ChemSearch Journal 13(2): 41 – 51, December, 2022
Publication of Chemical Society of Nigeria, Kano Chapter

Received: 29/08/2022 Accepted: 21/09/2022
http://www.ajol.info/index.php/csj

Health Risk Assessment of some Heavy Metals and Nitrate in Surface Water of River Kaduna, Nigeria

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ABSTRACT

Surface water, which is the most available source of water used for domestic purposes, is greatly impacted by various pollutants with serious health risks to the human population. In this study, health risk assessment of some metals (Cu, Cd, Cr, Zn, Pb, and Fe) and NO_3^- in River Kaduna was carried out by calculating the chronic daily intake (CDI), hazard quotient (HQ), hazard index (HI) and carcinogenic risk (CR), while statistical analysis was carried out using correlation, cluster analysis, and principal component analysis (PCA). The mean concentrations of the pollutants were in the following decreasing order: Fe > NO_3^-> Pb > Cr > Cu > Cd > Zn. Cluster analysis identified four distinct clusters namely (1) Pb and Fe, (2) Nitrate, (3) Cu, Cr, and Cd, and (4) Zn, while PCA yielded 3 components which explained 78.83 % of the total variance in the data set. Cu, Zn, and NO_3^- did not constitute a non-carcinogenic risk to the population through oral and dermal contacts (HQ < 1), while Cd, Cr, Pb, and Fe posed varying degrees of non-carcinogenic risks. The percentage contribution of each of the pollutants to the total non-carcinogenic risk is in the following order: Pb > Cr > Cd > Fe > Cu > NO_3^- > Zn. While Pb, Cr, and Cd are the major contributors to total non-carcinogenic risk and accounted for 96.27 % of the total risk, CR due to Pb, Cr, and Cd also exceeded the threshold, suggesting that lifetime exposure to these metals poses a cancer risk to the adult population in the area. The study showed that Cd, Cr, and Pb pollution in River Kaduna poses both non-carcinogenic and carcinogenic risks to the population.

Keywords: Carcinogenic risk, Health risk, Heavy metals, Nitrate, Toxicity, Water

INTRODUCTION

Due to the increasing trend of urbanization and industrialization, environmental pollution is also increasingly becoming a major global problem. This has resulted in the deterioration of water quality because of the use of the water body as an industrial waste bin. This is significant, not only to the industries and ecologists but also to the large populations of people who depend on polluted rivers for a variety of purposes including drinking, irrigation, recreational activities, etc. In most low-income countries water is usually abstracted from rivers, lakes, and dams and used without any form of treatment (Igwe *et al*., 2017; Madilonga *et al*., 2021)

Among the wide variety of pollutants impacting surface water, heavy metals and nitrates are of serious concern and have been widely studied as pollutants of concern in water resources (Adesuyi *et al*., 2015; Akinfolarin *et al.*, 2020; Ghahramani *et al*., 2020). Heavy metals are of particular attention due to their toxicity, non-biodegradability, bioconcentration, and bioaccumulation, which contribute to putting terrestrial consumers as well as humans at risk (UNEP GEM, 2008; Akinfolarin *et al*., 2020). The sources of surface water pollution include lithogenic inputs (e.g. soil erosion, weathering, etc.) and anthropogenic activities, (e.g. industrial wastewaters, sewage discharge, municipal waste, agrochemicals and agricultural practices, urban runoff, etc.), which is the major contributor to surface water pollution (Ali *et al*., 2019). Nitrates are derived mainly from agricultural practices, waste disposal, and sewage (Ami´c *et al.*, 2018).

Human exposure to heavy metals and other pollutants in water can occur via different pathways, which can be arranged in the following order of magnitude: direct ingestion> dermal contact > inhalation (Naveedullah, *et al*, 2014). Exposure to pollutants from water bodies can also occur indirectly from plant and aquatic food sources (Qu *et al*., 2018).

