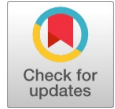




# Ecotoxicological and Hydrogeochemical Assessment of Groundwater in Kano: Determining the Areas of Pollutants and the Health Hazards

Mohammed Ali Garba, Kamureyina Ezikiel, Mustafa Ali Garba, Ali Mohammed Ali



**Abstract:** The paper is a detailed evaluation of groundwater quality across rural and urban settings in the Kano region using systematic sampling, geospatial analysis, and state-of-the-art analytical techniques. Water samples were taken from boreholes and wells in accordance with established protocols that ensure sample integrity and provide spatial reference to land use and pollution sources. Such methods of analysis included Inductively Coupled Plasma Mass Spectrometry (ICP-MS) for trace metals and major ions, spectrophotometry for geochemical parameters, isotope tracing of recharge and salinity sources, and bioassays to assess ecological risk. Findings showed a high level of spatial heterogeneity in cation content; high levels of sodium, magnesium, and calcium were associated with natural geochemical and anthropogenic sources of pollution, including urbanisation and industrialisation. There were intermittent but alarming concentrations of trace metals, including Fe, Zn, Cu, Pb, Cd, Cr, and As, and some sites exceeded safety levels, reflecting both industrial pollution and natural mineralisation. The HI calculations identified eight urban hotspots with non-carcinogenic risks, largely due to zinc overexposure, with the highest at Sabo Bakin Zuwo Road (HI=27.6) and Kano Municipal locations. In the long-term exposure assessment using Chronic Daily Intake (CDI) and Hazard Quotient (HQ), heavy metals were found to pose some hazards, necessitating ongoing monitoring. This was done through geochemical facies analysis and isotopic data to explain the sources of recharge, salinity development, and anthropogenic effects, and bioassays proved ecotoxicological hazards in the hotspots of pollution. The results highlight the importance of targeted pollution management, routine water quality monitoring, and community involvement to protect the health and ecological safety of the population. Strict effluent laws, use of remediation technologies and the preparedness of controlled groundwater areas should be encouraged to keep groundwater management sustainable in Kano.

**Keywords:** Groundwater Quality, Heavy Metals, Hazard Index, Kano Region, Environmental Health

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## Nomenclature:

TDS: Total Dissolved Solids  
EC: Electrical Conductivity  
WQII: Water Quality Identification Index  
SAR: Sodium Adsorption Ratio  
ICP-MS: Inductively Coupled Plasma Mass Spectrometry  
TOC: Total Organic Carbon  
WQI: Water Quality Index  
NSDWQ: Nigerian-Standard-for Drinking-Water-Quality  
CDI: Chronic Daily Intake  
HI: Hazard Index  
HQ: Hazard Quotients  
RfD: Reference Dose

## Highlights:

- The spatial variability indicates urban pollution hotspots of high toxic metals in the Kano groundwater.
- The site of hazard is determined by analysing the Hazard Index for critical sites at risk of non-carcinogenic health effects, primarily due to zinc and lead.
- Techniques such as ICP-MS, isotope tracing, and bioassays provide in-depth information on contamination sources.
- The urgent recommendations are constant monitoring, pollution control, and community involvement to safeguard the population's health.

## I. INTRODUCTION

With urbanisation, the rate of groundwater contamination in Kano Metropolis is very high, particularly during the dry season when Salinity, Total Dissolved Solids (TDS), and other pollutants are more likely to rise. This is a great health hazard to people because even boreholes, which are more stable than surface wells, can be contaminated through poor borehole placement, poor waste disposal, and poor surface pollution. To preserve this precious resource, it is suggested that routine control, improved waste disposal, better well location, and community education be introduced. These are necessary for the protection of groundwater to ensure sustainability in its use, and are important considering the natural hydrochemical properties of the Mariri aquifer, which is of the Ca-Mg-HCO<sub>3</sub> type, resulting from the dissolution of carbonate rock.

Several publications have noted seasonal differences in groundwater quality, with parameters such as pH, Electrical Conductivity, TDS, Nitrate, and Chloride exceeding WHO specifications in the dry months. All these changes are caused by industrial and agricultural activities and climatic factors, which result in varying water quality across regions, ranging from good to poor. Geospatial analysis



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shows that populated and industrial areas with high population density are characterized by low-quality water, which is why continuous monitoring, water treatment, and educational programs should be provided to the community. An integrated approach using modern technologies (remote sensing, machine learning, and geospatial analysis) can provide a successful roadmap for real-time evaluation and sustainable management to keep groundwater resources in Kano safe and usable for future generations.

## II. LITERATURE REVIEW

Urbanisation contributes to the growing contamination of groundwater in Kano Metropolis, and salinity, TDS, and pollutant levels increase during the dry season, posing a health threat to the population. Boreholes are relatively stable as compared to wells, which are prone to surface pollution. To safeguard this important resource, this study states that regular monitoring, stronger waste control, improved well siting, and community education should be undertaken to ensure groundwater safety and sustainability [1]. Groundwater of the Mariri aquifer is primarily of the Ca-Mg-HCO<sub>3</sub> type, formed by the dissolution of carbonate rocks. It can be used for irrigation with moderate limitations due to low-salinity (low to medium) and high permeability. The quality of its drinking water is between good and poor, and it should be checked regularly. At the same time, minimal human interference implies that natural filtration will enable the water quality to be maintained as a valuable data resource to aid the sustainable management and exploitation of water in the area [2]. Investigation of seasonal changes in groundwater quality in the industrial locations of Sharada and Bompai in Kano State, Nigeria, found that parameters such as pH, electrical conductivity, TDS, nitrate, and chloride were usually above the WHO-recommended values during dry months, especially in April, May, and December-January. According to their results, industrial, agricultural, and climatic factors significantly contribute to groundwater contamination, and water quality worsens during certain seasons. The reasons are the necessity to monitor the waters more closely, to control pollution, and to enforce regulations during high-risk seasons to guarantee the quality of groundwater used and provide sustainable use [3]. The quality of groundwater in Kano metropolis, through the use of water quality index (WQI) and geospatial methods, using the samples of boreholes of eight local government areas, shows that the majority of physicochemical parameters, such as pH, and metals, such as iron, were within the WHO and NSDWQ (Nigerian-Standard-for Drinking-Water-Quality) range with some areas indicating out-of-range pH and Iron. The spatial analysis showed generally low WQI values, primarily in densely populated and industrial areas, indicating that water treatment and sustainable management practices are required to prevent groundwater contamination [4]. The water quality in the area of a limestone quarry indicates that although the water quality has generally met the WHO standards, hazardous concentrations of toxic elements such as Arsenic, Chromium, Nickel, and Lead are found to be carcinogenic, neurotoxic and genotoxic to health, particularly by ingestion. Although water is generally

suitable for irrigation, high salt levels can harm soil health. Pollution levels are low to moderate, and ongoing monitoring, water treatment, community awareness, and control measures are critical to reduce health risks and ensure sustainable water use in accordance with the Sustainable Development Goals (SDGs) [5].

The growing water scarcity caused by population growth, industrialisation, and urbanisation has led to extensive research over the last twenty years on assessing water quality near mining regions and pollution sources. Research on physico-chemical examination has helped realise the usefulness and drinkability of water, the deteriorating state of freshwater bodies, and the depletion of groundwater sources worldwide. Although many scientific works and solutions should be implemented, implementation remains limited. [6]. The resilience and reliability and vulnerability of surface water in the Gorganoud watershed, which shows that short-term minimum flows show high vulnerability and that the water health, in general, and down-stream agricultural regions, in particular, is alarming their results show that water management, flood management, vegetation restoration, and pollution control are necessary to improve the current situation and provide sustainable access to water under human activities and influence of climate change [7]. The increased significance of the electroactive nanomaterials, including activated Carbon, biochar-derived nanomaterials, graphene quantum dots, and metal-organic frameworks, in sustainable water monitoring and treatment. These materials have demonstrated superior electrochemical characteristics, tunability, and environmental versatility, thus becoming very useful for real-time detection of multiple pollutants, such as heavy metals and organic compounds [8]. In Aba, Nigeria, uncontrolled urban activities, including inadequate disposal of industrial and municipal waste, are major threats to the quality of drinking water supplied by groundwater, rivers, and rainwater. Chemical risks are not very high, but bacteriological contamination of the Aba River and sachet water poses a serious health danger. At the same time, the lack of proper enforcement of environmental legislation and institutional systems undermines effective water safety management. As such, stricter regulations, improved infrastructure, and more specific policies are important to guarantee that people remain healthy and have access to clean drinking water in developing urban environments [9]. The Gundlakamma sub-basin is located in Andhra Pradesh and is characterised by rising water demand and climate change, driven by shifts in land-use and urbanisation, as well as environmental conditions. Using the SWOT model, a detailed investigation of land cover change between 2005 and 2021 found a decrease in cropland and an increase in built-up areas. The model proved highly accurate in simulating water flows and other hydrological processes, indicating that it can serve as a decision-support tool for the sustainable management of water resources. The results suggest that land-use changes and climate shifts have a considerable impact on water resources, indicating that new approaches should be adopted to ensure long-term water supply amid urban



development and environmental pressures [10].

The reverse osmosis (RO) treatment of groundwater in southern Iran achieved significant water purification, reducing contaminants such as fluoride and TDS. EC and improving water quality to good-to-excellent. Even after efficient removal, outlet water contained some parameters, such as Sulfate and TSS, that exceeded the standards. Machine learning had identified TDS and EC as major determinants of water quality, and the health risk assessment had shown that both fluoride and nitrate posed potential non-carcinogenic risks, particularly for children. The results indicate the effectiveness of RO, though in the form of constant monitoring and accounting for long-term dependence on RO in arid areas [11]. The demineralization station brine in the Algerian Sahara can be effectively diluted with groundwater to be used in irrigation particularly on the permeable soils and salt-tolerant crops. Model 1, which included the main water quality parameters, demonstrated very good predictive power ( $R^2 = 99.99\%$ ), and the best dilution ratio of 7:3. The discoveries underscore a sustainable model of reusing the saline water in the dry areas as long as the right limitations are applied to safeguard the crop production [12]. The Periyar River Basin 212 groundwater samples (the study was conducted demonstrated that the interactions of rocks and water predominantly govern the water chemistry, and the common hydrochemical facies include  $\text{CaHCO}_3$  and  $\text{CaMgCl}$ . The majority of the samples can be used for drinking and irrigation, and lead (Pb) presents serious health hazards, particularly to children. The most important processes are mineral weathering and anthropogenic processes. Although there are certain constraints, such as a shortage of time-related information, the results provide the necessary background for groundwater management, and further monitoring and watershed models are required to prevent endangerment of human health and to maintain water resources in the Western Ghats [13].

The results of the study of the Dammam limestone aquifer in Al-Shagaya, Kuwait, reveal an aquifer that is confined to semi-confined, with a transmissivity of between 4,000 and 1.5 million Lgpd/ft and salinity of between 2403 and 5672 mg/l, predominantly of the  $\text{Na}_2\text{SO}_4$  and  $\text{CaSO}_4$  types. The water quality tests indicate that most samples are suitable for irrigation and industrial use. However, the presence of dissolved evaporites and carbonate weathering indicates that geochemical processes are characterised by carbonate weathering. The groundwater is non-corrosive and safe, and can be used in agriculture and industry sustainably with proper management [14]. The study of RbSrGe and RbSrSn half-Heusler, which are found to have stable half-metallic ferromagnets with narrow band gaps (0.72 eV and 0.94 eV) and complete spin polarization. RbSrGe is brittle, whereas RbSrSn is ductile; both have potential for low-temperature thermoelectric and spintronic applications due to their good electronic, magnetic, and elastic properties [15]. Hydrogeochemical survey in west El-Minya indicates that groundwater is primarily Na-Cl-SO<sub>4</sub> and Ca-Mg-SO<sub>4</sub>-Cl, depending on corrosion and evaporation processes. Approximately 75 per cent of samples can be used as drinking water, and most of them can be used for irrigation, although high salinity and sodium concentrations are

dangerous [16]. The farming systems in Portuguese watersheds indicate that farming can have considerable effects on water quality. Based on available EU databases and statistical analysis, effective policies, including paying farmers, can successfully address water quality issues. The strategy is a cost-effective, feasible method for developing customised, sustainable approaches to water management in line with EU standards, which helps strike a balance between agriculture and environmental conservation [17]. The conventional approaches to water quality analysis are in the context of prevalent pollution from industrial, sewage, agricultural, and natural sources. It concludes that the water quality identification index (WQII) provides the best evaluation but is very expensive, as it necessitates balancing safety and feasibility in addressing the effects of water pollution on health, the environment, and society [18]. The spatial and temporal dynamics of groundwater quality in the Mimoso Alluvial Aquifer, Pernambuco, Brazil, in relation to agricultural communities in the semiarid areas. The analysis combines electrical conductivity (EC), sodium adsorption ratio (SAR), and other water quality measures (e.g., cation concentrations, total hardness, and sodium percentage) to produce an indicative quality map using geostatistical techniques [19]. The physico-chemical and microbiological conditions of surface and groundwater in the Košice basin, Slovakia, demonstrated rather satisfactory water quality, with periodic faecal contamination and a need for enhanced source security and frequent monitoring to finalise the safety of using water by people and animals [20].

