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ASSESSING WATER QUALITY AND THE NON-CARCINOGENIC HEALTH RISKS OF SURFACE AND GROUNDWATER IN IBI – TARABA STATE

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ABSTRACT

The high concentration of chemical and biological contaminants in rural water is known to cause waterborne and water-related diseases. This study provides insights into the quality of surface and groundwater used for consumption and other domestic uses in Ibi environs. It further assesses the association between water quality variables and evaluates the chronic non-carcinogenic health risk using hazard quotient and hazard index. Thirty water samples each from the river and hand-dug wells were collected and the values of 17 variables were measured. The results showed that 58.8% and 35.3% of surface and groundwater failed to conform to national drinking water guidelines. The result for correlation between measured variables indicates both positive and negative correlation between variables across both water sources with pH negatively correlating with turbidity (r = -0.832) and TDS (r = -0.714) while temperature correlated positively with turbidity (r = 0.925), TDS (r = 0.793) and TH (r = 0.847). The results of human health risk show NO_3^- as the most dominant variable in inducing non-carcinogenic health risk in surface water while F^- was the most inducing variable for groundwater. Based on the THI values, all the water sources showed long-term health risks above the safe limit even though some of the variables were within the national standards. There is therefore the need to address agricultural activities which is likely the major cause of nitrate in drinking water within the study region.

Keywords: contaminants, drinking water, health hazard, non-carcinogenic risks, water quality

INTRODUCTION

Water is an essential resource for the survival of humanity and the ecosystem. Access to safe, sufficient, affordable, and accessible drinking water and improved sanitation is considered a fundamental human right (UN, 2010; Sultana and Loftus, 2020). However, population growth, industrialization, and climate change are exerting ever-increasing pressure on the availability and quality of water (Chen *et al.,* 2017; Joshua, 2021a). The safety and accessibility of drinking water are becoming a major concern throughout the world and particularly in rural communities of developing countries (Aher *et al.,*2020). In Nigeria for instance, most rural areas are considered the food basket of the nation where agricultural activities take place, yet these areas are saddled with poor water quality due to lack of water treatment facilities and heavy pollution of water sources from agricultural activities (Joshua, 2021a). In addition, rural areas in many developing countries lack proper waste management systems thereby having a significant quantity of waste disposed of indiscriminately, and resulting in air, soil, and water contamination (Obongo *et al.,*2021). Other industrial, mining and mineral exploration which often occurs in rural areas have significantly affected water quality in Nigeria (Akoteyon *et al.,* 2018; Joshua *et al.,* 2016).

Water quality is an imperative matter which can directly be linked to human health and the general wellbeing of society (Aher *et al.,* 2020). However, due to the uneven distribution of freshwater and contamination from both natural and anthropogenic sources (Adegbola *et al.,* 2021; Hameed *et al.,* 2021), the provision of safe water is now a major challenge in most rural areas in Nigeria. Drinking water must be free from impurities or substances that can likely affect human health (Ajala *et al.,* 2020; Jabbo *et al.,* 2022). Drinking water quality has been used as a powerful environmental determinant of human health (UN-Water, 2019), therefore water availability must meet both quantity and quality across all uses and users. Although the quality of water is determined by its intended use, drinking water must be safe, sufficient, and available where and when needed (Ayandiran *et al.,* 2018; Usikalu *et al.,* 2021). The non-functional or in most cases, lack of water treatment and distribution systems in Nigeria's rural settlements have resulted in the use of unimproved alternative water sources which often leads to waterborne and water-related diseases. In addition, climate change is now one of the greatest threats to ensuring water security, particularly in the north-eastern and north-western states. Frequent drought and water scarcity including flash floods have severely impacted rural water supply systems leading to inadequate access to potable water, which is retarding the progress made so far in attaining sustainable development goals (Joshua, 2021b; Yunana *et al.,* 2017)

Access to potable water in Nigeria has over the years lagged behind many Sub-Saharan African countries despite Nigeria having one of the fastest-growing economies in Africa. For instance, most North-eastern states in Nigeria are among the lowest covered in terms of the number of persons with access to an adequate and improved source of water with only 18% of the population having access to improved water sources on their premises (World Bank, 2017). More so, most of those with coverage are domiciled in urban cities leaving the rural areas to access water from unimproved sources such as streams, rivers, lakes, shallow hand-dug wells, and rainwater harvesting (Joshua, 2015; Joshua, 2017). Current reports of cholera and other water-borne, and water-related diseases are found in rural areas. In addition, water-related projects aimed at the provision of potable water have not been effective, particularly because of poor monitoring and maintenance of water infrastructures. For instance, the hand-pump boreholes which have been used as a rural water supply project have been poorly managed and result in these infrastructures breaking down after a few months of operations.

