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Quality assessment of sachet and bottled water produced in Ile-Ife, Osun state, Nigeria

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Abstract
This study evaluates the quality of sachet and bottled water in Ile-Ife, Osun State, Nigeria. It also provides insights to achieve universal access to safe drinking water and sustainable water resource management.
A list of water production companies in the study area was obtained from the National Agency for Food and Drug Administration and Control (NAFDAC). Physical and chemical analyses; electrical conductivity (EC), total dissolved solids (TDS), turbidity, pH, total alkalinity, hardness, nitrates, and sulfites were conducted on each sample for quality and potability. Laboratory results were compared with the World Health Organization (WHO) and Nigeria Institute of Standards (NIS) publications on drinking water quality.
Based on the analysis of the results, out of the 58 samples collected, 16 samples (20.51%) of the samples shows total alkalinity levels below the WHO permissible limit of 20 mg/L, potentially affecting the water's buffering capacity and pH fluctuations. Additionally, 11 samples (14.10%) have total hardness levels exceeding the WHO limit of 100 mg/L. Furthermore, 38 samples (32.05%) shows pH levels below the NIS acceptable range (6.5-8.5), indicating potential acidity and corrosion risks. However, EC and turbidity levels are within limits for all samples, ensuring the water's mineral content and clarity meet the permissible standards.

Keywords: Water quality, sachet water, bottled water, Ile-Ife Osun State, drinking water

Introduction
Access to safe drinking water is a fundamental necessity for sustaining life, including human existence. The pursuit of Sustainable Development Goals (SDGs) is of paramount importance to address global challenges, particularly in the context of improving access to safe and clean drinking water [1]. SDG number 3, which focuses on "Good Health and Well-being," seeks to ensure universal access to safe and affordable drinking water for all. By evaluating the quality of sachet and bottled drinking water in Ile-Ife, this study directly aligns with SDG 3, as it assesses the safety and suitability of locally available water sources. Additionally, SDG number 6, "Clean Water and Sanitation," aims to ensure availability and sustainable management of water resources. Through comprehensive analyses of water parameters and identifying potential health risks, this research contributes valuable insights to achieve SDG 6, guiding policymakers and stakeholders in implementing sustainable practices to provide clean and safe drinking water to the communities in the study area. By addressing the specific challenges related to water quality, this study endeavours to support the broader global goals of improving health and access to clean water, ultimately contributing to the achievement of SDGs 3 and 6 in the region and beyond.
However, in many developing countries, the availability of clean water and proper sanitation remains a significant challenge, leading to the prevalence of waterborne infections and related health issues [2, 3]. Primary health care principles emphasize the importance of providing a safe and treated water supply, which is more readily achieved in developed countries compared to underdeveloped regions [4]. In this regard [5], emphasized the critical need to explore locally generated low-cost alternative drinking water systems, including locally produced sachet and bottled water, as a means to ensure sustainable access to safe water, particularly in rural and peri-urban regions.
The global impact of unsafe drinking water is evident from the staggering statistics of water-related diseases, resulting in millions of deaths annually, with children being the most vulnerable [6]. Safe drinking water is defined as water that does not pose significant health risks over a lifetime of consumption and requires appropriate protection, treatment, and

management to ensure its quality [7].

In Osun state, Nigeria, sachet and bottled water, commercially processed and packaged for human consumption, have gained popularity due to their affordability and accessibility [8]. However, there are growing concerns about the potential health hazards associated with the overall quality of the water, leading to diseases such as diarrhea, cholera, dysentery, and others [9]. Despite the prevalence of these packaged drinking water options, there is a limited documented evidence of their safety and quality, particularly.

This study aims to evaluate the physiochemical and important chemical composition of sachet and bottled water produced in Ile-Ife, Osun State, Nigeria.

Through the assessment of physiochemical parameters such as Total Dissolved Solids (TDS), electrical conductivity, and turbidity, along with crucial chemical parameters like pH, total alkalinity, hardness, nitrates (NO_3), and sulfites (SO_3^{2-}), and by conducting extensive analyses on the results of each parameter of the water samples, this research aims to determine the overall quality of the sachet and bottled water produced in the study area. The comprehensive examination of these water parameters will provide valuable insights into the safety and suitability of packaged water in the region.

Materials and Methods

Description of Study Area

Ile-Ife, a historic city in Osun State, Nigeria, is home to over 500,000 people. Positioned at approximately 7.51650° N Latitude and 4.52860° E Longitude, it is revered as the "Cradle of Yoruba Civilization," carrying significant cultural and mythological importance. The city's captivating history, vibrant traditional festivals, exquisite art, and skilled craftsmanship attract visitors from both local and international tourists, creating a distinctive fusion of education and cultural heritage.

