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Appraising Water Quality, Health Risk and Correlation of Water Quality Parameters of Kiri Dam Reservoir – Shelleng LGA

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Abstract: Surface water bodies have been identified as potential pathways to water-borne diseases primarily due to their susceptibility to contamination. In addition, rural communities in many developing countries utilise surface water as part or sole means of water supply with no treatment due to its ease and proximity. This study assesses reservoir water quality and the health risk impact of Kiri Dam. Water samples were collected and analysed from 52 sampling points along the reservoir. The results showed that colour (23.2 mg/L), turbidity (19.3 5mg/L), nitrate (124.40 mg/L), lead (0.11 mg/L), potassium (1.61 mg/L), phosphorus (0.07 mg/L), coliform count (13.86cfu m/L), and E. coli (6.47cfu m/L) were significantly above stipulated standards. In addition, human health risks showed severe risks for adults, children and infants, with nitrate constituting over 70% of non-carcinogenic health risks. Correlation indicates pH strongly correlates with nitrate, potassium, phosphate, calcium, lead, iron, coliform count, and E. coli. In addition, a strong positive correlation was also observed between turbidity-colour, turbidity-coliform count, and turbidity-E. Coli. The outcome suggests poor water quality, resulting in severe health concerns, particularly for children and infants. Surface water monitoring is therefore recommended, particularly within areas that solely depend on unprotected water sources for drinking.

Keywords: Health Risk, Kiri Dam, Surface Water, Water Contamination

INTRODUCTION

The depletion of freshwater reserves in most Sub-Saharan African countries due to climate change and over-exploitation is becoming unprecedented (Ighalo and Adeniyi, 2020; Kelly et al., 2020; Yunana et al., 2017). In addition, it has resulted in insufficient availability of potable water supply amidst increasing demand and contamination. This has necessitated the provision of alternative water sources for use locally. One such alternative is the construction of dams and reservoirs within communities for collecting and storing water. Dams are hydraulic structures built across rivers to store water for irrigation, hydroelectric power generation and domestic water supplies. Despite the numerous advantages of dams, they can negatively impact the environment. Dam failures can flood farmlands, impair water quality, and severely affect aquatic life (Amos et al., 2019). However, with adequate assessment and monitoring, dams can effectively supply water for domestic, agricultural, and hydroelectric power generation. For example, the Kiri dam was constructed for the sole purpose of water supply for domestic and irrigation. In addition, the dam has allowed communities to fish along the dam's shores. This has invariably increased the community's economic activities and provided thousands of people with jobs and livelihood sources (Gadiga and Garandi, 2018; Zemba et al., 2016). However, the consequences of agricultural and domestic activities on water bodies include pollution and environmental degradation. This contributes to the unavailability of potable freshwater, which can threaten the community's public health.

The completion of the Kiri dam has increased irrigated farmlands of about 5000 hectares within the community and over 6000 hectares of cane plantation (Shalleng and Daniel, 2017). The irrigation of this scale will necessitate the use of agro-allied chemicals such as fertilisers and pesticides. These chemicals are often washed into the dam reservoir through runoff, thereby constituting a source of pollution. In addition, the ineffective waste disposal within the dam's shores has also contributed to the pollution of the reservoir by heavy metals and other organic and inorganic waste. According to the Upper Benue River Basin Authority, there has not been a detailed water quality assessment in the region for over 25 years (Soro, 2016). Although Milam et al. (2012) studied heavy metals in fish found downstream of Kiri Dam, a study from Soro (2016) assessed a few parameters within the water body. This necessitated increasing the parameters and sampling points to cover a substantial dam reservoir area.

