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Health Risk Assessment of Nitrate Concentration in Soil and Water within the Sango area, Ibadan

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ABSTRACT

Nitrate contamination in drinking water sources poses significant health challenges globally, particularly in rapidly urbanizing areas. The problem of nitrate pollution in the Sango area of Ibadan metropolis has intensified due to poor sewage management and industrial waste discharge, creating serious public health concerns. This research aims to assess the nitrate concentration in drinking water sources in the Sango area of Ibadan metropolis. Twenty-two sampling points (SW1 - SW22) were selected using stratified sampling comprising 15 shallow wells, 4 boreholes, and 3 surface water sources distributed across residential, commercial, and mixed-use areas. Water samples were collected during both rainy and dry seasons. Physicochemical parameters, including nitrate concentration, pH, temperature, turbidity, dissolved oxygen, and electrical conductivity, were measured. Daily nitrate intake was estimated across age groups and compared with WHO guidelines. Nitrate levels ranged from 125 to 285 mg/L (rainy season) and 67.42 to 153.67 mg/L (dry season), significantly exceeding the WHO limits. pH ranged from 6.1 - 9.3 and 6.32 - 9.47; turbidity, 28.6 - 49.3 NTU and 20.34 - 34.54 NTU; DO, 5.02 - 8.9 mg/l and 4.54 - 7.63 mg/l; EC, 206.4 - 907.5 µS/cm and 230.72 - 980.44 µS/cm during rainy and dry seasons, respectively. Estimated nitrate intake across all adult age groups exceeded the WHO acceptable daily intake, indicating significant health risks. Elevated levels, especially during the rainy season, pose considerable health risks, surpassing WHO limits across seasons. Enhancing water treatment infrastructure and improving filtration systems during periods of peak contamination can significantly reduce nitrate exposure.

INTRODUCTION

Water and soil quality are interconnected components that are critical to the sustainability of environmental and public health. The potability of water sources, particularly shallow groundwater boreholes, depends on both the quality of the water itself and the characteristics of the surrounding soil matrix through which it percolates. Natural processes such as mineral leaching from soil and rock formations can introduce various substances into water sources, while anthropogenic activities significantly alter both soil chemistry and water composition (Martínez *et al*., 2020).

Soil contamination serves as a primary pathway for groundwater pollution, with contaminants migrating through soil layers into aquifer systems. The soil's physical and chemical properties, including bulk density, porosity, and organic matter content, influence the retention and transport of pollutants. Dense soils with high clay content typically retain more contaminants, while sandy soils with higher permeability allow faster migration of pollutants to groundwater sources (Seiyaboh and Izah, 2017). This soil-water interaction is particularly critical in urban areas where industrial activities, agricultural practices, and waste disposal systems directly impact both soil and water quality.

The quality of water significantly affects its potability and must meet specific physical, chemical, and microbiological standards set by health authorities. Pathogens like bacteria, viruses, and protozoa can cause waterborne diseases, while chemical contaminants can lead to long-term health issues, including cancer and neurological disorders (Okereke *et al*., 2016).

Nitrate concentration in both soil and water systems represents a critical environmental concern with significant implications for human health. Nitrates primarily originate from agricultural fertilizers, which are applied to enhance crop productivity but subsequently leach through soil layers into groundwater systems. The soil acts as both a reservoir and transport medium for nitrates, with soil characteristics determining retention capacity and migration rates. In soil systems, excessive nitrate accumulation can indicate over-fertilization and poor agricultural management practices, while in water systems, high nitrate concentrations reflect the cumulative impact of soil contamination on groundwater quality (Isiuku and Enyoh, 2020).

Urban areas face additional challenges as stormwater runoff carries nitrates from treated lawns and gardens through contaminated soils into water bodies. Industrial effluents, septic system discharges, and organic matter decomposition further contribute to nitrate loading in both soil and water environments. The conversion of nitrates to nitrites in the human body poses significant health risks, particularly for vulnerable populations, including infants, pregnant women, and elderly individuals. Understanding the relationship between soil nitrate contamination and water quality is essential for developing effective remediation strategies and protecting public health (Okereke *et al*., 2016).

