



Assessment of Physicochemical and Heavy Metals Analysis of Erinle Dam Reservoir Water, Osun State, Nigeria

¹Joseph Adeleke Adeyeye, ²Abidemi Anthony Sangoremi, ⁴Adebayo Emmanuel Adeleke, ¹John Omodara Akinremi, ³Oluwakemi Bolanle Akintan and ¹Temitope Oluwaseun Faloye

¹Department of Water Resources and Meteorology, Federal University Oye-Ekiti, Ekiti State, Nigeria.

²Department of Chemistry, Federal University Otuoke, Bayelsa State, Nigeria.

³Department of Geography and Physical Planning Sciences, Ekiti State University, Ado Ekiti, Nigeria.

⁴Department of Chemistry, Adeleke University Ede, Osun State, Nigeria.

*Corresponding authors' email: sangoremiaa@fuotuo.ke.edu.ng

ABSTRACT

A dam reservoir plays a vital role in the global freshwater supply. This study evaluates the water quality of Erinle Dam Reservoir in Osun State, Nigeria, recognizing the essential importance of clean water for human health and well-being, agriculture, industry, and overall environmental sustainability, especially amid increasing pollution threats. The research aims to assess physicochemical parameters such as pH, temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), and electrical conductivity (EC), examine bacteriological indicators like *Escherichia coli*, analyze heavy metal concentrations including zinc, cadmium, copper, lead, manganese, arsenic, iron, and chromium, and compare findings with WHO standards. It also seeks to identify pollution sources and recommend strategies for improving water quality. Twelve (12) water samples were systematically collected from different points across the reservoir and analyzed using the WHO and APHA standard laboratory procedures. Descriptive statistical analysis showed that parameters such as pH, temperature, and EC generally remained within acceptable limits; however, levels of cadmium, arsenic, and lead significantly exceeded WHO permissible limits, with calculated high heavy-metal health index risks for the users. Additionally, microbiological tests consistently detected high levels of *E. coli* in all samples, indicating widespread fecal contamination likely from agricultural runoff, industrial discharges, and domestic waste. Principal Component Analysis (PCA) highlighted spatial variations and pollution trends across sampling sites. The findings emphasize the urgent need for improved water quality monitoring, pollution control measures, and informed policy making to ensure sustainable water resource management in the region.

Keywords: Freshwater, Reservoir, Quality, Heavy metal, Monitoring, and Public Health

INTRODUCTION

Water is an essential natural resource crucial for supporting life, agriculture, industry, and ecosystem functions (Ighalo and Adeniyi, 2021). The availability and quality of water resources are vital for public health, economic growth, and environmental sustainability (Gleick, 2000). Reservoirs, such as Erinle Dam in Osun State, Nigeria, play a key role in supplying water for domestic, agricultural, and industrial use. However, rising pollution levels caused by human activities pose serious threats to water quality and human health (WHO, 2017). The physicochemical properties of water, including factors such as pH, temperature, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total dissolved solids (TDS), and electrical conductivity, provide important information about water quality (Ighalo and Adeniyi, 2020). These parameters determine the suitability of water for consumption, irrigation, and industrial applications. The presence of contaminants like heavy metals, organic pollutants, and excess nutrients can impair water quality, leading to ecological and health problems (Sonone et al., 2020). Bacteriological contamination is another key aspect of water quality assessment. Waterborne diseases, such as cholera, dysentery, typhoid, and diarrhea, are linked to microbial contaminants like total coliforms, fecal coliforms, and *Escherichia coli* (*E. coli*) (Adeyeye et al., 2018). According to the World Health Organization (WHO, 2017), access to microbiologically safe drinking water is essential for preventing waterborne disease outbreaks. Reservoirs

supplying potable water must therefore be regularly monitored to ensure compliance with drinking water standards set by organizations like the WHO and the Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) (SON, 2015).

Erinle Dam Reservoir, located in Osun State, is a critical water source for nearby communities. However, concerns about the impacts of urbanization, agricultural runoff, and waste disposal on its water quality have been raised (Oketola et al., 2013). Studies have shown that increased human activity around reservoirs can lead to deterioration of water quality, affecting both physicochemical and bacteriological parameters (Adewoye, 2011). Without proper water quality management strategies, contamination may jeopardize the safety of drinking water and cause public health emergencies (Adeleke et al., 2024). Evaluating the physicochemical and bacteriological parameters of Erinle Dam Reservoir is essential for understanding its current water quality status and identifying potential pollution sources. Such studies provide scientific data that support water resource management policies, improve treatment practices, and ensure the safety of water for human use and other purposes. The findings will contribute to ongoing discussions on water quality monitoring and sustainable water management in Nigeria. The primary goal of this study is to assess the physicochemical, microbial, and heavy metal characteristics of Erinle Dam Reservoir water in Osun State. Water quality is vital for protecting

public health, safeguarding the environment, and supporting economic development.

