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RESEARCH ARTICLE

Understanding Groundwater Quality Using Health-Related, Operational-Related, and Other Parameters of Human Health Concern in Western Sokoto Basin, Nigeria

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Abstract

This study evaluated the water quality of ten selected local government areas (LGAs) in Kebbi State, western Sokoto basin, using health-related, operational-related, and other parameters of human health concern. The study employed both in-situ and laboratory analysis. Physical parameters, i.e., pH, TDS, EC, Temperature, and Dissolved Oxygen, were determined in situ. Chemical parameters, including Ca, Mg, Na, P, and K, were determined using AAS. NO_3, PO_4, and Cl were analyzed using Automated Colorimetry. Results revealed that arsenic, iron, and turbidity in the studied LGAs are above WHO [1] and NSDWQ [2] recommended values. However, fluoride and nitrate concentrations in the studied LGAs are below the recommended values of the WHO [1] and NSDWQ [2]. The mean EC is less than 500 µS/cm, and the concentration of TDS in the studied LGAs is generally low (<500 mg/l). Based on pH, groundwater in the studied LGAs is slightly alkaline. Mean phosphate, chloride, and sodium concentrations in the studied LGAs are within the WHO [1] and NSDWQ [2] reference values for drinking water. Results showed that Fecal Coliform is available in the studied drinking water sources. Therefore, this study recommends programs against open defecation to curtail the spread of fecal coliform and other harmful bacteria in the environment. Furthermore, water quality monitoring is recommended for improved water quality and human health in the Western Sokoto basin, i.e., Kebbi State.

Keywords: Groundwater Quality, Operational-Related Parameters, Health-Related Parameters, Human Health.

1. Introduction

Freshwater, the essential natural resource on the planet, is a requirement for life and all life forms and an essential requirement of ecological diversity and sustainable development. However, the water crisis has become a global problem in the last decade [3-6]. The rapid increase in human population, urbanization, and industrialization have led to excessive water use from freshwater sources (e.g., rivers, lakes) for various daily needs [7, 8]. Consequently, the discharge of untreated water containing organic and inorganic compounds into water bodies from domestic wastes industry, and agricultural runoff has caused water quality deterioration and threatened public health by restricting water use [3, 9].

Estimates showed that 70% of surface water sources are used in irrigation and agriculture, while only 10% is used for domestic purposes [10, 11]. Around 850 million people on a global basis lack access to safe and clean drinking water [12, 13]. This condition is more pronounced in developing countries such as Nigeria. Nearly 80% of the illnesses in these poor countries are caused by polluted water [14]. One in five deaths in infants is caused by contaminated water consumption.

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Five hundred thousand people die of diarrhea due to drinking contaminated water. Approximately two billion people consume contaminated drinking water globally [3]. The water quality contamination indices are high globally, especially in developing countries [15]. Therefore, water quality analysis is required while scouting for improved community water supply.

Sources of drinking water are the most exposed resources to both anthropogenic and natural contamination. They are naturally affected by precipitation, weather conditions, and sediment transport. In the same vein, anthropogenic effects could exacerbate the adverse effects on the ecological character of the stream [3, 16, 17]. In particular, heavy metals (HMs) are among the most dangerous pollutants in aquatic environments due to their long-lasting, high bioaccumulation potential and toxicity [18]. Therefore, collecting reliable groundwater quality data, assessing its spatial and temporal fluctuations, identifying the contamination sources, determining the water quality, and monitoring water pollution are critical points for effective water quality management [3]. Figure 1 summarizes the environmental process which affects groundwater quality.

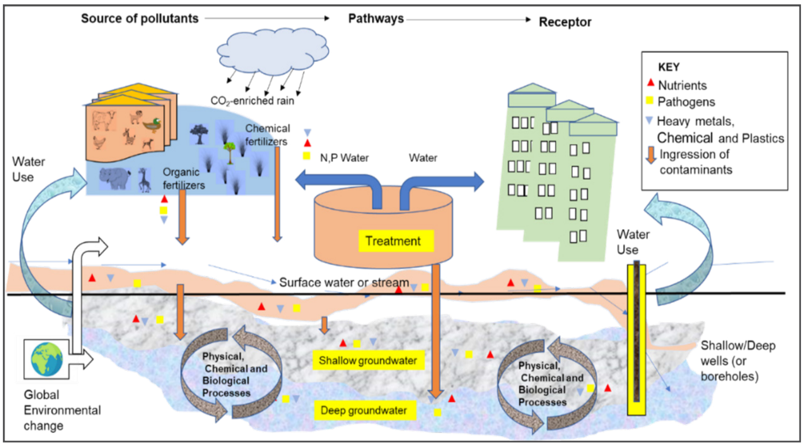

Figure 1. *Conceptualized model for water quality deterioration.*

Significant spatial and temporal variations occur in the groundwater quality. Thus, it is essential to understand the water quality status in Kebbi State. Consequently, physicochemical water quality parameters recommended by USAID's Water Quality Assurance Plan (WQAP) were analyzed. These parameter values are administered to determine water quality status and sometimes specific water uses. Therefore, they play a significant role in managing water resources for decision-makers. The water quality assessment has become a vital issue in the last decade due to the rapid deterioration in freshwater quality in semi-arid areas such as Kebbi State. Against this background,

2. The Study Area

Kebbi State (Figure 2) is located between latitude 100 8’ and 130 15’N and between longitude 30 30´ E and occupies a total land area of about 36,800km^2 [19]. The climate of the study area is characterized by a long dry season and a short but intensive wet season. Annual rainfall is highly variable and decreases in volume from the southern to northern parts of the state. Analyses of temperature over 40 years showed that the mean maximum temperature is highest in April (400C) and lowest in December (23^{o}C) [19]. Analysis of soil temperature suggests an Isohyperthermic soil temperature regime. The mean relative humidity is highest in August (90%) and is lowest in December (10 – 30%). However, the state has an overall increase in relative humidity from north to south [19]. Generally, the evaporation rate is high, and the state can be classified as having a ustic soil moisture regime. The geology of the study area is mainly sedimentary, with some outcrops of weathered basement complex rocks in the south. Underlying the sedimentary formations are crystalline rocks of pre-cretaceous age [19]. Groundwater in the upland areas of crystalline rocks of the southern part of Kebbi State is generally available in small quantities from fractures or other tabular partings and the regoliths. River Sokoto (Gulbin-Dukku), a principal tributary of River Niger, essentially drains the study area. Despite the potentials presented by aquifers in the state (e.g., Gwandu and Illo Formations), many communities are still without improved water supply systems and rely on individual and community hand-dug shallow wells for potable water supply [20]. While these hand-dug wells are poorly constructed, their water quality remains poorly known because most rural communities cannot test the suitability of water obtained from these wells.