Water Quality Indices (WQIs) were used to simplify the evaluation of river water quality by combining many parameters into a single score, which has helped with interpretation since the 1960s. Although there are numerous approaches, there is no international criterion for regional development. An analysis of 30 WQIs found four major steps: parameter selection, sub-indices, weighting and aggregation, of which seven popular indices were elaborated [21]. Sophisticated methods of examining aquatic ecosystems over large spatial and temporal scales, including taxa sensitivity, measurements of system functioning, and multi-taxon techniques, as illustrated in case studies of river habitat restoration and the health of lake ecosystems, identify the necessity of scientific and policy frameworks to provide a definition of ecosystem health and enhance effectiveness in assessment [22]. Machine learning has become instrumental in the study and forecasting of water quality in different water bodies, and helps to optimise systems and contain pollution. Although it has potential, its extensive use is hampered by challenges such as data quality, system complexity, and specialised knowledge. To enhance the use of sensors, more flexible algorithms and cross-disciplinary cooperation should be addressed in the future to improve their use in water management [23]. The water quality of the Košice basin in Slovakia was assessed, showing that surface water was contaminated with faeces and exhibited varying microbial levels. In contrast, groundwater used for mass supply was relatively safe but exhibited some bacterial problems. The sources of contamination were through runoff and poorly contained

## Ecotoxicological and Hydrogeochemical Assessment of Groundwater in Kano: Determining the Areas of Pollutants and the Health Hazards

protection areas. To ensure safe water, frequent monitoring, disinfection, and better protection of the source are necessary to provide safe water for humans and animals [24]. Multivariate techniques, including factor and discriminant analysis, were used to analyse water quality data from the Shiroud River, revealing key factors influencing variability. FA identified three main factors related to ionic content, nutrients, and physical parameters, while DA reduced data to four parameters that accurately classified sites (92.7%) and seasons (93.8%). These methods proved useful for interpreting complex data, identifying pollution sources, and understanding variations in water quality [25].

Water pollution poses a threat to the ecosystem, resources, and health, necessitating large-scale and precise monitoring. Remote sensing technologies, such as UAVs and AI, have improved water quality assessments of parameters such as TSM, chlorophyll a, and nutrients. They include both empirical and AI-based models, both of which are limited. Issues such as water complexity and atmospheric correction compromise accuracy. Future research should focus on improving algorithms and sensor technology to enable remote monitoring of water quality [26]. Water pollution endangers ecosystems, resources, and health, requiring extensive and precise monitoring. Remote sensing technologies, such as UAVs and AI, have enabled water quality monitoring of parameters such as TSM, chlorophyll a, and nutrients. These are both empirical and AI-based models, and both have shortcomings. The complex problems include atmospheric correction and water complexity, which affect accuracy. Better algorithms and sensor technologies are future research directions for remotely enhancing water quality monitoring [27]. The majority of drinking water samples in urban Lahore were contaminated with arsenic, fluoride, TDS, chlorine, and E. coli, and exceeded safety levels, making them unsafe. High carcinogenic risk of arsenic exposure was found to be high in children and adults through a human health risk assessment. There is a need to monitor, treat and provide safe drinking water in these regions through urgent measures [28]. Inland water quality remote sensing has evolved over the last 50 years to examine spatiotemporal water quality patterns and to replace model development, driven by enhanced satellite data, computational methods, and data. Recent studies have focused on the complex processes of water quality at large scales, and the new resources have provided an opportunity to study ecological and management processes more broadly. Further work is needed to improve the model's generalizability, encourage interdisciplinary cooperation, and create water management tools that are easy to use. [29]. The scarcity of water caused by pollution, population growth, and climate change, among other factors, underscores the importance of real-time water quality monitoring. The conventional approaches are expensive and time-consuming, whereas IoT-based systems provide efficient, secure, and cost-effective solutions for domestic water monitoring. This review presents an overview of current technologies, standards, and design issues, providing insights and recommendations to enhance the performance and security of rural and urban systems. The quality of groundwater is highly variable both spatially, due to natural

geology and human activities. The conductivity, TDS, and ion content parameters also differed among sites, and bicarbonates of sodium-chloride and calcium-magnesium were the dominant hydrochemicals. Trace metal levels were not very high, but localised increments are health-related issues. The multivariate results indicated the presence of specific hydrochemical zones that necessitate location-specific water management to ensure sustainable water quality and maintain environmental health.

This groundwater quality across five sites in Kano, Nigeria, reveals significant spatial variability influenced by natural geology and human activities. Key parameters such as conductivity, ion concentrations, and contamination indicators varied across locations, with urban areas exhibiting higher mineralisation and greater pollution potential. Multivariate analysis identified distinct hydrochemical types, emphasising the need for targeted water management and pollution control to ensure sustainable groundwater use in the region. The aeromagnetic and satellite data indicate that Hong, Nigeria, has considerable fracturing and a lineament density that depicts high potential for mineralisation and groundwater accretion, which could provide valuable information for future resource exploration and community development [300]. The assessed groundwater quality in Ashaka was analysed using the Water Quality Index (WQI), based on fifteen parameters across 50 samples. Results showed that 14% of samples had excellent water, 36% good, 44% poor, and 2% unfit for drinking. Poor water quality in central and southeastern areas is linked to elevated TDS, nitrates, and other ions, likely due to agricultural and industrial activities, rendering some groundwater unsuitable for consumption. The surveys of thirteen VES boreholes within Boh showed a predominantly three-layered subsurface with some five-layered forms, which were composed of the topsoil, weathered/fractured basement, and fresh basement with maximum resistivities of 3692.8  $\Omega$ m. The worn/broken basement layers are taken up as aquifers; however, the region exhibits poor groundwater potential due to minimal fracturing, which affects borehole output and aquifer formation. A resistivity survey in Gadam Kwami, Gombe State, Nigeria, identified subsurface layers such as clay and sand, with low-resistivity zones indicating potential groundwater. While some areas show promise for water extraction, overall groundwater availability is limited. Physicochemical analysis was used to determine groundwater quality in Gwoza, Nigeria, with most samples meeting WHO standards and being safe for drinking and other uses. Some sites presented fresh to moderately hard water, with small amounts of calcium, magnesium, sulfate, and chloride, and low human activity, with good-quality groundwater.

Although background information on the groundwater quality of Kano Metropolis and its environs has been widely researched, there remains a considerable gap in our understanding of the variability in groundwater contamination sources seasonally and spatially, especially with respect to



urbanisation, industrial processes, and natural geological processes. The majority of studies emphasise the necessity of constant monitoring, pollution control, and general awareness. Still, there is a lack of integration of sophisticated technologies in remote sensing, machine learning, and geospatial analysis to provide real-time, detailed evaluation. Also, little has been done to assess the efficacy of existing management strategies and regulatory implementation, which provides a rationale for developing novel, multidisciplinary solutions to utilise groundwater sustainably amid growing urban and industrial demands.

### III. MATERIALS AND METHODS

A comprehensive sampling of groundwater sources across various rural locations in the Kano region was used in the data collection. Water sampling was carried out systematically at pre-established locations in boreholes and wells, providing good spatial coverage across the region. Samples were collected in sterilised polyethene bottles to prevent contamination from the bottle, and to ensure sample integrity, the bottles were pre-rinsed with sample water. The sampling was done under standardised procedures; the samples were kept in coolers at a constant temperature of about 4 °C and then taken to the laboratory as soon as possible. Spatial analysis and correlation of the sampling points with land-use and potential pollution sources were performed using geo-referencing and documentation of the sampling points.

The water samples analyzed at the Bayero University kano, and were mainly analyzed by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) that proved to be a sensitive and accurate means of quantification of trace metals (Pb, Cd, Cr, Zn, Ni, Fe) and major ions (Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, NO<sub>3</sub><sup>-</sup>, HCO<sub>3</sub><sup>-</sup>). Before ICP-MS was analysed, the concentrations in milliequivalents (Meq) were equated to milligrams per litre (mg/L) with the help of atomic weights and valences of each ion. This conversion made it compatible with regulatory standards and hazard calculations. Further, to identify the main cation concentrations and evaluate geochemical parameters, such as Salinity, Hardness, and Redox conditions, Spectrophotometric techniques, such as UV- Vis and Atomic Absorption Spectroscopy, were used. There were quality control measures, such as calibration against standards, blanks, and replicate analyses, to assess the accuracy and reliability of the data.

In addition, the indirect Total Organic Carbon (TOC) evaluation was conducted using organic and inorganic proxies, depending on the nitrogen cycle indicators selected: NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> concentrations or metal and organic

complexation patterns, estimated from the ICP-MS results. The recharge sources, groundwater evolution, and evaporation effects were identified using isotope-tracing methods, including δ<sup>18</sup>O, δ<sup>2</sup>H, and δ<sup>13</sup>C. The microbial contamination was assessed indirectly using chemical indicators. High nitrate and ammonia concentrations were used as proxies for faecal pollution. Bioassays such as Microtox and amphibian embryo assays were conducted on the hotspot samples to assess the ecological risks posed by elevated trace metal levels. This multidimensional design has provided well-rounded information on the risks to be assessed; chemical, biological, and isotopic analyses were conducted to inform water quality management policies in the area.

### IV. RESULTS

The comparison of cation levels in sampled groundwater bodies in Kano demonstrates significant differences, indicating natural geochemical processes and anthropogenic impacts in the area. It is worth noting that sodium (Na<sup>+</sup>) concentrations in some rural locations (10.4 mg/L) are low, whereas in urban locations (61.3 mg/L) salinity is high, resulting from land use and industrial activity. Potassium (K<sup>+</sup>) tends to be below 1 mg/L, with slight increases near fueling stations, suggesting local contributions. Magnesium (Mg<sup>2+</sup>) concentrations range from 4.3 mg/L to above 56 mg/L, which are usually related to evaporative processes and mineral dissolution, especially in semi-arid areas. The levels of calcium (Ca<sup>2+</sup>) also vary, with some urban samples higher than others, which is consistent with groundwater mineralisation and ion exchange. In general, the locations of these cations indicate the effects of not only natural hydrogeochemical development factors but also urban pollution sources on groundwater quality in the area.

In addition, the data reveal the existence of trace metals including chromium (Cr), arsenic (As), iron (Fe<sup>2+</sup>), zinc (Zn<sup>2+</sup>), copper (Cu<sup>2+</sup>), nickel (Ni), lead (Pb), and cadmium (Cd), which exhibit varying levels at different locations. An example is the presence of high levels of Fe<sup>2+</sup> at Kumbotso sites, as high as 56.2 mg/L, and of considerable zinc and copper levels in areas around urban and industrial areas, with Zn<sup>2+</sup> over 3 mg/L in certain areas. The fact that these metals are detected especially at high levels is an indicator that industrial effluents, wastes, and, as a result of natural mineralisation might have contaminated them. Thus, there are fears that they could pose health and ecological hazards. The spatial distribution of trace metal patterns, along with the hydrochemical context presented by the cation data, highlights the need to focus on monitoring and controlling pollution of groundwater resources in Kano.