These systems have not been effective in meeting water access and quality needs thereby leaving rural communities at risk of diseases including diarrhea, cholera, and typhoid which are the leading contributors of child mortality in rural areas (Wiess *et al.,* 2016). Against this, the study investigates water quality and long-term non-carcinogenic health risks associated with the ingestion of surface and groundwater in adults, children, and infants. It further assesses the relationship between water quality parameters and identifies parameters exceeding national drinking water standards.

MATERIALS AND METHODS

Ibi Local Government Area (LGA) is one of the 16 local government areas located in southern Taraba. Ibi LGA shares boundaries with Plateau state to the north, Nasarawa state to the west, Gassol LGA to the east, and Wukari LGA to the south. It covers an area of 2,672 km^2, with an annual rainfall of 1016-1270 mm, and an average temperature ranging from 21℃ to 35℃ (Gabriel *et al.,* 2015). Fishing and agricultural activities are the major occupation with crops like yam, rice, maize, and guinea corn constituting the major crops found in Ibi (Gabriel *et al.,* 2015).

Sample Collection, ~~and~~ Physico-chemical and Microbial Analysis

Water samples were collected from River Ibi (surface water) and shallow hand-dug wells within the communities. A total of 30 sampling points each was identified, and water samples were collected in treated water bottles. Water bottles were washed with 0.5 HCl and then rinsed with the water sample thrice before collection. Parameters assessed were grouped into physical, chemical (non-metals and metals), and biological parameters. Temperature and pH were determined in-situ using a mercury thermometer and pH meter while colour and turbidity were determined using the standard comparison method and Nephelo turbidity meter (Radojevic and Bashkin, 2006). Fluoride was determined using the colorimetric SPADNS method and other non-metal and metals were determined using Atomic Absorption Spectrometer (AAS) as described by APHA, (1998); Radojevic and Bashkin, (2006). Biological contaminants were determined using presumptive count and differential count (Hallas and Monis, 2015) and the results were analysed descriptively and tabulated.

Health-Related Risks Assessment

The non-carcinogenic health risks was assessed and computed according to USEPA, (1991), USEPA, (2014). The human health risk assessment is becoming an excellent tool in appraising and monitoring water quality even when the concentration of contaminants is within the stipulated drinking water guidelines (Adimalla and Li, 2019, Chen *et al.,* 2017). This is important in safeguarding water supply systems and protecting public health. The average concentration of daily intake (CDI) expressed as mg/kg/day was computed using equation 1 (Adopted from USEPA, 1991) as follows:

$$\mathrm{CDI} = \frac{\mathrm{Cw\ X\ IR\ X\ ED\ X\ EF}}{\mathrm{AW\ X\ AT}} \qquad (1)$$

Where: Cw is the concentration of each parameter; IR, ingestion rate (taken from Narsimha and Rajitha, (2018); Ahada and Suthar, (2017) as 2.5 L, 0.78 L, and 0.3 L for adults, children, and infants respectively; ED, exposure duration adopted from Adimalla and Li, (2019) as 64, 12 and 1 year for adults, children, and infants; EF, exposure frequency which is taken as 365 days; AW is the average body weight adopted from Chen *et al.,* (2017) as 68 kg, 18 kg and 5 kg for adults, children, and infants respectively; AT is the exposure time over the exposure durations and taken as 23360 for adults, 4380 for children and 365 for infants.

In addition, the health quotient (HQ) was computed using equation 2

$$\mathrm{HQ} = \frac{\mathrm{CDI}}{\mathrm{RfD}} \qquad (2)$$

Where RfD is the reference dose of a specified parameter (mg/kg/day) and taken as 1.6 (nitrate), 0.4 (fluoride), 0.7 (iron) and 0.0035 (lead) (USEPA, 2014, Duggal *et al.,* 2017).

