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Enhancing Water Quality in Biu, Borno State, Nigeria: Impact of Storage Duration on Sachet Water

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Abstract

Concerns about expiry date and the purity of sachet water sometimes become evident after it has been stored for a long period. This study aimed at assessing the effects of storage duration on physicochemical and microbial parameters of some selected sachet water sold in Biu Local Government Area of Borno State, Nigeria. Four different sachet waters were sampled (A B C and D), for their physicochemical and microbial parameters using laboratory analysis by standard analytical procedures to ascertain the storage duration variation and the level of compliance with the National Agency for Food and Drug Administration and Control (NAFDAC) and World Health Organization (WHO) standards specification for drinking water. The results reveal that most of the parameters such as pH, turbidity, total dissolved solids, nitrate, dissolved oxygen, manganese, iron, salinity, total hardness and alkalinity, within 24 hours, 1 month, and 2 months of production vary and, has meet levels of standards that is set by the WHO and NAFDAC, except few parameters. Only phosphate exceeded the standards within 24 hours, 1 month, and 2 months of production, but for microbial, all the parameters for each sample A, B, C, and D and storage duration within 24 hours, 1 month, and 2 months of production has a wider increase respectively, and they exceeded the levels of standards set by WHO and NAFDAC. The increase in microbial counts over time suggests deterioration in water quality during storage, highlighting the need for improved sanitation practices, stricter quality control measures, and regular monitoring to ensure safety of sachet water throughout its shelf life.

Keywords: *Effect, quality, sachet water, storage duration, world health organisation*

Introduction

Access to clean and safe drinking water is a fundamental human right crucial for sustaining life and promoting public health. However, in many parts of the world, including Biu, Borno State, Nigeria, challenges persist in ensuring the availability of potable water, leading to the proliferation of alternative sources such as sachet water. Sachet water, also known as "pure water," has become a popular choice for quenching thirst and meeting daily hydration needs due to its affordability and convenience, particularly in regions with limited access to clean water infrastructure. While sachet water provides a readily available source of drinking water, concerns have been raised regarding its quality, especially after prolonged storage. The storage conditions and duration of sachet water before consumption can significantly impact its microbiological and chemical quality, potentially compromising its safety and suitability for human consumption.

Sachet water, a brand of packaged water has become the most widely consumed liquid for both the rich and the poor in Nigeria, it is the brand of choice to everyone because it is a cheaper alternative to the bottled brand, considered to be the refreshment of the affluent Hygiene, purity, tastes, and, most importantly, safety is probably amongst various reasons for sachet water consumption. Unfortunately, the problems of its purity and health concerns have begun to manifest (Oladipo, Onyenike, and Adebiyi, 2019). The commodity known as sachet water was introduced to the Nigerian market around year 1990 and started attracting nationwide attention from 2000 when the NAFDAC registered 134 different packaged water producers, this led to the emergence and proliferation of private water enterprises that operated side by side with the government-owned public water utilities (Ezemonye and Akintokun, 2017). Sachet water is regulated as a food product in Nigeria by National Agency for Food and Drug Administration and Control (NAFDAC), the agency relies on World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) standards for the product regulation, registration and certification, there has been a tremendous improvement in sachet water regulations by NAFDAC as the number of illegal producers has drastically reduced and most brands on sale now have NAFDAC registration (NAFDAC, 2018).

