

Assessment of Microbial Quality, Irrigation Suitability, and Human Health Risks of Surface Water Along the Middle Reaches of Rivers State, Nigeria

¹Elias, P. D., ²Ideriah, T. J. K., ¹Dollah, O. C & ¹Gobo, A. E

¹Institute of Geosciences and Environmental
Management, Rivers State University

Nkpolu-Oroworukwo Port Harcourt, Rivers State, Nigeria

²Institute of Pollution Studies Rivers State

University Nkpolu-Oroworukwo Port Harcourt, Rivers State, Nigeria

Corresponding Email: osademe.dollah@ust.edu.ng

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Abstract

*This study comprehensively assessed the microbiological content, Water Quality Index (WQI), agricultural irrigation suitability, and human health risks associated with surface water across Iwofe, Tombia, Bukuma, and Bakana along the Niger Delta river system. Field data from fifteen water samples were analyzed using standard analytical, mathematical, and probabilistic Monte Carlo simulation frameworks. The microbiological evaluation revealed dense total heterotrophic bacterial populations (averaging) sustained by organic loads and tropical conditions. Weighted arithmetic WQI values ranged from 948 at Iwofe to 1,464 at Bakana, classifying all sampled surface waters as entirely **unsuitable for drinking purposes**. Irrigation indices, including Sodium Percentage () and Sodium Adsorption Ratio (), coupled with Wilcox and USSS diagram classifications, indicated severe high-salinity and high-sodium hazards that threaten soil permeability. Furthermore, human health risk assessments demonstrated that cumulative Hazard Index values exceeded safe thresholds (), driven by extreme localized arsenic and chromium concentrations at Tombia (oral Hazard Quotient up to for children). Carcinogenic risks () severely exceeded US EPA safety standards, with pediatric cohorts exhibiting heightened vulnerability. The findings confirm that chronic anthropogenic pressures have severely degraded the river ecosystem, posing acute non-carcinogenic toxicity and lifetime cancer risks. Consequently, urgent regulatory interventions, restricted direct consumption, agricultural pre-treatment, and targeted bioremediation are imperative.*

Keywords: *Water Quality Index, Microbial Content, Irrigation Suitability, Heavy Metals, Health Risk Assessment, Niger Delta.*

Introduction

Aquatic environments within quickly growing estuarine and delta regions encounter significant human-induced stress, putting surface water resources at risk due to contamination from microbes, industrial waste releases, and chemical deterioration (Opara et al., 2021). The New Calabar River located in Rivers State, Nigeria, plays a crucial role as a water source that supports local fishing

activities, household purposes, and agricultural watering; nonetheless, increasing industrial activities, oil exploration, and urban runoff have steadily damaged its ecological balance (Anyanwu et al., 2021). It is essential to evaluate the drinkability, suitability for farming, and potential health risks for people linked to these surface waters to protect at-risk communities living near the riverbank (Chukwu et al., 2019). While many investigations have reported on general pollution levels in Niger Delta water bodies, thorough assessments that encompass microbiological loads, the National Sanitation Foundation Water Quality Index (NSF-WQI), agricultural irrigation hazards (like SAR, SSP, and Kelly's Ratio), and probabilistic evaluations of health risks for humans through Monte Carlo methods are needed for effective environmental stewardship. Consequently, this research examines the microbial levels, overall water quality index, suitability for irrigation, along with both non-cancerous and cancer-related health risks associated with surface water at significant monitoring points such as Iwofe, Tombia, Bukuma, and Bakana

Materials and Methods

The methodology details the systematic collection, field preparation, laboratory analysis, and mathematical modeling frameworks applied to evaluate surface water and soil quality along the Middle Reaches of the New Calabar River. Field data collection involved the systematic acquisition of fifteen water samples along the Middle Reaches of the New Calabar River utilizing a purposive sampling strategy to ensure spatial representativeness. Geographic coordinates of all sampling locations were recorded using a Garmin Channel 78 GPS model. All sample containers were rinsed in situ with the target water body prior to collection via a stainless-steel surface water sampler. Specifically, dissolved oxygen and biochemical oxygen demand samples were collected in two hundred fifty milliliter amber bottles and immediately fixed with two milliliters of Winkler I and II reagents, followed by incubation for five days at twenty degrees Celsius. Physicochemical parameters were gathered in two-liter polyethylene containers, whereas heavy metal sample aliquots were preserved in plastic vials acidified with two percent nitric acid to maintain sample integrity. Microbiological samples were drawn into sterile vials. All laboratory measurements were conducted in triplicate at ambient room temperature, recording mean values. Soil samples were concurrently collected from surrounding dumpsites using a stratified random sampling design with a three-inch nickel-plated carbon steel hand auger at surface, spanning zero to fifteen centimeters, and subsurface, spanning fifteen to thirty centimeters, depths. Composite soil samples were homogenized, sealed in zip-locked plastic bags, and transported in iced coolers to prevent thermal degradation. Laboratory procedures followed standard analytical protocols. Chloride concentrations were determined by titrating fifty milliliters of water sample against silver nitrate using potassium chromate as an indicator. Ammonia was quantified using sodium nitroprusside and a complexing oxidizing agent, measuring absorbance at six hundred thirty nanometers. Total hardness was measured by titrating twenty-five milliliters of sample against zero point zero one molar ethylenediaminetetraacetic acid utilizing Eriochrome Black T indicator. Sulphate and phosphate contents were analyzed spectrophotometrically using barium chloride and stannous chloride methods, recording absorbance at four hundred twenty nanometers and six hundred ninety nanometers, respectively. Heavy metal concentrations in both water and digested soil matrices were quantified via Atomic Absorption Spectrophotometry, aspirating atomized samples into a flame to measure characteristic absorption wavelengths against standard reference lamps. Soil pH was evaluated using a glass electrode in a one to two point five soil-water suspension. Total alkalinity, chemical oxygen demand via dichromate digestion, biological oxygen demand, total

nitrogen via the macro-Kjeldahl digestion method, available phosphorus using the Bray No. one method, exchangeable cations through ammonium acetate extraction and flame photometry, particle size distribution via the hydrometer method under Stokes' law, total organic carbon through the Walkley-Black wet combustion method, moisture content, bulk density, and total porosity were all determined using established standard analytical procedures. Microbiological quality was assessed using the Most Probable Number technique for total and faecal coliform bacteria. Diluted water samples were inoculated into single-strength and double-strength MacConkey purple broth media containing inverted Durham tubes. Inoculated tubes were incubated at thirty-seven degrees Celsius for twenty-four hours, after which gas production and color changes were recorded and referenced against standard statistical probability tables. The suitability of surface water for drinking was evaluated using the National Sanitation Foundation Water Quality Index approach. The quality rating scale was calculated using the equation: where indicates the concentration of the -th parameter and represents its standard permissible value. The relative weight was computed as:

such that is a proportionality constant. The overall water quality index was determined as: Agricultural irrigation quality was assessed through hydrochemical parameters including the Sodium Absorption Ratio, Soluble Sodium Percentage, Residual Sodium Carbonate, Permeability Index, Magnesium Absorption Ratio, and Kelly Ratio. The suitability of irrigation water was conceptualized as a functional relationship expressed as:

where represents irrigation water quality, denotes soil type, indicates salt tolerance, represents climate, and reflects soil drainage characteristics. Specifically, the Sodium Absorption Ratio was calculated as:

where ionic concentrations are expressed in milliequivalents per liter. The Soluble Sodium Percentage was evaluated using:

Residual Sodium Carbonate was determined via:

The Permeability Index was expressed as:

The Magnesium Absorption Ratio was computed as:

And the Kelly Ratio was formulated as:

Hydrochemical facies and evolutionary processes were further classified using Piper trilinear diagrams, Durov diagrams, Wilcox diagrams, and Gibbs diagrams. Human health risks associated with heavy metal exposure via ingestion and dermal contact for adults and children were quantified using standardized exposure models. The Average Daily Dose was calculated via US Environmental Protection Agency protocols. Non-carcinogenic risks were evaluated using the Target Hazard Quotient and Hazard Index, where the Target Hazard Quotient is expressed as:

with representing the average daily dose and denoting the reference dose. The cumulative non-carcinogenic risk across pathways was determined by the Hazard Index:

Carcinogenic risks were estimated using the relationship:

where represents the chemical-specific slope factor. To evaluate contamination severity in soil matrices, the Enrichment Factor and Pollution Load Index were computed. The Enrichment Factor was calculated as:

where represents the target metal and denotes the reference normalizing metal, iron. Furthermore, the Pollution Load Index was determined using the geometric mean of contamination factors across studied metals:

where represents the contamination factor for each respective metal.

Results

Research Question One: To determine the microbial content of the surface water.

Table 1: Microbial Content of Surface Water Across the Study Locations

Parameter	Unit	Iwofe	Tombia	Bukuma	Bakana
FCB	MPN/100 ml	5.00 ± 7.07	3.50 ± 3.54	0.00 ± 0.00	0.00 ± 0.00
TCB	cfu/ml	12.00 ± 1.41	5.50 ± 3.54	0.00 ± 0.00	18.00 ± 25.46
THB	cfu/ml	197.00 ± 258.80	216.00 ± 231.93	1.10E+05 ± 1.55E+05	169.50 ± 156.27

Table 1 shows Microbial Content across Sampling Locations, the spatial distribution of faecal coliform bacteria (FCB), total coliform bacteria (TCB), and total heterotrophic bacteria (THB) is detailed across Bukuma, Bakana, Iwofe, and Tombia. FCB counts range from 0.00 MPN/100 ml at Bukuma and Bakana up to 5.00 MPN/100 ml at Iwofe, while TCB values fluctuate between 0.00 cfu/ml at Bukuma and a peak of 18.00 cfu/ml at Bakana. Notably, total heterotrophic bacteria exhibit extreme spatial variation, with Bukuma recording an exceptionally high concentration of cfu/ml compared to much lower levels observed at Iwofe, Tombia, and Bakana.

Table 2: Summary Statistics and Table 4.20: Analysis of Variance (ANOVA) for Microbial Parameters in Surface Water

SUMMARY	Count	Sum	Average	Variance
FCB	4	8.5	2.125	6.39583333
TCB	4	35.5	8.875	61.0625
THB	4	110582.5	27645.625	3014330623
Iwofe	3	214	71.3333333	11856.3333
Tombia	3	225	75	14911.75
Bukuma	3	110000	36666.6667	4033333333
Bakana	3	187.5	62.5	8667.75

Source of Variation	SS	MS	F	P-value	F crit
Rows	2037270785	2	1018635392	1.01365719	0.417583
Columns	3013525317	3	1004508439	0.99959928	0.454875
Error	6029466754	6	1004911126		4.757063
Total	11080262856	11			

Table 2 revealed the summary statistics of microbial parameters; the aggregate distributional characteristics of the microbiological indicators are presented. Total heterotrophic bacteria (THB) dominate the summary metrics with the highest mean count of 27,645.63 cfu/ml and a massive variance of, reflecting wide dispersion across the sampled water bodies. Conversely, faecal coliform bacteria (FCB) record the lowest mean value of 2.13 MPN/100 ml, indicating lower overall concentrations relative to heterotrophic populations.

Table 3: Pearson Correlation Matrix of Microbial Parameters in Surface Water

	<i>FCB</i>	<i>TCB</i>	<i>THB</i>
FCB	1		
TCB	0.064306	1	
THB	-0.55995	-0.75739	1

Table 3 shows Pearson Correlation Matrix of Microbial Parameters in Surface Water, the quantitative relationships between faecal coliform bacteria (FCB), total coliform bacteria (TCB), and total heterotrophic bacteria (THB) are analyzed. A slight positive correlation is observed between FCB and TCB ($r = 0.064$), while THB reveals moderate to strong negative correlations with both FCB ($r = -0.560$) and TCB ($r = -0.757$).

Table 4: Pearson Correlation Matrix of Microbial Indicators and Physicochemical Parameters in Surface Water

Variable	FCB	TCB	THB	pH	Temperature	Turbidity	DO	BOD	COD
FCB	1								
TCB	0.0643	1							
THB	-0.5600	-0.757	1						
pH	-0.6098	-0.829	0.9321	1					
Temperature	-0.6697	-0.745	0.9799	0.9759	1				
Turbidity	-0.0831	-0.974	0.6565	0.8081	0.6844	1			
DO	-0.3409	0.9104	-0.5269	-0.534	-0.4538	-0.8546	1		
BOD	-0.2374	-0.517	0.1603	0.5046	0.3150	0.6962	-0.3020	1	
COD	-0.7696	-0.484	0.9349	0.8356	0.9331	0.3813	-0.1938	0.0142	1

Table 4 shows the results Pearson Correlation Matrix of Microbial Indicators and Physicochemical Parameters in Surface Water, the connections between bacterial populations and environmental factors are detailed. THB displays very strong positive correlations with pH ($r = 0.932$), temperature ($r = 0.980$), and Chemical Oxygen Demand ($r = 0.935$), but indicates a moderate negative correlation with Dissolved Oxygen ($r = -0.527$). In contrast, TCB has a strong positive relationship with Dissolved Oxygen ($r = 0.910$) and negative associations with turbidity ($r = -0.974$) and pH ($r = -0.829$), while FCB shows moderate to strong negative correlations with Chemical Oxygen Demand ($r = -0.770$), temperature ($r = -0.670$), and pH ($r = -0.610$).