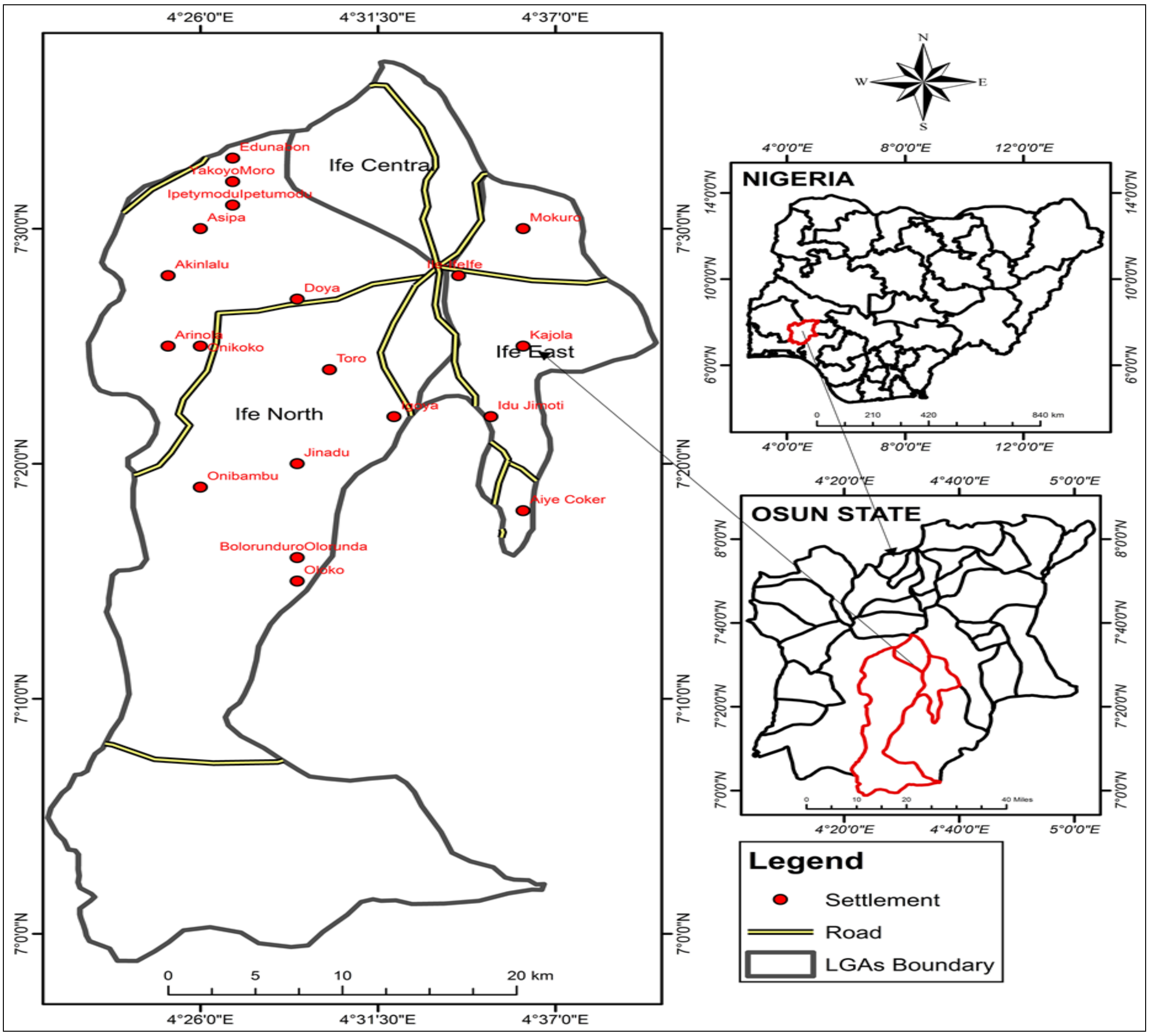

Fig 1: Map of the study area

Sample Collection and Preparation

The full list of sachet and bottled water produced in Ile-Ife, covering Ife North, South, Central, and Ife East, was obtained from the National Agency for Food and Drug Administration and Control (NAFDAC). This list served as a guide to select and purchase samples from the respective areas of coverage within Ife.

The samples were directly purchased from local markets to ensure authenticity, and immediate testing was conducted within three days of collection to preserve their original quality. No additional preparation was performed on the samples before testing. Prior to analysis, the samples were maintained at a room temperature of 25 °C.

Fig 2: Collected Samples of sachet and bottled water

Sample Size Determination

Given the extensive list of companies producing sachet and bottled water in Ile-Ife, a method for sample size determination was adopted to streamline the study while maintaining accurate outcomes. Statistical approaches were employed to optimize the list, reducing the number of companies without compromising the study's reliability.

The method chosen to determine the optimized sample size was the sample size formula due to its high level of accuracy. The formula is as follows:

$n_o = \frac{Z^2pq}{e^2}$ [10]

Where n_o = sample size, Z^2 = abscissa of the normal curve (from statistical tables), p = estimated variability of the population, q = 1-p, e = desired level of precision.