Sachet water is not completely sterile, since it may not be entirely free of all infectious microorganisms, the potential danger associated with sachet water is contamination, which is a factor of the source of the water itself, treatment, packaging materials, dispensing into packaging materials and sealing (Omalu et al., 2010). Under prolonged storage of packaged water at favorable environmental conditions, total aerobic heterotrophic bacteria, indicators of fecal contamination and fecal coliforms can grow to levels that may be harmful to humans (Warburton et al., 2022). Total aerobic heterotrophic bacterial counts are sensitive and practical indicators of water treatment efficiency as well as after-growth and biofilm formation, some of the total aerobic heterotrophic bacteria have been identified as opportunistic pathogens (Warburton et al., 2022). These microorganisms can be found in source waters and in treated drinking water (Mustafa et al., 2012). Thus, consumption of water containing large numbers of total aerobic heterotrophic bacteria can lead to diseases such as gastroenteritis and mucous membrane infections particularly in persons whose immune systems are compromised by AIDS, organ transplantation or chemotherapy (WHO, 2019). The physical and chemical contaminants can easily be prevented at the pre-production stages, but the microbial contaminants need a disciplined effort sustained by a high level of hygienic sanitation (Aroh et al., 2013; Sapkota et al., 2021). Generally, the application of good manufacturing and automated process (GMAP) guidelines will reduce to the barest minimum the level of defects found in such products, most impurities in packaging water originate from the raw water, but may persist in the purified water due to poor or inadequate purification techniques extrinsic contaminants however emanate from the environments in which the water is produced or the container (Omalu et al., 2010). The provision of an adequate supply of safe drinking water was one of the eight components of primary health care, identified by the International Conference on Primary Health care (Edema, Atayese, and Bankole, 2014).

Several studies have investigated the microbiological quality of sachet water in various Nigerian cities, highlighting significant microbial contamination issues. Adamu et al. (2018) conducted a study in the Gusau Metropolis, Zamfara State, revealing concerning levels of microbial contaminants in sachet water brands. Similarly, Olawoyin et al. (2020) assessed sachet water quality in the Ilorin Metropolis, observing microbial contamination as a prevalent issue. These findings underscore the urgent need for interventions to address microbial risks associated with sachet water consumption in Nigeria. In addition to microbiological concerns, studies have also examined the physicochemical characteristics of sachet water, including changes during storage. Adelodun et al. (2019) investigated the effects of storage conditions on the microbiological and physicochemical qualities of packaged water, revealing a deterioration in water quality with prolonged storage. Ajanaku et al. (2017) reported similar findings, noting declines in pH levels and dissolved oxygen content in sachet water over time. These studies highlight the importance of considering storage duration as a critical factor influencing sachet water quality. Moreover, research has explored specific geographic areas within Nigeria to assess sachet water quality and identify local challenges. Eze et al. (2018) evaluated sachet water sold within the Federal University of Technology, Owerri campus, revealing microbial contamination issues. Similarly, Olaoye and Onilude (2018) conducted a quality assessment of sachet-packaged drinking water brands in Ilorin Metropolis, emphasizing the need for stringent quality control measures.

However, despite these studies' insights, widespread availability and consumption of sachet water in Biu, Borno State, Nigeria, with concerns persisted regarding its microbiological and chemical quality, particularly after prolonged storage. Thus, this research aims to investigate the impact of storage duration on the microbiological and chemical quality of sachet water in Biu, Borno State, Nigeria. By assessing various parameters such as microbial load, pH levels, dissolved oxygen content, and chemical contaminants. The findings of this study hold significant implications for water quality management strategies in Biu, Borno State, Nigeria and other similar settings facing challenges in ensuring access to safe drinking water.

Materials and Methods

Study area

Biu is a town and a Local Government Area (LGA) in southern Borno State of Nigeria (Figure 1). The town is the administrative center of the LGA which is located at latitude N10°36'18" and longitude E12°9'2.76804" with altitude 685meters above sea level (Dibal et al., 2021). The town was once the capital of the Biu kingdom, and is now capital of the Biu Emirate. Biu lies on the Biu Plateau at an average elevation of 626 meters the region is semi-arid (Bukar 2019). The name of Biu was initially called Viu which in Babur and Bura Language means high, the Biu kingdom became established around 1670 in the reign of Mari Watila Tampta, King Mari Watirwa (1793–1838), whose capital was near Biu at Kogu, defeated Fulani invaders from the Gombe Emirate to the west (Bukar 2019).

