Spatial Variation of Water Quality in Nigeria

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Approximately 60 million Nigerians are living without access to basic drinking water. Datasets from over 200 studies of water samples collected from 37 regions in the country were collected and analyzed. This study analyzed 12 ions: phosphate ($PO_4{}^{3-}$)$, sulphate (SO_4{}^{2-}), chloride (Cl^-), nitrate (NO_3{}^-), potassium (K^+), sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+})$, zinc ($Zn^{2+}$), manganese ($Mn^{2+}$), iron ($Fe^{3+}$), and lead ($Pb^{2+}$). These ions were selected because they were the most tested. Analysis of the obtained data and ions whose values exceed WHO and USEPA guidelines was carried out, and the areas with the highest risk factor were identified using appropriate statistical descriptions. The Water Quality scale rating, Relative weight, and arithmetic water quality index for each sample were calculated. The results of this analysis revealed Pb^{2+}, Mn^{2+}, $PO_4{}^{3-}, Fe^{3+}$ as the parameters with the highest concentration in analyzed samples. Delta (57%), Jigawa (60%), and Ondo (66%) had the highest percentage of samples that scored high on the WQI Index making them the most polluted states (as determined by this study).

Introduction

Sustainable Development Goal Target 6.1 calls for universal and equitable access to safe and affordable drinking water. This remains a challenge in Nigeria, with the majority of Nigerians lacking access to a safe drinking water source. It is estimated that approximately 70% of Nigerians have access to basic water services and more than half of these water sources are contaminated. The average Nigerian only has access to nine liters of water per day for general use which is three liters below the global average recommended by the World Health Organization (WHO). At the current rate, the country will miss the SDG targets for people's access to water.

The health concerns associated with drinking water chemical constituents stem from their ability to cause adverse health effects after prolonged exposure. Aside from massive accidental contamination of a drinking water supply, some water chemical constituents can cause health problems with a single exposure. Due to the use of contaminated drinking water, the human population suffers from a variety of waterborne diseases such as cholera, Hepatitis, Shigellosis, and Typhoid Fever. Chemicals from pesticides and fertilizers that end up in water may increase the risk of cancer and reproductive problems, as well as impair eye, liver, kidney, and other body functions.

Due to increased human population, industrialization, use of fertilizers, and man-made activity, water is highly polluted with different harmful contaminants. Ground and surface waters are being polluted by indiscriminate disposal of sewage, industrial waste, and a plethora of human activities which affects their physicochemical characteristics[1]. These incidents make water unfit to drink due to an unacceptable taste, odor, and appearance.

The pollution of surface and groundwater is often caused by a variety of factors and stems from different sources. Pollutants encompass detergents, disinfection by-products like chloroform in chemically treated drinking water, food processing waste (oxygen-demanding substances, fats, grease), insecticides, herbicides, various organic halides, petroleum hydrocarbons (including fuels and lubricants from stormwater runoff), volatile organic compounds (e.g., industrial solvents from improper storage), chlorinated solvents (dense non-aqueous phase liquids), polychlorinated biphenyls (PCBs), perchlorate, chemicals from personal hygiene, cosmetic products, and pharmaceutical drug pollution (including drug residues and metabolites).

Nigeria has the world's highest number of deaths from waterborne diseases with an increase from 14.61% to 50.56% within three years[2]. 70% of water at the point of consumption is contaminated and 117,000 children alone die in Nigeria each year due to preventable water-related illnesses - the highest number of any nation[3]. Most studies carried out on water contamination only focus on specific regions and extensive studies of the general state of water have not been carried out yet. This study aims to give a proper analysis of the state of water in the country and provide a framework that informs general and specific economic decisions regarding access to clean water. The results of this study identify the most affected areas and generally provide a robust assessment of individual ions that constitute most polluted water.

Methods

Study Area

Datasets from over 240 studies of water samples collected from all 37 regions in the country were collected and analyzed. The