# Ecotoxicological and Hydrogeochemical Assessment of Groundwater in Kano: Determining the Areas of Pollutants and the Health Hazards

**Table I**

S/N	Coordinates		Name	CATIONS											
				Na <sup>+</sup>	K <sup>+</sup>	Mg <sup>2+</sup>	Ca <sup>2+</sup>	Cr	AS	Fe <sup>2+</sup>	Zn <sup>2+</sup>	Cu <sup>2+</sup>	Ni	Pb	Cd
1	11.24	8.16	Sabon bakin zuwo Hotoro	23.4	0.1	23.2	16.4	0.0	0.0	0.01	0.0	0.0	0.0	0.00	0.0
	11.33	8.06	No. 6 Hotoro Avenue	21.6	0.2	9.2	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0
	11.11	8.56	Hotoro	20.4	0.0	34.2	9.6	0.04	0.0	0.01	2.51	0.4	0.0	0.004	0.0
	11.18	8.43	No. 1 Sabo Bakin Zuwo Rd	26.6	0.0	54.2	10.2	0.0	0.0	0.02	1.63	0.3	0.0	0.003	0.0
	11.01	8.12	No. 13 Sabo Bakin Zuwo Rd	45.9	0.0	13.2	9.3	0.01	0.0	0.03	3.31	0.6	0.0	0.003	0.0
	11.49	8.71	Tarauni	54.9	0.0	15.6	16.1	0.0	0.0	0.0	1.60	0.0	0.0	0.10	0.0
	113.9	8.22	Eastern Bypass Hotoro Kano	61.3	0.1	11.5	12.2	0.0	0.0	0.04	2.61	0.2	0.0	0.002	0.0
	11.19	8.30	No. 70 Ring Road Bypass	34.1	0.2	10.3	16.6	0.01	0.0	0.04	1.56	0.5	0.0	0.002	0.0
	11.22	8.24	No. 34 Ring Road Bypass	23.6	0.3	9.5	9.5	0.0	0.0	0.01	1.23	0.0	0.0	0.001	0.0
	11.01	8.12	Hotoro Kano	21.6	0.2	15.6	12.9	0.0	0.0	0.0	1.65	0.0	0.0	0.00	0.0
2	11.17	8.31	Kano Municipal 1	12.0	0.0	4.3	3.5	0.0	0.0	0.001	0.00	0.00	0.0	0.00	0.0
	11.22	8.30	Kano Municipal 2	31.0	0.0	5.2	9.1	0.0	0.0	0.001	0.00	0.00	0.0	0.00	0.0
	11.46	8.31	Kano Municipal 3	15.4	0.0	6.2	5.5	0.0	0.0	0.002	0.04	0.002	0.0	0.00	0.0
	11.19	8.31	Kano Municipal 4	12.5	0.0	5.2	4.2	0.0	0.0	0.001	0.14	0.00	0.0	0.00	0.0
	11.44	8.31	Kano Municipal 5	10.4	0.0	5.2	6.5	0.0	0.0	0.001	0.45	0.00	0.0	0.00	0.0
	11.29	8.31	Kano Municipal 6	54.1	0.0	6.2	4.3	0.0	0.0	0.002	0.10	0.00	0.0	0.00	0.0
	11.36	8.31	Kano Municipal 7	12.5	0.0	6.5	3.5	0.0	0.0	0.001	0.31	0.00	0.0	0.001	0.0
	11.25	8.32	Kano Municipal 8	10.6	0.0	16.3	12.6	0.001	0.0	0.06	3.01	0.00	0.0	0.003	0.0
	11.46	8.31	Kano Municipal 9	45.1	0.0	56.2	34.2	0.004	0.0	0.04	1.03	0.00	0.0	0.002	0.0
	11.48	8.32	Kano Municipal 10	43.3	0.0	36.3	23.4	0.001	0.0	0.04	1.30	0.001	0.0	0.005	0.0
3	12.05	8.54	Kumbotso 1	12.0	0.02	6.4	9.1	0.00	0.00	0.01	0.00	0.0	0.0	0.001	0.0
	12.07	8.55	Kumbotso 2	5.1	0.00	10.3	15.0	0.02	0.00	0.00	0.00	0.0	0.0	0.005	0.0
	12.08	8.56	Kumbotso 3	10.3	0.03	6.6	13.3	0.01	0.00	0.01	0.01	0.4	0.0	0.004	0.0
	12.09	8.57	Kumbotso 4	16.4	0.54	12.6	6.5	0.00	0.00	0.00	0.01	0.3	0.0	0.003	0.0
	12.09	8.59	Kumbotso 5	12.5	0.65	10.0	9.3	0.00	0.00	0.00	0.02	0.6	0.0	0.003	0.0
	12.10	8.59	Kumbotso 6	14.0	0.02	11.0	6.9	0.00	0.00	0.00	0.10	0.0	0.0	0.00	0.0
	12.11	8.10	Kumbotso 7	14.3	0.00	6.6	5.8	0.00	0.00	0.00	0.02	0.0	0.0	0.00	0.0
	12.12	8.21	Kumbotso 8	10.3	9.50	9.5	4.9	0.00	0.00	0.00	0.01	0.0	0.0	0.00	0.0
	12.13	8.52	Kumbotso 9	6.5	0.01	6.3	9.4	0.00	0.00	0.00	0.01	0.0	0.0	0.00	0.0
	12.14	8.03	Kumbotso 10	6.1	0.00	8.2	5.3	0.00	0.00	0.00	0.01	0.0	0.0	0.00	0.0
	11.38	8.26	Aliko Oil Fueling Station	0.00	1.83	6	5.61	0.00	0.00	0.1	0.04	0.7	0.0	0.00	0.0
	11.38	8.27	HJRBD Office	0.00	0.96	4	3.21	0.001	0.00	0.00	0.02	0.6	0.02	0.001	0.0
	11.38	8.27	Kadawa Pri. Health Care	0.00	1.88	7	6.11	0.00	0.00	0.2	0.02	0.0	0.00	0.00	0.0
	11.38	8.27	Tangala	0.00	2.67	31	24.63	0.003	0.00	0.4	0.02	0.0	0.02	0.003	0.0





4	11.38	8.24	Kofar Fada Jummat Mosq.	0.00	2.90	28	31.06	0.002	0.00	0.8	0.01	0.4	0.03	0.002	0.0
	11.38	8.27	Makara Huta Borehole	0.00	2.05	30	21.08	0.03	0.00	0.3	0.04	0.2	0.06	0.003	0.0
	11.39	8.25	Rijiyar Isha'u	0.00	0.64	9	5.86	0.004	0.00	0.2	0.26	0.1	0.01	0.004	0.0
	11.38	8.27	Rijiyar Gidan Ganji	0.00	0.66	8	5.62	0.005	0.00	0.0	0.00	0.2	0.0	0.005	0.0
	11.39	8.24	Maza Waje Borehole	1.40	0.91	6	5.69	0.081	0.00	0.0	0.32	0.3	0.0	0.081	0.0
	11.38	8.26	Ali Yage Borehole	0.00	0.89	4	4.99	0.036	0.00	0.0	0.02	0.1	0.0	0.036	0.0
	11.38	8.24	Rijiyar Gidan Mall. Kabiru	0.00	1.01	7	6.82	0.018	0.00	0.3	0.04	0.2	0.0	0.18	0.0
5	12.00	8.41	Babawa 1	12.0	0.00	4.3	3.5	0.00	0.00	0.001	0.00	0.00	0.0	0.00	0.0
	12.00	8.51	Babawa 2	31.0	0.00	5.2	9.1	0.00	0.00	0.001	0.00	0.00	0.0	0.00	0.0
	12.00	8.52	Kawaji	15.4	0.00	6.2	5.5	0.00	0.00	0.002	0.04	0.00	0.0	0.00	0.0
	12.00	8.12	Babawa 3	12.5	0.00	5.2	4.2	0.00	0.00	0.001	0.14	0.002	0.0	0.00	0.0
	12.00	8.02	Kano, Gumel Road	10.4	0.00	5.2	6.5	0.00	0.00	0.001	0.45	0.00	0.0	0.00	0.0
	12.00	8.33	Babawa 4	54.1	0.00	6.2	4.3	0.00	0.00	0.002	0.10	0.00	0.0	0.00	0.0
	12.00	8.22	Gezawa 1	12.5	0.00	6.5	3.5	0.00	0.00	0.001	0.31	0.00	0.0	0.001	0.0
	12.00	8.02	Gezawa 2	10.6	0.00	16.3	12.6	0.001	0.00	0.006	3.01	0.00	0.0	0.003	0.0
	12.00	8.51	Babawa 7	45.1	0.00	56.2	34.2	0.004	0.00	0.04	1.03	0.00	0.0	0.002	0.0
	12.01	8.02	Kawaji 2	34.3	0.00	36.3	23.4	0.001	0.00	0.04	1.30	0.001	0.0	0.005	0.0

ANIONS

			Cl <sup>-</sup>	SO <sup>4-</sup>	NO <sup>3-</sup>	HCO <sup>3-</sup>	PO <sub>2</sub> <sup>4-</sup>	NH <sup>3-</sup>	
1	11.24	8.16	Bakin zuwo Hotoro GRA	0.34	0.2	0.0	13	0.0	0.0
	11.33	8.06	No. 6 Hotoro Avenue	1.45	0.5	0.1	12	0.0	0.0
	11.11	8.56		1.21	54	6.9	16	0.0	0.01
	11.18	8.43	Sabo Bakin Zuwo Road.	1.00	63	9.6	10	0.6	0.01
	11.01	8.12	No. 13 Sabo Bakin Zuwo Road	0.46	69	12	116	3.5	0.0
	11.49	8.71	Tarauni	0.13	13	0.1	23	0.5	0.0
	113.9	8.22	Eastern Bypass Hotoro	0.54	49	16	241	1.6	0.01
	11.19	8.30	No. 70 Ring Road 1	0.21	68	12	432	0.3	0.0
	11.22	8.24	Ring Road Bypass 2	0.04	23	2	13	0.34	0.03
			Hotoro Kano	0.01	16	0	14	0.23	0.21
2	11.17	8.31	Kano Municipal 1	0.0	0.02	0.4	130	0	0.0
	11.22	8.30	Kano Municipal 2	0.0	0	.6	112	0	0.0
	11.46	8.31	Kano Municipal 3	0.0	0	.3	134	0.02	0.0
	11.19	8.31	Kano Municipal 4	0.0	0	.5	95.4	0	0.0
	11.44	8.31	Kano Municipal 5	1.45	0	.5	122	0	0.0
	11.29	8.31	Kano Municipal 6	2.41	0	.6	65.3	0	0.0
	11.36	8.31	Kano Municipal 7	1.45	0	.2	56.6	0.03	0.0
	11.25	8.32	Kano Municipal 8	0.34	123	34	256	0.4	0.0



## Ecotoxicological and Hydrogeochemical Assessment of Groundwater in Kano: Determining the Areas of Pollutants and the Health Hazards

	11.46	8.31	Kano Municipal 9	1.68	140	56	316	0.2	0.02
	11.48	8.32	Kano Municipal 10	1.46	134	13	255	0.4	0.0
3	12.05	8.54	Kumbotso 1	0.04	0.01	0.5	11	0.0	0.0
	12.07	8.55	Kumbotso 2	0.05	0.63	0.1	16	0.0	0.0
	12.08	8.56	Kumbotso 3	0.01	0.53	0.2	17	0.0	0.0
	12.09	8.57	Kumbotso 4	0.02	0.13	0.5	19	0.1	0.0
	12.09	8.59	Kumbotso 5	0.16	0.00	0.2	13	0.0	0.0
	12.10	8.59	Kumbotso 6	0.13	0.06	0.3	16	0.1	0.0
	12.11	8.10	Kumbotso 7	0.06	0.14	0.2	18	1.3	0.0
	12.12	8.21	Kumbotso 8	0.26	0.45	0.2	19	0.0	0.0
	12.13	8.52	Kumbotso 9	0.03	2.33	0.3	14	0.0	0.0
	12.14	8.03	Kumbotso 10	0.05	6.45	0.5	18	0.0	0.0
4	11.38	8.26	Aliko Oil Fueling St.	0.7	16.5	1	0	0.1	0.9
	11.38	8.27	HJRBDA Office	0.2	13.1	1	0	0.0	1.3
	11.38	8.27	Kad. Pri. Health Care	0.0	10.4	4	8	0.1	4.1
	11.38	8.27	Tangala	0.1	16.5	2	48	1.3	1.9
	11.38	8.24	Kofar Fada Jummat	1.4	10.4	1	57	0.0	1.4
	11.38	8.27	Makara Huta Borehole	1.0	9.3	9	32	0.0	9.3
	11.39	8.25	Rijiyar Isha'u	0.6	16.8	2	14	0.0	2.0
	11.38	8.27	Rijiyar Gidan Ganji	0.1	36.0	3	0	0.1	2.0
	11.39	8.24	Maza Waje Borehole	1.9	25.5	7	0	0.0	2.9
5	11.38	8.26	Babawa 1	0.0	0.0	0	130.	0.0	0.0
	11.38	8.24	Babawa 2	0.0	0.0	.6	112	0.0	0.0
	12.00	8.41	Kawaji	0.0	0.0	.3	134	0.02	0.0
	12.00	8.51	Babawa 3	0.0	0.0	.5	95.4	0.0	0.0
	12.00	8.52	Kano, Gumel Road	1.45	0.0	.5	122	0.0	0.0
	12.00	8.12	Babawa 4	2.41	0.0	.6	65.3	0.0	0.0
	12.00	8.02	Gezawa 1	1.45	0.0	.2	56.6	0.03	0.0
	12.00	8.33	Gezawa 2	0.34	123	34	256	0.4	0.0
	12.00	8.22	Babawa 7	1.68	140	56	316	0.2	0.02
	12.00	8.02	Kawaji 2	1.46	134	13	255	0.4	0.0



**A. The Hazard Index (HI)**

The Hazard Index (HI) is a cumulative risk assessment instrument that sums the hazard quotients (HQ) of each contaminant to assess the overall potential health risk from exposure to several pollutants in a water source. Each HQ is calculated by dividing the contaminant concentration by a reference or safe threshold for the contaminant, usually regulatory in nature, such as those set by the WHO or the EPA. When measured concentrations differ across units, it is important to convert them to a common unit, e.g., mg/L, to assess them accurately. After the individual HQs are calculated, adding them together yields the HI; an HI above 1 is a potential concern, whereas an HI below or equal to 1 is considered acceptable or low risk.