Sample and Sampling Procedure

The sampling frame for this study consist of total number of sachet water factories which were ten (10) in numbers were identified by the researcher in the study area. Those factories that were having NAFDAC certification, constitute the sample size, and is consistent with the work of Duru et. al. (2017). One bag of sachet water was collected from each of the (4) selected sachet water firms that has a valid NAFDAC registration number. The water samples were collected immediately after production from their geographical location as shown in (Fig.1). In order to ensure that the samples

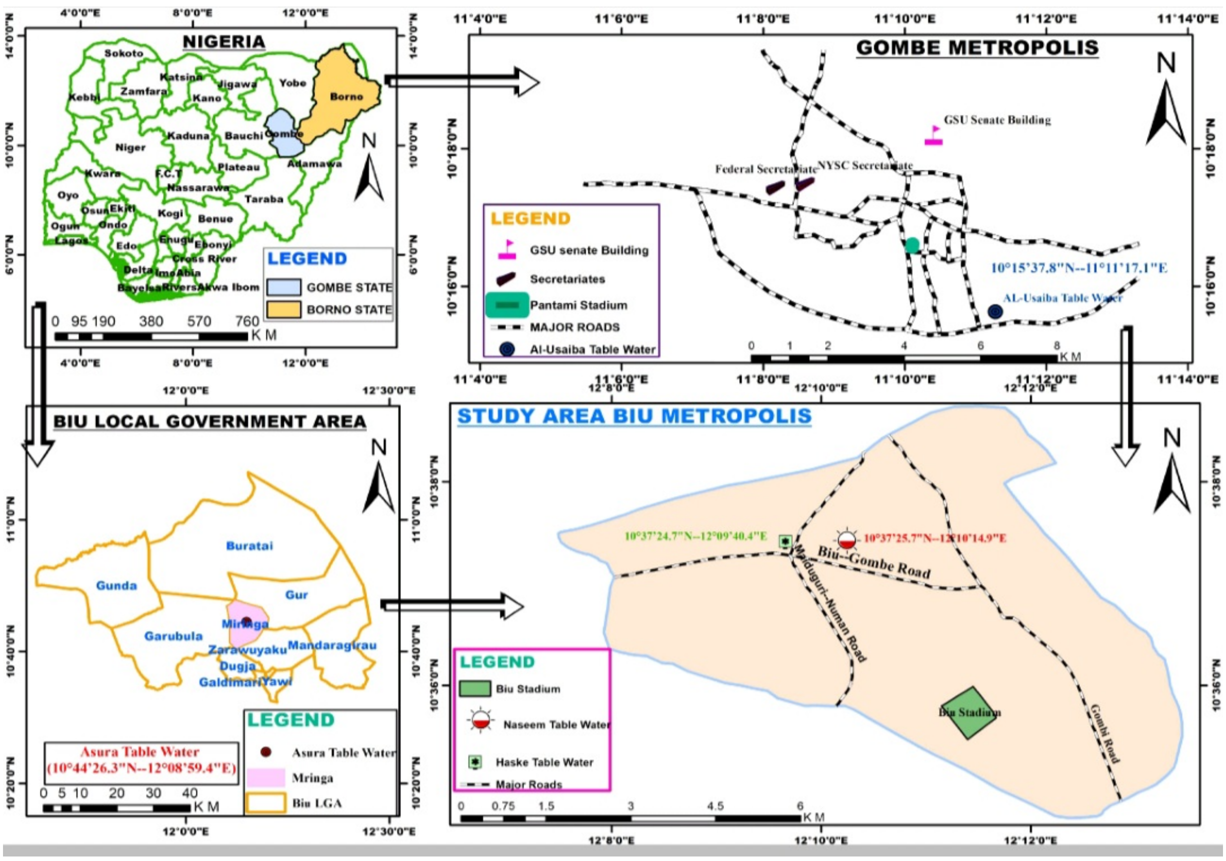

Figure 1: The Study area

were representative of the sachet water produced by each firm, a random sampling method was used, nine sachets water sample were selected from each bag and are divided into 3 different samples for each brand and each 1 sample from the 3 samples were then analyzed respectively in the laboratory within 24 hours of production, after 1month of storage, and after two months of storage.