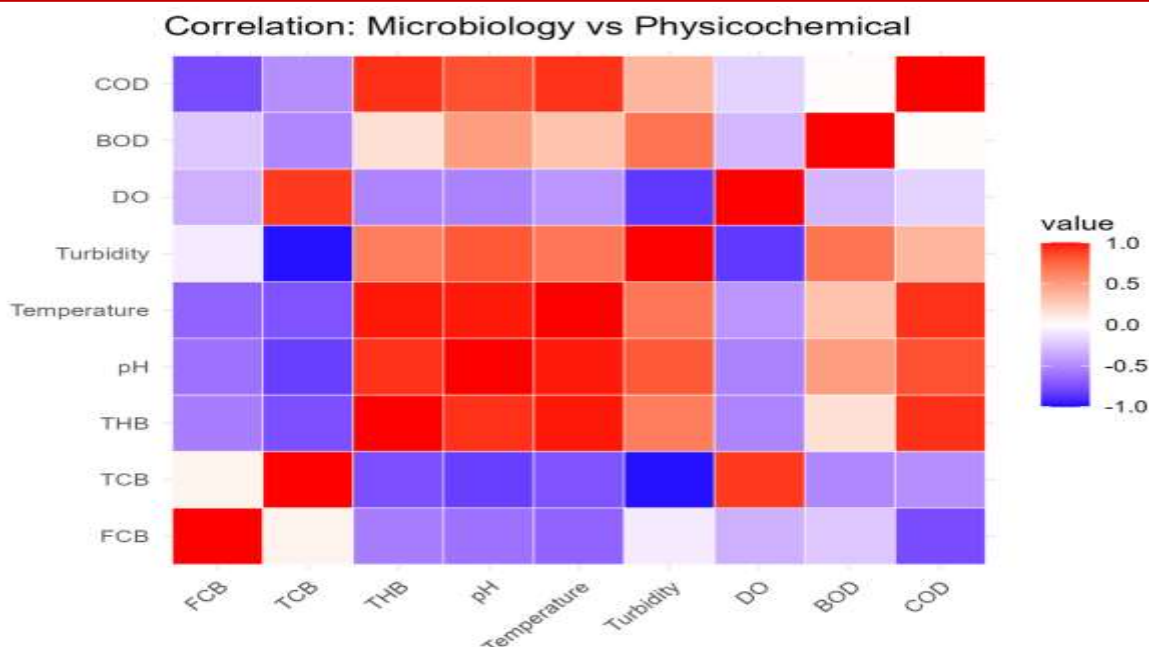


Figure 1: Correlation Heatmap of Microbial Indicators and Physicochemical Parameters in Surface Water

Figure 1 shows Correlation Heatmap of Microbial Indicators and Physicochemical Parameters in Surface Water, the correlation coefficients from Table 4 are represented visually using a color grading system. The heatmap showcases specific clusters with strong positive correlations—such as the relationships between THB, temperature, pH, and COD—alongside contrasting clusters featuring negative gradients like TCB with turbidity and FCB with chemical oxygen demand.

Table 5: Pearson Correlation Matrix of Microbial Indicators and Heavy Metal Concentrations in Surface Water

Variable	FCB	TCB	THB	Ni	Cr	Fe	Mn	As
FCB	1							
TCB	0.0643	1						
THB	-0.5600	-0.7574	1					
Ni	-0.4853	-0.8876	0.9598	1				
Cr	0.1865	0.7704	-0.9059	-0.8469	1			
Fe	-0.2679	0.2617	-0.4253	-0.2641	0.7365	1		
Mn	0.3625	-0.2879	-0.3331	-0.0552	0.3774	0.6255	1	
As	0.3614	-0.2905	-0.3305	-0.0524	0.3751	0.6246	1.0000	1

Table 5 shows the results of Pearson Correlation Matrix of Microbial Indicators and Heavy Metal Concentrations in Surface Water, the relationships between microbial populations and trace heavy metal levels are illustrated. THB presents a strong positive correlation with Nickel ($r = 0.960$) and a significant negative correlation with Chromium ($r = -0.906$). TCB shows a contrasting behavior, having a strong positive correlation with Chromium ($r = 0.770$) and a negative association with Nickel ($r = -0.888$), while Manganese and Arsenic reveal a perfect positive inter-metal correlation ($r = 1.000$) along with weak to moderate connections to bacterial parameters.

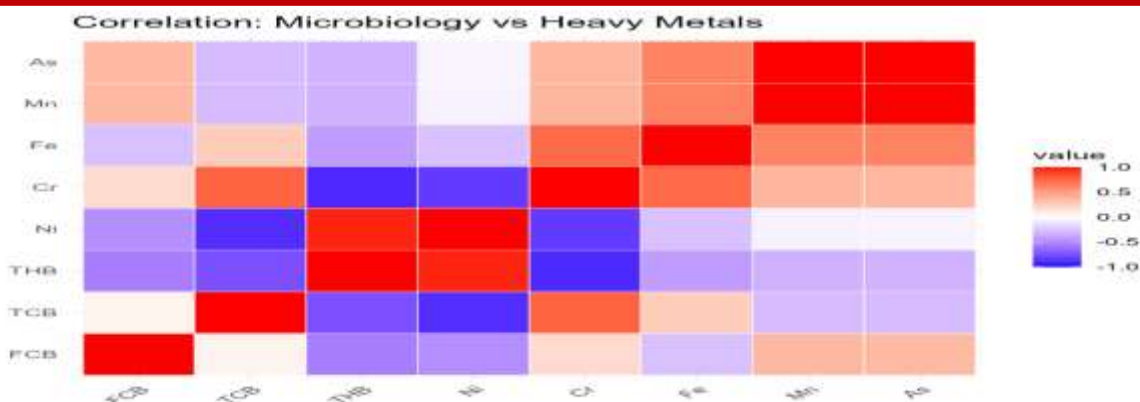


Figure 2: Correlation Heatmap of Microbial Indicators and Heavy Metal Concentrations in Surface Water

Figure 2 contains Correlation Heatmap of Microbial Indicators and Heavy Metal Concentrations in Surface Water, the linear relationships between microbial counts and heavy metals are depicted via a visual color scale. The illustration highlights the oppositional response patterns of TCB and THB concerning Nickel and Chromium, as well as the strong collinearity indicated by darker shades between Arsenic and Manganese concentrations.

Research Objective Two: Determine the water quality index of the river water.

Table 6: Water Quality Index (WQI) and Classification of River Water across the Study Locations

Location	WQI	WQI Class
IWOFE	948	Unsuitable
TOMBIA	1288	Unsuitable
BUKUNA	1138	Unsuitable
BAKANA	1464	Unsuitable

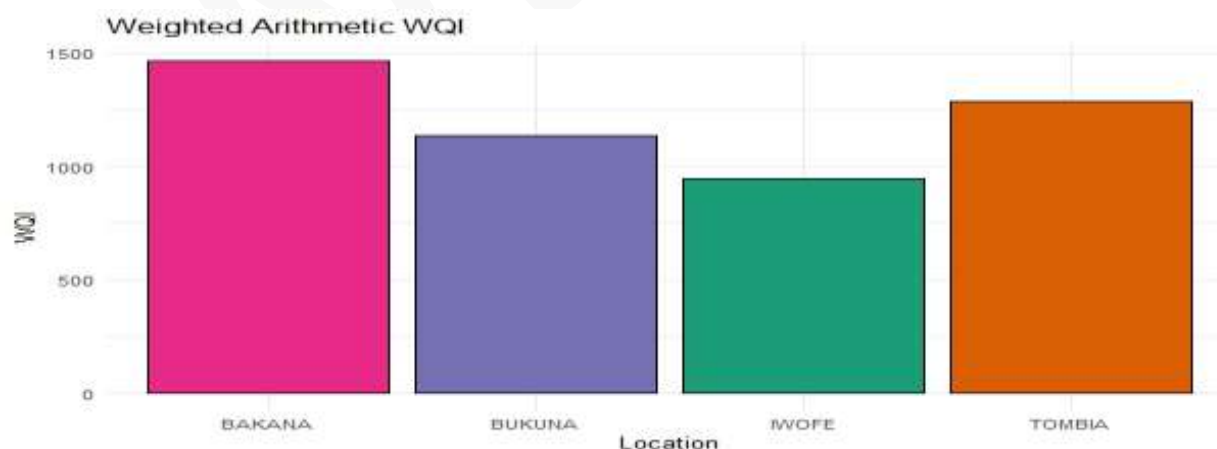


Figure 3: Weighted Arithmetic Water Quality Index (WQI) of River Water across Sampling Locations