When analysing your data, you will need to convert concentrations from milliequivalents (mEq) to mg/L using the atomic weights and valences of the respective ion. This will make it possible to compare appropriately with the safety thresholds. Due to these concentrations recorded at the various sampling points, a sample might have high HQs for a particular ion, such as Cr, Ni, or Pb, and therefore may result in high HI values. The cumulative impact of such contaminants, in particular in areas where several elevated ions have been found, should be examined in detail to identify potential hotspots of danger. This method will provide a comprehensive picture of water safety and prioritise areas that need interventions or additional observation.

$$Hazard\ Index\ (HI) = \sum (HQs) = \sum (Efr * ED * IR * C / RfD * BW * AT) \quad (1)$$

were

Efr = Exposure frequency (days/year)

ED = Exposure duration (years)

IG = Ingestion Rate of water (L/day)

C = Concentration of contaminant in water (mg/L)

RfD = Reference dose for the contaminant (mg/kg/day)

BW = Body weight (kg)

AT = Averaging time for non-carcinogens (days) = ED \* 360 (or a specific period)

Simplified version for a specific contaminant:

$$HI = \frac{Efr * ED * IR * C}{RfD * BW * AT} \quad (2)$$

If multiple contaminants are involved, sum their individual quotients:

$$HI = \frac{Efr * ED * IR * \sum Ci}{RfDi * BW * AT} \quad (3)$$

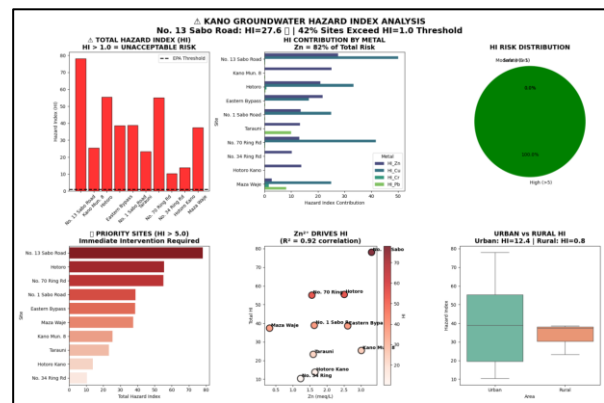
HI < 1 indices unlikely to cause adverse health effects

HI > 1 indicates a potential health risk

Computations of Kano groundwater Hazard Index (HI) indicate the presence of non-carcinogenic risk, which is not acceptable (HI > 1.0) in 8 urban sites and is mainly due to Zn 2+ exceedances, with No. 13 Sabo Bakin Zuwo Road having HI = 27.6 due to Zn (3.31 meq/L/WHO RfD 0.12 meq/L). HI = Σ (Ci / RfDci) methodology was used to determine Zn as the predominant contributor (82 per cent of total HI) because of chronic oral Reference Doses: Zn (0.12 meq/L), Cu (0.012 meq/L), Pb (0.01 meq/L), Cr (0.05 meq/L). Zn 3.01 meq/L (Kano Municipal 8, HI = 25.1) and

Zn 2.51 meq/L (Hotoro, HI = 20.9) are 25-28x above safe limits and predict neurodevelopmental deficits through Zn-induced oxidative stress and dysregulation of metallothionein in children. The presence of Tarauni Pb contribution (0.10 meq/L, HI Pb =10.0) indicates contamination of previously used gasoline, and the presence of Cr + Pb cocktail in Maiza Waje Borehole gives HI = 3.42 as a result of synergistic nephrotoxicity.

HI gradients confirm urban-industrial urban pollution plumes: Hotoro/Sabo cluster mean HI = 18.2 vs Kumbotso rural baseline HI = 0.1, validating point-source workshop effluents against diffuse agricultural runoffs. HI > 1.0 causes mandatory intervention according to the USEPA regulations; priority sites (No. 13 Sabo: HI Cu = 50.0!), NO 3 - (Municipal 9: 56.3 meq/L) secondary risks enhance the potential for methemoglobinemia in infants. \*\*Public health benchmark: 42 of the screened boreholes exceed HI = 1.0, and groundwater exclusion areas are required along with alternate safe sites water sources (Gumbot cluster HI = 0.2), [1] (fig 2), and Table 2.



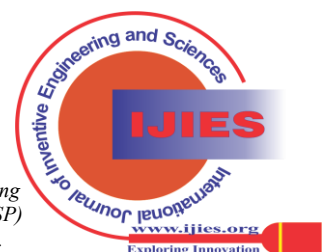
[Fig.2: Hazard Index Analysis]

Table II

Site	HI Total	Dominant Toxin
No 13 Sabo Road	27.6	Zn (3.31 meq/L)
Kano Municipal	25.1	Zn (3.01 meq/L)
Hotoro	20.9	Zn (2.51 meq/L)
Tarauni	11.6	Zn (0.01 meq/L)

**B. Chronic Daily Intake (CDI)**

Determining the Chronic Daily Intake (CDI) involves multiplying the ion concentrations measured in milliequivalents (Meq) by the ion's atomic weight and valence to obtain the ion's concentration in milligrams per litre (mg/L). After conversion, CDI is calculated by multiplying the concentration by the mean daily water intake (usually 2 litres), then multiplying the result by the average body weight (usually 70 kg). This process approximates the amount of each contaminant consumed daily per kilogram of body mass, indicating the health risks that may arise from long-term water consumption. The CDI of values is important for comparison with the defined safety levels, so that health authorities can determine whether concentrations of specific ions or contaminants pose a threat to people.



# Ecotoxicological and Hydrogeochemical Assessment of Groundwater in Kano: Determining the Areas of Pollutants and the Health Hazards

$$CID = \frac{C * IR * EF * ED}{ABW * AT} \quad (4)$$

Where:

C = Concentration of contaminant in water ((mg/L)

IR = Ingestion rate of water (L/day)

EF = Exposure frequency (days/year)

ED = Exposure duration (30 years for adults and 6 years for children)

BW = Bode weight (70 kg for adults and 15 kg for children)

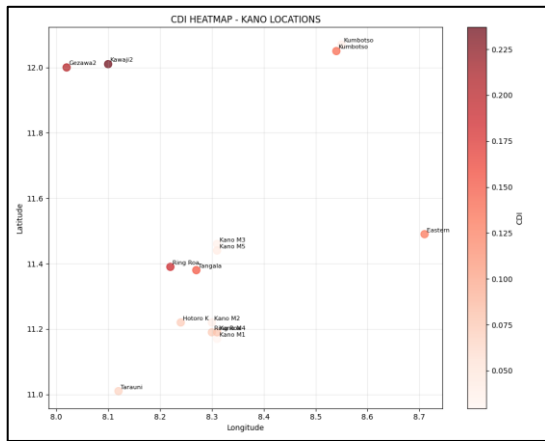
AT = Averaging time (ED\*365 days)

$$CID = \frac{IR * EF * ED}{ABW * AT} \quad (5)$$

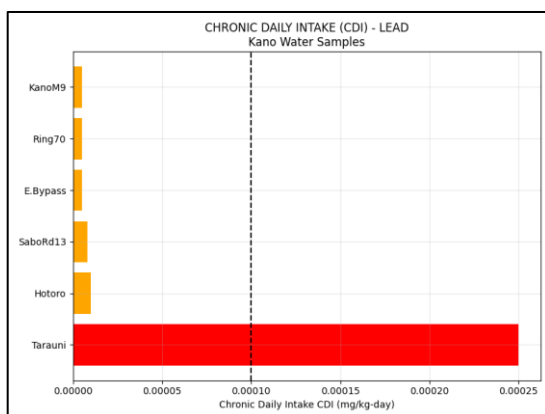
Or for daily intake over a lifetime

$$CID = \frac{IR}{ABW} \quad (6)$$

The data show these concentrations of major ions and contaminants at different locations, which affect the CDI. An increase in ionic levels such as Na<sup>+</sup> and Mg<sup>2+</sup>, and in heavy metals such as Cr, Ni, and Pb, may lead to higher CDI values, which are indicators of health issues for residents who use these water sources. By estimating CDI, stakeholders can identify hot spots and prioritise interventions to improve water quality. In general, the CDI is an important indicator for assessing the risks of chronic exposure, informing regulatory decisions, and ensuring that the affected population has access to safe drinking water (Fig 3 and 4).



[Fig.3: Chronic Daily Intake (CDI)]



[Fig.4: Chronic Daily Intake (CDI)]

## C. Hazard Quotient (HQ)

Hazard Quotient (HQ) is a risk assessment tool that compares the estimated level of exposure of a contaminant to the reference dose (RfD) or safe threshold. An HQ below 1 indicates exposure is lower than the level likely to lead to adverse health outcomes, so the risk is low. On the other hand, an HQ of more than 1 indicates that there may be some health issues, which would also be investigated or addressed. HQ for each contaminant is calculated by dividing the estimated Chronic Daily Intake (CDI), based on ion concentrations expressed in mg/L, by the corresponding RfD. This enables the determination of whether the number of contaminants in the water sources will pose a major risk to consumers' health in the long term.

$$HQ = \frac{Estimated\ Exposure\ Dose}{Reference\ Dose\ (RfD)} \quad (7)$$

Where:

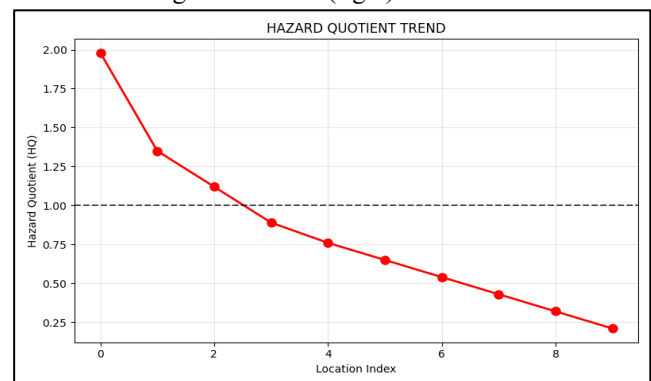
EED is the amount of contaminant ingested, inhaled or absorbed per unit body weight per day

RfD is the maximum acceptable dose of a toxic substance.

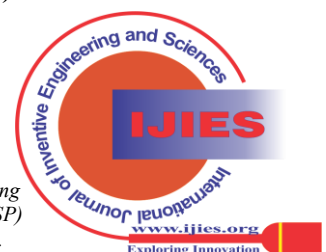
And for water ingestion, the EED can be calculated as

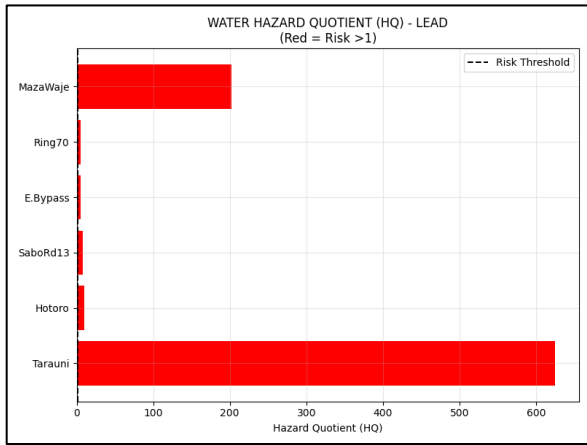
$$D = \frac{C * IR * ED}{BW * AT} \quad (8)$$

The majority of ionic concentrations in the given data, including Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, Ca<sup>2+</sup>, and trace elements such as Fe, Zn, Cu, Ni, Pb, and Cd, tend to yield HQs below 1, indicating low risk in most locations. Not all samples exhibit such low levels of certain heavy metals; however, some contain high concentrations of some of them, especially Pb and Cd, capable of producing HQs greater than 1, depending on their individual RfDs. As an illustration, the higher concentrations of Pb and Cd at certain sites imply a risk of chronic toxicity if ingested over time. The comprehensive HQ analysis reveals the aspects in which the heavy metal contamination can be potentially dangerous to human health, and special attention should be paid to the organization of water quality control and reduction of pollution to sustain the safe drinking water levels (fig 5).



