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Assessment of Physicochemical Properties of Water and Associated Human Health Risk Factors from Gitata River, Nasarawa State, Nigeria

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ABSTRACT
Water in regions affected by mining can be laden with toxic metals, posing a risk to nearby populations. Physicochemical characteristics, heavy metal concentration and the associated human health risks were examined in the surface water of Gitata River located in Nasarawa State, Nigeria. Water from five sites of the river were sampled, during the dry season and analysed using standard analytical procedures. Physicochemical parameters including pH 7.05-7.25; electrical conductivity 228-240 µS/cm; total dissolved solids 141-152 mg/L; turbidity 2.73-3.1 NTU; dissolved oxygen 6.2-6.8 mg/L; biochemical oxygen demand 2.1 to 2.4 mg/L; hardness 91.8-97 mg/L; chloride 17.9-20.3 mg/L; and nitrate 6.5-7.24, which all lie within the permissible limit of the World Health Organisation (WHO). Heavy metal concentration at different sites ranges from 0.000-0.803 mg/L for chromium, from 0.036-0.151 mg/L for cadmium, and from 0.001-0.321 mg/L for arsenic, with a 0.056-0.385 mg/L range for lead.Cadmium and arsenic exceeded the WHO and National Environmental Standard Regulation Agency (NESREA) limits at several locations. Exposure risk to humans was assessed using models provided by the United States Environmental Protection Agency (USEPA). Chronic daily intake (CDI) values were between 0.00 and 2.49×10^{-4} mg/kg/day for adults, and from 0.00 to 6.77×10^{-4} mg/kg/day for children, while hazard index (HI) ranged from 0.070 to 0.431 for adults and 0.189-1.170 for children, with the value greater than unity for children at Site E, mostly from cadmium and arsenic. The estimated risk of cancer associated with arsenic was 2.27×10^{-4}-1.12×10^{-3} higher than tolerable levels. The findings recommend risk-based water management practices, regulatory control of artisanal mining activities and continuous surface water quality monitoring in the study area.

Keywords:
Surface water
Contamination;
Heavy metals;
Health risk assessment;
Artisanal mining impact;
Carcinogenic risk

INTRODUCTION

Surface waters are an important water source for domestic consumption, irrigation and small scale industries in most of the developing countries. In Nigeria, access to treated water is limited and rural and peri-urban communities depend on rivers and streams for centuries as a source of water supply (WHO, 2017). However, water pollution of surface waters is increasing due to anthropogenic pressures such as from artisanal mining, agriculture, urban runoffs and improper waste disposal including heavy metals contaminating the groundwater sources in Northern Nigeria (Adefemi & Awokunmi, 2010; Khan *et al.*, 2023; Samaila *et al.*, 2025).

Small-scale mining is one of the important sources of heavy metal contamination in water bodies. Metals are introduced into neighbouring soils and water bodies by er osion, leaching and surface run-off during the extraction and processing of ores (Duncan *et al.*, 2018;Adeniyi & Laniyan, 2023). They are non-biodegradable, tend to bio-accumulate and become toxic risk factors to both aquatic organisms and humans once released into surface waters (Laoye *et al.*, 2025). Consumption of contaminated water and consumption through food chains are both routes of exposure.

Heavy metals such as chromium, cadmium, arsenic and lead are of particular concern due to their toxicity,

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persistence and ability to cause cancer or other non-cancer health effects. Long-term exposure has been associated with higher risk of cancer, neurological disorders, renal dysfunction and developmental disorders in children (Ugwu *et al.*, 2022; Ogoko, 2023). Therefore, health risk assessment models are regularly used to evaluate potential effects and international institutions have established guideline values to protect public health (USEPA, 2011; WHO, 2017). Introduction Nasarawa State is found in the North-central zone of Nigeria with abundant mineral resources and mining activities. High levels of heavy metals have been detected in the groundwater and surface water bodies across Karu and its environs; pointing towards wide contamination pathways, high hydrogeochemical connectivity (Kana, 2022; Ombugus *et al.*, 2021; Oshukunuofa *et al.*, 2024; Rilwan *et al.*, 2025). Despite the fact that the surrounding communities rely on Gitata River for domestic and small-scale agricultural activities, there is still limited systematic information about the quality of surface water in this river as well as its health risks.