METHODOLOGY

Study Areas

Sango is a densely populated area in Ibadan North West Local Government Area of Oyo State, Nigeria. Located at an elevation of 207 meters with coordinates 7°25'39" North and 3°52'49" East, it lies in the southwestern region of the country. With a population of over 215,000, Sango is a vibrant community known for its cultural significance and active commercial sector, supported by several markets and business centers, as shown in Figure 1.

Assessment of Soil Nitrate Contamination

The study aimed to assess the nitrate contamination levels in soil samples across the study area by collecting and analyzing data on bulk density and nitrate concentrations at a depth of 50 cm. This depth was selected based on previous studies (Ajibade *et al.* 2021), indicating that nitrate accumulation is most pronounced at depths where groundwater interaction occurs, typically between 200-300 cm in similar geological formations. Soil samples were collected from 22 different locations (SW 1 to SW 22), ensuring a comprehensive representation of the study area. Each sample was collected at a consistent depth of 50 cm to allow for uniformity in comparison. The samples were labeled accordingly (SW 1, SW 2, etc.) and were preserved for subsequent laboratory analysis. The bulk density of each soil sample was determined using the core method to assess the soil's porosity and compaction characteristics.

Laboratory Analysis Methods

Soil nitrate concentrations were quantified at the Environmental Chemistry Laboratory, University of Ibadan, using ion-selective electrode techniques. Three replicate measurements (Sample 1, Sample 2, and Sample 3) were collected for each location to ensure reliability and reproducibility. The nitrate concentrations were expressed in parts per million (ppm). The ion-selective electrode method involves direct measurement of nitrate ions in soil extracts using a nitrate-specific electrode calibrated with standard nitrate solutions.

Water samples were collected from 22 strategically distributed points across the Sango area, comprising 15 shallow wells (depths ranging from 3-8 meters), 4 boreholes (depths ranging from 15-25 meters), and 3 surface water sources (streams and ponds). The sampling points were distributed as follows: 8 points in residential areas, 7 points in commercial zones, 4 points in mixed-use areas, and 3 points in agricultural zones. Samples were collected during both the rainy season (June-September) and dry season (December-March) to capture seasonal variations in water quality.

Water samples were collected in pre-sterilized 500 ml plastic bottles following standard sampling procedures. Samples were preserved at 4 °C and transported to the laboratory within 6 hours of collection. Water quality parameters, including pH, temperature, turbidity, dissolved oxygen (DO), and electrical conductivity (EC), were measured using standard methods. Nitrate concentrations in water samples were determined using the same ion-selective electrode technique employed for soil analysis. All analyses were conducted in triplicate, and average values were calculated for statistical analysis. The separated ions were then detected and quantified, providing a detailed profile of nitrate concentrations in both soil and water samples. Data collected from these analyses were input into SPSS Statistics 27 for statistical analysis.

Figure 1: Map of the Study Area

Risk Assessment Data

The study performed a comprehensive risk assessment by estimating the daily intake of nitrates using one hundred and fifty (150) food frequency questionnaires distributed among residents across different age groups and socioeconomic backgrounds. The questionnaires were distributed using stratified random sampling across residential areas (60%), commercial areas (25%), and mixed-use zones (15%). Out of 150 questionnaires distributed, 120 were successfully retrieved and processed, representing an 80% response rate. The questionnaires were administered by trained enumerators over a period of four weeks and processed using statistical analysis software.

The chosen sample size was essential to ensure statistically meaningful and demographically representative data, thereby enhancing the accuracy and reliability of the dietary nitrate intake estimates within the population. Initially, the nitrate concentrations determined from the laboratory analyses served as the foundational dataset. These concentrations were compared against the World Health Organization (WHO) permissible limits for nitrate in drinking water to identify any exceedances and areas of concern. To estimate the daily intake of nitrates, the study employed dietary intake surveys and water consumption questionnaires distributed to the local population. These surveys gathered data on the average amount of water consumed daily by individuals, along with other potential dietary sources of nitrate.

