African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 466-480
http://www.ajaronline.com
http://doi.org/10.26437/ajar.30.06.2024.29

GROUNDWATER QUALITY ASSESSMENT: A CASE OF URBAN POPULATION DEMOGRAPHY AND NUTRIENT ENRICHMENT IN IBADAN, SOUTHWESTERN NIGERIA

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ABSTRACT

Purpose: This study examines sulphate, nitrate, ammonia, and phosphate concentrations in groundwater found within shallow hand-dug wells around residential areas with low, medium, and high population densities in Ibadan. Furthermore, it establishes seasonal variations of nutrients in groundwater sources.

Design/ Methodology/ Approach: The city's eleven Local Government Areas [LGAs] were classified into three zones of low, medium and high-density populated areas for groundwater sample collection. From each zone, three samples were collected from the dry season and three from the rainy season from hand-dug wells [about 5m], giving 198 samples. Grab samples were collected using water samples from the wells. The groundwater samples were analysed for sulphate by turbidimetric method, nitrate by phenoldisulphonic acid method, ammonia by nesslerisation method and phosphate by ammonium molybdate-ascorbic acid method using standard procedures.

Findings: Results show sulphate, nitrate, ammonia and phosphate levels in groundwater were generally high around high-density populated areas, especially during the dry season across the eleven LGAs. Mainly, sulphate and nitrate levels exceeded the NIS 977: 2017 standards of 100mg/L and 10mg/L in Ibadan Southeast and sulphate in Ibadan Northeast at high and medium populated density areas. Statistical T-testing (p=0.05) shows a significant difference in seasonal nutrient levels for all the LGAs. A positive correlation was observed in nutrient concentrations with a depth of the groundwater source.

Practical Implications: Nutrients are among the most potent contaminants of groundwater, which poses a significant threat to human capital development and health. High levels of sulphate and nitrate in the groundwater supply can lead to poor palatability and methemoglobinemia (blue baby syndrome) in babies.

Social Implications: Public enlightenment is needed on the dangers of high groundwater nutrient concentrations and their human health implications.

Originality and Value: This study provides much-needed data on groundwater nutrient levels since other available data centres focus primarily on trace metals and organics in groundwater within the Ibadan city demography.

Keywords: *Assessment. contamination. groundwater. nutrient. quality*

INTRODUCTION

Globally, groundwater is an essential and most valuable resource (FAO, 1997; Li et al., 2017). An estimated one-third of the world's population depends one way or the other on groundwater for potable water supply (International Association of Hydrogeologists, 2020). It is a crucial driver of sustainable development and a readily natural source of drinking water in most developing cities, especially in the absence of available public water utilities due to poor infrastructure and unfavourable economic standards. Groundwater quality depends mainly on geographical features, human activities, land utilisation and environmental factors. Most contaminants found in groundwater are generally of geogenic origin due to the dissolution of natural mineral deposits deep within the Earth's crust (Basu et al., 2014; Subba Rao et al., 2020; He & Wu, 2019a). However, with increasing urbanisation, industrialisation and population growth, there is an increasing impact of contaminants of anthropogenic origin (Li et al., 2021). Nutrients are one of the most potent contaminants of groundwater, and they pose a significant threat to sustainable socioeconomic development and human health (Li, 2020; Wu et al., 2020). High levels of nitrate, sulphate, phosphate and ammonia in groundwater supply are often associated with leaching of municipal sewage, effluent and fertilisers from agricultural applications. Wells most vulnerable to nutrient contamination are those sited within sandy aquifers and those with broken casings and fittings, which could allow seepage of waste from underground septic tanks or nearby agricultural activities. Children and infants are most susceptible to the effects of nutrient contamination of groundwater. For example, excess nitrate in groundwater causes an infant disease known as methemoglobinemia (blue baby syndrome). Infants under six months old stand a higher risk of contracting methemoglobinemia. This results in the skin turning bluish, resulting in severe illness or even death (Fewtrell, 2004). The maximum contaminant level (MCL) by the World Health Organisation (WHO), the United States Environmental Protection Agency (US-EPA) and the European Union (EU) for nitrate in drinking water quality is 10µg/mL (Van Maanen et al., 2000). The European Union has set a guideline of 0.5µg/ml phosphate in drinking water.

In a developing city like Ibadan, southwestern Nigeria, groundwater is a significant portable drinking water source for domestic, industrial and agricultural purposes. The need for a modern urban town planning structure has resulted in many unplanned shanty residential areas. These residential areas are often highly populated with little or no public water supply, leaving many indiscriminate diggings of shallow wells for drinking water supply. These wells are sometimes very shallow (about 5m) with no proper watertight casings and are often situated near septic tanks due to the unavailability of land space. Comprehensive studies have been conducted majorly to assess trace metals (Etim, 2017; Adeniran, 2018; Oloruntoba & Ogunbunmi, 2020; Ganiyu et al., 2021) and trace organics (Ololade et al., 2021) in these groundwater wells, however, very few studies have been done on groundwater nutrients contamination especially has it concerns it origin and demography. Therefore, this study examines sulphate, phosphate, nitrate and ammonia contaminations in the groundwater systems around residential areas with low, medium and high population density in Ibadan. Furthermore, it establishes the seasonal variations of nutrient contamination in groundwater sources and assesses the non-carcinogenic human health risks associated with nitrate levels in groundwater.

