Evaluation of the Physical, Chemical, Bacteriological and Trace Metals Concentrations in Different Brands of Packaged Drinking Water

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Abstract—**Human survival largely depends on potable water quality. This study used current analytical procedures and compared with the National Agency for Food and Drug Administration Control (NAFDAC) drinking water specification to evaluate the physio-chemical and microbiological characteristics of fifteen packaged water brands that are available locally. Atomic absorption spectroscopy was used to determine trace metals while instrumental techniques determined the physical and chemical parameters. The evaluation focused on the pH, colour, total dissolved solids, turbidity, dissolved oxygen, fluoride, chloride, iron, zinc, magnesium, calcium, potassium, and sodium. In all the samples examined, chromium, manganese, cadmium, and copper were not detected. However, total bacterial counts were discovered in samples (S1, S2, S3, B1 and B2) with values of 2, 3, 5, 3 and 1 cfu/100 ml, respectively. Packaged water containing these type and quantity of bacteria are not fit for consumption by human beings. It requires the most appropriate techniques for processing.**

Index Terms—**Contamination, packaged water, total bacterial count, turbidity, trace metals**

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I. Introduction

ALL living organisms existence is wholly based on water resource availability [1], which is a valuable resource required for their survival [2]. It is a significant nutritional element needed to maintain a healthy status [3]. In addition to drinking, water is largely used for many national, industrial and recreational functions, such as sporting operations, beverage bottling, laundry, bathing, brewing, cooking and food processing [4]. Major sources of water available for drinking include surface water, underground water and rainwater [5, 6].

Water is colourless in tiny quantities but appears pale blue in a profound column. It boils at 100ºC and freezes at 0ºC under standard atmospheric pressure of 760 mmHg. Many substances possess the potential of dissolving in water, giving it distinct tastes and odours [7]. It's a fluid that is clear, transparent, tasteless, and non-toxic, yet human and animal activities continue to threaten the wholesomeness of drinking water [8, 9].

Potable water accessibility and affordability are essential to sustainable development [10] as stated in SDG6 of the UN Sustainable Development Goals. Its quality and amount vary over time and space, and it is a significant element for the essential growth of any region. The system of equilibrium is troubled when changes in the natural water quality occur, thereby making it unfit for designated uses [11]. In line with the relevance attached to clean water, World Health Organization (WHO) published the first guideline for drinking water in 1983-84 and updated as seen

in Table I. The WHO guideline identified safe drinking water as that which do not pose important health risks over a lifetime of consumption, to including distinct sensitivities that may arise between phases of life. Water quality assessment is a resilient task that involves the bacteriological, chemical and physical parameters such as chloride, pH, Escherichia coli (E. Coli), colour, total dissolved solids, residual chlorine, iron, nitrate/nitrite, fluoride, total coliform count, dissolved oxygen etc. [12, 13]. In recent times, water contamination level has attracted a great deal of attention to environmentalist worldwide [14]. Introduction of solid waste, wastewater and other sources of pollution and contaminants into water sources in the last century has jeopardized drinking water security in a poor area. The consumption of unsanitary water could have catastrophic consequences for our health. Therefore, packaged water was designed and introduced to provide the public with clean, aesthetically pleasing and affordable drinking water as well as to reduce the severity of waterborne diseases in Nigeria [15].

TABLE I
WHO STANDARD FOR DRINKING WATER [16]

Parameters	Standard	Parameters	Standard
Colour	Colourless < 50	Magnesium	150
Odour	Odourless	Cadmium	0.003
Taste	Tasteless	Calcium	75-200
Turbidity	0.0 – 0.5	Chloride	700
pH	6.5 – 8.5	Copper	2.0
Total Solid	100	Chromium	0.05
Total Alkalinity	100	Fluoride	1.5
Total Hardness	250	Lead	0.01
Iron	0.05-0.3	Nitrite	3
Zinc	5	Nitrate	50
Sulphate	250	Total Count	0
Sodium	200	Escherichia	0
Manganese	0.5		

* Colour (Pt.Co.); Turbidity (NTU); pH, Total Count (cfu/ml): Escherichlua (cfu/ml)
* Unit for all other parameters are in mg/L

Approximately 42% of Nigeria's population today, lack access to quality drinking water, many of whom live in rural places [17]. Many rural community dwellers fulfil their daily water needs from wells, rivers, lakes, or reservoirs that are polluted and remote. The Nigerian government had recently decried Nigerians' low access to clean drinking water, resulting in elevated mortality rates from waterborne diseases such as diarrhoea, typhoid, cholera, and blindness from the river water source. Because of these, drinking water standard set by the National Agency for Food and Drugs Administration and Control (NAFDAC) shown in Table II was enforced.

Packaged (sachet and bottled) water has become a significant main water source for drinking, especially in urban regions, in reaction to serious municipal drinking water shortages, contaminations, increasing mortality rates and prevalence of waterborne diseases in the country [18]. In developing nations, packaged water consumption has risen in recent years [19]. It has become the major drinking water source for West Africans despite the continuing controversy over [20] uncertainties that travails the hygienic setting and circumstances under which most packaged water products are manufactured and stored [21]. The packaged water industry has seen a substantial number of manufacturers flocking throughout the country's towns and cities [22]. Packaged water filling the unmet need for a simple and affordable source of water [23].