The initial breakdown of the companies provided by NAFDAC included sixty-seven (67) producing 50 cl SACHET water, three (3) producing 75 cl PET bottles only, and eleven (11) producing both 75 cl PET bottles and 50 cl SACHET water. For this study, a precision level of ±5% and a confidence level of 95% were utilized. The Z value for a 95% confidence interval from the statistical table is 1.96. To ensure robust analysis, the population proportion (p) variability was assumed at its maximum of 50%, considering the lack of known variability in the population.

Sample Size Calculation:

Z = 1.96 (Z value for a 95% confidence interval), p = 50% = 0.5, q = 1 - 0.5 = 0.5, and e = 5% = 0.05

Substituting into the formula: $n_o = \frac{1.96^2 \times 0.5 \times 0.5}{0.05^2}$, the initial sample size was calculated to be 384 companies.

However, for the actual population, the sample size can be reduced using the formula:

$n = \frac{n_o}{1 + \frac{n_o - 1}{N}}$, where N = population size and n = sample size. With a total population size (N) of 81 companies; $n = \frac{384}{1 + \frac{384-1}{81}} = 67$. The final reduced sample size was calculated to be sixty-seven (67) companies.

The distribution of the reduced sample size among different categories is as follows:

a. Companies producing only 75 cl pet bottles: 3 companies
b. Companies producing only 50 cl sachet: 56 companies
c. Companies producing both 75 cl pet bottle and 50 cl sachet: 9 companies

However, in total, only 58 water samples were collected for testing. Among the collected samples, 1 company exclusively produced 75 cl PET bottles, while five (5) companies produced both 75 cl PET bottles and 50 cl SACHET water, and fifty-two (52) companies produced only 50 cl SACHET water. The reduction in the number of companies/samples with respect to what was initially considered was attributed to some companies no longer being in production.

Materials and Methods

1. Physiochemical characteristics

The physiochemical parameters considered were Electrical conductivity, Total Dissolved Solids (TDS), and Turbidity. Electrical conductivity (EC) was measured using a calibrated conductivity meter. The turbidity test was conducted using a calibrated Turbidity meter that is measuring in nephelometric turbidity units (NTU) calibrated using a standard reference solution with a known turbidity value. Gravimetric analysis was employed to determine the TDS of the samples, which involves measuring the weight of the particles or solids that remains after oven drying [11].

2. Chemical characteristics

The chemical parameters considered were pH, total alkalinity, total hardness, nitrates (NO_3), and sulfites (SO_3^2). The pH was measured directly using a pH meter. Titration method was used to determine the hardness of the water samples, using disodium ethylenediaminetetraacetic acid (EDTA) as the titrant, calcium carbonate (CaCO3) as the buffer solution, and Eriochrome black T indicator solution (EBT). Titration method was also used to determine the total alkalinity of the samples. The titration was carried out in two phases using two indicators: phenolphthalein and the mixed indicators of bromocresol green and methyl red [11]; [12].

The process for sulfite determination includes acidification of the water sample using hydrochloric acid (HCl) to convert sulfates (SO_4^{2-}) to sulfites (SO_3^{2-}). Subsequently, titration analysis is conducted using a standardized sodium thiosulfate solution ($Na_2S_2O_3$) as the titrant.

Statistical analyses used to evaluate the quality of the water samples collected including the Mean, Median, Standard Deviation, and Correlation Analysis. The Mean was used as a measure of central tendency, providing typical values for each parameter. The Median offered a stable representation of the central value, resistant to extreme values. The Standard Deviation quantified the variability of data points around the Mean, indicating the spread of data for each parameter. Correlation Analysis identified relationships and dependencies among the water quality parameters, revealing interconnected effects. These analyses provided insights into the overall water quality, contributing valuable information for making informed decisions and recommendations to improve sachet and bottled water production in Ile-Ife.

Results and Discussion

Electrical Conductivity

The electrical conductivity analysis presented Fig. 3 revealed notable variations in the water samples, with values ranging from 6.8 µS/cm (S42) to 79 µS/cm (S28), all below the NIS limit of 1000 µS/cm. The results indicate high water clarity with minimal dissolved substances affecting conductivity. The samples show a moderate standard deviation of 19.08 µS/cm, indicating a moderate level of dispersion from the mean.

Total Dissolved Solid

TDS analysis presented in Figure 4 revealed variable dissolved solid concentrations (80 mg/L to 680 mg/L) in the samples, with 6 samples exceeding the NIS limit of 500 mg/L, indicating the presence of dissolved solids (or minerals such as Sodium, Nitrates, etc.). Average TDS was 317.91 mg/L, median 285 mg/L, with a standard deviation of 152.5 mg/L, showing moderate variability around the mean. TDS values correlated with electrical conductivity positively. Further examination and treatment of samples exceeding NIS limits may be required.