ISSN: 2408-7920

African Journal of Applied Research
Vol. 10, No. 1 (2024), pp. 466-480
http://www.ajaronline.com
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MATERIALS AND METHOD

Study Area

Ibadan is considered the second largest city in West Africa and the capital of Oyo State, southwestern part of Nigeria, consisting of eleven local government areas. Its land area is about 3,080 km^2 and lies between 7^0 28′N and 3^0 48′E, with an estimated population of 1,889,776 (Fagbami & Shogunle, 1995; Federal Republic of Nigeria, 2006) from the last census conducted in 2006. It is in a tropical climate region with high temperatures, humidity and rainfall. The city demography can be classified into low-density [LD], medium-density [MD] and high-density [HD] residential areas (Figure 1). The city lacks a modern and proper urban town planning structure, specially built spaces with road networks, and is highly populated. Other common urban problems are inadequate sanitary infrastructure, poor drainage patterns, cultural practice of improper waste disposal systems and unregulated groundwater sourcing. Over 60.0% of city residents rely primarily on shallow hand-dug wells for domestic groundwater supply. The general geology of the city is the Precambrian basement complex of igneous and metamorphic rock formations. The shallow fractured zones of this basement complete rock formation are where groundwater aquifers are located (Akanbi, 2018).

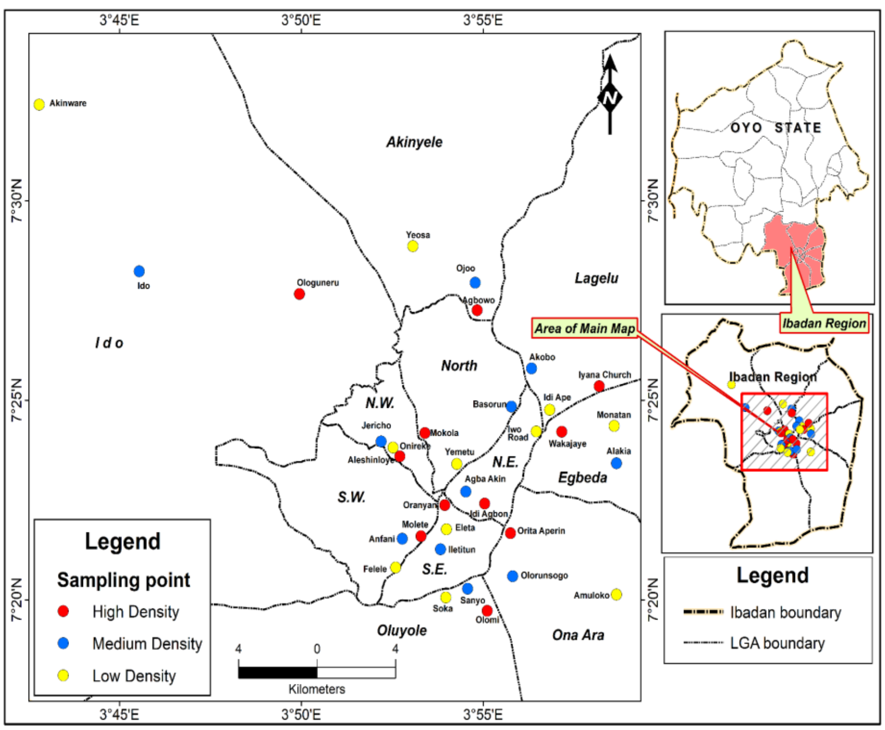

Figure 1: Map of Ibadan showing sampling demography

ISSN: 2408-7920

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Sampling Design and Collection

The Ibadan city demography was zoned into low, medium and high-density populated residential areas across all the eleven LGAs. Grab groundwater samples were collected from shallow hand-dug wells (about 5m) around the high, medium and low-density regions using a water sampler. One sampling location was chosen for each zone in the eleven LGAs. Sampling was done during the three months of the dry season [January, February and March] and three months of the rainy season [May, June and July] in 2023. A total of 18 groundwater samples were collected from each LGA, totalling 198 samples. One-litre plastic bottles, previously washed and rinsed with deionized water, were used for groundwater sample collection. Before sample collection, the bottles were thoroughly rinsed three times with the groundwater sample before filling. These samples were then stored in an ice chest at a temperature of 4^{0}C and transported to the laboratory for further analysis. Field blanks were incorporated during sampling and analysed accordingly to avoid contamination during sampling activity.

Chemical Analysis

For quality control, chemical reagents used for analysis were of AnalaR grade standard and sourced from reputable vendors. The conductivity and dissolved solids of the deionized water used for preparing the reagent were tested to ascertain the quality. Groundwater samples were analysed for nitrate [Phenoldisulphonic Acid Method], phosphate [Ammonium Molybdate-Ascorbic Acid Method], sulphate [Turbidimetric Method] and ammonia [Nesslerization Method] by the spectrophotometric [INESA UV-VIS Spectrophotometer] method described by in the procedures of the American Public Health Association, American Water Works Association and Water Pollution Control Federation. (APHA, 2005) and the Society for Analytical Chemistry (Jolly, 2012). The INESA UV-VIS Spectrophotometer was calibrated using certified standards with precision and accuracy of about 3% and 1%, respectively. No contamination was observed from the filled blank samples that were also analysed.