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Freshwater availability is required both in quantity and quality across several uses. Although the intended use of water determines the quality, it is imperative to ensure that water for domestic use is safe and potable (Ayandiran et al., 2018; Chigor et al., 2012; Usikalu et al., 2021). States within northeastern Nigeria have the lowest coverage in terms of the number of persons with an adequate and improved source of water when compared to the country. For instance, only 18% of the rural population in the northeast is covered with an improved water source (World Bank, 2017). Although the communities around Kiri Dam may use alternative sources such as wells and boreholes, many people use the dam reservoir as the primary water source for drinking and other domestic uses (Soro, 2016). Against this backdrop, this study aims to assess water quality in the dam reservoir. It further evaluates the human health risks and the correlation between water quality parameters. It suggests the need for consistent monitoring and assessment of water quality, especially since there has not been a detailed assessment within the area for a long time. The research hypothesis suggests that water quality in Kiri Dam has been severely affected by poor waste management and irrigation activities. In addition, the study hypothesised that a strong relationship exists between water quality parameters which could result in public health concerns. As a result, local community people are exposed to health concerns, particularly children and those with underlying health challenges.

METHODOLOGY

Study Area

Kiri Dam is located in Kiri village in Shelleng Local Government Area (LGA) of Adamawa State, Nigeria. It is situated on latitude 9° 42 North and longitude 12° 01 East and lies along the floodplain of the lower Gongola River and 25km upstream of its confluence with River Benue at Numan LGA (Zemba et al. 2016). The dam was commissioned in 1982 with an area of 134 km^2 from Shere Hills on the Plateau to Numan. Kiri village has an average annual rainfall of about 650mm with an average temperature between 18°C during the coldest month (December/January) and 36°C during the hottest month (March-May) (Tukur and Mubi, 2002). Kiri village residents are primarily farmers (irrigation and rainfed) and fishermen. Crops include sugarcane, rice, maise, beans, and soybeans.

Figure 1. Imagery of Kiri dam showing sampling points and Kiri village

Water Sampling

Water samples for the study were collected within the axis of the dam. Before sampling, a site visit was conducted in April to identify sampling points. Points where residents often collect water for domestic and agricultural uses were randomly identified as the best sampling points since these were the places the communities collect water. In addition, poor water quality at these points will likely result in public health concerns and, thus, regarded as the most important sampling points. As a result, 52 sampling points were identified, water was collected from all these points in November in triplicates, and the average was tabulated and used for further analysis. Water quality parameters analysed include colour, temperature, pH, turbidity, TDS, EC, hardness, nitrate, fluoride, magnesium, chloride, phosphate, potassium, calcium, manganese, iron, lead, coliform count, and E. coli.

Samples were collected in a sterilised and pre-treated 75cl plastic bottle container by washing the bottles with 0.05M HCl and rinsing them with distilled water as described by APHA (1998) and Radojevic and Bashkin (2006). In addition, sample bottles were rinsed thrice with water samples before collection to avoid alteration of results (Idoko and Oklo, 2012; Ogunbode et al., 2017). Each sample bottle was labelled, stored in ice coolers, and transported to the laboratory for further analysis under 4°C. Furthermore, fast-changing parameters like temperature, pH and conductance were measured in situ to avoid alteration in results (Olufemi et al. 2010).

Analysing Water Quality Parameters

Water sample parameters were divided into physical, chemical, and bacteriological parameters accordingly. This was according to the Nigerian Industrial Standards for drinking water (NIS, 2007). Electrochemical measurements involving electrodes were grouped and conducted in situ with parameters such as temperature (measured using a thermometer), pH (using a pH meter), and electronic conductivity (using a conductance meter with a scale of 0 – 2000units) as described by APHA, (1998); Radojevic and Bashkin, (2006); Chaurasia and Gupta, (2014). Turbidity was measured using a turbidimeter, colour using the Hazen method, and other parameters such as TDS, nitrate, sulphate, fluoride, lead, iron, phosphate, potassium, calcium, and magnesium were measured using standard laboratory procedures and flame absorption spectrophotometry as specified by APHA, (1998). Biological parameters were detected and quantified using Eosin Methylene Blue (EMB) Agar by incubating at 37°C and 44.5°C. Counts were expressed in CFU/100mL of water. Purified water through the distillation process described by NIS (2007) and APHA (1998) was used as a control, particularly in washing sample bottles, to avoid contamination and to correct analytical instruments to assess water quality parameters.