Finally, the total health index (THI) is computed as the sum of hazard quotients values of each contaminant using equation 3

$$\mathrm{THI} = \sum \mathrm{HQ} \qquad (3)$$

Statistical Analysis

The results were analysed descriptively as mean, min, max, and standard deviation. The significant difference between the concentration of parameters and the national standard was assessed using a 1-sample student t-test ($P<005$). Furthermore, analysis of variance between surface and groundwater variables was conducted at a 95% confidence level while the relationship between parameters was assessed using Pearson's correlation coefficient. The statistical analysis was performed using Minitab statistical tool version 20.0 and charts were plotted using Microsoft Excel.

RESULTS AND DISCUSSION

Presenting water quality parameters

Physio-chemical and bacteriological composition of surface and groundwater is given in table 1, while correlation matrix of water quality variables is given in table 2 and 3 respectively. The result of a 1-sample t-test indicates that temperature and pH in both surface and groundwater were within the acceptable range. In addition, chloride, calcium, magnesium, fluoride, and potassium in surface water were all within national limits while groundwater colour, TDS, chloride, nitrate, fluoride, iron, phosphate, potassium, and coliform were also within acceptable guidelines. Overall, the results showed that 58.8% of surface water parameters comprising of colour (50.82 TCU), turbidity (20.35 NTU), TDS (625.0 mg/L), total hardness (196.47 mg/L), nitrate (101.07 mg/L), iron (0.35 mg/L), lead (0.036 mg/L), phosphate (0.063 mg/L), coliform count (35.23 CFU/100mL) and E. coli (8.30 CFU/100mL) significantly exceeded national drinking water standards to varying degrees. This was however 35.3% in groundwater comprising of turbidity (5.47 NTU), total hardness (171.76 mg/L), calcium (76.72 mg/L), magnesium (35.08 mg/L), lead (0.02 mg/L) and E. coli (2.83 CFU/100mL). The concentration of nutrients in groundwater was generally within national limits (NIS, 2015) which suggest agricultural activities could likely be the most significant contributor of nutrients in surface water. Similar findings (Daramola *et al.,* 2021; Ighalo and Adeniyi, 2020; Joshua, 2021a; Sitotaw *et al.,* 2021) also highlighted surface water contamination from agricultural activities including disposal of waste and sewage, industrial waste, and leachate from waste disposal sites. Generally, the results suggest that both water sources were unsafe for consumption and can likely result in health issues particularly to children, the elderly, and visitors. For example, nitrate levels in surface water exceeded the national limits of 50 mg/L thereby highly likely to cause a blue baby syndrome in infants (Adimalla and Li, 2019; Aher *et al.,* 2020; Chen *et al.,* 2017; Chica-Olmo *et al.,* 2017; Hameed *et al.,* 2021). Similarly, both sources indicate bacteriological contamination above stipulated guidelines which can result in waterborne or water-related diseases such as cholera, typhoid, diarrhea, and dysentery (Sitotaw *et al.,* 2021). These are common diseases that are currently ravaging the nation's rural populace of which the case study area is not an exception.

Table 1: Physiochemical and bacteriological summary of surface and groundwater properties

Variables	Surface Water Sources			Ground Water Sources		
	Mean±St.D	**SIG**	**Min±Max**	**Mean±St.D**	**SIG**	**Min±Max**
Temp	22.82±0.76	WR	21.70±24.30	17.28±1.52	WR	15.0±20.20
Color	50.25±5.63	**0.000**	38.60±60.00	12.52±1.88	0.999	9.20±15.5
pH	7.03±0.62	WR	5.80±8.30	7.84±0.29	WR	7.40±8.40
Turbidity	20.35±3.32	**0.000**	13.10±26.40	5.47±0.51	**0.000**	4.60±6.30
TDS	625.0±79.60	**0.000**	468.6±785.0	236.0±38.46	1.000	180.8±300.2
Hardness	196.47±26.1	**0.000**	145.7±248.1	171.76±11.7	**0.000**	150.9±189.6
Chloride	23.58±4.91	1.000	13.50±32.30	28.31±3.04	1.000	23.5±33.30
Nitrate	101.07±15.6	**0.000**	70.50±123.9	41.25±2.43	1.000	37.2±45.60
Calcium	72.97±1.70	1.000	69.60±76.0	76.72±1.61	**0.000**	74.0±79.90
Magnesium	24.59±2.70	1.000	19.80±30.50	35.08±3.31	**0.000**	28.2±40.8
Fluoride	1.140±0.16	1.000	0.85±1.50	1.29±0.06	1.000	1.20±1.39
Iron	0.35±0.023	**0.000**	0.30±0.39	0.28±0.05	0.991	0.20±0.35
Lead	0.036±0.018	**0.000**	0.009±0.07	0.02±0.01	**0.000**	0.001±0.05
Phosphate	0.063±0.01	**0.000**	0.046±0.088	0.02±0.01	1.000	0.002±0.05
Potassium	0.956±0.029	1.000	0.90±1.01	0.76±0.09	1.000	0.60±0.90
Col. count	35.23±10.52	**0.000**	14.00±56.00	9.8±5.04	0.585	2.00±18.00
E. Coli	8.30±3.29	**0.000**	2.00±15.00	2.83±2.55	**0.000**	0.00±8.00