Table 7: Irrigation Indices of Surface Water across the Study Locations

Location	Na%	SSP	SAR	PI	KR	RSC	PS
IWOFE	81.935	80.092	30.032	80.726	4.023	-27.045	23.366
TOMBIA	84.648	83.407	40.084	83.747	5.027	-31.345	25.268
BUKUNA	48.29	46.234	13.943	46.463	0.86	-131.097	25.788
BAKANA	76.165	74.319	32.16	74.759	2.894	-60.581	15.331

Na%- Sodium percentage

SSP- Sodium soluble percentage

SAR- Sodium absorption ratio

PI- Permeabilty index

KR- Kelly's ratio

RSC- Residual sodium carbonate

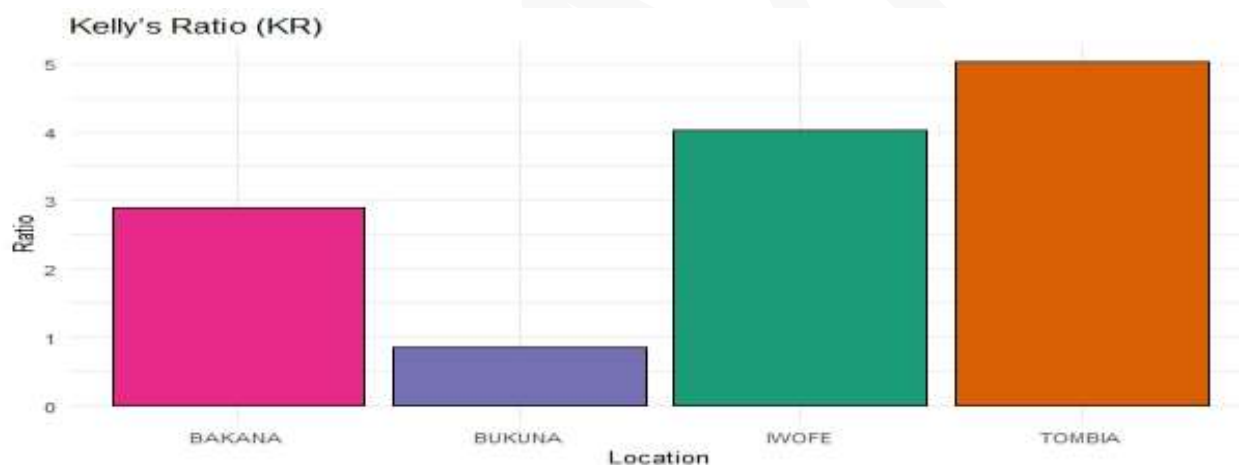


Figure 4: Kelly's Ratio (KR) of Surface Water Across the Study Locations

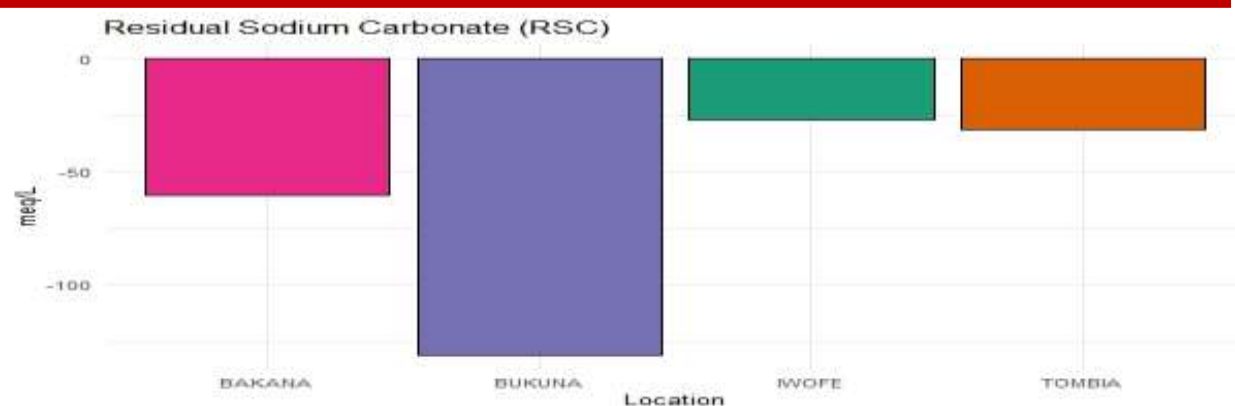


Figure 5: Residual Sodium Carbonate (RSC) of Surface Water across the Study Locations

