International Research Journal of Environmental Sciences ISSN 2319–1414
Vol. **13(1),** 1-9, January **(2024)** *Int. Res. J. Environmental Sci.*

Assessment of children and adult health risk factors associated with using portable water from the river Benue at Makurdi

Utor S.O.[1], Enokela O.S.[2*] and Awulu J.O.[2]
[1]LoS Water Engineering Nig Ltd, Suit DO5 J-Pius Plaza, 38 Jimmy Carter Street Asokoro Abuja, Nigeria
[2]Joseph Sanwuan Tarka University Makurdi, Nigeria
enokladish@gmail.com

Available online at: www.isca.in, www.isca.me
Received 11th October 2021, revised 13th September 2023, accepted 20th December 2023

Abstract

The non-carcinogenic and carcinogenic risk posed to children and adults by Cadmium, Nickel, Zinc and Lead concentration in River Benue water were evaluated in this study. Sampling for the metals was conducted on three locations in transect of north bank, middle stream and south bank making a total of nine stations. These metals were estimated as hazard index (HI) which took into account the combined effects from the heavy metals via the oral and dermal exposure pathways. It was found that the HI for children and adults via the injection pathway exceeded the safe limits in 100% of the sampling stations and was highest in ST3. For the dermal pathway, the HI was similar for both children and adults with highest in ST2 - ST3 and found to exceed the safe limit in 33.37% of all location chosen in this study. The lifetime cancer risk (CR) by ingestion of the water with respect to carcinogenic Pb and Cd were found to be high in all the sampling stations for both children and adults, while it did not pose any cancer risk by dermal pathways in children and adults in all sampling stations. It can be concluded that the river Benue water at Makurdi is polluted due to unregulated agricultural and commercial activities on the river banks. People using the water are exposed to both non-carcinogenic and carcinogenic risk.

Keywords: River Benue water, heavy metals, hazard index, health risk, children and adults.

Introduction

Sources of river water pollution are numerous; some originates from human activities like draining of sewerage, dumping of wastes and recreational centers while others can come from natural sources. Water pollution is primarily caused by runoff from agricultural fields, industrial centers and urban centers[1]. Runoff transports harmful, contaminants or unnatural chemicals substances that ultimately destroy the water therein. Agricultural runoff carry transports toxins found in pesticides and herbicides, urban runoff transport large amount of organic waste and industrial runoff often contains high amount of chemical toxins and residues. Any of these toxins entering a water source can cause multiple health challenges. This results to the spreading of dangerous diseases and potential premature death of human and other animal.

Pollution of river environment by heavy metals is a growing problem worldwide and currently it has reached an alarming rate[2]. There are numerous sources of heavy metals; some originates from human activities like draining of sewerage, dumping of Hospital wastes and recreational activities[3]. Conversely, metals also occur in small amounts naturally and may enter into river system through leaching of rocks, airborne dust, forest fires and vegetation. They are not degradable but are continuously being deposited and incorporated in water, thus causing pollution in river water bodies. The presence of heavy metals in the river water may have a profound effect on the microalgae which constitute the main food source for bivalve mollusks in all their growth stages, zooplankton (rotifers, copepods, and brine shrimps) and for larval stages of some crustacean and fish species[4]. Moreover, their bio-concentration and magnification could lead to high toxicity in organisms, even when the exposure level is low. Under such conditions, the toxicity of a moderately toxic metal could be enhanced by synergism and fish population may decline. Apart from destabilizing the ecosystem, the accumulation of these toxic metals in aquatic food web is a threat to public health and thus their potential long term impact on ecosystem integrity cannot be ignored[4]. Assessment of health risk in children and adults is a verified method that has been adopted extensively for the evaluation of potential hazards on human after being exposed to certain chemicals over a period[5]. The assessment is a function of hazard and exposure time and it is defined as the process of estimating the probability of occurrence of an event and the probable magnitude of adverse health effects on human exposures to environmental hazards over a specified period[6]. Different pathways have been identified through which humans can be exposed to chemical risk. They include inhalation, dermal and ingestion pathways. However, this study considered the dermal and ingestion pathways only because of the unavailability of the transfer efficiency of cadmium and lead from water to air and its inhalation reference dose. Furthermore, inhalation was not considered as a major exposure route for the metals as posited by National Academy of Science [7].

The River Benue: River Benue originates from Cameroonian mountains and flow westwards through Makurdi to meet the River Niger at Lokoja in Kogi State of Nigeria. At the reach of Makurdi, the river is 1.194Km wide with average depth and cross sectional area of 7.82m and 4608.42m^2 respectively. The valley bottom of the river is covered with meta sediments consisting of land area below 300m above sea level. The flood plain is characterized by extensive swamps that are good for dry season irrigated farming. The river provides natural water and sand in commercial quantities to the environs.

