Groundwater Quality Dynamics under Climate Change and Rapid Urbanization: A Multi Parameter Assessment

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ABSTRACT

This study assessed groundwater quality for human consumption in Abeokuta metropolis, Nigeria. 24 groundwater samples were collected from three sources (boreholes, hand-dug wells, and pipe-borne water) used for human consumption in the study area. Quantitative data were analyzed using laboratory and multivariate statistical techniques, while qualitative data from in-depth interviews were content analyzed. Most tested physicochemical parameters and heavy metal concentrations exceeded the NSWDI and WHO limits for quality water, with few exceptions. This indicates a high possibility of groundwater contamination. The study recommends an effective centralized urban water management system to provide safe, clean, and adequate water for human consumption.

Keywords: assessment, groundwater samples, physicochemical parameters, monitoring, drinking water; Nigeria

1. INTRODUCTION

Climate change, urbanization, and industrialization threaten the quality and quantity of groundwater and surface water. However, climate change and global warming pose more severe challenges to surface water than to groundwater. Consequently, groundwater is the primary accessible source of clean water (Egbueri et al., 2020; Khorrami and Malekmohammadi, 2021). More than half of the global population depends on groundwater resources (Mukherjee and Singh, 2020). Furthermore, in Urban Africa, groundwater is the primary source of potable water for domestic, industrial, and residential uses (Kodom et al., 2017; Vetrimurugan et al., 2020).

Furthermore, the following comparative advantages of groundwater over surface water have increased its use in this era of climate change. First, groundwater is rechargeable; second, it helps sustain the base flow of river systems; third, they have high self-cleansing power and ease of treatment; fourth, it is less polluted; and lastly, it provides better storage and supply of fresh water during critical times (Oluyemi et al. 2009; Fraser et al. 2020; Khorrami and Malekmohammadi, 2021). Similarly, groundwater is the primary water source in semi-arid regions for domestic and agricultural uses. Groundwater accounts for more than two-fifths of irrigation water and one-third of industrial water (UN-Water, 2018).

Meanwhile, continuous groundwater abstraction for human needs and consumption has compromised quality assessment and monitoring. For example, groundwater abstraction has tripled over the last decades (Van der Gun, 2012; UN-Water, 2018). However, over the same period, more than 80% of the global disease burden was reportedly linked to consuming poor-quality water (Mukherjee et al., 2021). Anthropogenic activities mainly drive groundwater contamination, while natural processes also influence groundwater quality. Anthropogenic activities in urban centers that contaminate groundwater for human consumption can be summarized as incompatible land uses around groundwater sources. These include poor waste disposal, pit latrines near water sources, industrial activities, intensive irrigation, overuse of fertilizer, and over-abstraction of groundwater. For

instance, Aboyeji and Eigbokhan (2016) assessed groundwater contamination around the Olusoun landfill in Lagos metropolis, Nigeria. The study found that groundwater contamination in areas adjoining the site was driven by its proximity to the landfill. More specifically, landfill leachates contaminated the following physicochemical parameters and heavy metals (pH, EC, TDS, Cd, Ag, Na, and K) (Jimoh and Famewo, 2025). Consequently, poor monitoring and assessment of groundwater quality for human consumption pose a grave public health challenge and worsen clean water scarcity. Developed countries such as Austria, Belgium, and Denmark, where most drinking water came from groundwater, have also been linked to high contamination levels (Zektser and Everett, 2004). China similarly sourced more than 70% of its water for human consumption from groundwater resources. Unfortunately, there have been reported cases of about 12,000 people diagnosed with waterborne diseases, while more than 6,000 mortality cases have been documented (Qiu, 2018). Similarly, in Pakistan, more than 90% of groundwater is reportedly contaminated (Daud et al., 2017). Lastly, in Bangladesh, a low-lying deltaic country, where an estimated 99% of the populace sources their drinking water from groundwater, there have been reported cases of 77 million people (about twice the population of California) facing health risks because of consuming contaminated water (Zahid et al., 2008; Edmunds et al., 2015).

Although groundwater contamination is a global problem, it varies by country in nature, climatic zones, geological characteristics, and dominant causal factors (Li et al., 2021). For instance, groundwater contamination on Bangladesh's southern coast is mainly due to saltwater intrusion and over-abstraction, creating severe drinking water vulnerabilities (Rakib et al., 2020). Mukherjee and Singh (2022) assessed the sources and factors influencing groundwater contamination in India's semi-arid region. The study found that mineral weathering, ion/reverse ion exchange, mixing, evaporation, and anthropogenic activities are the dominant causes of groundwater contamination. Meanwhile, several studies in southwestern Nigeria found that leachate from municipal solid waste dumpsites primarily caused groundwater contamination (Oluyemi et al. 2009; Oladimeji et al. 2010; Oyelami et al. 2013; Aboyeji and Eigbokhan, 2016). Similarly, a study conducted in a hospital environment in Port-au-Prince shows that microbiological contamination and the release of chemical substances from hospital wastewater are the dominant causes of groundwater contamination (Emmanuel et al., 2009). Thus, place-specific studies are needed to address groundwater contamination. Similarly, optimal remediation strategies are needed to manage groundwater contamination for drinking and domestic purposes.

Groundwater contamination also poses significant challenges for urban planners, climate scientists, and public health professionals, who often provide essential services such as adequate, high-quality urban water supplies for human consumption. Groundwater contamination is challenging for city and health planners because of its unique nature. First, groundwater contaminants are odorless and colorless. Second, they are responsible for many chronic diseases, such as cholera and diarrhea. Third, remediation is costly and difficult, especially for emerging cities in developing countries, where technical know-how in groundwater management is still in its infancy; lastly, natural purification takes longer than expected (Tatti et al. 2020; Li et al. 2021; Mukherjee and Singh, 2022).

The literature documents three main classes of groundwater contaminants: biological, chemical, and geological or radioactive (Emmanuel et al. 2009; Li et al. 2021). Common biological contaminants often come from algae and other microorganisms, including bacteria, protozoa, and viruses (Li et al., 2021). Drinking contaminated water is the leading cause of chronic cholera, typhoid, and diarrheal diseases (Li et al., 2021).

Over the last two decades, the Abeokuta metropolis has experienced cholera outbreaks and groundwater contamination (Shittu et al., 2010; Gyamfi, 2019). Chemical contaminants of groundwater resources include nitrogen compounds (nitrate, ammonia nitrogen). They are major components of fertilizers, wastewater, anions, oxyanions (SO4, Cl), cations (Mg, TDS), heavy metals (Zn, Pb, Hg, Cr, Cd), and metalloids (Se). Exposure to high concentrations of metals often leads to poisoning because of the carcinogenic nature of some of these elements and compounds. Radioactive contaminants are less common sources of groundwater contamination. However, when present, they come from either geological deposits of radionuclides or anthropogenic sources (Lytle et al., 2014).