RESULTS AND DISCUSSION

Soil Nitrate Contamination Analysis

The analysis of soil samples revealed significant variations in nitrate concentrations based on bulk density and spatial distribution across the study area. Sampling at a uniform depth of 250 cm revealed bulk density values ranging from 1.65 to 3.91 g/cm^3, with a consistent pattern of higher bulk densities correlating with elevated nitrate concentrations. For instance, the lowest nitrate concentration was observed in S 1, with a bulk density of 1.65 g/cm^3 and an average nitrate concentration of 164.54 ppm, reflecting reduced nitrate retention in less dense soils. Conversely, S 19, with the highest bulk density of 3.91 g/cm^3, recorded the highest average nitrate concentration of 390.50 ppm, supporting findings of Ajibade *et al.* (2021), who noted similar patterns in nitrate accumulation within confined aquifers. However, deviations from this trend were observed, indicating that additional factors, such as soil texture, organic matter content, and proximity to nitrate sources, also play a role. For example, S 5, with a bulk density of 2.94 g/cm^3, exhibited an average nitrate concentration of 294.02 ppm, while S 6, with a slightly lower bulk density of 2.38 g/cm^3, had a significantly reduced nitrate level of 238.25 ppm, as shown in Figure 2.

The consistently high nitrate levels across most samples present serious public health concerns. For instance, S 19, with an average nitrate concentration of 390.50 ppm, exemplifies the risks posed by contamination likely originating from agricultural or urban runoff. Similarly, S 22, with an average of 320.93 ppm, and S 7, averaging 335.05 ppm, highlight areas potentially exposed to direct contamination sources.

These findings support Kaluai (2022), who linked high nitrate concentrations in Nigerian urban settings to inadequate waste management and unregulated fertilizer use. The spatial distribution of nitrate concentrations further suggests varying exposure levels to contamination sources. Samples such as SW 18, SW 19, and SW 22 exhibited the highest nitrate averages, indicating proximity to intensive agricultural activities or direct nitrate inputs. Conversely, SW 1 and SW 2 had relatively lower concentrations as shown in Figure 2, suggesting reduced human activity influence or the benefits of natural filtration processes. This underscores the need for localized intervention strategies. Moloantoa *et al.* (2022) recommend targeted approaches, such as improved agricultural practices, controlled fertilizer application, and enhanced waste disposal systems, to mitigate nitrate contamination effectively. Generally, high values of ^{40}K were observed in all the samples. The observed high concentration of ^{40}K in all the sample types may be a result of the geological formation underlying the studied areas. As illustrated in Figure

2, activity concentrations of the radionuclides in the stone-dust samples were higher than those in the ¾ -down and ¾ - up samples. The order is Stone dust > ¾ - down > ¾ - up. This result is in agreement with earlier studies by Gbadebo (2011), Akinloye *et al*. (2019), that quarrying or quarry processes, which involve blasting, crushing, and processing of rocks into different aggregates (sizes), increase the activity concentrations of radionuclides in the production environment (Gbadebo, 2011; Akinloye *et al*., 2019).