Water from River Benue is used for domestic, industrial and agricultural purposes to supplement the existing surface water source in areas not covered by the current distribution network[8]. Incidences of water related diseases in Makurdi and environs are on rampage hence the need to study its raw water quality parameters in terms of cacogenic and non- cacogenic health risk effects on children and adults.

At the reach of Makurdi, the river is subjected to various sources of pollution such as; Industrial effluents channeled directly into river without treatment; wastes from markets and abattoir are washed into the river; faeces from humans defecating directly in the river; animal and human wastes washed from land to the river as well as fertilizers and other chemicals applied to the crops that are usually grown at the river banks[9].

Methodology

Sampling method: Thirty six (36) samples of raw water from the river were collected across the stretch (North bank-Middle stream-South bank) in transect and along the length (Ahum-Wurukum-Wadata) monthly from August – November, 2020 by grab method[10]. The sampling points were selected based on point source, non-point source pollution from land use classification. Samples were collected in sterilized sample bottles, labeled and preserved to the laboratory; temperature, pH, turbidity, total dissolved solids and conductivity were determined in-situ at the pint of collection.

Laboratory analysis: The presences of Cadmium, Lead, Nickel, Zinc, Sodium, Potassium and Magnesium were determined through the use of an Atomic Adsorption Spectrophotometer (PG 990 AAS) in accordance with the method described by Akinbili C.O. et al.[11] and Radojevic, M., & Bashkin, V.N.[12] at the National Research Institute for Chemical Technology (NARICT), Zaria.

Analytical process: The average daily dose (ADD) parameter for the intake of the heavy metals under study was calculated for both mode of transmissions for children and adult population using Equation (1) and (2) in accordance with USEPA[13] methods.

$$ADD/CDI_{Ingestion} = \frac{C \times IR \times ED \times EF}{BW \times AT} \qquad (1)$$

$$ADD/CDI_{Dermal} = \frac{C \times dAF \times SkA \times AdF \times EpT \times uCF \times ED \times EF}{BW \times AT} \qquad (2)$$

Where; *ADD/CDI* is the exposure duration (mg/kg-day) for either ingestion or dermal mode of transmission, *C* is the concentration of the contaminant in stream water (mg/l), *IR* is the ingestion rate per unit time (L/day), *ED* is the exposure duration (years), *EF* is the exposure frequency (days/year), *BW* is body weight (kg), *AT* is the average time (years), *dAF* is dermal adsorption fraction, *SkA* is the skin exposure area (cm^2), *AdF* is the adherence factor of the heavy metal (mg cm^2), *EpT* is the exposure time (hours/day), and *uCf* is termed the unit conversion factor (kg/mg).

The principal factors for the risk assessment calculations were adopted from[12] and are as shown in Table-1 and 2. In addition, the cancer risks assessment was estimated for adult and children to determine the propensity of the metal causing cancer while other health risk indices like Non-carcinogenic toxicity (hazard quotient or HQ) which measures the non-carcinogenic risk of an individual metal and the hazard index (HI) were used to estimate the non-carcinogenic risk effects for both children and adult. The indices or models were used to estimate the risk at the different exposure types as shown in Equation (3) to (5).

Similarly, the possibility of developing cancer as well as the non-carcinogenic risk exposed to children and adults through dermal and ingestion over their life time was estimated by prorating the exposure incurred over the exposure duration, over the expected life span. HQ and HI values were estimated with Equation (3) and (4)[5,19-20] and represented the HQ for the combined heavy metals concentration. HQ and HI values revealed absence and presence of hearth risk when less than or greater than 1, respectively[5, 20].

$$HQ_{Ingestion/Dermal} = \frac{CDI_{Ingestion/Dermal}}{RfD_{Ingestion/Dermal}} \qquad (3)$$

$$HI = \sum HQ_i \qquad (4)$$

Where: ADD/CDI (ingestion/dermal) is the average daily doses or chronic daily intake (mg/kg/day) and CSF is the cancer slope factor (mg/kg/day)$^{-1}$. The Cancer risk was calculated as outlined by Wongsasuluk P et al.[6].

$$\text{Cancer Risk} = \text{CDI} \times \text{CSF} \qquad (5)$$

Results and discussion

The mean station concentrations of heavy metals in the water samples were very high, while those of the trace metals were found to be low. The concentration (mg/L) of Cadmium, Lead, Nickel, Zinc, Sodium, Potassium and Magnesium ranged from 0.026 - 0.077, 0.043 - 2.19, 0.0098 - 0.028, 0.087 - 0.140, 9.31 - 21.31, 2.01-3.95 and 3.62-6.89 respectively.