Therefore, the objective of this investigation is to: determine the physicochemical properties and level of heavy metals in surface water of Gitata River; assess non-carcinogenic and carcinogenic health risk on adults and children (USEPA, 2011). The findings are expected to act as a reference point in the management of water resources and protection of public health in Nasarawa State.

MATERIALS AND METHODS

Study Area

The Gitata River is located in the Karu Local Government Area, Nasarawa State, North-central Nigeria (9°06'28.6"N; 7°56'49.9"E). The site is characterized by a tropical savanna climate, influenced by increasing per-urban settlements as well as agriculture and artisanal mining. The river is a major source of water supply for communities living within its environs for drinking, washing, irrigation and other domestic purposes (Kana, 2022; Rilwan *et al.*, 2025).

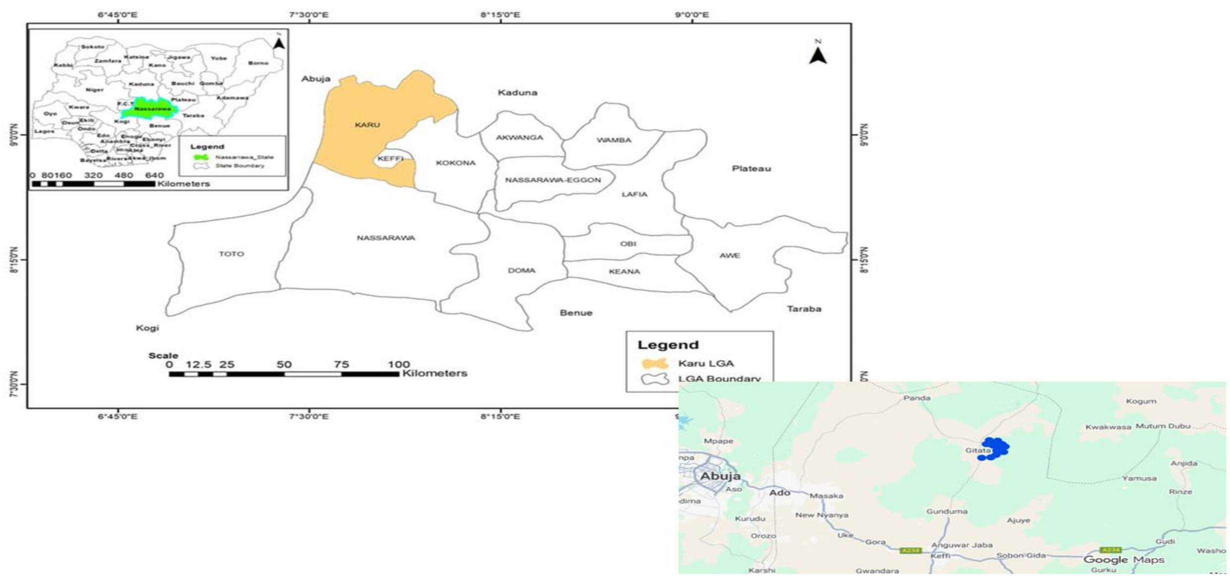

Figure 1: Map of Nasarawa State (inset) and Karu Local Government Area showing Gitata, the study location. Source: Nasarawa State Ministry of Lands and Survey, 2016.

Sample Collection and Preservation

Five specific sampling locations (A-E) along the river, representing upstream, midstream, and downstream sections, were used to gather surface water samples. All sampling sites (A-E) fell within a small reach of the Gitata River (less than 5 km in length) and were denoted by the central geographic coordinates 9°06′28.6″N, 7°56′49.9″E. In order to reduce the effects of dilution, sampling was done during the dry season (February-March 2025). One-litre polyethylene bottles that had been previously cleaned were used to collect samples in triplicate. Prior to heavy metal analysis, samples were stored at 4°C after being acidified in situ with concentrated nitric acid (HNO_3) to a pH of less than 2 (APHA, 2017).

Physicochemical Analysis

Standard procedures were used to determine the physicochemical parameters (APHA, 2017). A portable pH/temperature meter (HI9813-6, Hanna Instruments, Romania) was used to measure the temperature and pH in situ. A multi-parameter meter (HQ40d, Hach, USA) was used to measure electrical conductivity (EC) and total dissolved solids (TDS). A portable turbidimeter (2100Q, Hach, USA) was used to measure turbidity. The Winkler's titration method was used to measure dissolved oxygen (DO), and after five days of incubation, biochemical oxygen demand (BOD) was measured. EDTA titration was used to measure total hardness, argentometric titration was used to measure chloride, and UV-visible spectrophotometry was used to measure nitrate levels.