Assessing Non-carcinogenic Health Risk

The health risk associated with water consumption from the case study area was computed using the equation developed by the United States Environmental Protection Agency (USEPA, 1991; USEPA, 2014). First, the average chronic daily intake (CDI) was computed using equation (1) below

$$CDI = \frac{Cw*IR*ED*EF}{ABw*AEt} \tag{1}$$

Where *CDI* is the chronic daily intake (mg/kg/day), *CW* – is the concentration of contaminants, and *IR* is – the ingestion rate for adults, children and infants with values 2.5L, 0.78L and 0.3L, respectively (Ahada and Suthar, 2019; Narsimha et al. 2018). In addition, *ED* – is the exposure duration for adults, children and infants, which is taken as 64, 12 and 1 year (Adimalla and Li, 2019; Chen et al., 2017), *EF* – is the exposure frequency taken as 365 days, *ABw* – is the average body weight taken as 68, 18 and 5kg for the three human groups and *AEt* – is taken as 23360, 4380 and 365 days representing the average exposure time for adult, children and infants respectively (Chen et al. 2017).
Second, the Hazard quotient (HQ) was calculated using equation (2) as follows

$$HQ = \frac{CDI}{RfD} \tag{2}$$

HQ is the hazard quotient, and *RfD* is the reference dose of contaminants in mg/kg/day. The reference dose was 1.6, 0.4, 0.7 and 0.0035 (mg/kg/day) for nitrate, fluoride, iron and lead, respectively (USEPA, 2014; Duggal et al. 2017).
Finally, the hazard index (HI) was computed from equation (3) as the summation of the hazard quotient. In addition, the classification of the hazard index for the non-carcinogenic health impact was based on USEPA (1991) classification presented in Table 1.

$$HI = \sum HQ \tag{3}$$

Table 1. Classification of chronic non-carcinogenic health risk

Risk Level	Hazard Index (HI)	Risk Description
1	< 0.1	Negligible

2	≥ 0.1 < 1	Low
3	≥ 1 < 4	Medium
4	≥ 4	High/Severe

Statistical Analysis

The study result was descriptively analysed, and significant differences between WHO/NIS standards and the measured parameters were assessed. The T-test using Mini-tab version 18.0 was used to determine a significant difference in the mean of parameters compared with the NIS/WHO standards for drinking water. The mean values considered statistically significant ($p > 0.05$) suggest poor water quality that can likely constitute a public health concern. In addition, Pearson correlation was used to determine the association between parameters, indicating that changes in one variable are associated with an increase or decrease in other parameters.

Limitations of the Study

The study followed all experimental procedures as indicated in the literature. However, challenges arising from laboratory equipment, human errors, and the effect of distance between the sample site and the laboratory may or may not have affected the study outcome. To mitigate the challenges, triplicate sampling and analysis were carried out, and the computed average was used for the statistical analysis. Furthermore, ice packs in coolers were used to mitigate the temperature difference, especially since there are no water laboratories within the Kiri community. Finally, sampling was not conducted during the wet season because most community members indicated they harvest rainwater for use and are less likely to visit the dam for water collection. Thus, sampling was carried out at the onset of the dry season and when most people visited the dam for drinking water collection.

