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Assessment of nitrate concentrations in the shallow groundwater aquifer of Maiduguri and environs, Northeastern Nigeria

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ABSTRACT

Maiduguri and environs lie in the semi-arid region of Nigeria, characterized by low rainfall of approximately 600 mm per annum and high evapotranspiration of over 2000 mm per annum. Surface water is largely seasonal with rivers flowing for about three months in a year, although the Alau dam is an exception whose water is treated for supply to about 30% of the citizens of Maiduguri. Therefore, perennial water supply to the inhabitants is from groundwater, with the shallow Upper aquifer the dominant source. Assessment of quality of this water is thus fundamental. This is because of its susceptibility to contamination as a result of poor waste disposal from a rapidly growing population and industrialization. Water samples from 128 shallow boreholes were used to measure the EC, NO_3 and temperature using appropriate meters, in addition to taking the site coordinates. The values of the EC and NO_3 were used to evaluate the quality of this shallow groundwater. The results show a linear relationship between EC and NO_3, which indicate that NO_3 is a major contribution to the EC. NO_3 concentrations in some boreholes are over 700 ppm; considerably higher than the WHO and NSDWQ permissible limit of 50 ppm. These boreholes are in wards of older settlements and with high population density. Most of the water from boreholes having lower than 50 ppm average NO_3 are from wards that have low population density and usually of recent settlement. Although, for borehole sites close to the river channel, their NO_3 concentrations are low due to dilution. Distribution of the NO_3 concentrations over the study area indicates that the age of settlement and population density the major controls. There is the need to assess and constrain the source and mechanism of NO_3 leaching into the groundwater of this area. Ultimately, there will be a need to develop modern human waste disposal systems that will enhance protection and/or minimize groundwater contamination.

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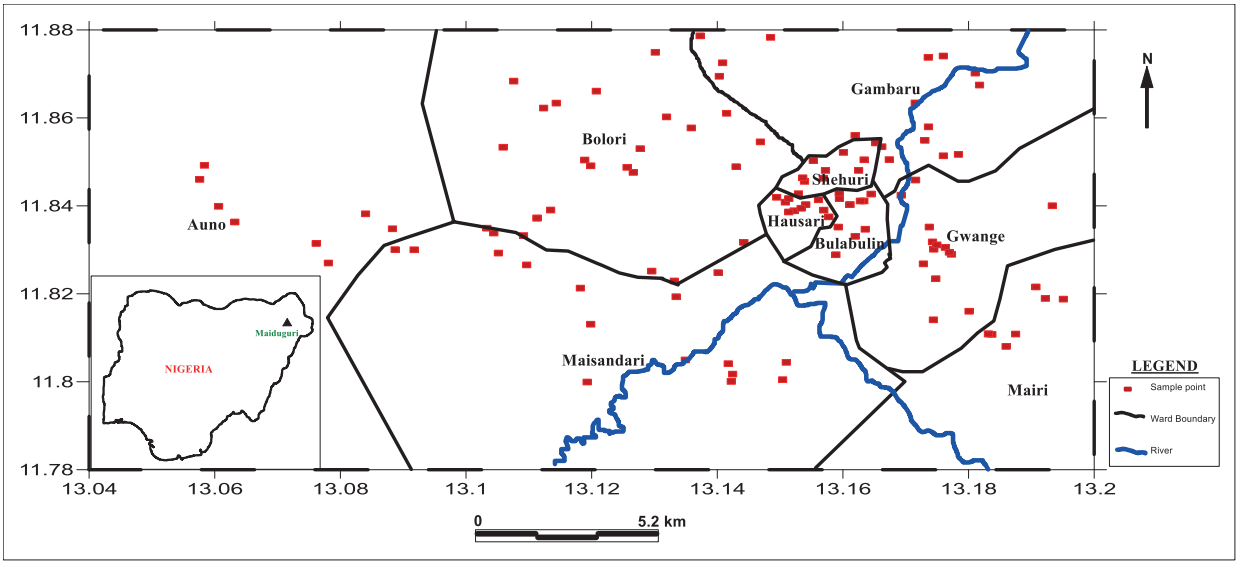


Fig. 1. Map of study area showing wards and sample locations. Inset is map of Nigeria with the locaion of Maiduguri in the Northeast.

