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Integrated Hydrochemical and Epidemiological Assessment of Groundwater Contamination and Disease Burden in Kano Metropolis, Nigeria

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Abstract

Groundwater contamination remains a critical threat to human health and environmental sustainability in rapidly urbanizing African cities. This study provides an integrated hydrochemical, microbiological, geostatistical, and epidemiological assessment of groundwater quality degradation and disease burden in Kano Metropolis, Northern Nigeria. A total of 480 well water samples were collected across eight Local Government Areas (LGAs) and analysed for 18 physicochemical, heavy metal, and microbial parameters using APHA-certified protocols. Results showed widespread exceedances of WHO and NSDWQ drinking-water limits, with particularly high concentrations of nitrate (up to 145.4 mg/L), turbidity (7.9 NTU), electrical conductivity (1341.6 µS/cm), chromium (5.11 mg/L), lead (0.48 mg/L), and E. coli (206 cfu/100ml) during the wet season. MANOVA confirmed significant spatial and seasonal variations ($p < 0.001$), while PCA revealed two major components explaining 72.8% of total variance, driven by heavy metal pollution and microbial contamination. Hospital data (2011–2022) recorded 172,592 water-related disease cases, with children (<18 years) disproportionately affected by gastroenteritis (68.9%), cholera (60.1%), and cyanosis (95%), while adults exhibited higher prevalence of kidney disease (92.5%), neurological disorders (87.4%), and cancer (85%). Strong correlations were observed between NO_3 and gastroenteritis ($r = 0.76$), EC–TDS ($r = 0.94$), and Cr–Pb ($r = 0.82$). Findings highlight the urgent need for decentralized water treatment, improved wastewater management, policy enforcement, and WASH interventions. The study contributes a comprehensive evidence base for water security planning and integrated urban environmental management in Nigeria.

Keywords: Disease burden, contaminated water, wastewater, heavy metal, physicochemical, microbial parameters

1. Introduction

One significant and valuable compound of the ecosystem all over the globe is 'water' which constitutes about 70% of the earth surface. Water is required by all living organisms without exception for day to day activities and generally for survival (UNESCO, 2019; WHO and UNICEF, 2017). Therefore, it is very imperative that the quality of drinking water be analysed at standard laboratory periodically to determine the permissible levels stipulated by national and international bodies such as World Health Organisation (WHO), Standard Organisation of Nigeria (SON) and European

Union (EU) among others to deter the occurrences of waterborne diseases such as cholera, gastroenteritis, neurological disorder, Cyanosis/asphyxia, cancer, and heart diseases among others as well as the devaluation of the environment (WHO, 2020; NSDWQ, 2015, Mshelia, et al., 2021; Balamurugan and Dheenadayalan, 2012; Nazma et al., 2024; Valipour, 2015).

Kano Metropolis, the largest city in Northern Nigeria, like other cities faces severe water quality challenges due to dense network of informal settlements, increasing population, industrial activities, and inadequate sanitation. These factors have contributed to the pollution of surface and groundwater sources that serve as the primary sources of water for domestic, industrial, and agricultural uses (Olalekan et al., 2020; UNESCO, 2022; Mshelia, 2024a). Water contamination in Kano arises from multiple sources: indiscriminate disposal of industrial effluents, leaching of agricultural chemicals, and improper disposal of domestic sewage (Raimi et al., 2021). Studies have documented the presence of heavy metals, pathogenic bacteria, and organic pollutants in major water bodies within the metropolis, such as the borehole and well water which the majority of the residents use for drinking as well as Jakara and Challawa Rivers (Abdullahi et al., 2015). The consequences are dire: outbreaks of waterborne diseases, ecological degradation, increased vulnerability of urban poor communities, climate change and loss of biodiversity (Mshelia & Bulama, 2023; WHO, 2020; 2023; Mshelia et al., 2024; Mshelia, 2024b; Eboagu et al. 2019; Amoo et al., 2018).

Despite the gravity of the problem, there remains limited integrated research on the health and environmental implications of water pollution, inadequate enforcement of environmental laws, lack of water treatment infrastructure, and poor inter-agency coordination in Kano. It is against this backdrop that the study addresses this gap by providing a holistic assessment of contamination sources, their effects on human health and the environment, the effectiveness of current management strategies towards meeting SDG 6 and 11 which are provision of safe water and clean settlements as well as sustainable cities and communities by the year 2030.

2. Material and Methods

2.1 Study Area

Kano Metropolis is located between latitudes 11^0 55′ 23.93″N to 12^0 3′ 53.10″N of the Equator and longitude 8^0 27′ 42.26″E to 8^0 3′ 41.62″E of the Greenwich Meridian (see Figure 1). It has total land coverage of 499km^2 and consists of eight LGAs which are Nasarawa, Dala, Gwale, Fagge, KMC, Kumbotso, Ungogo and Tarauni (Mshelia et al., 2020). The 2023 projected population is about 4,301,112 at growth rate of 2.8% (UN-World Population Review, 2022; Mshelia and Bulama, 2023). Kano Metropolis is usually hot throughout the year, though, from December to February, the city is noticeably cooler. Nighttime temperatures are cool during the months of December, January and early February, with average low temperatures of 11° - 14 °C in some cases (Nigerian Meteorological Agency [NIMET], 2021). During the wet season, heat

and humidity cause wastewater and other municipal wastes to be more turgid and stinks as well as in dry season due to absence of rainfall to dilute and infiltrate into soil. Similarly, high temperature raises the moisture contents of wastes of different sorts and provides breeding ground of mosquitoes, vectors and microbial organisms. Temperature is also a significant factor that facilitates chemical and biological activities in a community (Mshelia et al, 2024).