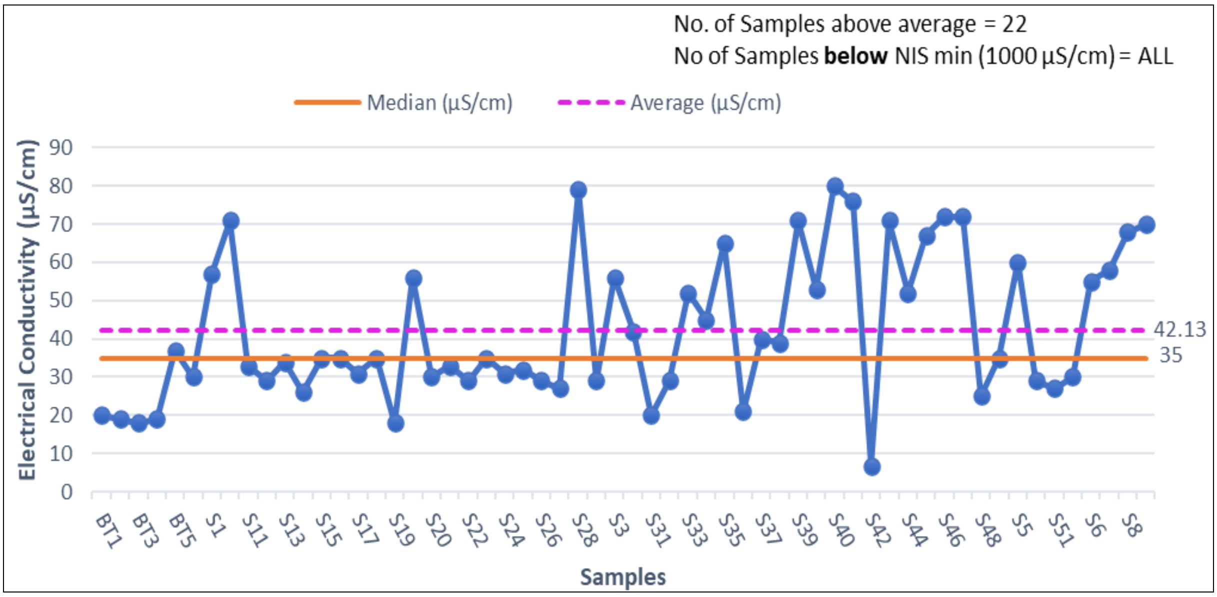

Fig 3: Variation in electrical conductivity

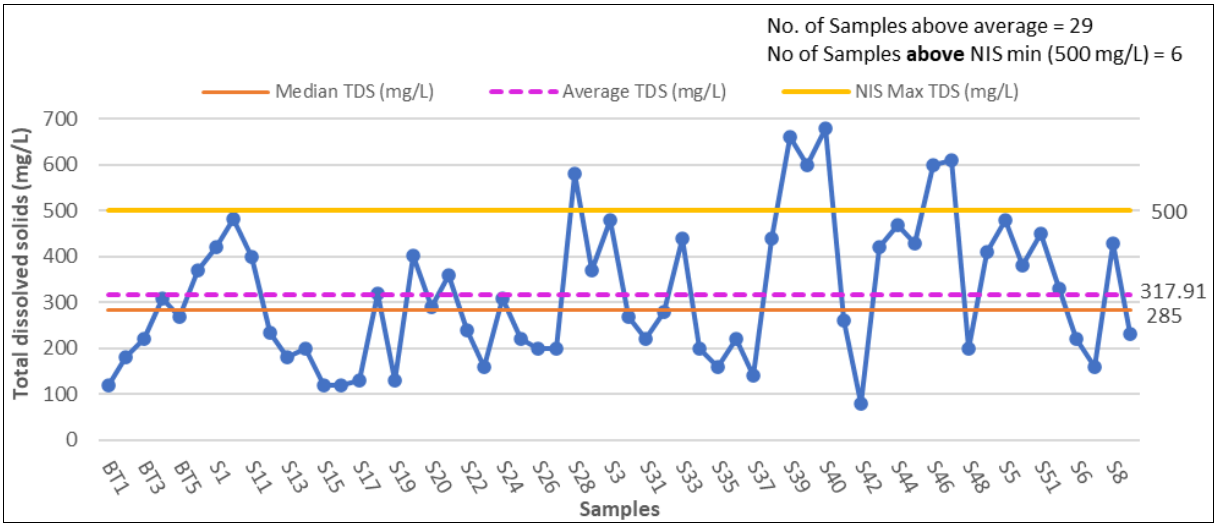

Fig 4: Variation in Total Dissolved Solid (TDS)

Turbidity

The Turbidity test analysis presented in Figure 3 revealed generally low turbidity levels in the water samples. The average turbidity was 1.5 NTU with a median of 1 NTU, indicating good water clarity. All 58 samples were below the NIS maximum turbidity limit of 5 NTU, confirming good water quality. The standard deviation of 0.66 suggested minimal variability among the samples, ensuring consistent water clarity. Most of the samples had turbidity levels of 1 NTU, further supporting the observation of low turbidity. Some samples exhibited slightly higher turbidity but still remained below the NIS limit.