Although many of these heavy metals (such as Fe, Cu, Co, and Zn) are necessary for the normal function of plants and animals and are considered essential elements, some (like As, Cd, Pb, and Hg) have no known function in plants and animals (Mertz, 1981). However, they are generally non-biodegradable and even those that are considered essential elements can accumulate to a toxic level (Nowrouzi and Pourkhabbaz, 2014). Many factors influence the toxicity of metals, such as interaction with essential metals, formation of a metal protein complex, age and stage of development, lifestyle, chemical form or speciation, and immune status of the host (Goyer, 1995). Heavy metals can also exert harmful effects on aquatic organisms, which include, but are not limited to, reduced growth rate, impaired reproduction, and sometimes death (UNEP GEM, 2008).

Several researchers have evaluated the level of toxic pollutants in water by comparing it with the standard permissible limit. This method alone cannot give quantitative insight into the risk posed by these pollutants. Human health risk assessment uses risk as an evaluation index to link environmental pollution with human health and quantitatively describes the risk of pollution to human health (Tian *et al.*, 2019; Onoyima and Ibraheem, 2021). Risk depends on the concentration of chemicals present in an environmental medium, the amount of contact (exposure) a person has with the pollutant in the medium, and the toxicity of the chemical (IPCS, 2010). Human health risk assessment methods, as recommended by the United States Environmental Protection Agency (USEPA, 1989) calculate non-carcinogenic risk values using chronic daily intake (CDI), hazard quotient (HQ), and hazard index (HI), while the carcinogenic risk is calculated with chronic daily intake (CDI) and cancer slope factor (CSF). The objective of the present study is to use the above-mentioned indices to evaluate the carcinogenic and non-carcinogenic risks posed to the adult population using water from River Kaduna via ingestion and dermal pathways.

MATERIALS AND METHODS

Sample Preparation and Analysis

Nine (9) composite samples were collected in dry season from each of the three sites in River Kaduna, namely: Nku (NK), Jifu (JI), and Muregi (MU) with an approximate distance of 500 m away from each other with sampling points identified with the use of GPS. Exactly 100 cm^3 of each water sample was collected in a 200 cm^3 beaker and was acidified with 5 cm^3 of concentrated HNO_3 and digested on a hot plate at 95 ^{0}C until the volume was reduced to 15-20 cm^3. The digested samples were quantitatively transferred into a 50 cm^3 volumetric flask and made up to mark using distilled water. The metals were determined using Atomic Absorption Spectrophotometer (AAS), while nitrates were determined following the method described by AOAC, (1998).

Statistical analysis

Multivariate statistical analysis was performed with the aid of Microsoft Excel and SPSS 20.0. Bivariate correlation analysis was carried out on the data, while cluster analysis was performed to classify the pollutants. The Hierarchical cluster analysis method was used in this study, and between-groups-linkage was chosen during the classifying procedure. Factor analysis, using the principal component method was also carried out on the data.

Health Risk Assessments

Exposure Assessments

The chronic daily intake (CDI) (mg/kg/day) was used to calculate the non-carcinogenic and carcinogenic risk of the toxic pollutant in the groundwater via ingestion and dermal routes of exposure. CDI via ingestion (CDI_{ing}) and dermal contact (CDI_{dern}) in this study were calculated using equations 1 and 2 as reported by USEPA, (1989).

$$CDI_{ing} = \frac{C_w \text{ x IR x EF x ED}}{\text{BW x AT}} \quad (1)$$

$$CDI_{derm} = \frac{C_w \text{ x } K_i \text{ x SA x EF x ED x BF x CF}}{\text{BW x AT}} \quad (2)$$

The detailed meaning and reference values of each parameter used for the calculation are presented in Table 1.