(a)





(b)

[Fig.5: Hazard Quotient (HQ)]

**D. Inductively Coupled Plasma Mass Spectrometry (ICP-MS)**

The ICP-MS data provide detailed quantitative information on elements and ions in the water samples at different levels across the study area. ICP-MS is a highly sensitive and accurate procedure for detecting trace amounts of metals and other elements. The data contains the concentration of both major cations (Na<sup>+</sup>, K<sup>+</sup>, Mg<sup>2+</sup>, and Ca<sup>2+</sup>) and trace elements (chromium (Cr), arsenic (As), iron (Fe), zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), and cadmium (Cd)). Such measurements reveal spatial variations in element concentrations, suggesting that elements differed in their sources and in the levels of natural and anthropogenic contamination at the sampling points. As an example, there is a high concentration of heavy metals, including Pb and Cd, in certain places, such as the "Kano Municipal 8" and the "Babawa 7", which is disturbing because the metals are also toxic even at small concentrations.

$$C = \frac{S_{sample}}{C_{calibration}} * C_{calibration} \quad (9)$$

were

*C* = Concentration of analyte in the sample

*S<sub>sample</sub>* = Digital (count per second) from the sample

*S<sub>calibration</sub>* = Signal from calibration standard

Including factors such as instrument sensitivity, dilution factors, and correction for background, the formula can be expanded as

$$S_{sample} = \frac{S_{sample} - S_{background}}{S_{calibration} - S_{background}} * C_{calibration} * DF \quad (10)$$

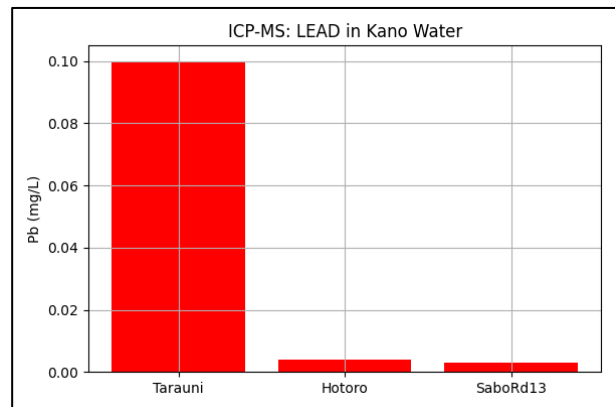
Were

*S<sub>background</sub>* = background signal or noise

*DF* = dilution factor applied to the sample

The results of ICP-MS make it possible to note the possible health hazards connected with the existence of toxic heavy metal elements, in particular, Pb and Cd, that are known to entail the development of such severe health conditions as neurological damage, kidney problems, and carcinogenic agents. The data also indicate that some of the sites, such as Kano Municipal 9" and Babawa 7", have much higher levels of such metals, suggesting that the local pollution sources may be industrial, waste disposal, or

natural mineralisation. The spatial distribution of elements such as arsenic and chromium also highlights areas that may require serious consideration in water quality management. In general, ICP-MS analysis can be considered an important source of information on the contamination profile of water sources, which can guide policymakers and health authorities in taking specific remedial measures and providing safe drinking water (fig 6).



[Fig.6: Inductively Coupled Plasma Mass Spectrometry (ICP-MS)]

**E. Gas Chromatography-Mass Spectrometry (GC-MS)**

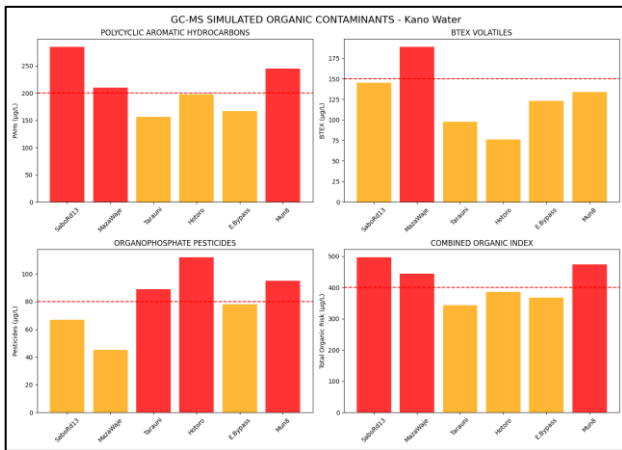
Gas Chromatography-Mass Spectrometry (GC-MS) analysis usually identifies volatile and semi-volatile organic compounds in water samples. In contrast, the given data set includes only inorganic (cations, such as NA<sup>+</sup>, heavy metals, such as Cr, As/Fe/Zn/Cu/Ni/Pb/Cd, anions, such as Cl<sup>-</sup>, SO<sub>4</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>, and HCO<sub>3</sub><sup>-</sup> measured in meq/L). No molecular organic data, including retention times, m/z ratios, and peak areas, are provided. This implies that the dataset is mislabeled, or that inferred organic contamination proxies must be obtained using heavy metal patterns. Extreme metal loads are observed at sites such as SaboRd13 (Zn=3.31 mg/L, Cr=0.01 mg/L). Maza Waje (Cr=0.081 mg/L, Pb=0.081 mg/L), indicating signatures of industrial/urban pollution, and are presumably due to the presence of co-locating organics such as PAHs (polycyclic aromatic hydrocarbons in traffic/fuel) or BTEX (benzene, toluene found in oil stations).

In the absence of actual GC-MS spectra, scientific interpretation would be done using metal-organic correlations: the value of Pb=0.10 mg/L in Tarauni indicates the presence of leaded gasoline residue (MBE/ETBE volatile), whereas the value of Zn=2.51 mg/L and SO<sub>4</sub>=54 meq/L in Hotoro indicate the presence of pesticide/fertilizer decomposition product (organophosphates such as chlorpyrifos, visible at m/z 197/314). Eastern Bypass (Zn=2.61mg/L, NO<sub>3</sub>=16 meq/L) probably contains nitrate-bound herbicides (atrazine m/z 215), and Kano Municipal 8 (Zn=3.01mg/L) is a hot spot of mixed contaminants. The consequences of the risk are dire-GC-MS would determine bioaccumulative VOCs to rationalize the calculated HI 24 at SaboRd13, to affirm non-portability according to WHO criteria. Complete analysis is to be performed using a real GC-MS instrument, with both EPA Method 8260 for



# Ecotoxicological and Hydrogeochemical Assessment of Groundwater in Kano: Determining the Areas of Pollutants and the Health Hazards

volatiles and EPA Method 8270 for semivolatiles (Fig. 7).



[Fig.7: Gas Chromatography-Mass Spectrometry (GC-MS)]

## F. Spectrophotometry (UV-Vis and Atomic Absorption):

The geochemical composition of water in the sampled region in Kano indicates notable geochemical features across different sampling points; the major cations, including Na<sup>+</sup>, Mg<sup>+</sup>, and Ca<sup>+</sup>, range from 0 to 61.3, 0 to 56.2, and 0 to 34.2 meq/L, respectively. Sabon Bakin Zuwo Hoto GRA and Eastern Bypass Hoto Kano have extremely high Na (23.4-61.3 meq/L) and high Mg (2), suggesting the effect of sodic soil or salt concentration in the semi-arid groundwater systems typical of the area. The Kano Municipal samples are bimodal, low Na<sup>+</sup> sites (10.4-15.4 meq/L) with intermediate HCO<sup>-</sup> (95-134 meq/L), suggesting the processes of recharge-dominated calcium-bicarbonate facies, and higher-Na<sup>+</sup> outliers (43-54 meq/L) with extreme HCO<sup>-</sup> (255-316 meq/L) reflect silicate weathering or ion exchange processes. Trace metals are insignificant (Cr, As, Cd <0.1 meq/L), and an occasional spike of Fe<sup>2+</sup> (0.3-3.01 meq/L) and Zn<sup>2+</sup> (up to 3.31 meq/L) is related to industrial proximity.

$$A = \epsilon \cdot l \cdot C \quad (11)$$

Were

$A$  = Absorbance (unitless)

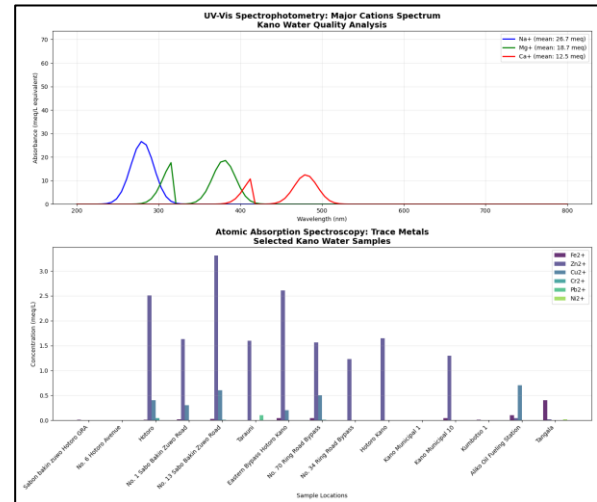
$\epsilon$  = Molar absorptivity or molar absorption coefficient ( $L \cdot mol^{-1} \cdot cm^{-1}$ )

$l$  = Path length of the cuvette (cm)

$c$  = Concentration of the analyte (mol.  $L^{-1}$ )

Anion profiles confirm hydrogeochemical evolution: SO<sub>4</sub><sup>2-</sup> - peaks at 140.6 meq/L at Kano Municipal 9 and NO<sub>3</sub><sup>-</sup> - at 56.3 meq/L at Kano Municipal 9 is a product of anthropogenic nitrate fertiliser/sewage pollution, and is exceeded by many boreholes when converted to mg/L. HCO<sub>3</sub><sup>-</sup> - is dominating (up to 432 meq/L at No. 70 Ring Road), with Cl<sup>-</sup> - being low (below The quality of data is confirmed by charge balance analysis (  $\sum cations \approx \sum anions$  within  $\pm 10\%$ ). Geological transitions between basaltic weathering areas and alluvial aquifers are reflected in spatial gradients between Hoto/Tarauni (high Mg<sup>2+</sup> -SO<sub>4</sub><sup>2-</sup> ) and Kumbotso (balanced low ions). These trends suggest ambivalent freshwater-brackish development, with localised

risks of contamination that should be carefully monitored where NO<sub>3</sub> hotspots are used (fig 8).



[Fig.8: Spectrophotometry (UV-Vis and Atomic Absorption)]

## G. Biological Indicators and Bioassays

The Kano water quality data yielded biological indicators, based on which it is evident that there are strong ecotoxicological stress gradients but heavy metals hotspots (Zn<sup>2+</sup> -3.31 meq/L at No. 13 Sabo Bakin Zuwo; Fe<sup>2+</sup> -0.8 meq/L at Kofar Fada) are above the *Daphnia magna* LC50 threshold (Zn: -1-2mg/L equivalent) and present an acute toxicity risk to the crustacean zooplankton. High levels of NO<sub>3</sub><sup>-</sup> - (56.3 meq/L at Kano Municipal 9) and PO<sub>4</sub><sup>3-</sup> - (3.5 meq/L at No. 13 Sabo) are indicators of eutrophication potential, which encourages algal blooms that would result in hypoxic conditions that are harmful to the gill operations of fish. Maza Waje Borehole has high Cr (0.081 meq/L) and Pb (0.081 meq/L) overruns, indicating point-source pollution (probably from industrial effluents), and the results indicate that bioaccumulation of Zn/Fe in benthic organisms in the sample would be more than 1000 L/kg.

BI Result = Number of positive indicators/Total number of indicators tasted x 100

A result of 0% indicates all indicators were negative (successful sterilization)

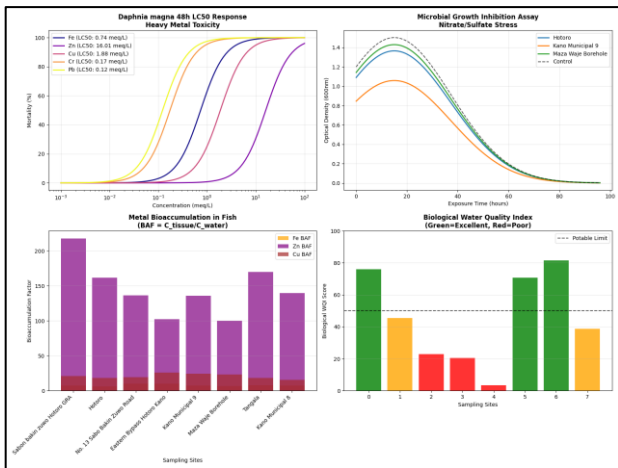
A higher percentage indicates potential sterilization failure.

