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Article

Appraising the heavy metal content of a man-made lake in Benin City, Nigeria in relation to its current uses

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Abstract
Man-made lakes are constructed for purposes such as water storage, irrigation, drinking water supply, recreation, flood control, and energy production. The heavy metal content of a man-made lake designated for flood control was assessed at two stations during two different seasons. The objective was to evaluate the suitability of the water for its current uses—fishing, recreation, and cattle watering. Eight heavy metals were analyzed and compared against established standards for aquatic life, recreational use, and livestock production. Additionally, the Water Pollution Index (WPI) was used to assess overall water suitability.
The concentration ranges of the metals were as follows: iron (1.08÷2.88 mg/L), manganese (0.54÷1.35 mg/L), zinc (0.78÷1.88 mg/L), copper (0.33÷1.11 mg/L), chromium (0.21÷0.74 mg/L), cadmium (0.11÷0.31 mg/L), nickel (0.08÷0.22 mg/L), and lead (0.15÷0.46 mg/L). All metals exceeded the permissible limits for aquatic life, recreation, and livestock production, except for zinc and copper (recreation), and zinc, chromium, and nickel (livestock production). The Water Pollution Index values were situated in the range: 161.0÷195.8 (aquatic life); 13.3÷16.2 (recreation); 3.3÷4.1 (livestock production). All WPI values were greater than 1, indicating that the water is highly polluted. The severity of pollution followed the order: $WPI_{aquatic\ life} > WPI_{recreation} > WPI_{livestock\ production}$. Generally, higher concentrations were recorded at Station 2 and during the dry season, although the differences were not statistically significant. The heavy metal content appeared to be influenced by diffuse sources of stormwater runoff entering the lake and seasonal variations. In conclusion, the surface water is not suitable for its current uses.

Keywords: *heavy metal, retention pond, season, flood control, index*

INTRODUCTION

Man-made lakes in Nigeria and other developing countries provide numerous socio-economic benefits; however, their construction often leads to considerable environmental risks [1]. These artificial water bodies are commonly formed through dam construction, stone quarrying, and soil excavation associated with road development activities [2].
Inland man-made lakes are typically freshwater systems that offer vital ecosystem services to human populations. They serve as essential surface water resources, supporting diverse biological communities and facilitating various human activities. Nevertheless, pollution—particularly following the industrial revolution—has significantly degraded surface water quality globally, with conditions continuing to deteriorate [3].
One of the most pressing environmental concerns in such systems is the accumulation of heavy metals in both water and sediments, which poses severe risks to aquatic life—including fish, plants, and microorganisms—as well as to human health [4]. Water bodies and their sediments act as both sinks and vectors for heavy metals, especially in land-water interface zones where up to 99% of these metals may be adsorbed and retained [5]. Heavy metals ranks as major polluting chemicals in both developed and developing countries [6]. Notably, the total concentration of heavy metals in urban street runoff is typically 2 to 15 times greater than that found in roof runoff [7, 8].

While retention ponds can effectively remove particulate-bound heavy metals via sedimentation, they are less efficient in retaining dissolved metal forms [9]. Heavy metals are particularly hazardous due to their distinct physical-chemical properties: they are non-biodegradable, tend to bioaccumulate, possess high densities and long half-lives, and are resistant to natural attenuation processes [5]. Although trace concentrations of metals occur naturally in aquatic systems, anthropogenic activities have introduced them at levels that far exceed natural baselines, raising critical environmental and public health concerns [10].

Retention ponds are increasingly used in urban flood control systems across the world [11÷13]. The heavy metal contents of floodwater and runoff are usually very high, especially in urban and industrial areas [14]. Shallow lakes can be easily influenced by external factors like rainfall and runoff, which in turn can determine the concentations of nutrients and pollutants including heavy metals [15]. In urban areas, the presence of extensive impervious surfaces usually results in flooding and discharge of organic and inorganic substances including heavy metals into nearby surface water ecosystems (rivers and lakes), through drainage networks [16]. Heavy metals are one of the most common pollutants in stormwater and urban runoffs [14, 17].