Table 1: The reference parameters of all pollutants (USEPA, 1989)

parameter	meaning	Value	Unit
EF	Exposure frequency	365	d/a
ED	Exposure duration	Non-carcinogens 30, Carcinogens 70	A
BW	Body weight	70	kg
AT	Average exposure time	Non-carcinogens 30, Carcinogens 70	A
IR	Ingestion rate	2	L/d
SA	Body surface area	16600	cm^2
BF	Bathing frequency	1	time/d
CF	unit conversion factor	0.002	L/cm^3
Ki	Dermal adsorption		cm/h
C_w	Concentration in water		mg/L

Non-carcinogenic Risk Assessment

The non-carcinogenic risk due to drinking water and dermal contacts were estimated using the hazard quotient (HQ) and hazard index (HI) as in equation 3.

$$HQ = \frac{CDI}{RfD} \quad (3)$$

Where RfD is the oral reference dose (mg/kg/day), defined as the daily oral exposure to a substance that will not result in any deleterious effect in a lifetime for a given human population (FAO/WHO, 2013). The RfD values for the assessed pollutants are listed in Table 2.

The scale of hazard quotient (HQ) based on average daily intake (CDI) and RfD is classified as follows: HQ≤ 1 (no risk); 1 < HQ ≤ 5 (low risk); 5 < HQ≤ 10 (medium risk); HQ > 10 (high risk) (USEPA, 1989).

The hazard index (HI) was calculated as the summation of the Hazard Quotient (HQ) arising from all the pollutants examined as in equation 4.

$$HI = \Sigma HQ \quad (4)$$

The value of the hazard index is proportional to the magnitude of the toxicity of the water to the population.

Carcinogenic Risk Assessment

Carcinogenic risk (CR) assessment estimates the probability of an individual developing cancer over a lifetime due to exposure to the potential carcinogen. CR was calculated using equation 5.

$$CR = CSF \times CDI \quad (5)$$

Where CDI and CSF are the chronic daily intake (mg/kg/day) and cancer slope factors $(mg/kg/day)^{-1}$ respectively. The CSF for the studied pollutants is listed in Table 2.

According to US EPA, (2011) CR between 1×10^{-6} to 1×10^{-4} represents a range of permissible predicted lifetime risks for carcinogens. Chemicals for which the risk factor falls below 1×10^{-6} may be eliminated from further consideration as a chemical of concern.

Table 2: Toxicological characteristics of the selected pollutants (FAO/WHO, 2013; US EPA, 2011)

Pollutants	Reference dose		Cancer slope factor	Permeability coefficient
	Oral route	Dermal route		
Cu	0.04	0.12	-	0.001
Cd	0.0005	0.00005	0.38	0.001
Cr	0.003	0.0006	0.5	0.002
Zn	0.3	0.06	-	0.0006
Pb	0.0014	0.0042	0.0085	0.004
Fe	0.7	0.45	-	0.001
NO_3^-	1.6	1.1	-	0.001

RESULTS AND DISCUSSION

Level of Pollutants in Water

The results of heavy metals and nitrate concentrations in water samples of River Kaduna have been analysed and the mean result is presented in Table 3: The results show that the pollutants concentrations (mg/kg dry weight) in the studied area were in the following range: Cu (0.157±0.008 – 0.347±0.003), Cd (0.037±0.004 – 0.103±0.034), Cr (0.416±0.106 – 0.786±0.014), Zn (0.009±0.001 – 0.012±0.001), Pb (0.099±0.032 – 0.994±0.081), Fe (22.656±0.179 – 34.500±1.037), NO_3^- (9.467±0.005 – 9.500±0.023). The mean concentrations of the pollutants followed the decreasing order: Fe > NO_3^-> Pb > Cr > Cu > Cd > Zn. While Cd, Cr, Pb, and Fe exceeded the WHO maximum permissible limit for drinking water, Cu, Zn, and nitrate were within the limit (WHO, 1993). The level of the pollutant alone does not determine the human risk posed by these pollutants as risk depends also on the amount of contact (exposure) a person has with the pollutant in the medium, and the toxicity of the pollutant (IPCS, 2010).