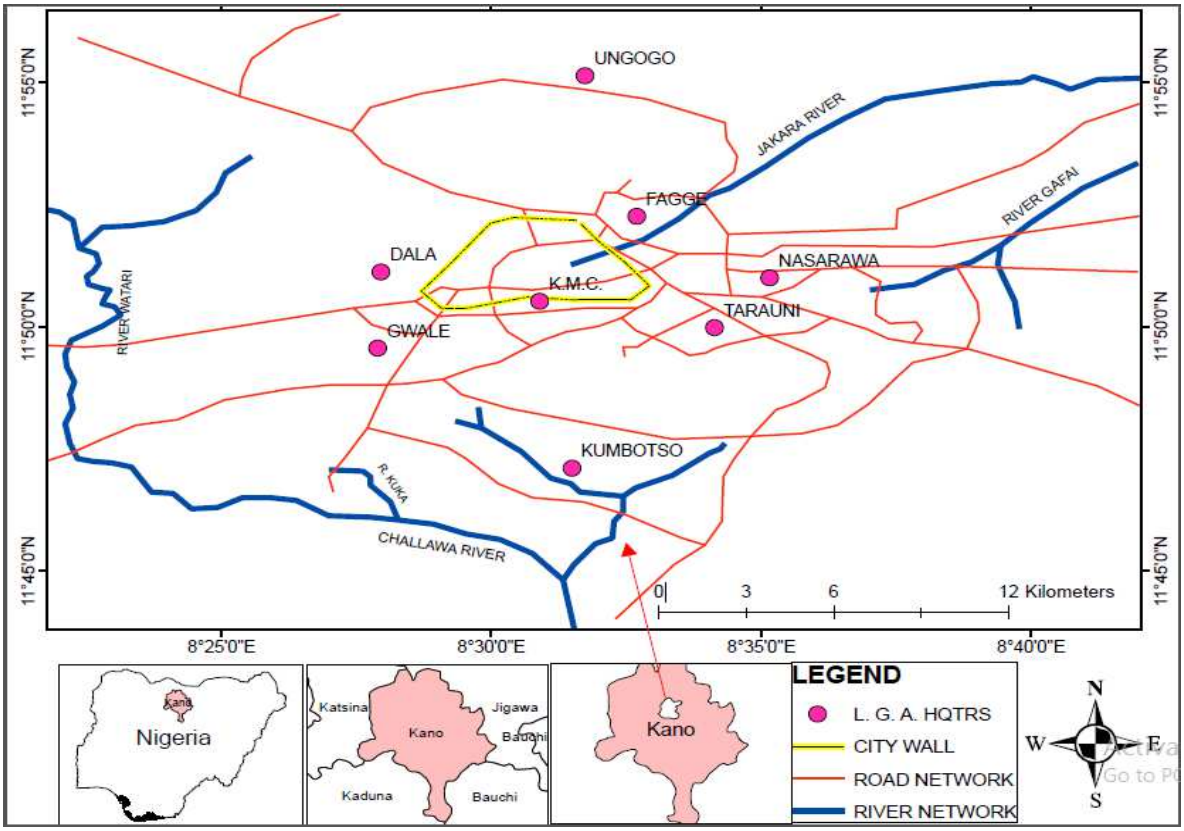


Figure 1. Kano Metropolis and its Rivers
Source: Mshelia and Bulama (2023).

2.2 Sample Collections

Systematic and random samplings were employed in the selection of the sampled points in the Metropolis. Ten wards were randomly selected in each of the eight LGAs. They were serially arranged in alphabetical pattern and assigned numbers 1 - 10. Even numbers: 2, 4, 6, 8 and 10 were selected in each LGA which form the sampled frame. Five (5) wells in each of the 8 sampled wards were randomly selected. This gave a total of forty (40) well and 480 water samples collected from the wells (see Table. 1).

Table 1. Groundwater collections in Kano Metropolis (from 10/08/2022 to 30/04/2023)

Season	Type of sample	Period collected	No of sampled points	Frequency of samples collected at each sampling point
Wet	Well	28-29/06 – 24-25/08/2023	40	6(40 x 6 = 240)
Dry	Well	28/2-01/3 – 26-27/04/2023	40	6(40 x 6 = 240)
Total			**80**	**480**

Source: Field Study (2023)

To further elucidate the health effects, one tertiary hospital (Aminu Kano Teaching Hospital) and six secondary hospitals in Kano Metropolis (see Table 2 and Figure 2) were purposefully selected based on their status and ability to conduct laboratory tests and admit patients. Records on waterborne and other water related diseases from January 2012 - January 2023 were obtained from the hospitals' Medical Records Departments (MRD) and also directly from the doctors and nurses interacted with. Interviews and data collection schedules were drawn and used for the collection of data on water related diseases from each of the selected hospitals. The results of the findings were analysed using simple descriptive analysis in frequency and percentage. The selected hospitals in the metropolis were presented on a map to show their spread in the Metropolis (see Figure 2). Each of the hospitals was visited and data on waterborne related diseases were recorded.

Table 2. Sampled Hospitals in Kano Metropolis

Name of Hospital	Location/Address	Coordinate
Aminu Kano Teaching Hospital	Zaria Road	$11^0$57' 51.3"N; $8^0$32′59.6"E
Murtala Muhammad Specialist Hospital	Kofar Mata, KMC	$11^0$59' 16.0"N; $8^0$32′21.1"E
Imam Wali General Hospital	Daurayi	$11^0$58' 32.4"N; $8^0$28′02.3"E
Muhammad Abdullahi Wase Specialist Hospital	Nasarawa	$11^0$59' 37.7"N; $8^0$32′40.6"E
Kofar Ruwa General Hospital	Kofar Ruwa Dala	$12^0$01' 19.1"N; $8^0$29′35.0"E
Amina Specialist Hospital	Fagge	$12^0$03' 33.4"N; $8^0$32′46.7"E
Maryam Sani Abacha General Hospital	Ungogo	$12^0$05' 16.9"N; $8^0$45′08.2"E

Source: Field Survey (2022)

2.3 Laboratory Analysis of water Samples

The water samples were subjected to laboratory analyses for the determination of the concentrations of physicochemical, heavy metals and microbial parameters. The Principal of Component analysis was employed and selected a total of 18 water quality parameters (WQP) as shown in Table 3. The concentrations of the WQP were determined in standard laboratory in accordance to the American Health Public Authority (APHA, 2005) using suitable methods of analysis for each WQP (see Table 4).

Table 3. Samples and parameters analysed

Sample	Physicochemical Parameter	Heavy Metals	Microbial Parameter

Surface/ Groundwater	Temperature pH	Cadmium (Cd) Chromium (Cr)	Total Coliform Count(TCC)
	Electric Conductivity (EC) Turbidity (TUR)	Mercury (Hg) Arsenic (As)	Escherichia Coli (E. Coli)
	Total Dissolved Solids (TDS)	Lead (Pb)	
	Total Hardness (TH)	Iron (Fe^{+2})	
	Dissolved Oxygen (DO) Nitrate (NO3)	Copper (Cu) Zinc (Zn)	

Source: Field Survey (2023)

Table 4. Summary of laboratory analyses of physicochemical, heavy metals and microbial parameters/elements

SN	Parameter	Unit	Methods	Instrument
1	Temperature	^0C	Thermometric APHA (1998)	Mercury bulb Thermometer (Jenway 3015)
2	pH	-	pH meter APHA (1998)	Digital pH Meter (HANNA 191300 Model)
3	Turbidity (Tur)	NTU	Nephelometric APHA (1998)	Digital Turbidity Meter (2100AN HARCH Model)
4	Electrical Conductivity (EC)	µs/cm	Electrochemical Method APHA (1998)	Digital Conductivity Meter (HARCH Model CM-230)
5	Total Hardness (TH)	mg/L	EDTA-Titrimetric AHPA (1998)	HACH Titrator (16900 Model)
6	Total Dissolved Solid (TDS)	mg/L	Standard Method 2540C (APHA, 1998)	Conductivity meter (Aquared AP-2000-D)
9	Nitrate (No)	mg/L	Cd Reduction Method (1998)	LAQUAtwin Ca^{2+} Meter Ca-11 Model.
10	Heavy Metals (Cd, Cr, Hg, Fe, Pb, As, Cu)	mg/L	Spectrophotometric Analysis APHA (1998)	Shimadzu Atomic Absorption Spectrophotometer (AAS Model AA-6800), Japan Model
11	TCC & E.Coli	cfu/100 ml	Membrane Filter (MF) technique (HACH, 1996)	Sterilized membrane filter