This study, therefore, aims to assess the heavy metal content of a man-made lake located in Benin City, Edo State, Nigeria, in relation to its current uses. The lake under study, is a retention pond specifically engineered to collect excess rainwater and surface runoff, subsequently releasing it into the nearest drainage basin to mitigate flood risks [11÷13]. To evaluate the suitability of this lake for its current uses—namely, fishing, recreation, and livestock watering—the Water Pollution Index (WPI) developed by Hossain and Patra [18] was employed. The health and ecological implications of using water from heavy metal-contaminated man-made lakes have been documented globally [19÷21]. Given the increasing reliance on such water bodies for socio-economic functions, especially in urban and peri-urban settings, assessing their water quality has become essential.

MATERIALS AND METHODS

Study area and sampling stations

The study was carried out in a man-made lake in Benin City, Edo State, Nigeria. The lake was constructed on land between the buffer zone of two high tension electricity transmission lines in Government Reserved Area (GRA), Benin City (Fig. 1). The lake is part of the Edo State government flood control programme in the reserved area [22] and it receives flood water and runoffs from parts of Ugbor and Abuja quarters (GRA), Oko and Irhirhi areas of Benin City. The lake's-built capacity was volume (95,383 m^3), surface area (4.1 Ha) and depth (6.8 m).

The lake has common features of a natural lake except for the presence of inlet and outlet channels to prevent overtopping.

Fig. 1. Picture of the man-made lake in GRA, Benin City, Nigeria

The study area is characterized by persistently high temperatures (25°C÷30 °C) and humidity levels (>60%) throughout the year; exhibiting a tropical monsoon climate (Köppen *Am*). There is notable seasonal variation with the period between July and September having reduced sunshine and increased rainfall [23, 24].

Station 1 (N6° 17' 20.2", E5° 36' 4.1"), situated near Abuja Quarter (Fig. 2), is characterized by a rapidly expanding informal settlement accompanied by intense commercial activities and inadequate sanitary infrastructure. Environmental degradation at the site is exacerbated by improper waste management practices, including solid waste disposal.

Station 2 (N6° 17' 17", E5° 35' 51.9"), located in the Irhirhi Quarter approximately 388.18 meters downstream of Station 1, lies at a lower elevation. A smaller informal settlement is present in the vicinity, with a cattle shed situated along the lake's edge. Predominant human activities observed at this station include cattle grazing and watering, as well as fishing and recreational swimming.