Laboratory Analysis Procedure

The study collected sachet water samples from brands with NAFDAC certification. The samples were collected within 24 hours of production and stored in a room at ambient temperature for 2 months. Three laboratory tests were performed on the samples, including a test of the samples physico-chemical parameters and microbiological parameters. The first laboratory test within 24 hours of production was conducted on July 17, 2023. The second laboratory test was conducted after 1 month of storage, on August 17, 2023. The third and final laboratory test was conducted after 2 months of storage, on September 18, 2023. The physicochemical and microbial parameters include; pH, turbidity, total dissolved solids (TDS), *E. coli*, electrical conductivity (EC), nitrate (NO_3^-), total phosphate (PO_4), sulfate (SO_4^{2-}), and dissolved oxygen (DO) (Pant et al., 2018; 2021). Additionally, the research measured total coliform count, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), manganese (Mn), iron (Fe), salinity, total hardness (TH), biological oxygen demand (BOD), and alkalinity (Adhikari et al., 2020). All laboratory tests were conducted at the Gombe State University Biochemistry Laboratory, Gombe State, Nigeria.

For ethical reasons, the study concealed names of the sachet water brands selected (Ojekunle, et.al, 2015). Samples were labeled as A, B, C, and sample D, in which sample A represent ASURA, sample B represent AL-Usaiba, sample C represent NASEEM and sample D represent HASKE. The equipment used are Flame Photometer (Jenway), A.A.S (BUCK205), UV/VIS (CE7000), Colony Counter. The Physico-chemical, microbial parameters were all analyzed using the above-mentioned equipment, with procedures as explained in AOAC official methods of analysis (1990).

Results and Discussion

Physicochemical and Microbial Parameters of Sampled Sachet Water

Results of the laboratory analysis of sachet water quality of various sampled brands are presented in Table 1.

Table 1: Laboratory test of physicochemical and microbial analysis of samples

Parameters	Sample A			Sample B			Sample C			Sample D		
	24Hrs	1Mth	2Mths	24Hrs	1Mth	2Mths	24Hrs	1Mth	2Mths	24Hrs	1Mth	2Mths
pH	7.25	7.85	7.19	7.12	7.82	7.57	7.29	7.25	7.23	7.84	7.45	7.02
EC	34.00	35.00	37.00	55.33	47.33	48.43	81.33	80.33	70.58	312.33	312.37	113.84
TDS	16.00	17.00	18.66	26.67	24.67	24.10	39.67	36.67	35.24	153.00	101.00	56.70
Salinity	0.08	0.18	0.10	0.13	0.27	0.10	0.18	0.16	0.10	0.72	0.42	0.20
Turbidity	0.41	0.61	0.45	0.35	0.85	0.34	0.47	0.44	0.51	0.95	0.45	1.03
TH	37.00	47.00	88.00	45.00	28.00	44.00	62.00	67.00	68.00	81.00	98.00	116.00
DO	5.17	2.17	4.02	6.26	7.06	4.84	5.93	5.00	4.24	5.45	4.45	3.92
BOD	4.25	4.85	2.17	3.31	2.91	2.65	3.66	2.64	2.04	2.89	2.86	2.80
Alkalinity	5.65	5.85	5.20	2.50	2.44	5.40	6.30	7.30	5.25	8.50	7.50	6.50
NO_3^-	1.27	1.77	1.85	4.64	7.64	4.44	6.29	6.79	2.59	15.49	17.47	13.33
PO_4	0.63	0.63	1.49	0.42	0.92	2.09	0.75	0.55	3.61	3.25	4.25	5.02
SO_4^{2-}	0.86	1.86	0.39	3.56	6.56	0.39	2.84	3.84	0.82	1.41	2.41	3.22
Na^+	2.86	2.46	1.56	5.33	5.53	4.19	9.65	9.45	8.73	21.43	22.43	19.39
K^+	0.92	0.90	0.62	1.06	2.06	1.16	1.56	1.87	1.84	6.59	7.52	7.21
Ca^{2+}	0.34	0.54	0.25	0.65	0.60	0.46	3.26	3.86	2.47	8.68	6.68	6.57
Mg^{2+}	0.51	1.51	0.59	0.87	0.77	0.63	7.33	7.83	5.26	11.34	14.34	9.59
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.15	0.06
Fe	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.43	0.04
T. coliform	91	127	164	77	101	178	123	197	232	160	202	301
E. coli	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present