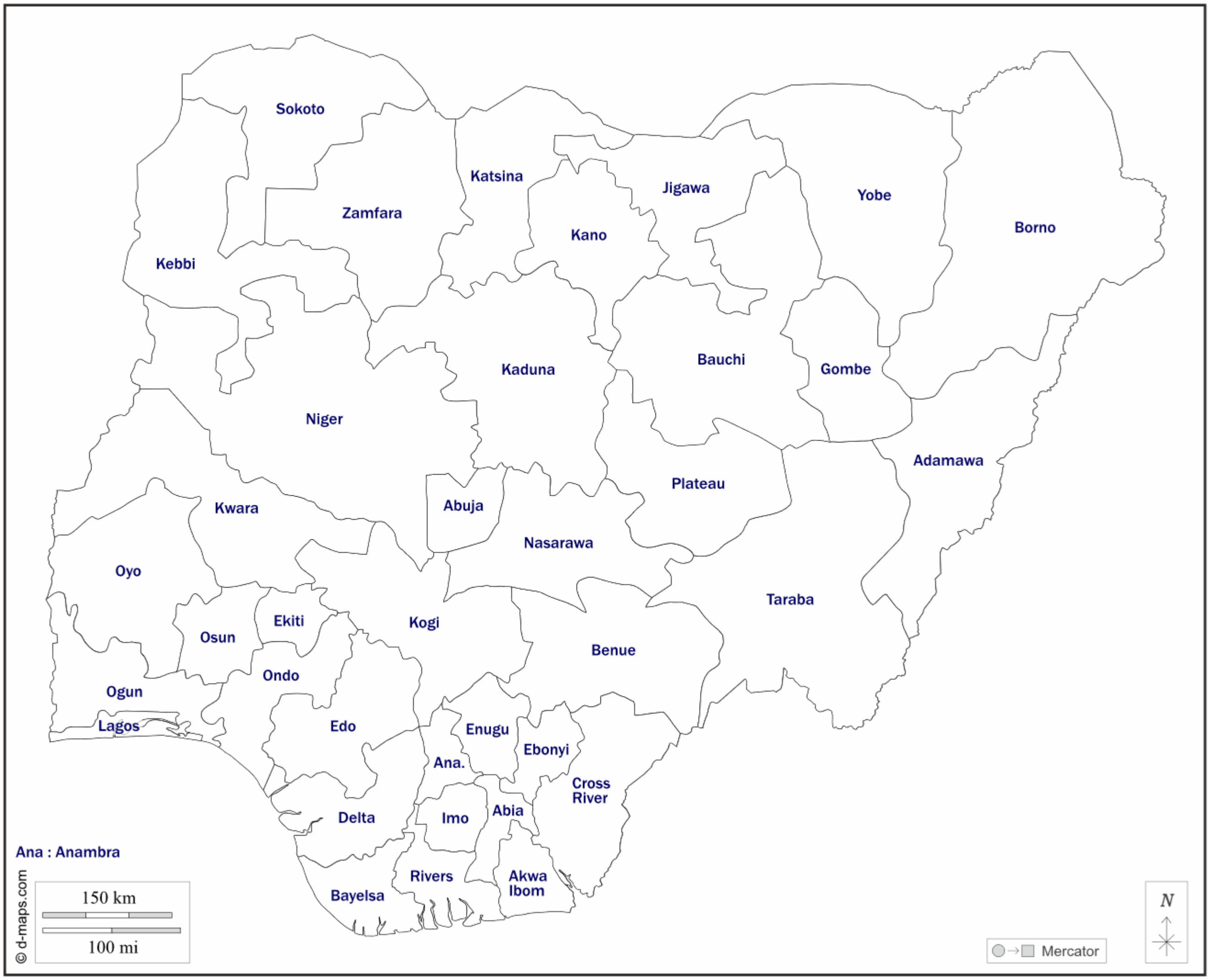

Fig. 1 Spatial distribution of samples across the study area.

samples were broadly collected from surface water (rivers, lakes, reservoirs, etc.), and groundwater (water from aquifers through sources such as wells and boreholes). The water quality parameters selected for this analysis were: Phosphate ($PO_4{}^{3-}$), Sulphate ($SO_4{}^{2-}$), Chloride (Cl^-), Nitrate ($NO_3{}^-$), Potassium (K^+), Sodium (Na^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Zinc (Zn^{2+}), Manganese (Mn^{2+}), Iron (Fe^{3+}), and Lead (Pb^{2+}). These ions were selected to ascertain the quality status of the ground and surface water unlike in some other works where few parameters were tested. The selected ions are only a general representation of the most tested isotopes. The datasets contained studies of various isotopes of several of these parameters. Analysis of the obtained data was carried out to identify samples that exceed WHO/USEPA recommended limits, and a plethora of statistical descriptions were used to identify areas with the highest risk factor. To better achieve an objective/standardized measurement, the Water Quality scale rating, Relative weight, and arithmetic water quality index for each sample were calculated.