Sachet water is any water designed for human consumption that is contained in sealed plastic and dispersed or sold [19]. Bottled water is described as water that was sealed in bottles with little or no additional nutrients except that it may contain appropriate fluorides [1]. Most packaged water are prone to microbial, poisonous organic and inorganic contamination [2]. As market share moves from cottage industry players to high-volume commercial manufacturers, the industry continues to mature. Advanced manufacturing lines of packaging are susceptible to biofilm growth, and traditional microbiological indicators of faecal water contamination in such a widely consumed commodity may not capture all potential hazards to human health. Therefore, accessible packaged water must be of the best quality to protect public health.

The basic concern for public health today is the continued proliferation and unjustified consumption of this packaged water. For safety purpose, it is more appropriate to understand their microbiological quality [19]. This presents an opportunity for the re-evaluation of packaged water quality in an urban setting that is rapidly industrializing Sokoto state, since producers are often more worried about their profits than with the quality of water sold to the public [5]. Therefore, this research work adopted the NAFDAC drinking water standard as a basis for comparison with the test result of the sample for quality test.

II. Materials and Methods

The method of study involves the collection of packaged water sample (sachet and bottle) from commercial selling points. The study used the standard method of collection and laboratory analysis since the interpretation of laboratory analysis depends on the condition of sampling. It also employed multiple sampling methods, average results taken and compared with NAFDAC standards for drinking water.

A. Study area

The study area is Sokoto, the main city in Sokoto State. It is located in the northwest region of Nigeria. The city covers an area of 25,973 km². As of 2006, the population of people living in the state is around 427,760. Sokoto State with latitude and longitude as 13.005873 and 5.247552 respectively, with an elevation of 304.291.

Goronyo Dam is the main water source in Sokoto. It was constructed by Sokoto state government and manged by the Sokoto Rima River Basin Development Authority (SRRBDA). The dam is located 25 km east of Goronyo town near Keta village and 90 km from Sokoto city. It is designed for multi-purpose storage with a capacity of nine hundred and forty-two million cubic meters (942 x 106 m^3)

of water. This Dam also supplies over eighty thousand million cubic meters (80 x 106 m^3) of water every year to Argungu, Birnin-Kebbi and Sokoto water supply schemes. Goronyo dam with a total length of 12.462 meters and natural embankment of 12.271 meters totalling to 24.733 meters consists of three banks, namely: secondary dam, main dam, sand and saddle dyke. The reservoir created by the dam covers an area of 200 km^2 (20,000 ha). The Goronyo dam used for the water supply of Sokoto & Kebbi states, irrigation, recharging of an aquifer, flood regulation, fisheries, and tourism.

TABLE II
NAFDAC DRINKING WATER STANDARD [24]

Parameters	Standard	Parameters	Standard
pH	6.5-8.5	Sulphate	250
Colour	Colourless < 50	Fluorides	1.3
Odour	Odourless	Nitrates	3.0
Taste	Tasteless	Total Dissolved Solids	500
Turbidity	5.0	Free Fluoride	0.30
Dissolved C_{O2}	50.0	Copper	2.0
Phenolphthalein Alkalinity	100	Calcium	75
Total Alkalinity	100	Lead	0.01
Chlorides	250	Iron	0.03
Acidity	2.0	Zinc	5.0
Total Hardness	100	Magnesium	50.0
Calcium Hardness	75	Total Bacterial Count	0
Magnesium Hardness	50		

* Colour (Pt.Co.); Turbidity (NTU); pH, Total Bacterial Count (cfu/ml)
* Unit for all other parameters are in mg/L

B. Samples and sampling technique

All the samples used in this research work were selected at random based on the list of packaged water product registered with the regulatory agency (NAFDAC) with attention to popular brand names commonly consumed locally. Fifteen (15) samples consisting of ten (10) brands of sachet water denoted as S1-S10 and five (5) brands of bottled water denoted as B1-B5 marketed in Sokoto metropolis and taken for water quality tests. Samples from each factory were purchased from vendors along Abdullahi Fodio Road corresponding to the primary commercial areas that serve as market centres for the contiguous communities of Sokoto North, collected in sterilized polythene bags, labelled appropriately, and transferred to the laboratory. Samples were stored in a refrigerator at 4ºC before analysis.

C. Materials

Several types of equipment and reagents were used to collect, preserve, characterize, and analyse samples [25-30]. This comprises ager powder, deionized water, thermometer, petri dish, test tube, acetate solution, colorimeter, pipette, beaker, stirrer, spadns reagent, brom cresol, green methyl red powder, pH/EC/TDS digital meter, glass container, distilled water, nitric acid, atomic absorption spectrophotometer and inductively coupled plasma.

D. Laboratory Test

Table III shows the categories of tests carried out using the standard laboratory techniques [22, 31, 32]. The ascertainment of trace metals concentration in the packaged water samples was conducted by Atomic Absorption Spectrometer (AAS) and Inductively Coupled Plasma (ICP) using the [33-35] Standard Method for water and wastewater evaluation. The analyses carried out in triplicate and acquired findings contrasted with the secondary information collected from NAFDAC standard papers shown in Table II.

TABLE III
LABORATORY TEST CONDUCTED

Physical Test	Chemical Test	Bacteriological Test	Trace Metals
Turbidity	pH	Total Bacterial Count	Copper
Colour	Dissolved Oxygen		Lead
Odour	Calcium		Zinc
Taste	Magnesium		Iron
Total Dissolved Solids	Chloride		Chromium
	Fluoride		Potassium
			Manganese
			Cadmium
			Sodium

III. Results and Discussion

The wholesomeness of the selected packaged (sachet and bottled) water brands sold and consumed in Sokoto state, that concerns physical, chemical, bacteriological parameters concentrations were determined in this study. Overall, 15 samples (10 sachets and 5 bottles), belonging to 15 different brands were analysed.