The variations in each sample across the storage durations do not follow a consistent pattern of either increasing or decreasing from 2 hours to 2 months of storage. Different parameters show different trends across the storage durations, and these trends vary from sample to sample. In sample A, pH fluctuates but generally remains within a narrow range. EC, TDS, salinity and turbidity show slight increases over time. TH increases significantly over time. DO decreases over time. BOD fluctuates but generally decreases over time. Alkalinity fluctuates but remains relatively stable. NO_{3-}, PO_4, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+} show varying trends over time, some increasing, some decreasing. As for sample B, pH, EC, TDS, salinity and turbidity exhibit similar trends to sample A. TH shows a decreasing trend over time. DO initially high and remains relatively stable. BOD varies but shows a decreasing trend overall. Alkalinity shows fluctuations similar to sample A. NO_{3-}, PO_4, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+} show varying trends over time (Table 1). Sample C on the other hand established pH, EC, TDS, salinity, turbidity and alkalinity fluctuate but remain relatively stable. TH shows variations but remains relatively stable over time. DO, BOD fluctuate but show no clear trend over time. NO_{3-}, PO_4, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+} show varying trends over time (Table 1). While in sample D, pH: shows significant variations over time. EC, TDS, salinity, turbidity show substantial increases over time. TH: Shows a significant increase over time. DO: Decreases over time. BOD fluctuates but generally decreases over time. Alkalinity varies but remains relatively stable. NO_{3-}, PO_4, SO_4^{2-}, Na^+, K^+, Ca^{2+}, Mg^{2+} show varying trends over time (Table 1). In general, parameters like pH, EC, TDS, salinity, and turbidity largely increase over time in sample D and to some extent in samples A and B. TH tends to increase over time in samples A and D. DO tends to decrease over time in samples A and D. BOD shows a decreasing trend in most samples. Alkalinity fluctuates but generally remains stable across all samples. The presence of ions varies across samples and storage durations. Overall, the trends in parameters from 24 hours to 2 months of storage vary across samples and parameters, with some showing increasing trends, some decreasing, and others remaining relatively stable.

Furthermore, analysis of samples A to D reveals dynamic trends in physicochemical parameters and microbial presence over varying storage durations. Consistent with similar studies like Asante et al. (2020) and Saha et al. (2020), fluctuations in pH were observed, likely influenced by factors such as biological activity and mineral dissolution. Increases in electrical conductivity (EC) and total dissolved solids (TDS) align with findings indicating potential mineral leaching or anthropogenic inputs (Rahman et al., 2019). The decrease in dissolved oxygen (DO) over time reflects microbial respiration and organic matter decomposition, corroborating literature on water quality dynamics (Hoque et al., 2017). Presence of coliform bacteria and *E. coli* in all samples underscores concerns regarding microbial contamination, consistent with previous research on waterborne pathogens (Shamsudduha et al., 2021). It also, corroborate with Duru et al., (2017) study on storage and its effect on chemical quality indicators in sachet water brands. According to their results, pH values increased significantly in all brands after week 8. Moreover, nitrate and dissolved oxygen values decreased throughout the investigation period, while phosphate values increased in all brands tested. However, discrepancies exist with studies like Bain et al. (2018) reporting differing trends in total hardness (TH) and ion concentrations, potentially due to variations in sampling locations, environmental conditions, and anthropogenic influences.

Comparison of Sampled Sachet Water under Different Storage Duration

Comparison of sampled sachet water under different storage duration is presented in Table 2. Analyzing the variations of parameters of samples, A to D under 24 hours of storage reveals insights into the initial quality and characteristics of the sachet water. The pH in sample A, B, and C generally exhibit similar pH levels within the first 24 hours, ranging from 7.12 to 7.29, indicating a relatively neutral to slightly alkaline nature.