Understanding the physicochemical and bacteriological attributes of reservoirs helps determine their suitability for various uses, including drinking, agriculture, and industry. This assessment is especially important in areas where reservoirs serve large populations. Erinle Dam Reservoir, situated in Osun State, Nigeria, is a crucial water source for domestic and agricultural activities. However, increasing urbanization, agricultural runoff, and industrial emissions have raised concerns about its water quality (Oketola et al., 2013). Key water properties, such as pH, temperature, turbidity, dissolved oxygen, and conductivity, greatly influence water's overall quality and usability (WHO, 2017). Similarly, bacteriological analysis, including the assessment of microbial contaminants like total coliforms and *Escherichia coli*, is vital for understanding potential health risks associated with water consumption (Odonko et al., 2020). Existing literature discusses how various factors, including human activities, climate change, and seasonal variations, influence physicochemical and bacteriological water quality (Adeyeye et al., 2021). These properties affect both the physical and chemical stability of water bodies and the biological processes within them. Commonly analyzed physicochemical parameters include temperature, pH, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC), total dissolved solids (TDS), and nutrient levels (WHO, 2017).

Bacteriological characteristics of water refer to the presence, abundance, and diversity of microbial organisms in a water body. The microbial quality of water is a crucial aspect of public health, as contamination with pathogenic bacteria can cause serious waterborne diseases, including cholera, typhoid, and dysentery (WHO, 2017). The presence of bacteria in water bodies such as reservoirs is influenced by various factors, including anthropogenic activities, natural runoff, and

animal waste depositions (Singh et al., 2024). Thus, the study assessed the physicochemical and heavy metal composition of the reservoir for public health safety.

MATERIALS AND METHODS

Study Area

Erinle Dam Reservoir is situated in Osun State, southwestern Nigeria, and acts as a vital water source for domestic, agricultural, and industrial needs. Built on the Erinle River, it is part of the Osun River Basin and plays an essential role in providing drinking water to both urban and rural communities, including Osogbo and Ede. The coordinates of Erinle Dam Reservoir are approximately between latitude 7°45'0" N and longitude 4°25'0" E. The reservoir spans about 12 square kilometers and reaches a maximum depth of around 18 meters (Figure 1). The area's climate is tropical, featuring distinct wet and dry seasons that greatly impact the hydrological and ecological conditions of the reservoir. Main land use activities nearby include farming, fishing, and urban settlements. Agricultural practices, especially the use of fertilizers and pesticides, pose a risk of nutrient buildup, which can lead to eutrophication. Furthermore, human activities such as improper waste disposal and direct wastewater discharge worsen water quality. Hydrologically, Erinle Dam Reservoir functions as a storage and flow regulation structure, managing seasonal water fluctuations. It is vital for flood control, irrigation, and hydroelectric power generation. The reservoir also supports a wide variety of aquatic life, including fish species that bolster local fisheries. As population growth and industrial development increase the demand for water resources, studying the physicochemical properties and heavy metals in Erinle Dam Reservoir is critical for sustainable water management and safeguarding public health. The results of this research will offer important insights into the water quality and guide policymakers in implementing measures to reduce contamination risks.

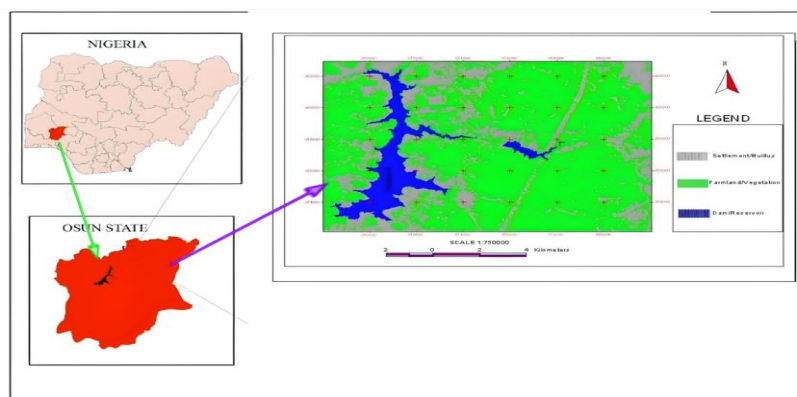


Figure 1: Map of Nigeria showing Erinle Dam Reservoir

Sampling Techniques and Sample Collection

Twelve (12) water samples were taken from twelve strategic locations within the reservoir, representing different ecological and human impact zones (Figure 2). The sampling points were selected based on accessibility, proximity to potential pollution sources, and hydrodynamic characteristics of the reservoir.