Introduction

Nitrate contamination of groundwater is globally wide-spread and in Nigeria it has been reported in various parts of the country [2,9,10,15,16,22]. Nitrate is found naturally at moderate concentrations in many environments but is often enriched to contaminant levels by anthropogenic activities from agriculture, human and animal wastes [19]. Although nitrate is harmless at low concentration, exposure to high level of nitrate can affect human health, particularly infants under the age of three months [25]. Hall, et al. [14] have equally reported that elevated nitrate concentrations in drinking water can cause methemoglobinemia in infants and stomach cancer in adults. WHO [25] has sets permissible nitrate concentration limit of 50 ppm for drinking water.

In the study area, deterioration of water supply situation and the inability of the government to meet the demands have resulted in individuals resorting to the construction of tube wells and washbores to the shallow aquifer system. There are thousands of these wells in the study area supplying water for domestic consumption; hitherto these are mainly used for horticultural activities. These schemes are cheap to construct and easy to maintain. Although, because of their shallow construction depth coupled with poor sanitation facilities and waste disposal system in the region, the scheme is vulnerable to contamination, with potential health implications.

There is a need to assess and monitor the quality of the shallow groundwater in this area, because of potential contamination threat as a result of rapid population growth. In Maiduguri, Pit latrine is a common form of excreta disposal just as it is the case in the developing world. This form of disposal is popular and widely used by low-income people because it is simple, cheap and efficient [20]. But, leachate from pit latrines is a potential source of contamination to groundwater, especially, where they are in proximity and with a suitable lithology. This, therefore, informed the need to carry out an assessment of nitrate concentrations in the shallow aquifer groundwater of the study area to evaluate its quality status. Nitrate is a good indicator of contamination and thus, it is used to assess the degree and spatial extent of groundwater contamination in the study area.

The study area

The study area is in Maiduguri and environs; Maiduguri is the capital city of Borno State in Northeastern Nigeria (Fig. 1). The study area is located between latitude 11.802273°N and 11.805671°N and longitude 13.177060°E and 13.224816°E, in a semi-arid region. Rainfall in the area is estimated at 600 mm per annum while evapotranspiration is over 2000 mm per annum [13]. Climatically, the study area is hot and dry for the greater part of the year. The rainy season is normally from June to September, while in a good year, it is from May to October with relative humidity of about 49%. The temperature ranges from 13 °C to 25 °C in October through February, while in March–May it is between 35 °C and 39 °C. Between May and June, that is, just before the rainy season, temperature may rise to 45 °C [11]. Daura [7] gave the daily average temperature for the study area throughout the year as ranging from 25 °C to 44 °C. In terms of population, Maiduguri town is the most populated in the subregion with over 1 million inhabitants. This has increased considerably as a result of the insurgency that led to influx of people from the rural areas.