Heavy Metal Determination

Water samples were digested for the release of bound metals using nitric and hydrochloric acid (HNO3/HCl, 3:1 v/v). The concentrations of chromium (Cr), cadmium (Cd), arsenic(As) and lead (Pb) were determined by anatomic absorption spectrophotometer (AAnalyst 400, PerkinElmer,USA). The same replicate sample analyses, calibration standards, and reagent blanks were used for maintaining analytical quality control. Recovery was in the range of 95-105%, and % Relative Standard Deviation (RSD) were all below 5%.

Human Health Risk Assessment

Health risk associated with the ingestion of the contaminated water was evaluated for adults (70 kg, 2 L/day) and children (15 kg, 1 L/day) by using United States Environmental Protection Agency models (USEPA, 2011).

Chronic Daily Intake (CDI):

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

Where C is the metal concentration (mg/L), IR in is the rate of ingestion, EF is exposure frequency (365 days/year), ED refers to exposure duration (30 years for adults and 6 years for children), BW means body weight, and AT stands for averaging time.

Non-Carcinogenic Risk:

Evaluated using the Hazard Quotient

$$HQ = \frac{CDI}{R_f D} \quad (2)$$

Hazard Index

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

The Reference Doses (RfD) utilized were: Cr (0.003), Cd (0.0005), As (0.0003), and Pb (0.0035) mg/kg/day [12]. An HI > 1 is suggestive of possible adverse health effects.

Carcinogenic Risk:

Assessed using Incremental Lifetime Cancer Risk (ILCR) and Total Cancer Risk (TCR)

$$ILCR = CDI \times SF \quad (4)$$

$$TCR = \sum_{i=1^n} ILCR_i \quad (5)$$

Slope Factors (SF) used were: Cr (0.5), Cd (6.3), As (1.5), and Pb (0.0085) $(mg/kg/day)^{-1}$. Acceptable risk limits are typically 1×10^{-6} to 1×10^{-4}

RESULTS AND DISCUSSION

Physicochemical Characteristics

Table 1 Physicochemical properties of water in the river Gitata. The pH and temperature values were consistent with near-neutral water chemistry, as well as the ambient environmental conditions. Electric conductivity and total dissolved solids exhibited similar pattern as other rivers in Nigeria but were within acceptable limits (Adefemi & Awokunmi, 2010; Khan *et al.*, 2023). BOD values indicated that the water wasnt much organically polluted and dissolved oxygen was present at acceptable levels.

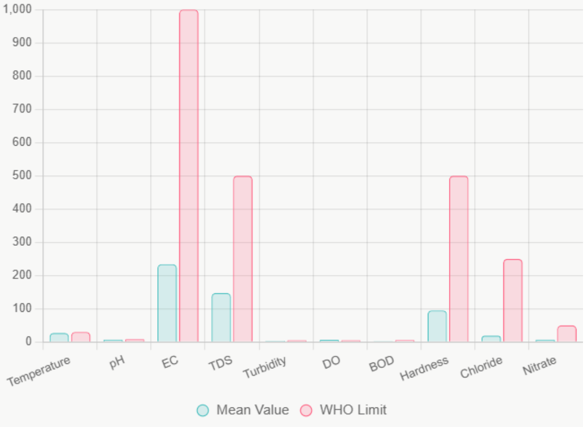

Figure 2: Comparison of mean physicochemical parameters of Gitata River water against WHO permissible limits.

Table 1: Physicochemical parameters of Gitata River water compared to WHO limits.