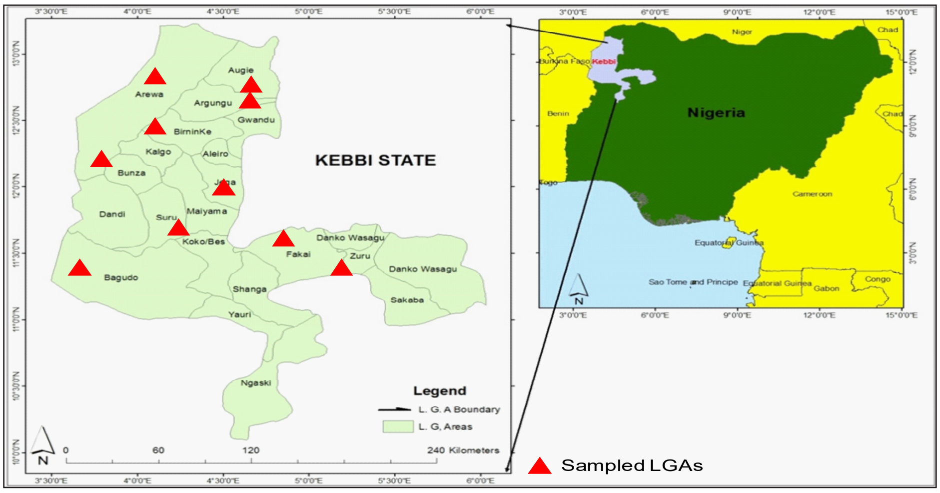

Figure 2. *The study area.*

3. Materials and Methods

3.1 Water Sampling and Laboratory Analysis

Water sampling was conducted across ten local government areas (LGAs) in Kebbi State. Representative samples were collected from the studied communities. Water samples were drawn from water used in schools and health care centers. These are sources constructed primarily by Government agencies or other agencies through intervention programs, such as UNICEF, WHO, USAID, Qatar Foundation, etc. Two groundwater samples were derived from the sampling locations, totaling 120 water samples. Likewise, Groundwater sampling, preservation, and analysis were conducted following WQAP-defined water sampling, storage, and analysis protocol [21]. Physicochemical and biological parameters were compared with the Nigerian Standard for Drinking-water Quality (NSDWQ, 2007) and WHO 2011/2017. In situ analysis of pH, TDS, EC, Temperature, and Dissolved Oxygen. Laboratory analysis of chemical and biological parameters. Fecal Coliform was analyzed using the MPN procedure [22]. Heavy Metals were analyzed using the MOP-AES machine (Model_4210). Other parameters of human health concerns (Ca, Mg, Na, P, K) were determined using AAS. NO_3, PO_4, and Cl were analyzed using Automated Colorimetry [23].

3.2 Suitability for Drinking

For quality control, the water quality analyses were carried out in triplicate, and results were found to be within ±0.5 error limits [24]. Afterward, water quality results were compared with World Health Organization (WHO, 2008) and Nigerian Standard for Drinking Water Quality (NSDWQ, 2007) reference guidelines . Subsequently, spatial interpolation with Inverse Distance Weighting (IDW) was applied to show the spatial distribution of elements in the studied LGAs.

3.3 Statistical Analysis

Descriptive statistics were used to summarise and standardize data. It comprised Mean, Minimum, Maximum, and Standard error.

3.3.1 Inverse Distance Weighting (Idw) Interpolation Method

Inverse distance Weighted interpolation is a deterministic spatial interpolation approach to estimate an unknown value at a location using some known values with corresponding weighted values [25] . The basic IDW interpolation formula can be seen in Equation 1. Where x* is the unknown value at a location to be determined, w is the weight, and x is the known point value. The weight is the inverse distance of a point to each known point value used in the calculation. Simply the weight can be calculated using Equation 1.

$$z_p = \frac{\sum_{i=1}^{n} \left(\frac{z_i}{d_i^{\,p}} \right)}{\sum_{i=1}^{n} \left(\frac{1}{d_i^{\,p}} \right)}$$

The sigma notation means adding whatever number of points that will be interpolated. Here we are simply summing the elevation values at each point for distance [25]. A smaller number in the denominator (more distance) affects the interpolated (xp) value. However, having values above or below the maximum and minimum known values is impossible. The analysis was carried out using Arc GIS (version 10.5).

4. Results and Discussion

4.1 Health-Related Parameters

The health-related parameters defined by USAID's WQAP are Arsenic, Fluoride, Nitrate, and Fecal coliform.

4.1.1 Arsenic

The mean arsenic concentration in the studied Local Government Areas (LGAs) is above WHO [1] and NSDWQ [2] recommended values, as shown in Table 1. Arsenic concentrations in natural waters generally range between 1 and 2 mg/l, although concentrations may be elevated (up to 12 mg/l) in areas containing natural sources. There remains considerable uncertainty over the actual risks at low concentrations, and available data on the mode of action does not provide a biological basis for linear or non-linear extrapolation. Because of the significant uncertainties surrounding the risk assessment for arsenic carcinogenicity, the practical quantification limit in the region of 1–10 mg/l, and the practical difficulties in removing arsenic from drinking water, the guideline value of 10 mg/l is retained by WHO [1]. Because of the scientific uncertainties, the guideline value is designated as provisional. Numerous epidemiological studies have examined the risk of cancers associated with arsenic ingestion through drinking water [26-31]. Many ecological-type studies suffer from methodological flaws, particularly in measuring exposure. However, there is overwhelming evidence that consumption of elevated levels of arsenic through drinking water is causally related to cancer development at several sites.Nevertheless, there remains considerable uncertainty and controversy over the mechanism of carcinogenicity and the shape of the dose-response curve at low intakes.

Table 1. *Health-Related Parameters*

LGA	Summary	EC	TDS	pH	TUR	Arsenic	Fluoride	Nitrate	Fecal Coliform
Argungu	Min	27.00	13.00	7.50	0.00	0.72	0.00	0.50	+ve
	Max	427.00	201.00	9.50	50.80	1.48	0.06	2.40	+ve
	Mean	186.88	88.00	8.56	12.70	1.20	0.02	1.55	+ve
	SE	50.53	23.75	0.32	7.73	0.06	0.01	0.12	+ve
Augie	Min	97.00	46.00	6.60	0.00	0.75	0.00	1.20	+ve
	Max	272.00	128.00	8.60	54.40	1.44	0.05	26.00	+ve
	Mean	179.38	84.50	7.94	20.10	1.23	0.01	4.84	+ve
	SE	29.32	13.76	0.29	10.24	0.05	0.00	1.66	+ve
Bunza	Min	27.00	13.00	7.60	0.00	0.05	0.00	1.20	+ve
	Max	1108.00	521.00	10.40	0.00	1.21	0.03	2.80	+ve
	Mean	403.63	190.00	8.86	0.00	0.97	0.01	1.66	+ve
	SE	160.93	75.63	0.39	0.00	0.08	0.00	0.10	+ve
Dandi	Min	23.00	11.00	5.60	0.00	0.08	0.00	0.10	+ve
	Max	955.00	449.00	8.40	0.00	1.42	0.13	2.80	+ve
	Mean	408.13	192.00	6.70	0.00	1.13	0.03	1.66	+ve
	SE	143.87	67.64	0.39	0.00	0.09	0.01	0.18	+ve
Gwandu	Min	38.00	18.00	6.40	0.00	0.09	0.00	0.18	+ve
	Max	182.00	86.00	8.00	0.00	1.72	0.07	2.40	+ve
	Mean	100.50	47.63	7.28	0.00	1.10	0.03	1.66	+ve
	SE	21.40	10.05	0.22	0.00	0.15	0.01	0.15	+ve
K/Besse	Min	34.00	16.00	6.70	0.00	0.15	0.00	0.15	+ve
	Max	981.00	471.00	8.70	51.50	1.72	0.07	3.00	+ve
	Mean	358.63	171.13	7.60	19.21	1.12	0.02	1.88	+ve
	SE	135.33	64.82	0.25	9.83	0.09	0.01	0.20	+ve