The health effects of drinking contaminated groundwater are serious, and the extent of the danger depends on the contaminant type. Consequently, groundwater used for household and neighborhood consumption needs periodic evaluation and monitoring. However, assessing and monitoring groundwater sources for human consumption has been downplayed, especially in urban Africa. This is mainly due to water scarcity, increasing urban population, and ineffective water resources management. Few studies have examined urban water assessment and groundwater quality monitoring**.** Several studies have examined aquifer vulnerability and the potential for groundwater contamination through leachate (Aboyeji and Eigbokhan, 2016; Kodom et al., 2017). However, none of these studies directly assessed groundwater contamination for human consumption. Therefore, this study assesses and monitors groundwater resources used for human consumption in the Abeokuta metropolis. The study area sources its drinking water from groundwater (boreholes, hand-dug wells, and piped-borne water). Poor sanitation practices and water scarcity characterize the area due to climate change and hydrogeological processes of river basin aquifers. The study uses a mixed-methods design to assess the current quality of household groundwater sources, the extent of contamination, associated waterborne diseases, consumption patterns, and factors influencing groundwater contamination. This will inform strategic approaches to practical household groundwater evaluation and quality monitoring, improving residents' health and livability.

2. MATERIAL AND METHODS

2.1.1 Description of the areas studied

Abeokuta Metropolis is in Nigeria's southwestern geopolitical zone, at 3°00'–5°00' E longitude and 6°20'00"–7°80'00" N latitude. The metropolis spans two local government areas (Abeokuta North and South). The area has a population of about 449,088 as of 2006 (National Population Census, 2006), and its temperature ranges between 26°C and 28°C, typical of a tropical climate. The metropolis experiences two climatic seasons: the rainy season, which begins in April and lasts till October, with slight interruptions in August. The dry season runs from November to March. The annual mean rainfall in the studied areas is about 963mm. However, precipitation has become unbalanced, mainly due to rising temperatures and anthropogenic activities. Two major rivers, Ogun and Oyan, drain the city. The rivers flow north-south along a relatively steep slope. As a result, they empty into the lagoon. Streams dominate the terrain, and the rocky hills and water system are relatively well developed. Because of the area's water challenges, the Oyan River was dammed in Abeokuta North, but the dam's water supply is unpredictable. The State also hosts the Ogun-Oshun River Basin Authority. However, this water resource serves Southwest states for industrial, irrigation, food processing, and electrification purposes. Thus, households and communities still have to source their own water. Waterborne diseases, especially cholera, have ravaged the metropolis (Gyamfi, 2019).