The highest/ lowest ratio were recorded in stations 3/7, 1/2, 3/4, 2/9, 9/3, 6/2, and 9/1 respectively (Table-3 and Figure-1). It was generally observed that high values of metals in the water samples were more prevalent in stations 3, 9, 1, 2 and 6 as compared to the other stations; a trend which can be related to the land use activities around the stations.

Table-1: Oral Reference Dose and Slope Factor for Heavy Metals[14,27].

Metal	Rf $D_{Ingestion}$ (mg/kg/day)	Rf D_{Dermal} (mg/kg/day)	Oral SF (mg/kg-day)
Ni	0.02	NA	NA
Zn	0.3	NA	NA
Pb	0.0035	NA	0.0085
Cd	0.035	NA	0.085

Table-2: Parameters used to determine the ADD for both modes of transmission and Computation of HQ values[14].

Input Parameter	Abbreviation	Unit	Value	Reference
Body Weight (Adult)	BW	Kg	70	15
Body Weight (Children)	BW	Kg	15	15
Ingestion Rate (Adult)	IR	L/day	3.7	16
Ingestion Rate (Children)	IR	L/day	1.7	16
Average Time	AT	Days	ED × 365	5
Exposure Frequency	EF	Days/Year	365	5
Exposure Duration (Adult)	ED	Years	30	17
Exposure Duration (Children)	ED	Years	6	17
Skin Exposure Area	SkA	cm^2	5700	18
Unit Conversion Factor	Ucf	kg/mg	10^{-6}	17
Adherence Factor	AdF	mg/cm^2	0.07	18
Dermal Absorption Factor	dAF	----	0.03	18

Table-3: Metal Concentration of River Benue Water. All parameters are in mg/L.

Parameter	Minimum	Maximum	Mean ±S.D	WHO Limit	% Violation/ Compliance
Potassium	1.30	6.86	2.95 ±1.55	10	0/100
Sodium	2.80	38.80	14.74 ±12.03	200	0/100
Lead	0.00	0.846	0.34 ±1.40	0.01	72.2/27.8
Nickel	0.00	0.06	0.019 ±0.02	0.02	44.4/55.6
Cadmium	0.01	0.13	0.049 ±0.039	0.01	75.0/25.0
Zinc	0.01	0.34	0.10 ±0.07	0.05	75.0/25.0
Magnesium	0.05	14.01	5.28 ±5.22	50	0/100