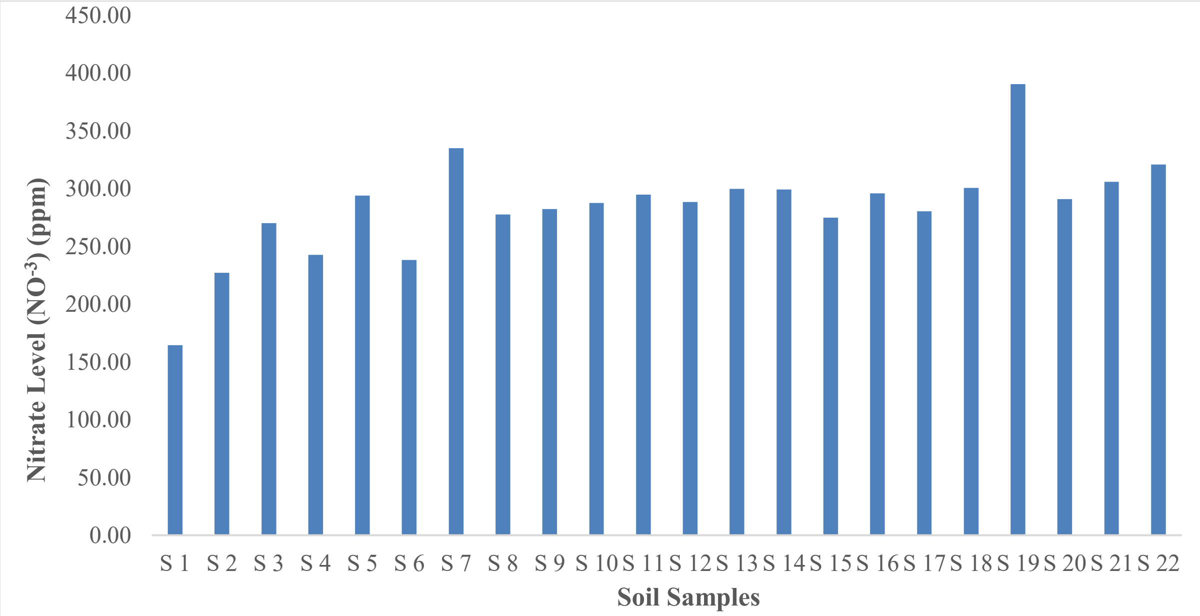

Figure 2a: Concentration of Nitrate Level in Soil across the Study Area

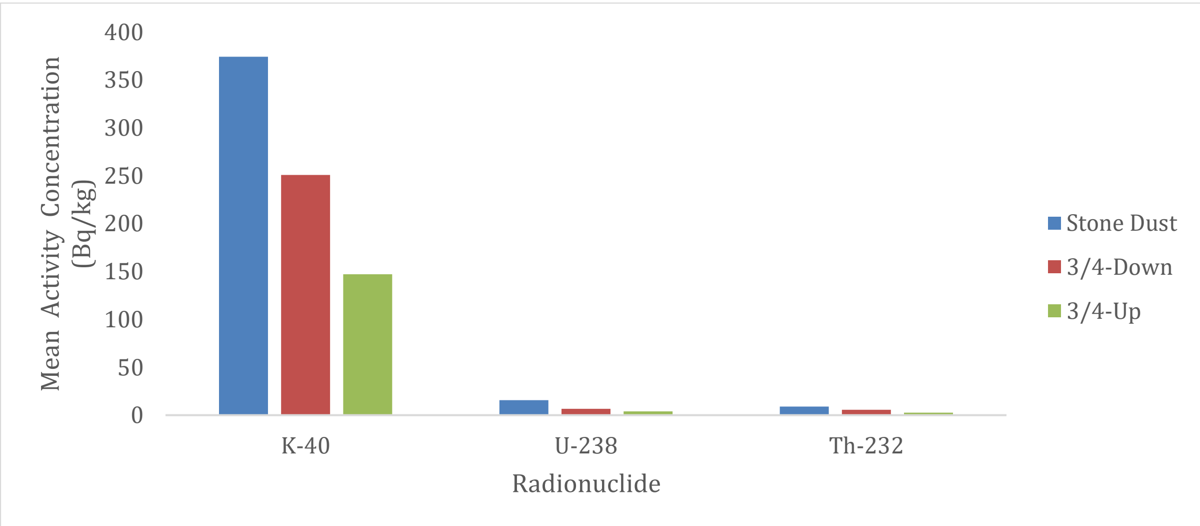

Figure 2b: Mean activity concentrations of each radionuclide according to sample types

However, this present study disagrees with Lawal (2019) claim that the higher the granite size, the higher the activity concentrations of the radionuclides. The results from this study showed clearly that the smaller the size, the higher the activity concentrations of the natural radionuclides in the samples, as revealed in Figure 2.