St. D- standard deviation, SIG – significant at P<0.05, min±max– minimum & maximum value

Assessing differences between water sources

Analysing differences between surface and groundwater indicates that there was a significant difference ($P < 0.05$) in all 17 water quality variables (Fig.1-3). This was however expected because surface water is known to be highly susceptible to contamination from anthropogenic sources (Joshua, 2021a, UN-Water, 2019). Although both water sources were not of sufficient quality, the result for difference suggests there are likely diverse factors as well as contaminants specific to each water source within the study region. For instance, while it is clear that factors such as improper disposal of waste (including municipal and industrial), agricultural activities, and the high prevalence of open defecation are responsible for surface water contamination (Daramola *et al.,* 2021; Mohammadi *et al.,* 2019; Sitotaw *et al.,* 2021), other factors like weathering of bedrock, hydrogeological interactions, and dissolution of minerals (Awomeso *et al.,* 2020; Ayedun *et al.,* 2019; Ighalo and Adeniyi, 2020; Lapworth *et al.,* 2017), the surface to groundwater interaction (UN, 2022), spatial and temporal factors and climate change (Aladejana *et al.,* 2020; Joshua, 2021a; Yunana *et al.,* 2017) may likely be responsible for groundwater contamination.

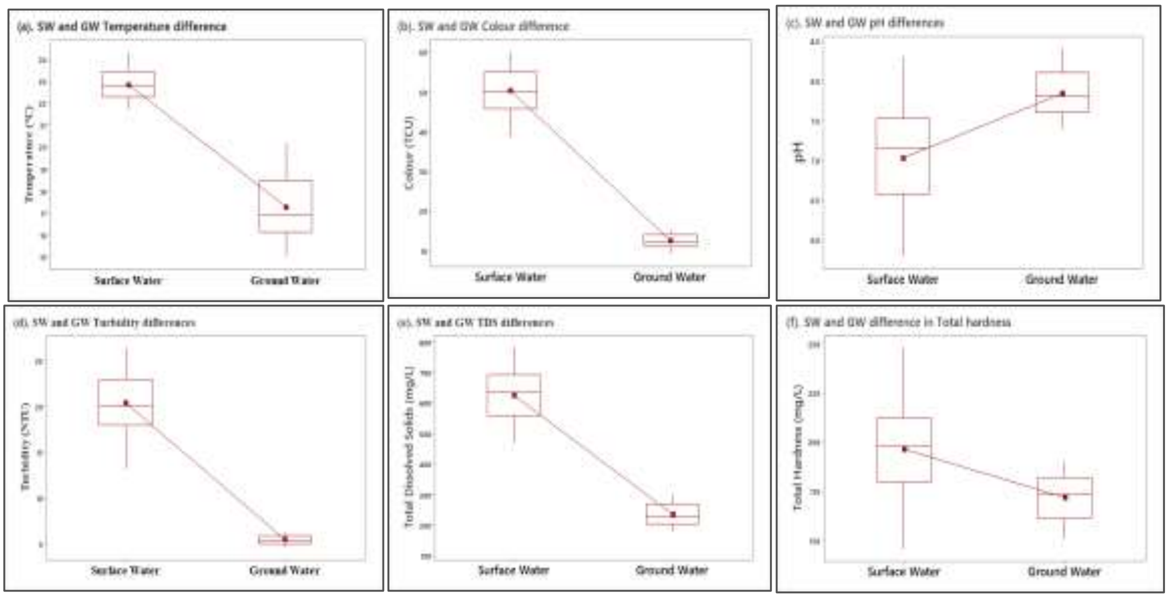

Figure 1: The significant difference in physical variables comprising of temperature (a), colour (b), pH (c), turbidity (d), TDS (e), and hardness (f) between surface and groundwater sources