Parameter	Unit	Site A	Site B	Site C	Site D	Site E	Mean ± SD	WHO Limit
Temperature	°C	27.4 ± 0.3	27.1 ± 0.2	26.9 ± 0.4	27.2 ± 0.5	27.3 ± 0.3	27.18 ± 0.18	≤ 30
pH	-	7.10 ± 0.15	7.25 ± 0.10	7.05 ± 0.12	7.18 ± 0.11	7.22 ± 0.10	7.16 ± 0.08	6.5 – 8.5
EC	µS/cm	234 ± 6.4	240 ± 5.9	228 ± 4.8	238 ± 5.2	231 ± 6.0	234.2 ± 4.9	≤ 1000
TDS	mg/L	145 ± 3.5	152 ± 4.1	141 ± 2.9	148 ± 3.4	150 ± 4.2	147.4 ± 4.0	≤ 500
Turbidity	NTU	2.8 ± 0.3	3.1 ± 0.2	2.9 ± 0.3	3.0 ± 0.2	2.7 ± 0.4	2.9 ± 0.16	≤ 5
DO	mg/L	6.5 ± 0.3	6.2 ± 0.4	6.8 ± 0.3	6.4 ± 0.4	6.6 ± 0.3	6.5 ± 0.23	≥ 5.0
BOD	mg/L	2.3 ± 0.2	2.4 ± 0.2	2.1 ± 0.3	2.2 ± 0.3	2.4 ± 0.2	2.28 ± 0.13	≤ 6
Hardness	mg/L	94.5 ± 4.2	97.0 ± 3.9	91.8 ± 4.1	95.4 ± 4.3	96.1 ± 4.0	95.0 ± 2.1	≤ 500
Chloride	mg/L	18.5 ± 2.1	19.8 ± 1.9	17.9 ± 1.8	20.3 ± 2.2	18.7 ± 1.7	19.0 ± 1.0	≤ 250
Nitrate	mg/L	6.8 ± 0.6	7.2 ± 0.5	6.5 ± 0.7	6.9 ± 0.6	7.0 ± 0.5	6.9 ± 0.28	≤ 50

Heavy Metal Concentrations

The levels of heavy metals varied at sampling sites (Table 2). Levels of lead, cadmium and arsenic possessed local enrichment, had excessive accumulations that exceed the critical values at certain sites. The highest concentrations of arsenic and chromium were recorded at Site E. These observations are in conformity with studies conducted on surface waters impacted by mining activities in Nasarawa State and elsewhere in Nigeria (Ombugus *et al*., 2021; Olowojuni *et al*., 2025; Rilwan *et al*., 2025; Samaila *et al*., 2025).

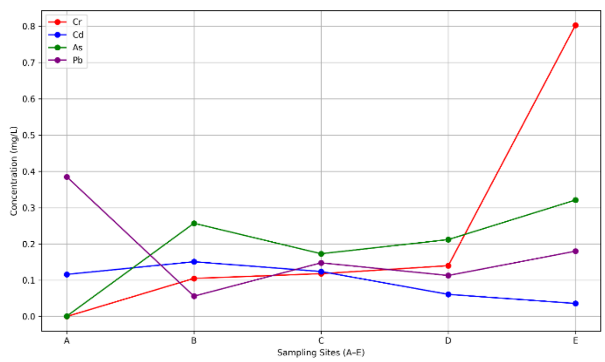

Figure 3: Spatial variation of heavy metal concentrations (Cr, Cd, As, Pb) across the five sampling sites.

Table 2: Mean concentration of heavy metals (mg/L) in water samples across sampling sites.

Metal	Site A	Site B	Site C	Site D	Site E	Mean ± SD	WHO/NESREA Limit
Cr	0.000	0.105	0.118	0.140	0.803	0.233 ± 0.312	0.050
Cd	0.116	0.151	0.124	0.061	0.036	0.096 ± 0.048	0.003
As	0.001	0.257	0.173	0.212	0.321	0.153 ± 0.128	0.010
Pb	0.385	0.056	0.148	0.113	0.180	0.176 ± 0.122	0.010

Non-Carcinogenic Health Risk Assessment
The chronic daily intake values for adults and children are shown in Table 3. Consistent in other Nigerian studies, children had higher intake values as a result of the use of lower body weight estimates (Ugwu *et al.*, 2022; Ogoko, 2023). The main contributors to non-carcinogenic risk were Cd and As (Hazard Quotients are shown in Table 4), as at the site E, HI for children have surpassed unity (>1) and may pose health risk.

Table 3: Chronic Daily Intake (CDI) (mg/kg/day) of heavy metals for adults and children.