Nitrate Health Risk Assessment

The non-carcinogenic health risk associated with long-term exposure to drinking groundwater with high nitrate concentrations was calculated in terms of hazard quotient (HQ) using the USEPA health risk assessment model (USEPA, Region 6, 2005), as expressed in equation (1).

$$HQ = CDI/RfD \quad (1)$$

Where CDI is the sum of nitrate intake via drinking water and is calculated using equation (2) (USEPA, 2001), and RfD is the nitrate reference dose-1.6mg/kg/day (IRIS, 2012).

$$CDI = C \times IR \times EF \times ED/(BW \times AT) \quad (2)$$

Where C is the average nitrate concentration in mg/L, IR water intake rate (1L/day for children and 2L/day for adults), EF is the exposure frequency (365days/year), ED is the exposure duration (6 years for children and 30 years for adults) BW is the body weight (15kg for children and 60kg

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for adults). AT is the average time (365 days/year x 6 years for children and 365 days/year x 30 years for adults). HQ greater than one is considered a significant non-carcinogenic risk (USEPA, 2013). The risk levels were classified into two: Low Risk (HQ ≤1) and High Risk (HQ≥ 1).

Statistical Analysis

Descriptive statistical analysis was performed to establish average and standard deviations of nutrient concentrations across the sampling locations. Statistical T-testing (P=0.05) and Analysis of Variance (P=0.05) were used to assess seasonal variations in nutrient levels and the relationship between sulphate, nitrate, ammonia, and phosphate levels and demography in the different LGAs.

RESULTS AND DISCUSSION

Groundwater Nutrient Quality

Table 1 shows the average nutrient concentrations in the groundwater supply within Ibadan city, emphasising high. medium and low-populated residential areas. Groundwater nutrient concentrations are of immense human health concern, especially for children, who are more susceptible to high nutrient concentrations in drinking water. Average groundwater sulphate levels from the eleven Local Government Areas of Ibadan ranged between 3.92 to 122mg/L with high density areas-26.0 to 122mg/L, medium density areas-18.9 to 117mg/L and low-density areas-3.92 to 103 mg/L. Sulphate levels in groundwater around high-density areas-103±6.29mg/L in Ibadan Northeast; high density areas-122±10.6, medium density areas-117±2.83 and low-density areas-103±0.71 in Ibadan Southeast were higher than in Nigerian Industrial Standards for drinking water quality standard of 100mg/L. Average nitrate levels were 3.02 to 16.4mg/L, with the highest concentrations observed in Ibadan Southeast, 16.4±2.12mg/L around high-density areas and 13.6±1.63mg/L around medium-density areas. These high nitrate levels also exceeded NIS 10.0mg/L recommended nitrate limits in drinking water supply. Other LAGs had relatively low groundwater sulphate and nitrate levels, irrespective of demography. Groundwater vulnerability to contamination from diffused sources has continuously been monitored through nitrate concentrations, a surrogate indicator (Fabro et al., 2015). Average ammonia and phosphate concentrations range between 0.171 to 0.661mg/L and 0.014 to 0.365mg/L respectively. Although there are no standards for ammonia and phosphate due to their low levels in groundwater, concentrations were not significantly different across the sampling locations, which is an indication of geogenic origin resulting from the dissolution of natural mineral deposits within the rock formation of Ibadan (Subba Rao et al., 2020). Analysis of variance showed significant differences (P=0.05) in sulphate, nitrate, ammonia and phosphate concentrations across the different LGAs, which suggest possible diffuse sources of contamination, especially around the Ibadan Southeast locations.

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Table 1: Average nutrient concentrations (mg/L) in groundwater