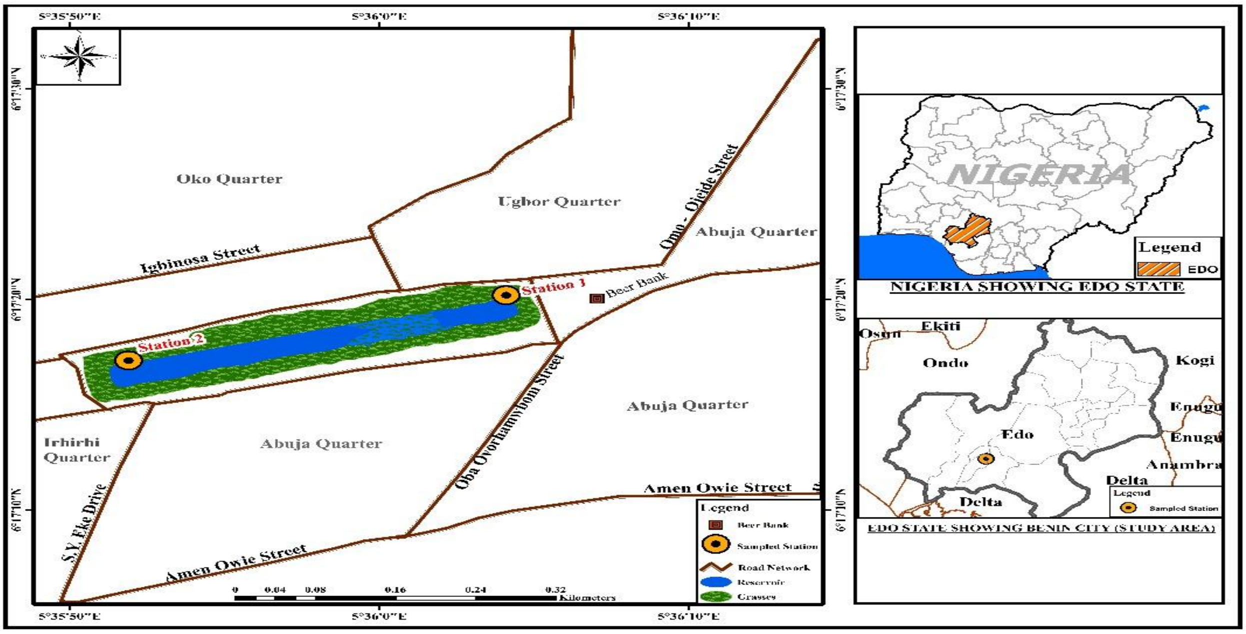

Fig. 2. Map of GRA Benin City, Nigeria showing the sampling Stations of the Lake

Samples collection, analyses and quality control

Water samples were collected from the lake in two stations and seasons – wet season (May ÷ July 2024) and dry season (November 2024 ÷ January 2025) with 1 L water sampler and stored in clean 250 ml plastic bottles. The samples were immediately acidified after collection with nitric acid (HNO3) as described by Sharma and Tyagi [25]. The water samples were digested as described by Zhang [26]. The determination of heavy metals concentrations was carried out directly with UNICAM Solaar 969 Atomic Absorption Spectrometer (AAS) (Cambridge, UK) with an acetylene-air flame and lamps with cavity cathodes..

Quality control and assurance

The working solutions were also prepared daily for the analysis of different metals by making a stock solution with the mixture of 65% (v/v) HNO3, 30% (v/v) H2O2 and H2O (v/v/v = 1:1:3) ratios. The analysis of each sample was in triplicate while the analytical blanks ran the same way as the samples, and the values recorded during the analysis were subtracted from each of the sample values to get the true values. Analyzed metals were iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), nickel (Ni), and lead (Pb), The stock concentrations for the metals were 2 mg/L, 4 mg/L, 6 mg/L, 8 mg/L and 10 mg/L (Red Analytical, Cambridgeshire, UK) and the calibration curves were plotted according to ISO standard method [27].

Statistical analysis

The spatial and seasonal data were summarized with Microsoft Excel for mean, standard error of the mean, minimum and maximum for the metals while paired students t-test was used to test for significant differences among the stations and seasons.

Water pollution index (WPI)

Eight heavy metals were evaluated to assess the water quality of the lake using the novel water pollution index. The water pollution index was determined using the equation described by Hossain and Patra [18]. First step was to determine the pollution load of i^{th} parameter:

$$PLi = 1 + (C_i - S_i)/S_i \quad (1)$$

where, C_i is the concentration of i^{th} parameter, S_i is the highest acceptable limit for the parameter. Secondly, the water pollution index of water sample with n number of variables (parameters) was determined by summing up all the pollution loads and dividing with n (equation 2). Parameters with values of 0 were not included in the total 'n' of any sample.

$$\mathrm{WPI} = \frac{1}{n}\sum_{i=1}^{n} \mathrm{PL_i} \quad (2)$$

According to the literature, the WPI values can be classified into four categories based on n number of parameters: WPI<0.5 (excellent quality), 0.5>WPI<0.75 (good quality), 0.75>WPI< 1 (moderately polluted water) and WPI>1 (highly polluted water) [18].

The standards used to compare the water quality were Guidelines and Standards for Environmental Pollution Control in Nigeria for aquatic life (NESREA, [28]), Nigerian standard for drinking water quality, used also for recreation (SON, [29]) and data provided by Ayers and Westcot [30] for livestock production. The limits data set for metals are presented in table 1.