Source: APHA (2005); Authors Compilations (2023)

3. Results and Discussion

3.1 Sources of contaminated water

Kano Metropolis, the largest city in Northern Nigeria, like other cities faces severe water quality challenges due to increasing population density, industrial activities, and inadequate sanitation. This contributes to the generation of high volume of municipal solid wastes and wastewater in the Metropolis, indiscriminate disposal of industrial effluents, leaching of agricultural chemicals, and improper disposal of domestic sewage (Raimi et al., 2021; Mshelia 2024a, Mshelia et al., 2020) as shown in Figure 2. Zhang et al., (2021) also reported in the study pollutants in the Sinkhole Region of

Winkler County, Texas that groundwater pollution in different regions can cause risks to the health of human beings.

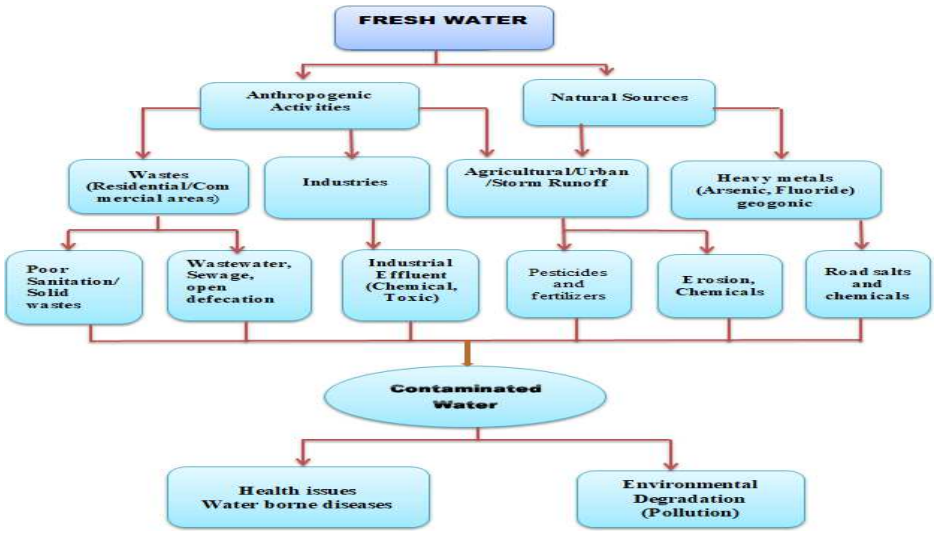


Figure 2: Contaminants of Fresh Water and its health and Environmental Issues
Source: Field survey (2025)

3.2 Laboratory Analysis of Physicochemical, Heavy Metals and Microbial Parameters

The collected water samples in the Metropolis were subjected to laboratory analyses where the concentrations of physicochemical, heavy metals and microbial parameters were determined to ascertain the likely health effects. Most of the wells recorded high concentrations above the WHO (2020) and NSDWQ (2015) permissible limits especially during the wet season. The mean values of the analysed parameters were presented in Table 5; 6 and 7.

The laboratory analysis of the sampled well water in the metropolis showed high mean concentrations of temperature, pH, EC, Tur, TH and NO^3 raged between 27 – 30.2^0C; 4.6 – 9.1, 586.5 – 1341.6 µS/cm, 5.6 – 7.9NTU, 86.7 – 285.2mg/L and 55 – 145.4mg/L during the wet season respectively while the dry season recorded 27 – 29^0C, 6.25 – 8.52, 371.6 – 1041 µS/cm, 3.4 – 5.61NTU, 395 – 615.2mg/L, 54.32 – 180.2mg/L and 24.5 – 83.4mg/L respectively (see Table 4). The mean values in some of the parameters at certain points such as EC at Fagge: 1172µS/cm and Nasarawa: 1341.6µS/cm recorded higher than the recommended guidelines of WHO (2020) and NSDWQ (2015) standard during the wet season. Similarly, pH recorded above permissible at Dala and Kumbotso. Turbidity values, TDS at Dala and Fagge, TH in all the wells except mean wells in Ungogo and all the wells in the Metropolis measured NO3 above the threshold of 150mg/L as shown in Table 5.

The results show high nitrate levels in both seasons, values in KMC, Kumbotso, Nasarawa exceed WHO/NSDWQ limits of 50 mg/L, which is linked to cyanosis/asphyxia (methemoglobinemia). Similarly, high turbidity, TDS and EC which is consistently above permissible limits, indicating potential microbial contamination and poor filtration**.** On the other hand extremes pH 9.8 and 4.07 of alkaline and acidic conditions at Dala and Hwombotso respectively, both of which affect metal solubility and bioavailability.

During the wet season, heavy metals (mg/L) such as Cd, Cr, Hg, As, Pb, Cu and Mn at Kofar Mazugal, Danmarke, Fagge D, Giginyu, Brigade, Makera and Gandu recorded mean concentrations of 0.015, 5.11, 0.052, 0.06, 0.32, 4.11 and 4.1(mg/L) respectively (Table 6) well above the permissible limit for drinkable water as stipulated by WHO (2020) and NSDWQ (2015). Laboratory values of Chromium, Lead, and Arsenic often exceed WHO limits (Cr: 0.05 mg/L, Pb: 0.01 - 0.03 mg/L). Highest Cr at Fagge recorded 5.11 mg/L) very well above the thrashed hold shows high potential carcinogen risk while Lead and mercury values are alarmingly high in several locations. The high values are attributable to infiltration of wastewater into the ground and contaminated groundwater. Similar values were also observed on the study of River Damodar water quality (Singh, 2019). The findings are similar to that reported by the study on the physicochemical properties of residential groundwater in Lagos (Lekan et al., 2021).

Similarly, microbial parameters recorded TCC mean concentrations ranged between 72 – 176cfu/100ml; 34 – 132cf/100ml and E. Coli 52 - 206cfu/100ml; 34 – 170cf/100ml during wet and dry seasons respectively. In the aspect of the microbial parameters E. coli levels in many wells especially at KMC and Gwale) are above zero, indicating fecal contamination. Similarly, E. coli counts (up to 203 cfu/100ml in wet season) strongly suggest exposure risk to gastrointestinal diseases**,** cholera**,** and skin infections. The results showed very high concentrations of the microbial parameters. The result is also in agreement with the investigation on seasonal hydro-chemical groundwater quality in northwest, China (Li et al., 2019).