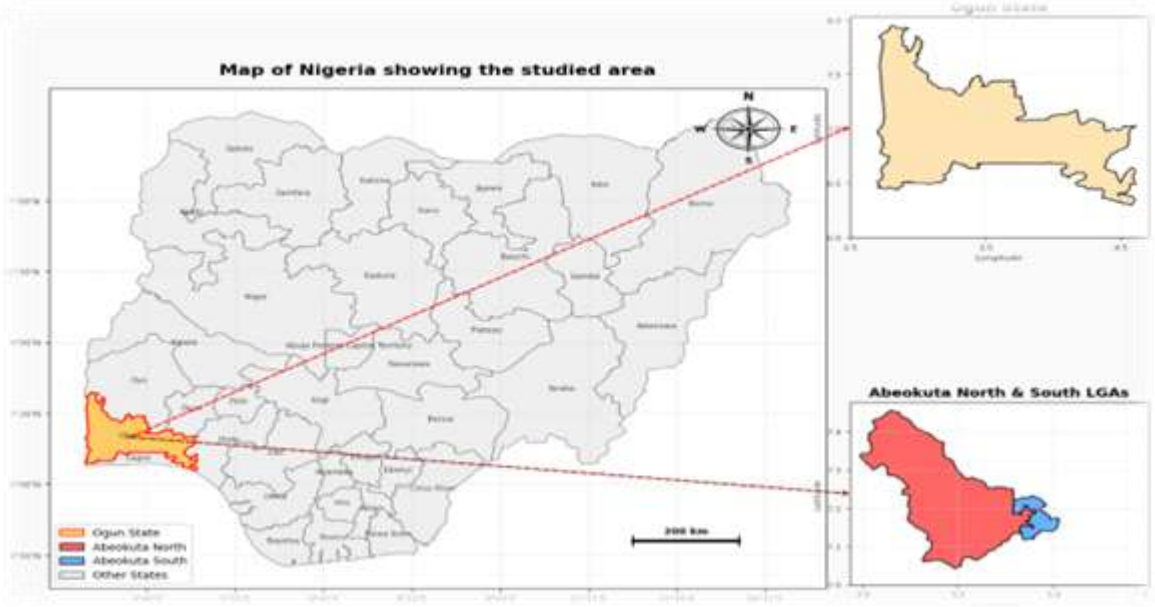

Fig 1: Studied Area in the context of Nigeria

Source: Google Earth

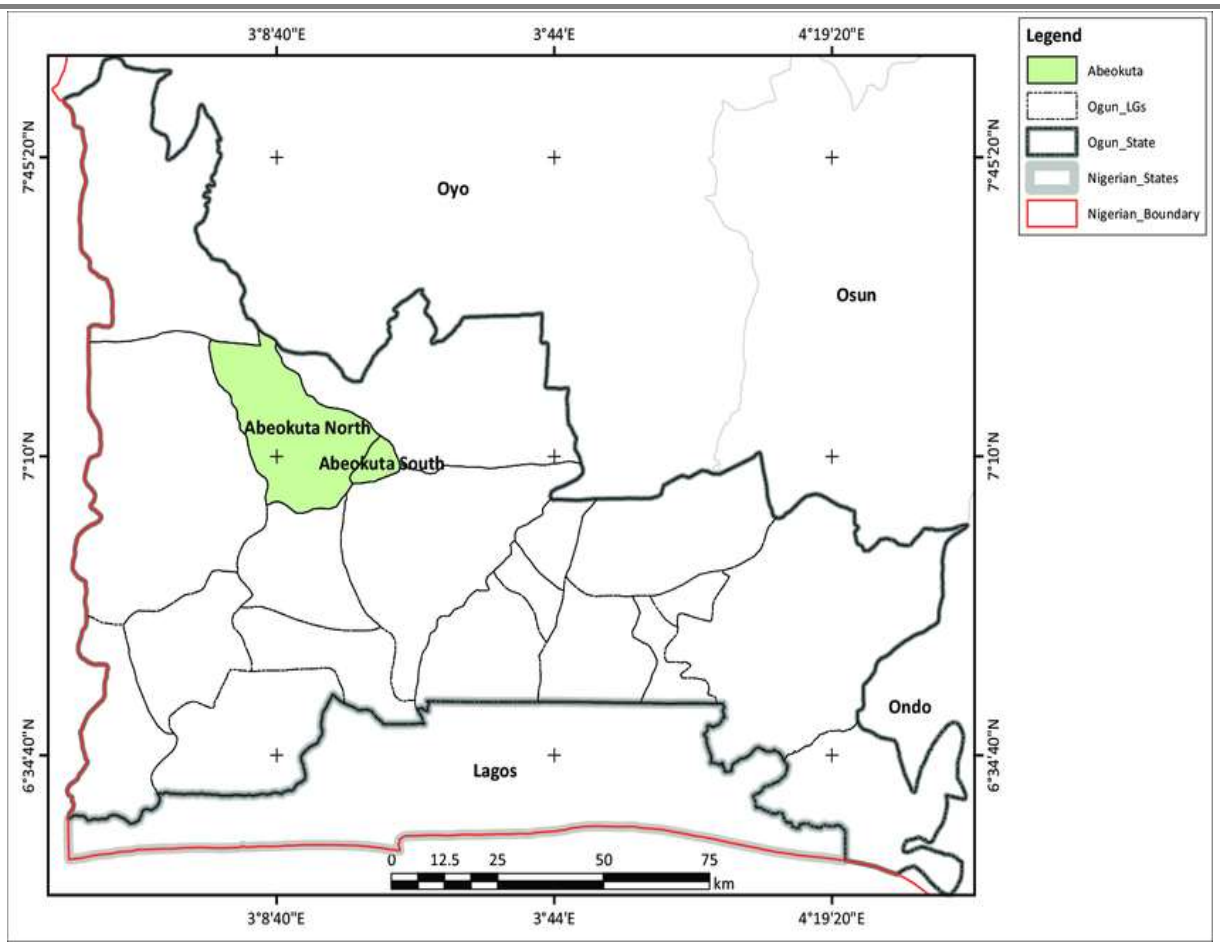

Fig 2: The study areas in the context of Ogun State

Source: *Ogun State Ministry of Environment (2019).*

2.1.2 Geology of the area studied and Hydro geochemical processes

The area's geology consists mainly of basement complex rocks. These rocks are generally Precambrian and were deformed during the Paleozoic era. They exhibit folds, faults, foliation, and other structural complexities, and comprise six main lithological components: quartzite, banded gneiss, biotite gneiss, biotite schist, quartz-biotite schist, and pegmatite (Ufoegbune et al., 2009). Many of these rocks are crystalline and relatively impermeable, including schist, gneiss, quartzite, and granite. Figure 3 provides a broad description of the study area's geology and shows Precambrian bedrock formations. Each lithological unit has distinct hydrogeological features. The area's topography is characterized by north-south-oriented highlands and slopes, so the river systems follow this pattern and flow from north to south. Flow is faster in the north and slower in the south, where the gradient is gentle. The region is tectonically stable because it has experienced little past disturbance.

As a result, underground faults are limited, and these hydrogeological features influence groundwater conditions. In the north, pegmatite overlies granite; in the south, granitic gneiss is typical, with a transition zone to a sedimentary basin.

The area's hydrogeology affects water availability and quality. Ayoade (2003) defines hydrogeology as the scientific study of groundwater, emphasizing its geology, occurrence, movement, and characteristics. Hand-dug wells are common in this study area and dry up during the dry season. Ufoegbune et al. (2009) stated that these hand-dug wells fail to reach water during the dry season because they do not reach the expected depths. Urban residents with greater financial capacity often overcome dryness by drilling boreholes. Based on the area's history, its hydrogeology is relatively satisfactory. Accordingly, fluctuations in groundwater levels in the studied area are likely driven by natural and human-related processes within and outside the aquifer system. Over-extraction can make these aquifers vulnerable and weaken them over time.

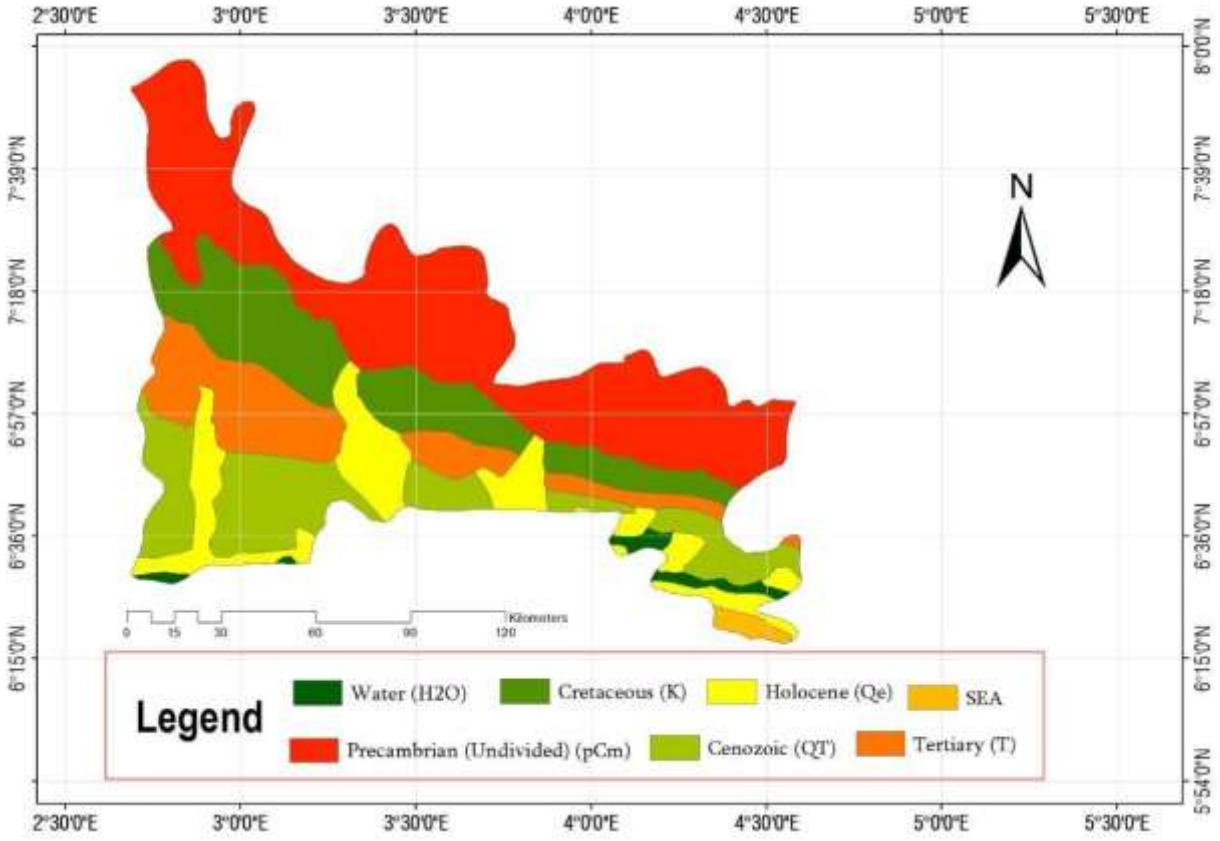

Fig 3: Broad geology of the studied area

2.2 Methods

The study uses mixed research methods, including surveys, phenomenology, and laboratory research.