Table 3: Mean concentrations (mg/kg) of heavy metals and nitrate

	Cu	Cd	Cr	Zn	Pb	Fe	NO_3^-
MU	0.157±0.008	0.047±0.005	0.416±0.106	0.009±0.001	0.981±0.089	28.100±0.542	9.500±0.023
JI	0.324±0.022	0.103±0.034	0.786±0.014	0.012±0.001	0.099±0.032	22.656±0.179	9.470±0.013
NK	0.347±0.003	0.037±0.004	0.731±0.177	0.012±0.001	0.994±0.081	34.500±1.037	9.467±0.005

Results of Statistical Analysis

Multivariate statistical analysis can be used for pollution status and source identification of water resources (Okibe *et al.,* 2019). A significant positive correlation between pollutants in an environmental medium may indicate a similar source or similar controlling factor, while a significant negative correlation is an indication of an inverse relationship (Yisa *et al*., 2011; Onoyima and Okibe, 2021). The matrix of linear correlation coefficient (Table 4) shows that there was a significant positive correlations (0.05 level, 2-tailed) between Cu and Cd (r = 0.466), Zn (r = 0.403), and Cr (r = 0.472). Pb also correlated positively (0.01 level, 2-tailed) with Fe (r = 0.739). This may indicate common anthropogenic input. Significant negative correlations were also observed between nitrate and Cu (r = -0.531), Cd (r = -0.384), and Cr (r = -0.421), and between Pb and Cd (r = -0.420). The negative correlations between nitrate and the heavy metals indicated that the factors that increase nitrate may have an inverse effect on the level of heavy metals. Nitrate in water is increased by rain, snow, fog, and decomposition of organic matter (Ami´c *et al*., 2018). A complex series of processes and the physicochemical properties of the water such as pH, temperature, redox potential, etc. significantly control the distribution, solubility, and mobility of ions in water (Verla *et al.,* 2020). Studies showed significant negative correlation between nitrate and pH, while metal solubility correlated positively with pH(Marques *et al*., 2006; Verla *et al*., 2020). It was also shown that pH is one of the major factors which influence the release of heavy metals from the sediments to the overlying water through the process of ion exchange, dissolution, and desorption (Zhang *et al*., 2018).

Table 4: Pearson correlation coefficients of metals and nitrate in River Kaduna

	Cu	Cd	Cr	Zn	Pb	Fe	NO_3^-
Cu	1						
Cd	0.466*	1					
Cr	0.472*	0.260	1				
Zn	0.403*	-0.028	-0.093	1			
Pb	-0.335	-0.420*	-0.237	-0.168	1		
Fe	0.133	-0.373	0.198	-0.148	0.739**	1	
NO_3	-0.531**	-0.384*	-0.421*	-0.129	0.286	-0.102	1

*Correlation is significant at the 0.05 level (2-tailed)
**Correlation is significant at the 0.01 level (2-tailed)

Cluster analysis was used to classify the studied surface water pollutants that are similar. Dendogram of the hierarchical cluster analysis using average linkage (Between Group) as shown in Figure 7 identified four distinct clusters namely (1) Pb and Fe, (2) Nitrate, (3) Cu, Cr, and Cd, and (4) Zn. Pb and Fe in cluster '1' are closely clustered and are also positively correlated, indicating a common source. Nitrate is clustered separately in cluster 2 because of its negative relationship with most heavy metals. A high concentration of nitrate in surface water is an indication of pollution from domestic and industrial wastewater and nitrogenous fertilizers (Dadgar and Payandeh, 2017; Mutlu and Durnaz, 2018). Metals in cluster 3 are also positively correlated. This group of metals was likely from industrial sources such as electroplating, batteries, paints, etc. (WHO, 2007). Zn correlated with Cu but exist separately in cluster 4, indicating a possible mixed origin for this metal. A similar observation was made by Yisa *et al*., (2011) and Okibe *et al*., (2020).