A. Physical Parameters: Taste and Odour

As these are parameters that affect water acceptability for domestic usage, an analysis conducted on all the packaged (sachet and bottled) water samples revealed that they are tasteless and odourless which conforms to the NAFDAC standard for drinking water. Therefore, the samples do not contain organic and mineral matter in excessive quantities. This may be due to the use of activated carbon and sand filters in all sachet water companies during processing [36].

B. Physical Parameters: Colour

The results obtained for colour shown in Figures 4.1a and 4.1b indicates that the sachet samples were within the range of (3-24) Pt-Co. which is less than 50 Pt-Co. while the bottled samples were all 0 Pt-Co. thereby conforming to the NAFDAC standard.

C. Physical Parameters: Turbidity

The existence of suspended solids results in turbidity that measures the cloudiness in water. It completely depends on the quantity of particulate matter in it. Thus, slightly turbid water indicates the presence of total suspended solids. The highly turbid water prevents visibility of the glass containing it [37]. The results of the analysis presented in figures 4.2a and 4.2b showed that the selected brands of sachet water (S1-S10) sold in Sokoto metropolis was observed to have

turbidity that ranged from (2-5) NTU respectively. Samples S4 and S5 with the highest turbidity values of 5.0 NTU and 4.0 NTU respectively can be described as slightly turbid while samples S6 and S7 had the lowest of 0.0 NTU. These values are however, still within the allowable limit of 5.0 NTU suggested by the WHO, National Industrial Standard (NIS) and NAFDAC of less than 5.0 NTU as shown in (Tables I & II). Furthermore, 0.0 NTU turbidity value was also obtained for all the selected brands of bottled water (B1-B5).

D. Physical Parameters: Total Dissolved Solids

The total dissolved solids describe the inorganic salt and a small amount of organic matter in solution or liquid. The presence of TDS in water can influence its taste. Nonetheless, drinking water with low TDS concentration may be inappropriate due to its flat insipid taste. TDS value of 15 - 140 mg/L (S1-S10) was recorded for sachet water samples while 21 – 91 mg/L (B1-B5) for bottled water samples. All values as illustrated in figures 4.3a and 4.3b and are within the 500 mg/L limit stipulated by NAFDAC standard.