2.2.1 Survey instrument

The survey used a sample size of 0.06% (300) of the total population of Abeokuta Metropolis (544,000) (United Nations, 2021). The sample size was chosen due to time and cost constraints. However, it remains within the acceptable ranges specified in literature as a representative fraction of the population. The survey instruments collected information on respondents' social, economic, and demographic characteristics; primary sources of drinking water and household consumption; and reported cases of waterborne diseases within the two months before the study. The questionnaire items aligned with the study's literature review. The survey sampled household heads or adult representatives aged 18 and above. Every fourth house was randomly sampled.

2.2.2 Phenomenological study

In-depth interviews and discussions were conducted with twelve landlords in the study areas, who reported contracting waterborne diseases (Cholera, typhoid) from drinking contaminated water from boreholes or wells. Each of the respondents is identified as GRW1-GRW12. The interview guide was grouped into three themes:

- Sources of contamination of groundwater;
- Clean water scarcity in the area;
- Impacts of urbanization and climate change on household water consumption;

2.2.3 Laboratory study

We randomly collected 24 samples from three water sources (boreholes, hand-dug wells, and piped-borne

water) in the study areas. The selected water sources were designated for drinking. Before water collection, the water source (i. e wells) was purged for 3 min to drain stagnant groundwater and stabilize unstable physicochemical indicators. We adopted this method from a previous study (Vetrimurugan et al. 2020). Similarly, we rinsed the sampled bottles three times with water from each source and filtered them on-site using a 0.45 um Millipore membrane filter to analyze anions and cations. Cation samples were acidified in situ with nitric acid to stop microbial activity. We measured groundwater parameters such as Temperature, pH, and TDS in situ using a portable digital meter and a portable multiprobe (Aquaprobe A-700), respectively, in accordance with the American Public Health Association (APHA, 2012). We measured other groundwater parameters within 24 h at the laboratory in triplicate and performed standard checks. The mean values were recorded. TSS and TDS were measured gravimetrically. The heavy metals were analyzed using direct digestion/air–acetylene flame method with a Flame Atomic Absorption Spectrometer (AAS, PerkinElmer Analyst 400). We ensured quality assurance by verifying that the laboratory analysis met the sampling and analytical conditions specified by APHA (2012). Ion balance error was calculated to ascertain analytical precision within the acceptable limits of ±5. We used the Nigerian Standard for Water Quality (NSWQ) and World Health Organization (WHO) acceptable ranges to assess the samples' physicochemical parameters for drinking purposes.

2.2.4 Data analysis

The survey instrument was analyzed using descriptive and inferential statistics in IBM SPSS Statistics 25. The data were presented in Tables. In addition, we conducted correlation analysis (CA) and principal component analysis (PCA).

CA

Pearson correlation was used. This analysis evaluated and compared all examined groundwater parameters. We calculated correlations for five principal physicochemical parameters and three heavy metals.

PCA

Principal component analysis (PCA) was used to determine the main water quality parameters (physicochemical parameters and heavy metal ions). PCA is a multivariate technique that transforms a dataset of interrelated variables into a smaller set of variables referred to as components. This study analyzed eight physicochemical parameters and heavy metal ions. First, the data were subjected to Kaiser-Meyer-Olkin (KMO) (Li et al., 2020) and Bartlett tests to assess their suitability for PCA. PCA simplifies the dataset by transforming the original variables into orthogonal dimensions that preserve variance.

2.2.5 Study Limitations

Due to financial constraints, the study could only take a few water samples across the studied areas. The study also focused on relatively few water parameters that previous studies have shown strongly influence groundwater quality. Consequently, the study focused more on these water parameters and heavy metals than on anions and cations.

3.0 RESULTS

3.1 Socio-economic and demographic characteristics of respondents

Table 1 presents the socio-economic and demographic characteristics of respondents. The study found more male respondents (55%) than female respondents (45%). Furthermore, more than half (57%) of respondents were married. The study found that residential land use dominates the study area (78.3%). Consequently, demand for clean water for human consumption will be high. The study revealed that most respondents (80.7%) sourced their water from groundwater. Two main toilet facilities used in the areas studied are pit latrines (65.7%) and water closets (34%). The proximity of groundwater sources to toilet facilities can increase the probability of microbiological contamination.

Regarding reported waterborne diseases, about one-third (28.3%) of respondents reported contracting waterborne diseases within the two months before the study. Elemile et al. (2021) opined that waterborne

diseases result from pathogenic microbial contamination. Thus, anthropogenic activities in these areas must have contributed to the onset of waterborne diseases. Additionally, among reported cases, about one-third (31%) of respondents reported typhoid, 29% reported cholera, 16.5% reported dysentery, and 12.9% reported diarrhea. These results implied a high probability of groundwater contamination.

Consequently, improving household-level hygiene and sanitation and water-source management would go a long way toward improving the quality of water available to households. Further, waterborne treatments adopted by respondents were assessed. Most respondents used local herbs (47.1%) or obtained drugs from local pharmaceutical shops (41.1%). Jimoh and Famewo (2021) highlighted significant inequality in the provision of primary health care centers in Nigeria's urban centers. Consequently, residents often resort to self-care and orthodox medicines.

Table 1: Social-economic and social-demographic characteristics of respondents

Social-economic characteristics	**Respondents**	**Percentage**
Sex		
Male	165	55
Female	135	45
Total	300	100
Marital status		
Single	73	24.3
Married	171	57
Others	56	18.7
Total	300	100
The primary use of land		
Residential	135	78.3
Mixed	65	21.7
Total	300	100
Types of toilet facility		
Pit latrine	197	65.7
Water closet	102	34
Others	1	0.3
Total	300	100
Main water source		
Groundwater(borehole, wells, pipe-borne)	242	80.7
Surface water(rivers, streams)	58	19.3
Total	300	100
Reported cases of waterborne diseases (WBD)		
Cholera	29	34.1
Typhoid	31	36.5
Dysentery	14	16.5
Diarrhea	11	12.9
Total	85	100
Adopted Treatment for WBD		
Visit local pharmaceutical shops and patent medicine stores to purchase drugs	35	41.1

Use of traditional herbs	40	47.1
Both herbs and drugs	10	11.8
N	85	100

3.2 In-depth interviews

3.2.1 Sources of groundwater contamination

Regarding sources of groundwater contamination in the study area, seven (58.3%) of the twelve respondents reported that contamination mainly results from house owners' failure to consider water quality when digging wells. However, water is a public good. Thus, a centralized water provision and management system should be created at the neighborhood level to effectively provide, manage, and give access to safe, clean, and quality water for residential areas.