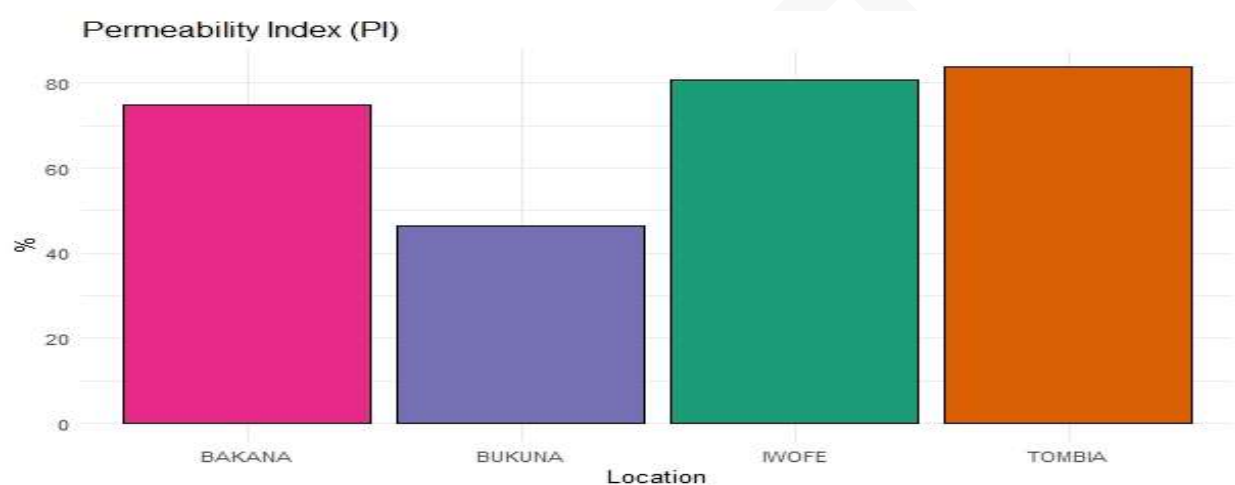


Figure 4.6: Permeability Index (PI) of Surface Water Across the Study Locations

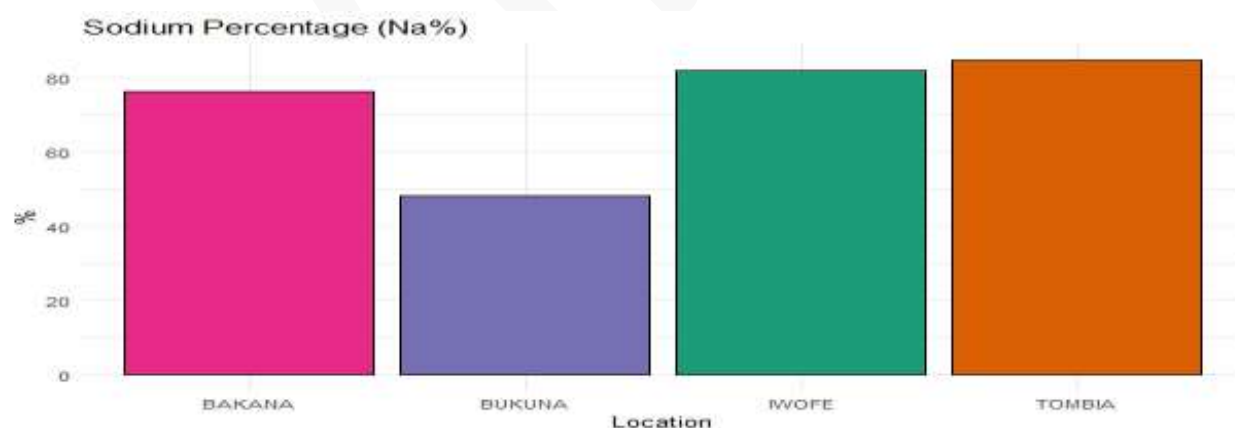


Figure 7: Sodium Percentage (Na%) of Surface Water Across the Study Locations

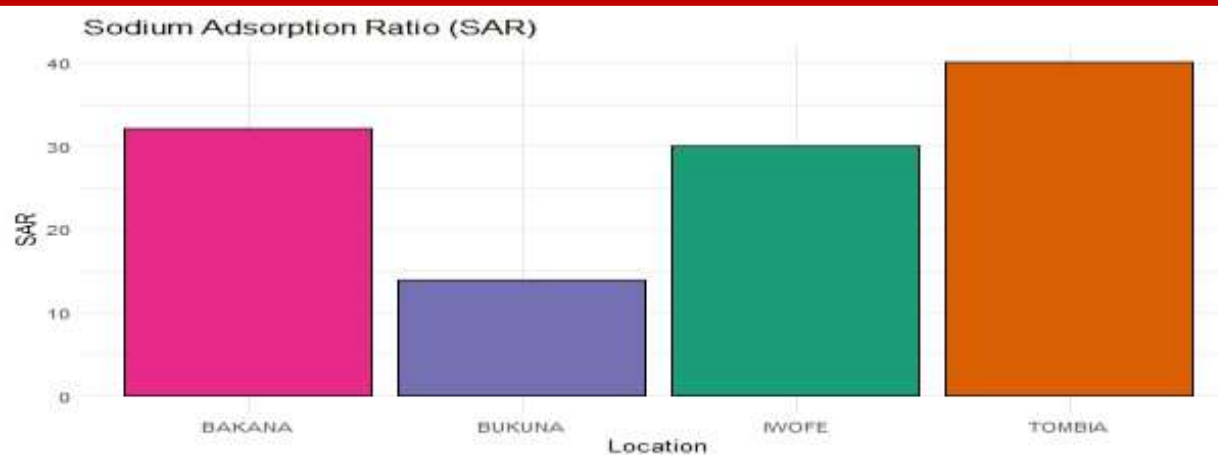


Figure 8: Sodium Adsorption Ratio (SAR) of Surface Water across the Study Locations

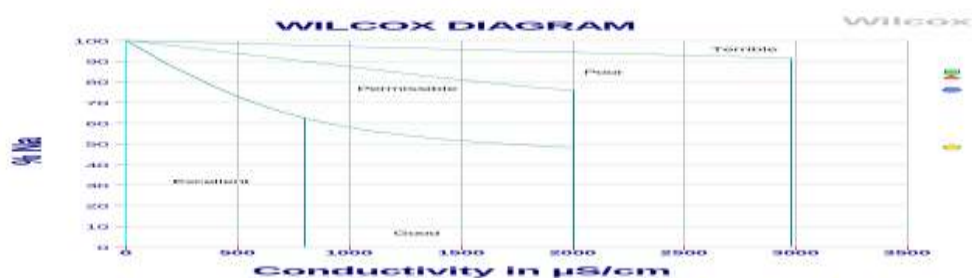


Figure 9: Wilcox Diagram Showing Sodium Hazard Classification of Surface Water

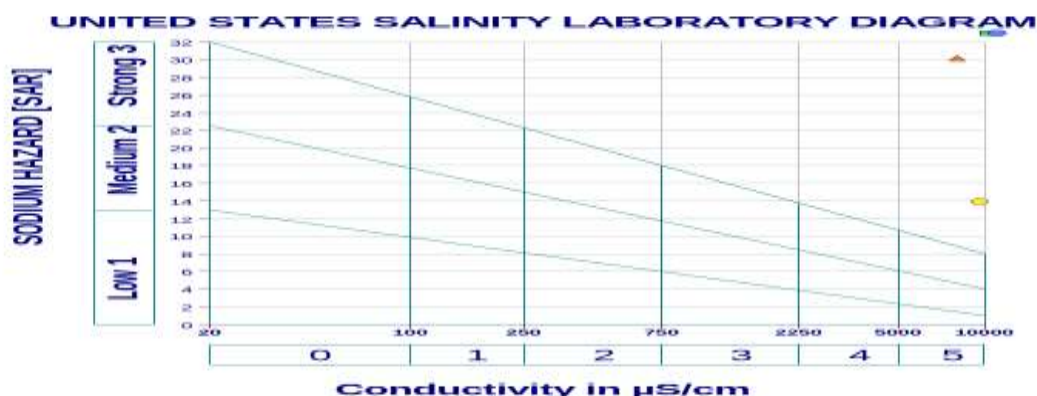


Figure 10: United States Salinity Laboratory (USSL) Diagram Showing Sodium and Salinity Hazards of Surface Water

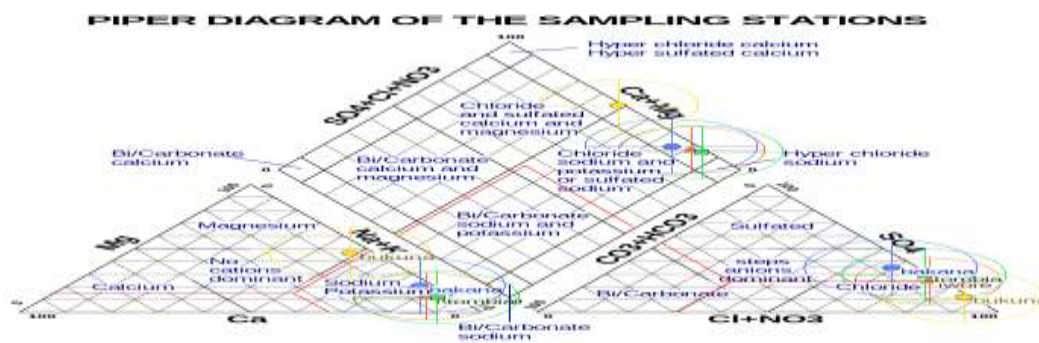


Figure 11: Piper Diagram Showing Hydrochemical Facies of Surface Water Across Sampling Locations