Polyethylene bottles were cleaned and pre-washed using double-distilled water and 20% HNO_3 for the purpose of collecting water samples. The water samples were then

filtered utilizing a 0.45- μm Whatman pore membrane and were acidified with 3 ml of nitric acid (HNO_3 , 69%) to inhibit the adsorption and crystallization of trace elements before further analysis (APHA, 2005). Subsequently, the water samples were transported in cool, dark containers and stored in a refrigerator at 4 °C until they could be analyzed in the laboratory. Samples were collected using sterilized 1-liter polyethylene bottles, following standard protocols outlined by the American Public Health Association (APHA, 2017), and the coordinates were recorded.

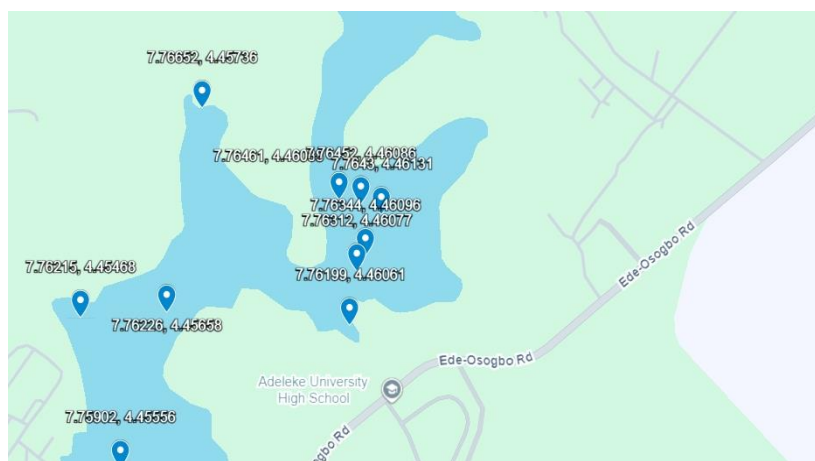


Figure 2: Map Showing the Coordinates of the Sampling Points on the Dam/Reservoir

Water Analysis

Parameters such as temperature, pH, conductivity, and dissolved oxygen were measured on-site with standard, calibrated portable meters and a kit. A Hatch Multimeter was used for monitoring temperature, pH, and conductivity, while a Hanna Dissolved Oxygen Kit was used to determine dissolved oxygen. Other water physico-chemical and microbiological parameters were analyzed in the laboratory using methods prescribed by APHA (1998). Heavy metals in the water samples were analysed using an Atomic Absorption Spectrophotometer (AAS) after preconcentration. According to Akoto et al. (2008), concentrated HNO_3 was used to digest samples for metal detection. In a 100 mL beaker, 50 mL of the water sample was mixed with 5 mL of concentrated HNO_3 . On a hot plate, this was cooked until its volume dropped to roughly 20 mL. After adding 5 mL of concentrated HNO_3 , the mixture was heated for an additional 10 minutes. The sample was left to come to room temperature. After rinsing the beaker's edges with about 5 mL of HNO_3 , the solution was quantitatively transferred into a 50 mL volumetric flask and adjusted with distilled water. For every batch of samples for heavy metals analysis, spiked distilled-deionized water was treated in the same manner as the samples for the accuracy study, with recovery ranging between 96.5% - 98.9%. An atomic absorption

spectrophotometer (Model Bulk Scientific Accusys 211) was used to analyze heavy metals.

Quality Assurance

To maintain the integrity of analytical findings, standard protocols were adhered to in conjunction with laboratory quality assurance measures. Analytical grade reagents, boasting a certified purity level of 99.9%, were utilized throughout the analytical process. Pyrex glassware and sampling containers were thoroughly cleaned with detergents and deionized water. The glassware and containers were soaked overnight in a solution consisting of 10% HNO_3 and 1% HCl, rinsed again with deionized water, and subsequently dried in an oven. All reagents employed for measuring anion concentrations were obtained from the manufacturer. The analysis of the data for mean and standard deviation was conducted using IBM SPSS version 23. Additionally, pollution assessments and quantitative health risk evaluations were carried out to determine the likelihood of water contamination and the associated risks of consuming groundwater from the studied locations.