“ In the determination of water source to be abstracted for water consumption, most landlords are concerned with areas where there is relatively enough water supply above the water table level and not concerned about the geological features of the underlying rocks (GRW2).”

"Most contamination would be from the water source point. For instance, when I dug my water, we found that the water tasted bad and was not fit for drinking. So we usually boil the water before use and depend more on sachet water for drinking purposes (GRW11)".

“I was one of the first landowners in this community; when we moved here, we had a challenge with water as everywhere we dug, there were underlying rocks, so when we finally got water, we were so elated and not concerned with the quality, since we found it good for drinking based on our assumption (GRW 4)".

"I do not think anyone tests the quality of the borehole they dug in their house, irrespective of the use of the borehole (public or private consumption). All we need is water, and once we have it, all other factors don't matter unless it is urgent. Nevertheless, unfortunately, rivers run dry during the dry season; many houses are not connected to the Ogun-Oshun River basin water management scheme. So we must find our own water, and groundwater is the easiest source (GRW9).

3.2.2 Clean water scarcity in Abeokuta metropolis

Broadly, water scarcity can result from pollution, climate change, increased freshwater demand, aquifer overuse, and low recharge. Therefore, the study sought to identify the factors responsible for clean water scarcity in the study area. Most respondents (83.3%) said the main challenge of clean water in the area is the terrain's rocky nature, which makes it difficult to dig boreholes in some areas, and the over-dependence on power supply for pumping water amid rising diesel and fuel costs. Consequently, water scarcity in the area mainly stems from inadequate water management and the nature of the underlying rocks.

“I have to use the generator to pump water, as many residents in this area depend on me for their drinking water. However, the increasing fuel price forced me to stop selling water, as it had increased my cost functions and induced negative externalities, such as a reduction in revenue due to a fall in quantity demanded. The pressure led to several repairs and the need to get a new one through a loan(...). The local government should take full responsibility for basic infrastructure, such as water provision, through the CDA (Community Development Association). The assistance should be centered on finances, technical, capacity building, quality assessment, monitoring, and good planning to address water scarcity (GW3)”.

"It is difficult to keep depending on residents to provide water with the increasing population and water demand in the area. It was possible to know everyone in this community some decades ago, but not now. So the growing population and changing weather patterns affect water availability (GW1).

"Water has always been challenging in Abeokuta because of our terrain. As for me, we depend on streams and rivers for domestic water, while we augment this with sachet water. However, there is no difference between

sachet water produced by many firms and stream water. Except that the streams often dry up during the dry season and are often polluted during heavy rainfall during the wet season (GW7)".

"I am fed up with the water challenge. I paid water boy #700 every two weeks to get water for drinking and household chores, and I have a large family to keep (GW5)".

3.3.3 Impacts of urbanization and climate change on household water consumption

Regarding the impacts of urbanization and climate change on household water consumption, the respondents affirmed that these two factors further complicated household water consumption in the metropolis.

For instance, a respondent commented:

"The increasing population and the challenge of changes in weather patterns have negatively complicated water availability issues in recent times. As a result, more people need water, and more are moving into areas where the water level is under stress (GW8)."

Another respondent further reported:

"Our wells and rivers are always dry during the dry season and overflow their banks during the heavy rains, so most households depend on other residents whose wells do not dry up. This increasing pressure often affects water availability (GW6)."

Commenting, another respondent averred:

"So far this year, we have had relatively little rain compared to Lagos, a nearby city but a coastal city with more rain than us. Without sufficient rain, groundwater will not recharge. The government needs to help us (GW12).

"It is glaring that changes in the weather pattern and increase in population are making the water situation in the city a great concern. We need a holistic measure at the community level (GW5)".

3.3 Descriptive statistics for physicochemical parameters

Table 2 presents the physico-chemical parameters of groundwater in the study area. The groundwater temperature (mean ± standard deviation) in the study area was 26.91 ± 0.28. The pH value of groundwater in the area was 7.27±0.50, indicating that groundwater ranges from slightly acidic to neutral and slightly alkaline (6.84-8.62). Groundwater pH values slightly exceed NSDWI and WHO acceptable ranges. Though pH is an important water quality parameter, it does not directly affect human health. DO ranges from 1.88 to 8.12 mg/l, with a mean of 6.38 mg/l, exceeding the NSDWI and WHO limits. TSS ranges from 1.02 to 320.11 mg/l, with a mean average of 22.53 mg/l. High TSS concentration in drinking water may increase water temperature and decrease natural dissolved oxygen. TDS has a mean value of 84.69 mg/l and ranges from 4.09 to 87.12 mg/l, below the acceptable limits of NSWDI (500) and WHO (1000). TDS is a vital water parameter that determines water quality for human consumption. A higher TDS implies pollution of the water source. However, the mean TDS value falls within acceptable limits compared with NSDWI and WHO values.

Table 2: Descriptive statistics for Physic-chemical parameters

Parameters	Unit	Min	Max	Mean± SD	NSDWI	WHO
Physical parameters						
Temp	^{o}C	26.3	27.4	26.91±0.28	25-30	25-30
pH	-	6.84	8.62	7.27±50	6.5-8.5	6.5-8.5
DO	mg/L	1.88	8.12	6.38±1.44	≥5	≥5
TSS	mg/L	1.02	320.11	22.53±65.93	<10	NA
TDS	mg/L	4.09	87.12	84.69±176.47	500	1000

NB: NA- Not Available

3.2 Heavy metal concentration in groundwater samples

Iron (Fe), Zinc (Zn), and Lead (Pb) are among the most commonly detected heavy metals in groundwater. Higher concentrations of heavy metals are dangerous for humans and the natural environment. For example, most heavy metals are essential micronutrients at low doses but can cause severe poisoning and become carcinogenic at higher concentrations (Li, Karunanidhi, Subramani, and Srinivasamoorthy, 2021). Meanwhile, in the environment, heavy metals are key indicators of ecosystem health, such as in coastal systems (Wang et al., 2020). The three heavy metals tested (Fe, Zn, and Pb) exceeded the NSDWI and WHO acceptable ranges, except for Zn, which was slightly below the NSDWI acceptable range but exceeded the WHO acceptable values. Heavy metals in water often result from hydrogeochemical processes in parent materials and occur in ionic form. The heavy metals tested were at higher concentrations than the national and global acceptable limits. However, of the three tested, only high levels of Pb pose significant hazards to human consumption, while Zn and Fe primarily affect taste and appearance when they exceed threshold limits. Thus, monitoring heavy metal levels in groundwater is necessary.

