

Full Length Research Paper

Nitrate concentration in drinking water supplies in selected communities of Ibadan Southeast local government, Ibadan, Nigeria

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Elevated levels of nitrate in drinking water have been associated with adverse health effects. Most susceptible to nitrate toxicity are infants under six months of age and pregnant women. This study assesses the nitrate concentration of 48 randomly selected wells in an urban-slum setting in Ibadan South East Local Government Area (IBSELGA), Nigeria. The coordinates of the wells were mapped with a hand-held Global Positioning System (GPS). The nitrate concentration ranged between 0.00 and 42.80 mgL⁻¹ with a mean of log₁₀ of 0.735 and a geometric mean of 5.43 mgL⁻¹; and 0.00 and 93.30 mgL⁻¹ with a mean of log₁₀ of 0.696 and a geometric mean of 4.97 mg L⁻¹ for the wet and dry seasons, respectively. During the wet season, the levels of nitrate in all the wells were within the WHO permissible limit of 45 mg L⁻¹ NO₃. However, during the dry season, few of the wells; six (12.5%) dried up completely. Out of the remaining 42 wells, six (14.3%) had nitrate concentration which exceeded the permissible limit. This same set of wells lacked sanitary features such as lining and cover. Out of the 48 wells, 30 (62.5%) and 24 (50%) were located at ≤10 m from the septic tank/pit latrine and refuse dumps, respectively. Nitrate maps were developed using Georeferenced data for the water points. The nitrate exceedence map produced showed water sources within the study area with nitrate concentration exceeding the recommended limit and therefore requiring urgent intervention. The results of this study will serve as indicator for determining risk areas with respect to nitrate concentration in drinking water and therefore help in decision making activities.

Key words: Global positioning system, Ibadan, nitrate, nitrate exceedence, wells, urban slum.

INTRODUCTION

The general practice in many developing countries in the past was that a large proportion of people in the urban areas had access to piped water supply to the neglect of those in the rural and peri-urban areas; but now, the

situation has changed. For instance, in Ibadan, Nigeria, the Water Corporation of Oyo State supplies 107 million liters of water/day for a population of 3.6 million through the Eleyele and Asejire dams. This quantity is ade-

quate for only 20% of the population (Itama et al., 2006). The outcome of this inadequacy is that most people in the city resort to water from other sources such as boreholes (for institutions and privileged few), dug wells, springs (both protected and unprotected), ponds and streams. Study by Ochieng et al. (2011) assessed the sanitary features, prevailing pollution and quality of water in some communities in IBSELGA of Ibadan metropolis. They concluded that 85% of the respondents were dependent on wells for drinking, while the remaining 15% depends on other drinking water sources such as public tap, pond and water from commercial vendors. The same water sources were also used for cooking, washing, toileting and other household works. The study area, Ibadan South East Local Government Area (IBSELGA) is one of the five urban local councils in Ibadan metropolis. It is a densely populated area and fit the description of an urban slum.

In an interview conducted by Fourchard in 2002, the Chairman of IBSELGA defined slums as “areas which concentrate low income earners, low cost houses, possibly mud houses, no layout and poor inhabitants” (Fourchard, 2003). Fourchard (2003) identified three types of slums in Ibadan based on age, location and size. These include:

- i) The oldest and largest slum is the core area of the city, which covers the entire pre-colonial town. A large part of the ancient walled city can be seen as a slum, even if the inhabitants do not agree that they live in a slum for historical reasons.
- ii) A few small-scale slums, on land occupied illegally by squatters, can be found at the margins of the planned city.
- iii) Numerous slums, generally occupied by tenants on legal lands, are found at the outskirts of the city along major roads or close to local labour markets. Their size, history, socio-economic and cultural features differ from one slum to another.

This study restricted itself to the first type of urban slum, the core area of the city. Many communities in the study area belong to the category. The inner city area is the oldest, has the lowest quality residence and the highest population density in the city. According to Asiyanbola (2012), the traditional core, high density or indigenous areas of Ibadan correspond roughly with Mabogunje's core and older suburbs and Ayeni's high density residential areas. Also, in terms of ethnic status, traditional core areas are relatively homogeneous in the sense that majority of the residents are indigenes of Ibadan. Nitrate represents the most oxidized chemical form of nitrogen found in natural systems. Nitrate concentrations of less than one (1) mgL^{-1} as nitrate-N in natural groundwater sources is not a major source of exposure. However, excessive amounts can pass through

the soil and contaminate groundwater (Bernard et al., 1998). Elevated levels of nitrate in groundwater may result from human activities such as overuse of chemical fertilizers and improper disposal of human and animal wastes (Nugent et al., 1993). Municipal and industrial wastewaters, animal pens, runoff or leachate from refuse dumps, manured or fertilized agricultural lands, urban drainage and on-site sanitary systems (pit latrines/septic tanks) are the major sources in fast growing urban centres. Power plants and automobiles may also contribute through emissions containing nitrogen compounds, which are carried through rainfall.