RESULT AND DISCUSSION

Comparing Results to Drinking Water Standard

The results for physical, chemical, and bacteriological parameters were subjected to statistical analysis to identify parameters that fail to meet the WHO/NIS standards for drinking water. The T-test analysis indicates that colour, turbidity, nitrate, lead, potassium, phosphorus, coliform count, and E. coli were the parameters that failed to conform to the standards for drinking water (Table 2). Their respective means were statistically greater than the stipulated standard for drinking water and hence considered unsuitable for consumption without further treatment. Although the residents of the Kiri Dam community have been using the reservoir water as means of drinking water and other domestic uses (Soro, 2016), long-term exposure will likely increase the health risk, especially among children and the elderly (Jaji et al., 2007; Kolawole et al., 2011; Oboh and Agbala, 2017). Furthermore, a study by Milam (2012) shows the associated risk of heavy metals like lead in different parts of fish in Kiri Dam. This indicates that apart from the direct threat to the health of residents who often consume the reservoir water, there is the indirect risk from consuming fish that take up these contaminants. This finding further conforms to the results of heavy metals in surface water in rural areas by Ayandiran et al. (2018). In addition, findings of biological parameters exceeding the WHO/NIS standards, particularly in rural surface water, were also found by Joshua (2015), Joshua (2021), and Tenebe et al. (2020), which supports the findings of this study.

Table 2. Mean, standard deviation and P-values of physical, chemical, and bacteriological properties in comparison to NIS/WHO drinking water Standards

Parameters	**NIS/WHO Standards**	**Mean/Std Dev.**	**p-value**
Temperature (℃)	Ambient	21.53	-
pH	6.8 – 8.5	7.6	-
Colour (TCU)	15	**23.20** ± 2.16	**0.000**
Conductivity (μs/cm)	1000	39.77 ± 6.35	1.000
Turbidity (NTU)	5	**19.35** ± 1.82	**0.000**
T.D.S (mg/L)	500	468.4 ± 117.4	0.943
Chloride (mg/L)	250	57.41 ± 5.61	1.000

Nitrate (mg/L)	50	**124.40** ± 4.99	**0.000**
Fluoride (mg/L)	1.5	0.98 ± 0.11	1.000
Calcium (mg/L)	75	73.38 ± 3.04	0.999
Sulphate (mg/L)	100	67.28 ± 12.93	1.000
Magnesium (mg/L)	30	28.00 ± 2.63	1.000
Lead (mg/L)	0.01	**0.10** ± 0.03	**0.000**
Iron (mg/L)	0.3	0.22 ± 0.10	1.000
Manganese (mg/L)	0.05	0.03 ± 0.01	1.000
Potassium (mg/L)	1	**1.61** ± 0.38	**0.000**
Phosphate (mg/L)	0.05	**0.07** ± 0.01	**0.001**
Hardness (mg/L)	150	126.93 ± 16.75	1.000
Coliform Count (cfu/100mL)	10	**13.86** ± 4.24	**0.000**
E. Coli (CFU/100mL)	0	**6.47** ± 3.20	**0.000**

Remarks in bold indicate that means are significantly more significant than the stipulated standard, Std. Dev – standard deviation, NIS - Nigerian Industrial Standard, WHO – World Health Organisation

Non-carcinogenic Health Assessment

The non-carcinogenic health impact was computed for adults, children and infants. The mean results for the hazard quotient (HQ) and total hazard index (THI) were computed and presented in Figure 2. According to the results, the non-carcinogenic risk was in the order of – nitrate > lead > fluoride > iron for all human groups (adults, children and infants). This shows nitrate accounting for 68.9%, 72.1% and 70.6% of non-carcinogenic health risks in adults, children and infants. Studies from Aher et al. (2020); Barzegar et al. (20219); Chica-Olmo et al. (2017); Golaki et al. (2022); Kusa and Joshua (2022); Mohammadi et al. (2019) show similar findings indicating nitrate significantly contributing to health risks, particularly in children and infants. The ingestion of water containing nitrate over the permissible limit is known to cause a blue baby syndrome in infants (Hameed et al., 2021); hence it is imperative to protect infants and children from exposure to water in the reservoir without any treatment to remove nitrate and other contaminants.