Table 3: Descriptive statistics for heavy metal concentration in water samples in the study area

Heavy metals concentration	Unit	Min	Max	Mean± SD	NSDWI	WHO
Fe	mg/l	0.82	5.17	1.28±0.86	0.5	0.3
Zn	mg/l	0.66	11.69	2.43±2.82	3	0.01
Pb		0	1.02	0.05±0.21	0.01	0.01

3.3 Statistical Analyses of water parameter

3.3.1 Correlation Analysis of parameters

A correlation matrix was used to evaluate and compare the tested water quality parameters. Table 4 reports the correlation matrix results for groundwater samples. Temp. showed a significant positive correlation with DO and Zn but a negative correlation with TSS, TDS, Fe, and Pb ($p \leq 0.05$). In contrast, pH positively correlated with all water parameters tested but not with Pb or DO. DO showed a negative correlation with all parameters tested except Pb, which showed a significant correlation of 0.6 with DO.

In contrast, TSS showed a significant correlation with TDS, Fe, Zn, and Pb but a negative correlation with Temp. and DO. However, TDS showed no correlation with Temp., pH, TSS, or DO but was positively correlated with Fe, Zn, and Pb. Furthermore, Fe was negatively correlated with Temp. and DO but positively correlated with pH, TSS, Zn, and Pb. Zn showed no significant correlation with DO, but it was significantly correlated with Temp., pH, TSS, TDS, Fe, and Pb. Similarly, Pb was not significantly correlated with Temp. but was positively correlated with all other parameters tested. The high prevalence of positive correlations, especially among the heavy metals, suggests that the pollutants likely originated from the same source.

Table 4: Correlation matrix of water quality parameters

Parameters	Temp	pH	DO	TSS	TDS	Fe	Zn	Pb
Temp	1							
pH	-0.276	1						
DO	.547**	-389	1					
TSS	-0.403	.604**	-.776**	1				
TDS	-441*	593**	-.823**	.992**	1			
Fe	-385	.584**	-.780**	.997**	.990**	1		
Zn	.632**	.490*	-779**	.821**	.842**	.819**	1	
Pb	-330	.580**	.580**	.976**	.961**	.975**	.729**	1

NS: **correlation significant at the 0.01 (2-tailed)

*Correlation significant at the 0.05 (2-tailed)

3.3.2 Principal Component Analysis

The KMO test yielded 0.85, and the Bartlett test was 0.00 (< 0.05), indicating the validity and suitability of PCA. This implies that the samples were adequate, the variables were independent, and the correlation matrix was not an identity matrix (Li et al., 2020; Elemile et al., 2021). In PCA, PCs are often selected using the Kaiser criterion; thus, PCs with eigenvalues greater than 1.0 are often retained (Li et al., 2020; Vetrimurugan et al., 2021). This study follows a similar path. Based on the PCA, we extracted and rotated two PCs that accounted for significant variance in the dataset. The first PC accounted for 74.7% of the total variance, while the second PC accounted for 11.7%. The PCA results are consistent with the earlier correlation analysis. PC1 correlated with pH+TSS+TDS+Fe+Zn+Pb, while PC2 correlated with the eight examined variables (Physicochemical and heavy metals). Table 5 shows the other Eigenvalues, percentages of variance, and cumulative percentages. The positive loadings for pH, TSS, TDS, Fe, Zn, and Pb reflect similar sources. Positive correlations and factor loadings for pH, TSS, and TDS suggest an anthropogenic source, as shown in similar studies (Ganiyu et al., 2018; Li et al., 2020). Similarly, heavy metals may have the same origins, as similar results were obtained in studies such as (Vetrimurugan et al., 2020; Elemile et al., 2021; Luo et al., 2022). The scree plots showing the number of PCs extracted and the rotated factor loadings for the two PCs are shown in Figs. 4 and 5, respectively.

Table 5: Principal Component Analysis for groundwater quality (KMO=0.85; Bartlett test of Sphericity=0.00)

Variables	PC1	PC2	Eigenvalue	Communalities	% of variance	Cumulative %
Temp	-0.546	0.776	5.973	0.298	74.663	74.663
pH	0.644	0.274	0.937	0.414	11.714	86.377
DO	-0.849	0.239	0.628	0.721	7.851	94.228
TSS	0.977	0.977	0.255	0.955	3.183	97.411
TDS	0.986	0.107	0.184	0.972	2.296	99.706
Fe	0.973	0.973	0.015	0.947	0.193	99.899
Zn	0.891	0.891	0.006	0.794	0.078	99.977
Pb	0.934	0.934	0.002	0.872	0.023	100

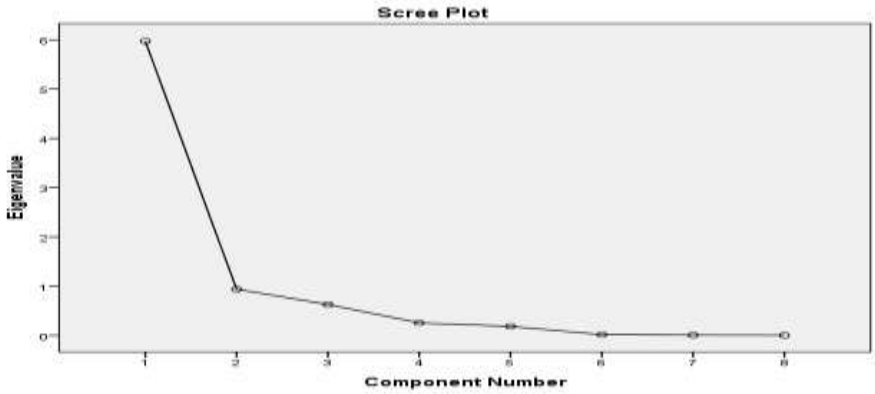

Fig 4: Scree plots used to identify the number of PCs in PCA obtained from eigenvalues (> 1)