The assessment of nitrate concentration in drinking water sources in Pakistan by Tahir and Rasheed (2008) revealed that 19% of the total samples (747) collected from a wide range of irrigated or non-irrigated regions in 16 cities had nitrate concentration greater than the permissible safe limit of 10 mg/L falling in the concentration range of 11 to 160 mg/L nitrate. Also, study by Mondal et al. (2008) to determine the extent of nitrate and the possible sources of nitrate pollutants in groundwater in selected regions of north and south Krishna Delta, India revealed that nitrate concentration ranged from nitrate from 10 to 135 mg/L with about 39% of 79 groundwater samples showing high nitrate contents which is more than the permissible limit of 50 mg/L in drinking water. Nitrate pollution level was found more in dug wells compared to hand pumps/bore wells. The study identified the possible sources of high nitrate level in groundwater to be excessive utilization of nitrogenous fertilizers for agricultural purposes. Contamination of drinking water by nitrate is an evolving public health concern globally. Nitrate in groundwater is of concern not only because of its toxic potential, but also because it may indicate serious groundwater pollution (Nugent et al., 1993). Ingested nitrate from dietary sources and drinking water can be converted to nitrite and ultimately to N-nitroso compounds, many of which are known carcinogens (Sandor et al., 2001; Weyer et al., 2006). When present in high concentrations, they may give rise to potential health risks particularly in bottle-fed infants (methemoglobinemia) and pregnant women (Jennings and Sneed, 1996; Kelter et al., 1997; Kempster et al., 1997; NRDC, 2003). Nitrate toxicity also can cause recurrent acute diarrhoea (Gupta et al., 2001). However, a study of methemoglobin levels in infants receiving low dietary nitrates in Eastern Nigeria conducted by Mbanugo et al. (1990) concluded that there was no significant association between high methemoglobin levels observed in the blood of infants and levels of nitrate ingested.

Ward et al. (2010) investigated the association of nitrate intake from public water supplies and diet with the risk of thyroid cancer and self-reported hypothyroidism and hyperthyroidism in a cohort of 21,977 older women in Iowa who were enrolled in 1986 and who had used the

same water supply for >10 years. Outcome of the study revealed an increased risk of thyroid cancer with higher average nitrate levels in public water supplies and with longer consumption of water exceeding 5 mg/L nitrate-N [for ≤ 5 years at >5 mg/L, relative risk (RR) = 2.6 (95% confidence interval (CI) = 1.1-6.2)]. Even though there was no observed association with prevalence of hypothyroidism or hyperthyroidism; increasing intake of dietary nitrate was associated with an increased risk of thyroid cancer [highest vs. lowest quartile, RR = 2.9 (1.0 to 8.1); P for trend = 0.046] and with the prevalence of hypothyroidism [odds ratio = 1.2 (95% CI = 1.1 to 1.4)], but not hyperthyroidism. Khademikia et al. (2013) also investigated the relationship between the amounts of nitrate, nitrite, and total organic carbon (TOC) in two drinking water sources used for drinking, industrial and agricultural consumption in Iran and their relationship with some gastrointestinal diseases. Even though the study did not document significant association of nitrite, nitrate, and TOC content of water with gastrointestinal diseases, it concluded that such health hazards may develop over time, and the quality of water content should be controlled to prevent different diseases.

In Nigeria, there is still a dearth of information on nitrate levels and its health effects. The few studies available (Mbonu et al., 1991; Onianwa et al., 1999; Arowolo, 2005) are sporadic generalized water quality assessments. Global information systems (GIS) technology allows location-specific data from different sources to be joined and mapped to display important geographic relationships (Reissman et al., 2001). It uses a location reference system such as longitude, latitude and elevation. In recent years, GIS has been used widely in different studies: land use planning (Tong and Chen, 2002; Stout and Lee, 2004), watershed management (Lively and Czapar, 2002), risk of lead exposure (Reissman et al., 2001), and ecological implications of Fulbe pastoralism (Omotayo, 2003). However, spatial data to allow targeting water sources and quality to households are presently inadequate. The study combined GIS data with nitrate concentration of wells used as household drinking water sources during the wet and dry seasons to produce nitrate and nitrate exceedence maps for the study area. This has helped to highlight areas of health risks to the inhabitants in the study area, particularly, infants and pregnant women who are more vulnerable.

MATERIALS AND METHODS

This study was carried out in Ibadan South East Local Government Area (IBSELGA), one of the five urban local government areas of Ibadan metropolis, the capital of Oyo State. Ibadan, the largest indigenous urban center in Africa south of the Sahara lies on longitude 03° 53' 47" East of the Greenwich Meridian and latitude 07° 23' 16" North of the equator (Maplandia, 2005). It has a popula-

tion of 1.34 million (Federal Republic of Nigeria, 2007) and covers an area of over 100 km². Its elevation is 210 m above sea level with isolated ridges and peaks rising to an elevation of 274 m (Udo, 1994). The study area (Figure 1) falls in the indigenous area of the city, with high population density (11,298.8/km²), low level of sanitation and lack of safe water supply, with most people depending on shallow wells. The study area is made up of 30 localities and a population of 266,046. From this area, 48 household wells were selected randomly for monitoring during the wet and dry seasons. Two sets of water samples were collected from each well in polyethylene bottles (after they had been scrupulously cleaned) and stored in the refrigerator. Nitrate as NO₃⁻ was determined using the phenoldisulfonic acid method described by APHA/AWWA/WPCF (1975). The absorbance of the yellow color developed on reacting the nitrate in the sample with phenoldisulfonic acid was measured with UV spectrophotometer at a wavelength of 410 nm and related to the concentration of prepared standards. An observation checklist was used to assess the sanitary conditions (such as nearness to pollution sources such as septic tanks, refuse heaps, animal dung, drainage) around the wells.