Table 5. Well Mean Concentration of Physicochemical in Kano Metropolis during Wet and Dry Seasons

	Dala	Fagge	Gwale	KMC	Kumb Otso	Nasa Sawa	Tarauni	Ungogo	WHO (2020)	NSDWQ (2015)
Parameters	W1	W2	W3	W4	W5	W6	W7	W8		
W Urban WS										
Temp (^{0}C)	27	28	30.2	29.5	30.0	28.5	27.0	30	27-28	27 -28
pH	9.8	8.1	7.1	7.82	9.1	4.07	6.6	7.0	6.3-8.5	6.5-8.3
EC (µS/cm)	651.5	1172	586.5	1202	476.5	1341.6	805.3	864.3	1000	1000
Turbidity (NTU)	5.4	6.27	6.0	5.5	7.9	5.4	6.5	7.5	5.0	5.0
TDS (mg/L)	762	655	712	721.7	543	385	464	667.7	500	500

TH (mg/L)	152.3	143	285.2	204.6	165.8	252.1	215.6	86.67	100	150
Nitrate (mg/L)	65	55.6	55.0	132.2	145.4	56.6	88.8	64.1	50	50
W Urban DS										
Temp (^{0}C)	26.5	27.5	27.1	27.5	27.0	27.2	29.0	27.5	27-28	27-28
pH	7.28	7.51	7.25	7.82	7.23	7.37	8.52	7.46	6.5-8.5	6.5-8.5
EC (µS/cm)	517.5	371.6	386.5	602	476.5	1041.6	405.3	464.3	1000	1000
Turbidity (NTU)	4.45	5.61	4.26	3.46	5.17	5.31	4.07	5.33	5.0	5.0
TDS (mg/L)	461.3	642.7	615.2	587.2	395	543.8	436.5	467.3	500	500
TH (mg/L)	66.2	54.32	78.3	180.2	96.8	126.2	170.5	86.67	100	150
Nitrate (mg/L)	24.5	28.3	83.4	95	72.12	48.34	38.2	28.4	50	50

W= Well, WS= Wet Season, DS= Dry Season.
Source: Field Survey (2022)

Table 6. Well mean concentration of heavy metals in Kano Metropolis during wet and dry seasons

	Dala	Fagge	Gwale	KMC	Kumbo Tso	Nasar Awa	Tarauni	Ungogo	WHO (2020)	NSDWQ (2015)
Parameters	W1	W2	W3	W4	W5	W6	W7	W8		
W Urban WS										
Cadmium (mg/L)	0.009	0.009	0.012	0.015	0.012	0.009	0.009	0.010	0.003	0.003
Chromium(mg/L)	1.72	5.11	2.62	1.61	0.75	3.42	2.51	0.56	0.05	0.05
Mercury (mg/L)	0.004	0.001	0.002	0.0113	0.004	0.004	0.012	0.052	0.001	0.001
Arsenic (mg/L)	0.04	0.015	0.05	0.08	0.04	0.06	0.01	0.02	0.01	0.01
Lead (mg/L)	0.32	0.3	0.21	0.23	0.25	0.22	0.15	0.28	0.3	0.3
Iron (mg/L)	2.62	1.50	0.55	1.85	0.5	0.4	0.4	0.21	0.3	0.3
Zinc (mg/L)	4.18	3.11	3.00	3.74	3.25	5.62	5.12	2.34	3.0	3.0
Copper (mg/L)	5.12	2.54	4.11	4.23	2.98	1.30	2.10	1.0	2.0	1.0
W Urban DS										
Cadmium (mg/L)	0.005	0.01	0.015	0.009	0.012	0.008	0.006	0.01	0.003	0.003
Chromium(mg/L)	0.54	3.38	0.78	0.65	0.55	0.90	0.73	0.66	0.05	0.05
Mercury (mg/L)	0.003	0.001	0.001	0.002	0.001	0.005	0.003	0.002	0.001	0.001
Arsenic (mg/L)	0.015	0.03	0.07	0.02	0.015	0.01	0.01	0.02	0.01	0.01
Lead (mg/L)	0.03	0.01	0.4	0.03	0.04	0.02	0.015	0.2	0.3	0.3
Iron (mg/L)	2.40	3.1	2.15	2.15	2.34	2.32	2.05	2.01	0.3	0.3
Zinc (mg/L)	2.48	1.53	1.25	1.50	1.44	2.52	2.54	1.12	3.0	3.0

Copper (mg/L)	2.03	0.56	2.15	1.25	1.00	0.30	1.20	0.45	2.0	1.0

W= Well, WS= Wet Season, DS= Dry Season; Source: Field Survey (2022)

Table 7. Well mean concentration of microbial parameters in Kano Metropolis during wet and dry seasons

	Dala	Fagge	Gwale	KMC	Kumb Otso	Nasar Awa	Tarauni	Ungogo	WHO (2020)	NSDWQ (2015)
Parameters										
W Urban WS	W1	W2	W3	W4	W5	W6	W7	W8		
TC (cfu/100ml)	76	76	142	176	94	104	72	110	10	10
E-coli (cfu/100ml)	52	70	145	203	64	82	186	65	0	0
W Urban DS										
TC (cfu/100ml)	46	45	96	132	127	89	62	34	10	10
E-coli (cfu/100ml)	34	46	105	170	34	54	73	61	0	0

WS= Wet Season; DS= Dry Season; W= Well; Source: Field Survey (2022).

Wastewater is one of the fundamental factors responsible for outbreaks of epidemic or flare cholera and diarrhea (Anne et al., 2013) Most often, the wastewater drains into water body, others flows and dispersed into the community and occupies available space attributed to poor drainage network. The wastewater overtime seep or infiltrate into the aquifer of the groundwater increasing the concentrations of the physicochemical and microbial parameters as well as the heavy metals. The parameters when exceeded the WHO and other regulatory body standards, contaminate the water and become harmful when consumed (Mshelia & Mbaya, 2024; Ngang and Agbaz, 2016). From 2010 – 2019, Nigerian Centre of Disease Control (NCDC) in collaboration with Ministry of Health Kano State recorded 18,483 cases of cholera and out the number, 617 died from the infection (Ngang and Agbaz, (2016). National Bureau of Statistics NBS reported that from October, 2020 – October, 2021 a total of 93,598 cases of cholera and 3,298 deaths were recorded in Nigeria. In Kano alone, from April – August, 2022, a total of 186 cases of cholera with 5 deaths were recorded (NBS, 2021; Ngwa et al., 2021).