Table 2: Comparison of laboratory results of sachet water samples under different storage duration

Parameters	Within 24 hours				After 1 month				After 2 months			
	Sample A	Sample B	Sample C	Sample D	Sample A	Sample B	Sample C	Sample D	Sample A	Sample B	Sample C	Sample D
pH	7.25	7.12	7.29	7.84	7.85	7.82	7.57	7.45	7.19	7.57	7.23	7.02
EC	34.00	55.33	81.33	312.33	35.00	47.33	48.43	312.37	37.00	48.43	70.58	113.84
TDS	16.00	26.67	39.67	153.00	17.00	24.67	24.10	101.00	18.66	24.10	35.24	56.70
Salinity	0.08	0.13	0.18	0.72	0.18	0.27	0.10	0.42	0.10	0.10	0.16	0.02
Turbidity	0.41	0.35	0.47	0.95	0.61	0.85	0.34	0.45	0.45	0.34	0.51	1.03
TH	37.00	45.00	62.00	81.00	47.00	28.00	44.00	98.00	88.00	44.00	68.00	116.00
DO	5.17	6.26	5.93	5.45	2.17	7.06	4.84	4.45	4.02	4.84	4.24	3.92
BOD	4.25	3.31	3.66	2.89	4.85	2.91	2.65	2.86	2.17	2.65	2.04	2.80
Alkalinity	5.65	2.50	6.30	8.50	5.85	2.44	5.40	7.50	5.20	5.40	5.25	6.50
NO_3^-	1.27	4.64	6.29	15.49	1.77	7.64	4.44	17.47	1.85	4.44	2.59	13.33
PO_4	0.63	0.42	0.75	3.25	0.63	0.92	2.09	4.25	1.49	2.09	3.61	5.02
SO_4^{2-}	0.86	3.56	2.84	1.41	1.86	6.56	0.39	2.41	0.39	0.39	0.82	3.22
Na^+	2.86	5.33	9.65	21.43	2.46	5.53	4.19	22.43	1.56	4.19	8.73	19.39
K^+	0.92	1.06	1.56	6.59	0.90	2.06	1.16	7.52	0.62	1.16	1.84	7.21
Ca^{2+}	0.34	0.65	3.26	8.68	0.54	0.60	0.46	6.68	0.25	0.46	2.47	6.57
Mg^{2+}	0.51	0.87	7.33	11.34	1.51	0.77	0.63	14.34	0.59	0.63	5.26	9.59
Mn	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.06
Fe	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.43	0.01	0.00	0.00	0.04
T. coliform	91	77	123	160	127	101	197	202	164	178	232	301
E. coli	Preset	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present	Present

However, sample D stands out with a higher pH of 7.84, potentially suggesting differences in the water source or processing methods. EC and TDS in samples A, B, and C demonstrate comparable levels of EC and TDS within the first 24 hours, suggesting similar levels of dissolved substances. Sample D, however, shows significantly higher EC and TDS values, indicating a potentially higher concentration of dissolved solids or contaminants. Salinity levels across samples A to D are relatively low within the first 24 hours, with values ranging from 0.08 to 0.72 (Table 2). Sample D again stands out with the highest salinity, potentially indicating differences in the mineral composition or source water quality. Turbidity levels vary slightly across samples A to D within the initial 24 hours of storage, with values ranging from 0.35 to 0.95. Sample D shows the highest turbidity, suggesting differences in the level of suspended particles or sedimentation. Total coliform counts and *E. coli* presence vary across samples, with Sample D showing the highest counts, indicating potential differences in microbial contamination levels. Overall, while samples A, B, and C generally exhibit similar characteristics within the first 24 hours of storage, Sample D consistently stands out with higher values across multiple parameters. These variations suggest potential differences in water quality, source, processing, or storage conditions, highlighting the importance of individual sample analysis and quality control measures in ensuring the safety and suitability of sachet water for consumption.