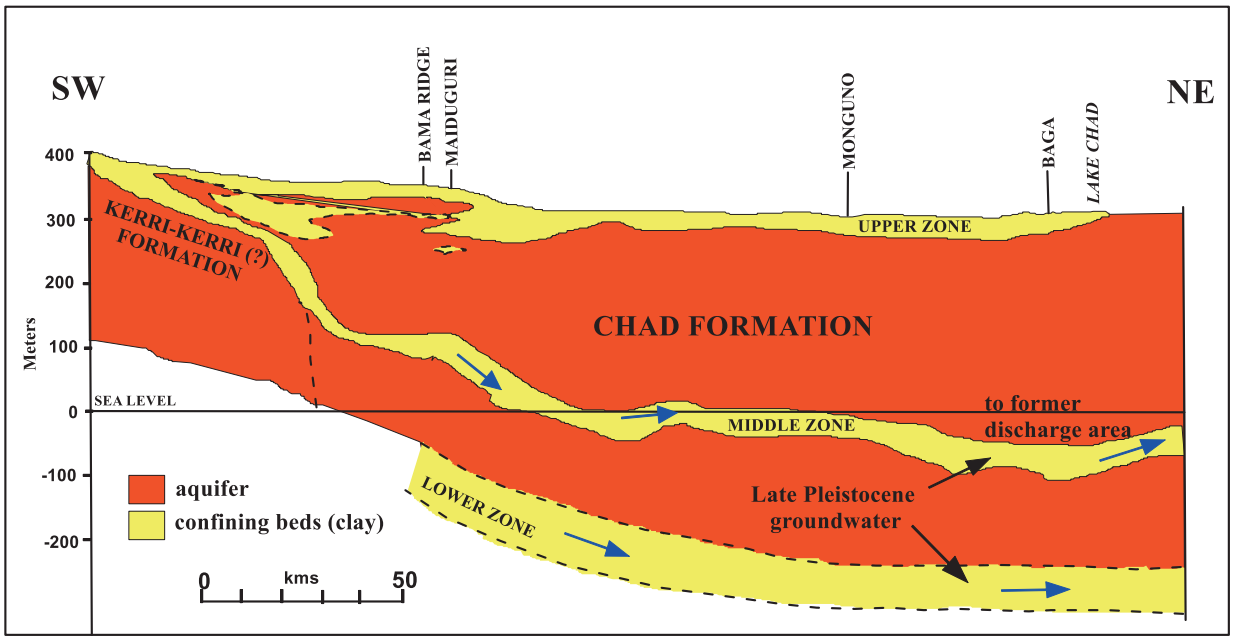


Fig. 2. Geological cross section of aquifers in the Chad formation (modified from [4]).

The hydrological characteristics of the study area is such that surface water is largely seasonal with rivers flowing for about three months in a year. Although, the Alau dam, located about 15 Km south of Maiduguri is an exception, whose water is treated for supply to the citizens of Maiduguri. This supply covers about 30% of the population of the area and thus, perennial supply to the inhabitant of Maiduguri is from groundwater resources.

Hydrogeologically, the study area is characterized by groundwater occurring in the Plio-Pleistocene Chad Formation and the overlying superficial deposits. Adelana et al. [3] state that "groundwater in the Chad Formation occurs under water table condition, in perched condition, in semi-confined and confined conditions. Three well-defined arenaceous horizons within the argillaceous Chad Formation constitute the aquifers, and Barber and Jones [5] named them the Upper, Middle and Lower aquifers (Fig. 2)". In the study area, the Upper aquifer occurs within the superficial deposits and is composed of alluvium and aeolian sands and gravel lay down during recent times [3]. Around Maiduguri, "the Upper aquifer includes not only a surface zone of recent sands with an unconfined water table, but deeper layers of sands of the Chad Formation complexly intercalated between clays and partially confined by these clays" [3]. The work is carried out within Maiduguri on the shallow aquifer of the Chad Formation.

Beacon Services Ltd and Consulint International [6] called the Aquifer a system because of three definable unit, which they termed A, B and C Units. The A-Unit is a water table aquifer at depths of up to 60 m, largely within the superficial deposits; the B-Unit is artesian to leaky artesian, within a depth range of 70–90 m; while the C-Unit is artesian with negligible leakage at depths of 90–120 m (Fig. 3). "These units seem to be restricted to Maiduguri and environs, which is an ancient shoreline of mega Chad; deposits of these units have been associated with beach or deltas and tend to exhibit extremely variable thicknesses" [3]. Most tube wells drilled recently especially those by the manual drilling are tapping the A unit. Although, this unit is believed to be recharged annually from precipitation and possibly from River Ngadda seepage, although, rates of these are not clearly understood. This recharge character underscores the permeable nature of the unsaturated zone lithology of the area and thus its susceptibility to potential contaminants.

Methodology

The study starts by identifying and demarcating the various wards of the study area as well as locations borehole tapping the shallow aquifer. The ward's boundaries used in this study were estimated and for convenience some of these words, such as Gwange I, II & III; Bolori I & II; etc., are merged together to just Gwange ward and Bolori ward respectively (Table 1). Fig. 1 shows the distribution of locations of the selected boreholes, which fall mostly within Maiduguri, but few locations fall in the neighboring Local Government areas of Jere and Konduga in Borno State.

The concentrations of nitrate and other physical parameters of Electrical Conductivity (EC) and temperature across the nine wards were measured. Depth of each of the borehole could not be obtained, but they all fall within the Upper aquifer system of the Chad Formation and between the depths of 45–70 m as the limit of the manual drilling method.