Kalgo	Min	40.00	19.00	6.60	0.00	0.09	0.00	0.20	+ve
	Max	372.00	175.00	8.70	62.30	1.31	0.14	2.00	+ve
	Mean	185.00	87.00	7.79	22.69	0.78	0.03	1.28	+ve
	SE	42.03	19.74	0.27	11.49	0.07	0.01	0.12	+ve
Maiyama	Min	74.00	34.00	6.60	0.00	0.07	0.00	0.12	+ve
	Max	1119.00	526.00	8.90	0.00	1.44	0.14	2.60	+ve
	Mean	382.38	179.38	7.68	0.00	1.15	0.03	1.69	+ve
	SE	149.51	70.38	0.39	0.00	0.10	0.01	0.16	+ve
Ngaski	Min	144.00	68.00	5.70	0.00	0.10	0.00	0.16	+ve
	Max	455.00	214.00	8.20	59.10	1.13	0.06	3.00	+ve
	Mean	317.14	149.29	7.03	31.83	0.83	0.02	1.74	+ve
	SE	50.98	23.93	0.40	10.96	0.07	0.01	0.22	+ve
Suru	Min	53.00	25.00	7.10	0.00	0.28	0.00	1.00	+ve
	Max	559.00	263.00	8.80	88.10	0.77	0.14	3.00	+ve
	Mean	268.25	126.75	7.88	36.91	0.57	0.03	2.12	+ve
	SE	75.34	35.64	0.27	17.05	0.04	0.01	0.14	+ve
Guideline Values	WHO (2008)	1000	500	6.5-8.5	5NTU	0.01	1.5	50.0	
	NSDWQ (2007)	1000	500	6.5-85	5NTU	0.01	1.5	50.0	

Note: *All concentrations are in mg/l, except fecal coliform.*

Figure 3a illustrates the spatial distribution of Arseni in Kebbi State. Augie and Argungu LGAs have the highest Arsenic concentrations. It has been established that long-term exposure to arsenic in drinking water is causally related to increased cancer risks in the skin, lungs, bladder, and kidneys, as well as other skin changes, such as hyperkeratosis and pigmentation changes [6, 31]. Therefore, the observed high Arsenic concentrations in Kebbi State posed a health concern. Thus, there is a need for more analytical epidemiological studies to determine the dose–time response for skin lesions and cancer to assist in developing suitable interventions and determining applicable intervention policies for Kebbi State.

4.1.2 Fluoride

The mean Fluoride concentration in the studied LGAs is below the WHO [1] and NSDWQ [2], as shown in Table 1 and Figure 3b. Fluorine is a common element widely distributed in the Earth's crust and exists in fluorides in several minerals, such as fluorspar, cryolite, and fluorapatite [32, 33]. Thus, traces of fluorides are present in many glasses of water, with higher concentrations often associated with underground sources. In areas rich in fluoride-containing minerals, well water may contain up to 10 mg per liter, although much higher concentrations can be found [34]. Epidemiological evidence shows that concentrations above this value increase dental fluorosis risk, and progressively higher concentrations increase skeletal fluorosis risk [35]. Thus, the value is higher than recommended for artificial fluoridation of water supplies, usually 0.5–1.0 mg/l. Total daily fluoride exposure can vary markedly from one region to another. It will depend on the concentration of fluoride in drinking water, the amount drunk, levels in foodstuffs, and the use of fluoridated dental preparations [36]. In addition, fluoride exposure in some areas is considerably higher due to various practices, including consuming brick tea and cooking and drying food with high-fluoride coal [37, 38]. Nevertheless, the observed Fluoride concentrations in Kebbi State posed no health risk.

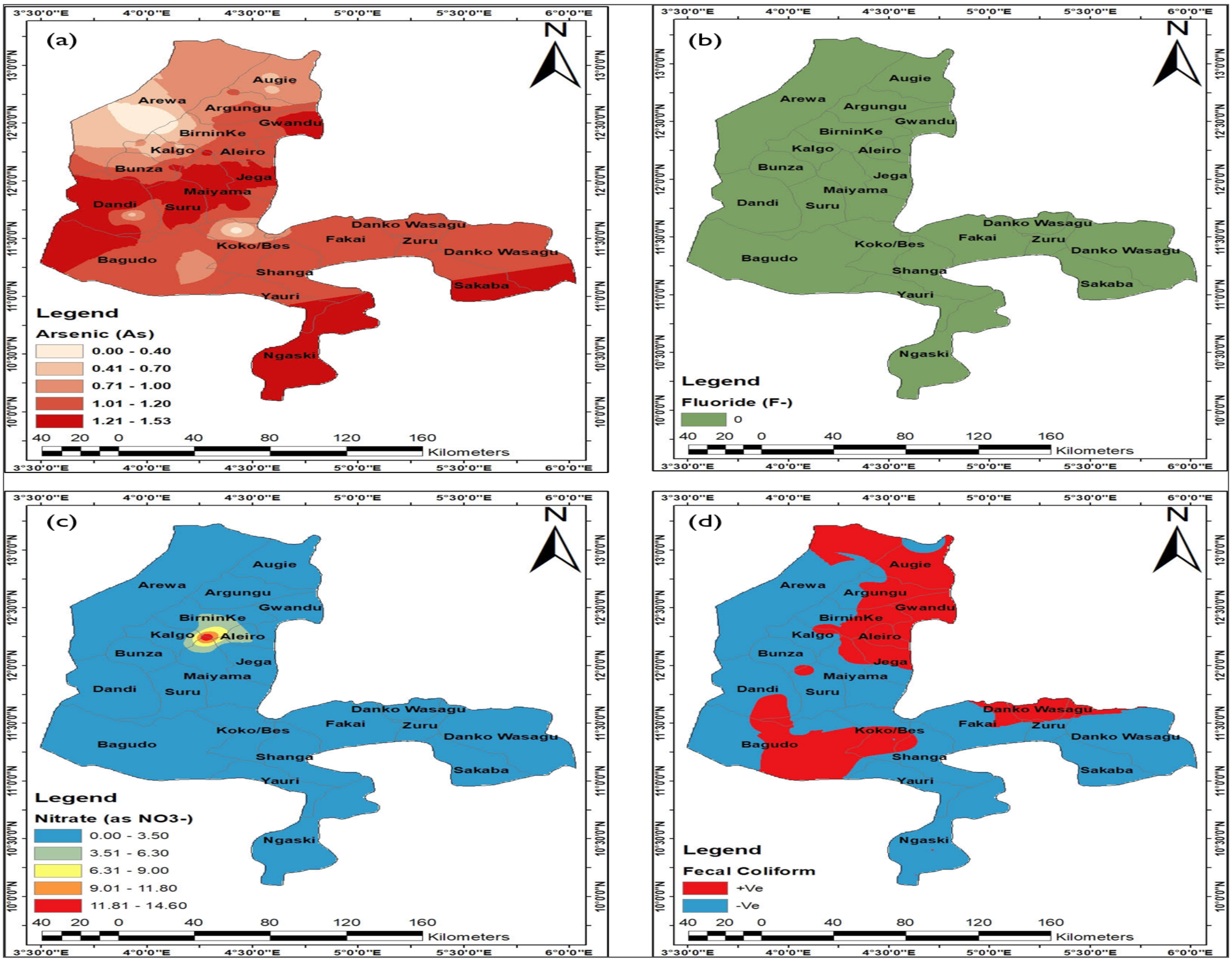

Figure 3. *Health-related parameters (a) Arsenic, (b) Fluoride, (c) Nitrate, and (d) Fecal Coliform.*