A hand-held global positioning system (GPS) receiver (Garmin GPS 12 Personal Navigator) was used to locate the position of the 48 wells by measuring the coordinates (longitude, latitude and altitude), which were recorded in a notebook and later transferred into Microsoft Excel™ spreadsheet. Due to the skewness of nitrate concentrations in water samples during the two seasons, data were log transformed using SPSS 15.0 for Windows, and expressed as geometric mean. Nitrate concentrations in samples were compared with WHO permissible limit. Statistical analyses were performed using descriptive statistics and spearman's correlation coefficient at 5.0% level of significant. Spatial data saved in a Microsoft Excel™ spreadsheet were imported into ArcGIS™ 9.0 (ESRI, 2004) to produce nitrate and nitrate exceedence maps for the study area.

RESULTS

The distance in meters between the selected households and drinking water sources (wells) are shown in Table 1. Majority of the households 36 (75%) were at a distance between 1 and 10 m from the drinking water sources, while nine (19%) were between 11 to 20 m. Only 3 (6%) wells were at a distance 21 m and above from the households. Nitrate was detected in 98% of the wells tested and the concentration during the wet season ranged between 0.00 and 42.80 mgL⁻¹, with a geometric mean of 5.43 mgL⁻¹ and a median of 4.59 mgL⁻¹. During the dry season, the range was 0.00 to 93.30 mgL⁻¹ with a geometric mean of 4.97 mgL⁻¹ and a median of 5.02 mgL⁻¹. The means of the transformed values were 0.735 and 0.696 for the wet and dry seasons, respectively (Table 2). During the wet season, all the samples had nitrate concentrations that were lower than 45 mgL⁻¹ NO₃, whereas, the nitrate values for some of the samples increased during the dry season. About 13% of the wells dried up completely for three months while the nitrate values for a large number of the remaining samples (52.4%) increased by 2 to 26 fold. Also, 12.5% of the wells had values which exceeded the WHO limit. The nitrate map of the study area is shown in Figure 2. The

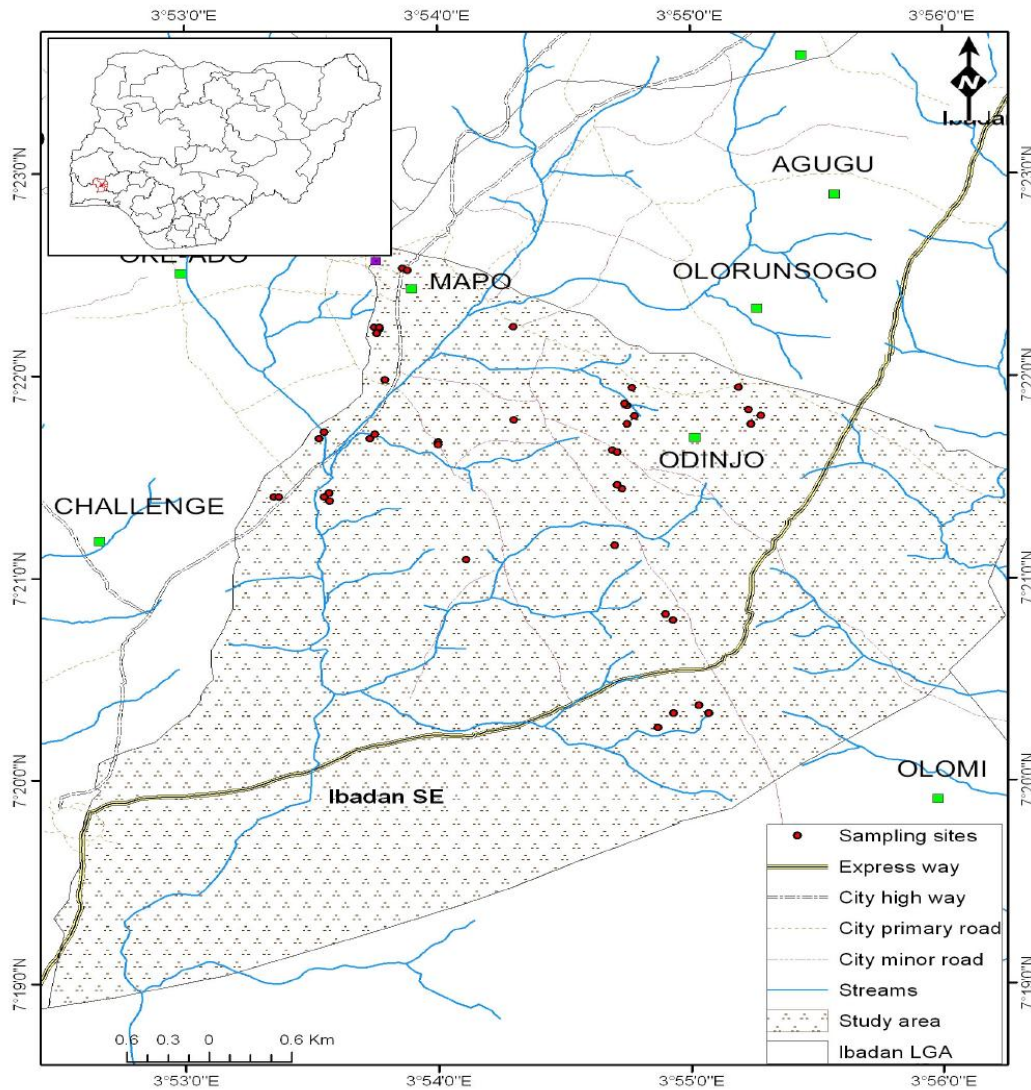


Figure 1. Map of study area showing the sampling sites.