Specifically, the EC and temperature were measured using Hanna (Dist 4) field kit by dipping the probe into the water sample of the borehole at the site. In the case of nitrate, the Laquatwin Compact NO_3 meter B-74X is used to measure it at

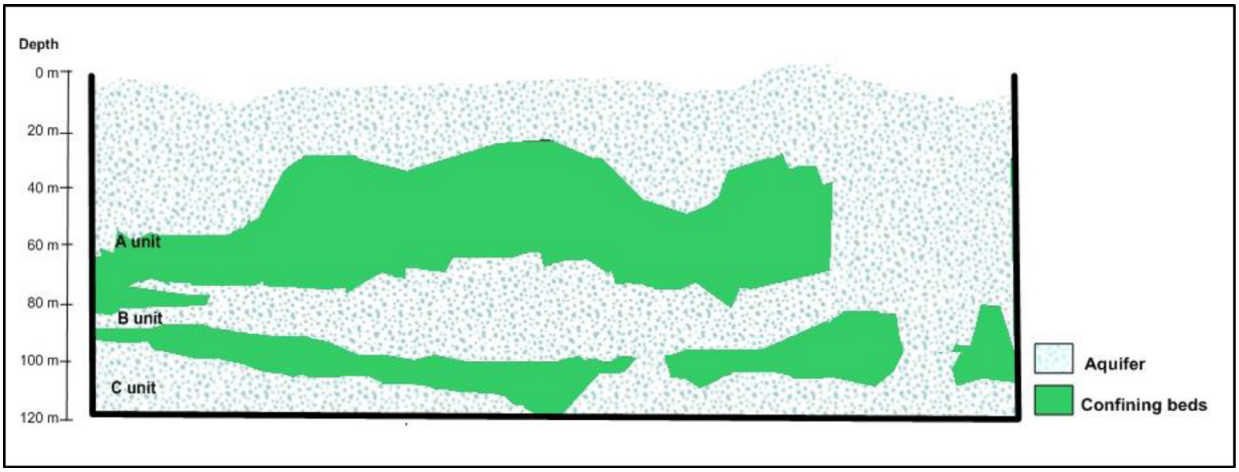


Fig. 3. Conceptual cross section of the upper aquifer system (modified from [6]).

Table 1
Wards in the study area, their estimated year of development and number of samples analyzed (Modified from M. Waziri [24]).

S/N	Ward	Estimated year of creation	No. of samples	Population density
1	Auno	2001	8	Low
2	Bolori	1978	20	Moderate
3	Bulablin	1924	10	High
4	Gambaru	1924	15	Moderate
5	Gwange	1953	17	High
6	Hausari	1918	11	High
7	Mairi	1964	10	Moderate
8	Maisandari	2001	27	Low
9	Shehuri	1918	10	High

the field borehole site. The equipment is first calibrated using standard solution and thereafter water sample is dropped on the sensor and measurement of the concentration of nitrate is done directly in ppm. The equipment has an accuracy limit of ± 10% of the reading value. Groundwater from 128 boreholes across nine wards in the study area (Fig. 1) were used to measure EC and nitrate concentrations at the borehole sites.

Results

Results of nitrate and EC show a widely varying concentration from 1–770 ppm and 0.11–3.43 mS/cm respectively. The distribution of NO_3 across the study area is shown on a bubble plot in Fig. 4. The size of the bubble in Fig. 4 indicates NO_3 concentration and clearly shows higher concentration in the central and eastern parts, while the western part is relatively low. The EC values tend to mirror the NO_3 concentration values and show that the central and eastern parts have very high EC while the western part has relatively low values.

Linear plots of NO_3 against EC are shown in Fig. 5a and b. Fig. 5a shows the NO_3 – EC relationship based on the wards of the study area. Fig. 5b show the NO_3 – EC relationship for NO_3 concentrations that are less than 50 ppm and for those greater than 50 ppm and their corresponding R^2 values, which is used to evaluate the contribution of NO_3 to the EC values. The results clearly show that NO_3 at higher concentration is a major contributor to the EC in the study area with a R^2 value of 0.86 (Fig. 5b). However, at lower concentration (less than 50 ppm), it is not a major contributor to the EC as shown by an R^2 value of 0.11 (Fig. 5b).