The high concentrations of pH, EC, Tur, TDS, TH and NO^3 that recorded 9.1, 1341.6µS/cm, 7.9NTU, 285.2mg/L and 145.4mg/L while dry season recorded 8.52, 1041µS/cm, 5.61NTU, 180.2mg/L and 83.4mg/L respectively, attributed to particles such as clay, silt, organic, and inorganic matter resulted to water hardness similarly, high turbidity levels in drinking water is associated with acute gastrointestinal illness seasonal variations of physicochemical parameters in urban centre of Kano metropolis as also reported by Rohit et al., (2018); Jonah & Mendie, (2024); Saravanakumar et al., (2022). Higher concentration of parameters were also recorded during the wet season ascribed to rainstorm that carries dirt of all sorts and

transported them down stream where good numbers of wells are located. The wet season also aids infiltrations as it opens up the soil pores for easy penetration of water contents down to aquifer level as equally reported by Mshelia & Mbaya (2024) in their work on suitability of groundwater quality for drinking using water quality index in Kano Metropolis, Nigeria.

Findings also showed that most of the wells located close to soakaways, pit latrines, wastewater canals and places common to open defecation such as Hawar Wanki, Unguwar Dacci, Sheka and Gurin Gawa recorded higher values of TCC and E.Coli especially along Jakara wastewater canals (Mustapha et al., 2019). Wastewater poorly discharged into the environment without treatment produces foul smelling odour, infiltrates and pollutes the groundwater and when consumed can results into health effects as shown in Table 8 (Mshelia et al., 2024).

Exposure to high concentrations of water quality parameters (wastewater) has been associated to different kinds of health effects, including waterborne diseases such as cholera, typhoid and diarrhea which are mostly cost by consumption of polluted water, habitation in a poor sanitation environment or through direct contact with wastewater (Ibienebo, & Imachrist, 2024; UN-Water Annual Reports World Development Reports, 2023). Furthermore, the exposure to wastewater can result to respiratory problem, skin irritation and in long run terminal diseases such as cancer. For instance, pH concentration when acidic is reported to cause irritation due to corrosion effects and to aggravate existing skin conditions at high levels (Ahmad et al., 2022; Qui Da et al., 2019). Similarly, the high concentration of Fe^{+}, NO3, Cd and Cr which is in agreement with the result in the studied monitoring strategies of groundwater quality for human consumption in India and recorded high Fe^{+}, NO3, Cd and Cr concentration ranged 2.62, 132.2, 0.015 and 3.22 respectively, likely to cause nusea, kidney and liver issues (Lazar, 2024).

3.3 Geo-Spatial Location Analysis of Sampled Hospitals in Kano Metropolis

The sampled hospitals are spatially distributed across Kano Metropolis with a noticeable concentration of hospitals such as the AKTH, Murtala and Wase in the central axis**.** Kofar Ruwa General Hospital, found in the older part of Kano (Dala), is significant for its proximity to historic communities and markets, supporting a large working-class population**.** Imam Wali General Hospital which is also located slightly westward is positioned to cater to growing suburban settlements like Daurayi, which are often underserved. Likewise Maryam Sani Abacha General Hospital located in Ungogo in the eastern part of Kano serves the outskirts and rapidly urbanizing parts of Kano North-East, bridging the healthcare gap in less-central neighborhoods (see Figure 3. These peripheral hospitals serve expanding urban frontiers, highlighting efforts to decentralize healthcare access as shown in Figure. However, the relative

clustering in the city center suggests a need for better distribution planning to reach under-served suburban and rural-urban fringe populations.

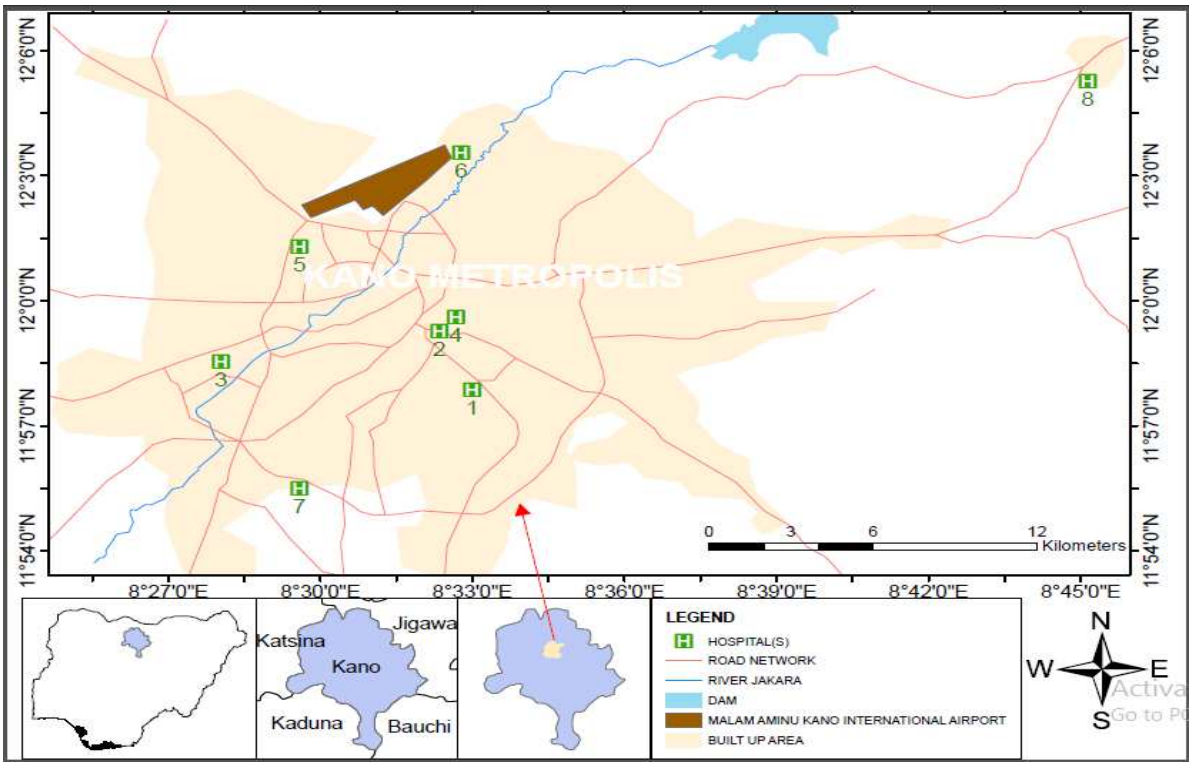


Figure 3. Geo-spatial Location of Sampled Hospitals in Kano Metropolis.

