. Comparable I-geo values greater than zero were also reported by [60] in the Tiber River within urban Italy, and by [61] in the shipyard sediments in the Amazon delta estuary of Northern Brazil.

A seasonal trend was evident, with generally higher metal levels and contamination indices recorded during the drier period compared to the rainy phase. This variation can be attributed to lower water volumes and reduced dilution capacity during dry months, which often lead to the concentration and subsequent accumulation of metals in sediments. Evaporation may also contribute to this effect by intensifying the concentration of solutes. These findings are consistent with those of [62], who linked higher contamination during arid periods to such hydrological conditions.

In contrast, the rainy season typically brings increased water flow, which enhances dilution and promotes the dispersion of metals. Additionally, runoff and sediment resuspension during intense rainfall may result in the removal of contaminated particulates, thereby lowering contamination levels[62].

3. Conclusion

The results of the pollution indices (PI < 1) and geo-accumulation indices (Igeo < 0) for all assessed heavy metals indicate that the sediments from the studied dams are essentially unpolluted

While sediment concentrations of Cd, Ni, Pb, and Zn in Gwaigwaye, Maska, and Zobe dams were within NOAA/ USEPA limits and pollution indices indicated no significant contamination, the impact of climate change on metal mobility and bioavailability cannot be ignored. Thus, the dams cannot be considered entirely pollution-free, and continuous monitoring is recommended to ensure long-term environmental safety.

4. Recommendations

- Community education programs should be implemented to raise awareness about the importance of protecting water quality. The risks associated with improper disposal of industrial, agricultural, and domestic wastes should be communicated to residents.
- Sustainable farming methods, such as the reduction of chemical fertilizer and pesticide usage, the adoption of organic alternatives, and the establishment of buffer zones to minimize runoff, should be encouraged among farmers.
- Environmental regulations related to waste disposal near water bodies should be strictly enforced. Effective community-level waste management systems should be established and maintained to reduce pollution sources.
- Local stakeholders should be involved in routine monitoring of sediment and water quality through participatory surveillance programs. Training and resources should be provided to enable early detection and reporting of pollution events.
- Partnerships between academic institutions, environmental agencies, and local governments should be fostered to facilitate regular environmental assessments. Findings from such research should be used to inform evidence-based policies and develop region-specific environmental protection measures.
- It is advisable that future studies be broadened to include other highly toxic metals such as arsenic (As) and mercury (Hg), which are of significant environmental and public health concern due to their persistence and strong bioaccumulative properties. In addition, the inclusion of biotic components—particularly the analysis of fish and other aquatic organisms—should be considered to evaluate the potential for trophic transfer and biomagnification of heavy metals within the aquatic food chain. This expanded scope would allow for a more comprehensive assessment of ecological risks and human exposure pathways associated with contamination in these ecosystems.

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Conflict of interest

The Authors have declared that no conflict of interest exists.

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