Table 1. Limit values for aquatic life, recreation and livestock production (mg/L)

Metal	NESREA [28]	SON [29]	Ayers and Westcot [30]
Fe	0.05	0.30	-
Mn	-	0.20	0.05
Zn	0.01	3.00	24
Cu	0.001	1.00	0.50
Cr	0.001	0.05	1.00
Cd	0.005	0.003	0.05
Ni	0.01	0.02	1.00
Pb	0.01	0.01	0.10

RESULTS AND DISCUSSION

The spatial and temporal variations of the heavy metals in the man-made lake were determined by the structure of the lake and season. The lake is a retention pond constructed to recieve and hold excess flood water and runoff from the reserved area during the wet season.

The summary of the heavy metal concentrations is presented in Table 2. The heavy metal content was influenced by the diffused sources of flood water and runoff channeled into the lake and season

Fe values ranged between 1.08 and 2.88 mg/L in both stations and seasons. The values were higher than 0.3 mg/L set by SON [29] for recreation and 0.05 mg/L set by NESREA [28] for aquatic life. Although mean concentrations at Station 2 were higher during the wet season, the difference was not statistically significant ($p > 0.05$). The elevated mean concentration observed at Station 2 likely results from its downstream position, which facilitates the accumulation of heavy metals. Similarly, higher values recorded during the wet season may be attributed to increased terrestrial runoff. While Fe concentrations in this study exceeded permissible limits for recreation and aquatic life, comparable or even greater concentrations have been reported elsewhere in Nigeria. For example, Abdus-Salam et al. [31] measured iron levels in Kwara State dams as follows: Agba (0.95÷2.46 mg/L), Igbaja (3.27÷12.79 mg/L), Oloru (4.39÷13.95 mg/L), and Omu-Ara (3.19÷8.27 mg/L). Similarly, Ezeonu et al. [32] recorded iron concentrations between 4.37 and 5.41 mg/L in a man-made lake at Abakiliki, Ebonyi State.

Outside Nigeria, lower iron concentrations (ranging from 0.50 to 0.67 mg/L) were reported by Al-Hasawi [33] in the artificial Domat Al-Gandal Lake in Saudi Arabia. Elevated levels of Fe in water can induce oxidative stress at the cellular level, disrupting cell membranes, proteins, and pigments, and even causing DNA damage—effects that may ultimately lead to organism death [34]. Humans can also accumulate heavy metals such as iron during recreational activities through dermal absorption or incidental ingestion, posing serious health risks [35, 36]. Although there is no established limit for Fe in livestock production water [30], concentrations exceeding 2 mg/L may negatively impact cattle health and milk yield. These effects are likely due to alterations in Fe metabolism, antioxidant imbalance, oxidative stress, or reduced water consumption resulting from poor palatability [37].

Table 2. The summary of the heavy metal values recorded in lake surface water (mg/L)

Metal	Station 1 MEAN±SEM	Station 2 MEAN±SEM	Wet Season MEAN±SEM	Dry Season MEAN±SEM	Spatial *p*-value	Season *p*-value
Fe	1.79±0.24 (1.08÷2.77)	2.14±0.24 (1.22÷2.88)	2.01±0.34 (1.59÷2.42)	1.92±0.07 (1.85÷1.99)	p> 0.05	p> 0.05
Mn	0.83±0.13 (0.54÷1.35)	0.91±0.09 (0.71÷1.23)	0.77±0.12 (0.64÷0.89)	0.97±0.04 (0.94÷1.01)	p> 0.05	p> 0.05
Zn	1.17±0.16 (0.78÷1.80)	1.33±0.14 (0.86÷1.88)	1.26±0.26 (1.00÷1.52)	1.24±0.10 (1.14÷1.33)	p> 0.05	p> 0.05
Cu	0.57±0.13 (0.33÷1.11)	0.61±0.07 (0.45÷0.87)	0.51±0.10 (0.41÷0.60)	0.67±0.06 (0.62÷0.73)	p> 0.05	p> 0.05
Cr	0.39±0.09 (0.21÷0.74)	0.43±0.05 (0.33÷0.61)	0.38±0.06 (0.32÷0.43)	0.45±0.02 (0.43÷0.47)	p> 0.05	p> 0.05
Cd	0.17±0.03 (0.11÷0.31)	0.20±0.02 (0.15÷0.27)	0.17±0.03 (0.14÷0.20)	0.21±0.00 (0.20÷0.21)	p> 0.05	p> 0.05
Ni	0.13±0.02 (0.08÷0.22)	0.14±0.01 (0.11÷0.18)	0.12±0.02 (0.09÷0.14)	0.15±0.01 (0.14÷0.16)	p> 0.05	p> 0.05
Pb	0.26±0.05 (0.15÷0.46)	0.30±0.02 (0.24÷0.38)	0.25±0.05 (0.21÷0.30)	0.31±0.00 (0.30÷0.31)	p> 0.05	p> 0.05