4.1.3 Nitrate

Generally, Nitrate concentrations in the Studied LGAs are below the WHO [1] and NSDWQ [2] recommended values, as shown in Table 1 and Figure 3b. However, Augie LGA had the highest Nitrate concentrations, with a mean value of 4.84 mg/l. Nitrate can reach surface water and groundwater due to agricultural activity (including the excess application of inorganic nitrogenous fertilizers and manures) from wastewater disposal and oxidation of nitrogenous waste products in human and animal excreta, including septic tanks [39, 40]. Surface water nitrate concentrations can change rapidly due to fertilizer's surface runoff, phytoplankton uptake, and bacteria denitrification, but groundwater concentrations generally show relatively slow changes [40]. Some groundwater bodies may also have nitrate contamination due to leaching from natural vegetation [41, 42]. Nevertheless, nitrate concentration in the studied LGAs posed no significant health risk, as shown in Table 4. And Figure 3c.

4.1.4 Fecal Coliform

Results showed that Fecal Coliform is available in the studied LGAs, as shown in Table 1 and Figure 3d. It presents a significant health risk in Kebbi State. Some of these bacteria are excreted in the faces of humans and animals, but many coliforms are heterotrophic and can multiply in water and soil environments [43]. Fecal coliforms can also survive and grow in water distribution systems, particularly in the presence of biofilms [44]. Coliforms should be absent immediately after disinfection, and the presence of these organisms indicates inadequate treatment [45, 46]. Total coliforms in distribution systems and stored water supplies can reveal regrowth and possible biofilm formation or contamination by ingressing foreign material, including soil or plants [47]. Open defecation is the primary source of fecal coliform in Kebbi State. Open defecation leads to the spread of fecal coliform and other harmful bacteria in the environment. Thus, waterborne diseases such as cholera can be encountered in those communities. However, cholera outbreaks occur and are still unresolved in many communities in Kebbi State (e.g., Dakin Gari). Therefore, besides environmental policies, more sensitization is required to foster health, and environmental education is required in Kebbi State. Thermotolerant coliform or E.coli are associated with urinary tract infections, bacteremia, meningitis, diarrhea, acute renal failure, and hemolytic anemia [2, 48, 49].

Fecal coliforms originate in human and animal waste. Total coliforms include fecal and other bacteria with similar properties, which originate in soil and are nonfecal [50, 51]. For improved safety, the practice has been to monitor indicator organisms which, by definition, should be (i) quickly detected and identified, (ii) of the exact origin as the pathogens (i.e., from the human or animal intestine), (iii) present in far greater numbers than the pathogens, and (iv) present whenever the pathogens are likely to be present. In addition, they should show the same or better survival characteristics than the pathogens; of course, they must not be pathogenic in themselves [52]. Currently, the universal indicator organisms have been coliforms, specifically Escherichia coli. These bacteria are of definite fecal origin (human and animal), excreted in vast numbers [9, 53]. Therefore, their presence in a water supply proves that fecal contamination has occurred, which indicates the risk of pathogens. On the other hand, the absence of these fecal coliforms strongly indicates the probability that pathogens are absent [54, 55]. Therefore, disinfection programs are recommended. Thus, proper fecal disposal and sanitation are needed to improve Kebbi State's healthy living.

The philosophy adopted universally is to use coliforms as definite indicators of sewage (fecal) pollution and apply strict limits on their presence in water sources and supplies [56]. The interpretation of the results of the analysis may be summarized as follows: Where E. coli are present in large numbers, the inference is that heavy, recent pollution by human or animal wastes has occurred; if the B. coli numbers are low, it is inferred that pollution from the same source(s) is either less recent or less severe. If coliforms, not including E. coli, are observed, the indication is either the pollution is recent and nonfecal or of remote, fecal origin such that the intestinal coliforms have not survived [52].

4.2 Operational-Related Parameters

Based on USAID's WQAP, the operational parameters are electrical conductivity (EC), total dissolved solids (TDS), Hydrogen Potential (pH), and Turbidity. These parameters are otherwise referred to as physical parameters and can be determined in situ.

4.2.1 Electrical Conductivity

Mean EC is less than 500 µS/cm in the studied LGAs, as Table 2 and Figure 4a illustrate. The WHO [1] and NSDWQ [2]. Though EC is a parameter of little importance to a water analyst; however, it is related to the ionic content of the water since it informs the range in which ion concentrations in water are likely to fall. Since EC is related to the sample's ionic content, which is, in turn, a function of the dissolved (ionizable) solids concentration, the relevance of easily performed conductivity measurements is apparent [52]. Pure water is not a good conductor of electricity. Ordinary distilled water in equilibrium with carbon dioxide of the air has a conductivity of about 10 x 10-6 W-1*m-1 (20 µS/m) [57]. Because the ions transport the electrical current in the solution, the conductivity increases as the concentration of ions increases [58]. Thus, conductivity increases as water dissolve ionic species. Based on the current EC values in Kebbi State, the studied water sources are suitable for drinking.

4.2.2Total Dissolved Solids

The concentration of TDS in the studied LGAs is generally low (<500 mg/l), as shown in Table 2 and Figure 4b. The significance of TDS is that high ingestion may be connected to the strength of the joints, gallstones, kidney stones, inurement, or blockage of veins [59]. TDS measures the total ions in solution often correlated positively with EC. TDS and EC are reasonably comparable [60, 61]. The palatability of water with a total dissolved solids (TDS) level of less than 600 mg/l is generally considered good; drinking water becomes significantly and increasingly unpalatable at TDS levels greater than 1000 mg/l. High levels of TDS may also be objectionable to consumers owing to excessive scaling in water pipes, heaters, boilers, and household appliances [62]. Reliable data on possible health effects associated with TDS ingestion in drinking water are unavailable, and no health-based guideline value is proposed. However, high levels of TDS in drinking water may be objectionable to consumers [63].