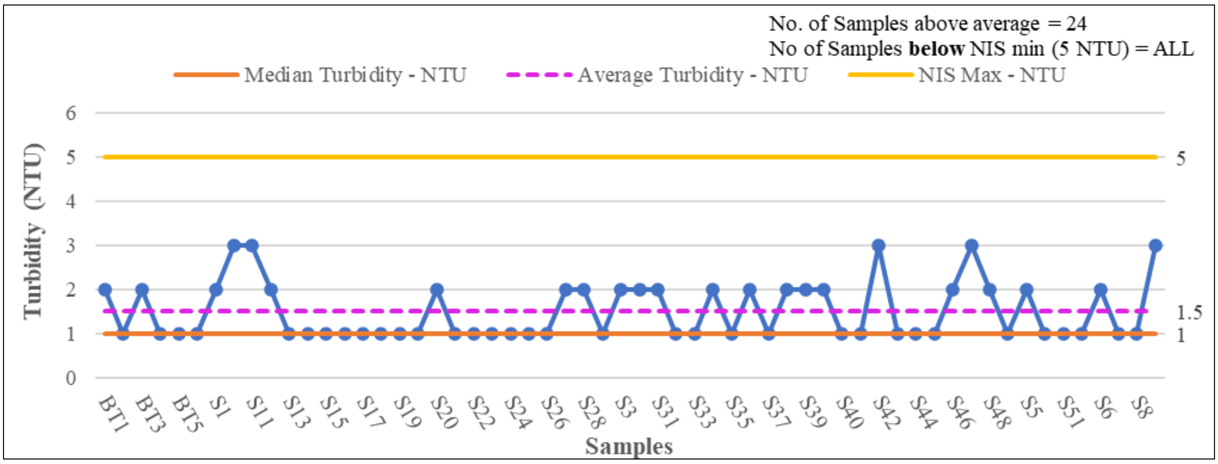

Fig 5: Variation in Turbidity

Hydrogen ion (pH) concentration

The pH analysis of the water samples shown in Figure 6 revealed a range of acidity levels, with an average pH of 6.66 and a median of 6.5. Most samples fell within the slightly acidic to neutral range, with 25 samples below the NIS minimum pH range of 6.5-8.5. However, 25 samples exhibited pH levels above the average, indicating some samples had high pH values as well. The low standard deviation of 0.453 indicated relatively consistent and stable pH levels among the samples. The distribution of samples showed a significant portion with slightly acidic to neutral pH values. Only 11 samples had pH values above neutral (7). Health implications associated with consuming water with pH values below the minimum permissible limit include potential dental enamel erosion and digestive problems. While water with high pH may lead to scale buildup in pipes and fittings.

Total Alkalinity

The alkalinity analysis of the water samples presented in Fig. 7 revealed a wide range of values, with an average of 40.77 mg/L and a median of 35.25 mg/L. The data showed high variability, as indicated by the significant standard deviation of 27 mg/L. Among the 58 samples tested, 21 had alkalinity levels above the average, while 16 samples fell below the WHO minimum limit of 20 mg/L, indicating acidity. However, all samples remained below the WHO maximum limit of 200 mg/L.

The presence of alkaline substances like bicarbonates and carbonates which are usually derived from geological formations contribute to higher alkalinity, while regions with low carbonate rock content will likely have lower alkalinity values. Alum addition during water treatment can also reduce alkalinity and pH, particularly in water with initially low alkalinity. Alkalinity plays a vital role in resisting pH changes and preventing sudden drops in pH, which can affect water quality. Both low and high alkalinity levels may have implications for health and water palatability.