RESULTS AND DISCUSSION

The physicochemical and microbiological characteristics of the groundwater are presented in Tables 1, 2, 3, and 4.

Table 1: Physicochemical and Microbiological Properties with WHO Standards

Sample	pH	Temperature (°C)	Dissolved Oxygen (mg/L)	Total dissolved solids (mg/L)	TDS (mg/L)	Biochemical oxygen demand (BOD) mg/L	Electrical Conductivity (EC) $\mu\text{S}/\text{cm}$	Escherichia coli counts (cfu/ml)
1	6.13	29.7	7.2	12.2	15.2	166.6	0.7x10 ⁵	
2	6.06	29.2	7.18	12.3	15.4	166.6	0.8x10 ⁵	
3	6.16	29.5	11.66	13.4	17.8	175	0.6x10 ⁵	
4	6.27	29.3	11.62	12.8	18	175	0.6x10 ⁵	
5	6.27	29.4	18.35	11.8	16.9	188.5	0.7x10 ⁵	
6	6.36	29.3	15.18	11.7	17	188.6	0.6x10 ⁵	
7	6.5	29.5	9.36	10.5	16.4	204.8	0.6x10 ⁵	
8	6.64	29.2	9.51	10.7	16.4	204.1	0.6x10 ⁵	
9	6.52	29.1	11.81	13.3	18.1	170.1	0.7x10 ⁵	
10	6.68	29.5	9.32	12.5	18.3	171.3	0.8x10 ⁵	
11	6.26	29.4	12.35	11.3	17.7	172.3	0.7x10 ⁵	
12	6.73	29.3	6.95	12.5	18.3	178.9	0.8x10 ⁵	
WHO	6.5-8.5	-	-	-	< 6 mg/L	-	0 cfu/100 ml	

Table 2: Heavy Metals Levels with WHO Standards

Sample	Zinc (Zn)	Cadmium (Cd)	Copper (Cu)	Lead (Pb)	Manganese (Mn)	Arsenic (As)	Iron (Fe)	Chromium (Cr)
1	0.17	3.25	0.02	0.07	0.09	0.18	0.8	0.12
2	0.36	7.29	0.01	0.23	0.07	0.44	0.8	0.05
3	0.23	7.92	0.01	0.15	0.01	0.3	0.7	0.23
4	0.49	6.94	0.04	0.05	0.01	0.38	0.7	0.34
5	0.51	5.25	0.15	0.18	0.1	0.18	0.6	0.17
6	0.32	2.42	0.11	0.33	0.05	0.35	0.5	0.38
7	0.27	6.55	0.12	0.31	0.01	0.17	0.5	0.13
8	0.45	5.16	0.18	0.27	0.09	0.24	0.4	0.19
9	0.3	1.72	0.14	0.11	0.1	0.38	0.3	0.08
10	0.21	6.15	0.18	0.05	0.09	0.17	0.3	0.25
11	0.42	6.98	0.16	0.11	0.04	0.35	0.5	0.23
12	0.52	7.45	0.2	0.17	0.02	0.45	0.3	0.31
WHO	3.0 mg/L	0.003 mg/L	2.0 mg/L	0.01mg/L	0.4 mg/L	0.01mg/L	0.3 mg/L	0.05 mg/L

Table 3: Descriptive Summary of the Physicochemical and Heavy Metals

Parameter	Mean	Std Dev	Min	25%	Median	75%	Max
Sample	6.50	3.61	1.00	3.75	6.50	9.25	12.00
pH	6.38	0.23	6.06	6.23	6.31	6.55	6.73
Temperature	29.37	0.17	29.10	29.27	29.35	29.50	29.70
DO	10.87	3.41	6.95	8.79	10.56	11.95	18.35
TDS	12.08	0.92	10.50	11.60	12.25	12.57	13.40
BOD	17.12	1.09	15.20	16.40	17.35	18.02	18.30
EC	180.15	13.43	166.60	171.00	175.00	188.53	204.80
E_coli	68333.33	8348.47	60000.00	60000.00	70000.00	72500.00	80000.00
Zn	0.35	0.12	0.17	0.26	0.34	0.46	0.52
Cd	5.59	2.08	1.72	4.68	6.35	7.06	7.92
Cu	0.11	0.07	0.01	0.04	0.13	0.17	0.20
Pb	0.17	0.10	0.05	0.10	0.16	0.24	0.33
Mn	0.06	0.04	0.01	0.02	0.06	0.09	0.10
As	0.30	0.11	0.17	0.18	0.32	0.38	0.45
Fe	0.53	0.19	0.30	0.38	0.50	0.70	0.80
Cr	0.21	0.10	0.05	0.13	0.21	0.27	0.38