Table 6 and Figure 3 show that weighted arithmetic WQI values ranged from 948 at Iwofe to 1464 at Bakana, with intermediate values of 1138 at Bukuna and 1288 at Tombia. The spatial ranking of WQI values followed the order Bakana > Tombia > Bukuna > Iwofe, reflecting progressive variation in cumulative physicochemical load across the river system (Table 4.6; Figure 4). Irrigation indices presented in Table 7 and Figures 5–9 indicate that sodium percentage (Na%) ranged from 48.29% at Bukuna to 84.65% at Tombia, while soluble sodium percentage (SSP) varied from 46.23 to 83.41 across locations. Sodium adsorption ratio (SAR) values ranged between 13.94 at Bukuna and 40.08 at Tombia, with Iwofe and Bakana recording values of 30.03 and 32.16, respectively (Table 7; Figure 9).

Permeability index (PI) values varied from 46.46 at Bukuna to 83.75 at Tombia, whereas Kelly's ratio (KR) ranged from 0.86 at Bukuna to 5.03 at Tombia (Table 4.7; Figures 4.8 and 4.30). Residual sodium carbonate (RSC) values were negative at all locations, ranging from -27.05 at Iwofe to -131.10 at Bukuna, as shown in Table 7 and Figure 10. The Wilcox diagram (Figure 3) shows that all samples plotted within the high sodium percentage field across varying electrical conductivity ranges, with Bukuna positioned closer to the lower sodium boundary compared to other locations. The USSL and Piper diagrams (Figures 10 and 11) indicate that samples clustered within high salinity-high sodium hazard zones and predominantly within the sodium-chloride hydrochemical facies.

Research Objective Three: To determine Health risk assessment of the measured water

Table 8: Health Risk Assessment Indices (HQ, HI, and CR) for Adult and Child Exposure to Surface Water

CATEGORIES	Location	BAKANA	BUKUNA	IWOFE	TOMBIA
ADULT	HQ oral	3.223697	13.75801	4.770235	11065.07
	HQ dermal	0.929895	2.176267	0.754646	1750.293
	CR oraL	0.004259	0.005995	0.001932	6.076545
	CR dermal	0.040424	0.003312	0.016978	0.028836
	HI oral	1.077116	2.800005	1.117622	2998.075
	HI dermal	0.271948	0.445656	0.239167	474.3259
CHILDREN	HQ oral	12.30684	52.45195	18.12982	41483.87
	HQ dermal	2.747239	6.410794	2.216118	5070.25
	CR oraL	0.014482	0.021273	0.00773	4.531349
	CR dermal	0.106203	0.006448	0.056687	0.049207
	HI oral	4.119252	10.67018	4.245361	11860.76
	HI dermal	0.80388	1.312002	0.702956	1449.901