LGAs	Density	Sulphate	Nitrate	Ammonia	Phosphate
Ibadan N	HD	78.2±9.33	7.87±0.70	0.444±0.04	0.035±0.21
	MD	67.5±1.20	4.94±0.76	0.367±0.04	0.053±0.13
	LD	21.7±1.91	4.16±0.30	0.298±0.13	0.045±0.22
Ibadan NW	HD	52.3±4.24	5.48±1.80	0.391±0.41	0.066±0.41
	MD	34.1±8.06	4.26±0.97	0.296±0.36	0.039±0.22
	LD	14.0±0.71	4.67±0.11	0.274±0.06	0.016±0.31
Ibadan NE	HD	103±6.29	5.84±1.42	0.559±0.05	0.107±0.31
	MD	91.3±4.67	4.75±0.05	0.507±0.07	0.066±0.23
	LD	95.2±1.98	3.21±1.03	0.430±0.01	0.053±0.62
Ibadan SW	HD	93.5±3.04	5.69±1.53	0.353±0.11	0.043±0.32
	MD	77.1±15.6	4.51±0.09	0.274±0.01	0.033±0.32
	LD	55.3±3.85	4.77±0.02	0.311±0.14	0.023±0.41
Ibadan SE	HD	122±10.6	16.4±2.12	0.661±0.04	0.279±0.12
	MD	117±2.83	13.6±1.63	0.536±0.10	0.136±0.13
	LD	103±0.71	8.85±0.98	0.417±0.02	0.035±0.42
Oluyole	HD	68.4±9.40	4.80±0.05	0.482±0.16	0.108±0.62
	MD	66.5±7.35	4.60±0.03	0.374±0.03	0.078±0.51
	LD	39.3±2.48	4.65±0.13	0.230±0.41	0.052±0.33
Ona-Ara	HD	64.9±0.28	5.59±0.04	0.460±0.22	0.033±0.16
	MD	49.8±3.96	4.49±0.21	0.483±0.21	0.015±0.13
	LD	41.1±6.72	4.64±0.04	0.455±0.10	0.014±0.16
Akinyele	HD	26.0±0.49	4.61±0.45	0.454±0.14	0.038±0.11
	MD	18.9±4.80	4.64±0.18	0.424±0.13	0.027±0.42
	LD	3.92±0.12	3.09±0.35	0.171±0.15	0.120±0.31
Lagelu	HD	55.9±0.57	8.36±2.16	0.390±0.11	0.085±0.43
	MD	40.5±9.90	4.84±0.19	0.281±0.01	0.056±0.10
	LD	23.5±5.87	4.78±0.00	0.210±0.06	0.365±0.12
Egbeda	HD	55.1±0.35	5.75±1.44	0.440±0.05	0.150±0.14
	MD	34.0±13.9	4.23±0.57	0.463±0.02	0.084±0.32
	LD	26.0±3.54	3.21±0.87	0.403±0.04	0.073±0.43
Ido	HD	47.2±9.76	6.89±2.84	0.271±0.04	0.076±0.00
	MD	29.7±3.04	3.41±0.69	0.280±0.23	0.050±0.21
	LD	12.5±0.07	3.02±0.09	0.176±0.03	0.031±0.14

HP-High Density. MD-Medium Density. LD-Low Density

Seasonal variations in sulphate and nitrate concentrations show that Ibadan Northeast and Ibadan Southeast had relatively high sulphate and nitrate levels in groundwater during dry and wet seasons, particularly in high and medium-density residential areas (Table 2). These levels were also found to exceed the NIS standards, which suggests the possible inclusion of nutrients associated with the nearness of groundwater wells to septic waste tanks and improper sanitary

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conditions around these locations. Sulphate and nitrate levels were often found to be high during dry seasons compared to the rainy seasons, which could be due to the concentration effect and low volume of water. Statistical T-testing showed a significant difference (p=0.05) in groundwater sulphate, nitrate, ammonia and phosphate levels for the dry and rainy seasons, indicating surface runoff and percolation effects on groundwater quality. Shallow groundwater wells are known for higher nutrient levels (Martinez et al., 2014).

Table 2: Average seasonal nutrient concentrations (mg/L) in groundwater

LGAs	**Density**	**Sulphate**		**Nitrate**		**Ammonia**		**Phosphate**	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Ibadan N	HD	84.8±1.68	71.6±2.11	7.37±0.43	8.36±0.52	0.475±0.73	0.412±0.44	0.026±0.61	0.043±0.98
	MD	68.3±1.18	66.6±2.21	5.48±1.73	4.40±1.03	0.396±0.22	0.338±0.18	0.079±0.15	0.026±0.07
	LD	23.0±1.16	20.3±1.17	4.37±1.10	3.95±1.18	0.321±0.45	0.274±0.18	0.046±0.13	0.043±0.11
Ibadan NW	HD	55.3±1.84	49.3±2.17	6.75±1.29	4.20±2.14	0.415±0.33	0.366±0.72	0.074±0.73	0.057±0.08
	MD	39.8±0.27	28.4±0.44	4.94±1.10	3.57±1.32	0.330±0.62	0.261±0.27	0.055±0.32	0.022±0.27
	LD	14.5±0.19	13.5±1.10	4.74±2.61	4.59±1.63	0.315±0.32	0.232±0.25	0.017±0.04	0.015±0.02
Ibadan NE	HD	107±3.04	98.1±1.94	6.84±1.83	4.83±1.73	0.595±0.17	0.523±0.13	0.114±0.47	0.099±0.56
	MD	94.6±3.31	88.0±2.00	4.78±1.16	4.71±2.04	0.556±0.14	0.458±0.22	0.087±0.33	0.045±0.37
	LD	93.8±2.86	96.6±2.09	3.94±2.16	2.48±1.33	0.438±0.21	0.421±0.02	0.064±0.04	0.041±0.34
Ibadan SW	HD	95.6±2.77	91.3±1.75	6.77±3.72	4.61±2.10	0.430±0.18	0.276±0.17	0.044±0.55	0.042±0.32
	MD	88.1±1.74	66.1±2.40	4.57±1.11	4.44±0.79	0.283±0.33	0.264±0.12	0.034±0.11	0.031±0.21
	LD	65.5±2.46	45.1±2.66	4.78±2.43	4.75±2.29	0.363±0.26	0.259±0.11	0.028±0.14	0.018±0.16
Ibadan SE	HD	129±4.23	114±2.43	17.9±3.18	14.9±3.74	0.689±0.43	0.633±0.61	0.294±0.17	0.264±0.26
	MD	119±3.29	115±2.95	14.7±1.06	12.4±1.32	0.597±0.72	0.474±0.44	0.138±0.05	0.133±0.07
	LD	102±6.55	103±2.59	9.54±2.10	8.15±1.88	0.430±0.17	0.404±0.32	0.036±0.61	0.033±0.13
Oluyole	HD	75.0±5.43	61.7±2.88	4.83±1.73	4.76±1.85	0.491±0.16	0.472±0.37	0.123±0.79	0.092±0.37
	MD	71.7±2.84	61.3±2.30	4.62±1.03	4.58±1.22	0.359±0.55	0.389±0.18	0.088±0.56	0.067±0.22
	LD	41.0±1.03	37.5±.1.33	4.74±.1.76	4.56±1.07	0.234±0.27	0.226±0.21	0.057±0.62	0.047±0.53
Ona-Ara	HD	65.1±.1.94	64.7±3.22	5.61±2.10	5.56±3.10	0.453±0.09	0.467±0.15	0.040±0.53	0.026±0.16