Water Quality Assessment

The comprehensive analysis of water samples from 22 locations during rainy and dry seasons revealed concerning levels of nitrate contamination alongside other water quality parameters. Nitrate concentrations in water samples ranged from 125-285 mg/L during the rainy season and 67.42-153.67 mg/L during the dry season, significantly exceeding the WHO limits of 50 mg/L for drinking water. The elevated concentrations during the rainy season reflect increased runoff from contaminated soil sources and agricultural activities.

Physical and chemical parameters showed considerable seasonal variation. pH values ranged from 6.1-9.3 in the rainy season and 6.32-9.47 in the dry season, with some locations showing alkaline conditions potentially linked to geological factors and contamination sources. Turbidity levels were consistently high, ranging from 28.6-49.3 NTU in the rainy season and 20.34-34.54 NTU in the dry season, exceeding WHO guidelines of 5 NTU. High turbidity correlates with increased particulate matter during rainfall, potentially carrying additional contaminants.

Dissolved oxygen levels varied from 5.02 - 8.9 mg/L during the rainy season and 4.54 - 7.63 mg/L during the dry season, with some locations showing oxygen depletion consistent with organic contamination. Electrical conductivity ranged from 206.4-907.5 µS/cm during the rainy season and 230.72-980.44 µS/cm during the dry season, indicating varying levels of dissolved ions and overall water mineralization.

Risk Assessment Data

The assessment of nitrate concentration in drinking water sources in the Sango area, Ibadan, involves evaluating the daily intake of nitrates to determine potential health risks and comparing the findings against established safety guidelines and thresholds to ascertain compliance and potential hazards. The elevated nitrate concentrations in water samples directly correlate with the risk assessment findings, demonstrating the pathway from soil contamination to human exposure through drinking water consumption.

Daily Intake of Nitrates

The analysis of nitrate intake across different age groups in the Sango area, Ibadan, reveals significant variations in water consumption and dietary habits that affect nitrate exposure, particularly during the rainy and dry seasons. The study was based on data obtained from 150 questionnaire responses, which provide insights into the relationship between age, water intake, and dietary patterns related to nitrate consumption.

In the age group 18-35, respondents reported consuming between 2 to 3 liters of water during the rainy season and 3 to 4 liters during the dry season. These individuals also had a relatively high frequency of vegetable consumption, ranging from 3 to 5 times per week, but consumed processed meats infrequently (1–2 times per week). Moreover, this age group primarily consumed soft drinks and other beverages. The nitrate intake from water during the rainy season was estimated at 415.46 mg/day, which reduced to 229.46 mg/day in the dry season. Their total nitrate intake, considering both water and vegetable consumption, was 437.06 mg/day in the rainy season and 251.06 mg/day in the dry season. For individuals aged 36-50, there was a noticeable decrease in water consumption during both seasons, with 1 to 2 liters consumed in the rainy season and 3 to 4 liters in the dry season. This group exhibited a daily vegetable consumption pattern but rarely consumed processed meats, as illustrated in Table 1. Furthermore, the primary beverages consumed were herbal teas and soft drinks. The nitrate intake from water in the rainy season was 207.73 mg/day, which dropped to 114.73 mg/day in the dry season.

However, nitrate intake from vegetables was significantly higher in this group, with an intake of 150 mg/day in both seasons. As a result, the total nitrate intake during the rainy and dry seasons was 359.16 mg/day and 266.16 mg/day, respectively. This demonstrates that, despite lower water intake compared to the younger age group, vegetable consumption significantly contributes to nitrate exposure in this demographic.