The total hazard index (THI) shows values of 4.02, 4.52 and 6.4 for adults, children and infants. This was significantly above the permissible limit of 1THI for low-risk (See Table 1), suggesting that all human groups are at severe risk of non-carcinogenic health impacts. Therefore, continuous water ingestion from the reservoir without treatment should be discouraged to protect the community's health and well-being, especially since there is no water treatment before use. In addition, the community should result in other alternative water sources like groundwater that are protected from external sources of contamination.

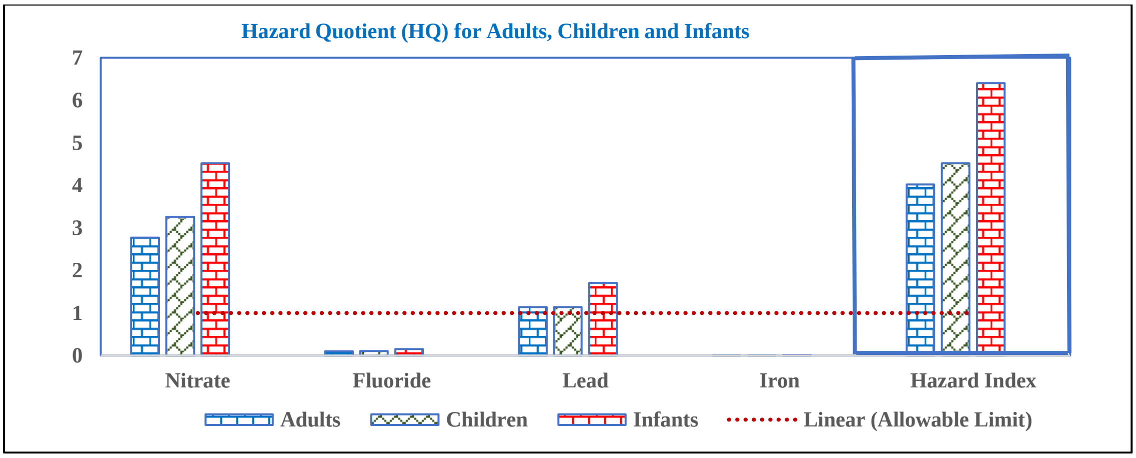
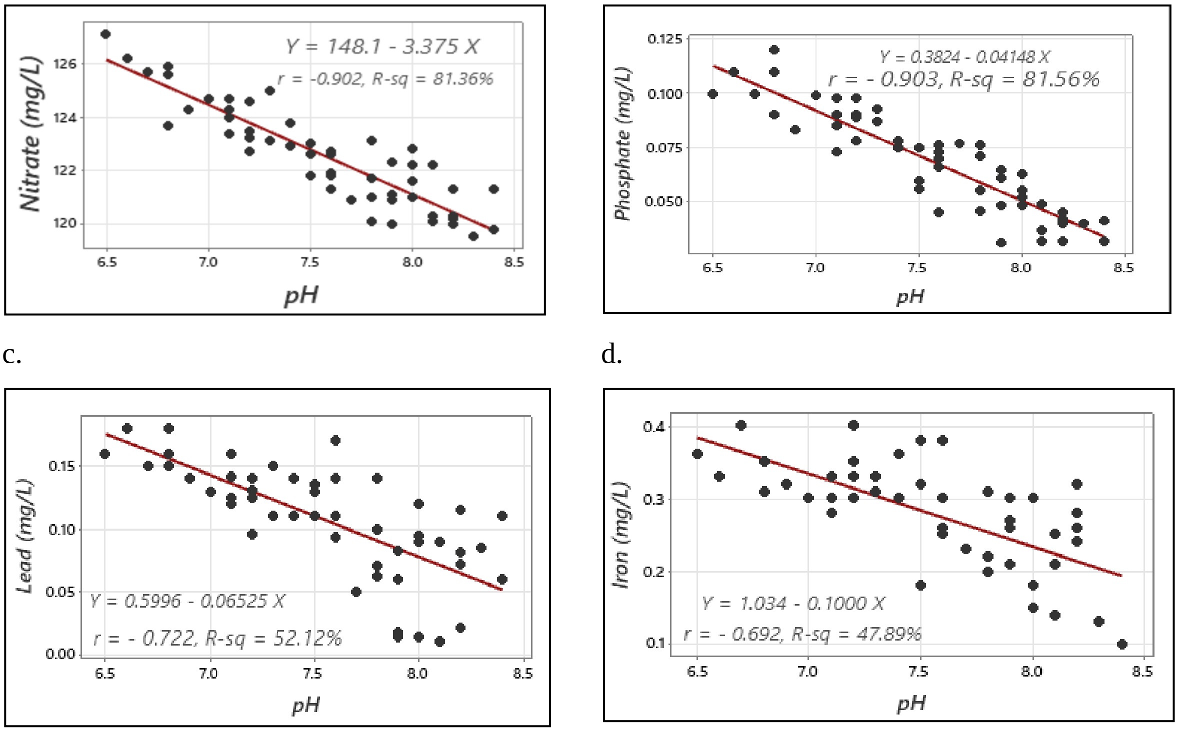