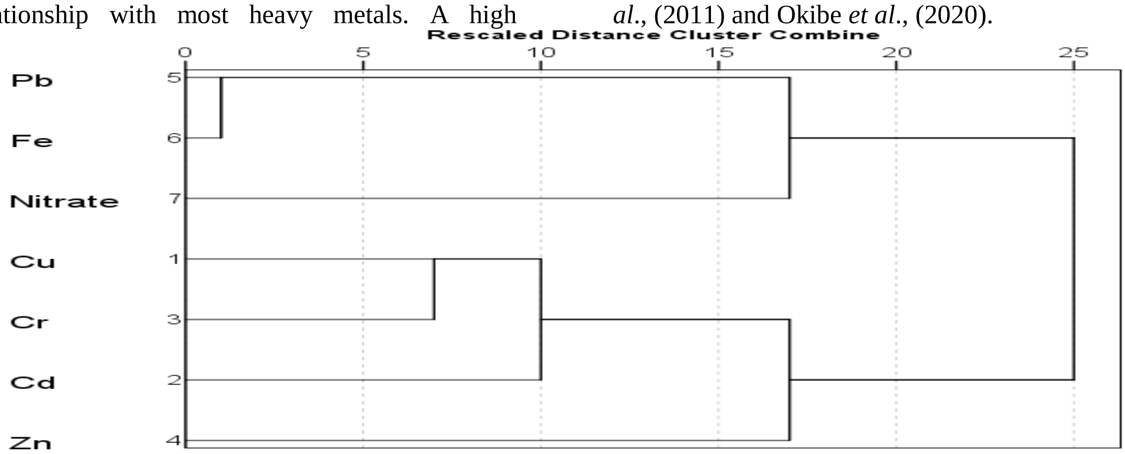

Figure 1: Dendogram of the hierarchical cluster analysis of metals and nitrate

Table 5 shows the result of the principal component loadings for metals and nitrate of the study area, while Figure 2 represents the component plot. The PCA yielded 3 components which explained 78.83 % of the total variance in the data set, indicating that the remaining 21.17% were not explained by these axes. The first component accounts for 37.89 % of the total variance and has strong positive loadings for Cu, Cd, and Cr and also strong negative loading for nitrate. Component two accounts for 24.65 % of the total variance with strong positive loadings for Cr, Fe, and Pb, while component 3 accounts for 16.30 % of the total variance and has strong positive loading for Zn.

Table 5: Principal component loadings for metals and nitrate

	component		
	1	2	3
Cu	0.779	0.383	0.286
Cd	0.724	-0.151	-0.309
Cr	0.557	0.505	-0.330
Nitrate	-0.688	-0.391	0.021
Fe	-0.344	0.917	0.063
Pb	-0.726	0.547	0.08
Zn	0.304	-0.091	0.918
% Variance	37.89	24.65	16.30
Cumulative %	37.89	62.53	78.83

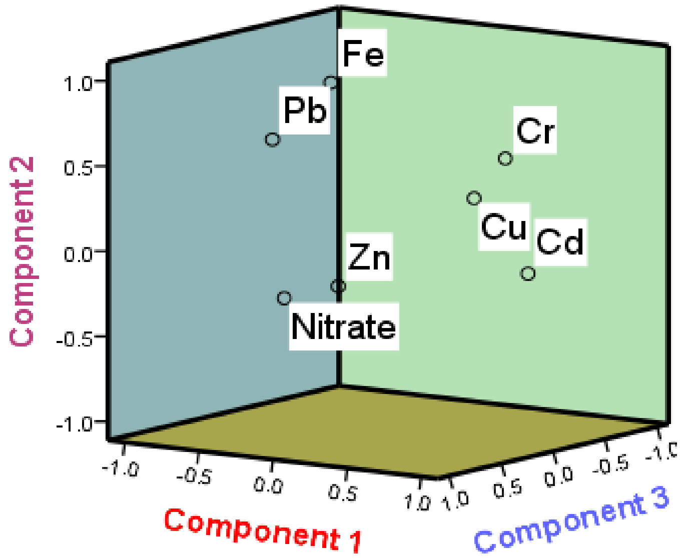

Figure 2: Principal component plot

Health Risk Assessment

Non-carcinogenic risk assessment

The study of the effect of heavy metals and nitrate in water resources is not limited to the presence, level, and sources of these pollutants, but also includes the possible risk to human health. Exposure assessment using the chronic daily intake (CDI) of the pollutants through oral ingestions and dermal contact is shown in Table 6. The results show that average human exposure to the pollutants through oral route are in the following order: Fe > NO_3^-> Pb > Cr > Cu > Cd > Zn, while exposure through dermal contact are far less and are in the following order: Fe > NO_3^-> Cr > Pb = Cu > Cd > Zn.