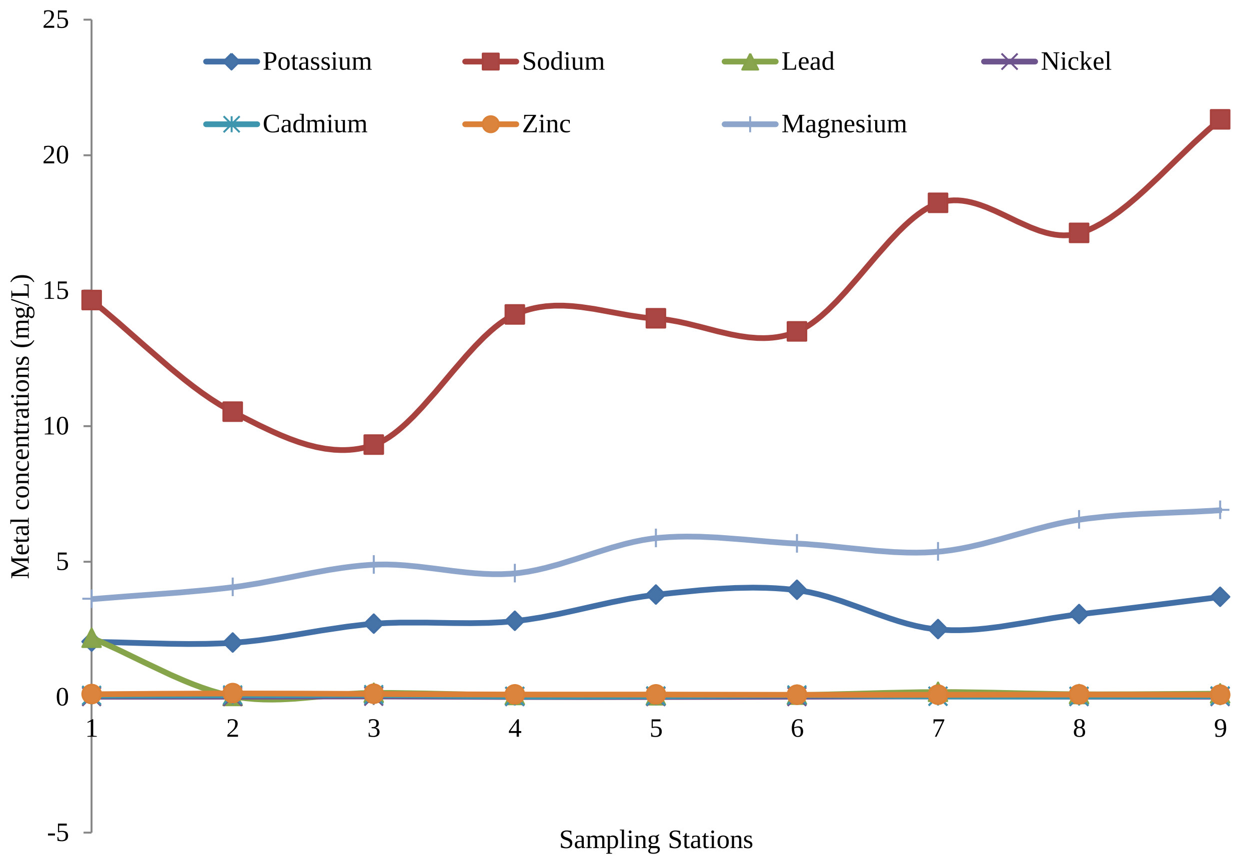

Figure-1: Locational /station mean concentrations of metal in River Benue water.

On the other hand, the concentrations of K, Na, Pb, Ni, Cd, Zn and Mg in mg/L were found to range from 1.30 - 6.86, 2.80 - 38.80, 0.00 - 8.46, 0.00 - 0.06, 0.01 - 0.13, 0.01 - 0.34 and 0.05 - 14.01 with mean ± S.D. values of 2.95 ± 1.55, 14.74 ± 12.03, 0.33 ± 1.40, 0.019 ± 0.02, 0.049 ± 0.039, 0.10 ± 0.07 and 5.28 ± 5.22 respectively.

On the contrary, it was noticed that about 72.2, 44.4, 75.0, 75.0 % of the water samples had Pb, Ni, Cd, Zn concentrations that violated the WHO stipulated limits of 5 NTU, 0.02, 0.01, 0.05 and 0.7 mg/L respectively. This group of parameters was observed to be responsible for the overall poor quality of river Benue water and are also of great concern for human health as most of these parameters are reported to be carcinogenic if consumed in excess of the stipulated limits.

Children and Adult exposures Analysis: Concentrations of pollutants in water were used to assess children and adults exposure through injection and dermal. In Makurdi, the calculated chronic daily intake ($CDI_{ingestion}$) values for consumption of water by adults suggest that, people have consumed surface water contaminated with heavy metals nutrients and other pollutants, the maximum CDI values were as contained in Table-4 and Table-5 for children and adults respectively. CDI indices in the water were found in the order of Pb>Zn > Cd>Ni. In drinking water, the high CDI values of Zn, Mn and Pb may be attributed to the Pb–Zn sulfide mineralization, while that of Cr and Ni may have resulted from the mafic and ultramafic bed rocks hosting chromite deposits as supported from Miller D.J. et al.[21] and Ashraf, M. and Hussian, S.S.[22].

The Non-carcinogenic toxicity (hazard quotient or HQ**)** from the results indicated that, Zn had HQ value greater than 1 for Adult while the values for other metals were ranged from 0.1 to 1.4 which is within the reported range by Schmitt C. et al.[23]. In this study, although the observed values of HQ for Pb, Cd, Ni, Cu were lower than the safe standard of 1, but that of Zn and ΣHQ of these metals (HI) were higher than 1. The calculated HI (0.88 and 2.81) for children and adult indicates that adults are in the risk level while children are in safe level. The total HI resulting from exposure to metals through water ranged from 0.00 – 0.008 to 0.66 for adults. In children, HI levels decreased between 0.00 and 0.003 respectively this is in deviance from the report of Renato I.S. et al.[24] that indicated higher risk in children than in adult. Non-cancer risk were associated with the metals although[24] revealed that the presence of natural occurring element, may also be attributed to anthropogenic activities, such as the use of herbicides[25].

Table-4: Exposures analysis for children.