Source: Cartography Unit Geography Department Federal University Gashua (2023)

3.4 Comparative Analysis of Waterborne Diseases by Age Group in Kano Metropolis (2011–2022)

A review of hospital medical records and field survey data from 2011 to 2022 in Kano Metropolis shows significant variations in the prevalence of waterborne diseases between children less than 18 years and adults aged 18 years and above (Table 8). The table reveals a recorded number of 172,592 water related cases in the Metropolis, consisting 96,181 cases (55.74%) in children and 76,411 cases (44.26%) in adults**.**

Children (<18 years) Age-Specific Disease Burden

Children displayed a significantly higher frequency of infectious waterborne diseases than the adults in the Metropolis, especially those caused by microbial parameters in the class of biological pathogens such as viruses, bacteria, protozoa, and parasites as shown on Table 6. This sequence deepens the exposures of children to fecal oral and skin contact diseases as a result of poor sanitation, inadequate access to portable water, and weakened immune defenses. Most worrisome is the cyanosis,

often linked to water contamination by nitrate recorded 95% cases of blue baby syndrome affecting children which are very dangerous to infants (see Table 8)

Adults (≥18 years) Age-Specific Disease Burden

Adults were disproportionately affected by chronic and degenerative conditions associated with long-term exposure to chemical contaminants, especially heavy metals such as cadmium (Cd), mercury (Hg), lead (Pb), and chromium (Cr). Dominant conditions in this group include: The results of the findings reveal the increasing public health of the non-communicable diseases (NCDs) in the metropolis as a result of continued exposure of the population to polluted water. This in tells that wastewater, other industrial and domestic wastes are still being disposed indiscriminately in addition to dilapidated water infrastructure leading to cumulative toxicological impact on adult health (see Table 8).

Table 8: Disease-Specific Comparative Analysis

Disease	Children (<18)	% of Total (per disease)	Adults (≥18)	% of Total (per disease)	Most Affected Group
Gastroenteritis	25,805	68.98%	11,607	31.02%	Children
Cholera	17,145	60.05%	11,405	39.95%	Children
Schistosomiasis / Helminthiasis	23,370	65.92%	12,084	34.08%	Children
Skin Infections	12,948	58.72%	9,102	41.28%	Children
Kidney Diseases	346	7.49%	4,273	92.51%	Adults
Neurological Disorders	662	12.58%	4,600	87.42%	Adults
Cancers	1,242	15.01%	7,037	84.99%	Adults
Cyanosis/Asphyxia	10,783	95.07%	559	4.93%	Children
Cardiovascular Diseases	3,880	19.77%	15,744	80.23%	Adults

The study further showed that people, especially children residing in places with high volume of wastewater, ponds and wastewater canals in the Metropolis such as Kofar Ruwa, Marke, Danagundi and Fagge Jakara River Sides are liable to high risk of contracting waterborne diseases as reported by Lawrence & Mshelia (2024) in their study on effects of physicochemical parameters on river Jakara water quality in Kano Metropolis, Nigeria compared to those in less polluted places such as the Government Residential Areas (GRA) Doctors Quarters and State House Area. The finding is in agreement with that of WHO (2023) which reported that contaminated water leads to health issues, where diarrheal diseases alone claim over 70,000 children under five annually (WHO, 2023) and poor environmental quality such as land degradation (see Figure 4).

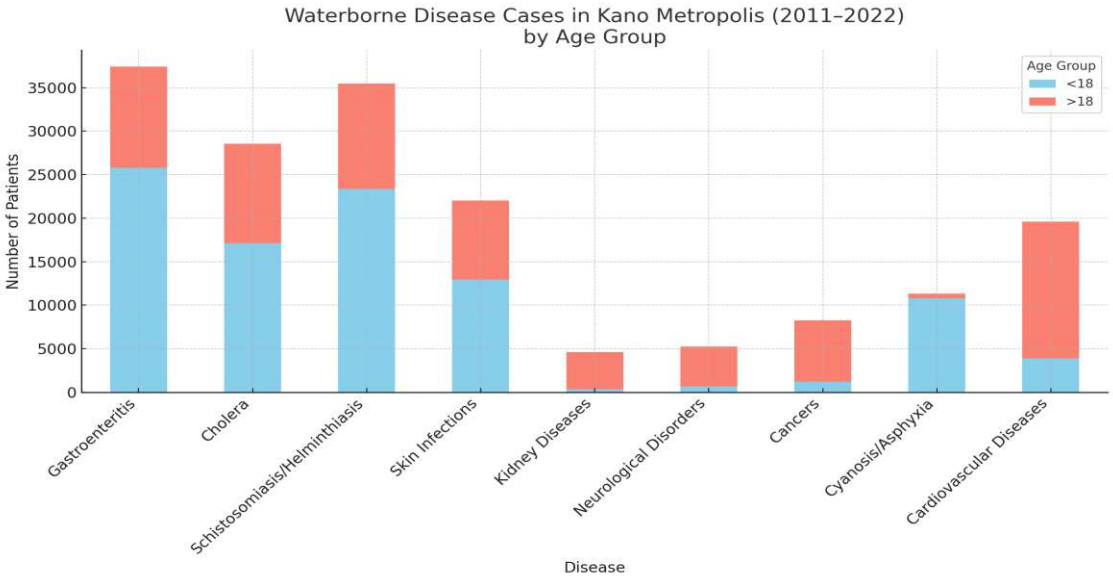


Figure 4: Number of Patients by Disease and Age Group

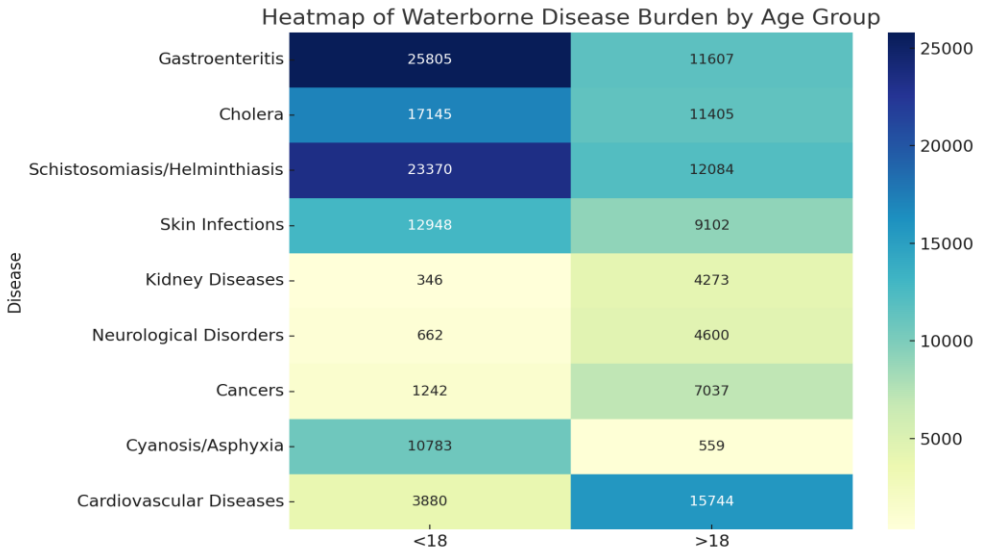


Figure 5: Waterborne Disease Burden by Age Group

Similar results were obtained in the work assessment of urban wastewater reuse in selected African countries (Meneses, et al., 2010) as well as the study on cardiovascular risk factors in adult general outpatient clinics in Nigeria and linked some of the diseases directly or indirectly to consumption of contaminated water (Geoffrey et al., 2017; Global Water Partnership, International Network of Basins Organisations 2009; Mshelia et al., 2020). Similar hospitals investigation on health effects of contaminated water in Tanzania reported cardiovascular diseases more in adult and gastroenteritis (Anne et al., 2013; Ngwa et al., 2021; Nse et al. 2023). They studied water-related diseases, using municipal wastewater in Tanzanian capital and

reported hospital records of gastroenteritis, cholera, schistosomiasis, cardiovascular and cyanosis diseases over a period of ten-year recorded number of patients as 24,931, 71,541, 27,410, 18,920, 10,321 and 7,889 respectively and attributed the diseases to contact with contaminated water as a result of poor disposal of wastewater in the community (Nse et al., 2023; Joshua et al., 2021).