Figure 2. HQ and THI for the different age groups – adults, children and infants

Correlation and Association of Water Quality Parameters

A correlation was used to assess the association between variables. The correlation was classified according to Wang's (2018) classification, with r < 0.3 considered irrelevant, 0.3 – 0.49 as less relevant, 05 – 0.69 as moderately correlated and r > 0.7 as strongly correlated. The Pearson correlation analysis (Table 3) showed that pH has a strong negative correlation with nitrate (r = - 0.902), potassium (r = - 0.800), phosphate (r = - 0.903), and lead (r = - 0.722), while moderately correlated with iron (r = - 0.692), and calcium (r = - 0.539). The negative correlation implies that as pH decreases, there is an associated increase in nitrate, potassium, phosphate, lead, iron, and calcium, respectively (Fig. 3 a-d). As water becomes acidic (decreases in pH), more chemicals are dissolved, thus increasing the concentration of these contaminants in water. Similar results of a strong negative correlation between pH and heavy metals were found by Amfo-Otu et al. (2014), supporting this study's findings. In addition, a moderate negative correlation was observed between calcium and phosphate (r = - 0.513), indicating that a decrease in calcium is associated with an increase in phosphate and vice versa.


a.

b.

c.

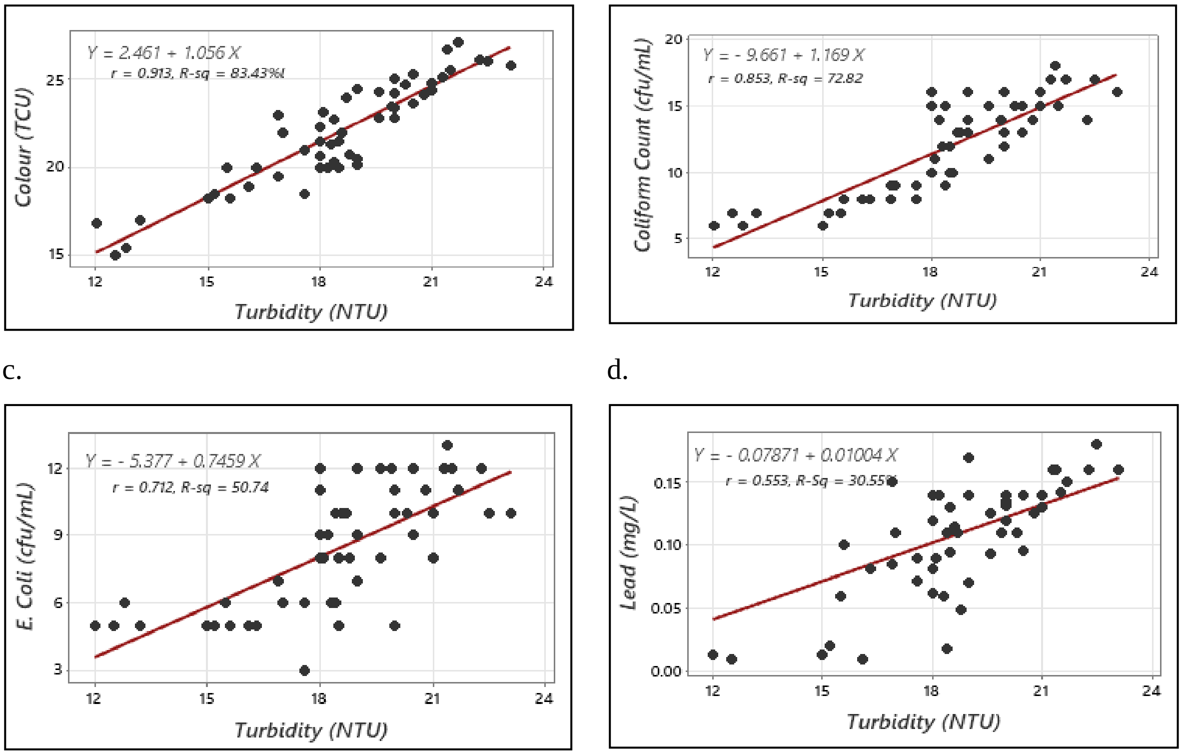
d.