Table 1. Distance between selected households and drinking water sources (wells).

Distance of source SE to household (m)	No. of wells
1 - 10	36 (75%)
11 - 20	9 (19%)
21 - 30	1 (2%)
31 - 40	1 (2%)
>40	1 (2%)

Table 2. Mean nitrate concentration and Log₁₀ transformed values.

Season	Arithmetic mean of NO ₃ mg L ⁻¹	Range of NO ₃ mgL ⁻¹	Log ₁₀ of NO ₃ mgL ⁻¹	Geometric mean of NO ₃ mg L ⁻¹
Wet	8.2675±9.047	0.00 - 42.80	0.735	5.43 mgL ⁻¹
Dry	15.6638±23.3494	0.00 - 93.30	0.696	4.97 mgL ⁻¹

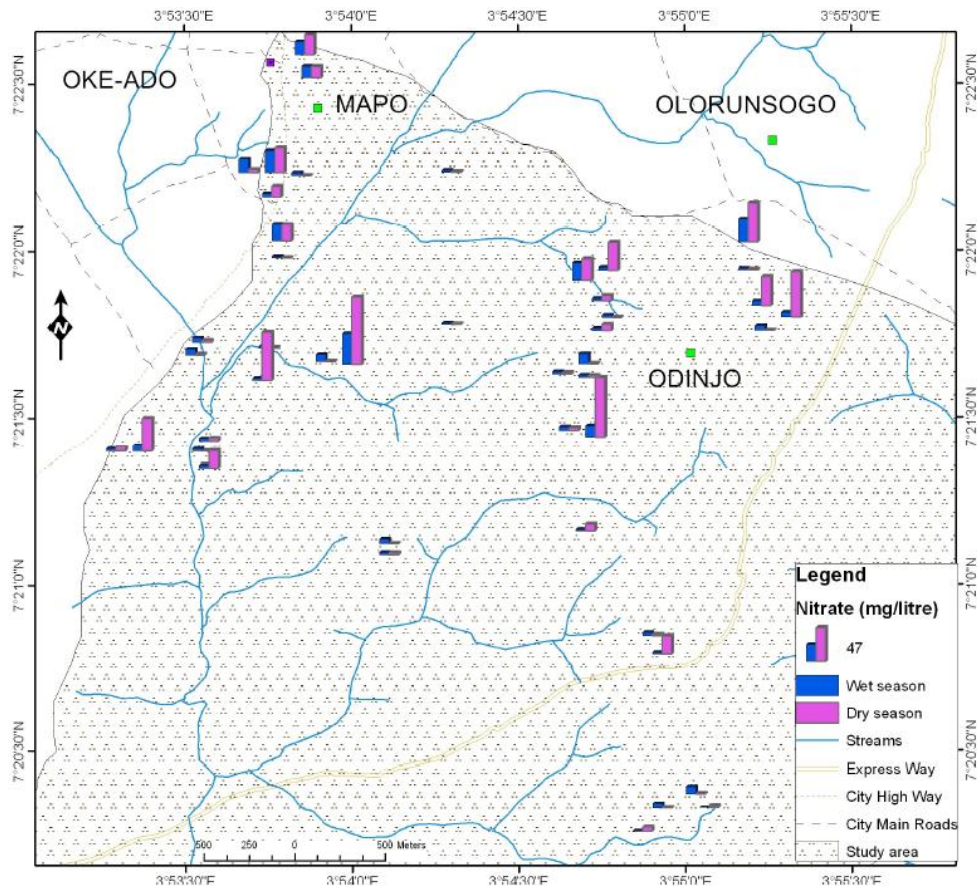


Figure 2. Nitrate map for the study area.

purple and blue bar graphs in Figure 2 represent nitrate concentrations in the sampled wells during the dry (purple) and wet (blue) seasons. The bar graph is measuring at the unit of nitrate concentration. Nitrate concentrations at different locations (during the two seasons) are indicated by the height of the bar. The number 47 is the scale which refers to the height of the purple one on the bar graph. It means that wherever the bar height is half, the size of the bar labeled 47 (purple), nitrate concentration is $47/2 = 23.5 \text{ mgL}^{-1}$; where it is twice the height, the nitrate concentration is also twice ($47 \times 2 = 94 \text{ mgL}^{-1}$). Also, Figure 3 shows the map of nitrate exceedence for wells in the study area during the dry season. These were wells with nitrate concentration higher than the WHO permissible limit (WHO, 1995, 1996).