	MD	52.6± 1.40	47.0± 2.10	4.63± 2.59	4.34± 2.14	0.486±0.63	0.479±0.38	0.016± 0.28	0.014± 0.44
	LD	45.8± 1.77	36.3± 2.17	4.67± 0.95	4.61± 1.55	0.478±0.17	0.431±0.26	0.015± 0.36	0.012± 0.26
Akinyele	HD	26.3± 2.19	25.6± 1.33	4.92± 2.28	4.29± 0.85	0.469±0.22	0.439±0.32	0.045± 0.37	0.030± 0.32
	MD	22.3± 1.48	15.5± 1.20	4.76± 2.63	4.51± 1.18	0.432±0.28	0.415±0.12	0.038± 0.23	0.016± 0.21
	LD	3.83± 1.43	4.00± 2.84	3.34± 1.32	2.84± 1.77	0.182±0.16	0.160±0.05	0.130± 0.37	0.110± 0.43
Lagelu	HD	55.5± 0.94	56.3± 1.75	9.89± 2.94	6.83± 1.89	0.470±0.43	0.310±0.29	0.094± 0.28	0.076± 0.37
	MD	47.5± 1.65	33.5± 1.25	4.97± 1.94	4.70± 2.94	0.289±0.03	0.273±0.14	0.060± 0.52	0.052± 0.44
	LD	27.6± 1.22	19.3± 1.84	4.78± 2.22	4.78± 2.10	0.255±0.33	0.164±0.15	0.45± 0.11	0.28± 0.10
Egbeda	HD	55.3± 3.84	54.8± 1.55	6.76± 2.70	4.73± 1.77	0.477±0.13	0.402±0.62	0.180± 0.37	0.120± 0.18
	MD	43.8± 1.33	24.1± 2.04	4.63± 4.13	3.83± 0.94	0.475±0.20	0.451±0.14	0.099± 0.83	0.068± 0.14
	LD	28.5± 1.85	23.5± 1.38	3.82± 1.06	2.59± 3.14	0.430±0.16	0.376±01.3	0.087± 0.31	0.059± 0.52
Ido	HD	54.1± 2.44	40.3± 1.22	8.90± 1.37	4.88± 2.16	0.299±0.15	0.242±0.16	0.076± 0.27	0.076± 0.44
	MD	31.8± 2.76	27.5± 1.34	3.89± 3.04	2.92± 2.55	0.277±0.30	0.283±0.12	0.054± 0.48	0.046± 0.26
	LD	12.5± 2.10	12.4± 1.06	3.08± 0.47	2.95± 0.73	0.199±0.22	0.152±0.21	0.040± 0.13	0.022± 0.24

As shown in Figure 2, groundwater nutrient distribution in Ibadan city was in the following order of magnitude: sulphate>nitrate>ammonia>phosphate, with significantly higher concentrations found within high and medium-density populated residential areas. Sulphate concentration was higher than nitrate in groundwater, with Ibadan Southeast and Northeast having the highest levels (Figure 3). Similarly, ammonia levels were higher than phosphate, with Ibadan Southeast and Northeast having the highest concentrations (Figure 4). High nitrate groundwater pollution is associated chiefly with septic waste leakages and poor sanitary conditions, common in the Ibadan Southeast and Northeast and significantly threaten human health.