Figure 3. Linear relationship showing a negative correlation between pH & nitrate, phosphate, lead & iron

Consequently, a strong positive correlation was observed between colour-turbidity (r = 0.913), colour-coliform count (r = 0.715), phosphate-nitrate (r = 0.880), phosphate-potassium (r = 0.784), lead-potassium (r = 0.717), turbidity-coliform count (r = 0.853), turbidity-E. Coli (r = 0.712), potassium-coliform count (r = 0.717), and E. coli-coliform count (r = 0.820). This conforms to findings from Awomeso et al. (2020). Additionally, a moderate positive correlation was also observed between colour-nitrate (r = 0.531), colour-potassium (r = 0.612), colour-phosphate (r = 0.530), colour-lead (r = 0.559), and colour-E. Coli (r = 0.661), turbidity-lead (r = 0.553), turbidity-potassium (r = 0.665), turbidity-phosphate (r = 0.524), lead-nitrate (r = 0.689), lead-phosphate (r = 0.694), iron-nitrate (r = 0.615), iron-potassium (r = 0.616), iron-phosphate (r = 0.573, calcium-nitrate (r = 0.540), phosphate-coliform count (r = 0.566), potassium-E. Coli (r = 0.659), phosphate-E. Coli (r = 0.539), and Lead-E. Coli (r = 0.536). Positive correlation implies that an increase in one parameter is associated with an increase in the second variable and vice versa. A linear relationship chart (Fig. 4 a-d) further shows the relationship between some selected parameters with similar findings observed by Aladejana et al. (2020) and Almuktar et al. (2020).

a.

b.



c. d.

Figure 4. Linear relationship showing a positive correlation between turbidity & colour, coliform count, E. coli & lead

Plausible Source of Contamination and Public Health Implication

Water's characteristics (physical, chemical, and bacteriological) are often used to describe its suitability for use. However, these characteristics can be influenced by natural and artificial factors (Joshua, 2015; Yunana et al., 2017). Human activities within Kiri Dam can play a significant role in water quality within the reservoir. For instance, heavy metals such as lead exceeding the permissible limit of 0.01 mg/L can be attributed to improper waste disposal of substances like lead batteries from mechanical workshops and plausibly from natural origins. Furthermore, nutrients (nitrate, phosphate, and phosphorus) can be attributed to the irrigation and rainfed agricultural activities within the dam region. The unprecedented increase in irrigated farmland within the area will likely influence the presence of nutrients within the reservoir. Bacteriological contamination, on the other hand, is likely due to animal faeces and the high rate of open defecation within most rural settlements in Nigeria (World Bank, 2017). This further supports the research hypothesis and asserts the need for water management in Kiri communities and nationally, specifically in riverine communities.