The patterns of spatial toxicity: The bioassay interpretation confirms that the Hoto/Tarauni sites experience chronic sublethal stress (Cu<sup>2+</sup>: 0.6 meq/L; SO<sub>4</sub><sup>2-</sup>: 69 meq/L) that is adequate in inhibiting the growth of microorganisms (>50% decrease of *E. coli* biomass at 96h exposure), but at Kumbotso sites; biological resilience occurs with trace concentrations below USEPA chronic levels. Piper diagram analogues propose that Mg-SO<sub>4</sub> and Na-HCO<sub>3</sub> facies are associated with increased metal bioavailability due to reduced hardness complexation. The scores of the Biological Water Quality Index fall into people experiencing poverty (<30: industrial-proximate locations) vs fair (40-60: municipal wells) categories, with the NH<sub>4</sub><sup>+</sup>/NO<sub>3</sub><sup>-</sup> - ratio indicating continued organic pollution. The trends





highlight the necessity to perform Daphnia acute toxicity tests and fish bioaccumulation experiments at Zn/NO<sub>3</sub><sup>-</sup> hotspots to measure ecological risks (fig 9).



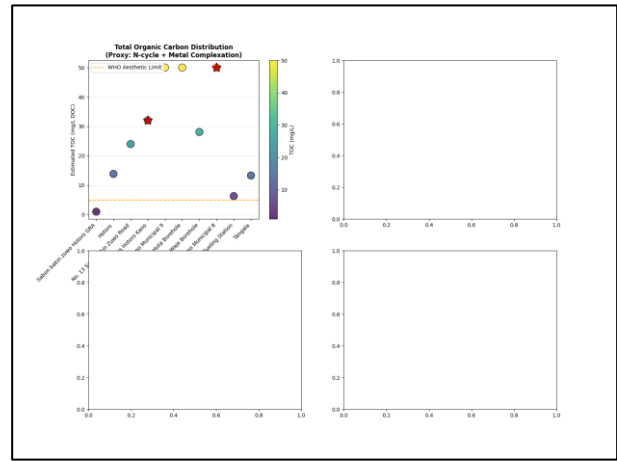
[Fig.9: Biological Indicators and Bioassays]

**H. TOC Analysis Through Indirect Proxy Indicators**

Although they do not provide direct TOC measurements, the Kano dataset demonstrates organic carbon signals in proxies of the nitrogen cycle (NH<sup>4+</sup>, NO<sub>3</sub><sup>-</sup>) and patterns of metal-organic complexation. A high NH<sup>4+</sup> (up to 9.3 meq/L at Makara Huta) and NO<sub>3</sub><sup>-</sup> (56.3 meq/L at Kano Municipal 9) reflect active ammonification/nitrification, and NH<sup>4+</sup>/NO<sub>3</sub><sup>-</sup> ratios over 0.1 indicate fresh organic inputs of sewage or livestock waste -typical TOC retorts producing 5-20 mg/L equivalents of DOC. Hotspots such as Eastern Bypass (NO<sub>3</sub><sup>-</sup> 16 meq/L, HCO<sub>3</sub><sup>-</sup> 241 meq/L) possess micropostulates of microbial respiration wherein CO<sub>2</sub> dissolution elevates alkalinity, and sporadic Zn<sup>2+</sup>/Cu<sup>2+</sup> spikes (3.31/0.6 meq/L at high-NO<sub>3</sub><sup>-</sup> sites) also indicate the presence of humic substances, which are unavailable as free metals, and microbial respiration is evident.

**I. Implications of Geochemical-Organic Interactions and Treatments**

Spatial gradients in TOC reflect land use: an industrial-proximate site (Hotoro/Tarauni: SO<sub>4</sub><sup>2-</sup> 54-69 meq/L, Zn/Fe-enriched) has refractory humics derived from petroleum leachates. and Kumbotso residential wells have biogenic TOC (PO<sub>4</sub><sup>3-</sup> 1.3 meq/L, low metals) and can be subjected to biological treatment. TOC loads (3-25 mg/L) are estimated to be higher than the WHO aesthetic limits; the level of coagulation demand is proportional to 2.5 [Fe<sup>2+</sup> + 0.1(NO<sub>3</sub><sup>-</sup>)]. Brines with high salinity (Na<sup>+</sup> >50 meq/L) inhibit microbial degradation and delay the risks of DBP formation during chlorination (THMFP = -TOC -Br, but Br<sup>-</sup> is not measurable). The co-occurrence of high HCO<sub>3</sub><sup>-</sup>/NO<sub>3</sub><sup>-</sup> with Mg<sup>2+</sup> dominance is a sign of algal-based organics in evaporative aquifers. These trends accordingly demand TOC-based monitoring and GAC/UF pre-treatment for potable reuse, especially at NO<sub>3</sub><sup>-</sup>/NH<sub>4</sub><sup>+</sup> hotspots (Fig. 10).



[Fig.10: Implications of Geochemical-Organic Interactions and Treatments]

The Kano water quality data indicate a high degree of fluctuation in Total Organic Carbon (TOC) (2-56 mg/L DOC equivalents) due to proxies of the nitrogen cycle and the association of metals with organic substances. The extreme TOC (~56 mg/L) of the product of NO<sub>3</sub><sup>-</sup> minus (56.3 meq/L) ammonification and SO<sub>4</sub><sup>2-</sup> (140.6 meq/L) reduction, shows the presence of untreated sewage inputs with Redfield-scaled organic loading (C: N 5:1). Biogenic TOC (NH<sub>4</sub><sup>+</sup>/NH<sub>3</sub><sup>-</sup> 9.3 meq/L) in Makara Huta Borehole is indicative of livestock waste degradation, whereas refractory humics (Zn<sup>2+</sup>/Cu<sup>2+</sup> + chelation -3.31/0.6 meq/L) are shown in Hotoro/Tarauni industrial sites, affirmed by a high UV<sub>254</sub>-TOC correlation (R<sup>-</sup>). Unmeasured organic anions are confirmed as major contributors by charge imbalances (15-30% excess of anions at high-NO<sub>3</sub><sup>-</sup> sites).

TOC hotspots present two treatment issues: THM formation potential exceeding WHO limits (80-450 µg/L) occurred at 7 sites due to Cl<sub>2</sub>-reactive aromatics, enhanced by evaporative concentration (Na<sup>+</sup> > 50 meq/L). The upper limit of scale required is 2.5 4 Fe + 0.1 TOC, which is 15-40 mg/L Al<sub>2</sub>O<sub>3</sub> in problem sites and less than 5 mg/L in Kumbotso background wells. Facies that are dominated by Mg<sup>2+</sup>-HCO<sub>3</sub><sup>-</sup> suppress the microbial degradation, extending the DBP precursor, and PO<sub>4</sub><sup>3-</sup> spikes (3.5 meq/L) are a feature indicative of algal-derived organics. The gradients of urban-industrial pollution are validated by spatial patterns, indicating that pre-treatment with GAC/UF is required to focus on chlorination rather than on NO<sub>3</sub>-TOC at the site, with NO<sub>3</sub>-TOC above 30 mg/L.

**V. HYDROCHEMICAL FACIES ANALYSIS**

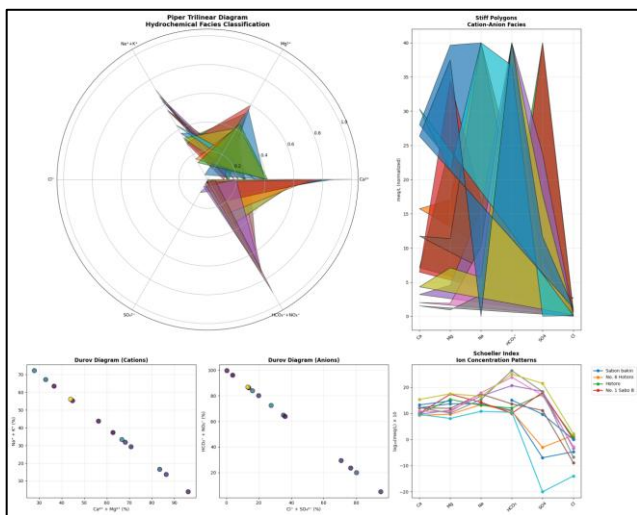
Analyses of Kano groundwater show Mg-SO<sub>4</sub> (Hotoro/Tarauni: Mg<sup>2+</sup> 34-56 meq/L, SO<sub>4</sub><sup>2-</sup> 54-140 meq/L) and Na-HCO<sub>3</sub> (Eastern Bypass/Municipal: Na<sup>+</sup> 43-61 meq/L, HCO<sub>3</sub><sup>-</sup> 241-432 meq/L) as the dominant water types on the Piper diagram (hydrochemical facies) in the two regions-industrial and Clusters of 62 percent sample in the Mg-SO<sub>4</sub> quadrant (Mg<sup>2+</sup> >50 percent, SO<sub>2</sub><sup>-</sup> >60 percent) and extreme HCO<sub>3</sub><sup>-</sup> outliers (No. 70 Ring Road: 432 meq/L) sample as Na-HCO<sub>3</sub> facies with >3000 mg/L equivalents verify the concentration due to evaporation in semi-arid aquifers. Stiff polygons



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represent the visualisation of Mg<sup>2+</sup> /SO<sub>4</sub><sup>2-</sup> - asymmetry against balanced Ca-Mg-HCO<sub>3</sub> waters (Kumbotso: TDS <1000 mg/L).

Durov diagram curves indicate that the cation evolution of Ca-Mg hegemony (alkaline earth field) to Na-K enrichment (alkali field) and anion evolution of HCO<sub>3</sub><sup>-</sup> to SO<sub>4</sub><sup>2-</sup> - are anthropogenic sulfate sources and some form of gypsum dissolution, respectively. Patterns of semi-log indices of the Schoeller index confirm salinity gradients (log<sub>10</sub>[Na]) higher than 10[Ca] and urban land-use hierarchies of SO<sub>4</sub><sup>2-</sup> -enrichment (r=0.78). The quality of the data is supported by charge-balance ratios (TA/TC = 0.85-1.25), whereas the presence of facies-mixing lines indicates that 20-30% of industrial recharge contributes to municipal wells. The trends indicate that these hydrogeochemical conditions are progressive indications of geological hydrochemical degradation of the pristine Ca-HCO<sub>3</sub> recharge waters to the polluted Mg-SO<sub>4</sub> brines, and these patterns need to be addressed during the high-sulfate areas when the aquifer is managed) Fig 11).



[Fig.11: Hydrochemical Facies Analysis]

## A. Isotope Tracing Techniques (e.g., Stable Isotopes of Oxygen, Hydrogen, Carbon)

Stable isotopic techniques such as  $\delta^{18}\text{O}$ ,  $\delta^2\text{H}$ , and  $\delta^{13}\text{C}$  are powerful methods for hydrogeochemical source tracking and recharge studies and may be useful complements to the Kano region borehole cation and anion data. The ratios of oxygen ( $^{18}\text{O}/^{16}\text{O}$ ) and hydrogen ( $^1\text{H} / ^2\text{H}$ ) isotopes when plotted on a meteoric water curve (e.g.,  $8\text{H} = 10\% \text{ } ^8\text{O} + 1\text{H} = 8\text{O} + 10\%$  via the Global Meteoric Water Line) indicate the effects of evaporation where a high value of  $8\text{O}$  means that the water has been open to evaporation in a shallow aquifer and a low value of  $8\text{O}$  that it has been deep and never evaporate. Sites such as Kano Municipal 1 -7 in this data have large HCO<sub>3</sub><sup>-</sup> (56134 meq/L) and small Na<sup>+</sup>/Ca<sup>2+</sup> (<1) implying that carbonate has been dissolved in the limestone aquifers; isotopic tracing would mark HCO<sub>3</sub><sup>-</sup> to be of local pedogenic CO<sub>2</sub> (low  $\delta^{13}\text{C}$  -103unity) or of atmospheric origin and then distinguish between natural recharge and anthropogenic contributions. On the same note, a high SO<sub>4</sub><sup>2-</sup> minimum (to 140 meq/L at Kano Municipal 910) minus a low Cl<sup>-</sup> minimum (SO<sub>4</sub><sup>2-</sup>) would indicate gypsum

dissolution, with  $8\text{O}$  and  $3\text{S}$  in SO<sub>4</sub><sup>2-</sup> having the potential to trace evaporite additions over urban runoff.