Discussion

Anthropogenic sources of NO_3 in groundwater are usually domestic waste and fertilizer [12]. NO_3 is soluble in water and very stable, which means that it rarely combines with other compounds. It also does not bind to soil particles like other water contaminants but rather percolates into groundwater through the soil. This means it will move with groundwater for several km from its potential source and remain for years after its initial infiltration [12]. “Under aerobic conditions, nitrate can percolate in relatively large quantities into the aquifer when there is no growing plant material to take up the nitrate and when the net movement of soil water is downward to the aquifer. Degradation or denitrification occurs only to a small extent in the soil and in the rocks forming the aquifer” [25]. In the WHO [25] document it states that “The presence

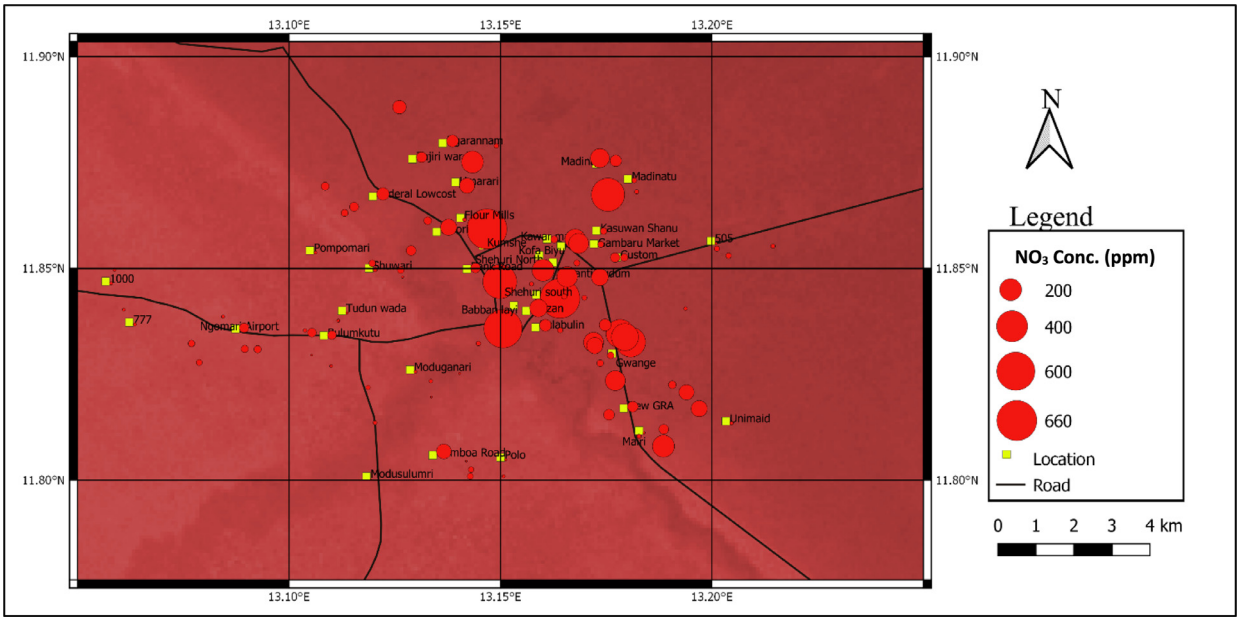
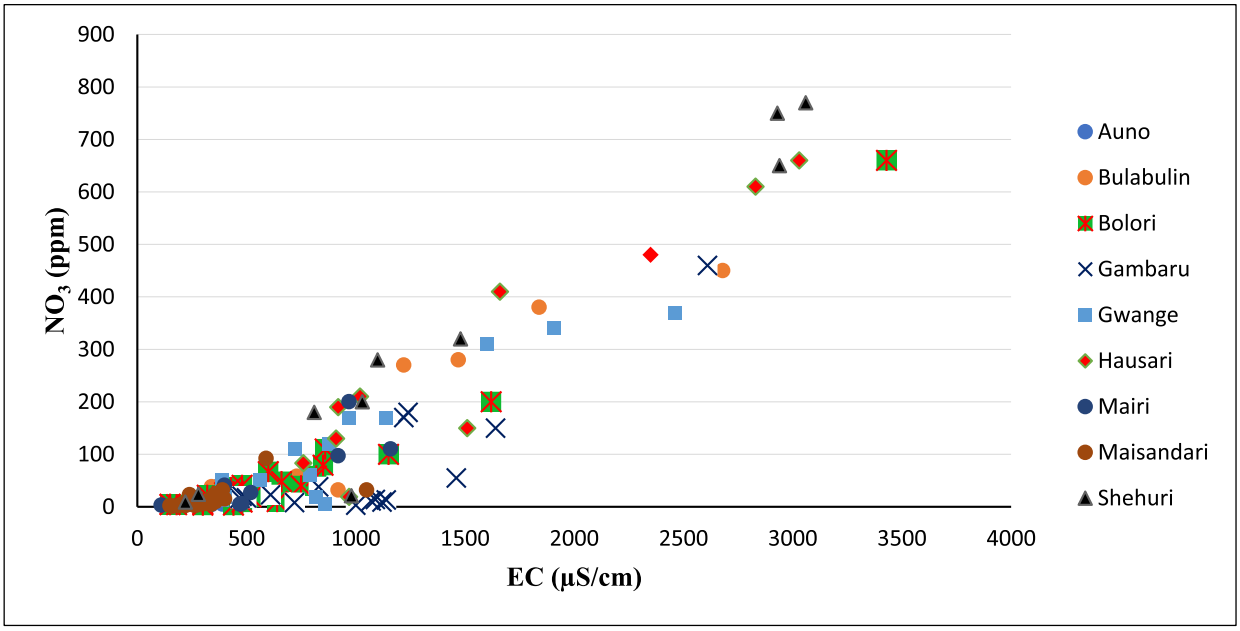