Selection Criteria/Sample Size

Selection of parameters was based on the number of completed studies that have been conducted. Important parameters including fluoride and copper ions were left out of the study because enough studies have not been done to conduct a proper synthesis analysis for those ions. Over 250 studies conducted on relevant ions were analyzed. Most datasets collected from studies carried out in all the regions contained measurements for multiple parameters.

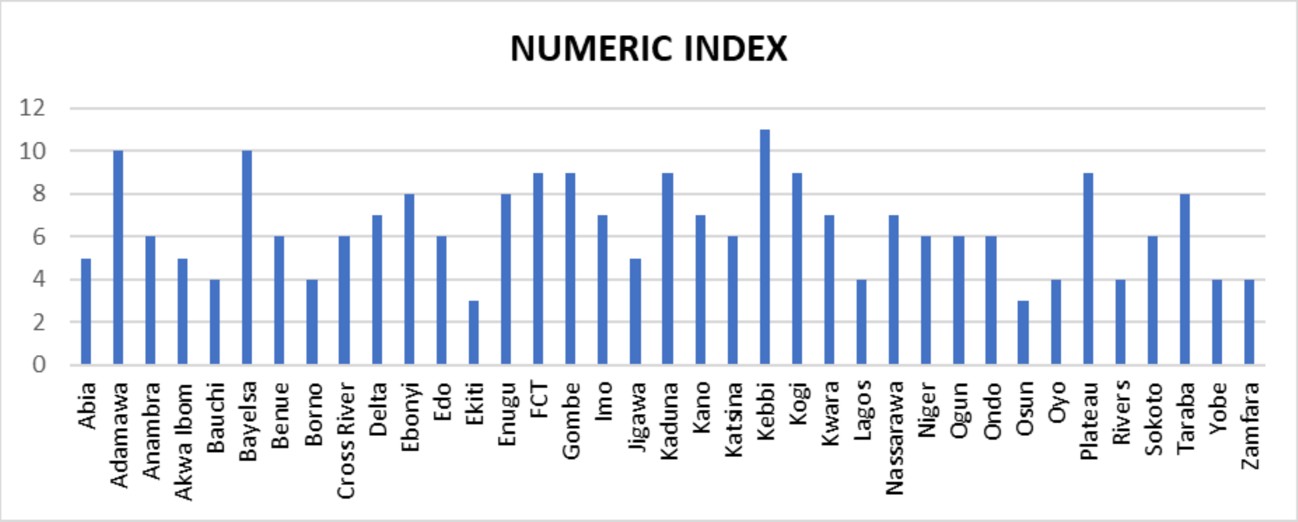

Fig. 2 Number of samples in each state

Geology

The geology of the study area is such that the savannah biome accounts for more than 86% of the region's vegetation cover. The greater percentage of geologic features like mountains are mostly found towards the north. Nigeria has an estimated 215 billion m^3 of surface water and 87 billion m^3 of groundwater, but these resources are not spread out evenly. Almost 80% of the country's surface water comes from the southern part of the country, while the northern part mostly depends on groundwater.

Data Analysis

The statistical description of sampled parameters and their corresponding values are presented in Table **??**. The values marked in red are values for parameters that are above WHO/USEPA safe levels. A mean value test was conducted and gives the average value of each parameter. The maximum and minimum values indicate the highest and lowest possible values of each ion. The median gives a better measure of central tendency for ions whose samples contain disproportionate outliers, while the standard deviation values give an estimate of distribution and spread of data.

Weighted Arithmetic Water Quality Index (WQI) Calculation

The WQI is an effective tool for communicating water quality to the general public, policymakers, and stakeholders. It is an unambiguous tool that enables the integration of the water parameters which are deemed important to the quality of the water accordingly and reflects the combined impact of various water quality parameters on overall water quality (Brown et al., 1970). For this study, the WQI was calculated using the weighted arithmetic index method in assessing groundwater quality for each region. Once the WQI scores were determined, they were compared to a scale.

WATER QUALITY RATING BASED ON ARITHMETIC METHOD

Water Quality Index Level	Rating of Water Quality	Grade
0-25	Excellent water quality	A
26-50	Good water quality	B
51-75	Poor water quality	C
76-100	Very poor water quality	D
> 100	Unsuitable for drinking	E

Table 1 Water Quality Index scale.

The water quality rating scale, relative weight, and overall WQI were calculated by the following formulae:

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \tag{1}$$

where q_i, C_i, and S_i indicate the quality rating scale, the concentration of the ith parameter, and the standard value of the ith parameter, respectively.