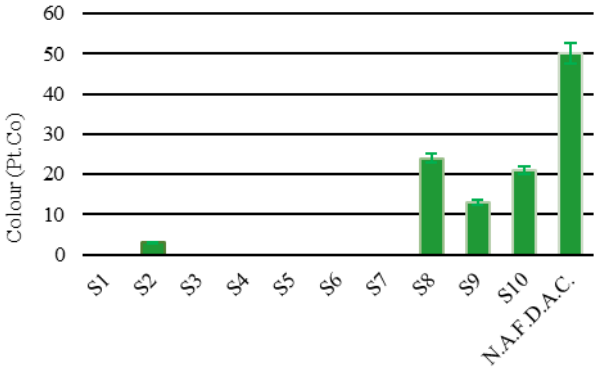

Fig. 4.1a: Colour for Sachet Water Samples

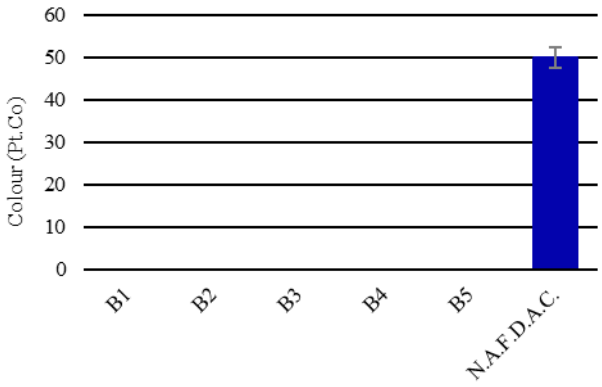

Fig. 4.1b: Colour for Bottled Water Samples

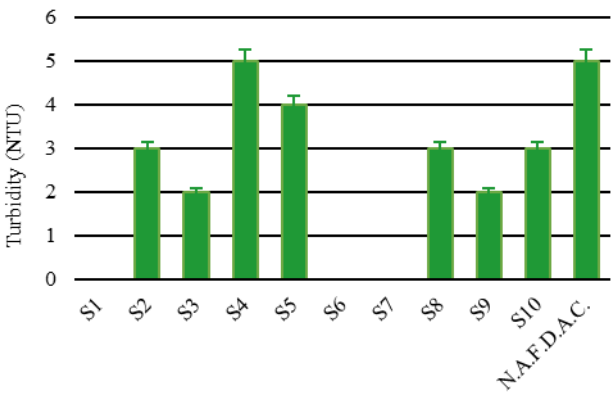

Fig. 4.2a: Turbidity for Sachet Water Samples

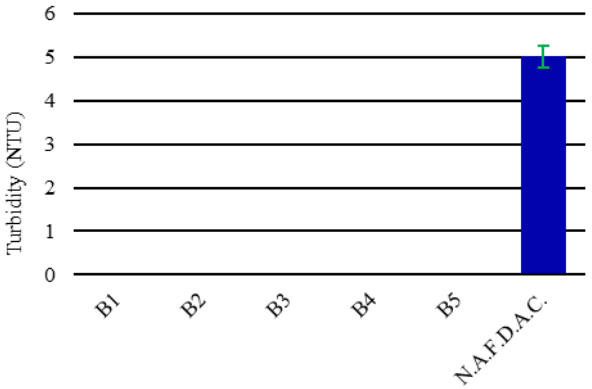

Fig. 4.2b: Turbidity for Bottled Water Samples

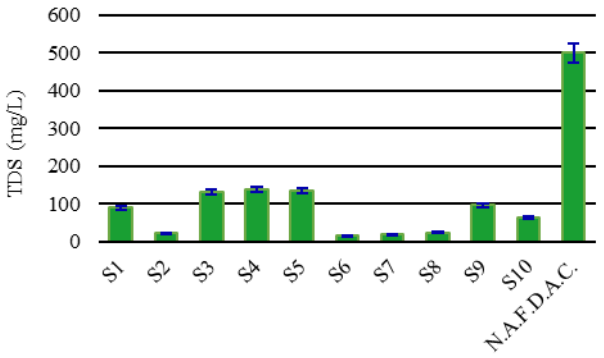

Fig. 4.3a: Total Dissolved Solids for Sachet Water Samples

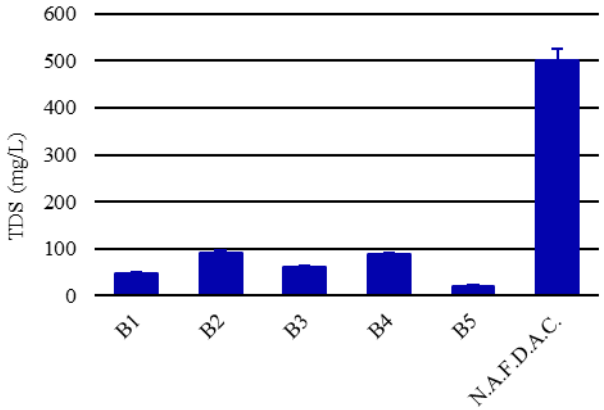

Fig. 4.3b: Total Dissolved Solids for Bottled Water Samples

E. Chemical Parameters: pH

The pH of water is known to be one of the essential

parameters for water quality because a high pH is an acrid taste for drinking water [38, 39]. Figures 4.4a and 4.4b showed the results on the packaged water samples from the test conducted. The pH values fluctuated within (7.4-8.3) for sachet water and (6.6-7.5) for bottled water, which is all within the recommended acceptable limit of (6.5-8.5) for NAFDAC drinking water standard. It was also observed that slightly alkaline pH was recorded in most samples, whereas sample B2 recorded slightly acidic pH. It is very important to conclude that water samples that has pH values within the regulatory guideline do not pose threat to human health.

F. Chemical Parameters: Dissolved Oxygen

The results obtained for dissolved oxygen (DO) of the samples as presented in figures 4.5a and 4.5b were within a range of (4.54-6.32) mg/L for sachet water and (5.27-5.81) mg/L for bottled water. These values are however still within the ranges of values stipulated by NAFDAC standard. An extremely high or low level of dissolved oxygen can damage aquatic life and affect the quality of water.

G. Chemical Parameters: Chloride, Fluoride, Calcium, and Magnesium

All the packaged water samples analysed had a chloride content of 0.1 mg/L except for S3 with 0.0 mg/L. The result is appreciably within the NAFDAC maximum permissible value of 250 mg/L desirable for drinking water. However, no reports on the adverse health effects from the intake of water containing high concentrations of chloride [40], although high concentration of chloride ions in drinking water can adversely increase the taste of the water. The result showed that the fluoride content of the analysed sachet water samples was within a range of (0.03-0.69) mg/L while bottled water samples were within (0.06-0.70) mg/L. It was observed from figures 4.6a and 4.6b that samples S2, S3, B2, and B4 recorded 0.00 mg/L concentration of fluoride. Samples analysed were all below 1.3 mg/L as recommended by NAFDAC about fluoride. Epidemiological evidence revealed that people consuming water with concentrations beyond 1.3 mg/L are at risk of dental fluorosis, while higher concentrations lead to increased risk of skeletal fluorosis. According to [25], an intake of more than 6 mg/L of fluoride per day results in fluorosis.

Figures 4.7a and 4.7b showed the concentration of calcium, varying from (0.2 –51.4) mg/L and (2.0 –20.3) mg/L for sachet and bottled water respectively. The observed values in all the analysed water samples are satisfactorily below 75 mg/L as recommended by NAFDAC. Excess calcium may influence a salty taste in water. Similarly, sachet water analysed has recorded a magnesium concentration that ranged between (4.6-25.5) mg/L and the bottled water from (11.5-28.0) mg/L as illustrated in figures 4.8a and 4.8b respectively. The analysed results indicated that the values obtained were within the acceptable limit of 50 mg/L recommended by NAFDAC.