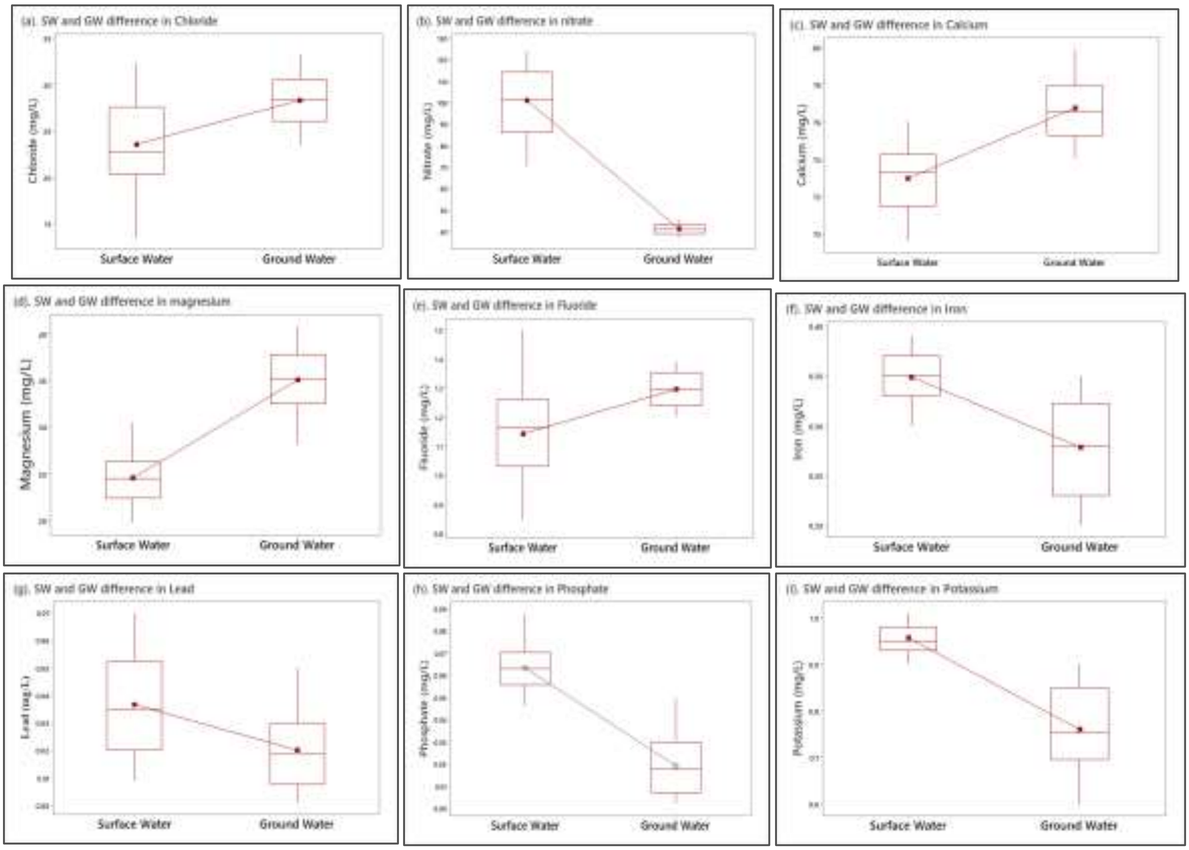

Figure 2: The Significant difference in chemical variables comprising of Cl^- (a), NO_3^- (b), Ca^{2+} (c), Mg (d), F^- (e), Fe (f) Pb (g), K (h), and PO_4^{3-} (i) between surface and groundwater sources

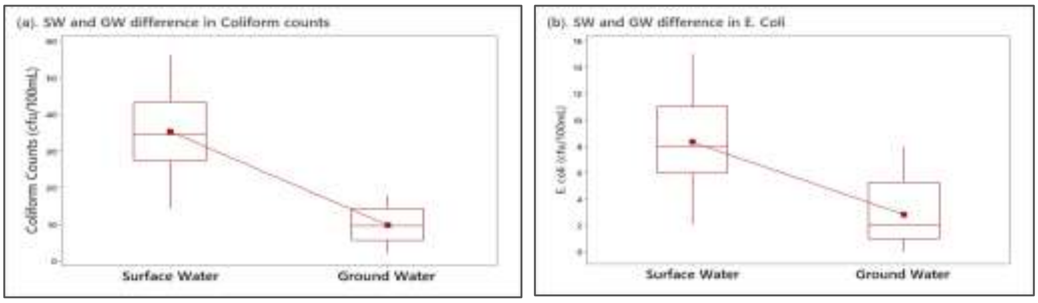

Figure 3: The significant difference in bacteriological variables comprising of coliform counts (a), and E. coli (b) between surface and groundwater sources