Table 6: Chronic Daily Intake (CDI) of the metals and nitrate

SITES		Cu	Cd	Cr	Zn	Pb	Fe	NO_3^-
MU	OR	4.49×10^{-3}	1.34×10^{-3}	1.19×10^{-2}	2.57×10^{-4}	2.80×10^{-2}	8.03×10^{-1}	2.71×10^{-1}
	DER	7.45×10^{-5}	2.23×10^{-5}	3.95×10^{-4}	2.56×10^{-6}	1.86×10^{-3}	1.33×10^{-2}	4.51×10^{-3}
JI	OR	9.26×10^{-3}	2.94×10^{-3}	2.25×10^{-2}	3.43×10^{-4}	2.83×10^{-3}	6.47×10^{-1}	2.71×10^{-1}
	DER	1.54×10^{-4}	4.89×10^{-5}	7.45×10^{-4}	3.42×10^{-6}	1.88×10^{-4}	1.08×10^{-2}	4.49×10^{-3}
NK	OR	9.91×10^{-3}	1.06×10^{-3}	2.09×10^{-2}	3.43×10^{-4}	2.84×10^{-2}	9.86×10^{-1}	2.70×10^{-1}
	DER	1.65×10^{-4}	1.76×10^{-5}	6.93×10^{-4}	3.42×10^{-6}	1.89×10^{-3}	1.64×10^{-2}	4.49×10^{-3}

OR = ORAL; DER = DERMAL

Total HQ and total HI due to a combination of oral ingestion and dermal contact pathways were estimated and the result is summarized in Table 7. The total HQ for Cu, Zn, and NO_3^- are all less than one (HQ < 1), showing that these pollutants did not constitute a non-carcinogenic risk to the population through oral and dermal contacts. Cu and Zn are nutritionally essential elements in low concentrations, whose deficiency results in some health consequences (WHO, 1993; Cousins, 1996). Although with low toxicity profiles, both Zn and Cu have been reported to result in acute toxicity from excessive ingestion resulting in gastrointestinal distress, nausea, vomiting, and diarrhoea (Lam *et al*., 1985; Piazzaro *et al*., 1999; Madilonga *et al*., 2021). Exposure to an increased level of Zn has also been linked to a decrease in HDL and decrease in iron store (Hughes and Sammon, 2006), while Wilson's disease (hepatolenticular degeneration) is caused by excessive accumulations of Cu in the liver, brain, kidney, and cornea (Frydman *et al*., 1985; ATSDR, 2002). The most commonly reported adverse effect of a high level of nitrate in drinking water is the blue baby syndrome (methemoglobinemia) (Wakawa *et al*., 2008; Levallois and Villanueva, 2019). However, evidence of cardiovascular damage (Jerkovi´c *et al*., 2016), and congenital defects (Bander *et al*., 2013) have been reported.

Cd constituted low risk at MU and NK, and medium risk at JI. The toxicity of Cd has been well documented (ATSDR, 2012). Long-term exposure to Cd causes renal tubular cell, and glomerular toxicity (nephrotoxicity) (Kjellstroem, 1985; Bawaskar *et al*., 2010); leads to calcium loss, resulting in bone pain, osteomalacia, and/or osteoporosis (Buha *et al*., 2019); hypertension and cardiovascular effect, and neurological disorders (Wu *et al*., 2010); liver damage, anaemia and retarded growth (Tinkov *et al*., 2018). Cd interferes with essential biomolecules, altering their homeostasis and also disrupting their biological function (Wang *et al*., 2018).