Fig. 4. Bubble plot of NO_3 concentrations (ppm) over the study area.

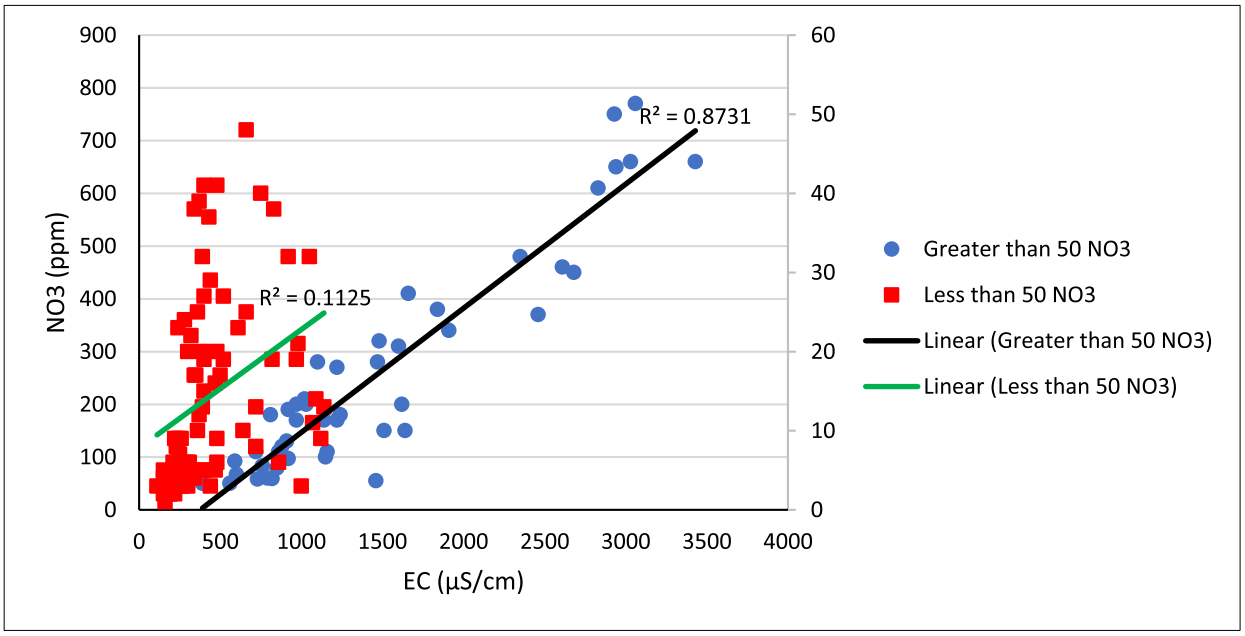
of high or low water tables, the amount of rainwater, the presence of other organic material and other physicochemical properties are also important in determining the fate of nitrate in soil [8,23]". The study area is largely a settlement town and not much of an agricultural area and therefore NO_3 contamination is more likely to be from excreta disposal rather than fertilizer. Results of the average NO_3 concentration over the different wards in the study area is shown in Fig. 6. An evaluation of the distribution indicates that two factors control the concentration of NO_3 in the study area, which are the age of development of the wards and population density.