Relationship and correlation between water quality parameters

The relationship between water quality parameters was assessed using the Pearson correlation coefficient and presented in the correlation matrix (Table 2 & 3) for surface and groundwater sources. Correlation was classified according to Wang, (2018) classification which indicates correlation coefficient r > 0.7 < 0.5 > 0.49 as strong, moderate and weak correlation respectively. The Pearson correlation results for surface water sources (table 2) showed a strong negative correlation between pH – turbidity (-0.832) and TDS (-0.714) while temperature indicated a strong positive correlation with turbidity (0.925), TDS (0.793), and total hardness (0.847). In addition, colour, and turbidity, showed a strong positive correlation with TDS, iron, and total hardness while nitrate correlated positively with coliform count and E. coli. A negative correlation suggests that as one variable increases, the other variable decreases while a positive correlation implies that an increase in one variable is associated with an increase in another variable. The negative correlation of pH and other variables implies that as water becomes more acidic (decrease in pH), more chemicals are likely to be dissolved thereby increasing the concentration of other variables. This conforms with findings from Amfo-Otu *et al.,* (2014) suggesting that pH is an important determinant of the chemical composition in water samples. Subsequently, correlation in groundwater (Table 3) showed that pH was negatively correlated with TDS, calcium, magnesium, while temperature negatively correlated with calcium and TDS. In addition, turbidity displaced a strong positive correlation with colour, TDS, iron, coliform count, and E. coli while total hardness correlated with magnesium and calcium.

The results suggest that while anthropogenic activities may likely be playing a significant role in the concentration of some of the variables (particularly in surface water), the relationship and association between these variables is also increasing the concentration of other contaminants while decreasing others. In groundwater, however, natural factors such as temperature and weathering of materials could likely be increasing the concentration of some variables and while these variables are having a significant association with other variables, the concentration of contaminants is increasing beyond drinking water standards. For instance, as temperature increased, an associated increase was observed in turbidity, TDS, colour, and total hardness. This implies that temperature is strongly contributing to the dissolution of variables that impact the colour and turbidity of water. Findings from other studies (Aladejana *et al.,* 2020; Amfo-Otu *et al.,* 2014; Khatri and Tyagi, 2015; Kurilic *et al.,* 2015) further support this suggestion that both natural and anthropogenic factors are together playing a key role in surface and groundwater water quality.

Table 2: Correlation coefficient matrix among surface water quality variables

Parameters	**pH**	**Temp**	**Col**	**Turb**	**TDS**	**TH**	**Cl^-**	**NO_3^-**	**Ca^{2+}**	**Mg^{2+}**	**F^-**	**Fe^{2+}**	**Pb^{2+}**	**PO_4^{3-}**	**K**	**TCC**	**E. coli**
pH	1.000																
Temp	-0.498	1.000															
Colour	-0.553	0.604	1.000														
Turbidity	**-0.832**	**0.925**	**0.747**	1.000													
TDS	**-0.714**	**0.793**	0.657	**0.714**	1.000												
Hardness	-0.675	**0.847**	**0.733**	**0.804**	**0.919**	1.000											
Chloride	-0.046	-0.029	-0.367	0.049	-0.239	-0.163	1.000										
Nitrate	-0.157	0.282	0.588	0.376	0.354	0.466	-0.031	1.000									
Calcium	0.528	-0.499	-0.447	-0.538	-0.498	0.485	0.237	-0.126	1.000								
Magnesium	0.433	-0.446	-0.339	-0.547	-0.407	0.543	0.094	**-0.710**	0.357	1.000							
Fluoride	0.162	-0.252	-0.325	-0.217	-0.321	-0.275	0.070	0.188	0.213	-0.263	1.000						
Iron	-0.610	0.059	**0.886**	**0.792**	0.073	-0.009	-0.549	-0.271	0.014	0.203	-0.108	1.000					
Lead	0.416	-0.182	-0.247	-0.353	-0.023	-0.088	0.058	0.134	0.369	0.047	0.062	0.001	1.000				
Phosphate	-0.086	0.413	0.346	0.274	0.438	0.377	-0.369	0.022	-0.369	-0.242	-0.418	0.455	0.100	1.000			
Potassium	-0.047	0.017	-0.052	0.035	-0.064	0.074	0.493	0.113	0.260	-0.043	-0.070	-0.165	0.227	-0.155	1.000		
Coliform	-0.191	0.218	0.141	0.259	0.219	0.344	-0.564	**0.751**	-0.082	**-0.770**	0.332	0.052	0.184	0.166	0.203	1.000	
E. coli	-0.067	-0.090	-0.084	-0.106	-0.032	-0.067	**-0.739**	**0.782**	0.131	-0.427	0.060	0.173	-0.013	0.054	0.179	0.504	1.000