The relative weight (w_i) is calculated by:

$$w_i = \frac{1}{S_i} \tag{2}$$

where the standard value of the ith parameter is inversely proportional to the relative weight.

The Water Quality Index (WQI) is calculated using the following formula:

$$\text{WQI} = \sum_{n=1}^{i=n} q_i w_i \tag{3}$$

Finally, the overall WQI is calculated according to the following expression:

$$\text{Overall WQI} = \frac{\sum_{n=1}^{i=n} q_i w_i}{\sum_{n=1}^{i=n} w_i} \tag{4}$$

Results

The results of the synthesis analysis of the datasets are presented in figures 2-4 and tables 4-7. Table 4 gives the total number of collected samples and number of that exceed W.H.O limits. Figure 4 gives the percentage of samples that exceed W.H.O Safe levels for each ion.

STATISTICAL DESCRIPTION OF IONS

From Table 2, the values that exceed WHO and USEPA safe levels are shown in red. Parameters whose minimum is given as <0.001 were below the detection limit. The WHO and USEPA limit for phosphate (PO_4^{3-}) is 0.1 mg l-1. In this study, the phosphate (PO_4^{3-}) levels ranged between 0.001 mg l-1 and 146.7 mg l-1. The estimated standard deviation for phosphate (PO_4^{3-}) is 18.33 mg l-1, and the median is 0.77 mg l-1. The mean value is 5.6 mg l-1, and is above both WHO and USEPA limits. Nitrate (NO_3^-) concentrations in the samples ranged from <0.001 mg l-1 (below detection limit) to 329 mg l-1, with an average value of 23.36 mg l-1. The standard deviation for NO_3^- is 49.70 mg l-1, and the median is 3.91 mg l-1. The WHO maximum permissible limit of NO_3^- in drinking water is 10 mg l-1. Most values are within the permissible limit of WHO and USEPA standards. The WHO standard limit of sulfate in drinking water is 250 mg l-1. The concentration of sulfate (SO_4^{2-}) in this study ranged from <0.001 mg l-1 to 968.1 mg l-1. Most values were within USEPA's limit of 250 mg l-1. The mean and standard deviation were calculated to be 134.02 mg l-1 and 51.8 mg l-1 respectively. The median value is 9.35 mg l-1. Chloride (Cl^-) concentrations in water samples range between <0.001 mg l-1 and 8029 mg l-1, with a standard deviation value of 696.70 mg l-1. Both the mean (131.65 mg l-1) and median (29.55 mg l-1) values in ground and surface water samples fall within WHO and USEPA limits of 200 mg l-1 and 250 mg l-1 for drinking water.

According to WHO and USEPA standards, the permissible limit of magnesium in drinking water should be 50 mg/l. Magnesium (Mg^{2+}) concentration ranged from <0.001 mg l-1 to 292.67 mg l-1. The concentration of Mg^{2+} in all the water samples from the study area is generally low with mean and median values of 23.57 mg l-1 and 8.5 mg l-1. The estimated standard deviation of Mg^{2+} is 54.81 mg l-1. The WHO and USEPA guideline for calcium (Ca^{2+}) ions in drinking water is 200 mg l-1. The results of the study show that the concentration of Ca^{2+} ranges from 0.005 mg l-1 to 479 mg l-1 with an average of 44.94 mg l-1. The estimated standard deviation is 74.28 mg l-1, and the median is 21.07 mg l-1. Iron (Fe^{3-}) concentrations range between 0.0028 mg l-1 and 161 mg l-1 with a very high mean value of 5.02 mg l-1. Fe^{3-} concentration in ground and surface water samples are mostly above the permissible WHO and USEPA limits for drinking water (68%) with Edo, Ogun, and Jigawa having the highest values. The median measured is 0.4 mg l-1 with a standard deviation of 22.07 mg l-1. The USEPA lead standard for drinking water quality is 0.05 mg l-1, while WHO recommends 0.01 mg l-1 as the maximum permitted amount. The mean (2.62 mg l-1) value for lead (Pb^{2+}) is significantly above WHO limits and the standard deviation is 17.43 mg l-1. The minimum and maximum values reported are <0.001 mg l-1 and 145.71 mg l-1, while the median is 0.08 mg l-1.