Cr constituted low risk at MU and medium risk at JI and NK. Cr (IIII) and Cr (VI) are the most stable oxidation states of Cr present in the environment. While Cr (III) is considered an essential trace nutrient with some physiological roles, Cr (VI) is highly toxic. The toxicity of Cr (VI) is believed to be due to its ability to reduce to Cr (III) in physiological conditions leading to intermediates such as Cr (V), Cr (IV), as well as reactive oxygen species (ROS) which damage cell biomolecules, and cause functional degradation (Shi *et al*., 1992; Patlolla *et al*., 2009; Sobol and Schiest, 2012). Occupational and environmental exposure to high a concentration of Cr (VI) causes tubular and glomerular damage, liver damage, chronic ulceration, and perforation of nasal septum and other skin surfaces, allergy/asthma (Genchi *et al*., 2020).

Pb constituted low risk at JI and high risk at MU and NK. Pb mimic or inhibit the action of Ca. it binds to biological molecules (e.g. enzymes) and interferes with their function. The critical and most sensitive effect of Pb is in infants and involves the nervous system. It impairs neurodevelopment, interferes with neurotransmitter function, and disrupts calcium metabolism (ATSDR, 2007). Other adverse effects of Pb include renal toxicity, developmental delays, hypertension, anaemia, memory loss, anorexia, and brain damage (Malik and Khan, 2016; Madilonga *et al*., 2021) There has also been an inconsistent report of reproductive toxicity and immune system suppressive ability of Pb (McCabe and Lawrence, 1991; Bonde *et al*., 2002).

Fe constituted no risk at JI and low risk at MU and NK. Fe is an essential element with the most common nutritional deficiency worldwide, affecting older infants, young children, and women of childbearing age. However, chronic Fe toxicity occurs by excessive accumulation of Fe in the body, either through transfusion siderosis, hereditary hemochromatosis, or excessive dietary intake. The clinical effects include disturbances in liver function, diabetic Mellitus, and even endocrine disturbances and cardiovascular effects (Salomen *et al*., 1992). It also causes congestion of blood vessels, leading to increased respiration rate and hypertension (Madilonga *et al*., 2021).

The percentage contribution of each of the pollutants to the total non-carcinogenic risk (Figure 3) can be arranged in the following order: Pb > Cr > Cd > Fe > Cu > NO_3^- > Zn. The result shows that Pb, Cr, and Cd are the major contributors to total non-carcinogenic risk and accounted for 96.27 % of the total risk. HI is the cumulative effect of all the studied pollutants. Total HI (HI_{oral}+ HI_{derm}) as shown in Table 7 shows that the order of human health risks due to the studied pollutants from the surface water of River Kaduna are as follows: NK > MU > JI.

Table 7: Total hazard quotient (HQ) and Hazard Index (HI) of the metals and nitrate

Sites	Cu	Cd	Cr	Zn	Pb	Fe	NO_3	HI
MU	0.113	3.129	4.621	0.0009	20.463	1.177	0.174	29.67
JI	0.233	6.857	8.726	0.00116	2.065	0.949	0.174	19.01
NK	0.249	2.471	8.116	0.00116	20.733	1.444	0.174	33.19