WQI	Concentration	$ADD/CDI_{Ingestion}$	ADD/CDI_{Dermal}	$HQ_{Ingestion/Dermal}$
Temperature	26.62	0.612	7.081×10^{-7}	NA
pH	7.57	0.174	2.012×10^{-7}	NA
Elect. Cond	47.09	1.083	1.253×10^{-7}	NA
TDS	29.90	0.688	7.953×10^{-8}	NA
Turbidity	221.31	5.090	5.887×10^{-6}	NA
Potassium	2.95	0.068	7.85×10^{-7}	NA
Sodium	14.74	0.339	3.921×10^{-8}	NA
Lead	0.34	0.008	0.94×10^{-8}	0.026
Nickel	0.019	0.000	0.05×10^{-0}	0.00
Cadmium	0.049	0.001	0.13×10^{-8}	0.285
Zinc	0.10	0.002	0.27×10^{-8}	0.57
Magnesium	5.28	0.121	1.405×10^{-7}	NA
Phosphate	1.24	0.029	3.30×10^{-8}	NA
Ammonium	0.07	0.002	0.19×10^{-8}	NA
Nitrate	17.13	0.394	4.557×10^{-7}	NA
$HI = \sum HQ_i$				0.881

Table-5: Exposures analysis for Adult.

WQI	Concentration	$ADD/CDI_{Ingestion}$	ADD/CDI_{Dermal}	$HQ_{Ingestion/Dermal}$
Temperature	26.62	1.384	3.54×10^{-7}	NA
pH	7.57	0.39	1.00×10^{-7}	NA
Elect. Cond	47.09	2.448	6.26×10^{-7}	NA
TDS	29.90	1.554	3.97×10^{-7}	NA
Turbidity	221.31	11.058	2.94×10^{-6}	NA
Potassium	2.95	0.153	3.82×10^{-8}	NA
Sodium	14.74	0.766	1.96×10^{-7}	NA
Lead	0.34	0.017	0.45×10^{-8}	0.056
Nickel	0.019	0.000	0.55×10^{-9}	0.00
Cadmium	0.049	0.003	0.65×10^{-9}	0.85
Zinc	0.10	0.005	0.13×10^{-8}	1.43
Magnesium	5.28	0.275	7.02×10^{-8}	NA
Phosphate	1.24	0.064	1.65×10^{-8}	NA
Ammonium	0.07	0.004	0.9×10^{-9}	NA
Nitrate	17.13	0.890	2.27×10^{-7}	NA
$HI = \sum HQ_i$				2.81

Discussion: Children and Adult Health Risk Analysis (CAHRA): The USEPA human health risk assessment methodology was adopted and utilized in the computation of the risk posed to humans by heavy metals in river Benue water via the oral and dermal exposure pathways. Non-carcinogenic risks in terms of HQ were computed for; Cd, Pb. Ni and Zn for the nine sampling station. HQ via the ingestion route ($HQ_{ingestion}$) for Cd ranged from 2.97 – 8.36 for children and 1.27 – 3.59 for adults with the lowest and highest values occurring at ST8 and ST2 respectively. Similarly, those for Pb were found to range from 1.29 – 5.43 for children and 0.48 – 2.33 for adults, with the lowest and highest values observed at ST5 and ST1 respectively. Those for Ni ranged from 0.05 – 0.09 for children and 0.02 – 0.04 for adults, with the lowest and highest figures found for ST1, ST5 and ST3, ST7, ST8 respectively. The $HQ_{ingestion}$ for Zn ranged from 0.019 – 0.026 for children and 0.0083 – 0.011 for adults with lower values occurring at ST9, while higher values were obtained at ST3. Generally heavy metal content in the studied river were found to pose great health concerns for both children and adults as the $HQ_{ingestion}$ values exceeded the threshold value of 1 in 100 and 66.7 % of sample locations for Cd and Pb respectively. However the $HQ_{ingestion}$ for Ni and Zn were observed to be below the acceptable limits for both children and adults. Thus the $HQ_{ingestion}$ was found to be in the order of Cd >Pb> Ni > Zn.

Similarly, for the dermal exposure route the HQ_{dermal} values were only of concern for Cd as it was found to exceed the threshold in 7.69 % of the samples for children and adults especially at ST2, ST3 and ST7. All other heavy metal did not pose any adverse non-carcinogenic risk to humans. Thus it was evident that the consumption of river Benue water in its current form without adequate treatment is of great health implications to the various age categories that indulge in such practices in the study area and must be avoided. The use of the water for recreation is only prohibitive at the sampling stations (ST2, ST3 and ST7) where elevated concentrations of Cd and Pb were recorded. High concentrations of Cd and Pb at these locations were ascribed to the excessive washing of fertilizers, herbicides and leachates into the river from diffuse sources around these locations.