Manganese (Mn^{3+}) concentrations measured in water varied from ¡0.001 mg l-1 to 152 mg l-1. A high average concentration value of 5.52 mg l-1 was obtained. Similar to iron, ¿ 60% of the samples evaluated for Mn^{3+} concentration is above the limits recommended by the two standards considered in this study. The estimated standard deviation is 33.89 mg l-1 with a median value of 0.18 mg l-1. The concentration of zinc (Zn^{2+}) in the samples ranged between 0.004 mg l-1 and 398 mg l-1. Statistical analysis revealed 6.08 mg l-1 and 0.3 mg l-1 as the mean and median values. The standard deviation of Zn^{2+} was 44.70 mg l-1. According to WHO standards, the recommended concentration of sodium in drinking water should fall within 100-200 mg l-1. The range of Na^+ ions in the water samples varied from 0.005 mg l-1 to 900 mg l-1. The mean and median values obtained are 57.49 mg l-1 and 8.54 mg l-1. Most samples were within the WHO and USEPA standards. The concentration of potassium (K^+) in water samples ranged from 0.01 mg l-1 to 322 mg l-1 with an average value of 5.7 mg l-1. The median and standard deviation values obtained are 5.53 mg l-1 and 48.86 mg l-1. Most samples are within the standards recommended by WHO and USEPA.

SAMPLE FREQUENCY

From Table 3, the total number of samples obtained from all the regions is 249. Out of the total number of samples, 125 samples were from surface water (including lakes, dams, reservoirs, and running water like rivers and streams), and 129 from ground water (aquifers, wells, and boreholes). Out of 125 samples obtained for surface water, 27 of them had values that were above WHO limits, accounting for 21.6% of the total surface water samples. Out of 129 samples obtained for ground water, 18 of them had values that were above WHO limits, accounting

Table 2 DESCRIPTION OF SAMPLED PARAMETERS. (<0.001 = BDL)

	IONS (mg l^{-1})											
	PO_4^{3-}	NO_3^-	SO_4^{2-}	Cl^-	Mg^{2+}	Ca^{2+}	Fe^{3+}	Pb^{2+}	Mn^{3+}	Zn^{2+}	Na^+	K^+
USEPA	**0.1**	**50**	**–**	**200**	**50**	**200**	**0.1**	**0.05**	**0.05**	**5**	**–**	**30**
WHO	**0.1**	**–**	**250**	**250**	**50**	**200**	**0.3**	**0.01**	**0.05**	**5**	**100-200**	**30**
MEAN	5.6	23.36	51.8	131.65	23.57	44.94	5.02	2.62	5.52	6.08	57.49	18.89
MINIMUM	<0.001	<0.001	<0.001	<0.001	<0.001	0.005	0.0028	<0.001	0.001	0.004	0.005	0.01
MAXIMUM	146.67	329.4	968.1	8029	292.67	479	161	145.71	152	398	900	322
MEDIAN	0.77	3.91	9.35	29.55	8.5	21.07	0.4	0.08	0.18	0.3	8.54	5.53
ST. DEV	18.33	49.7	134.02	696.7	54.81	74.28	22.07	17.43	33.89	44.7	157.67	48.86

Table 3 Surface and Groundwater composition

Type of water	**Total number of Samples**	**Number of Polluted Samples**	**Percentage of total samples that are polluted**
Surface water	125	27	21.60%
Groundwater	129	18	13.90%

for 13.9% of the total ground water samples. While more than 92% of the datasets contained at least one parameter whose value was above WHO and USEPA limits, the percentages of polluted samples presented in Table 3 are calculated from the cumulative values obtained from each dataset.

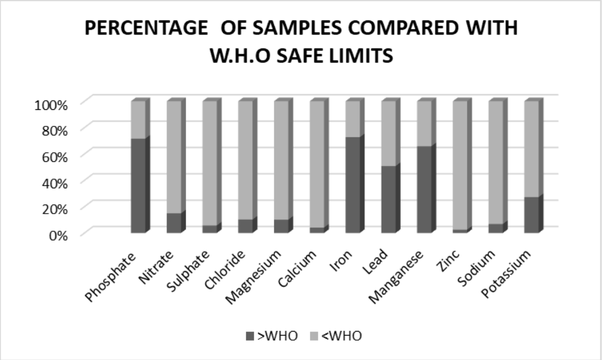

Fig. 3 For each ion, the percentage of samples that exceed the W.H.O. recommended limits is given.