Mn concentrations ranged from 0.54 to 1.35 mg/L across both stations and seasons, with higher mean values observed at Station 2 and during the dry season; however, these differences were not statistically significant ($p > 0.05$). The recorded concentrations exceeded the limits set by the Standards Organization of Nigeria (SON) at 0.2 mg/L for recreational use [29], and the 0.05 mg/L recommended by Ayers and Westcot for livestock production [30]. The elevated levels at Station 2 may be attributed to similar factors influencing Fe concentration, while the higher values during the dry season could result from metal concentration due to reduced rainfall, lower water volume, decreased flow, and increased evaporation [38, 39]. This seasonal increase in Mn poses serious concerns, as water demand for recreation, livestock, and other human activities typically rises during the dry season [40], thereby increasing exposure risks for both humans and aquatic life [41, 42]. Supporting evidence from related studies includes findings by Abdus-Salam et al. [31], who reported elevated Mn concentrations in four dams in Kwara State, Nigeria: Agba (0.95÷2.46 mg/L), Igbaja (3.27÷12.79 mg/L), Oloru (4.39÷13.95 mg/L), and Omu-Ara (3.19÷8.27 mg/L). In contrast, Oyeniyi and Lawal [43] recorded much lower concentrations (0.0006÷0.002 mg/L) in Sallari Pond, Kano State. Outside Nigeria, Al-Hasawi [33] similarly found low Mn levels (0.021÷0.022 mg/L) in the artificial Domat Al-Gandal Lake, Saudi Arabia.

Elevated Mn exposure—particularly through dermal contact and incidental ingestion during swimming—can lead to neurological complications, including cognitive and behavioral disorders, alongside aesthetic concerns [44]. While Mn is essential for livestock, excessive concentrations can disrupt biological systems [45]. Nevertheless, Mn toxicity in humans is rare due to its low intestinal absorption and the liver's efficient removal via bile [46, 47]. Although the National Environmental Standards and Regulations Enforcement Agency (NESREA) [28] does not specify a guideline for manganese in aquatic ecosystems, toxicity can occur when concentrations surpass the threshold of biological necessity and regulatory capacity. At such levels, Mn can induce oxidative stress, activate cell death pathways, and function as an immunosuppressant [48].

Zn values ranged between 0.78 and 1.88 mg/L in both stations and seasons. Higher mean values were recorded in station 2 in wet season, but not significant ($p > 0.05$) differences were reported. The values were higher than the 0.01 mg/L set by NESREA [28] for aquatic life, but lower than 3 mg/L set by SON [29] for recreation and 24 mg/L set by Ayers and Westcot [30] for livestock production. Zn exhibited similar spatial and seasonal variation patterns as Fe, likely due to the same influencing factors. In related studies, Abdus-Salam et al. [31] reported lower concentrations in four dams in Kwara State, Nigeria: Agba (0.56÷1.29 mg/L), Igbaja (0.41÷1.61 mg/L), Oloru (0.30÷0.80 mg/L), and Omu-Ara (0.42÷0.76 mg/L). Ezeonu et al. [32] also observed lower values (0.016÷0.024 mg/L) in a man-made lake in Abakaliki, Ebonyi State, Nigeria. Similarly, outside Nigeria, Al-Hasawi [33] recorded even lower concentrations (0.011–0.021 mg/L) in the artificial Domat Al-Gandal Lake, Saudi Arabia.