ISSN: 2408-7920

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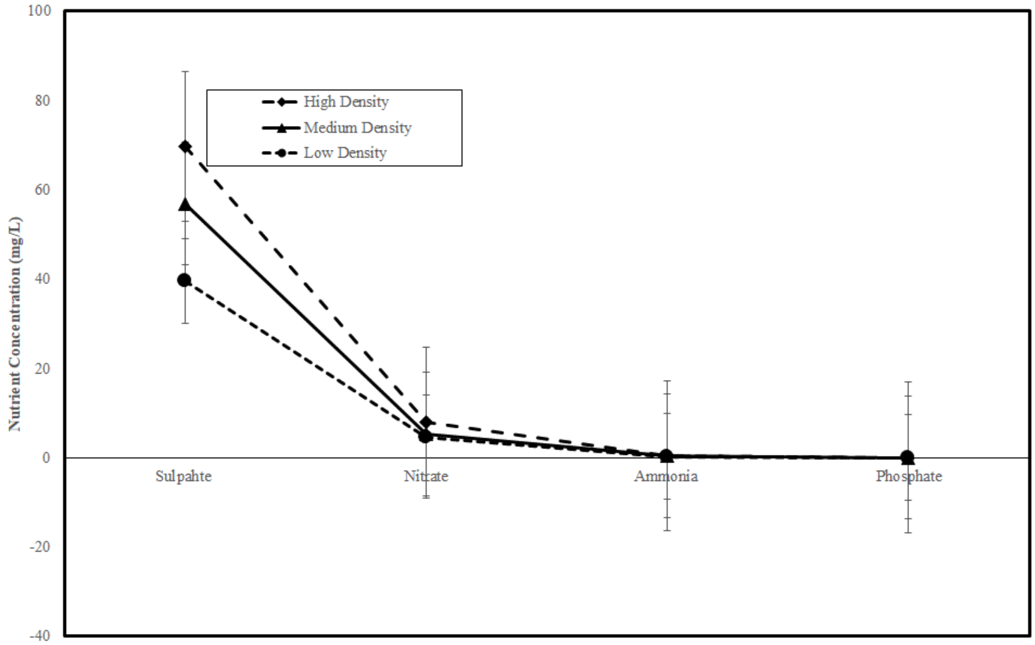

Figure 2: Nutrient distribution to population density

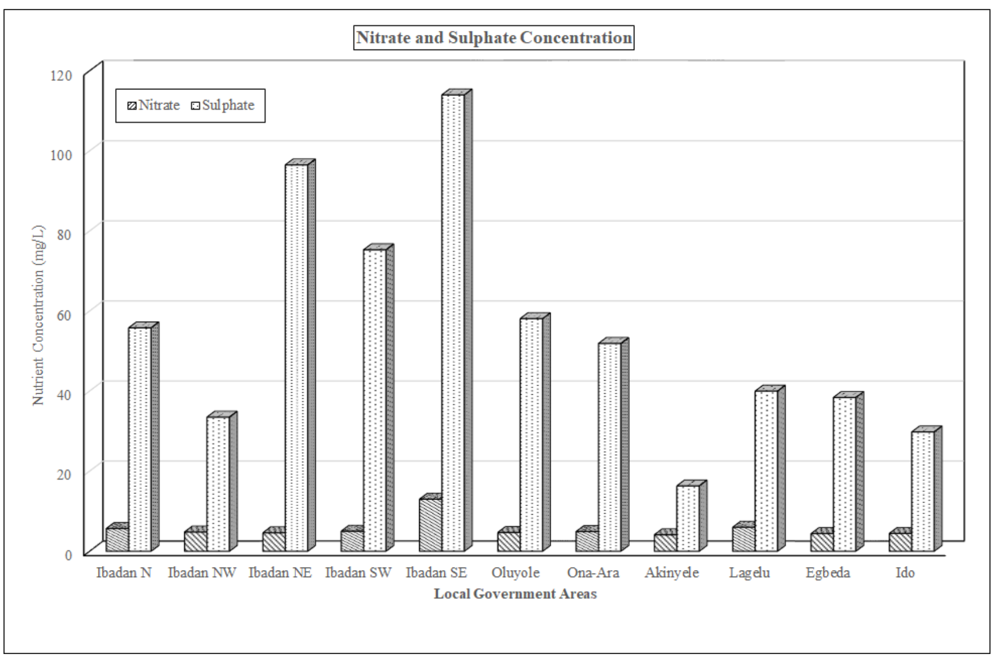

Figure 3: Sulphate and nitrate concentrations in the LGAs

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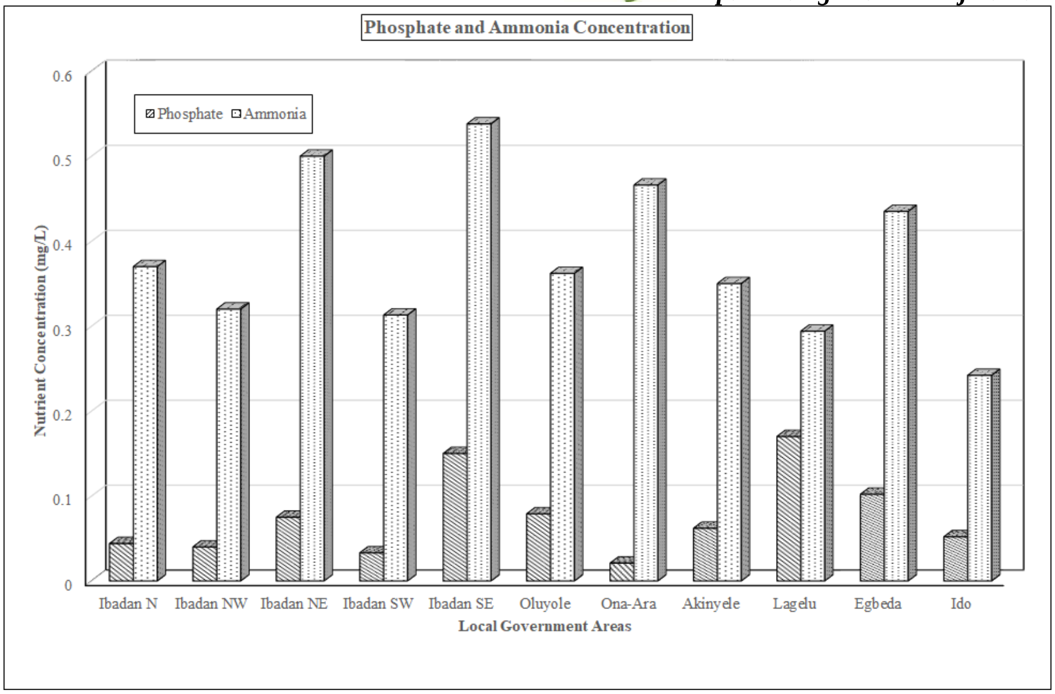