The health implication of consuming contaminated water is likely to be severe, especially among children and the elderly, who are considered vulnerable (Joshua, 2020). Continuous exposure to water containing lead beyond the stipulated 0.01 mg/L can likely interfere with vitamin D metabolism, impair infant mental development and be toxic to the central nervous system, which can cause cancer (Brown and Margolis, 2012; Pelfrêne et al., 2013). Nitrate in water exceeding 50 mg/L can cause cyanosis and asphyxia (blue baby syndrome) in infants under three months (Mortada and Shokeir, 2018; Pacheco and Fernandes, 2016). In addition, nitrate, phosphorus, and potassium cause eutrophication in water bodies. Eutrophication causes algal bloom, which decreases the amount of dissolved oxygen in water, significantly impacting aquatic life (Joshua, 2021). The colour indicates the presence of dissolved and suspended solids in water. However, organisms can utilise these solids, thereby increasing the bacteriological presence of contaminants in water (Joshua, 2021; Kumar et al., 2018). Bacteriological contaminants cause cholera, typhoid fever, diarrhoea, and dysentery. These are diseases that have been reported within many rural communities in Nigeria.

CONCLUSION

This study collected and analysed surface water samples from Kiri Dam for physical, chemical and biological parameters. The results indicate that the reservoir water failed to conform to the stipulated standards (WHO/NIS) to qualify as adequate for drinking. Although the residents of Kiri village have been using the water for drinking and other uses, continuous exposure without any form of treatment can likely result in chronic health-related impacts, including non-carcinogenic effects amongst children, visitors and the elderly. Agricultural activities, improper waste disposal and the prevalence of human and animal excreta have been attributed to be the likely cause of contamination. Therefore, the need to effectively assess and monitor surface water quality within riverine communities. This is paramount since rivers flow from upstream to downstream, and contamination can occur upstream without downstream water users' knowledge. The Upper Benue River Basin Authority and the Federal and State Ministries of Water Resources and Environment must protect water sources from anthropogenic contamination, especially from improper disposal of waste substances. In addition, agricultural chemicals such as fertilisers and pesticides must be regulated to avoid contamination of water bodies. As a matter of urgency, communities should be enlightened on the dangers of consuming contaminated water and simple measures to employ to treat water before use and protect water sources.

Table 3. Correlation coefficient (r) between selected physicochemical and bacteriological water quality parameters

Parameters	pH	Colour	Turbidity	Nitrate	Potassium	Phosphate	Calcium	Lead	Iron	Coliform	E. coli
pH	1.000										
Colour	-0.461	1.000									
Turbidity	-0.470	**0.913****	1.000								
Nitrate	**-0.902****	**0.531***	0.468	1.000							
Potassium	**-0.800****	**0.612***	**0.665***	0.801	1.000						
Phosphate	**-0.903****	**0.530***	**0.524***	**0.880****	**0.784****	1.000					
Calcium	**-0.539***	0.096	0.163	**0.540***	0.456	**-0.513***	1.000				
Lead	**-0.722****	**0.559***	**0.553***	**0.689***	**0.717****	**0.694***	0.337	1.000			
Iron	**-0.692***	0.340	-0.346	**0.613***	**0.616***	**0.573***	0.321	0.436	1.000		
Coliform	**-0.521***	**0.715****	**0.853****	0.455	**0.717****	**0.566***	0.230	0.499	0.386	1.000	
E. coli	**-0.530***	**0.661***	**0.712****	0.487	**0.659***	**0.539***	0.340	**0.536***	0.462	**0.820****	1.000

*Significant values are in bold and represented by **, implying variables are Strongly correlated, while * indicates moderately correlated*

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