Table 2. *Operational-Related Parameters*

LGA	Summary	EC	TDS	pH	TUR
Argungu	Min	27.00	13.00	7.50	0.00
	Max	427.00	201.00	9.50	50.80
	Mean	186.88	88.00	8.56	12.70
	SE	50.53	23.75	0.32	7.73
Augie	Min	97.00	46.00	6.60	0.00
	Max	272.00	128.00	8.60	54.40
	Mean	179.38	84.50	7.94	20.10
	SE	29.32	13.76	0.29	10.24
Gwandu	Min	27.00	13.00	7.60	0.00
	Max	1108.00	521.00	10.40	0.00
	Mean	403.63	190.00	8.86	0.00
	SE	160.93	75.63	0.39	0.00
Dandi	Min	23.00	11.00	5.60	0.00
	Max	955.00	449.00	8.40	0.00
	Mean	408.13	192.00	6.70	0.00
	SE	143.87	67.64	0.39	0.00
Kalgo	Min	38.00	18.00	6.40	0.00
	Max	182.00	86.00	8.00	0.00
	Mean	100.50	47.63	7.28	0.00
	SE	21.40	10.05	0.22	0.00
Bunza	Min	34.00	16.00	6.70	0.00
	Max	981.00	471.00	8.70	51.50
	Mean	358.63	171.13	7.60	19.21
	SE	135.33	64.82	0.25	9.83
Suru	Min	40.00	19.00	6.60	0.00
	Max	372.00	175.00	8.70	62.30
	Mean	185.00	87.00	7.79	22.69
	SE	42.03	19.74	0.27	11.49
K/Besse	Min	74.00	34.00	6.60	0.00
	Max	1119.00	526.00	8.90	0.00
	Mean	382.38	179.38	7.68	0.00
	SE	149.51	70.38	0.39	0.00
Maiyama	Min	144.00	68.00	5.70	0.00
	Max	455.00	214.00	8.20	59.10
	Mean	317.14	149.29	7.03	31.83
	SE	50.98	23.93	0.40	10.96
Ngaski	Min	53.00	25.00	7.10	0.00
	Max	559.00	263.00	8.80	88.10
	Mean	268.25	126.75	7.88	36.91
	SE	75.34	35.64	0.27	17.05
Guideline Values	WHO (2008)	1000	500	6.5-8.5	5NTU
	NSDWQ (2007)	1000	500	6.5-85	5NTU

Note. *EC (µS/cm), TDS (mg/l), pH (Unit), and Turbidity (NTU)*

Generally, the TDS level between 50-150 is considered the most suitable and acceptable for drinking. However, a low concentration of TDS has been found to give water a balanced taste, which is undesirable to many people [64]. Increased concentrations of dissolved solids can also have technical effects. Dissolved solids can produce hard water, which leaves deposits and films on fixtures and the insides of hot water pipes and boilers. Soaps and detergents do not produce as much lather with hard water as soft water [65, 66]. Likewise, high amounts of dissolved solids can stain household fixtures, corrode pipes, and taste metallic. In addition, hard water causes water filters to wear out sooner because of the number of minerals in the water. TDS in drinking water originates from natural sources, sewage, urban runoffs, industrial wastewater, chemicals in the water treatment process, chemical fertilizers used in the garden, and plumbing. Water is a universal solvent that quickly picks up impurities and absorbs and dissolves these particles [67-69]. Although elevated TDS levels in drinking water are not a health hazard, they lend the water a bitter, salty, or brackish taste. Calcium and magnesium, two minerals commonly found in TDS, can also cause water hardness, scale formation, and staining [59].

4.2.3 Turbidity

Turbidity measures the degree to which the water loses its transparency due to the presence of suspended particulates [70]. The more total suspended solids in the water, the murkier it seems and the higher the turbidity. Therefore, turbidity is considered a good measure of the quality of water. Clay particles, sewage solids, silt and sand washings, and organic and biological sludges cause turbidity [71]. Table 2 and Figure 4c show that mean turbidity is above 30NTU in Maiyama and Ngaski LGAs, above the WHO [1] and NSDWQ [2] recommended values. Accordingly, Turbidity is above 20.70 NTU in Augie and Suru LGAs. it is 12NTU in Argungu and 19.21 NTU in Bunza LGAs.

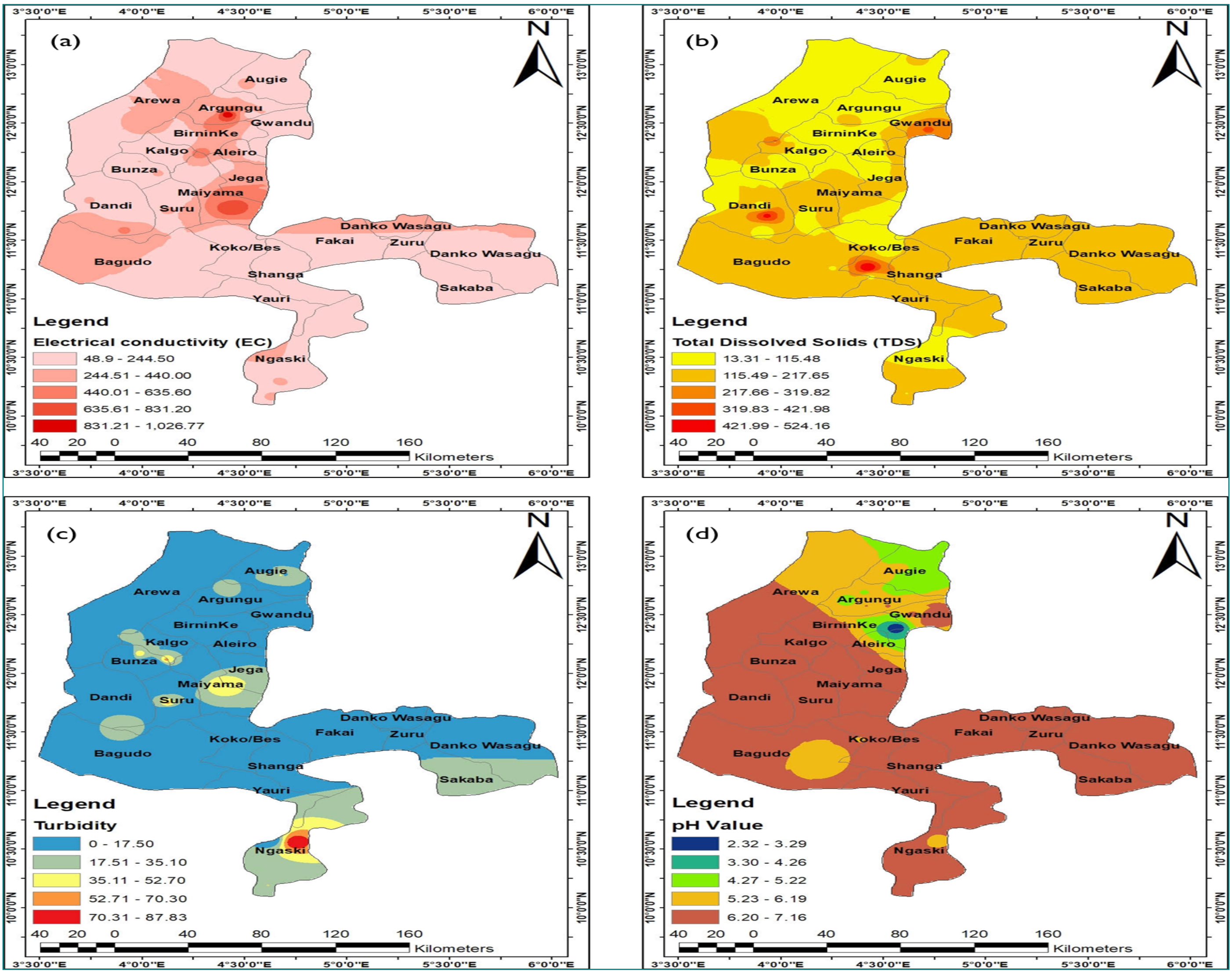

Figure 4. *Operational-Related Parameters (a) Electrical Conductivity, Total Dissolved Solids, (c) Turbidity, and (d) pH.*