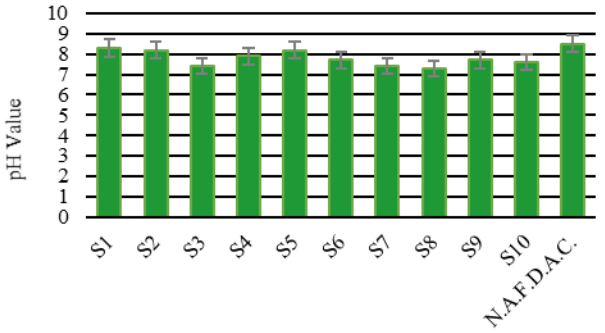

Fig. 4.4a: pH of Sachet Water Samples

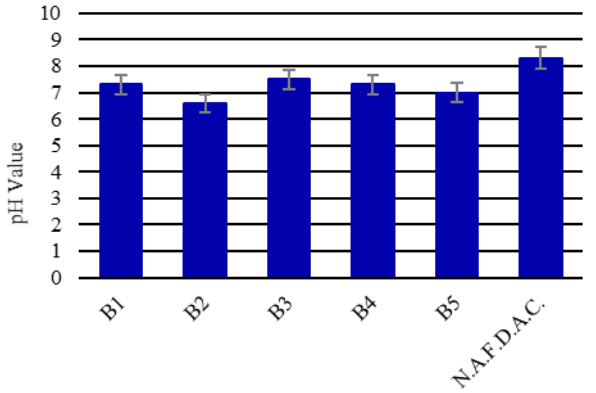

Fig. 4.4b: pH of Bottled Water Samples

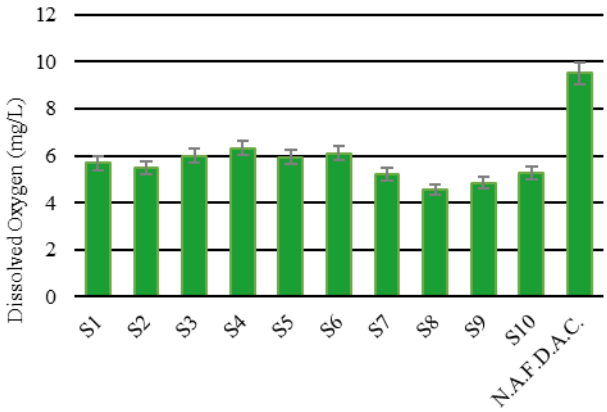

Fig. 4.5a: Dissolved Oxygen for Sachet Water Samples

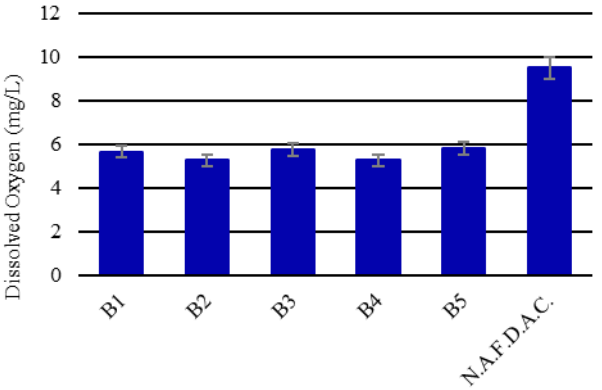

Fig. 4.5b: Dissolved Oxygen for Bottled Water Samples

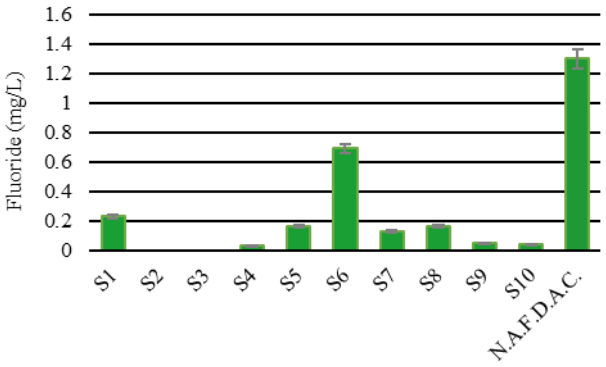

Fig. 4.6a: Fluoride Concentration for Sachet Water Samples

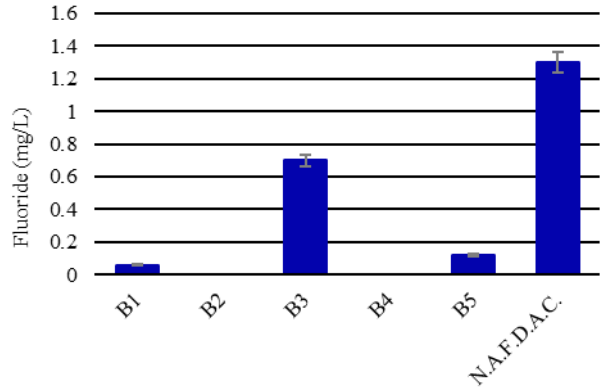

Fig. 4.6b: Fluoride Concentration for Bottled Water Samples

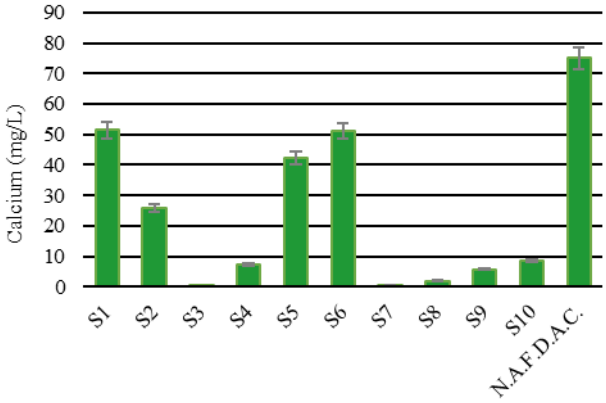

Fig. 4.7a: Calcium Concentration for Sachet Water Samples

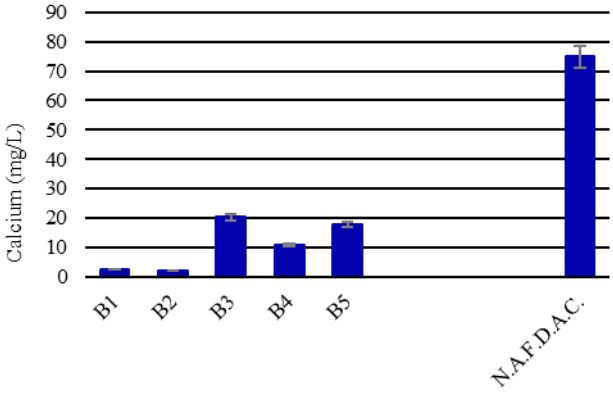

Fig. 4.7b: Calcium Concentration for Bottled Water Samples

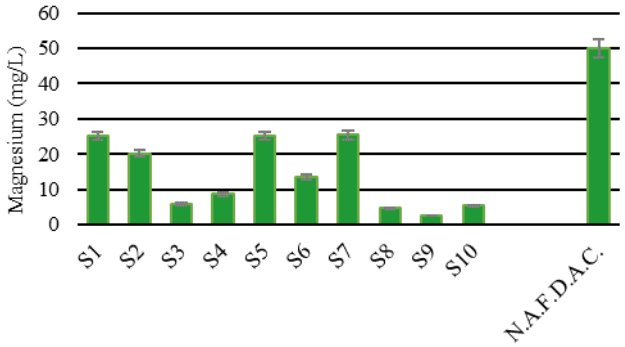

Fig. 4.8a: Magnesium Concentration for Sachet Water Samples

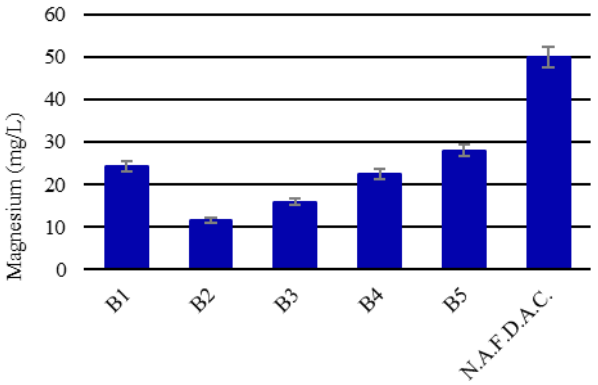

Fig. 4.8b: Magnesium Concentration for Bottled Water Samples

H. Chemical Parameters (Trace metals): Chromium, Manganese, Cadmium, Copper

Results from the assessment for all water samples investigated, indicated the absence of chromium traces. Therefore, water samples conform to NAFDAC standard. Chromium concentration higher than 0.05 mg/L as stipulated by NAFDAC may likely pose a significant health risk in drinking water. The laboratory result indicated the absence of trace concentration of manganese in all the water samples examined. An abundance of manganese influences tastes in water and encourage the growth of bacteria, however, not hazardous but can be unpleasant. A large dose of manganese has also been reported to cause water related diseases [41]. This could lead to the growth of psychological symptoms such as aggressiveness, irrefutable laughter, impulsive actions, and absenteeism [42-44]. The result showed no traces copper in all the water samples analysed. The NAFDAC recommended concentration of copper in drinking water S set at a maximum of 2 mg/L [45, 46]. The study further observed that, in all the sachet and bottled water samples analysed, none of the test result contained this trace element higher than the stipulated maximum concentration. High level of copper is not desirable in drinking water, as that could cause the gastrointestinal disorder.