Table 4: World Health Organization Permissible Standards

Parameter	WHO Limit	Range in Samples
pH	6.5 - 8.5	6.06 - 6.73
Temperature	No guideline	29.10 - 29.70
DO	≥ 5 mg/L (aquatic life)	6.95 - 18.35
BOD	< 6 mg/L (rivers)	15.20 - 18.30
TDS	1000 mg/L	10.50 - 13.40
Cd	0.003 mg/L	1.72 - 7.92
Pb	0.01 mg/L	0.05 - 0.33
Cu	2.0 mg/L	0.01 - 0.20
Zn	3.0 mg/L	0.17 - 0.52
Fe	0.3 mg/L	0.30 - 0.80
Mn	0.4 mg/L	0.01 - 0.10
As	0.01 mg/L	0.17 - 0.45
Cr	0.05 mg/L	0.05 - 0.38
E coli	0 cfu/100 ml	60000.00 - 80000.00

Physicochemical Properties

The pH of the samples ranged from 6.06 to 6.73, with a mean value of 6.38, indicating slightly acidic to neutral water. Although this range is only marginally below the WHO-recommended range of 6.5–8.5, prolonged consumption of water with a pH below 6.5 can lead to pipe corrosion, increased metal leaching, and potential gastrointestinal discomfort (Gonzalez et al. 2013). The narrow range also suggests that pH levels are relatively consistent across the

locations, likely influenced by similar geological or hydrological characteristics. All samples had temperatures between 29.1 °C and 29.7 °C, with minimal variation. While the WHO does not set a guideline for temperature in drinking water, elevated temperatures can influence biological and chemical reaction rates, including oxygen solubility and microbial proliferation (Noll et al. 2013). The consistently high temperatures may favor microbial activity, potentially exacerbating contamination in stagnant or slow-moving water

sources. Dissolved Oxygen (DO) values varied significantly from 6.95 mg/L to 18.35 mg/L. DO values above 5 mg/L generally support healthy aquatic life, but extremes may indicate biological activity or pollution events. The high DO in some samples could be a result of photosynthetic activity from algae, while lower levels might reflect oxygen consumption due to microbial degradation of organic matter (Han et al. 2013). A closer correlation with BOD confirms this. Biochemical Oxygen Demand (BOD) values, which ranged from 15.2 to 18.3 mg/L, were significantly higher than the standard for clean surface water (<6 mg/L). Elevated BOD implies the presence of biodegradable organic matter, possibly from domestic or agricultural waste (Srivastava et al. 2013). This is a critical indicator of pollution and suggests the water may not be suitable for direct consumption or even recreational purposes without treatment. Total Dissolved Solids (TDS) and Electrical Conductivity (EC) values remained well within the WHO guideline of 1000 mg/L, ranging from 10.5 to 13.4 mg/L, indicating low ionic content and mineralization. EC values (166.6 – 204.8 $\mu\text{S}/\text{cm}$) align with the low TDS, further confirming minimal salt content in the samples. These parameters reflect the dissolved inorganic content, and low readings suggest little risk of salinity-related issues. However, the variation in EC may indicate differential exposure to ionic pollutants or varying geological substrates (Awogbami, 2023).

Microbiological Quality

The presence of *Escherichia coli* (*E. coli*) at 6.0×10^5 – 8.0×10^5 cfu/ml in all samples represents a serious health concern. WHO recommends zero *E. coli* per 100 ml for potable water. This extreme deviation indicates severe fecal contamination, likely from runoff, sewage leakage, or improper waste disposal. Immediate remediation, disinfection, and public health intervention are required (Too, 2023).

Heavy Metal Contamination

Cadmium (Cd)

Cadmium concentrations ranged from 1.72 to 7.92 mg/L, far exceeding the WHO permissible limit of 0.003 mg/L. Cadmium is highly toxic even at low concentrations and may lead to kidney damage, skeletal problems, and cancer (Sangoremi, 2013). The extremely elevated levels suggest

industrial pollution or leaching from cadmium-containing materials, making these water sources highly unsafe.