High turbidity can have an undesirable effect on consumer acceptability of water due to visible cloudiness [72]. Although turbidity is not necessarily a threat to health, it is an essential indicator of the possible presence of contaminants that would be of health concern, especially from inadequately treated or unfiltered surface water. For example, emerging data show an increased risk of gastrointestinal infections correlating with high turbidity and turbidity events in distribution [62]. It may be because turbidity indicates possible sources of microbial contamination. Therefore, turbidity events should be investigated and the causes corrected.

In contrast, turbidity should be minimized as far as possible within the constraints of the type of system and the resources available as one part of managing distribution to achieve water safety [62]. Turbidity is also an important consideration when investment decisions are made regarding sources and treatment for water supplies and should be identified in the water safety plan for Kebbi State as a hazard that needs to be controlled. It is essential to reduce the turbidity of water in order to disinfect it effectively. Turbidity can act as a shield against pathogens, and the particles that cause turbidity can harbor bacteria and viruses [73, 74]. Our multi-barrier water treatment process removes turbidity, including coagulation, flocculation, sedimentation, filtration, and disinfection.

4.2.4 pH

The pH value of a water source is a measure of its acidity or alkalinity. The mean pH in the studied LGAs is within The WHO [1] and NSDWQ [2], as illustrated by Table 2 and Figure 4d. Groundwater is slightly alkaline to alkaline to alkaline in the study area. While pH has a more negligible effect on consumers, it is fundamental to understanding the chemical composition of groundwater. A moderate pH level is required depending on the composition of groundwater and aquifer properties [61, 66, 75]. Pure water would have a pH of 7.0, but water sources and precipitation tend to be slightly acidic due to contaminants in the water. Based on pH level, water sources in Kebbi State are suitable for drinking.

4.3 Other parameters of local concern

Table 3 summarizes the concentrations of other parameters of local concern. They are iron (Fe^{3+}), Phosphate, Chloride, Sodium, Calcium, and Magnesium. These parameters were studied owing to their significance in drinking water. Although they have not been associated with health risks, previous studies in the Sokoto basin [59-61, 76-79] have revealed higher concentrations of these ions above the recommended guidelines for drinking water quality.

4.3.1 Iron

Iron (Fe^{3+}) is one of the most abundant metals in the Earth's crust. It is found in natural freshwaters at 0.5 to 50 mg/l levels. Iron may also be present in drinking water due to corrosion of iron coagulants, steel, and cast-iron pipes during water distribution. Iron concentration was above WHO [80] and NSDWQ [2] in Augie, Dandi, Koko-Besse, Kalgo, Maiyama, and Ngaski LGAs, as shown in Table 3 and Figure 5a. Current results are concurrent with Anderson and Ogilbee [78]. Iron is the second most abundant metal in the Earth's crust, accounting for about 5% [80]. Elemental iron is rarely found in nature, as the iron ions Fe^{2+} and Fe^{3+} readily combine with oxygen- and sulfur-containing compounds to form oxides, hydroxides, carbonates, and sulfides. Iron is most commonly found in nature in the form of its oxides. Iron is an essential element in human nutrition. Estimates of the minimum daily requirement for iron depend on age, sex, physiological status, and iron bioavailability and range from 10 to 50 mg/day [80]. Objections to Fe^{3+} in drinking water are primarily organoleptic, but there has been growing medical concern about elevated Fe^{3+} levels [69].

Table 3. *Other parameters of local concern*

LGA	Summary	Iron(+++)	Phosphate	Chloride	Sodium	Calcium	Magnesium
Argungu	Min	0.02	0.16	1.00	0.30	50.00	37.20
	Max	0.17	0.27	2.00	0.50	98.00	96.00
	Mean	0.06	0.20	1.51	0.41	73.25	60.90
	SE	0.01	0.01	0.07	0.02	3.52	4.34
Augie	Min	0.03	0.16	1.10	0.20	24.00	44.40
	Max	8.45	0.22	3.30	0.80	140.00	106.80
	Mean	1.26	0.19	1.87	0.41	68.50	72.00
	SE	0.57	0.00	0.16	0.05	8.99	5.04

Bunza	Min	0.02	0.00	0.16	0.05	8.99	5.04
	Max	0.57	0.26	2.00	1.90	370.00	222.00
	Mean	0.11	0.17	1.37	0.67	120.00	87.47
	SE	0.04	0.02	0.12	0.14	27.28	15.86
Dandi	Min	0.02	0.02	0.12	0.14	27.28	15.86
	Max	4.26	0.23	3.70	1.50	280.00	234.00
	Mean	0.72	0.16	1.82	0.66	125.04	99.12
	SE	0.31	0.01	0.26	0.11	20.68	15.34
Gwandu	Min	0.02	0.15	1.20	0.20	36.00	15.60
	Max	0.16	0.23	2.30	1.50	244.00	172.80
	Mean	0.06	0.19	1.69	0.68	119.00	62.31
	SE	0.01	0.01	0.08	0.11	19.50	13.17
K/Besse	Min	0.01	0.01	0.08	0.11	19.50	13.17
	Max	3.32	0.60	4.00	1.30	252.00	78.00
	Mean	0.53	0.22	2.20	0.50	84.43	54.25
	SE	0.24	0.03	0.29	0.08	15.55	4.57
Kalgo	Min	0.03	0.15	0.90	0.30	46.00	43.20
	Max	2.48	0.24	1.80	0.70	98.00	74.40
	Mean	0.47	0.19	1.42	0.42	66.57	59.23
	SE	0.18	0.01	0.08	0.03	4.25	2.92
Maiyama	Min	0.06	0.01	0.08	0.03	4.25	2.92
	Max	18.43	0.25	1.80	3.00	590.00	86.40
	Mean	3.72	0.17	1.24	0.83	156.51	53.76
	SE	1.43	0.01	0.11	0.20	40.50	6.03
Ngaski	Min	0.02	0.16	0.50	0.30	40.00	54.00
	Max	9.13	0.28	3.40	1.20	212.00	133.20
	Mean	1.37	0.19	1.87	0.61	106.14	79.80
	SE	0.67	0.01	0.24	0.08	14.53	5.97
Suru	Min	0.02	0.16	0.50	0.20	26.00	34.80
	Max	1.16	0.31	2.20	0.50	84.00	87.60
	Mean	*0.31*	0.21	1.39	0.29	46.13	58.80
	SE	0.10	0.01	0.11	0.02	3.82	3.63
Guideline Values	WHO (2008)	0.3*	0.2	250	12	**75-200	0.20
	NSDWQ (2007)	0.3	0.2	200	200	-	0.20