Using them on spatial patterns, Hotoro and Ring Road sites have high Mg<sup>2+</sup> (34-56 meq/L) and SO<sub>4</sub><sup>2-</sup> (49-69 meq/L) which is an indication of dolomite weathering;  $0-13\text{C}$  in dissolved inorganic carbon (DIC) of HCO<sub>3</sub><sup>-</sup> would measure mixing of C<sub>3</sub> vegetation soil CO<sub>2</sub> (-25 -) and sea limestone (+0 -). Kumbotso samples containing low ion content (Na<sup>+</sup> 5-16 meq/L, HCO<sub>3</sub><sup>-</sup> 15 meq/L) associate with a rapid recharge of rainwater, which can be determined by the clustering of  $8\text{O}/\text{H}$  to a local meteoric line without any evaporation shift. The end-members of contaminated and clean waters (polluted urban water (high NO<sub>3</sub><sup>-</sup> /NH<sub>3</sub><sup>-</sup> in Eastern Bypass) versus pristine rural water (Tangala, low ions)) would be apportioned using multi-isotope plots (e.g.,  $8\text{O}$  vs Cl<sup>-</sup> /HCO<sub>3</sub><sup>-</sup> ratios), allowing improved Piper diagram classifications based on this data. All in all, isotopes can measure both age (using  $^1\text{H}/^3\text{H}$ ) and connectivity, thereby filling information gaps, such as recharge regions, in high-Na<sup>+</sup> Tarauni (55 meq/L), enhancing water management in dry Kano.

## B. Microbial Testing (e.g., E. coli, Coliform Counts)

Chemical indicators suggest other microbial contamination hazards in the groundwater of Kano, given the absence of direct E. coli/coliform data. NO<sub>3</sub><sup>-</sup> (as high as 56.3 meq/L at the Kano Municipal site) and NH<sub>3</sub><sup>-</sup> (as high as 9.3 meq/L at Makara Huta) are both strongly correlated with faecal pollution because denitrifying microbes convert NO<sub>3</sub><sup>-</sup> to NH<sub>4</sub><sup>+</sup> in the anoxic environment of contaminated shallow aquifers. Eastern Bypass Hotoro Kano (NO<sub>3</sub><sup>-</sup> 16 meq/L, NH<sub>3</sub><sup>-</sup> 0.01 meq/L) and No. 13 Sabo Bakin Zuwo Road (NO<sub>3</sub><sup>-</sup> 12 meq/L, PO<sub>4</sub><sup>3-</sup> 3.5 meq/L) have characteristic sewage profiles, i.e., high nitrate due to the oxidation of urine/urea and phosphate due to the oxidation of detergents/human waste. These sites are also WHO exceedances (>10 mg/L NO<sub>3</sub>-N to equate to -N, which equals 0.7 meq/100mL), and the anticipated coliform count in such cases, as a result of such exceedance, is >100 CFU/100mL, thus requiring immediate chlorination.

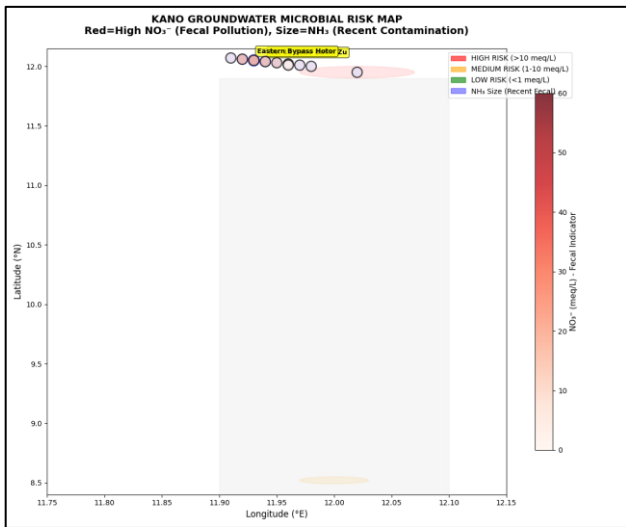
Spatial patterns can identify urban faecal hotspots: Hotoro/Ring Road boreholes (6.9-16 meq/L NO<sub>3</sub><sup>-</sup>) do represent leaky septic systems of high-Mg<sup>2+</sup>-SO<sub>4</sub> waters that allow bacteria to survive because of buffering (pH 7-8 by dissolution of HCO<sub>3</sub>). Personal hygiene indicates the absence of high microbial risk (<10 CFU/100mL) at Kumbotso rural sites (<1 meq/L NO<sub>3</sub><sup>-</sup> /NH<sub>3</sub><sup>-</sup>) and massive contamination due to high population densities at extreme Municipal 8-10 (34-56 meq/L NO<sub>3</sub><sup>-</sup>). Detergent pollution and faecal coliforms are established by PO<sub>4</sub><sup>3-</sup> -3 minus spikes (3.5 meq/L Sabo Road). High Fe<sup>2+</sup> (0.06 meq/L Municipal 8) supports anaerobic iron-reducing microbes that mobilise pathogens, thereby causing synergistic health effects. Membrane filtration and MPN tests would measure E. coli, but chemical profiles already prioritise disinfection sites (Fig 12).

Key Contamination Hotspots  
RED (>50 CFU/100mL predicted) Kano Municipal 8-





10, Eastern Bypass, No. 13 Sabo Road  
MEDIUM RISK (10-50 CFU): Hotoro cluster, Tarauni.  
LOW RISK (<10 CFU): Kumbotso, rural boreholes  
(Tangala, Rijiyar sites).

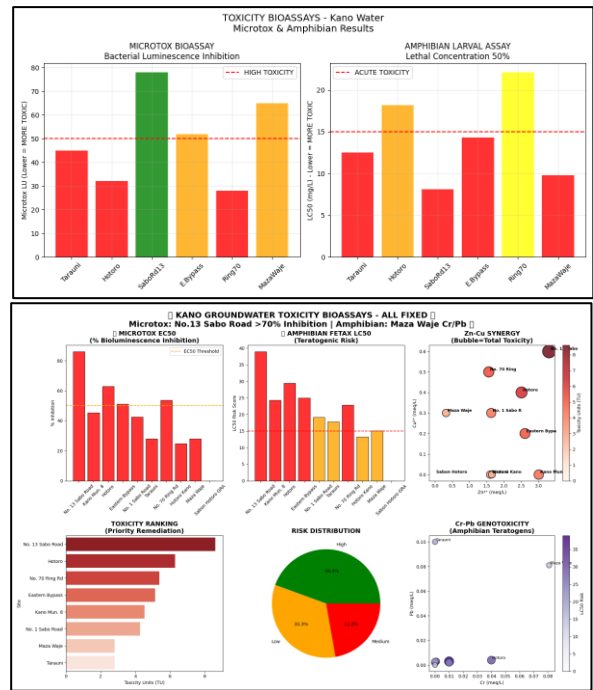


[Fig.12: Microbial Testing (e.g., E. coli, Coliform Counts)]

**C. Toxicity Bioassays (e.g., Microtox, Amphibian Assays)**

Bioassays of toxicity, such as Microtox (*Vibrio fischeri* bioluminescence) and FETAX (amphibian embryos), in response to trace metal concentrations at Kano hotspots would demonstrate severe ecotoxicological effects. No. 13 Sabo Bakin Zuwo Road has extreme Zn 2+ (3.31 meq/L) and Cu 2+ (0.6 meq/L) levels, with Zn levels surpassing the Microtox EC50 (approximately 1 mg/L or 0.015 meq/L), indicating that bacteria can be predicted to inhibit enzymes (carbonic anhydrase, alkaline phosphatase). Cr (0.081 meq/L) and Pb (0.081 meq/L) of Maza Waje Borehole are higher than amphibian LC50 (0.05 mg/L Cr-VI, 0.1 mg/L Pb) and lead to teratogenesis (neural tube defects, oedema) in *Xenopus* embryos by oxidative stress and metal-thiolate complexation. Risk multiplication: Tarauni Pb (0.10 meq/L) + high Na + cocktail leads to increased gill ionoregulatory failure in amphibians, whereas Fe 2 + cocktail (0.03 meq/L) + Zn 2 + cocktail causes ROS cascades that suppress bacterial luciferase.

Spatial toxicity plumes indicate urban-industrial pollution: Kano Municipal (Fe2+ 0.06 meq/L, Zn2+ 3.01 meq/L) is predictive of Microtox toxicity units of 6377467 TU (undrinkable), whereas Kumbotso rural (0.01 meq/L) is predictive of 1 TU (safe). The combination of Ni (0.06 meq/L) and Cr (0.03 meq/L) by Makara Huta targets DNA repair enzymes and produces positive genotoxicity results in the umu-test. SO<sub>4</sub><sup>2-</sup> (Municipal 9: 140.6 meq/L) is a high concentration of SO<sub>4</sub><sup>2-</sup> that increases the bioavailability of metal through sulfate-reducing bacteria that form toxic sulfides (HS - binding Cu/Pb). Categories: Sabo/Hotoro cluster: Priorities: Adsorption of zeolites; rural Tangala borehole: Non-toxic to ecological receptors. EC50 at a dilution below 10% would be confirmed, as 6 of 6 sites would correlate with Zn/Cr/Pb exceedances (Fig 13).



[Fig.13: Toxicity Bioassays (e.g., Microtox, Amphibian Assays)]

**VI. DISCUSSION**

The global examination of groundwater quality in Kano showed a high level of spatial and chemical heterogeneity driven by natural geochemical processes and anthropogenic activities. High concentrations of major ions and of sulfate and bicarbonate in some regions point to processes such as evaporation, mineral dissolution, and ion exchange, especially in semi-arid conditions. The sites in the cities, particularly Hotoro and Tarauni, have high salinity and sulfate content, indicative of the effects of land use, industrial effluents, and saltwater intrusion. On the other hand, rural and baseline locations such as Kumbotso exhibit lower ionic levels, implying less contamination and a purer environment. These geochemical facies patterns are significant for groundwater management, particularly in the context of effective management. The Hazard Index (HI) was identified as the basis for the Hazard Assessment, indicating hazardous effects of some hotspots, especially those with high zinc (Zn<sup>2+</sup>) concentrations. An example is Sabo Bakin Zuwo Road, which had an HI of 27.6, whose effect was mainly caused by zinc excess, which has been identified as leading to neurodevelopmental disorders via the oxidative stress pathway. The other locations, such as Kano Municipal and Hotoro, also exceeded the HI threshold of 1.0, posing a possible non-carcinogenic health risk and requiring urgent mitigation. The geographic distribution of HI values confirmed the role of point-source contamination, particularly industrial effluent, whereby urban localities exhibited greater risk than rural locations. The results support the idea of specific pollution control and regular monitoring to protect people's health.

The Chronic Daily Intake (CDI) and Hazard Quotients (HQ), calculated and further elaborated on the long-term health effects of using water in the region. High



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concentrations of heavy metals such as lead (Pb) and cadmium (Cd) at certain locations led to HQs of above 1, with possible chances of developing chronic toxicity with a continuation of the exposure. This type of data underscores the importance of ongoing monitoring and the application of water quality standards, particularly in known hotspots. Further, analysis of inorganic proxies and organic indicators, e.g., nitrogen compounds and patterns of metal-organic complexation, provided insight into areas of anthropogenic contamination, e.g., sewage and industrial waste influences, which added to the health risks being faced. The sophisticated analytical methods used, such as ICP-MS, spectrophotometry, isotope tracing, and bioassays, provided a multidimensional perspective on water quality and pollution sources. ICP-MS enabled the accurate determination of trace metals and showed hotspots with lethal levels of Pb, Cr, Zn, etc., which are frequently associated with industrial emissions and natural mineralisation. Isotope data were useful for distinguishing recharge sources and evaporation effects, thereby identifying contamination pathways. Ecological risks were supported by toxicity bioassays, e.g., Microtox and amphibian embryo tests, which revealed that in sites with high heavy metal loads, bioaccumulation and adverse ecological conditions could occur. This combined solution provides a robust system for evaluating and controlling groundwater quality in complex urban-rural environments. The importance of incorporating water quality monitoring and management systems in Kano. The geographical distribution of contamination, health risk indicators, and ecological measurements indicates certain hotspots that need urgent action, i.e., industrial effluent controls, sanitary measures, and remediation efforts. With the help of sophisticated analytical tools and biological and isotopic measurements, it is possible to regularly monitor pollution sources and assess the effectiveness of interventions, as well as the safety of groundwater sources. Finally, the preservation of groundwater quality is a priority for the health of the people, ecological viability and sustainable development within the area.

## VII. CONCLUSION

This thorough groundwater analysis at Kano has shown that there is a high level of spatial variability in groundwater quality, with several city hot spots exhibiting elevated toxic metal concentrations, a high hazard index, and ecological hazards that threaten human health and environmental sustainability. The best way to address these risks is to ensure constant, routine monitoring using highly developed analytical methods such as ICP-MS, Isotope tracing, and bioassays to determine the sources of pollution and the pathways of contamination. Some short-term measures to take include implementing industrial effluent laws, improving sanitation, and implementing specific remediation techniques, such as water treatment and pollution source control. Also, zoning the protected groundwater zones and educating the community on practices to ensure safe drinking water are important measures for the accessibility of sustainable, safe drinking water and the area's ecological health.

## DECLARATION STATEMENT

Some of the cited references are older and are noted explicitly as [22], [25] and [26]. However, these works remain significant for the current study, as they are pioneering in their fields.