Table 3: Correlation coefficient matrix among groundwater quality variables

Parameters	**pH**	**Temp**	**Col**	**Turb**	**TDS**	**TH**	**Cl^-**	**NO_3^-**	**Ca^{2+}**	**Mg^{2+}**	**F^-**	**Fe^{2+}**	**Pb^{2+}**	**PO_4^{3-}**	**K**	**TCC**	**E. coli**
pH	1.000																
Temp	0.250	1.000															
Colour	0.403	0.050	1.000														
Turbidity	-0.698	0.057	**0.869**	1.000													
TDS	**-0.716**	**-0.745**	0.245	**0.756**	1.000												
Hardness	0.606	0.037	-0.171	0.249	-0.191	1.000											
Chloride	0.189	0.377	0.156	0.076	0.078	0.014	1.000										
Nitrate	-0.114	0.378	0.051	0.097	0.108	-0.284	0.304	1.000									
Calcium	**-0.881**	-0.504	0.172	-0.166	0.248	0.593	-0.169	-0.339	1.000								
Magnesium	**-0.763**	-0.450	0.161	-0.367	0.451	**0.742**	-0.191	-0.257	**0.819**	1.000							
Fluoride	0.392	0.189	0.263	-0.231	0.142	0.349	0.400	-0.177	0.147	0.015	1.000						
Iron	-0.310	0.003	0.185	**0.766**	0.037	-0.286	-0.024	0.267	0.074	0.111	-0.240	1.000					
Lead	-0.053	-0.387	-0.175	0.068	-0.232	0.282	-0.452	-0.298	0.383	0.155	-0.366	-0.064	1.000				
Phosphate	-0.148	0.099	-0.047	0.483	-0.256	0.130	0.261	0.616	-0.232	-0.337	-0.276	0.220	0.011	1.000			
Potassium	0.467	-0.285	0.278	-0.203	-0.047	0.372	-0.128	0.523	0.353	0.012	0.294	-0.410	0.405	-0.096	1.000		
Coliform	-0.545	0.543	0.112	**0.719**	0.482	-0.168	-0.371	0.254	-0.140	0.022	-0.030	-0.223	-0.519	0.339	0.219	1.000	
E. coli	-0.471	0.481	0.032	**0.725**	0.352	-0.235	-0.396	0.121	-0.128	-0.005	-0.115	-0.119	-0.417	0.401	0.239	**0.953**	1.000

Non-carcinogenic health risk assessment

The chronic non-carcinogenic health risk posed by ingesting surface and groundwater for different age groups was computed and the mean values for CDIs and HQs are presented in table 4. The health risk was assessed using four parameters: nitrate, fluoride, iron, and lead (Kusa and Joshua, 2022). The order of severity in terms of HI contribution to health risk was as follows: $NO_3^- > F^- > Pb > Fe$ across all human classification in surface water, while $F^- > NO_3^- > Pb > Fe$ were the orders across adults, children, and infants in groundwater sources. This order indicates that nitrate contributed to over 60% of non-carcinogenic health impact for surface water while fluoride, lead, and iron contributed around 26%, 7%, and 0.5% respectively. Fluoride, on the other hand, contributed to most of the health hazards in the groundwater with over 50% (fluoride), 40% (nitrate), 8% (lead), and 0.6% (iron). These findings corroborate with the findings from Aher *et al.*, (2020); Golaki *et al.*, (2022); Mohammadi *et al.*, (2019) and supports our claim that in the study area, agricultural activity is considered the biggest threat to surface water while hydrogeochemical and weathering activities are the threat to groundwater.