Figure 4: Phosphate and ammonia concentrations in the LGAs

The absence of portable municipal water supply within the city may lead to high dependency of residents, especially in Ibadan Southeast and Northeast, to shallow groundwater systems for domestic water supply. The implication is that groundwater consumption with high nitrate levels will lead to infant methemoglobinemia. Vomiting, stomach cramps, headaches, decreased blood pressure and increased heart rate are some other symptoms which are frequently associated with methemoglobinemia. Recent scientific evidence shows adults can also experience these symptoms after consuming groundwater with high nitrate levels over time (He et al., 2019b; Karunanidhi et al., 2019; Mthembu et al., 2020; Ji et al., 2020). From the present data obtained, there is a high likelihood that groundwater nitrate levels may increase in other LGAs with much lower concentrations in a few decades to come due to groundwater movement. However, it isn't easy to estimate precisely when that will happen because of the complexity of the groundwater flow system, which is governed by groundwater age and geochemical conditions. Average phosphate levels in groundwater from the different locations of this study were significantly lower than 8.74±2.56mg/L reported in groundwater in Kura Town, Kano State-Nigeria (Sa'id & Mahmud, 2013) but within the range of 0.10 to 0.49mg/L reported for in groundwater in Manzini and Lubombo Regions of Swaziland (Fadiran et al., 2008). Similarly, groundwater nitrate levels were also well below 17.8±4.49mg/L in Kura Town, Manila-23.9mg/L, Bangkok-9.70mg/L and Jakarta-13.6mg/L (Umezawa et al., 2008).

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http://doi.org/10.26437/ajar.30.06.2024.29

Human Health Risk Assessment

Nitrate is a good indicator of groundwater contamination. Therefore, assessing non-carcinogenic risk factors is essential to avoid health conditions associated with long-term exposure of humans to high nitrate concentrations in drinking water. The risk assessment results showed hazard quotient (HQ) values ranged between 0.126 to 0.683 for children and 0.062 to 0.340 for adults (Table 3). The highest HQ (0.683) was observed for the Ibadan Southeast high-density residential area. Generally, the HQ were less than one, which means low risk is associated with nitrate concentration in groundwater within Ibadan city, as shown in Figure 5.

Table 3: Non-carcinogenic health risk of nitrate in groundwater

LGAs	Density	Children		Adults	
		CDI	HQ	CDI	HQ
Ibadan N	HD	0.525	0.328	0.262	0.164
	MD	0.330	0.206	0.165	0.103
	LD	0.280	0.173	0.139	0.087
Ibadan NW	HD	0.370	0.230	0.183	0.114
	MD	0.284	0.180	0.142	0.089
	LD	0.311	0.195	0.156	0.100
Ibadan NE	HD	0.390	0.243	0.194	0.122
	MD	0.320	0.198	0.158	0.098
	LD	0.214	0.134	0.107	0.066
Ibadan SW	HD	0.380	0.240	0.189	0.118
	MD	0.300	0.189	0.150	0.094
	LD	0.318	0.199	0.159	0.099
Ibadan SE	HD	1.093	0.683	0.546	0.342
	MD	0.906	0.567	0.453	0.283
	LD	0.590	0.370	0.295	0.184
Oluyole	HD	0.320	0.200	0.160	0.100
	MD	0.307	0.192	0.153	0.095
	LD	0.310	0.194	0.155	0.096
Ona-Ara	HD	0.373	0.233	0.186	0.116
	MD	0.299	0.187	0.149	0.093
	LD	0.309	0.193	0.155	0.096
Akinyele	HD	0.307	0.192	0.154	0.096
	MD	0.309	0.193	0.154	0.096
	LD	0.206	0.129	0.103	0.064
Lagelu	HD	0.557	0.348	0.278	0.174
	MD	0.323	0.202	0.161	0.100
	LD	0.319	0.199	0.159	0.099
Egbeda	HD	0.383	0.240	0.191	0.119
	MD	0.282	0.176	0.141	0.088
	LD	0.214	0.134	0.107	0.066
Ido	HD	0.459	0.287	0.229	0.143