Site	Cr (Adult)	Cr (Child)	Cd (Adult)	Cd (Child)	As (Adult)	As (Child)	Pb (Adult)	Pb (Child)
A	0.00	0.00	$3.58×10^{-5}$	$9.73×10^{-5}$	0.000	0.00	$1.19×10^{-4}$	$3.22×10^{-4}$
B	$3.26×10^{-5}$	$8.86×10^{-5}$	$4.67×10^{-5}$	$1.27×10^{-4}$	$7.96×10^{-5}$	$2.16×10^{-4}$	$1.64×10^{-5}$	$4.45×10^{-5}$
C	$3.66×10^{-5}$	$9.96×10^{-5}$	$3.83×10^{-5}$	$1.04×10^{-4}$	$5.98×10^{-5}$	$1.63×10^{-4}$	$4.58×10^{-5}$	$1.25×10^{-4}$
D	$4.34×10^{-5}$	$1.18×10^{-4}$	$1.89×10^{-5}$	$5.13×10^{-5}$	$6.53×10^{-5}$	$1.78×10^{-4}$	$3.49×10^{-5}$	$9.50×10^{-5}$
E	$2.49×10^{-4}$	$6.77×10^{-4}$	$1.12×10^{-5}$	$3.03×10^{-5}$	$9.64×10^{-5}$	$2.62×10^{-4}$	$5.56×10^{-5}$	$1.52×10^{-4}$

Table 4: Hazard Quotient (HQ) and Hazard Index (HI) for heavy metal exposure.

Site	HQ Cr (Ad)	HQ Cd (Ad)	HQ As (Ad)	HQ Pb (Ad)	HI (Adult)	HQ Cr (Ch)	HQ Cd (Ch)	HQ As (Ch)	HQ Pb (Ch)	HI (Child)
A	0.000	0.036	0.000	0.034	**0.070**	0.000	0.097	0.000	0.092	**0.189**
B	0.011	0.047	0.265	0.005	**0.328**	0.030	0.127	0.720	0.013	**0.890**
C	0.012	0.038	0.200	0.013	**0.263**	0.033	0.104	0.543	0.036	**0.716**
D	0.014	0.019	0.218	0.010	**0.261**	0.039	0.051	0.593	0.027	**0.710**
E	0.083	0.011	0.321	0.016	**0.431**	0.226	0.030	0.871	0.043	**1.170**

Key: Ad= Adults, Ch= Children

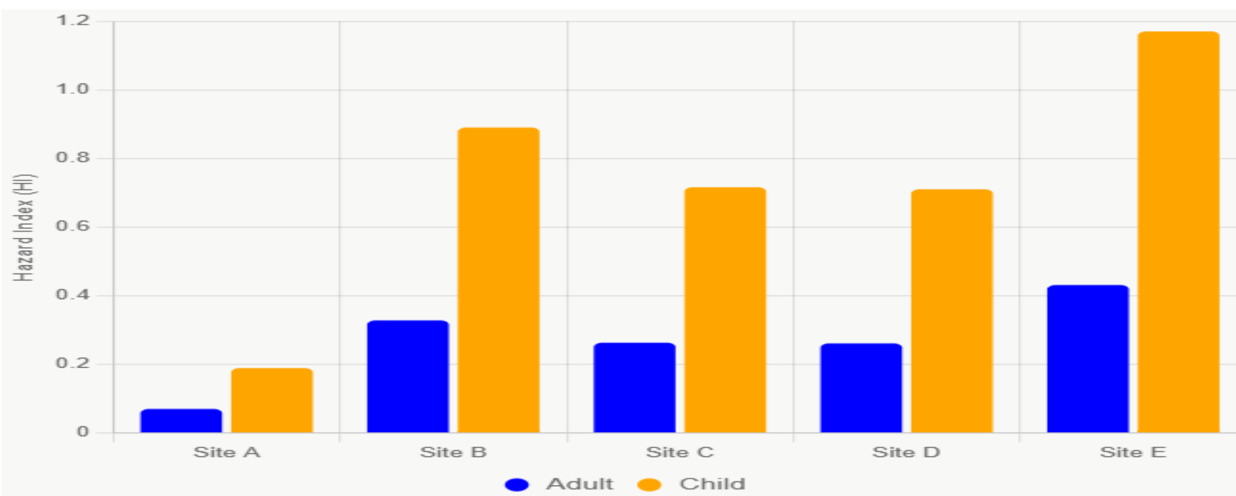

Figure 4: Hazard Index (HI) for adult and children across sampling sites

Carcinogenic Risk Assessment
The estimates of total cancer risk and incremental lifetime cancer risk are listed in Table 5. At several places the cancer risk values due to arsenic exceeded permissible limits especially for children. Surface waters in Nigeria and other West African countries have also been associated with similar elevated cancer risks upon ingestion of As (Duncan *et al.*, 2018; Ombugus *et al.*, 2021). TCR level ($1.12×10^{-3}$) appeared relatively higher among children in Site B, indicating a significant long-term risk

Table 5. Incremental Lifetime Cancer Risk (ILCR) and Total Cancer Risk (TCR).