Table 4: Mean chronic daily intake and hazard quotient for adults, children, and infants across surface and groundwater sources

Water	Human	Nitrate		Fluoride		Iron		Lead	
Source	**Group**	**CDI**	**HQ**	**CDI**	**HQ**	**CDI**	**HQ**	**CDI**	**HQ**
Surface	Adults	3.721	2.325	0.042	1.050	0.013	0.019	0.001	0.286
Water	Children	4.381	2.738	0.049	1.225	0.015	0.0214	0.002	0.571
	Infants	6.060	3.787	0.068	1.700	0.021	0.03	0.002	0.571
Ground	Adults	1.521	0.951	0.047	1.175	0.010	0.0143	0.0007	0.200
Water	Children	1.788	1.118	0.056	1.400	0.012	0.0171	0.0008	0.229
	Infants	2.475	1.547	0.077	1.925	0.017	0.0243	0.001	0.286

The total health hazard indicates that none of the water samples were within the health risk classification (Table 5) according to USEPA, (1999). Surface water showed THI as a medium, severe, and severe for adults, children, and infants respectively (Fig. 4). similarly, groundwater showed THI of moderate range for all human groups. Although variables like nitrate in groundwater, fluoride in both surface and ground were all within national standards, the THI values show a moderate to severe health risk which further supports findings from Adimalla and Qian, (2019); Adimalla and Li, (2019); Chen *et al.*, (2017) that water quality variables can be within stipulated guidelines yet cause a long-term health risk, particularly in children and infants.

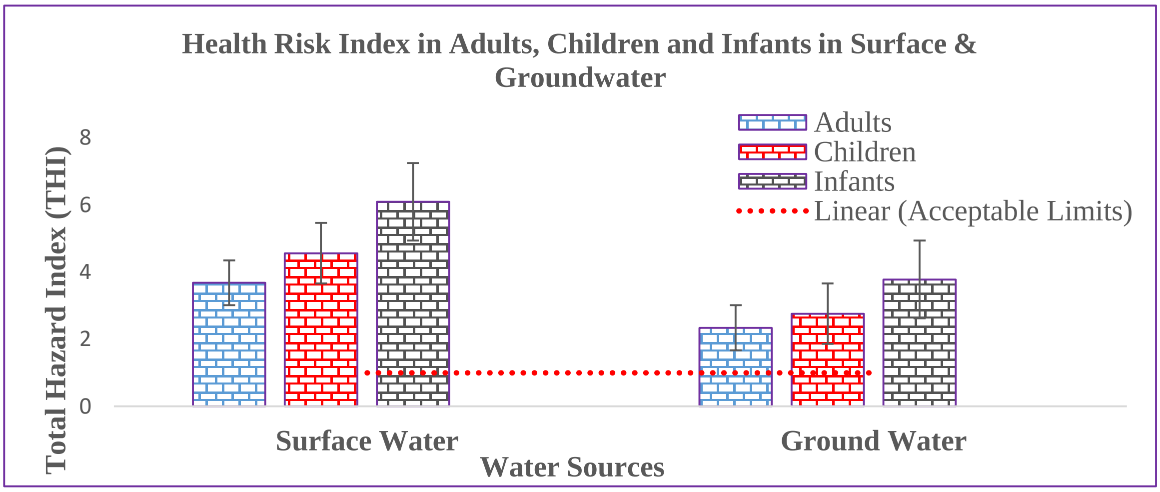

Figure 4: Total hazard index in adults, children, and infants across surface and groundwater

Table 5. Chronic (non-carcinogenic) health risk classification

Risk Level	HI	Chronic risk description
1	< 0.1	Negligible
2	≥ 0.1 < 1	Low
3	≥ 1 < 4	Medium
4	≥ 4	High or Severe

CONCLUSION

The study set out to investigate the current state of surface and groundwater quality in Ibi and the association between water quality variables. The chronic health impact has also assessed the findings show that certain activities particularly waste management and agricultural activities are amongst the threat to water security within the study area. In addition, weathering of bedrock and other geochemical reactions is also likely to deteriorate groundwater quality with associated health risks on all human groups. Although children and infants were found to be at severe health risk, all human groups including adults are at long-term risk. A carcinogenic health risk assessment is recommended to understand the state of water quality and also, adequate measures to minimize the excessive use of agrochemicals and improper disposal of waste are highly encouraged. Finally, nature-based solutions particularly around surface water are recommended to protect surface water from external contamination.

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