Elevated Zn concentrations in aquatic environments can have harmful effects on aquatic organisms such as fish, invertebrates, and microorganisms. Acute toxicity, particularly in fish, may impair gill function and hinder oxygen exchange. Chronic exposure to sublethal levels can lead to reduced growth, reproductive issues, and behavioral changes [49].

Cu concentrations ranged from 0.33 to 1.11 mg/L across both stations and seasons, with higher mean values recorded at Station 2 and during the dry season. However, these differences were not statistically significant ($p > 0.05$). The observed concentrations were below the recreational water quality limit of 1.0 mg/L set by the Standards Organization of Nigeria (SON) [29], but exceeded the thresholds of 0.5 mg/L and 0.001 mg/L established by Ayers and Westcot [30] and NESREA [28] for livestock production and aquatic life, respectively. Cu showed similar spatial and seasonal distribution patterns as Mn, likely driven by the same environmental factors.

In related studies, Abdus-Salam et al. [31] reported lower Cu levels in four dams in Kwara State, Nigeria: Agba (0.07÷0.19 mg/L), Igbaja (0.07÷0.24 mg/L), Oloru (0.08÷0.22 mg/L), and Omu-Ara (0.10÷0.33 mg/L). Cu was not detected by Ezeonu et al. [32] in a man-made lake in Abakaliki, Ebonyi State, while Oyeniyi and Lawal [43] recorded very low values (0.0011÷0.005 mg/L) in Sallari Pond, Kano State. Similarly, outside Nigeria, Al-Hasawi [33] documented lower concentrations (0.019÷0.020 mg/L) in the artificial Domat Al-Gandal Lake, Saudi Arabia.

Cu is an essential micronutrient for aquatic organisms in trace amounts; however, elevated levels can disrupt physiological processes, cause cellular damage, and ultimately lead to mortality [50]. In livestock, copper supports growth and overall health when present at appropriate levels. Nevertheless, excessive intake can result in toxicity, with adverse effects on animal well-being and potential environmental implications [51, 52].

Cr concentrations ranged from 0.21 to 0.74 mg/L across both sampling stations and seasons. Although higher mean values were observed at Station 2 and during the dry season, these differences were not statistically significant ($p > 0.05$). The recorded levels exceeded the permissible limits of 0.05 mg/L and 0.001 mg/L set by SON [29] for recreational water and NESREA [23] for aquatic life, respectively. However, concentrations remained below the 1.0 mg/L threshold recommended by Ayers and Westcot [30] for livestock use. Cr showed similar spatial and seasonal variation patterns as manganese and copper, due to reduced rainfall, lower water volume, decreased flow, and increased evaporation [38, 39]

Comparable studies have reported varying levels of chromium. For example, Ezeonu et al. [32] found no detectable Cr levels in a man-made lake in Abakaliki, Ebonyi State, Nigeria, while Oyeniyi and Lawal [43] reported extremely low concentrations (≥0.002 mg/L) in Sallari Pond, Kano State. Outside Nigeria, Al-Hasawi [33] recorded similarly low levels (0.019÷0.020 mg/L) in the Domat Al-Gandal artificial lake in Saudi Arabia.

Elevated Cr concentrations, particularly of the hexavalent form Cr(VI), are known to be toxic to aquatic organisms, potentially causing tissue damage, behavioral changes, and mortality [53]. In recreational waters, high Cr levels may also pose human health risks, including skin irritation, allergic reactions, and an increased risk of cancer [54].

Cd concentrations ranged from 0.11 to 0.31 mg/L across all stations and seasons, with higher mean values at Station 2 and during the dry season, though not statistically significant ($p > 0.05$). These levels exceeded the limits set by SON (0.003 mg/L) for recreation, NESREA (0.005 mg/L) for aquatic life, and Ayers and Westcot (0.05 mg/L) for livestock use. Cd followed similar spatial and seasonal patterns as Mn, Cu, and Cr, likely due to shared environmental factors.
Lower Cd levels were reported in related studies, including dams in Kwara State (0.02÷0.08 mg/L) [41], a lake in Abakaliki (1.19÷1.34 mg/L) [32], and a lake in Saudi Arabia (0.010÷0.012 mg/L) [33]. Prolonged exposure to elevated Cd can cause kidney and bone damage, reproductive issues, and increased cancer risk in humans [55, 56], as well as health and productivity issues in livestock, including reduced growth and reproduction [57].