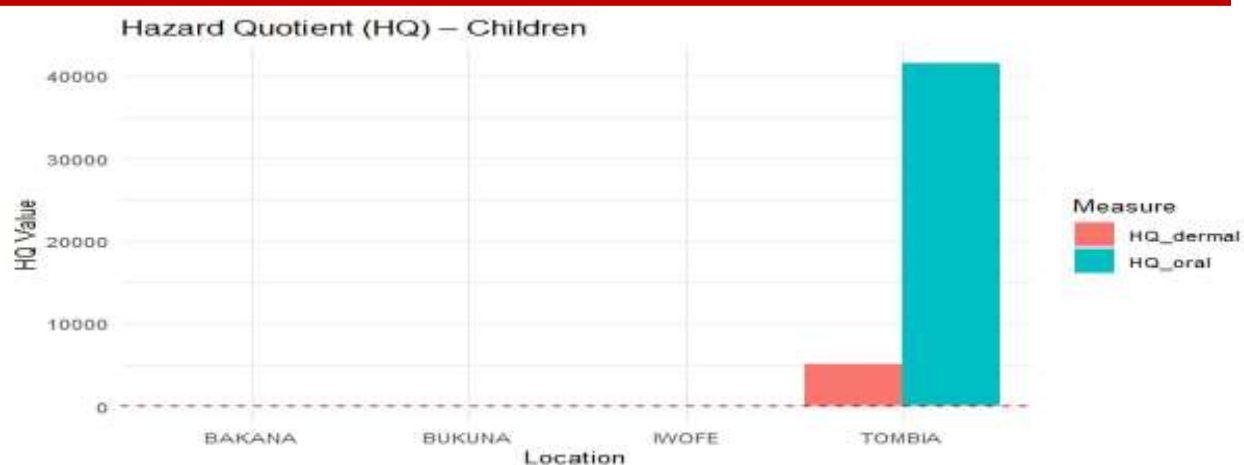


Figure 12: Hazard Quotient (HQ) for Children via Oral and Dermal Exposure

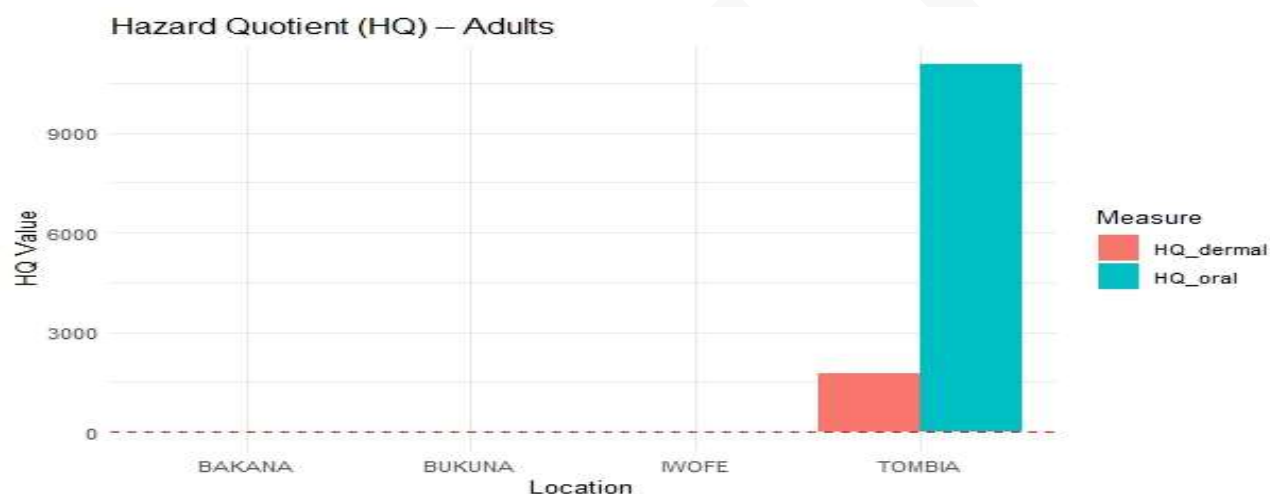


Figure 4.13: Hazard Quotient (HQ) for Adults via Oral and Dermal Exposure

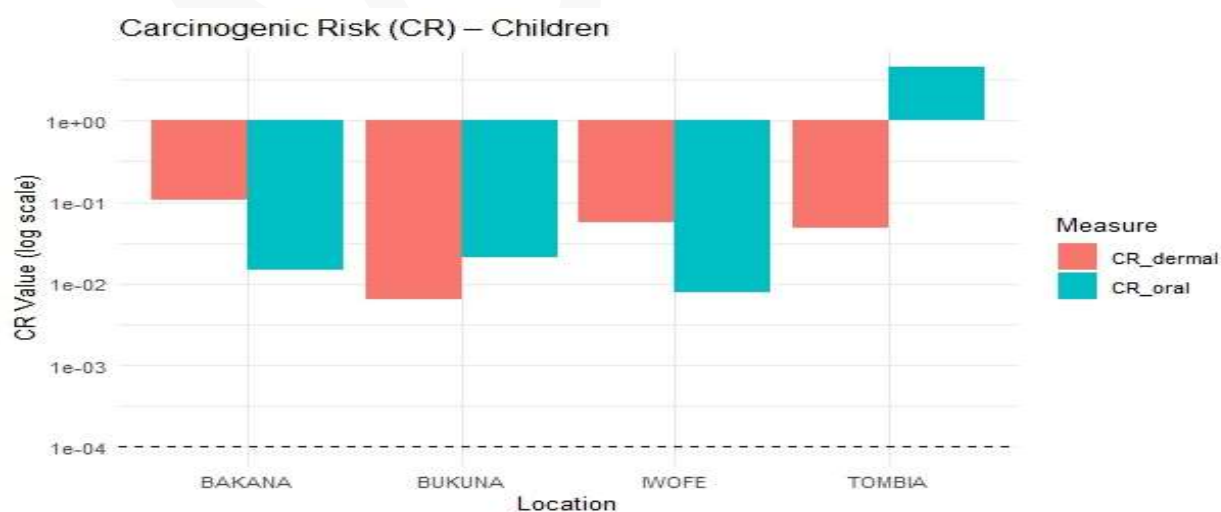


Figure 14: Carcinogenic Risk (CR) for Children via Oral and Dermal Exposure

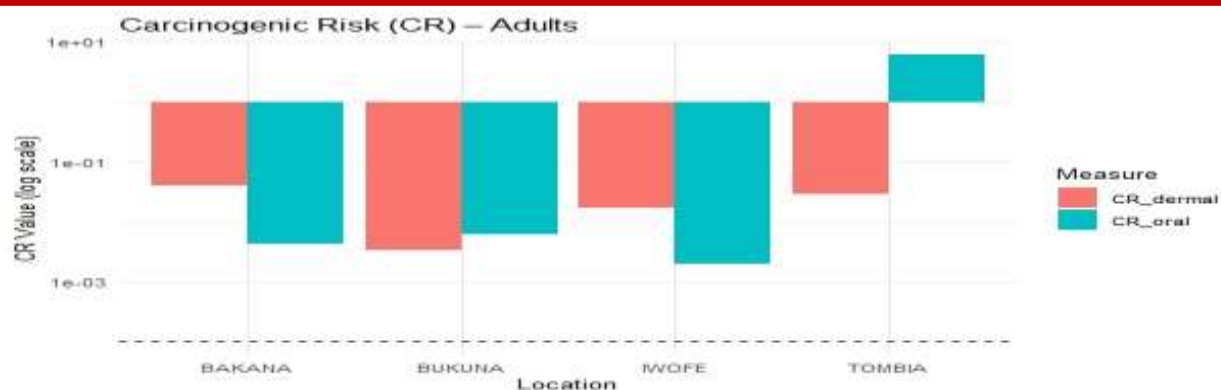


Figure 15: Carcinogenic Risk (CR) for Adults via Oral and Dermal Exposure

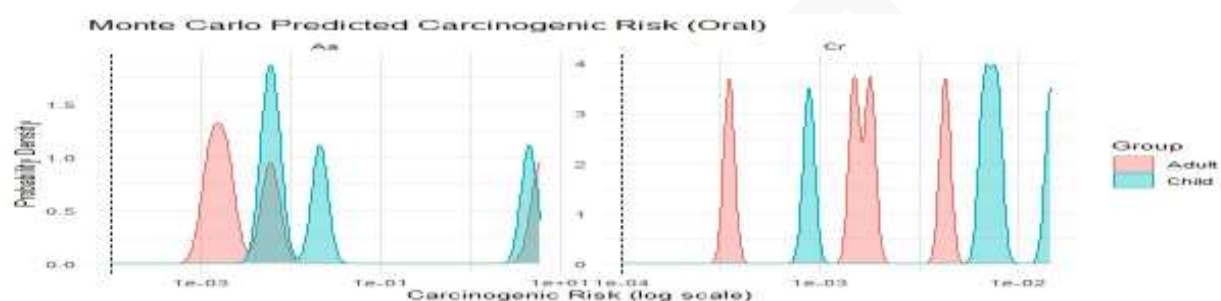


Figure 16: Monte Carlo Predicted Carcinogenic Risk Distribution (Oral Exposure)

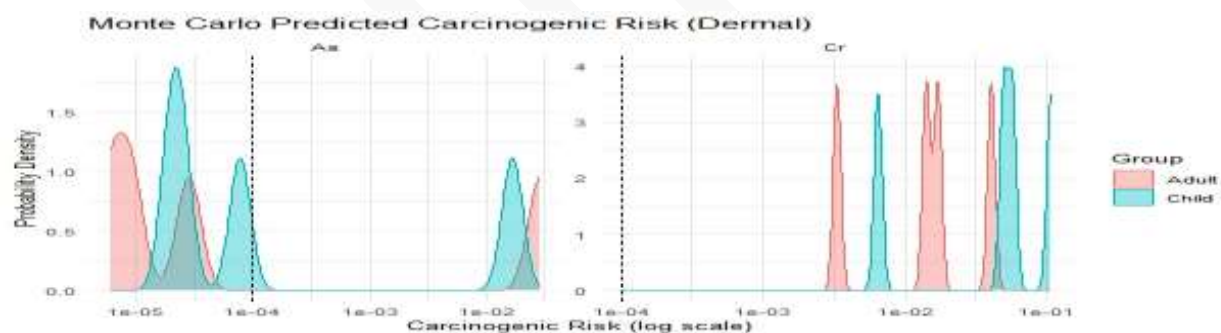


Figure 17: Monte Carlo Predicted Carcinogenic Risk Distribution (Dermal Exposure)