Similarly, the age group 51–65 showed comparable water consumption patterns to the 36–50 group, with an intake of 1 to 2 liters during the rainy season and 3 to 4 liters during the dry season, as presented in Figure 3. This group also exhibited daily vegetable consumption, coupled with daily processed meat consumption. The nitrate intake from water was 415.46 mg/day in the rainy season and 229.46 mg/day in the dry season, reflecting similar trends as seen in the 18–35 age group. However, the nitrate intake from processed meats was higher in this age group, at 20 mg/day in the rainy season, contributing to an overall total nitrate intake of 585.46 mg/day during the rainy season and 399.46 mg/day during the dry season.

Table 1: Nitrate Intake Factors by Age Group and Seasonal Water Consumption

Age Group	Water Intake (Rainy Season, L/day)	Water Intake (Dry Season, L/day)	Vegetable Consumption	Processed Meat Consumption	Beverage Consumption	Nitrate Intake Factor (mg/day)
18 - 35	2 - 3 liters	3 - 4 liters	3 - 5 times/week	1 - 2 times/week	Soft drinks/Other	Rainy: 437.06 Dry: 251.06
36 - 50	1 - 2 liters	3 - 4 liters	Daily	Rarely	Herbal teas/Soft drinks	Rainy: 359.16 Dry: 266.16
51 - 65	1 - 2 liters	3 - 4 liters	Daily	Daily	Packaged juices/Herbal teas	Rainy: 585.46 Dry: 399.46
>65	<1 liter	<1 liter	Daily	Rarely	Packaged juices/Herbal teas	Rainy: 357.73 Dry: 264.73

In contrast, the >65 age group showed a significant reduction in water intake, consuming less than 1 liter per day during both seasons. Despite the low water consumption, this group still reported daily vegetable consumption, but processed meat consumption was minimal. The nitrate intake from water in this age group was lower than that of the other groups, at 207.73 mg/day in the rainy season and 114.73 mg/day in the dry season. The nitrate intake from vegetables remained consistent at 150 mg/day, but processed meat intake contributed 0 mg/day in the rainy season, resulting in a total nitrate intake of 357.73 mg/day during the rainy season and 264.73 mg/day in the dry season. These findings are consistent with research conducted by Adebayo *et al*. (2021), who reported that water intake and dietary habits significantly influence nitrate exposure, with varying contributions from different food sources such as vegetables and processed meats.