I. Chemical Parameters (Trace metals): Sodium, Potassium, Iron, and Zinc

The analysed results showed that the concentration of sodium in the sachet water ranged from (2 - 13) mg/L and the bottled water brands varied from (2 - 12) mg/L. The

NAFDAC guideline stipulates a maximum concentration level of sodium in drinking water to be 200 mg/L. The sodium concentration level in both bottled and sachet water brands in this study presented in figures 4.9a and 4.9b are within the permissible limit. Potassium from previous studies has shown to be a necessity for the sustenance of biological systems [47]. All the packaged water samples studied contained this mineral element. Figures 4.10a and 4.10b presented the concentration of potassium in this study varying from (1.0 – 5.0) mg/L and (2.0 – 3.0) mg/L for sachet and bottled water respectively. The observed values are satisfied within the 12 mg/L benchmark set by NAFDAC.

Iron concentration was not detected in about 30 % of sachet water analysed while in the remaining 70 %. The result presented in figure 4.11a revealed a varied concentration of iron from (0.1 – 0.2) mg/L while in the bottled water, 60 % contained iron at a concentration varying from (0.1 – 0.2) mg/L in figure 4.11b. These observed values are lower than 0.3 mg/L stipulated by NAFDAC for drinking water. Higher concentrations of trace iron can render the water unfit for consumption and adequate treatment mechanism should be put in place for the processing and preservation of water free from trace iron concentration [48]. Figures 4.12a and 4.12b highlighted that the sachet water has a zinc concentration range from (0.01-0.03) mg/L while the bottled water from (0.01-0.06) mg/L. Results of the analysis depicts that, values obtained were within the 5 mg/L acceptable limit recommended by NAFDAC. Higher concentrations above threshold limit values for sodium and zinc in the water meant for consumption are responsible for stringent tastes. These tastes are very undesirable.