**=WHO [80]. **WHO [81].*

4.3.2 Phosphate

Mean phosphate concentrations in the studied LGAs are within the WHO [1] and NSDWQ [2] reference values for drinking water. The relevance of PO_4^{3-} is mainly related to the rate of eutrophication in surface water bodies [66]. Natural waters have a phosphorus concentration of approximately 0.02 parts per million (ppm), limiting plant growth. On the other hand, large concentrations of this nutrient can accelerate plant growth. Phosphate Dosing in Drinking Water Distribution Systems Promotes Changes in Biofilm Structure and Functional Genetic Diversity [82]. Adding large quantities of phosphates to waterways accelerates algae and plant growth in natural waters, enhancing eutrophication and depleting the water body of oxygen. It can lead to fish kills and habitat degradation with species loss. Large algae mats can form and, in severe cases, cover entirely small lakes [83-85].

Consequently, water can become putrid from decaying organic matter. When the concentration of phosphates rises above 100 mg/l, the coagulation processes in drinking water treatment plants may be adversely affected. Artificial phosphate sources include human sewage, agricultural runoff from crops, animal feedlots, the pulp and paper industry, vegetable and fruit processing, chemical and fertilizer manufacturing, and detergents [84, 86]. Therefore, there is a need to continuously monitor phosphate concentration in surface and groundwater in kebbi due to the continuous application of phosphate fertilizers.

4.3.3 Chloride

Chloride (Cl$^-$)concentration is generally low in the studied LGAs (<5 mg/l). Mean Cl$^-$ was highest in Koko-Besse LGA (2.20 mg/l), as shown by Table 3 and Figure 5c. No specific adverse treatment-related effects have been observed in humans and experimental animals exposed to chlorine in drinking water. Chloride in drinking water originates from natural sources, sewage and industrial effluents, urban runoff containing de-icing salt, and saline intrusion. [87, 88]. Shallow aquifers seldom hold Cl$^-$ above 50 mg/l. Any substantial rise could lead to suspicion of contamination from human activities, mainly if NH_3 is also elevated [69].

4.3.4 Sodium

The mean sodium concentration in the studied LGAs is less than 1mg/l, as shown in Table 3 and Figure 4.4. The mean sodium concentration is the highest (0.83 mg/l) in Maiyama LGA. The taste threshold concentration of sodium in water depends on the associated anion and the temperature of the solution [63, 66]. At room temperature, the average taste

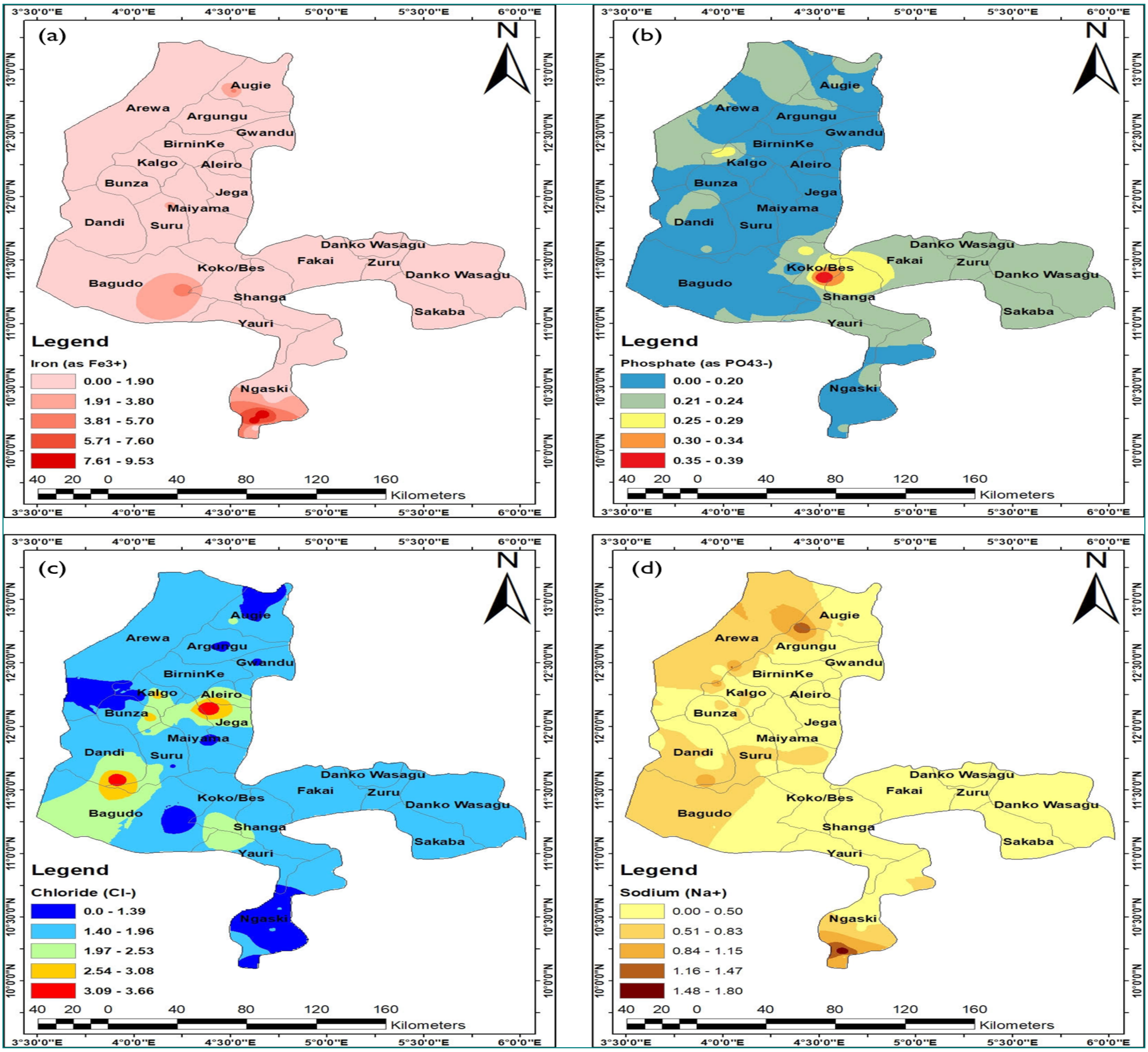

Figure 5. *Other parameters of local concern are (a) Iron, (b) Phosphate, (c) Chloride, and (d) Sodium.*

threshold for sodium is about 200 mg/l. Salinity in drinking water and the risk of (pre)eclampsia and gestational hypertension were reported from different parts of the world [89]. Although many studies suggest an association between water sodium and human blood pressure (more consistently for DBP), however, it is still inconclusive because of the small number of studies (mainly in young populations) and the cross-sectional design and methodological drawbacks [90]. Based on the current analysis, the sodium level in Kebbi State posed no health risk. However, in a clean-room environment, the human being has been identified as one of the significant sources of sodium [91]. Therefore, future increases in sodium should be monitored in Kebbi State.