Lead (Pb)

Lead values (0.05–0.33 mg/L) also significantly exceeded the WHO limit of 0.01 mg/L. Chronic exposure to lead is hazardous for children and pregnant women, leading to cognitive impairment, anemia, and developmental issues (Sarkar et al. 2013). These levels likely originate from corroded plumbing or industrial effluents.

Arsenic (As)

Measured arsenic values ranged from 0.17 to 0.45 mg/L, which are 17 to 45 times the WHO guideline of 0.01 mg/L. Long-term exposure to arsenic causes serious health issues, including skin lesions, cancer, and cardiovascular disease (Ziarati et al. 2013). This suggests potential natural geogenic sources (arsenic-rich rocks) or human-induced contamination.

Zinc (Zn), Copper (Cu), Iron (Fe), and Manganese (Mn)

These metals were within or below the WHO permissible levels. For instance, Zn (max 0.52 mg/L vs. 3.0 mg/L limit), Cu (max 0.2 mg/L vs. 2.0 mg/L), Mn (max 0.1 mg/L vs. 0.4 mg/L), and Fe (max 0.8 mg/L vs. 0.3 mg/L guideline for taste) do not pose significant health risks in current concentrations but may affect water taste or cause staining at higher levels.

Chromium (Cr)

Cr ranged from 0.05 to 0.38 mg/L, surpassing the WHO limit of 0.05 mg/L in most samples. Chromium, especially hexavalent Cr (VI), is toxic and carcinogenic. Its presence may indicate industrial discharge or corrosion from steel pipes.

Statistical and Multivariate Interpretation

Principal Component Analysis (PCA)

PCA (Figure 3) reveals that the samples' differences were driven by a few key contaminants, most especially, heavy metals and microbial content. Samples that clustered together in the PCA plot shared similar profiles, suggesting geographical or source-related similarity. The two principal components effectively captured the contrast between relatively clean and contaminated samples.

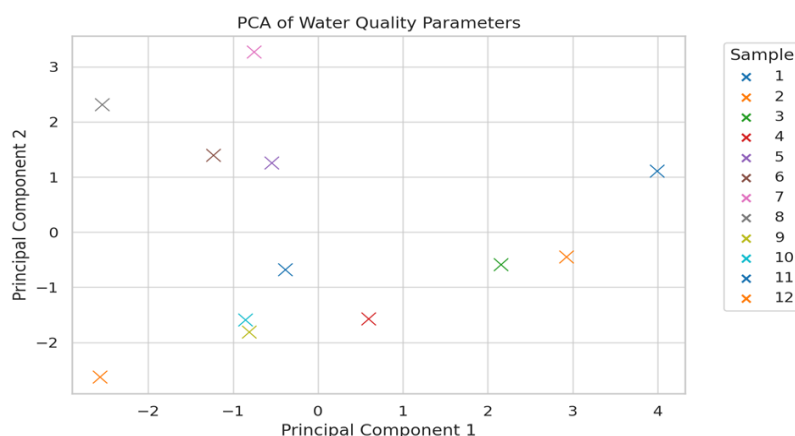


Figure 3: Plate Count Agar of the Samples

Health Risk Assessment

The health risk assessment evaluated eight heavy metals (Fe, Zn, Cu, Pb, Cd, Mn, As, and Cr) found in the dam. The

average daily dose (ADD) from ingesting contaminated water was calculated using Equ (1).

$$ADD = \frac{C_w \times RI \times FE \times DE}{(Bw \times AT)} \text{ In mg/L/day} \quad (1)$$

To calculate the average daily dose of metals through the ingestion of water (mg/kg/day), we use the following parameters: C_w represents the average concentration of estimated iron (Fe) in water (mg/L); the ingestion rate (RI) is set at 2.2 L/day for adults and 1.8 L/day for children. The exposure frequency (FE) is considered to be 365 days per year, while the exposure duration (DE) is 70 years for adults and 6 years for children. The average body weight (BW) is 70 kg for adults and 15 kg for children. The averaging time (AT) is calculated as 365 days/year multiplied by 70 years for adults and 365 days/year multiplied by 6 years for children, as described in earlier reports (USEPA, 1989; USEPA, 2011).