Site	ILCR Cr (Ad)	ILCR Cd (Ad)	ILCR As (Ad)	ILCR Pb (Ad)	TCR (Adult)	ILCR Cr (Ch)	ILCR Cd (Ch)	ILCR As (Ch)	ILCR Pb (Ch)	TCR (Child)
A	0.00	2.26×10^{-4}	0.00	1.01×10^{-6}	**2.27×10^{-4}**	0.00	6.13×10^{-4}	0.00	2.74×10^{-6}	**6.16×10^{-4}**
B	1.63×10^{-5}	2.94×10^{-4}	1.19×10^{-4}	1.39×10^{-7}	**4.29×10^{-4}**	4.43×10^{-5}	7.98×10^{-4}	3.24×10^{-4}	3.82×10^{-7}	**1.12×10^{-3}**
C	1.83×10^{-5}	2.41×10^{-4}	8.97×10^{-5}	3.89×10^{-7}	**3.71×10^{-4}**	4.98×10^{-5}	6.56×10^{-4}	2.45×10^{-4}	1.06×10^{-6}	**9.52×10^{-4}**
D	2.17×10^{-5}	1.19×10^{-4}	9.80×10^{-5}	2.96×10^{-7}	**2.36×10^{-4}**	5.90×10^{-5}	3.24×10^{-4}	2.67×10^{-4}	8.10×10^{-7}	**6.61×10^{-4}**
E	1.25×10^{-4}	7.04×10^{-5}	1.45×10^{-4}	4.73×10^{-7}	**3.46×10^{-4}**	3.38×10^{-4}	1.89×10^{-4}	3.95×10^{-4}	1.29×10^{-6}	**9.29×10^{-4}**

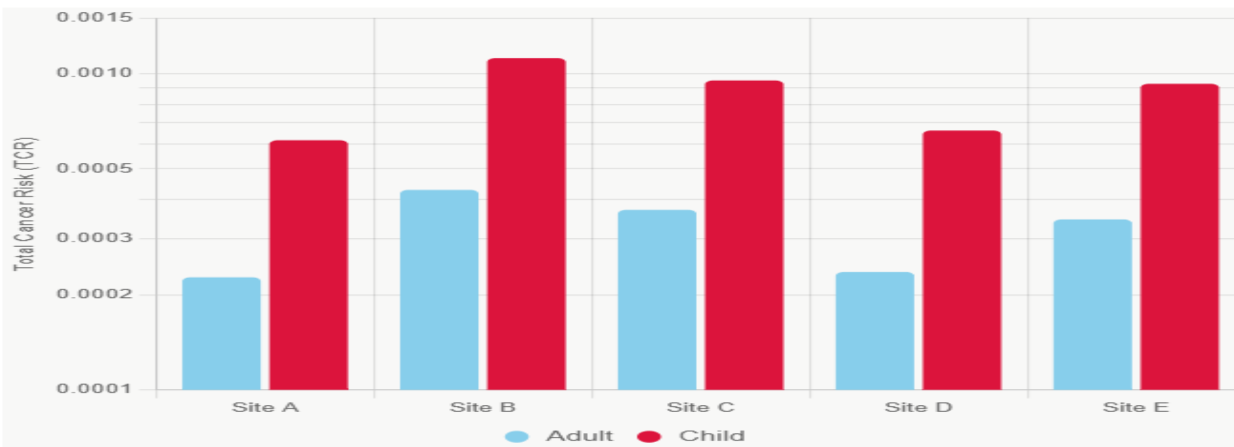

Figure 5: Total Cancer Risk (TCR) for adults and children

CONCLUSION

The surface water quality of the Gitata River in Nasarawa State was analyzed for physicochemical parameters and heavy metal health risks. Except for a few exceptions the downstream sites exhibited higher levels of As and Cd, although all other physicochemical parameters were within WHO prescribed limits. Children were at greater risk than adults, based on health risk assessments, with non-carcinogenic risks (HI) and carcinogenic (TCR) exceeding safe limit in some collection points. In order to protect public health in the study area, these results highlight an urgent need for more frequent environmental monitoring, improved regulation for mining operations, and supply of safer alternative water sources.

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