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http://doi.org/10.26437/ajar.30.06.2024.29

	MD	0.227	0.142	0.113	0.071
	LD	0.201	0.126	0.100	0.062

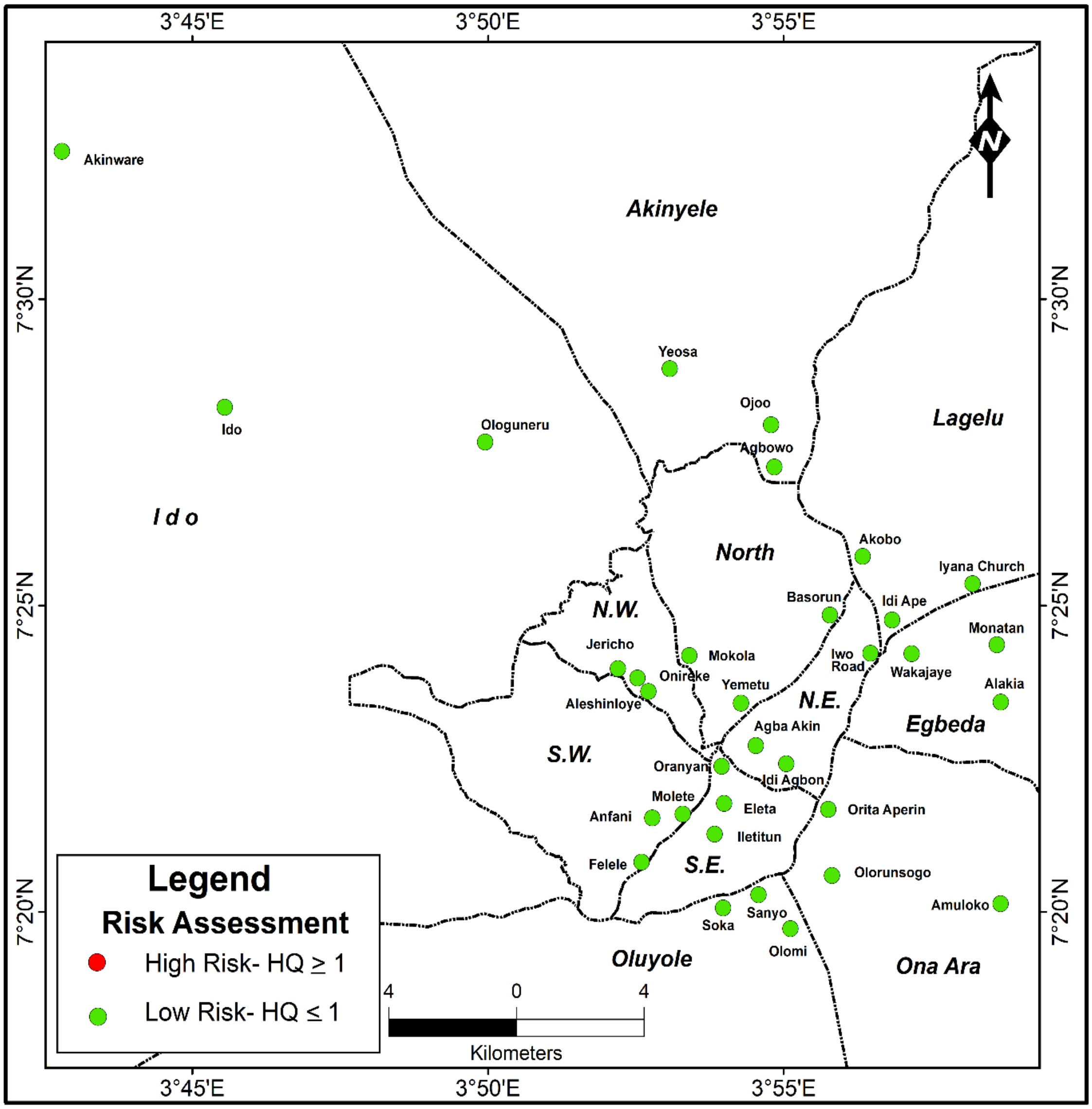

Figure 5: Non-carcinogenic health risk of nitrate in groundwater

CONCLUSION

The study found sulphate and nitrate levels in groundwater, primarily within Ibadan Southeast and Ibadan Northeast, to be high enough to suggest possible health implications, especially for children. These levels were mainly noticeable around high-density and medium-density populated residential areas with higher values during the dry seasonal months. The implication of consuming groundwater with high nitrate levels is infant methemoglobinemia with symptoms such as decreased blood pressure, increased heart rate, headaches, stomach cramps, and vomiting among both children and adults alike. It's, therefore, important to educate residents within these areas about the possible health impact of high sulphate and nitrate levels in their drinking water supply. This study has provided the much-needed groundwater nutrient levels since other available data are primarily on trace metals and organics in Ibadan. Finally, proactive measures are needed to improve sanitary conditions and discourage indiscriminate digging of shallow wells for domestic and drinking water purposes. Further studies are required to monitor the nutrient levels over time and determine the relationship between well depth and water quality.

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ISSN: 2408-7920

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