The potential non-carcinogenic risks were assessed using the Hazard Quotient (HQ) and the Hazard Index (HI) for several metals, including iron (Fe), zinc (Zn), copper (Cu), lead (Pb), cadmium (Cd), manganese (Mn), arsenic (As), and chromium (Cr). The HQ for each metal was calculated as the ratio of the average daily dose (ADD) to the reference dose (RfD) Table 5, using Equation (2).

$$HQ = \frac{ADD}{RfD} \quad (2)$$

The RfD values used for each metal are presented in Table 4. The cumulative non-carcinogenic risk (HI) was obtained as the sum of individual HQs for all metals expressed in Eq. (3)

$$HI = \sum_{i=1}^n HQ_i \quad (3)$$

Table 5: Reference Dose U.S. EPA IRIS (N.D.)

RfD	mg/kg-day
Zn	5
Cd	0.005
Cu	1
Mn	0.002
As	0.05
Fe	0.05
Cr	0.1
Pb	0.15

Non-Carcinogenic Health Risk Assessment

The non-carcinogenic risk was evaluated using the calculated Hazard Quotient (HQ) and Hazard Index (HI) for both adults and children (see Tables 6 & 7, respectively). The HQ values for all metals varied significantly across the samples, indicating spatial differences in potential exposure risks.

Adults' Health Risks from Metal Exposure

In adults, cadmium (Cd) exhibited the highest HQ values, ranging from 10.81 to 49.78, followed by manganese (Mn) with values between 0.16 and 1.57, and arsenic (As) with values from 0.11 to 0.28. Other metals, such as zinc, copper, chromium, and lead, showed HQ values below 1.0. According to USEPA guidance, HQ values exceeding 1.0 indicate a potential for non-carcinogenic health effects, with concern levels increasing proportionately with values above this

threshold (USEPA, 1989). The HI values for adults ranged from 12.86 to 50.67, indicating significant non-carcinogenic risks associated with the combined effects of the metals, primarily influenced by cadmium and manganese concentrations.

The predominance of cadmium in the HI suggests that cadmium contamination is the main contributor to non-carcinogenic risk for adults. This finding aligns with studies by Kapoor et al. (2024) and Vetrinurugan et al. (2017), who reported elevated non-carcinogenic risks from cadmium in groundwater in both urban and agricultural settings. Similarly, Chakraborty et al. (2022) found that approximately 97% of groundwater samples analyzed for adults exhibited high non-carcinogenic health risks, primarily driven by contamination from arsenic, iron, and manganese.

Table 6: Hazard Quotient (HQ) and Hazard Index (HI) of Heavy Metals for Adults through Water Ingestion

	HQ								HI
	Zinc (Zn)	Cadmium (Cd)	Copper (Cu)	Manganese (Mn)	Arsenic (As)	Iron (Fe)	Chromium (Cr)	Lead (Pb)	
1	0.001	20.429	0.001	1.414	0.113	0.503	0.038	0.015	22.513
2	0.002	45.823	0.000	1.100	0.277	0.503	0.016	0.048	47.769
3	0.001	49.783	0.000	0.157	0.189	0.440	0.072	0.031	50.674
4	0.003	43.623	0.001	0.157	0.239	0.440	0.107	0.010	44.581
5	0.003	33.000	0.005	1.571	0.113	0.377	0.053	0.038	35.161
6	0.002	15.211	0.003	0.786	0.220	0.314	0.119	0.069	16.725
7	0.002	41.171	0.004	0.157	0.107	0.314	0.041	0.065	41.861
8	0.003	32.434	0.006	1.414	0.151	0.251	0.060	0.057	34.376
9	0.002	10.811	0.004	1.571	0.239	0.189	0.025	0.023	12.865
10	0.001	38.657	0.006	1.414	0.107	0.189	0.079	0.010	40.463
11	0.003	43.874	0.005	0.629	0.220	0.314	0.072	0.023	45.140
12	0.003	46.829	0.006	0.314	0.283	0.189	0.097	0.036	47.757

Children's Health Risks from Metal Exposure

The risks associated with metal exposure for children are significantly higher than those for adults. The Hazard Quotient (HQ) for cadmium (Cd) ranged from 41.28 to 190.08, while manganese (Mn) and arsenic (As) also exceeded the safe limit, with values of 0.6–6 and 0.43–1.24,

respectively (HQ > 1). The Hazard Index (HI) for children ranged between 49.12 and 193.48, which is approximately three to four times higher than that for adults. This increased risk can be attributed to children's higher intake rates per unit of body weight and their developing physiological systems,

making them particularly vulnerable to metal toxicity (USEPA, 2004).