Table 4 gives the number of studies conducted for each parameter, the region with the highest average value, and the percentage of samples exceeding WHO limits. Out of 81 phosphate (PO_4^{3-}) samples, 58 exceeded the WHO limit, with the peak value recorded from Enugu. Among 148 nitrate (NO_3^-) samples, 22 exceeded the WHO limit, with the highest value recorded from Niger. For sulfate (SO_4^{2-}) and chloride (Cl^-), a small fraction of 7 and 13 samples out of a total of 122 and 138 samples, respectively, were above the WHO limit. The highest average values were from FCT and Ondo. Magnesium (Mg^{2+}) had 12 polluted samples out of 122, with the peak value from Rivers. Calcium (Ca^{2+}) recorded the lowest rate of polluted samples per total number of samples among all parameters, with 5 polluted samples out of 122 and the highest value from Kebbi. In contrast, iron (Fe^{3+}) had a high number of 96 polluted samples out of a possible 132, with high iron levels mostly found in Ogun. Lead (Pb^{2+}) had a high number of 42 polluted samples out of 69, with the peak value from Ondo. Manganese (Mn^{3+}) also had high values, with 50 polluted samples out of 92, and Kano recorded the highest values. Zinc (Zn^{2+}) had only 2 polluted samples out of 79, all of which were from Osun. Sodium (Na^+) had 4 polluted samples out of 59, with peak values in Zamfara, and potassium (K^+) also recorded a similar number with 6 polluted samples out of 59, with the highest values coming from Ogun.

Figure 4 shows the measure of pollution of each ion as a percentage. 71.6% of phosphate samples exceeded the limits, while 14.9% of nitrate samples exceeded the WHO limits. 5.7% of sulfate samples exceeded the limits, and 10.2% of chloride samples were above WHO standards. Magnesium and calcium recorded 10.1% and 4.1% of samples above the limits, respectively. 72.7% of iron samples were above WHO limits, while 60.9% of lead samples exceeded the limits. Manganese and zinc recorded 65.8% and 2.5% of samples that exceeded the limits, while 6.8% and 10.9% of sodium and potassium samples, respectively, were found to be above the standard.

Calculation of the arithmetic water index shows that 75% of the water scored between 0-25. Approximately 7 percent of the water scored between 26-50. Just under 2% of samples scored between 51-100. and over 17% of water scored above 100. While these values give a general picture of water quality, most samples have high concentrations of certain ions that the indexing does not account for. Water quality is more unsuitable than is shown because of high concentration of these specific ions.

Table 4 Number of samples above W.H.O limits.

S/N	Compound	Number of samples	Number of samples that exceed WHO limits	Percentage of samples that exceed WHO limits (%)	Region with the highest average value
1	**Phosphate**	81	58	71.6	Enugu
2	**Nitrate**	148	22	14.7	Niger
3	**Sulphate**	122	7	5.7	FCT
4	**Chloride**	138	13	9.4	Ondo
5	**Magnesium**	119	12	10.1	Rivers
6	**Calcium**	122	5	4.1	Kebbi
7	**Iron**	132	96	72.7	Ogun
8	**Lead**	69	42	60.7	Ondo
9	**Manganese**	76	50	65.8	Kano
10	**Zinc**	79	2	2.5	Osun
11	**Sodium**	59	4	6.8	Zamfara
12	**Potassium**	55	6	10.9	Ogun

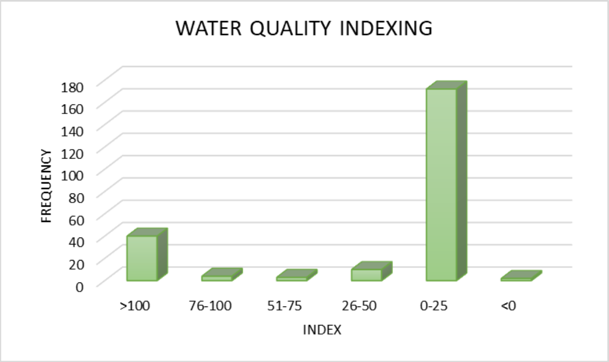

Fig. 4 Water Quality Index

Discussion

The WHO and USEPA limit for phosphate (PO_4^{3-}) is 0.1 mg l^{-1}. Phosphate is one of the parameters with a very high mean and standard deviation of 5.60 ± 18.33 mg l^{-1}. The PO_4^{3-} values contain outliers, which significantly influence the mean. Because the data is skewed, the median provides a more useful midpoint, with a value of 0.77 mg l^{-1} for PO_4^{3-}. High PO_4^{3-} levels are very toxic and can cause calcification of body organs. Samples with high PO_4^{3-} (≥ 50 mg l^{-1}), with the highest being 146.7 mg l^{-1}, mostly came from the north. This is attributed to high livestock production and agricultural runoff due to intense agricultural activities. While nitrate (NO_3^-) concentrations in some samples reached unprecedented levels, i.e., $100 \leq x \leq 329$ mg l^{-1}, most samples were within the limits, with a central tendency of 23.36 ± 49.70 mg l^{-1}, a value below half the WHO limit of 50 mg l^{-1}. The high values obtained were mostly from tests conducted on surface water found near areas with high industrialization. This indicates significant anthropogenic pollution, primarily resulting from industrial waste.