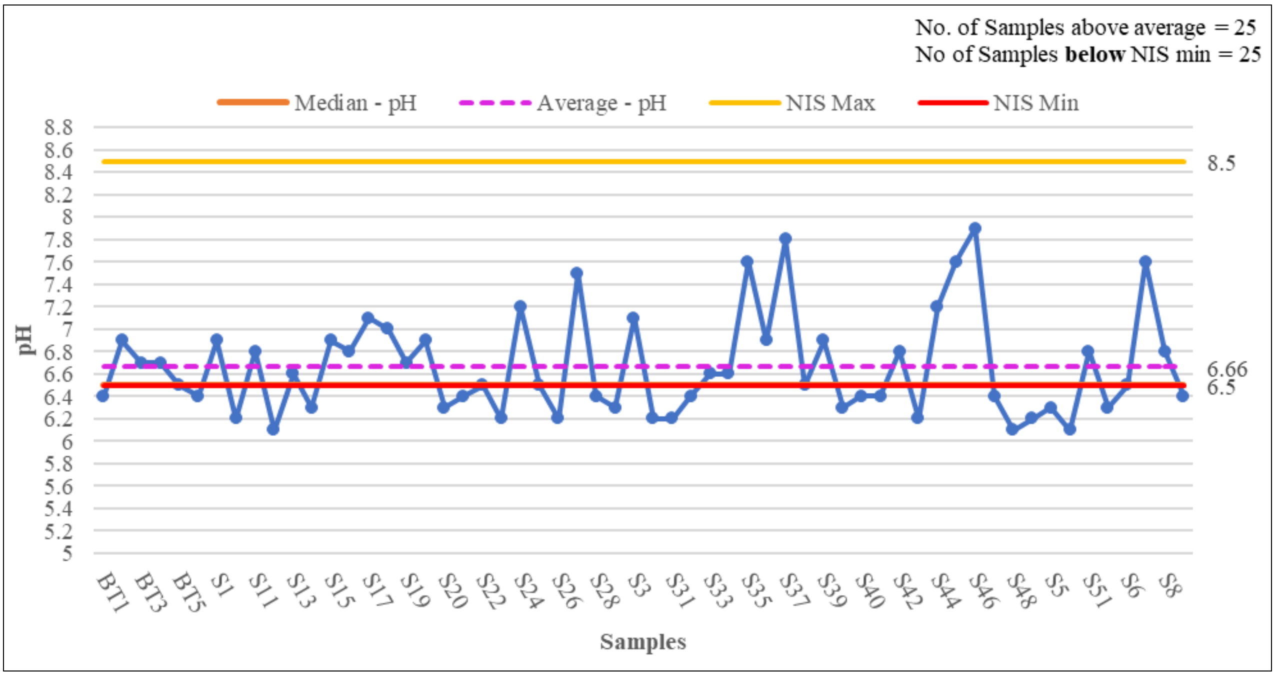

Fig 6: Variation in pH

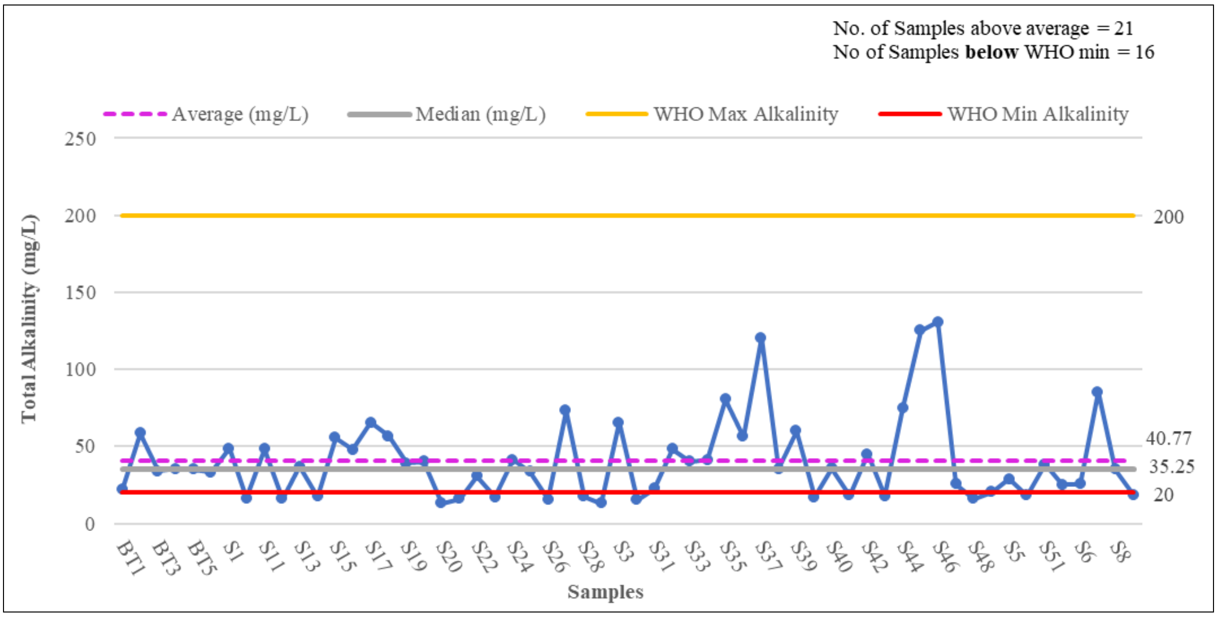

Fig 7: Variation in total alkalinity

Total Hardness

The Total Hardness analysis of the water samples presented in Figure 8 showed an average value of 66.97 mg/L, a median of 54.8 mg/L, and a standard deviation of 31.54 mg/L, indicating significant variability in hardness levels among the samples. Out of the 58 samples, 24 had hardness values above the average, while 11 samples were below the WHO minimum standard of 100 mg/L. The higher average hardness suggests the presence of significant amounts of calcium and magnesium in the water. A significant number of samples exhibited moderate hardness levels, while some samples showed elevated hardness levels above the WHO recommended limit. The health effects of water hardness are uncertain, with inconclusive evidence of negative impacts. Some studies suggest potential protective benefits, but more research is needed to fully understand the relationship with health outcomes (WHO, 2004).