Eslami et al. (2022) reported mean HQ values for arsenic in children at 9.246, over three times higher than the values for adults, which were 2.972, in Iranian groundwater resources. Additionally, Ghosh et al. (2020) highlighted that, although

non-carcinogenic health risks from iron and manganese were greater among adults in absolute terms, children remain the most vulnerable population. They require special protection from metal toxicity due to their developing bodies and higher exposure levels per unit of body weight.

Table 7: Hazard Quotient (HQ) and Hazard Index (HI) of Heavy Metals for Children through Water Ingestion

	HQ								HI
	Zinc (Zn)	Cadmium (Cd)	Copper (Cu)	Manganese (Mn)	Arsenic (As)	Iron (Fe)	Chromium (Cr)	Lead (Pb)	
1	0.004	78.000	0.002	5.400	0.432	1.920	0.144	0.056	85.958
2	0.009	174.960	0.001	4.200	1.056	1.920	0.060	0.184	182.390
3	0.006	190.080	0.001	0.600	0.720	1.680	0.276	0.120	193.483
4	0.012	166.560	0.005	0.600	0.912	1.680	0.408	0.040	170.217
5	0.012	126.000	0.018	6.000	0.432	1.440	0.204	0.144	134.250
6	0.008	58.080	0.013	3.000	0.840	1.200	0.456	0.264	63.861
7	0.006	157.200	0.014	0.600	0.408	1.200	0.156	0.248	159.833
8	0.011	123.840	0.022	5.400	0.576	0.960	0.228	0.216	131.252
9	0.007	41.280	0.017	6.000	0.912	0.720	0.096	0.088	49.120
10	0.005	147.600	0.022	5.400	0.408	0.720	0.300	0.040	154.495
11	0.010	167.520	0.019	2.400	0.840	1.200	0.276	0.088	172.353
12	0.012	178.800	0.024	1.200	1.080	0.720	0.372	0.136	182.345

Comparative Interpretation of Metal Exposure

Across both age groups, the order of metal contribution to the HI was generally as follows: Cd > Mn > As > Fe > Cr > Pb > Cu > Zn. The predominance of cadmium and manganese in both exposure groups suggests significant anthropogenic inputs. Yuan et al. (2019) noted that industrial production accounts for approximately 62.1% of total anthropogenic cadmium emissions, with additional sources—including aquaculture, wastewater treatment, and agricultural activities—contributing to over 90% of environmental cadmium contamination. In the context of the Erinle Dam study area, potential sources of contamination include agricultural runoff from cadmium-containing fertilizers, industrial discharges, and atmospheric deposition from vehicular emissions and combustion processes, which align with findings from environmental assessments of trace metal pollution (Kubier et al., 2019).

The HI values exceeding one at all sampling points indicate potential non-carcinogenic health risks for both adults and children. This conclusion is consistent with observations by Vetrinurugan et al. (2017), who reported that silver, lead, nickel, cadmium, and manganese predominantly contributed to health hazards in an intensively irrigated river delta, with HI values signifying non-carcinogenic risks across all age groups.

Implications for Public Health and Environment

The elevated levels of cadmium, arsenic, and lead are alarming. Chronic exposure to these heavy metals is linked to multi-organ damage, cancer, and developmental disorders. Additionally, the high BOD and E. coli levels suggest severe organic and microbial pollution, likely from human activity. These conditions make the water unfit for drinking or domestic use without proper treatment.

CONCLUSION

This study analyzed the physicochemical, microbiological, and heavy metal content of twelve (12) water samples from Erinle Dam, using laboratory-based methods. Descriptive statistical analysis revealed that while some parameters, such as pH, EC, and temperature, were within acceptable ranges,

others, especially cadmium, arsenic, and lead, significantly exceeded WHO permissible limits. The microbiological analysis showed unacceptable levels of E. coli in all samples, indicating fecal contamination. PCA supported these findings, highlighting variations in pollution levels and patterns among the samples. The findings of this study indicate that the water samples analyzed are significantly contaminated, particularly with heavy metals such as cadmium, lead, and arsenic, as well as with microbiological agents like Escherichia coli. These contaminants pose severe health risks and render the water unfit for human consumption without adequate treatment. The consistency of certain parameters across samples suggests common geological or environmental influences, while the variation in others may point to localized pollution sources. However, immediate remediation and regulatory intervention are required to mitigate these health risks and to safeguard public health.

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