The scatter plot was constructed to examine the type of pattern of relationship between the nitrate concentration (NC) during the dry and wet seasons. In Figure 4, the data revealed that slight linear pattern was displayed by the NC of the wells in the dry and wet seasons. Figures 5 and 6 represent the histogram of the distribution of the

NC during the wet and dry seasons. In these figures, there was an indication of skewness in the NCs for dry and wet seasons. The data is also evidenced that NCs of the wells during the two seasons were positively correlated ($r = 0.390$; $p = 0.011$).

Variation in distance of wells to sources of pollution

Table 3 shows the location of wells used by selected households to sources of pollution. Majority (50%) of the wells used as drinking water sources were at a $> 10 \text{ m}$ from refuse dumps. Also, about 21% of the wells were at a distance less than 1 m and only 10.4% were at a distance between 6 and 10 m from refuse dumps. Among households who use pit latrine/septic tank, 4.2% of the wells were located at less than 1 m away, 56.3% were between 1 to 10 m , while 39.5% of the wells were at $> 10 \text{ m}$ away from pit latrines/septic tanks. Table 4 shows the six wells that had nitrate concentration exceeding the WHO limit in relation to their location to sources of pollution, while Plate 1 show some of the wells in the study area.

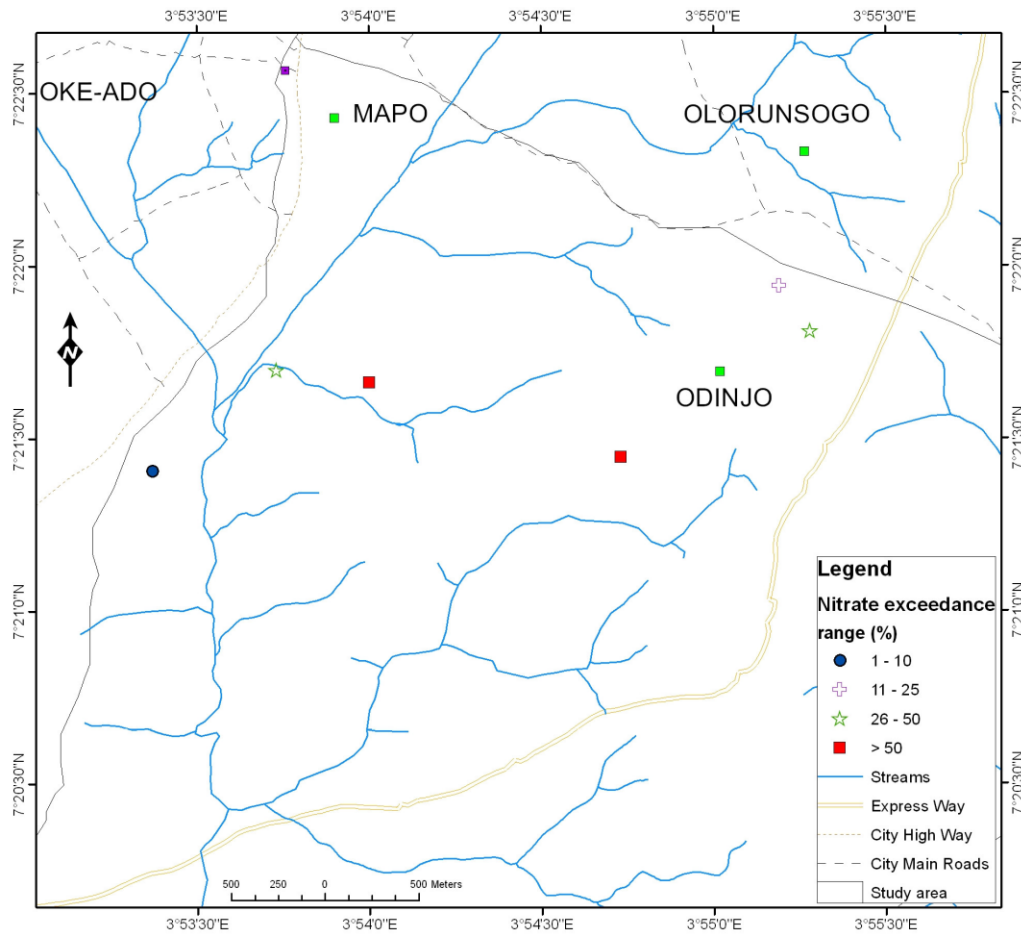


Figure 3. Nitrate exceedance map.