The oldest settlements in the study area are Hausari, Shehuri, Bulabulin and Gamboru wards, formed almost 100 years ago (Table 1). Incidentally, these wards have the highest average NO_3 concentration in the study area, except for Gambaru ward in which it has a lower higher average NO_3 concentration than the Gwange ward that is relatively younger in creation (Table 1). The relatively low NO_3 concentration in the Gamboru ward is attributed to relatively low population density (moderate density) when compared to the Hausari, Shehuri or Bulabulin wards (high population density). The same reason can be advanced for the relatively higher NO_3 concentration in the Gwange ward, which has high population density (Table 1). This is because low population density corresponds to low human waste generation and thus low potential contamination. This explains the case of Mairi ward (moderate population density), which is as old as Gwange ward but with low average NO_3 concentration because of low population density when compared to Gwange ward. The case of Maisandari ward is obvious, as it is composed of the low-density Government Reservation Area (GRA) and in terms of age, it is the youngest ward in this study (created in 2001). This ward has a very low average NO_3 concentration, well below the WHO [25] and NSDWQ [17] limits. What is clear from these analyses is the correlation between the NO_3 concentration and age of the wards. Although, Rasolofonirina, et al. [18] correlates NO_3 concentration to the age of water well. In the study area, all wards that are above 50 years have their groundwater contaminated with NO_3 to levels above the WHO permissible limits (Fig. 6). Templeton, et al. [21] used the advection-dispersion-reaction model to estimate a minimum of 50 years for NO_3 concentration to exceed the WHO limit of 50 mg/l for an area with a bottom of pit latrine that is about 5 m to groundwater level.

The concentrations of nitrate in the older wards is attributable to pit latrines, which are probably the only mode of excreta disposal then. Pit latrines have been observed to be the major source of NO_3 in shallow groundwater [1,18]. Over the long-term interval, this may percolate through the unsaturated zone and reach the groundwater zone. The recent younger wards have relatively low nitrate concentration in their groundwaters at least from these analyses, which is explained as probably due to the short residence time. What is very important in these analyses is the fact that over 60% of the wards in the study area have NO_3 concentrations above the WHO [25] and NSDWQ [17] permissible limits of 50 ppm (Fig. 6). Mairi and Bolori wards are at the threshold of permissible concentration limits, while Maisandari ward has NO_3 concentration well below the permissible limits. This is because of its young age and low population density. Although, the impact of river water is worth noting. For examples, borehole water from Kulogumna primary school and Kangarmakka in the Bulabulin ward has NO_3 concentration values of 6 and 25 ppm respectively. Similarly, borehole water from Modube, Waziri Habib and Bukar Imam boreholes in the Gwange ward has NO_3 concentration values of 3, 13 and 12 ppm respectively. All these sites are within 50 m from the River Ngadda channel, which is believed to have diluted the groundwater at these boreholes and



a



b

Fig. 5. (a) A plot of NO_3 against EC based on wards of the study area. (b) A plot of NO_3 of <50 ppm (in red square) and >50 ppm (in blue circles) against EC for the study area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

thus significantly reduced their NO_3 concentrations; bearing in mind that Bulabulin and Gwange are wards with generally with high average NO_3 concentrations values because of their age and population density. In general, the main control for leachates leading to groundwater contamination or dilution of solute concentration is the hydraulic conductivity of the unsaturated zone of the area.