Result of the CAHRA is presented in Table-6 for the non-carcinogenic Hazard Index (HI) considering four heavy metals (Zn, Cd, Pb and Ni) for the nine (9) sampling stations considered in this study. Similarly, the result for the lifetime carcinogenic risk considering Pb and Cd is presented in Table-7 for all sampling stations.

Children and Adult Hazard Assessment: Furthermore the Hazard Index (HI), which is an aggregation of the various HQ from individual heavy metals were also computed to provide a more holistic appraisal of the water quality with regard to the non-carcinogenic human health concerns. These were also computed separately for children and adults, while considering the ingestion and dermal pathways in each case. It was observed that the $HI_{ingestion}$ for children ranged from 4.44 – 10.69 and from 1.82 – 4.58 for adults (Table-6). In each case the lowest values were obtained from ST5, while the highest values were gotten for ST3. As earlier stated Cd and Pb were the major contributors to the HI values of the water at these locations. These very high $HI_{ingestion}$ values are of great adverse health implications for the various age categories in the study area that use the water for drinking purposes as earlier presented from the WQI analysis. On the other hand, the HI_{dermal} was same for both children and adults in all sampling locations and exceeded the threshold value of 1 in 33.3 % of the samples in both the case of children and adults. This exceedance was principally seen in ST2, ST3 and ST6. Thus it would be apt to infer that at the reach of Makurdi water from river Benue is unsuitable for both drinking and recreational purposes especially at Sampling Stations 2, 3 and 6.

Table-6: Non-Carcinogenic Hazard Index (HI) for All Sampling Stations.

Station	Axial Location	$HI_{Ingestion}$		HI_{Dermal}	
		Children	Adult	Children	Adult
Abua	ST1	10.34	4.43	0.74	0.74
	ST2	9.33	4.00	1.29	1.29
	ST3	10.69	4.58	1.18	1.18
Wurukum	ST4	5.77	2.48	0.67	0.67
	ST5	4.44	1.82	0.47	0.47
	ST6	8.25	3.50	1.02	1.02
Wadata	ST7	6.96	2.91	0.47	0.47
	ST8	5.20	2.23	0.47	0.47
	ST9	6.42	2.76	0.62	0.62

Table-7: Lifetime Cancer Risk (CR) for All Sampling Stations.

Station	Axial Location	$CR_{Ingestion}$		CR_{Dermal}	
		Children	Adult	Children	Adult
Abua	ST1	0.036	0.015	1.0×10^{-4}	1.0×10^{-4}
	ST2	0.018	0.007	1.2×10^{-4}	1.2×10^{-4}
	ST3	0.027	0.012	1.4×10^{-4}	1.4×10^{-4}
Wurukum	ST4	0.013	0.006	6.6×10^{-5}	6.6×10^{-5}
	ST5	0.012	0.005	4.8×10^{-5}	4.8×10^{-5}
	ST6	0.019	0.008	1.0×10^{-4}	1.0×10^{-4}
Wadata	ST7	0.024	0.010	5.7×10^{-5}	5.7×10^{-5}
	ST8	0.015	0.007	5.7×10^{-5}	5.7×10^{-5}
	ST9	0.019	0.008	8.6×10^{-5}	8.6×10^{-5}

$\text{Cancer Risk} = \text{CDI} \times \text{CSF}$

The lifetime cancer risk (CR) posed by heavy metals in river Benue water via the oral and dermal pathways for children and adults were computed with respect to only Cd and Pb. It was found that the $CR_{ingestion}$ for children ranged from 0.012 – 0.036, while the $CR_{ingestion}$ for adults ranged from 0.005 – 0.015 with the lowest and highest risk seen in ST5 and ST1 respectively in each case. The $CR_{ingestion}$ values obtained signify that 100% of the sampling locations pose cancer risk to humans that uses river Benue water for drinking purposes as all locational values exceeded the allowable limit of 10^{-6} to 10^{-4}. More significantly, the $CR_{ingestion}$ was found to be higher in children than in adults, which was in conformity with an earlier report from Taiyuan, China [26] but contradictory with the reports from Southwest, Nigeria[19].

For the dermal pathway, the CR_{dermal} indicated that it ranged from 4.8×10^{-5} - 1.4×10^{-4} for both children and adults and were found to be within the acceptable limits for no cancer threat in all the 9 locations considered in this study. This signifies that bathing/recreational activities with this water would not be of any significant health threats with regard to cancer for all age categories in the area. This finding was in tandem with those of Emenike C.P; et al.[19] and those of Duggal, V. and Rani, A.[27] who documented similar evidence in their separate studies.