4.3.5 Calcium

Over 99% of total body calcium is found in bones and teeth, a critical structural element. The remaining body calcium functions in metabolism, signaling vital physiological processes, including vascular contraction, blood clotting, muscle contraction, and nerve transmission [92]. Therefore, the mean calcium concentration in the studied LGAs is within WHO [81] reference guidelines. The Maiyama LGA had the highest calcium level (156. 51 mg/l). Other LGAs have calcium levels above 75 mg/l, as shown in Table 3 and Figure 4.4a: Bunza, Dandi, Gwandu, and Koko-Besse. High calcium level in water is often associated with hardness [66]. However, inadequate calcium intake has been associated with increased risks of osteoporosis, nephrolithiasis (kidney stones), colorectal cancer, hypertension and stroke, coronary artery disease, insulin resistance, and obesity. Most of these disorders have treatments but no cures. Due to a lack of compelling evidence for the role of calcium as a single contributory element concerning these diseases, estimates of calcium requirement have been made based on bone health outcomes to optimize bone mineral density [81].

4.3.6 Magnesium

Generally, magnesium concentration is high in the studied LGAs, as shown in Table 3 and Figure 6. Magnesium occurs in water due to groundwater dissolving magnesium from soils or dolomite rock [60]. Magnesium is an essential nutrient and is considered beneficial to health, although the amount found in water is generally a tiny portion of magnesium compared to what we get from a healthy diet [93]. Magnesium is related to hardness and can contribute to scale formation when found at high concentrations. Typical values for Wisconsin generally range between 3 and 35 mg/L of magnesium in unsoftened healthy water. The mean magnesium concentration is above NSDWQ [2]. The mean concentration is above 50 mg/l in the studied LGAs.

Excessive magnesium intake is associated with many health issues. The primary cause of hypermagnesemia is renal insufficiency, associated with a significantly decreased ability to excrete magnesium [94]. Increased intake of magnesium salts may cause a temporary adaptable change in bowel habits (diarrhea) but seldom causes hypermagnesemia in persons with normal kidney function [95]. Drinking water in which magnesium and sulfate are present at high concentrations (above approximately 250 mg/l each) can have a laxative effect, although data suggest that consumers adapt to these levels as exposures continue [96]. Laxative effects have also been associated with excess magnesium intake taken in supplements but not with magnesium in the diet [97]. Therefore, it is essential to establish the source of high magnesium in Kebbi State. Correspondingly, continuous monitoring of water quality is required in Kebbi State.

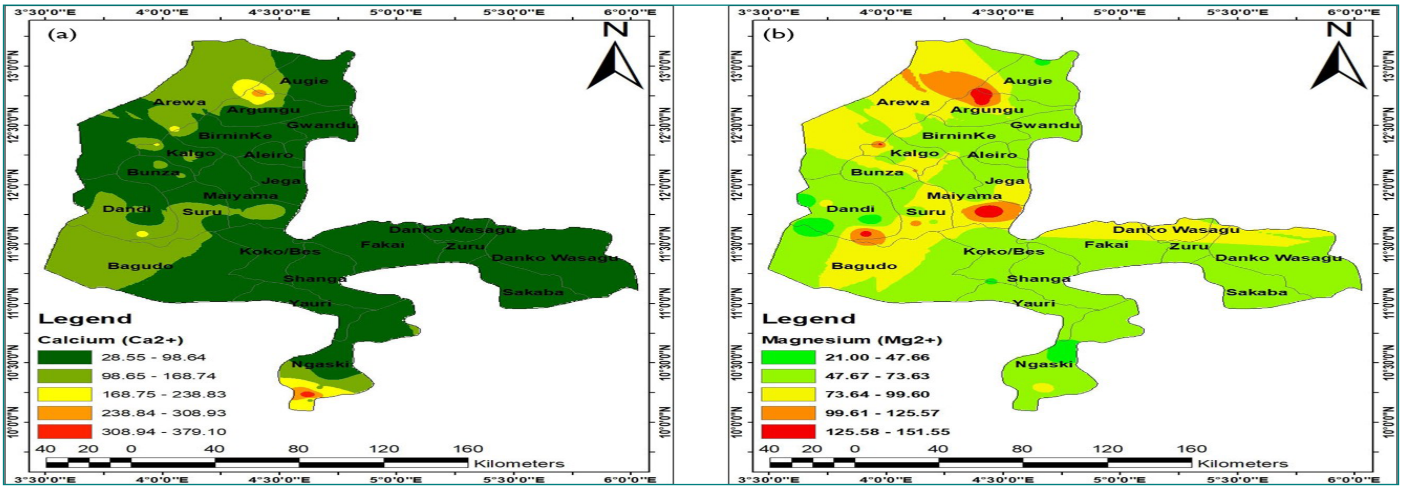

Figure 6. *Other parameters of local concern are (a) Calcium and (b) Magnesium.*

5. Conclusion

This study evaluated the water quality of 10 selected LGAs in Kebbi State. The USAID's WQAP guided the parameter selection.

1. The mean arsenic concentration in the studied Local Government Areas (LGAs) is above WHO [1] and NSDWQ [2] recommended values.

2. The mean Fluoride concentration in the studied LGAs is below the WHO [1] and NSDWQ [2].

3. Generally, Nitrate concentrations in the Studied LGAs are below the WHO (2008) and NSDWQ (2007) recommended values.

4. Results showed that Fecal Coliform is available in the studied LGAs. Therefore, open defecation leads to the spread of fecal coliform and other harmful bacteria in the environment.

5. Mean EC is less than 500 µS/cm in the studied LGAs, as Table 2 and Figure 4a illustrate. The WHO [1] and NSDWQ [2].

6. The concentration of TDS in the studied LGAs is generally low (<500 mg/l) in the studied LGAs. Therefore, TDS levels below 500 mg/l are mainly required for drinking water.

7. Table 2 and Figure 4c show that mean turbidity is above 30NTU in Maiyama and Ngaski LGAs, above the WHO (2008) and NSDWQ (2007) recommended values.

8. The mean pH in the studied LGAs is within The WHO (2008) and NSDWQ (2007); it is slightly alkaline.

9. Iron concentration was above WHO [80] and NSDWQ [2] in Augie, Dandi, Koko-Besse, Kalgo, Maiyama, and Ngaski LGAs.

10. Mean phosphate concentrations in the studied LGAs are within the WHO [1] and NSDWQ [2] reference values for drinking water.

11. Chloride (Cl-)concentration is generally low in the studied LGAs (<5 mg/l). The mean sodium concentration in the studied LGAs is less than 1mg/l.

13. The Maiyama LGA had the highest calcium level (156. 51 mg/l). Other LGAs have calcium levels above 75 mg/l, as shown in Table 3 and Figure 4.4a: Bunza, Dandi, Gwandu, and Koko-Besse.

Consequently, further water quality evaluation is recommended to verify the current results and evaluate drinking water sources in other LGAs that were not studied. Furthermore, water quality monitoring is recommended for improved WASH services in Kebbi State.

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