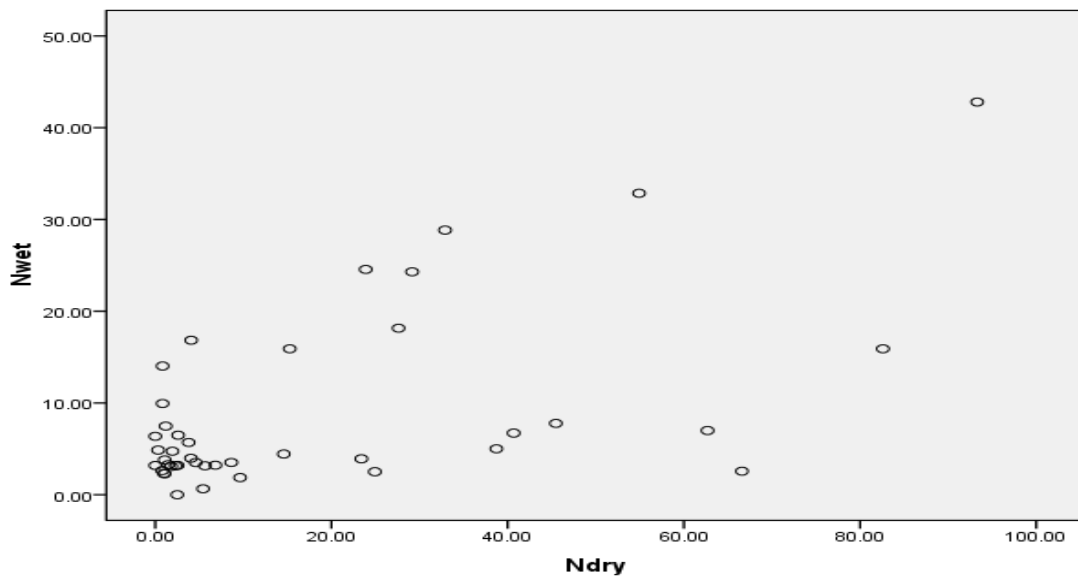


Figure 4. Scatter plot of the nitrate concentration in the analysed wells between the dry and wet seasons.

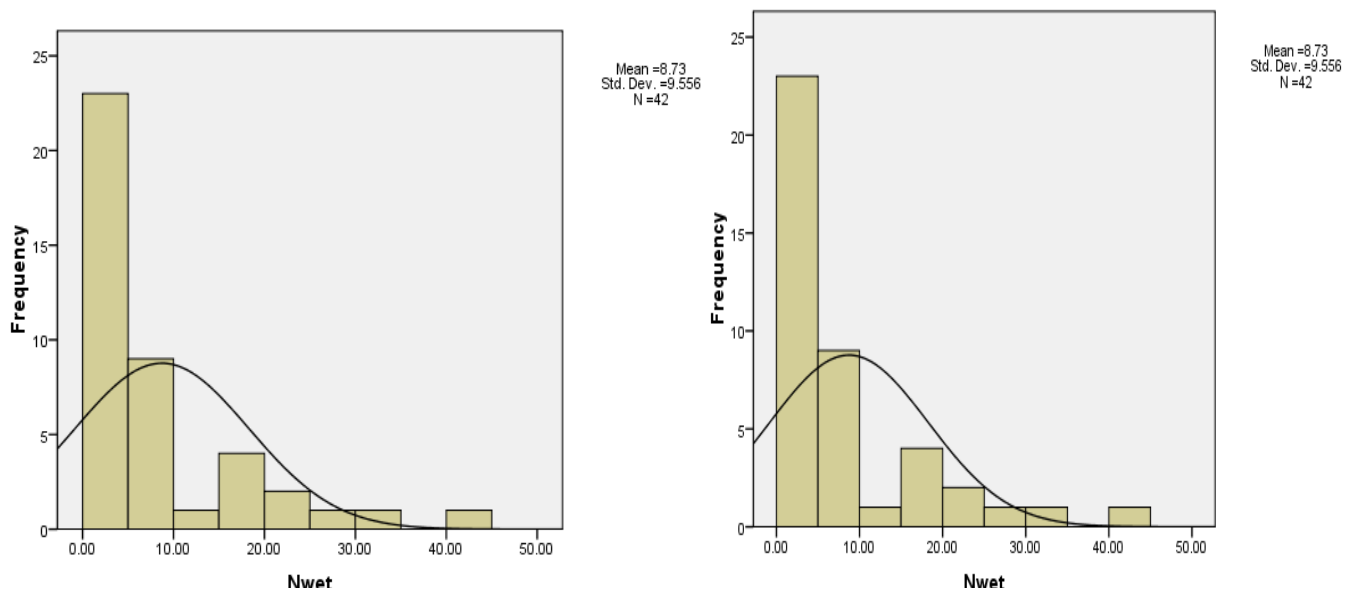


Figure 5. Histograms and superimposed normality curve of the nitrate concentration in the analysed wells between the dry and wet seasons.