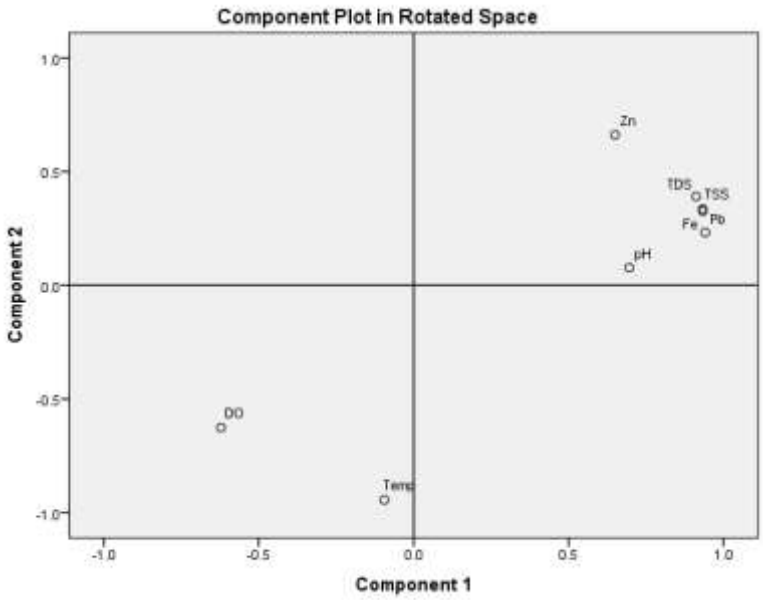

Fig 5: Loadings of the first two factors in 3-dimensional space showing a correlation between groundwater parameters

4.0 DISCUSSION

Iron (Fe), zinc (Zn), and lead (Pb) are among the most commonly detected heavy metals in groundwater. High concentrations of heavy metals pose risks to humans and the natural environment. At low doses, most heavy metals are essential micronutrients, but at higher concentrations they can cause severe poisoning and become carcinogenic (Li et al., 2021). In the environment, heavy metals are key indicators of ecosystem health, particularly in coastal systems (Wang et al., 2020). The three tested heavy metals (Fe, Zn, and Pb) exceeded the NSDWI and WHO limits, except for Zn, which was slightly below the NSDWI limit but above the WHO limit. This suggests that residents who drink this water may face serious health risks.

5.0 CONCLUSION AND RECOMMENDATIONS

This study examined groundwater quality in an urban center in Nigeria. Statistical analyses showed that groundwater samples across the study area contained higher concentrations of heavy metals and other water parameters, exceeding national and global limits. We infer that these elevated concentrations, especially heavy metals, likely result from hydrogeochemical processes in parent materials, often in ionic form. Anthropogenic activities may have further exacerbated them. These results imply that residents may have faced potential health risks from consuming these water sources.

Moreover, the study found that breakdowns in public services, including water provision, health facilities, electricity, and public transportation, primarily drive groundwater over-abstraction by urban residents in Nigeria. In addition, extant literature reports an estimated 66.3 million people in Nigeria lack access to potable drinking water. Thus, most people source water from groundwater resources through hand-dug wells or boreholes, depending on their socio-economic status.

Consequently, the following substantive recommendations were proposed to address poor water quality and groundwater over-abstraction. First, infrastructural breakdown should be addressed holistically through integrated management to resolve water scarcity in urban and rural areas. For instance, reliable electricity is needed to keep water supply schemes operational, and sound urban planning is needed to ensure water infrastructure projects meet people's needs.

Similarly, groundwater over-abstraction often leads to water-source pollution and the onset of waterborne diseases. Thus, measures should address pollution at the source. Furthermore, the study posited that groundwater

contamination may arise from residents' anthropogenic activities, rock lithology, and hydrogeochemical processes. Therefore, a centralized urban water system with a monitoring and control unit should be established to manage the urban water supply. Adequate water quality monitoring and control would address the water quality challenge for household consumption.

REFERENCES

1. Aboyeji, O.S and Eigbokhan, S.F., (2016). Evaluations of groundwater contamination by leachates around water Olusoun open dumpsite in Lagos Metropolis, southwest Nigeria. *Journal of Environmental Management,* Volume 183, pp. 333-341.
2. Akinde, S., Nwachukwu, M., and Ogamba, A., (2011). Storage effects the quality of sachet water produced within Port Harcourt Metropolis. *Nigeria Jordan Journal of Biological Sciences,* Volume 147.
3. American Public Health Association, A., (2012). *Standard Methods for the Examination of Water and Wastewater.* 22nd ed. Washington, DC: American Public Health Association, APHA
4. National Population Commission. Census, (NPC) (2006). *National Population Census Housing Priority Tables,* Abuja: National Population Commission.
5. Daud, M. Nafees, M., Ali, S., Bajwa, R., Shakoor, M., Arshad, M., Chatha, S., Deeba, F., Murad, W., Malook, I., and Zhu, S., (2017). Drinking water quality status and contamination in Pakistan. *Biomedical Research International,* pp. 1–18.
6. Edmunds, W.M., Ahmed, K. M., & Whitehead, P.G (2015). A review of arsenic and its impacts in groundwater of the Ganges-Brahmaputra- Meghna delta, Bangladesh. *Environ. Sci. Process Impacts,* pp. 1032–1046.
7. Egbueri, J. Ameh, P. and Unigwe, C., (2020). Integrating entropy-weighted water quality and multiple pollution indices to better understand drinking water quality in Ojoto Area, SE Nigeria. *Scientific African,* Volume 10.
8. Ekere, N.R., Agbazue, V.E., Ngang, B., and Ihedioha, J., (2019). Hydrochemistry and water quality index of groundwater resources in Enugu north district, Nigeria. *Environment Monitoring Assessment,* Volume 191.
9. Elemile, O, Ibitogbe, E, Adewumi, J, Folrunsho, O, and Osueke, C, (2021). *Health Risk Assessment of Groundwater in Omu Aran Nigeria.* s.l., IOP Publishing.
10. Emmanuel, E., Pierre, M. G., and Perrodin, Y., (2009). Groundwater contamination by microbiological and chemical substances released from hospital wastewater: Health risk assessment for drinking water consumers. *Environment International,* Volume 35, pp. 718-726.
11. Fraser, C.M Kalin, R.M., Kanjaye, M., and Uka, Z., (2020). A methodology to identify vulnerable transboundary aquifer hotspots for multi-scale groundwater management. *Water International,* 45(7-8), pp. 865-863.
12. Ganiyu, S, Badmus, B., Olurin, O., and Ojekunle, Z, (2018). Evaluation of seasonal variation of water quality using multivariate statistical analysis and irrigation parameter indices in the Ajakanga area, Ibadan, Nigeria. *Applied Water Science,* 8(1), pp. 1-15.
13. Gyamfi, C. (2019). *Cholera outbreak: Ogun confirms five deaths, begins extensive fumigation,* s.l.: Guardian Newspaper.
14. Jimoh, U and Famewo, A., (2021). *Inequality of Public health and Effects of health care Accessibility on Patient Referral System in Ondo State.* s.l., International Health Areas Congress.
15. Jimoh, U. and Famewo A., (2025). Environmental Impacts of E-waste Activities on Major Landfill Sites in Lagos, Nigeria. *Journal of Urban and Environmental Management* 5 (1)
16. Khorrami, M. and Malekmohammadi, B., (2021). Effects of excessive water extraction on groundwater ecosystem services: Vulnerability assessments using biophysical approaches. *Science of the Total Environment,* Volume 799, pp. 1-14.