3.5 Multivariate Statistical Outcomes

A comprehensive Multivariate Analysis of Variance (MANOVA) was conducted to assess both spatial (across eight LGAs) and seasonal (wet and dry seasons) variations in water quality parameters within Kano Metropolis as employed by Lazar et al. (2024). The analysis yielded significant multivariate effects for both location and season (Table 9), thereby rejecting the null hypothesis of homogeneity across the studied factors.

Table 9. Summary of MANOVA Results

Factor	Wilks' Λ	F-value	p-value / Conclusion
Location (LGA)	0.038	12.67	<0.001 / Significant difference
Season	0.142	18.93	<0.001 / Significant difference
Location × Season	0.211	5.84	<0.001 / Significant interaction

The significant interaction between spatial and seasonal factors implies that water quality dynamics vary across LGAs depending on the season. Notably, the wet season recorded higher contamination levels, especially in parameters such as heavy metals (Cr, Cu, Fe) and microbial counts (E. coli, TC), largely attributed to increased surface runoff and leaching during rainfall periods.

3.6 Post-Hoc Spatial Variation Analysis

Table 10. Seasonal Variation in Physicochemical Parameters (Tukey HSD)

Parameter	Season	Critical Range	Significant LGA Pairs (p < 0.05)
EC	Wet	112 µS/cm	Nasarawa > Fagge, Kumbotso, Ungogo
NO_3	Wet	28 mg/L	Kumbotso > Dala, Gwale, Nasarawa, Ungogo
TDS	Dry	85 mg/L	Gwale > Kumbotso, Tarauni

Table 11. Seasonal Variation in Heavy Metals

Metal	Season	Critical Range	Peak Contamination Sites (mg/L)
Cr	Wet	1.2 mg/L	Fagge (5.11), Nasarawa (3.42)
Cu	Wet	0.8 mg/L	Dala (5.12), KMC (4.23)
Fe	Dry	0.5 mg/L	Fagge (3.10), Gwale (2.15)

The Tukey's HSD test revealed pronounced inter-LGA variations across key physicochemical and heavy metal parameters (Tables 12 and 13). Nasarawa and Fagge LGAs exhibited significantly higher Electrical Conductivity (EC) and Chromium (Cr) concentrations during the wet season, reflecting the influence of industrial effluent discharge and poor waste management practices.

3.7 Health Implications and Disease Correlations

Table 12. Chi-Square Test of Disease-Age Group Association

Disease Category	χ^2	p-value	Predominant Group
Gastroenteritis	214.3	<0.001	Children (68.98%)
Kidney Diseases	387.6	<0.001	Adults (92.51%)
Cyanosis/Asphyxia	10,521	<0.001	Children (95.07%)

A Chi-square test revealed strong associations between waterborne diseases and demographic groups (Table 12). Children were disproportionately affected by microbial-related infections such as gastroenteritis and cyanosis, whereas adults exhibited higher incidences of kidney-related diseases linked to chronic exposure to heavy metals.

3.8 Principal Component Analysis and Correlation Structure of Water Quality Parameters

Principal Component Analysis (PCA) was applied to the standardized dataset comprising physicochemical, heavy metal and microbial parameters across the eight LGAs to identify major pollution signatures and latent contamination processes influencing groundwater quality. The PCA yielded two dominant components with eigenvalues >1, jointly explaining 72.8% of total variance, underscoring a strong multivariate structure in the dataset. PC1 (48.7% of variance) was heavily loaded on chromium (Cr), copper (Cu), lead (Pb), iron (Fe), electrical conductivity (EC), total dissolved solids (TDS), and nitrate (NO_3). This component represents anthropogenic–industrial contamination, driven by effluent discharge, metal-laden wastewater infiltration, and leaching from waste dumps. High PC1 scores were concentrated in industrialized LGAs such as Fagge and Nasarawa, consistent with their proximity to tanneries, metal workshops, and dyeing facilities. PC2 (24.1% of variance) exhibited strong loadings on turbidity, total coliform (TC), and E. coli, indicating microbial contamination pathways, mainly from pit latrines, unlined soakaways, and stormwater runoffs. Elevated PC2 scores were observed in Gwale, KMC and Kumbotso, where high population density and inadequate sanitation infrastructures promote fecal infiltration into shallow wells. These findings are in agreement with the works of Mshelia et al. (2024) on the seasonal variations of heavy metals and microbial parameters on well water quality in urban centre, effluent locations and non-effluent location of Kano Metropolis, Nigeria. To complement PCA, a bivariate correlation analysis was conducted to quantify pairwise relationships among parameters and identify co-occurrence patterns indicative of shared pollution sources (see table 13).

Table 13. Correlation Matrix of Major Water Quality Parameters (r-values)

SN	Parameter Pair	r-value	Interpretation
1	EC – TDS	**0.94**	Strong ionic mineral content linkage
2	Cr – Pb	**0.82**	Common source from industrial effluents
3	NO_3 – Gastroenteritis cases	**0.76**	Nitrate-driven health risk (cyanosis, GI infections)
4	Turbidity – TC	**0.71**	Suspended solids promote microbial growth
5	E. coli – TC	**0.88**	Fecal contamination indicator co-occurrence
6	Pb – Kidney Disease	**0.69**	Chronic heavy metal health implication
7	As – Cr	**0.74**	Overlapping geogenic–anthropogenic influence
8	Fe – Turbidity	**0.63**	Particulate oxide contamination correlation
9	Cu – EC	**0.58**	Ionic contributions from anthropogenic inflow
10	pH – Metal Solubility Index	−0.55	Acidic conditions enhance metal mobility

(Significant correlations at $p < 0.05$ highlighted in bold)

Note: *Correlation coefficients reflect pooled seasonal values (wet + dry) across 480 samples.*

Correlation analysis further established strong interdependencies between selected parameters. EC and TDS were highly correlated ($r = 0.94$, $p < 0.001$), while NO_3 levels showed a positive association with gastroenteritis cases ($r = 0.76$, $p < 0.01$), signifying direct human health risk linkages. The combined PCA and correlation evidence reveals that industrial discharge, domestic wastewater, and poor sanitation are the dominant pollution drivers. The clustering pattern further suggests a spatially differentiated contamination regime where LGAs exhibit distinct pollution signatures reflective of their socio-environmental activities.