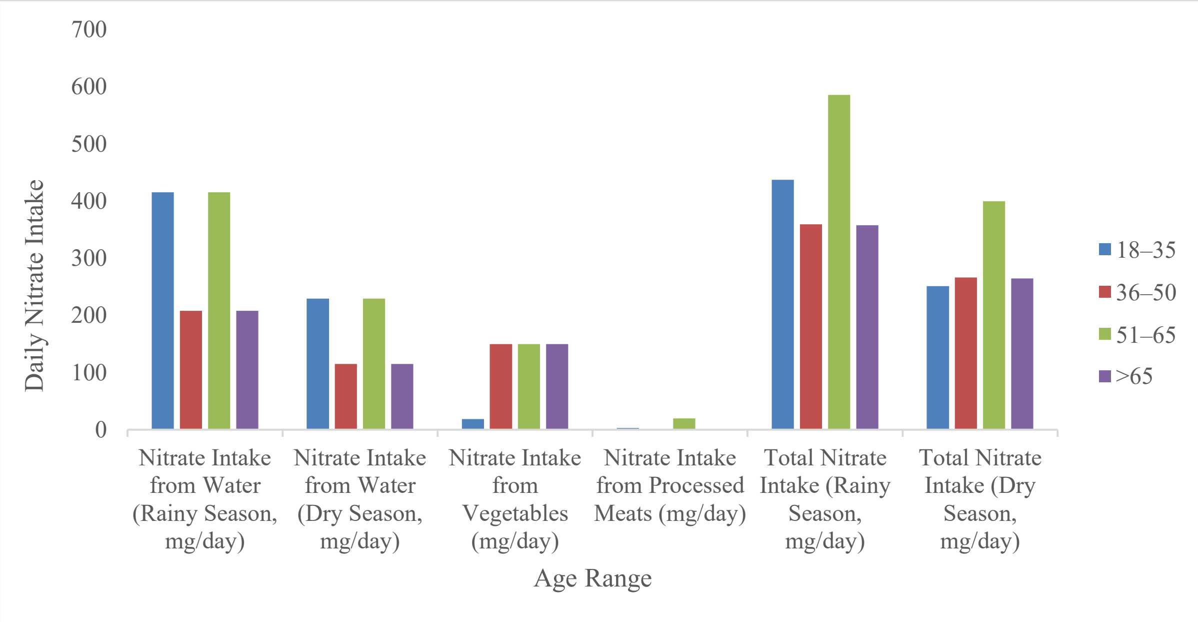

Figure 4: Nitrate intake based on Season and age across the Study Area

Additionally, seasonal variations in water quality were found to play a crucial role in determining the levels of nitrate contamination in drinking water.

Comparison with Established Safety Guidelines and Thresholds

The assessment of nitrate intake across various age groups and body weights in the Sango area, Ibadan, highlights both the seasonal variations in nitrate concentrations and their potential impact on health. The World Health Organization (WHO, 2019) has set an Acceptable Daily Intake (ADI) for nitrates at 3.7 mg/kg body weight per day, which serves as the baseline for evaluating the safety of nitrate exposure through drinking water and dietary sources. This study uses WHO guidelines to compare total nitrate intake across different body weights and seasons.

In the case of a person weighing 45 kg, the WHO's recommended nitrate intake is 166.5 mg per day, which is significantly lower than the total nitrate intake in both the rainy and dry seasons. During the rainy season, the total nitrate intake was 437.06 mg/day, while in the dry season, it was 251.06 mg/day. This stark difference indicates that individuals in this weight category are exposed to levels of nitrate far exceeding the WHO's acceptable limits, particularly during the rainy season when nitrate concentrations in water are elevated due to runoff from agricultural activities.

For individuals weighing 55 kg, the estimated acceptable nitrate intake is 203.5 mg/day, but total nitrate intake in the rainy season reached 359.16 mg/day and 266.16 mg/day in the dry season. These figures suggest that even with a slightly higher body weight, the intake still exceeds the WHO's ADI, especially in the rainy season.

For individuals with a body weight of 65 kg, the WHO's acceptable intake is 240.5 mg/day, but the total nitrate intake during the rainy season is much higher, at 585.46 mg/day, and 399.46 mg/day during the dry season. This clearly demonstrates that even larger individuals, with a higher acceptable intake threshold, are exposed to nitrate levels that exceed safe limits, particularly during the rainy season.

For individuals with a body weight of 75 kg, the WHO's estimated nitrate intake is 277.5 mg/day, which still falls below the total nitrate intake in both the rainy and dry seasons. In this group, the total nitrate intake was 357.73 mg/day during the rainy season and 264.73 mg/day in the dry season, which