Table 8 and Figures 12–13 show that non-carcinogenic risk via oral exposure was dominant across all locations, with adult oral HQ values ranging from 3.22 at Bakana to 13.76 at Bukuna and peaking sharply at 11,065.07 at Tombia, while corresponding dermal HQ values ranged from 0.75 at Iwofe to 1,750.29 at Tombia. For children, oral HQ values were substantially higher, varying from 12.31 at Bakana to 52.45 at Bukuna, with an extreme maximum of 41,483.87 at Tombia, whereas dermal HQ values ranged from 2.22 at Iwofe to 5,070.25 at Tombia (Table 8; Figure 15). The cumulative hazard index (HI) for adults ranged from 1.08 to 2,998.08 for oral exposure and from 0.24 to 474.33 for dermal exposure, with the highest values consistently recorded at Tombia (Table 8; Figure 13). Similarly, children exhibited higher cumulative HI values, with oral HI ranging from 4.12 to 10.67 and dermal HI ranging from 0.70 to 1,449.90, again with Tombia

showing the maximum values (Table 8). Carcinogenic risk results presented in Figures 4.14 and 4.39 indicate that adult oral CR values ranged from 1.93×10^{-3} at Iwofe to 6.08 at Tombia, while dermal CR values ranged between 3.31×10^{-3} at Bukuna and 4.04×10^{-2} at Bakana. For children, oral carcinogenic risk values ranged from 7.73×10^{-3} at Iwofe to 4.53 at Tombia, whereas dermal CR values ranged from 6.45×10^{-3} at Bukuna to 1.06×10^{-1} at Bakana (Table 8; Figures 14–4.15). Monte Carlo simulation results for oral exposure (Figure 16) showed probability distributions for arsenic and chromium largely centered between 10^{-3} and 10^{-1} for both adults and children, with child distributions consistently shifted toward higher risk values. For dermal exposure, the Monte Carlo simulations (Figure 17) produced broader distributions generally spanning 10^{-4} to above 10^{-2} , with higher probability densities observed for chromium relative to arsenic across both population groups.

Discussion of Findings

The microbiological analysis conducted in Iwofe, Tombia, Bukuma, and Bakana (refer to Table 1) indicates inconsistency in bacterial populations across various locations. The presence of faecal coliform bacteria (FCB) ranged from 0.00 MPN/100 ml in Bukuma and Bakana to 5.00 MPN/100 ml in Iwofe, while total coliform bacteria (TCB) reached its highest at 18.00 cfu/ml in Bakana. Significantly, total heterotrophic bacteria (THB) represented the bulk of the biological load (see Table 2), showing an average value of 27,645.63 cfu/ml and a maximum concentration of 1.10×10^5 cfu/ml in Bukuma. The variance analysis (see Table 4.20) revealed that the differences among microbial species ($F = 1.01$, $p = 0.418$) and sampling points ($F = 1.00$, $p = 0.455$) were not statistically significant at a 5% threshold. Pearson correlation evaluations (refer to Table 4.3, Table 4.4, Table 4.5, Figure 4.1, Figure 4.2) indicated robust positive relationships between THB and environmental variables such as pH ($r = 0.932$), temperature ($r = 0.980$), Chemical Oxygen Demand ($r = 0.935$), and Nickel ($r = 0.960$). On the other hand, TCB showed a positive correlation with Dissolved Oxygen ($r = 0.910$) and Chromium ($r = 0.770$). These results coincide with the findings from water quality assessments by Opara et al. (2021) and Chukwu et al. (2019), which suggested that the heightened levels of heterotrophic bacteria within the Niger Delta estuarine waters are supported by increased organic matter influx and warm tropical conditions.

The Weighted Arithmetic Water Quality Index calculated (see Table 6, Figure 3) reported figures ranging from 948 at Iwofe to 1,464 at Bakana (in order: Bakana > Tombia > Bukuma > Iwofe). Since all WQI results significantly surpass the acceptable limit of 100, the surface water in each of the four sites is deemed Unsuitable for Drinking Purposes. Analysis of agricultural irrigation indicators (refer to Table 7, Figures 4.4–4.11) highlighted serious sodium and salinity risks: Sodium Percentage (Na%) varied from 48.29% to 84.65%, Soluble Sodium Percentage (SSP) ranged from 46.23% to 83.41%, Sodium Adsorption Ratio (SAR) fluctuated between 13.94 and 40.08, Permeability Index (PI) went from 46.46 to 83.75, and Kelly's Ratio (KR) lay between 0.86 and 5.03. The values for Residual Sodium Carbonate (RSC) were consistently negative (-27.05 to -131.10). The Wilcox diagram (see Figure 4.9), along with the USSL diagram (Figure 10) and Piper trilinear diagram (Figure 11), confirms that the river water aggregates in areas of high sodium and salinity hazards, mainly categorized under the sodium–chloride hydrochemical facies. These results reinforce previous environmental assessments by Aladejana and Talabi (2013) and Sener et al. (2017), demonstrating that substantial sodium accumulation and increased electrical conductivity impair soil permeability, making coastal surface waters unfit for agricultural irrigation without appropriate treatment prior to use.

Human health risk indicators (Table 8, Figures 12–17) reveal notable non-carcinogenic and carcinogenic risks for both adults and children, with the latter group encountering significantly heightened risk levels. Oral Hazard Quotient (HQ) values for adults varied from 3.22 at Bakana to 13.76 at Bukuna, peaking at an alarming 11,065.07 at Tombia due to extreme localized arsenic levels. In the case of children, oral HQ values were notably higher, spanning from 12.31 at Bakana to 52.45 at Bukuna, reaching a staggering 41,483.87 at Tombia. The cumulative Hazard Index (HI) values for both oral and dermal exposure routes surpassed the safe limit in all assessed locations. Carcinogenic risk (CR) values for oral and dermal routes considerably exceeded the acceptable safety standards set by the US EPA, with adult oral CR peaking at 6.08 and child oral CR reaching 4.53 at Tombia. Monte Carlo probabilistic simulations (Figures 16–17) affirmed that the risk distributions for arsenic and chromium consistently lean towards higher risk bands for children compared to adults. These findings correspond with environmental toxicology research by Anyanwu et al. (2021) and USEPA (2004) guidelines, validating that contamination from heavy metals in coastal river systems presents significant non-carcinogenic organ toxicity and long-term cancer risks to local populations relying on untreated surface water.

Conclusion

This research assessed the microbiological presence, overall water quality index, suitability for agricultural irrigation, and risks to human health associated with surface water in Iwofe, Tombia, Bukuma, and Bakana. The results lead to the following conclusions: The surface water contains total heterotrophic, total coliform, and faecal coliform bacteria, with heterotrophic bacteria reaching high densities sustained by organic loads and favorable physicochemical conditions. The river water from all examined sites is entirely inappropriate for drinking and presents serious sodium and salinity risks), thereby limiting its direct application in agricultural irrigation due to possible soil degradation and sodium-related toxicity. The presence of trace heavy metals (notably localized arsenic peaks at Tombia) presents severe non-carcinogenic hazard risks and intolerable long-term carcinogenic threats for both adults and minors, with children exhibiting increased sensitivity through oral exposure pathways.

Recommendations

1. Public health officials in Rivers State need to urgently advise local residents against directly consuming, using domestically, or applying untreated surface water from the monitored river areas. Establishing safe, treated municipal water systems should take precedence to avert epidemic outbreaks and heavy metal poisoning.
2. Local agricultural cooperatives and extension services ought to incorporate required water treatment measures—like desalinization, ion-exchange, or dilution blending—prior to utilizing river water for irrigation, thus avoiding soil pore clogging and decreasing crop yield due to high sodium content and salinity.
3. State environmental regulatory bodies should impose stringent limits on industrial waste discharges, artisanal refining processes, and untreated municipal runoffs along the river basin, while launching targeted bioremediation initiatives to lower dissolved heavy metal levels (particularly arsenic and chromium) in high-risk areas such as Tombia.

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