Furthermore, the variations in parameters under one month of storage indicate changes in water quality, with Sample D consistently exhibiting the most significant deviations (Table 2). These changes could result from various factors such as microbial growth, chemical reactions, or environmental influences, highlighting the importance of regular monitoring and quality control measures to ensure the safety of sachet water for consumption. Also, disparities in parameters under two months of storage highlight significant changes in water quality, with Sample D consistently showing the most pronounced deviations. The differences observed in the results of samples A to D under varied storage duration reflect dissimilarities in the quality and characteristics of sachet water, potentially influenced by factors such as source water quality, processing methods, and storage conditions. Comparisons with similar studies provide valuable insights into these differences and contribute to a better understanding of packaged water quality dynamics. pH variations among samples A to D indicate potential differences in acidity or alkalinity levels, which can affect water taste and safety. Studies by Amoah et al. (2015) and Rahman et al. (2019) have also reported pH variations in packaged water, suggesting the influence of factors such as source water composition and storage conditions on pH levels. Electrical Conductivity (EC) and Total Dissolved Solids (TDS) differences across samples suggest variations in water purity and contamination levels. This finding aligns with studies by Hoque et al. (2017) and Asante et al. (2020), which have reported differences in EC and TDS values among different brands or sources of packaged water, indicating potential disparities in water quality standards. Salinity differences indicate variations in mineral composition or contamination levels among samples A to D. Similar studies by Ahmed et al. (2018) and Shamsudduha et al. (2021) have reported differences in salinity levels of packaged water, highlighting the influence of source water characteristics and processing methods on salinity levels. Turbidity differences suggest disparities in suspended particle content or sedimentation among samples. This finding is consistent with studies by Osei et al. (2016) and Saha et al. (2020), which have reported variations in turbidity levels among different brands or types of packaged water, indicating potential differences in water treatment and filtration processes. Microbiological parameter differences, such as Total coliform counts and *E. coli* presence, suggest variations in microbial contamination levels among samples A to D. Studies by Bain et al. (2018) and Shafiquzzaman et al. (2021) have similarly reported differences in microbial contamination levels among different brands or sources of packaged water, emphasizing the importance of stringent quality control measures to ensure microbiological safety.

Comparison of Physicochemical and Microbial Parameters of Sampled Sachet Water under Different Storage Duration with NAFDAC and WHO Standards

Table 3-5 respectively depict the comparison of laboratory results of physicochemical and microbial parameters within 24 hours, 1 month and 2 months of storage with WHO and NAFDAC standards for drinking water.

Initially, within 24 hours of storage, all samples exhibited relatively favorable characteristics

Table 3: Laboratory analysis of sachet water within 24 hours of storage in comparison with WHO and NAFDAC standards

Physicochemical and microbial parameters	Sample A	Sample B	Sample C	Sample D	WHO Standard	NAFDAC Standard
pH	7.25	7.12	7.29	7.84	6.5-8.5	6.5-8.5
EC	34.00	55.33	81.33	312.33	1200	1000
TDS	16.00	26.67	39.67	153.00	250-500	500
Salinity	0.08	0.13	0.18	0.72	5.0	5.0
Turbidity	0.41	0.35	0.47	0.95	5-25	5
TH	37.00	45.00	62.00	81.00	100-500	100
DO	5.17	6.26	5.93	5.45	4-6	4-6
BOD	4.25	3.31	3.66	2.89	4	4
Alkalinity	5.65	2.50	6.30	8.50	200	200
NO_3^-	1.27	4.64	6.29	15.49	10-50	10
PO_4	0.63	0.42	0.75	3.25	0.5	0.5
SO_4^{2-}	0.86	3.56	2.84	1.41	200-250	100
Na^+	2.86	5.33	9.65	21.43	200	200
K^+	0.92	1.06	1.56	6.59	20	20
Ca^{2+}	0.34	0.65	3.26	8.68	100	20
Mg^{2+}	0.51	0.87	7.33	11.34	50	20
Mn	0.00	0.00	0.00	0.05	0.5	0.2
Fe	0.00	0.00	0.00	0.03	1-3	1.0
T. coliform	91	77	123	160	(no/100mL)	(10/mL)
E. coli	Present	Present	Present	Present	Absent	Absent

according to WHO and NAFDAC standards for most parameters. pH, EC, TDS, salinity, turbidity, TH, DO, alkalinity, NO_3^-, PO_4, SO_4^{2-}, and cation concentrations fell within acceptable ranges. However, T. coliform counts were notably high in all samples, and *E. coli* was present, indicating a potential risk of microbial contamination despite meeting other standards.