3.9 Temporal Trends in Waterborne Diseases (2011–2022)

Time-series modeling revealed consistent upward trends in major waterborne diseases over the 12-year period (Table 14). Gastroenteritis and cholera showed the steepest slopes, reflecting progressive degradation of water infrastructure and sanitation facilities.

Table 14. Time-Series Trend Analysis of Hospital Data (2011–2022)

Disease	Annual Slope (%/year)	R^2	Trend Interpretation
Gastroenteritis	+6.2	0.87	Rapidly increasing
Cholera	+4.8	0.79	Increasing
Kidney Diseases	+3.1	0.62	Moderately increasing

3.10 Implications for Public Health and Water Policy

The study clearly shows that children in the metropolis and by extension in Nigeria and developing countries data face acute, preventable infections while the adults who are exposed to a prolong contaminated water suffer from toxic chemical related diseases. This call for the urgent need for implementation of water sanitation and hygiene (WASH) in homes, schools and health centers as well as ensuring water

quality parameters are within the permissible limits stipulated by World health Organisation, standard organization (SON) and National Standard for Drinking Water Quality (NSDWQ) among others. Further statistical test showed that there was also a significant association between the frequency of water intake and health effects reported (p-value < 0.001) when the null hypothesis was tested using the T-test statistical analysis. The findings demonstrated that contaminated water in Kano Metropolis, Nigeria is a significant health hazard which is associated with various health effects as also observed by (Rohit et al., 2018) and Wu et al. (2018) who studied groundwater delineation based on matter extentionanalysis in a wastewater irrigation area of Northwest China. The findings thus provide a robust evidence base for environmental health policy, demonstrating how integrated geostatistical and epidemiological analyses can illuminate pathways for sustainable water resource management in urban Africa.

3.11 Environmental Impacts of High Concentration of WQP

The discharge of industrial effluents, domestic wastewater, agricultural runoff, and poor waste management has significantly aided the contamination of water sources, soil and air pollution, biodiversity loss, climate change and socio-economic impacts in Kano Metropolis (Mshelia 2024a). Wastewater when poorly released into the environment has the potential to harm plants in proximity and aquatic organisms such as fish and destroy or interrupt the communities of living organisms habiting a particular place. Similarly, apart from the offensive the pungent and foul smells in the environment degraded of water quality increases the rate of greenhouse gas emissions and significant economic losses such as extra cost of drainage constructions, disrupt agricultural activities which in turn affect food security. This observation was also reported by Mshelia et al., (2023; 2021), in their works on socioeconomic effects of wastewater on the environment in Kano metropolis and Gashua in Yobe State, Nigeria as well as that of Jonah and Mendie (2024) who investigated monitoring of the environmental and associated health risks in toxic elements in River Water, Akwa Ibom and Mshelia et al., (2024) that studied seasonal variations of heavy metals and microbial parameters on well water quality in urban centre, effluent locations and non-effluent location of Kano Metropolis.



Figure 3.Industrial wastewater: loss of biodiversity pungent smell,
Field survey (2023)



Figure 4.Domestic Wastewater: Dirty
Field survey (2023)

4. Conclusion

This study provides a rigorous and integrated assessment of groundwater quality degradation and associated disease burden in Kano Metropolis, revealing critical environmental and public health challenges in one of Northern Nigeria's most densely populated urban regions. The hydrochemical and microbiological analysis demonstrated that a substantial proportion of wells exceed WHO and NSDWQ permissible limits for key parameters, particularly nitrate, turbidity, TDS, electrical conductivity, chromium, lead, arsenic, and microbial contaminants. Seasonal variations were pronounced, with the wet season amplifying pollutant concentrations due to enhanced surface runoff and subsurface leaching. Multivariate analyses (MANOVA, PCA, and correlation structure) confirmed distinct contamination regimes across LGAs, driven by industrial activities, domestic wastewater discharge, high-density residential settlements, and inadequate sanitation systems. Heavy metal pollution was strongly associated with industrial zones, while microbial contamination was more prevalent in densely populated neighbourhoods with poor sanitation infrastructure. These findings collectively reveal an interconnected pattern of hydro-environmental degradation affecting both shallow aquifers and public health outcomes.

Epidemiological evidence from hospital records spanning 2011–2022 indicated a significant burden of water-related diseases, with 172,592 recorded cases. Children disproportionately suffered from acute infections (gastroenteritis, cholera, helminthiasis, cyanosis), while adults exhibited chronic conditions (kidney diseases, neurological disorders, cardiovascular diseases, and cancers) linked to long-term exposure to contaminated water. The strong statistical associations between pollutant concentrations (particularly NO_3, Cr, Pb) and disease outcomes underscore the urgent need for targeted mitigation strategies. Given these findings, the study concludes that the deteriorating quality of groundwater in Kano Metropolis constitutes a major environmental and health hazard necessitating immediate and coordinated

interventions. Priority actions include: establishing decentralized water treatment facilities; enforcing environmental compliance for industries; rehabilitating drainage and sanitation infrastructure; implementing community-level WASH programmes; regular groundwater monitoring; and integrating water quality management into urban planning policies.

Lastly, this study contributes a robust scientific evidence base for policymakers, environmental managers, and public health authorities. It underscores the imperative of adopting sustainable water governance frameworks to safeguard groundwater resources, protect human health, and support long-term urban resilience in Nigeria and comparable Sub-Saharan African environments. Absence of centralized municipal wastewater collection systems, integrated municipal wastes of different types, bad drainage channels are some of the contribution factors that aid in the contamination of water quality in the metropolis which when consumed or come into contact with is likely to result to health issues. Therefore, reinforces:

- The important role of effective environmental interventions to improve water quality in the region.
- Establishing decentralized water treatment and quality monitoring systems.
- Strengthening environmental enforcement mechanisms and industrial compliance.
- Enhancing public awareness and hygiene education on water safety.
- Promoting eco-friendly waste disposal and sanitation systems.
- Integrating water management into urban planning and public health policies.
- Interventions aimed at enhancing public awareness and improving access to safe drinking water, as well as proper sanitation and hygiene practices, should be implemented in order to reduce the burden of water-related illnesses in Kano Metropolis.

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The datasets generated during and/or analysed during the current study are not publicly available due to ethical and privacy restrictions, as they contain sensitive hospital-based and patient-related information. However, the data are available from the corresponding author on reasonable request, subject to institutional approval and adherence to data protection regulations.

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