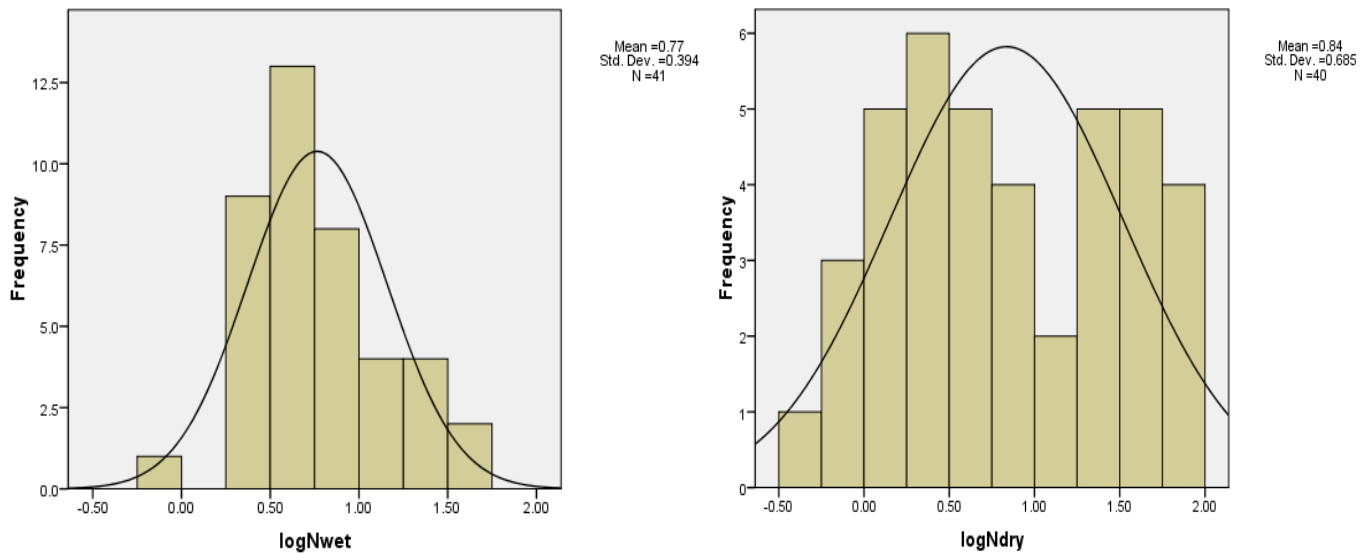


Figure 6. Histograms and superimposed normality curve of the log₁₀ transformation of the nitrate concentration in the analysed wells between the dry and wet seasons.

Table 3. Distance between wells and sources of pollution.

Pollution source	Number of wells located at specified distances from pollution sources			
	<1 m	1-5 m	6-10 m	>10 m
Refuse dump	10 (20.8%)	9 (18.8%)	5 (10.4%)	24 (50.0%)
Pit latrine/septic tank	2 (4.2%)	15 (31.3%)	12 (25.0%)	19 (39.5%)

*Figures in parentheses are percentages.

Table 4. Nitrate concentration in wells relative to distance from pollution sources.

Pollution source	Nitrate concentration (as NO ₃ ⁻ in mg/L) in wells located at specified distances from pollution source					
	1-5 m		6-10 m		>10 m	
Refuse dump	*W3 (NL)	62.69			IBSE W42 (NL)	66.60
	W25 (NL)	54.92	IBSE W47 (NL)	82.60		
	W39 (NL)	45.48			IBSE W31 (NL)	93.30
Pit latrine/ septic tank	W25	54.92	IBSE W3	62.69	IBSE W39	45.48
	W42	66.60	IBSE W31	93.30	IBSE W47	82.60

*W3 is a well location; NL, well not lined.



Plate 1. Picture of sampled well in the study area.

DISCUSSION

The results obtained show that only few: six (14.3%) of the wells had nitrate levels exceeding the WHO permissible limit during the dry season. Even though the range of the concentrations was wide, the findings are comparable to those in the study in the basement complex region of North-central, Nigeria (Mbonu et al., 1991) which reported that four (4) of the groundwater points sampled had nitrate levels $> 100 \text{ mgL}^{-1} \text{ NO}_3$. Similarly, Nieeko et al. (2001) and Gelberg et al. (1999) discovered nitrate levels higher than the WHO limit in wells from the parish of Szydłowiec, Swietokrzyskie province and rural New York State in USA. Mbanugo et al.

(1990), however, reported nitrate levels in tap waters, boreholes and rivers ranging from 1.10 to 48.4 mgL^{-1} with a mean of 10.20 mgL^{-1} in south-eastern part of Nigeria. The study revealed that high concentration of nitrate in the wells may be due to their closeness to sources of pollution such as septic systems, refuse dumps and the fact that some of the wells lacked sanitary features such as cover, apron and lining. Nolan et al. (1998) and Alhajar et al. (1990) reported that the water table in shallow wells is closer to the land surface and to potential sources of contamination such as septic systems and their leachates. The lower nitrate concentration in some of the wells during the rainy season may be due to the dilution or flushing action of increased water throughput

in the wells. The majority of the wells are located between 1 and 10 m from sources of pollution, which is below the 30 m distance recommended as a minimum (Morgan, 1990).

Conclusion

This study presents the concentration of nitrate in 88 samples from 48 wells used as drinking water sources in both dry and wet seasons in an urban-slum setting in Ibadan Southeast local government area of Oyo state. Contaminating point sources located not farther than 10 m from wells may influence the quality of water, thus putting the lives of consumers at risk. The exceedence map identified those areas at risk; which therefore require urgent intervention. The results of this study will provide background information that will assist the local government officials to put in place appropriate regulatory actions to improve drinking water quality in their domain. The implementation of actions to prevent degradation, and to maintain and improve water quality is imperative. This study, therefore, recommends routine investigation and monitoring of nitrate levels in wells used as drinking water sources.