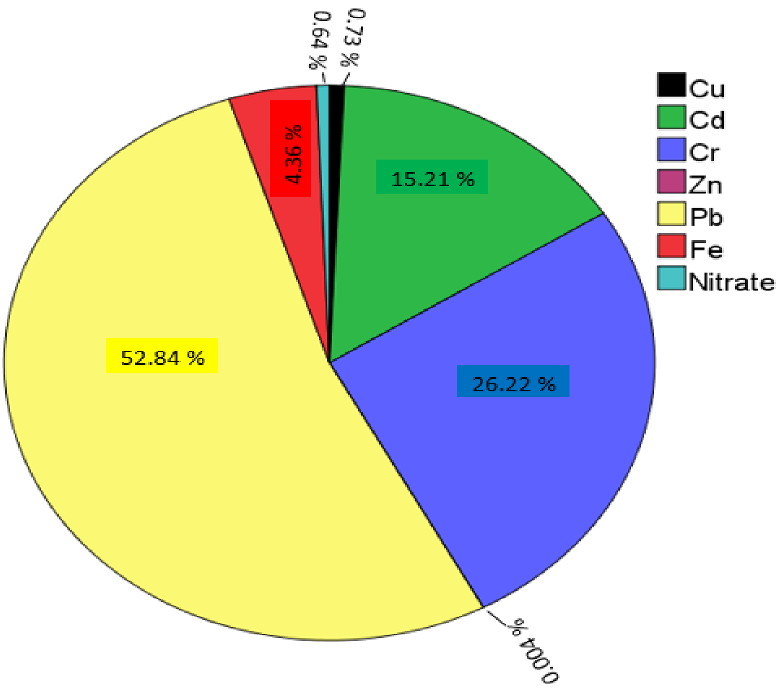

Figure 3: Percentage contributions of the pollutants to non-carcinogenic risk

Carcinogenic Risk Assessment

Carcinogenic Risk is the incremental risk or the probability of an individual developing cancer over a lifetime (Gebeyehu and Bayissa, 2020). The normal range set by USEPA is from 1.0 x 10^{-6} to 1.0 x 10^{-4} (USEPA, 2011). The Carcinogenic risk was calculated only for the pollutants with carcinogenic or mutagenic data, which include Cd, Cr, and Pb. Cd and Cr are category 1 carcinogens, while Pb is classified as a 2B carcinogen (IARC, 1989). The results as presented in Table 8 show that the cancer risk due to Cd ranged from 4.83 x 10^{-4} to 1.11 x 10^{-3}, Cr ranged from 5.95 x 10^{-3} to 1.12 x 10^{-2}, while Pb ranged from 2.40 x 10^{-5} to 2.41 x 10^{-4}. These results indicate that the carcinogenic risk due to ingestion and dermal contact of water containing Cd, Cr, and Pb exceeded the acceptable limit, suggesting that lifetime exposure to these metals poses a cancer risk to the adult population in the area. Heavy metal-induced carcinogenesis occurs through induced oxidative stress, DNA damage, and cell death (Kim *et al.*, 2015).

Cd inhibits the biosynthesis of certain proteins leading to the transformation of normal epithelial cells into carcinogenic cells (Sharma *et al.*, 2015). Environmental Cd exposure has been associated with cancer of the lung (the most definitely established human carcinogenesis), prostate, kidney, liver, hematopoietic system and stomach (Waalkes *et al.*, 1996). It also disrupts the endocrine, especially reproductive hormones which increase the risk of ovarian cancer and breast cancer (Yang *et al.*, 2015). Cr, on the other hand, has proven mutagenic and genotoxic effects (Sawicka *et al.*, 2021), while the most common

tumours found for Pb were of the respiratory and digestive systems, although renal adenocarcinoma has been reported in workmen with prolonged occupational exposure to Pb (Baker *et al*., 1980).
It is pertinent to state that there are many uncertainties involved in quantifying cancer risk. The absorption, release, and excretion of metals are influenced by age, health, nutritional state, body burden, and exposure duration. Carcinogenic risk is also related to a process or a group of metal compounds rather than a single substance (Goyer, 1995).

Table 8: Carcinogenic risk of the pollutants in the surface water of River Kaduna

Sites	Cd	Cr	Pb
MU	5.09×10^{-4}	5.95×10^{-3}	2.38×10^{-4}
JI	1.11×10^{-3}	1.12×10^{-2}	2.40×10^{-5}
NK	4.83×10^{-4}	1.04×10^{-2}	2.41×10^{-4}

CONCLUSION

The mean concentrations of the pollutants can be arranged in the following decreasing order: Fe > NO_3^-> Pb > Cr > Cu > Cd > Zn. The total HQ level for Cu, Zn, and NO_3^- are all less than one (HQ < 1), showing that these pollutants did not constitute a non-carcinogenic risk to the population through oral and dermal contacts, while Cd, Cr, Pb, and Fe constituted varying degrees of non-carcinogenic risk. Pb, Cr and Cd were the major contributors to total non-carcinogenic risk and accounted for 96.27 % of the total risk. Carcinogenic risk due to Cd, Cr, and Pb exceeded the threshold, suggesting that lifetime exposure to these metals poses a cancer risk to the adult population in the area.

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