Ni values ranged between 0.08 and 0.22 mg/L in both the stations and seasons. Higher mean values were recorded in station 2 and dry season, these differences were not statistically significant ($p > 0.05$). The values were higher than 0.02 mg/L and 0.01 mg/L set by SON [29] and NESREA [28] for recreation and aquatic life respectively, but lower than 1.0 mg/L set by Ayers and Westcot [30] for livestock production. Ni exhibited the same spatial and seasonal variations with Mn, Cu, Cr and Cd, likely due to common influencing factors. In related studies, Ni was not assessed by Abdus-Salam et al [31] and Oyeniyi and Lawal [43] and below detection level in Ezeonu et al [32]. However, outside Nigeria, Al-Hasawi [33] recorded values (0.22÷0.25 mg/L) within the range of this study in a man-made Domat Al-Gandal lake, Saudi Arabia.
Elevated Ni concentrations can negatively impact aquatic life, leading to death, impaired growth, and reduced reproduction in fish, amphibians, and invertebrates [58]. Dermal exposure and incidental ingestion during swimming can result in allergic reactions and potential cancer development because nickel is carcinogen [59].

Lead (Pb) concentrations ranged from 0.15 to 0.46 mg/L, with higher mean values at Station 2 and during the dry season, though differences were not statistically significant ($p > 0.05$). These levels exceeded regulatory limits set by SON and NESREA (0.01 mg/L) and Ayers and Westcot (0.1 mg/L) for recreation, aquatic life, and livestock production. Pb followed similar spatial and seasonal trends as Mn, Cu, Cr, Cd, and Ni, likely due to common influencing factors.
Compared to this study, lower Pb levels were reported by Ezeonu et al. [32] (≥0.09 mg/L) in Abakaliki, Nigeria, and by Al-Hasawi [33] (0.017÷0.020 mg/L) in Domat Al-Gandal Lake, Saudi Arabia. High Pb concentrations can harm aquatic organisms, causing oxidative stress, neurotoxicity, and immune disruption [60]. In recreational waters, exposure may lead to cognitive and neurological issues in humans [61]. For livestock, elevated Pb can impair growth, reproduction, and overall health, with symptoms such as muscle spasms and blindness [62].

Water Pollution Index
The water pollution index has been extensively used by researchers to determine the quality of water for different purposes [63÷66].
In our study, the water pollution index (WPI) for aquatic life ranged between 161.0 and 195.8, the recreation WPI ranged between 13.3 and 16.2 while the livestock production WPI ranged between 3.3 and 4.1. The data are presented in table 3.

Table 3. WPI values for each station and season

Metal	Station 1	Station 2	Wet Season	Dry Season
WPI (NESREA)	169.4	185.7	161.0	195.8
WPI (SON)	13.3	15.5	13.4	16.2
WPI (Ayers and Westcot)	3.5	3.9	3.3	4.1

Higher WPI values were recorded in station 2 and dry season. The order of magnitude was $WPI_{aquatic\ life} > WPI_{recreation} > WPI_{livestock\ production}$. All the WPI values were >1, indicating the water was highly polluted with heavy metals.

CONCLUSIONS

Heavy metal concentrations in the lake's surface water exceeded permissible limits for its current uses, including support for aquatic life, recreation, and livestock watering. These elevated levels were largely attributed to diffuse pollution sources such as floodwater and surface runoff, as well as the lake's structural characteristics and seasonal variations. The Water Pollution Index indicated that the lake water is unsuitable for aquatic life, recreational activities, and livestock use. Continued use of the lake for these purposes poses significant health and ecological risks and is therefore strongly discouraged.

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