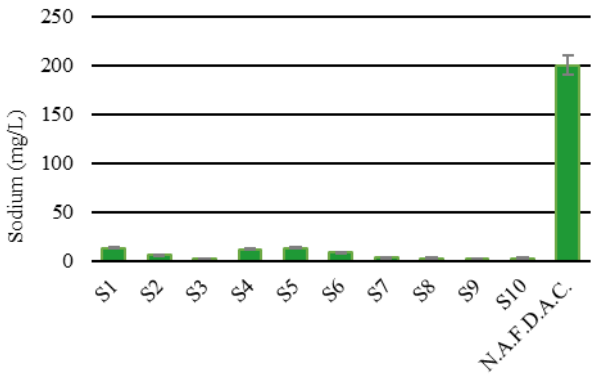

Fig. 4.9a: Sodium Concentration for Sachet Water Samples

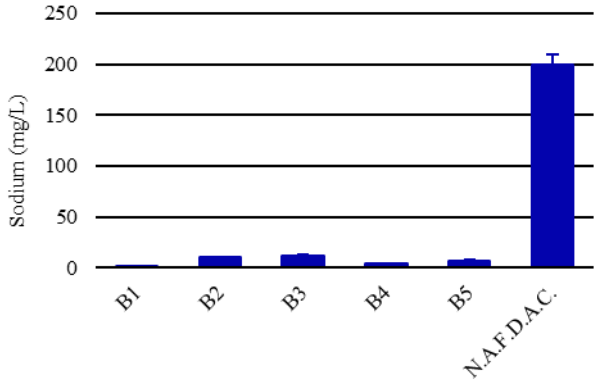

Fig. 4.9b: Sodium Concentration for Bottled Water Samples

J. Total Bacterial Count

The multiple tube fermentation technique was used to evaluate the bacteriological features of water samples. Contrary to the recommendation of zero cfu/100ml by NAFDAC, results presented in figures 4.13a and 4.13b showed that 3 brands of sachet water (S1, S2, and S3) had total bacterial counts (TBC) of 2 cfu/100ml, 3 cfu/100ml, and 5 cfu/100ml respectively. 2 brands of the bottled water (B1 and B2) had TBC of 3 cfu/100ml and 1cfu/100ml respectively. This indicates that samples S1, S2, S3, B1, and B2 are unfit for human consumption. Hence, biological treatment should be carried out using the most appropriate method because the water treatment process may generate sludge to be released in an eco-friendly manner [49, 50].