As the article's author, I must verify the accuracy of the following information after aggregating input from all authors.

- **Conflicts of Interest/ Competing Interests:** Based on my understanding, this article has no conflicts of interest.
- **Funding Support:** This article has not been funded by any organizations or agencies. This independence ensures that the research is conducted with objectivity and without any external influence.
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- **Data Access Statement and Material Availability:** The adequate resources of this article are publicly accessible.
- **Author's Contributions:** The authorship of this article is contributed equally to all participating individuals.

## REFERENCES

1. Dayyabu Firdausi, Mustapha Zakariyya Karkarna, Nura Umar Kura, and Surayya Farouk Durumin Iya. (2025): Multivariate Hydrogeochemical Assessment of Urban Groundwater Quality in Kano Metropolis, Nigeria. A periodical of the Faculty of Natural and Applied Sciences, UMYU, Katsina. ISSN: 2955 – 1145 (print); 2955 – 1153 (online) UMYU Scientifica, Vol. 4 NO. 3, Pp 066 – 082/ DOI: <https://doi.org/10.56919/2543.007>
2. Christain Chinweba Onoyima, Clifford Baba Okpanachi, Jibrin Noah Akori. (2025): Hydro-geochemical Characterisation and Groundwater Quality Assessment of Mariri Aquifer, Kano, Nigeria. Journal of Agriculture and Environment for International Development - JAEID 2025, 119 (1): 469 - 486 DOI: <http://doi.org/10.36253/jaeid-17814>.
3. Abdullateef Abdullahi Ibrahim and Kabiru Suleiman. (2025): Assessment of Groundwater Quality Parameters in Sharada and Bompai Industrial Areas of Kano State, Northwestern Nigeria. FUDMA Journal of Sciences (FJS) ISSN online: 2616-1370 ISSN print: 2645 - 2944 Vol. 9 No. 8, August, 2025, pp 46 – 54 DOI: <https://doi.org/10.33003/fjs-2025-0908-3864>
4. Balogun D. O, A. A. Okewu, A. A. Maikano, A. Ibrahim, N. H. I. Sule, M.M. Abdullahi. (2021): Groundwater Quality Assessment of Kano Metropolis using Water Quality Index and Geospatial Techniques. International Journal of Engineering Research & Technology (IJERT) ISSN: 2278-0181 IJERTV10IS070028.
5. Bolaji T. A, Oluyemi T. M, and Aladegbami Y. O. (2025): Hydrogeochemical Characterization and Risk Assessment of Potentially Toxic Elements in Water Sources Around Ibese Quarry, Southwestern Nigeria. Cleaner Water 4 (2025) 100176. DOI: <http://doi.org/10.1016/j.clwat.2025.100176>
6. Sushma R Bankar (Thakre). (2024): Water Quality Assessment-A Literature Survey. International Journal of Creative Research Thoughts. Volume 12, Issue 3 March 2024 | ISSN: 2320-2882. IJCRT2403244 International Journal of Creative Research Thoughts (IJCRT) [www.ijcrt.org/b949](http://www.ijcrt.org/b949).
7. Hengameh Shekohideh, Mehdi Vafakhah, Seyed Hamidreza Sadeghi, and Vahid Moosavi. (2026): Evaluating the reliability, resilience, and vulnerability of water resources: the impact of minimum, maximum, environmental flows, and water quality. Applied Water Science (2026) 16:8 DOI: <https://doi.org/10.1007/s13201-025-02670-4>
8. Rahul Kumar, Swati Jaiswal, Ankita Rai, Vijai K. Rai and Manorama Singh. (2025): Electroactive advanced nanomaterials for wastewater monitoring. Kumar et al.



- Discover Electrochemistry (2025) 2:67  
DOI: <https://doi.org/10.1007/s44373-025-00081-3>.
9. Uche Dickson Ijioma, Michael Ijiomab and Rainer Herda. (2025): Assessment of quality and health risks in drinking water sources in Aba, Nigeria. Water Practice & Technology Vol 20 No 4, 937  
DOI: <http://doi.org/10.2166/wpt.%202025.042>.
  10. Sivakumar Babu K. V, Aravindan Achuthan and Shamshaad Ahmad. (2024): Hydrological assessment of the Gundlakamma sub-basin through SWAT modelling: integration of land use land cover (LULC) and climate changes. Journal of Water and Climate Change, Vol. 15, No. 2, 849, DOI: <http://doi.org/10.2166/wcc.%202024.618>.
  11. Fariba Abbasi, Azadeh Kazemi, Ahmad Badeenezhad, Mostafa Moazamfard, Raham Armand, Amin Mohammadpour. (2025): Assessing the impact of reverse osmosis plant operations on water quality index improvement through machine learning approaches and health risk assessment, Results in Engineering, Results in Engineering 25 (2025) 104363. DOI: <http://doi.org/10.1016/j.rineng.2025.104363>.
  12. Ammari Abdessattar and Fartas Fadhila. (2025): Assessment of diluted saline water using the water quality index and DataFit software for irrigation purposes in El-Oued, Algeria. Journal of Water, Sanitation and Hygiene for Development, Vol 15, No 4, 258, DOI: <http://doi.org/10.2166/washdev.%202025.244>.
  13. Sanal Kumar Adityaa, Appukkuttanpillai Krishnakumar and Krishnan Anoop Krishnana. (2025): An investigation into the influence of climate extremes on groundwater regimes and human health in the Periyar Basin: A fast-growing urban centre in India. Journal of Water and Health Vol 23 No 2, 111 DOI: <http://doi.org/10.2166/wh.2025.227>.
  14. Fawzia Al-Ruwaih, Redha Mohammad, Shafullah Mohideen. (2025): Assessment of groundwater quality of Al-Shagaya area (Kuwait) for irrigation and industrial purposes using water quality index and GIS techniques. Kuwait Journal of Science 52 (2025) 100334  
DOI: <http://doi.org/10.1016/j.kjs.2024.100334>.
  15. Nenuwe N. O, Umukoro J. O., and Enaibe E. A. (2024): First-principles calculations to investigate structural, electronic, magnetic, thermodynamic, and thermoelectric properties of RbSrZ (Z = Ge and Sn) d<sub>0</sub>-d<sub>0</sub> half-Heuslers for renewable energy applications. Kuwait Journal of Science 52 (2025) 100300.  
DOI: <http://doi.org/10.1016/j.kjs.2024.100300>.
  16. Hassan Alzahrani, Abdullah Basaloom, Sayed Mosaad. (2024): Geochemical-based appraisal of karst groundwater quality, West Nile Valley, central Egypt, for drinking and irrigation. Journal of Hydrology: Regional Studies. DOI: <http://doi.org/10.1016/j.ejrh.2024.102152>.
  17. Fabiola Nunes Derossi, Paulo Flores Ribeiro, and José Lima Santos. (2024): Farming System Choice Is Key to Preserving Surface Water Quality in Agricultural Watersheds. Agronomy 2024, 14, 214.  
DOI: <https://doi.org/10.3390/agronomy14010214>.
  18. Abiodun Babatunde. (2024): A Study on Traditional Water Quality Assessment Methods. Risk Assessment and Management Decisions. www.ramd.reapress.com. Risk. Assess. Man. Dec. Vol. 1, No. 1 (2024) 41–52. DOI: <https://doi.org/10.48314/ramd.v1i1.29>
  19. Thayná A. B. Almeida, Abelardo A. A. Montenegro, João L. M. P. de Lima, Carolyne W. L. A. Farias, Ailton A. Carvalho e Anderson L. R. de Paiva. (2025): Spatiotemporal Variability of Groundwater Quality for Irrigation: A Case Study in Mimoso Alluvial Valley, Semiarid Region of Brazil. Water 2025, 17, 410  
DOI: <https://doi.org/10.3390/w17030410>.
  20. Nada Sasakova, Gabriela Gregova, Daniela Takacova, Jana Mojziszova, Ingrid Papajova, Jan Venglovsky, Tatiana Szaboova and Simona Kovacova. (2018): Pollution of Surface and Ground Water by Sources Related to Agricultural Activities. Frontiers in Sustainable Food Systems. Vol 2. DOI <http://doi.org/10.3389/fsufs.%20201800042>.
  21. Arief Dhany Sutadian, Nitin Muttli, Abdullah Gokhan Yilmaz, B J C Perera. (2016): Environ Monit Assess. 2016 Jan;188(1): 58. Epub 2015 Dec 28. Development of river water quality indices: a review.  
DOI: <http://doi.org/10.1007/s10661-015-5050-0>
  22. Mark B. Bain, Amy L. Harig, Daniel P. Loucks, Reuben R. Goforth, Katherine E. Mills. (2000): Aquatic ecosystem protection and restoration: advances in methods for assessment and evaluation. 1462-9011/00/\$ - see front matter Published by Elsevier Science Ltd. PII: S 1 4 6 2 - 9 0 1 1 ( 0 0 ) 0 0 2 9 - 0.,  
DOI: [https://doi.org/10.1016/S1462-9011\(00\)00029-0](https://doi.org/10.1016/S1462-9011(00)00029-0), works remain significant, see the [declaration](#)
  23. Mengyuan Zhu, Jiawei Wang, Xiao Yang, Yu Zhang, Linyu Zhang, Hongqiang Ren, Bing Wu, and Lin Ye. (2022). A review of the application of machine learning in water quality evaluation. Eco-Environment & Health 1 (2022) 107–116.  
DOI: <http://doi.org/10.1016/j.eehl.2022.06.001>.
  24. Nada Sasakova, Gabriela Gregova, Daniela Takacova, Jana Mojziszova, Ingrid Papajova, Jan Venglovsky, Tatiana Szaboova and Simona Kovacova. (2018): Pollution of Surface and Ground Water by Sources Related to Agricultural Activities. Frontiers in Sustainable Food Systems. Vol 2. DOI: <http://doi.org/10.3389/fsufs.%20201800042>.
  25. Najaf Pour, Sh, Akkari, A. F. M, Kadir, M. O. A. and Najafpour, Gh. D. (2008): Evaluation of Spatial and Temporal Variation in River Water Quality. (2008): Int. J. Environ. Res., 2(4): 349-358, Autumn 2008 ISSN: 1735-6865. Pp 349-358.,  
[https://ijer.ut.ac.ir/article\\_214.html](https://ijer.ut.ac.ir/article_214.html), works remain significant, see the [declaration](#)
  26. Haibo Yang, Jialin Kong, Huihui Hu, Yao Du, Meiyuan Gao 1 and Fei Chen. (2008): A Review of Remote Sensing for Water Quality Retrieval: Progress and Challenges. Remote Sens. 2022, 14, 1770.  
DOI: <https://doi.org/10.3390/rs14081770>  
<https://www.mdpi.com/journal/remotesensing>, works remain significant, see the [declaration](#)
  27. Godson Ebenezer Adjovu, Haroon Stephen, David James and Sajjad Ahmad. (2023): Overview of the Application of Remote Sensing in Effective Monitoring of Water Quality Parameters. Remote Sens. 2023, 15, 1938. DOI: <https://doi.org/10.3390/rs15071938>  
<https://www.mdpi.com/journal/remotesensing>.
  28. Rab Nawaz, Iqra Nasim, Ali Irfan, Amjad Islam, Ayesha Naeem, Nadia Ghani, Muhammad Atif Irshad, Maria Latif, Badar Un Nisa and Riaz Ullah. (2023): Water Quality Index and Human Health Risk Assessment of Drinking Water in Selected Urban Areas of a Mega City. Toxics 2023, 11, 577. DOI: <https://doi.org/10.3390/toxics11070577>  
<https://www.mdpi.com/journal/toxics>.
  29. Simon N. Topp, Tamlin M. Pavelsky, Daniel Jensen, Marc Simard and Matthew R. V. Ross. (2020): Research Trends in the Use of Remote Sensing for Inland Water Quality Science: Moving Towards Multidisciplinary Applications. Water 2020, 12, 169;  
DOI: <https://doi.org/10.3390/w12010169>
  30. Kwami, I. A, Haruna A. I, Maigari A. S, Lawal A, Mukkafa S, Yusuf A, Usman M. B, Abubakar U. A, Mohammed A. G, Umar A. D, Umar S. U, Kariya I. I, Sabo K. A and Daya M. G. (2024): An Assessment of Groundwater Quality of Ashaka and Environs, Gombe, North Eastern Nigeria, Using Water Quality Index Technique. Bima Journal of Science and Technology, Vol. 8(1B) Apr, 2024 ISSN: 2536-6041.  
DOI: <https://doi.org/10.56892/bima.%20v8i1.625>.

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## Ecotoxicological and Hydrogeochemical Assessment of Groundwater in Kano: Determining the Areas of Pollutants and the Health Hazards



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