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REFERENCES

- Alhajar BT, Chesters G, Harkin JM (1990). Indicators of chemical pollution from septic systems. *Groundwater* 28:559-568.
- APHA /AWWA/ WPCF (1975). Standard methods for the examination of water and wastewater, 14th edition Washington DC, Maryland, USA.
- Arowolo TA (2005). Seasonal variation of nitrate-N in surface and ground-waters of South Western Nigeria: A preliminary survey. *Chem. Ecol.* 21(2):83-89.
- Bernard TN, Barbara CR, Kerrie JH, Dennis RH (1998). A national look at nitrate contamination of ground water. *Water Cond. Purif.* 39:76-79.
- Gelberg KH, Church L, Casey G, London M, Roerig DS, Boyd J, Hill M (1999). Nitrate levels in drinking water in rural New York State. *Environ. Res.* 80(1):34-40.
- Gupta SK, Gupta RC, Gupta AB, Seth AK, Bassin JK, Gupta A, Sharma MI (2001). Recurrent diarrhoea in children living in areas with high levels of nitrate in drinking water. *Archives of Environmental Health July issue.* Retrieved February 18, 2007 from http://www.findarticles.com/p/articles/mi_m0907/is_4_56/ai_79124886
- Itama E, Olaseha IO, Sridhar MKC (2006). Springs as supplementary potable water supplies for inner city populations: A Study from Ibadan. *Urban Water J.* 3(4):215-223.
- Jennings GD, Sneed RE (1996). Nitrate in drinking water, North Carolina Cooperative Extension Service, Publication No. AG 473-4.
- Kelter PB, Grundman J, Hage DS, Carr JD (1997). A discussion of water pollution in the US and Mexico with high school laboratory activities for analysis of lead, anthrazine and nitrate. *J. Chem. Educ.* 74(12):1413-1418.
- Kempster PL, Van Vliet HR, Kuhn A (1997). The Need for guidelines to bridge the gap between ideal drinking-water quality and that quality which is practicably available and acceptable. *Water SA* 23(2):163-167.
- Lively TJ, Czapar GF (2002). Evaluating conservation practices using GIS and virtual reality modeling language. *J. Nat. Resour. Life Sci. Educ.* 31:38-43.
- Mbanugo JI, Sridhar MKC, Anunuso CI (1990). Methaemoglobin levels in infants receiving low dietary nitrates in Eastern Nigeria. *Toxicol. Environ. Chem.* 25:195-199.
- Mbonu M, Travi Y, Guuidaud R (1991). Groundwater quality in the basement complex region of North-Central, Nigeria: A precursory survey of nitrate concentration. In: E.O.A. Aina and N.O. Ogundipe (Eds), *Water Quality Monitoring and Environmental Status in Nigeria.* FEPA Monograph 6:176-190.
- Morgan P (1990). Sanitary surveys of wells and tubewells. In *Rural Water Supplies and Sanitation: A text from Zimbabwe's Blair Research laboratory: 58-60* Macmillan Education Ltd., London.
- Nieeko J, Sobotka M, Kukulka-Nieeko U, Nieeko M (2001). The levels of nitrate in drinking water of selected water wells situated in the Parish of Szydłowice. *Przegląd Lekarski* 58(7): 25-29.
- Nolan BT, Ruddy BC, Hitt KJ, Helsel DR (1998). A national look at nitrate contamination of groundwater. *Water Cond. Purif.* 39(12):76-79.
- NRDC (2003). Common tap water contaminants: Health effects, treatment and recommendations. In: *What's on tap? Grading drinking water in U.S.*
- Nugent M, Kamrin MA, Wolfson L, D'Itri. (1993). Nitrate-a drinking water concern. Michigan State University extension, Extension Bulletin WQ-19.
- Omotayo AM (2003). Ecological implications of fulbe pastoralism in Southwestern Nigeria. *Land Degradation Dev.* 14: 445-457
- Onianwa PC, Ogunniyi OJ, Ogunnowo AA (1999). General physico-chemical analysis of drinking water in Ibadan, Nigeria. *Int. Environ. Educ. Inf.* 18(2):143-154.
- Reissman DB, Staley F, Curtis GB, Kaufmann RB (2001). Use of geographic information system to aid health department decision making about childhood lead poisoning prevention activities. *Environ. Health Perspect.* 109(1):89-94.
- Sandor J, Kiss I, Farkas O, Ember I (2001). Association between gastric cancer mortality and nitrate content of drinking water: Ecological study on small area inequalities. *Eur. J. Epidemiol.* 17(5): 443-447.
- Stout HM, Lee BD (2004). Land use planning exercise using geographic information systems and digital soil survey. *J. Nat. Resour. Life Sci. Educ.* 33:11-15.
- Tong STY, Chen W (2002). Modeling the relationship between land use and surface water quality. *J. Environ. Manage.* 66(4) 377-393.
- Udo RK (1994). Ibadan in its regional setting. In: MO Filani, FO Akintola, C.O. Ikporukpo (Eds.), *Ibadan region: 6-17.* Rex Charles Publication and Department of Geography, University of Ibadan.
- Weyer PJ, Smith BJ, Feng Z, Kantammenl JR, Riley DG (2006). Comparison of nitrate levels in raw water and finished water from historical monitoring data on Iowa Municipal drinking water supplies. *J. Environ. Monit. Assess.* 116(1-3):81-90.
- WHO (1995). Guidelines for drinking water quality, Vol. 1, Second Edition: Recommendations. Geneva, WHO: 174-181.
- WHO (1996). Guidelines for drinking water quality, Vol. 2, Second Edition: Health Criteria and Supporting Information. Geneva WHO (2):1-94.