17. Kodom, K., Komet, D., Preko, K. Danuoro, S., and Boamah, D., (2017). Preliminary Evaluation of groundwater Vulnerability to contamination using the Drastic Model; A case of Greater-Accra Region, Ghana. *Journal of Scientific and Engineering Research,* 4(8), 266-277.
18. Li, O., Zhang, H., Guo, S., Fu, K., Liao, L., Xu, Y., & Cheng, S. (2020). Groundwater pollution source apportionment using Principal component analysis in multiple land-use in southwestern China. *Environmental Science and Pollution Research,* Volume 27, pp. 9001–9011.
19. Li, P., Karunanidhi, D., Subramani, T., and Srinivasamoorthy, K.,, (2021). Sources and Consequences of Groundwater Contamination. *Archives of Environmental Contamination and Toxicology,* Volume 80, pp. 1-10.
20. Luo, M., Zhang, Y., Li, H., Hu, W., Xiao, K., Yu, S., Zheng, C., & Wang, X. (2022). Pollution assessment and sources of dissolved heavy metals in coastal water of a highly urbanized coastal area: The role of groundwater discharge. *Science of the Total Environment,* Volume 807.
21. Lytle, D. A., Sorg, T. Wang, L., and Chen, A., (2014). The accumulation of radioactive contaminants in drinking water distribution systems. *Water Resource,* Volume 50, pp. 396-407.
22. Mukherjee, I, Singh, U. K., and Singh, R. P. (2021). An overview on heavy metal contamination of water system and sustainable approach for remediation. In: A. A. M. a. A. S. Singh, ed. *Water Pollution and Management Practices.* Singapore: Springer, pp. 255–277.
23. Mukherjee, I and Singh, U. (2020). Delineation of groundwater potential zones in a drought-prone semi-arid region of east India using GIS and analytical hierarchical process techniques. *Catena,* Volume 194.
24. Mukherjee, I. and Singh, U.K., (2022). Hydrogeochemical characterizations and quality evaluation of groundwater in the major river basins of India's geologically and anthropogenically driven semi-arid track. *Science of the Total Environment,* Volume 805.
25. United Nations, UN. *World Population Prospects.* [Online] Available at: https//population.un.org/wpp [Accessed 11 March 2022].
26. Oladimeji, M.O., Abata, E., Dawodu, M., and Ipeaiyeda, A., (2010). Effect of refuse dumps on the physicochemical properties of surface water, groundwater, and soil in Owo township, Ondo State, Nigeria. *Toxicol. Environ. Chemistry,* Volume 91, pp. 979-987.
27. Oluyemi, E.A., Makinde, W.O., and Oladipo, A.A.,(2009). Potential groundwater contamination with toxic metals around refuse dumps in some parts of Lagos metropolis, Nigeria. *Toxicol. Environ. Chem.,* Volume 91, pp. 933-940.
28. Oyelami, A. C., Aladejana, J. A., and Agbede, O.O., (2013). Assessment of the impact of open waste dumpsites on groundwater quality: a case study of Onibu-Eja dumpsite southwestern Nigeria. *Procedia Earth Planet Sci.,* Volume 7, pp. 648-651.
29. Qiu, J. (2018). Safeguarding China's water resources. *National Science Review,* Volume 5, pp. 102–107.
30. Rakib, M.A., Sasaki, J., Matsuda, H., Shamshad, B., Quraishi, M., Mahmud, J., Bodrud-Doza, Ullah, A., Fatema, M., Newaz, A., bhuiyan, M., (2020). Groundwater salinization and associated co-contamination risk increase severe drinking water vulnerabilities on the southwestern coast of Bangladesh. *Chemosphere,* Volume 246.
31. Shittu, O.B., Akpan, I., Popoola, T. O., Oyedepo, J. A and Ogunshola, E. O., (2010). Epidemiological features of a GIS-supported investigation of cholera outbreak in Abeokuta, Nigeria. *Journal of Public Health Epidemiology,* 1(7), pp. 152-162.
32. Su, Z., Wu, J., he, X., and Flumalai, V.,, (2020). Temporal changes in groundwater quality within the groundwater depression come and prediction of confined groundwater salinity using the Grey Markov model in the Yinchuan area of northwest China. *Expo Health,* Volume 12, pp. 447-468.
33. Tatti, F., Papini, M., Torretta, V., Mancini, G., Boni, M., and Viotti, P., (2019). Experimental and numerical evaluation of groundwater circulation wells as a remediation technology for persistent, low permeability contaminant source zones. *Journal of Contamination Hydrology,* Volume 222, pp. 89-100.

34. Turkey, P., Bhattacharya, T., Chakraborty, S., & Barack, S (2017). Assessment of groundwater quality and associated health risks: A case study of Ranchi city, Jharkhand, India. *Groundwater Sustainable Development,* Volume 5, pp. 85–100.
35. UN-Water, (2018). *Groundwater overview: making the Invisible visible,* s.l.: International Groundwater Resources Assessment Centre.
36. Van der Gun, J., (2012). *Groundwater and global change: Trends, opportunities, and challenges,* s.l.: United Nations Water Assessment Programme.
37. Vetrimurugan, E., Nethononda, V., Manivannan, V., Rajmohan, N., Li, P., and Elango, L., (2020). Groundwater quality assessment and application of multivariate statistical analysis in Luvuvhu catchment, Limpopo, South Africa. *Journal of Earth Sciences,* Volume 171.
38. Wang, X., Fu, R., Li, H., Zhang, Y., Lu, M., Xiao, K., Zheng, C., & Xiong, Y. (2020). Heavy metal contamination in surface sediments: A comprehensive, large-scale evaluation for the Bohai Sea. *China Environment Pollution,* Volume 260, pp. 1–11.
39. Wu, J., Zhang, Y., & Zhou, H. (2020). Groundwater chemistry and groundwater quality index incorporating health risk weighting in Dingbian County, Ordos basin of northwest China. *Geochemistry,* 80(4).
40. Zahid, A Hassan, M., Balke, K.D., Flegr, M., and Clark, D.,(2008). Groundwater chemistry and occurrence of arsenic in the Meghna floodplain aquifer, southeastern Bangladesh. *Environment Geology,* Volume 54, pp. 1247-1260.
41. Zektser, I., and Everett, L., (2004). *Groundwater Resources of the World and their Use Paris,* s.l.: s.n