Conclusion

The assessment children and adults health risk factors of river Benue water at Makurdi was undertaken in the current study. Spatial variations of the water quality from nine (9) sampling stations violated the set limits by 5.5, 100, 72.2, 44.4, 75.0, 75.0 and 77.8% for pH, turbidity, Pb, Ni, Cd, and Zn. The overall Water Quality Index (WQI) value of the river was obtained to be 388.78 which classified the water to be unfit for drinking purposes. Furthermore, Pb, Cd and turbidity were among the contaminants contributing to the overall poor quality of the river. Among the heavy metals, Zn was observed to display moderate positive relationships with pH, EC, TDS, turbidity, Na, K and Cd, which shows its sources were from both anthropogenic and natural processes.

Non-carcinogenic risk posed to children and adults by heavy metals was estimated as the hazard index (HI) which took into account the combined effects from the four heavy metals (Zn, Ni, Cd and Pb) on both children and adults via the injection and dermal exposure pathways. It was found that the HI for children was higher than that of adults via the injection exposure pathways. The HI for both children and adult exceeded the safe limits in 100% of the sampling stations and was highest in ST3. For the dermal pathway, the HI was similar for both children and adults with highest in ST2 - ST3 and found to exceed the safe limit in 33.37% of all location chosen in this study. The lifetime cancer risk (CR) for ingestion of the water with regard to the carcinogenic heavy metals (Pb and Cd) was found to be high in all the sampling stations for both children and adults, while it did not pose any cancer risk considering the dermal exposure pathways for both children and adults in all sampling stations.

In conclusion, river Benue water at reach of Makurdi is polluted from influence of unregulated agricultural and commercial activities. Children and adults using water from the river are being exposed to both non-carcinogenic and carcinogenic risk.

Recommendations: From the findings of this research, the water quality of river Benue at the reach of Makurdi is not suitable for drinking because pollutant were observed to be above the referenced values set by the world health organization. Hence, the following recommendations are made: i. Waste management techniques should be adopted at domestic, industrial and commercial sources to help in reducing pollution tendencies. ii. Waste analysis/treatment policy should be implemented to meet minimum standards before discharging into the river to mitigate chemical pollution. iii. Regular water assessment and public enlightenment campaign should be intensified to educate the people on the dangers associated with the use of untreated water from the river for drinking and recreational purposes. iv. As earlier suggested by Aguoru C.U. and Alu C.A.[28] the agency responsible for solid waste management (BENSESA) and Private Waste Managers in Makurdi should be properly provided with enough equipment, qualified personnel and funds for more effective and efficient service delivery.

References

1. Schnoor J.L. (2014). Water Quality and Sustainability. In: Ahuja S. (ed.) Comprehensive Water Quality and Purification. 4, 427–449

2. Hussain, J., Husain, I. and Arif, M. (2017). Studies on heavy metal contamination in Godavari river basin. *Appl Water Sci.*, 7, 4539–4548. https://doi.org/10.1007/s13201-017-0607-4

3. Ruqia N, Muslim K, Muhammad M, et al. (2017). Accumulation of Heavy Metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water Collected from Tanda Dam kohat. *J. Pharm. Sci. & Res*., 7(3), 89–97.

4. Ogoyi D.O, C.J. Mwita, E.K. Ngu and P.M. Shiundu. (2011). Determination of Heavy Metal Content in Water, Sediment and Microalgae from Lake Victoria, East Africa. *The Open Environmental Engineering J.*, 4(1), 156–161.

5. United States. Environmental Protection Agency. Office of Emergency, & Remedial Response. (1989). Risk Assessment Guidance for Superfund: pt. A. Human health evaluation manual (Vol. 1). Office of Emergency and Remedial Response, US Environmental Protection Agency.

6. Wongsasuluk P, Chotpantarat S, Siriwong W, et al. (2014). Heavy metal contamination and human health risk assessment in drinking water from shallow groundwater wells in an agricultural area in Ubon Ratchathani province, Thailand. *Environ Geochem Health*, 36(1), 169–182.

7. NRC, U. (2006). Fluoride in drinking water. A scientific review of EPA's standards. National Research Council, Committee on Fluoride in Drinking Water. Measures of Exposure to Fluoride in the United States. The National Academies Press, Washington, DC.

8. Anhwange, B. A., Agbaji, E. B., & Gimba, E. C. (2012). Impact assessment of human activities and seasonal variation on River Benue, within Makurdi Metropolis. International journal of Science and Technology, 2(5), 248-254.