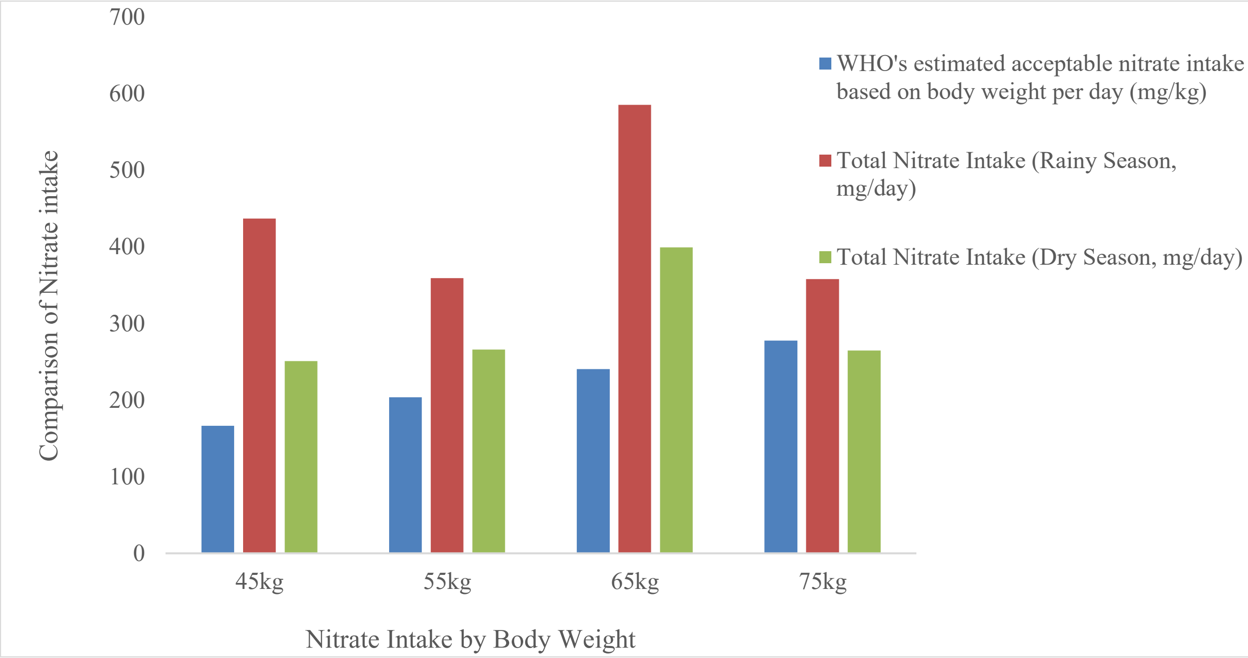

Figure 4: Comparison of Nitrate Intake Relative to Body Weight.

also exceeds the acceptable levels recommended by the WHO.

CONCLUSION

This comprehensive study reveals that nitrate contamination in both soil and water systems in Sango, Ibadan, presents a significant environmental and public health challenge. The assessment demonstrates clear linkages between soil contamination and water quality degradation, with anthropogenic activities such as agricultural runoff and poor waste disposal practices serving as primary contamination sources.

The water quality assessment revealed nitrate concentrations ranging from 125-285 mg/L during the rainy season and 67.42-153.67 mg/L during the dry season, significantly exceeding the WHO limits of 50 mg/L. Physical and chemical parameters, including pH (6.1-9.47), turbidity (20.34-49.3 NTU), dissolved oxygen (4.54-8.9 mg/L), and electrical conductivity (206.4-980.44 µS/cm), further confirmed the extent of water quality degradation. Seasonal variations were particularly pronounced, with elevated contamination during the rainy season reflecting increased runoff from contaminated soil sources.

Soil analysis revealed nitrate concentrations ranging from 164.54 to 390.50 ppm, with higher bulk density soils showing greater nitrate retention. The correlation between soil contamination and groundwater nitrate levels confirms the soil-water contamination pathway. Nitrate intake levels across all age and weight categories exceeded WHO recommended limits, with individuals aged 51–65 and those weighing 65 kg experiencing the highest exposure, reaching 585.46 mg/day during the rainy season compared to WHO limits of 240.5 mg/day.

To mitigate these risks, the study recommends adopting sustainable waste and agricultural management practices, including reduced fertilizer use and improved runoff control. Regular seasonal monitoring of nitrate levels in both soil and water, especially during the rainy season, is essential for guiding interventions. Enhancing water treatment infrastructure, promoting rainwater harvesting, and improving filtration systems during periods of peak contamination can significantly reduce nitrate exposure. Public health campaigns targeting vulnerable populations such as children and the elderly should be prioritized, alongside community-based water management initiatives. These comprehensive strategies aim to improve both soil and water quality while safeguarding the health of residents in the Sango area of Ibadan.

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