The concentration of sulfate (SO_4^{2-}) in this study ranges from < 0.001 mg l^{-1} (BDL) to a high maximum of 968.1 mg l^{-1}. However, the mean and standard deviation were calculated to be 134.02 ± 51.8 mg l^{-1}. This indicates that most values were within the USEPA's limit of 250 mg l^{-1}. SO_4^{2-} is abundantly found in almost all water bodies and is mainly derived from the dissolution of salts of sulfuric acid. The concentration of SO_4^{2-} in natural water ranges from a few to several hundred mg per liter, but no major negative impact of SO_4^{2-} on human health has been reported. High concentrations of SO_4^{2-} may be due to the oxidation of pyrite and mine drainage, among other sources (Mohsin et al., 2013).

Chloride (Cl^-) concentrations in water samples range between < 0.001 mg l^{-1} and 8029 mg l^{-1}, with a standard deviation value of 696.70 mg l^{-1}. This high standard deviation value is due to the variable spread of chloride in samples. Industries and sectors differ in their contribution to chloride contamination, with many regions exhibiting high, average, and low chloride content. The maximum value of 8029 mg l^{-1} represents the greatest outlier in this study. In contrast, both the mean (131.65 mg l^{-1}) and median (29.55 mg l^{-1}) values in ground and surface water samples fall within the WHO and USEPA limits of 200 mg l^{-1} and 250 mg l^{-1} for drinking water. High concentrations of Cl^- impart a salty taste to water and beverages. Taste thresholds for the chloride anion depend on the associated cation and are in the range of 200-300 mg l^{-1}. Concentrations in excess of 250 mg l^{-1} are increasingly likely to be detected by taste, but consumers may become accustomed to low levels of Cl^--induced taste (WHO, 2006). The Cl^- content investigated is less than the tolerable limits.

The WHO and USEPA permissible limit of magnesium in drinking water is 50 mg l^{-1}. Magnesium (Mg^{2+}) concentration values range from < 0.001 mg l^{-1} to 292.67 mg l^{-1}. The concentration of Mg^{2+} in all the water samples from the study area gave mean and median values of 23.57 ± 54.81 mg l^{-1} and 8.5 mg l^{-1}, respectively. The concentration of Mg^{2+} in all the water samples from the study area is generally low. The development of Mg^{2+} in drinking water is mostly attributed to the dissolution of minerals in the various basement rocks underlying the studied areas.

The WHO and USEPA limit for calcium (Ca^{2+}) ions in drinking water is 200 mg l^{-1}. The high level of Ca^{2+} is an indication of water hardness. The results of the study show that the concentration of Ca^{2+} ranges from 0.005 mg l^{-1} to 479 mg l^{-1} with an average of 44.94 ± 74.28 mg l^{-1}. Ca^{2+} may dissolve readily from carbonate rocks and limestone or be leached from soils. Other sources include industrial and municipal discharges. Ca^{2+} is an essential nutritional element for human beings and aids in maintaining the structure of plant cells and soils. Its deficiency may lead to protein energy malnutrition. The high deficiency of Ca^{2+} in humans may cause rickets, poor blood clotting, bone fractures, etc., and exceeding the limit of calcium can produce cardiovascular diseases[4].

Iron (Fe^{3-}) concentrations range from 0.0028 mg l^{-1} to 161 mg l^{-1} with a very high mean value of 5.02 ± 22.07 mg l^{-1}. These high values indicate significant Fe^{3-} concentration in ground and surface water samples. Fe^{3-} concentrations in ground and surface water samples are mostly above permissible WHO and USEPA limits for drinking water. The implication of a high amount of Fe^{3-} on human health is iron overload, which can cause diabetes, hemochromatosis, stomach problems, and nausea. A high concentration of iron in ingested water can cause significant damage to the liver, pancreas, and heart.