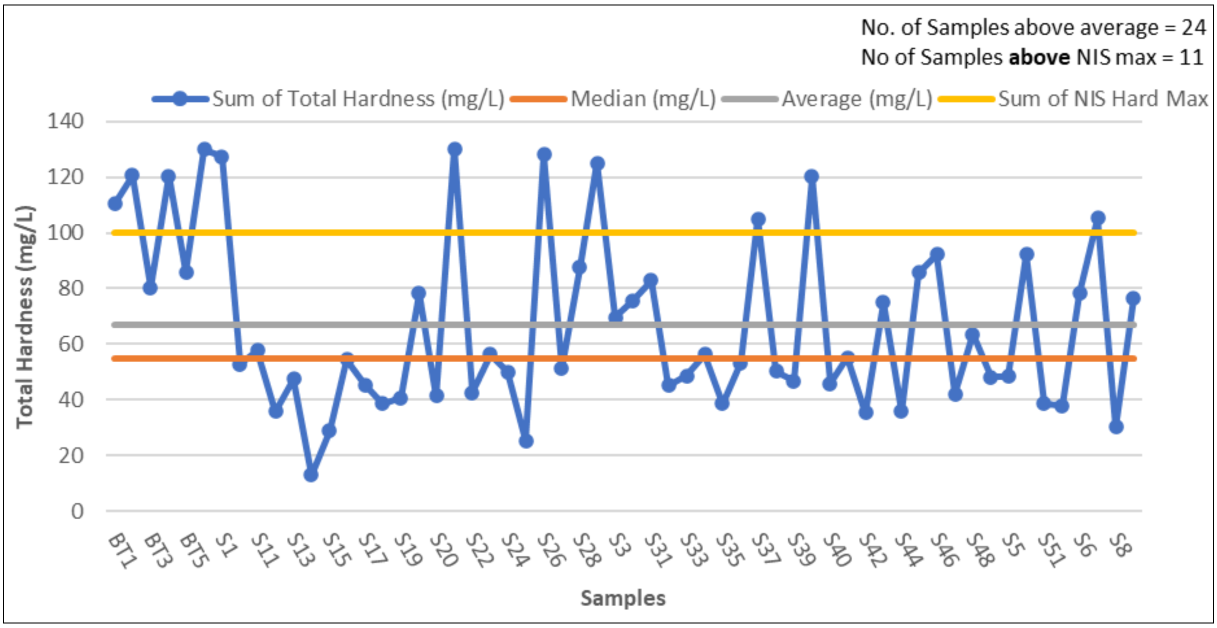

Fig 8: Variation in Total Hardness

Nitrates concentration

The analysis of nitrate levels in the water samples shown in Figure 9 revealed significant variability, with an average concentration of 19.81 mg/L and a median of 9.1 mg/L. Some samples showed considerably higher nitrate levels than others, indicated by the wide standard deviation of 24.83. Twenty samples exceeded the average, and eight samples surpassed the NIS maximum permissible limit of 50 mg/L. High nitrate levels in drinking water, often from agricultural and sewage sources, can pose health risks, particularly for vulnerable populations like infants and pregnant women.

Sulfites concentration

The sulfite test results presented in Fig. 8 with an average concentration of 7.89 mg/L and a median of 6.9 mg/L, with considerable variability indicated by the standard deviation of 6.35. Out of the 58 samples, 19 had sulfite levels above the average, while 11 exceeded the WHO's maximum permissible limit of 10 mg/L, raising concerns about water quality. Consuming water with high sulfites levels can trigger allergic reactions, especially in individuals with sensitivity or asthma, and may lead to respiratory issues.