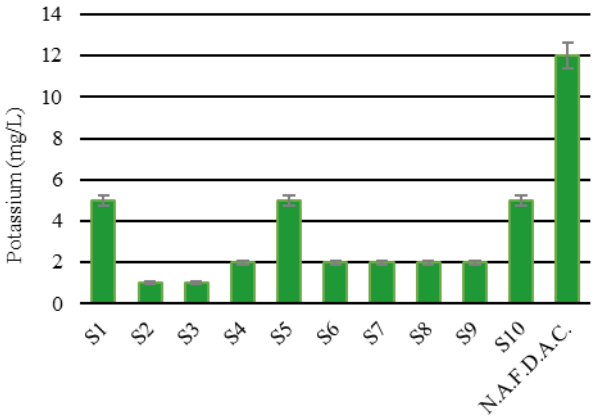

Fig. 4.10a: Potassium Concentration for Sachet Water Samples

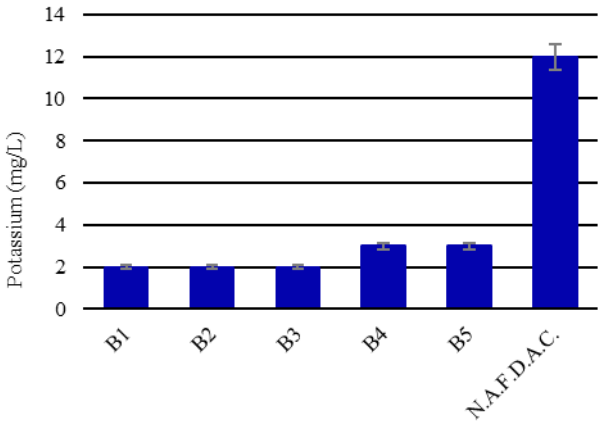

Fig. 4.10b: Potassium Concentration for Bottled Water Samples

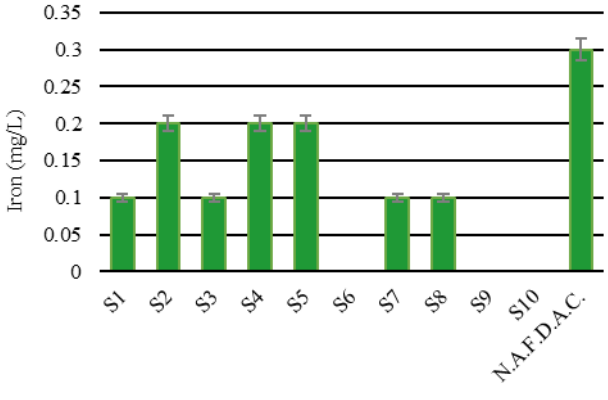

Fig. 4.11a: Iron Concentration for Sachet Water Samples

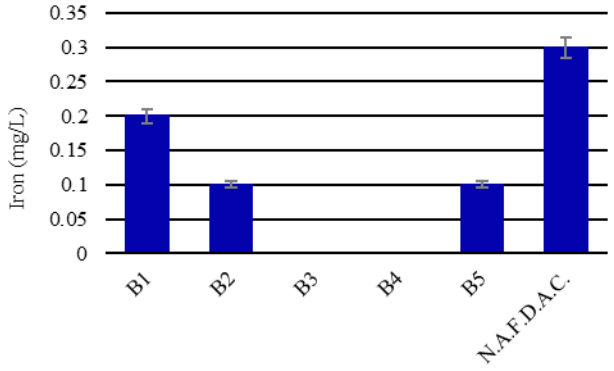

Fig. 4.11b: Iron Concentration for Bottled Water Samples

Fig. 4.12a: Zinc Concentration for Sachet Water Samples

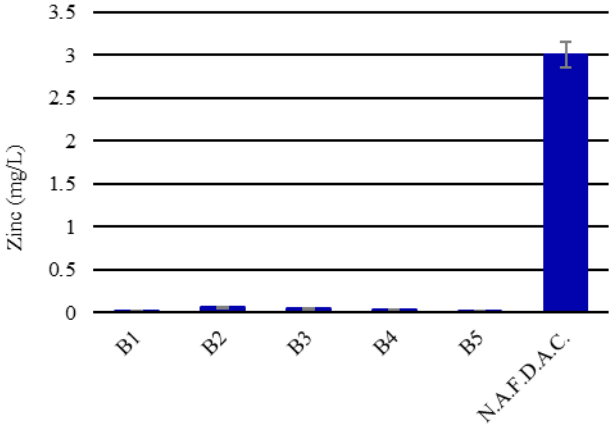

Fig. 4.12b: Zinc Concentration for Bottled Water Sample

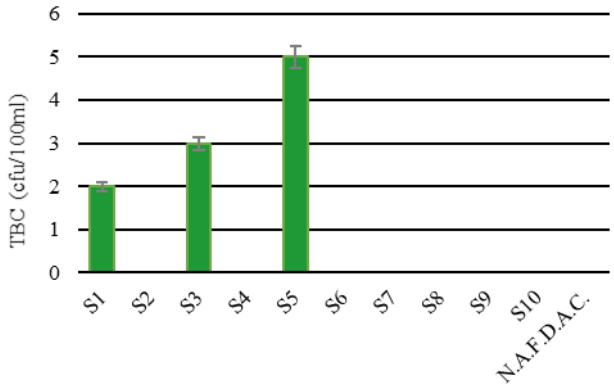

Fig. 4.13a: Total Bacterial Count for Sachet Water Samples

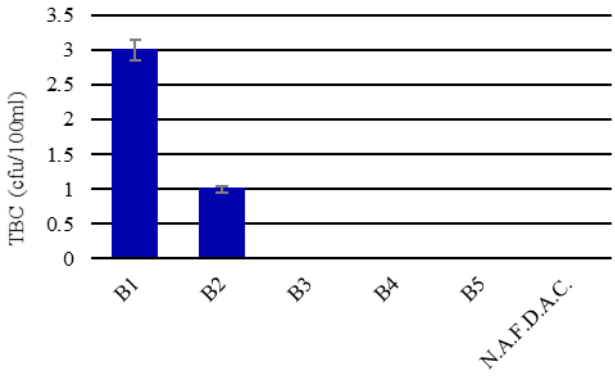

Fig. 4.13b: Total Bacterial Count for Bottled Water Samples

IV. Conclusion

This study evaluated various brand of packaged sachet and bottled water in Sokoto metropolis to acquire qualitative information on the physical, chemical, and bacteriological characteristics of the water samples. The supplied data and information would be required for regulatory actions to improve water pollution treatment and quality management. The evaluation revealed that all samples met the aesthetic requirement of drinking water, as all were clear with neither taste nor smell. Samples S4 and S5 were described as mild turbid having the highest turbidity values of 5.0 NTU and 4.0 NTU respectively. It was observed that slightly alkaline pH was recorded in most samples, whereas sample B2 recorded slightly acidic pH. Except for S3 with 0.0 mg/L, analysed samples had a chloride content of 0.1 mg/L. Traces of Chromium, Manganese, Cadmium, and Copper were absent in all samples examined. Although, there are traces of Sodium, Potassium, Iron, and Zinc. However, they still conform to the NAFDAC standard. On an average scale, the study deduced that all the physical and chemical parameters investigated conform to the NAFDAC recommended values. However, the study gives baseline information about the occurrence of E. coli in packaged drinking water. It was discovered that water samples analysed are fit for drinking except for S1, S2, S3, B1, and B2 having bacterial coliform count greater than 0 cfu/100ml recommended by NAFDAC. The presence of bacteria could originate from improper handling, storage facilities, purification processes, and the after-production unhygienic activities. Therefore, samples S1, S2, S3, B1, and B2 are not safe for human consumption. Hence, should be treated using the most appropriate biological treatment method. The study finally recommended that, state water regulatory agencies and NAFDAC should put in place stricter control measure such as routine inspection of activities in the packaged drinking water industry and water quality evaluation at different production and post-production stages to curb the spread of contaminants in water.

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