USEPA lists 0.05 mg l^{-1} as the maximum permitted Pb^{2+} level in drinking water, while WHO recommends 0.01 mg l^{-1}. The health implications of Pb^{2+} presence in excess of 0.05 mg l^{-1} in drinking water include cancer, interference with vitamin D metabolism, slowing down of mental development in infants, and toxicity to the central and peripheral nervous systems. The mean (2.62 ± 17.43 mg l^{-1}) value for Pb^{2+} is significantly above WHO limits and is extremely harmful to health. Such high levels indicate severe contamination. Unsafe mining and ore processing are the biggest contributors to high lead levels in water. Proper control of these activities will help reduce lead contamination.

Manganese (Mn^{3+}) falls above the WHO permissible standard for drinking water. Mn^{3+} concentrations measured in water varied from < 0.001 mg l^{-1} to 152 mg l^{-1}. A high average concentration value of 5.52 ± 33.89 mg l^{-1} and a median value of 0.18 mg l^{-1} were obtained. Anaerobic groundwater often contains elevated levels of dissolved manganese. High concentrations of Mn^{3+} can cause mental diseases such as Alzheimer's, which affect the intellectual functions of children below 10.

Similar to Fe^{3+}, Pb^{2+}, and Mn^{3+}, studies of the samples evaluated for zinc concentration mostly obtained values above W.H.O and USEPA guidelines. The concentration of Zn^{2+} in the samples ranged between 0.004 mg l^{-1} and 398 mg l^{-1}. Statistical analysis revealed 6.08 ± 44.70 mg l^{-1} as the average value. The mean is also significantly higher than the limit. Very high levels of Zn^{2+} can cause nausea and vomiting.

The WHO sodium limit in drinking water should ideally be within 100-200 mg l^{-1}. The range of Na^{+} ions in the water was $0.005 \leq x \leq 900$ mg l^{-1}. The mean and median values obtained were 57.49 ± 157.67 mg l^{-1} and 8.54 mg l^{-1}, respectively. Most samples were within the WHO and USEPA standards. Higher concentrations of Na^{+} ions in drinking water may cause heart problems. Excessive amounts of Na^{+} ions in water normally affect the palatability of the water. Proper quantities of sodium in the human body prevent many fatal diseases like kidney damage, hypertension, headache, etc.[5]. Most samples were within the permissible limit of WHO and USEPA standards. The concentration of potassium in water samples from our study ranges from $0.01 \leq x \leq 322$ mg l^{-1} with an average value of 5.7 ± 48.86 mg l^{-1}. Most samples are within the standards recommended by W.H.O and USEPA.

Groundwater accounted for nearly one-third of water samples that scored high on the WQI index, while surface water accounted for only about 37% of high scoring samples. Similarly, surface water accounted for 60% of polluted samples compared to groundwater's 40%. (Table 3). Based on this result, surface water is more polluted. From figure 2, five regions had 9 samples each (FCT, Gombe, Kaduna, Kogi, and Plateau). Two regions had up to ten samples obtained (Adamawa and Bayelsa), while Kebbi state had more than 10 samples, making it the most polluted state (as determined by this study). Osun and Ekiti emerged as the states with the lowest pollution with three samples each, all of which scored well on the WQI index (Figure 1).

Tables 4 and Figure 4 give the number of studies conducted for each parameter, the amount that exceeds WHO limits, and their relative percentages. Phosphate, iron, and manganese had more than 50% of samples exceeding WHO levels. Generally, calcium and zinc posed little risk with less than 5% of samples above WHO limits. Based on these results, phosphate, iron, and manganese posed the highest risk to health due to their high concentrations in water.

The regions with the highest average recorded values for each ion are given in Table 4. Ogun had the highest values for K^{+} and Fe^{3+} ions. This is most likely due to the high mining operations carried out in the region and heavy use of potassium-rich fertilizers, which ultimately affect water bodies. Ondo recorded the highest average values for Cl^{-} and Pb^{2+} ions because of heavy industrialization in the region. Most regions with the highest ion values are found in the southwestern and northwestern regions of the country, which are the most industrially active regions.

Conclusion

The results show that majority of the samples contain large quantities of ions that are harmful to health. The samples that contain high levels of heavy metal will pose the greatest risk. More analyses must be carried out continuously to obtain relevant information of the state of the art of ground and surface water across all regions in the country.

The primary limitation to the generalization of these results is the omission of important ions like copper and fluoride due to insufficient studies. This affects the overall assessment of water quality. This can be addressed in future research by conducting more studies that involve ions of fluorine, copper, and other important heavy metals, then including them in overall quality assessments. This will give a more accurate picture of water quality.

Another limitation of this study is the absence of temporal assessment. An analysis of these ions and their values over time will give a better understanding of their trend and inform better decisions.

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