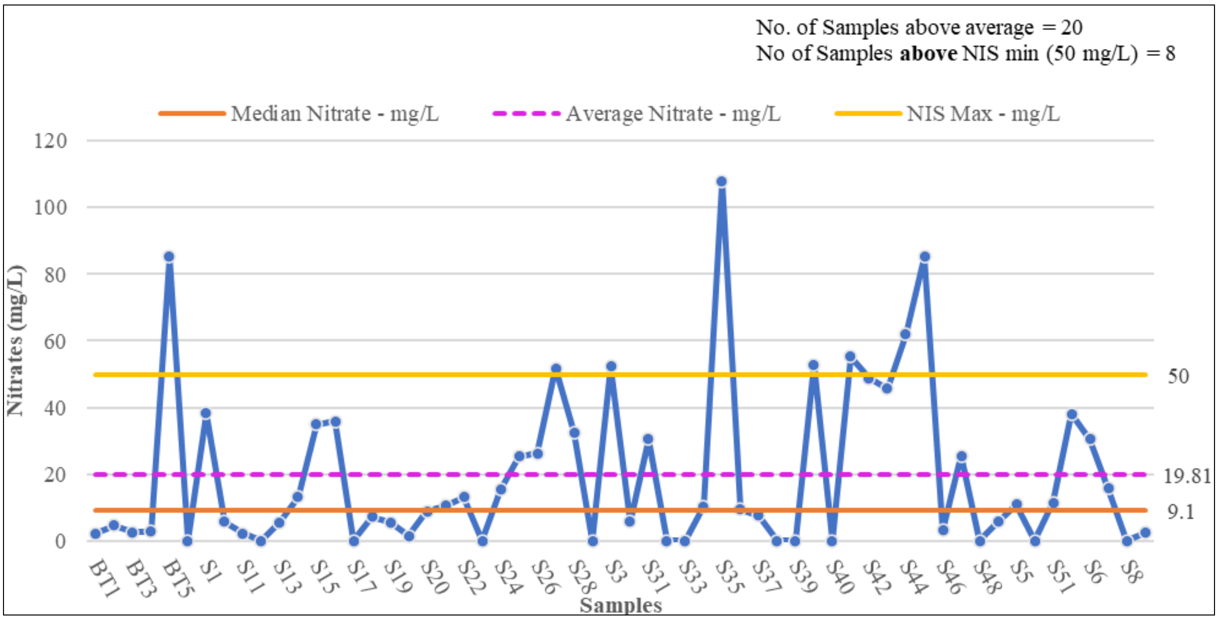

Fig 9: Variation in Nitrates

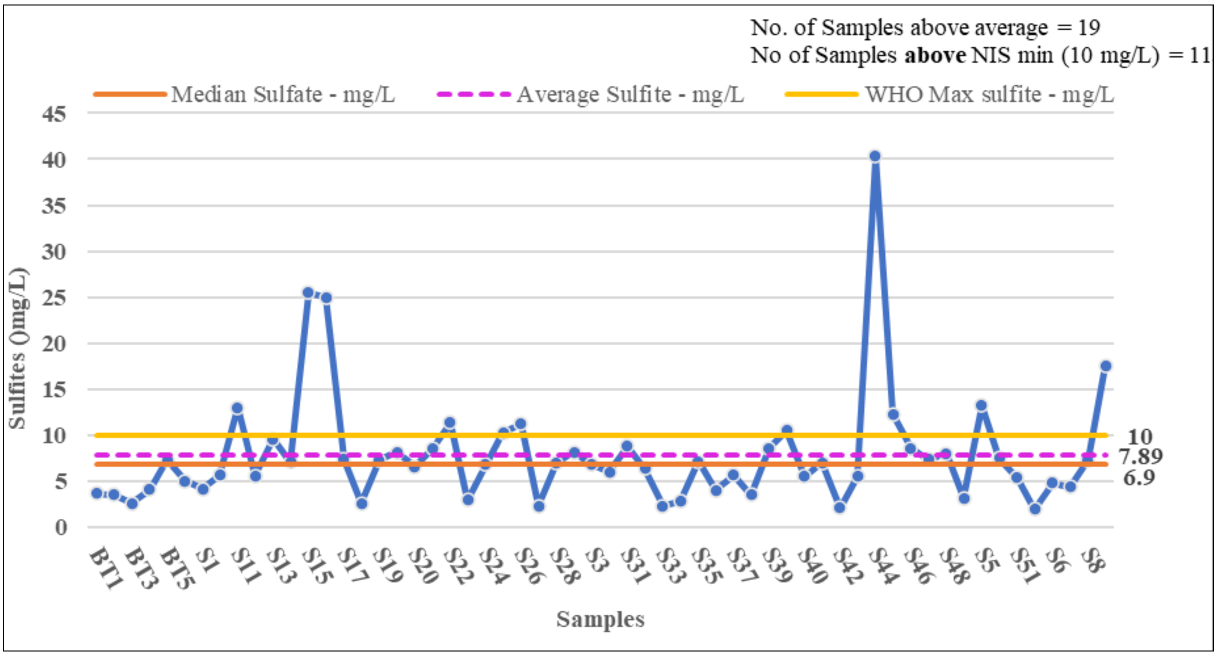

Fig 10: Variation in Sulfites

Conclusion

In conclusion, analysis of sachet and bottled water produced in Ile-Ife reveals the quality of the major drinking water source in the region. While parameters such as electrical conductivity and turbidity generally meet permissible standards, the presence of high levels of total hardness, nitrate, and sulfite raises health concerns as well as low levels of total alkalinity. These findings accentuate the need for ongoing monitoring and effective water treatment measures to ensure the safety and suitability of drinking water.

To address the identified challenges and contribute to the achievement of SDG goals particularly SDG 3 (Good Health and Well-being) and SDG 6 (Clean Water and Sanitation), it is recommended that collaborative efforts among relevant stakeholders be promoted. Public health authorities should establish regular monitoring programs to assess water quality parameters and promptly address any deviations from permissible limits. Employing appropriate water treatment processes such as ion exchange, reverse osmosis, and chemical oxidation can effectively reduce high hardness, nitrate, and sulfite levels. Additionally, public awareness campaigns should be launched to educate communities about the importance of clean drinking water, proper water storage, and preventive measures against contamination.

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