9. Madison, R. J., & Brunett, J. O. (1985). Overview of the occurrence of nitrate in groundwater of the United States. US Geological Survey water supply paper, 2275, 93-105.

10. US Environmental Protection Agency. (2001). Trace elements in water, solids, and biosolids by inductively coupled plasma-atomic emission spectrometry.

11. Akinbili C.O; Suffian Y,M; Talib S,H,A, et al. (2013). Qualitative analysis and classification of surface water in Bukit Merah Reservoir in Malaysia. *Water Science & Technology Water Supply*., 13(4), 1138-1145 DOI:10.2166/ws.2013.104

12. Radojevic, M., & Bashkin, V.N. (2020). Practical Environmental Analysis. Science Park, Cambridge, UK: Royal School of Chemistry, Thomas Graham House. 645 p.

13. Telliard, W. A. (1996). Sampling ambient waters for trace metals at EPA water quality criteria levels, US EPA method 1669. Washington, DC.

14. Emenike, C. P., Tenebe, I. T., & Jarvis, P. (2018). Fluoride contamination in groundwater sources in Southwestern Nigeria: Assessment using multivariate statistical approach and human health risk. Ecotoxicology and environmental safety, 156, 391-402.

15. USEPA (1991). Methods for the Determination of Metals in Environmental Samples. U.S. Environmental Protection Agency, Washington, D.C.. epa/600/4-91/010 (ntis pb9123 1498).

16. Van Graan, L. A., Lemieux, L., & Chaudhary, U. J. (2013). Scalp and intracranial EEG-fMRI in epilepsy. J. Neurol. Neurophysiol, 4, 1-9.

17. U.S. EPA. Draft action plan: Development of a framework for metals assessment and guidance for characterizing metals. 2002. EPA/630/P-02/003A. Washington, DC.

18. USEPA (United States Environmental Protection Agency) Exposure factors Handbook 2011 edition (Final). Washington, DC, USA: Office of Emergency and Remedial

19. Emenike, P. C., Nnaji, C. C., & Tenebe, I. T. (2018). Assessment of geospatial and hydrochemical interactions of groundwater quality, southwestern Nigeria. Environmental monitoring and assessment, 190, 1-17.

20. Su, K., Zhou, Y., Wu, H., Shi, C., & Zhou, L. (2017). An analytical method for groundwater inflow into a drained circular tunnel. Groundwater, 55(5), 712-721.

21. Miller, D. J., Loucks, R. R., & Ashraf, M. (1991). Platinum-group element mineralization in the Jijal layered ultramafic-mafic complex, Pakistani Himalayas. Economic Geology, 86(5), 1093-1102.

22. Ashraf, M., Hussian, S.S., 1982. Chromite occurrencein Indus suture ophioliteof 311 Jijal,Kohistan Pakistan. In: Sinha, K.A. (Ed.), Contemporary GeoscientificResearchesin Himalaya, Dehra Dun, India, pp. 129–131

23. Schmitt, C. J., Brumbaugh, W. G., Linder, G. L., & Hinck, J. E. (2006). A screening-level assessment of lead, cadmium, and zinc in fish and crayfish from Northeastern Oklahoma, USA. Environmental Geochemistry and Health, 28, 445-471.

24. Alves, R. I., Sampaio, C. F., Nadal, M., Schuhmacher, M., Domingo, J. L., & Segura-Muñoz, S. I. (2014). Metal concentrations in surface water and sediments from Pardo River, Brazil: human health risks. Environmental research, 133, 149-155.

25. Christodoulidou, M., Charalambous, C., Aletrari, M., Kanari, P. N., Petronda, A., & Ward, N. I. (2012). Arsenic concentrations in groundwaters of Cyprus. Journal of Hydrology, 468, 94-100.

26. Duan, B., Zhang, W., Zheng, H., Wu, C., Zhang, Q., & Bu, Y. (2017). Comparison of health risk assessments of heavy metals and as in sewage sludge from wastewater treatment plants (WWTPs) for adults and children in the urban district of Taiyuan, China. International Journal of Environmental Research and Public Health, 14(10), 1194.

27. Duggal, V., & Rani, A. (2018). Carcinogenic and non-carcinogenic risk assessment of metals in groundwater via ingestion and dermal absorption pathways for children and adults in Malwa Region of Punjab. Journal of the Geological Society of India, 92(2), 187-194.

28. Aguoru, C. U., & Alu, C. A. (2015). Studies on Solid Waste Disposal and Management Methods in Makurdi and its Environs North Central Nigeria. Greener Journal of Environmental Management and Public Safety, 4(2), 019-027.