There is the need to critically assess and constrain the source and mechanism of NO_3 leaching into the groundwater of these wards. Knowledge of the lithology and texture of the unsaturated zone in these wards would be important in understanding the rate of pollutant movement from the surface to the groundwater zone. This is critical, as it will help water resources managers of the region in planning and developing remedial measures to minimize the impact. What will

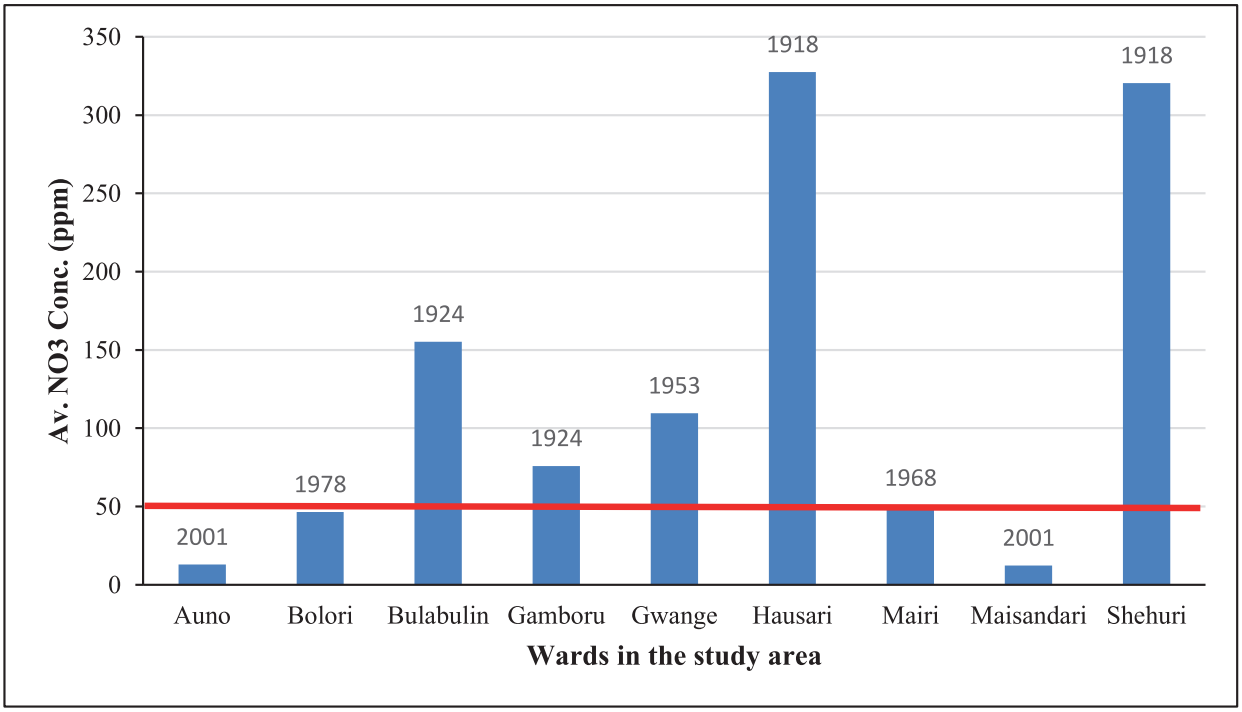


Fig. 6. Bar chart showing groundwater NO_3 average concentrations in different wards of the study area. Red line indicates ([25] and [17]) permissible NO_3 concentration limit of 50 ppm. The number above each bar indicates estimated year of beginning of development of the ward. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

be more critical is the development of waste disposal systems and the selection of sites in the study area that will enhance protect and minimize groundwater contamination.

Conclusion

In the study area, the shallow groundwater is the perennial source of water supply to the citizens of Maiduguri and environs. This shallow system is susceptible to anthropogenic contamination in the study area, especially, from pit latrines. Results of nitrate concentration from 128 boreholes were used to assess the degree and spatial extent of groundwater contamination in the study area. The results show very high NO_3 concentrations in the eastern and central parts, while the western part is relatively low. This corresponds to the wards in the study area that are of older settlements and with higher population densities. Out of the nine wards of the study area, five of the wards have average NO_3 concentration above the recommended permissible limits of 50 ppm. The wards with the average NO_3 concentrations within the permissible limits of 50 ppm are those with younger than 20 years settlements and with relatively lower population densities. There is a need to assess and constraint the source and mechanism of NO_3 leaching into the groundwater of the study area. Knowledge of the lithology and texture of the unsaturated zone would be important in understanding the rate of pollutant movement from the surface to the groundwater zone. This will help water resources managers in the region to plan and develop remedial measures to minimize the impact. Ultimately, there would be the need to construct modern human waste disposal system and/or develop household sewage treatment and management that will enhance protection of the groundwater and minimize contamination.

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