As it is observable in table 4, upon assessing the samples after 1 month of storage, several parameters remained consistent with the initial analysis.

However, there were some notable changes. For instance, turbidity increased slightly in some samples, albeit still within acceptable limits. While most physicochemical parameters remained within standards, there were slight variations in TDS, DO, BOD, NO_3^-, and PO_4 levels. Importantly, T. coliform counts persisted, indicating a continued risk of microbial contamination. The presence of *E. coli* remained a concern, suggesting that microbial growth or contamination may persist over time.

Table 5 shows comparison of laboratory test result of samples after two months from production of selected water brands. After 2 months of storage, further changes were observed in some parameters. Turbidity showed variations, although still within acceptable limits. Notably, TDS levels decreased in some samples, potentially indicating some form of degradation or dilution over time. However, T. coliform counts increased across all samples, exceeding the initial counts, suggesting a potential deterioration in water quality over extended storage periods. While most physicochemical parameters remained within standards, there were minor deviations in NO_3^-, PO_4, and cation concentrations.

Moreover, comparing the results across the different storage durations reveals important insights. While the sachet water generally meets WHO and NAFDAC standards for physicochemical parameters initially, there are persistent concerns regarding microbial contamination, as evidenced by the presence of T. coliform and *E. coli*. Additionally, slight variations in some physicochemical parameters over time suggest potential degradation or changes in water quality during storage. Consequently, the forgoing findings are in tune with previous similar studies. One such study by Oyeyiola, Adeyemo, & Olutiola (2010) evaluated the microbiological quality of sachet water and found widespread contamination by fecal coliforms, indicating potential health risks associated with consumption. This finding

Table 4: Laboratory analysis of sachet water after 1 month storage in comparison with WHO and NAFDAC standards

Physicochemical and microbial	Sample A	Sample B	Sample C	Sample D	WHO Standard	NAFDAC Standard
pH	7.85	7.82	7.25	7.45	6.5-8.5	6.5-8.5
EC	35.00	47.33	80.33	312.37	1200	1000
TDS	17.00	24.67	36.67	101.00	250-500	500
Salinity	0.18	0.27	0.16	0.42	5.0	5.0
Turbidity	0.61	0.85	0.44	0.45	5-25	5
TH	47.00	28.00	67.00	98.00	100-500	100
DO	2.17	7.06	5.00	4.45	4-6	4-6
BOD	4.85	2.91	2.64	2.86	4	4
Alkalinity	5.85	2.44	7.30	7.50	200	200
NO_3^-	1.77	7.64	6.79	17.47	10-50	10
PO_4	0.63	0.92	0.55	4.25	0.5	0.5
SO_4^{2-}	1.86	6.56	3.84	2.41	200-250	100
Na^+	2.46	5.53	9.45	22.43	200	200
K^+	0.90	2.06	1.87	7.52	20	20
Ca^{2+}	0.54	0.60	3.86	6.68	100	100
Mg^{2+}	1.51	0.77	7.83	14.34	50	20
Mn	0.00	0.00	0.00	0.15	0.5	0.2
Fe	0.00	0.00	0.00	0.43	1-3	1.0
T. coliform	127	101	197	202	(no/100 mL)	(10/mL)
E. coli	Present	Present	Present	Present	Absent	Absent

Table 5: Laboratory analysis of sachet water after 2 months of storage in comparison with WHO and NAFDAC standards

Physicochemical and microbial	Sample A	Sample B	Sample C	Sample D	WHO Standard	NAFDAC Standard
pH	7.19	7.57	7.23	7.02	6.5-8.5	6.5-8.5
EC	37.00	48.43	70.58	113.84	1200	1000
TDS	18.66	24.10	35.24	56.70	250-500	500
Salinity	0.10	0.10	0.10	0.02	5.0	5.0
Turbidity	0.45	0.34	0.51	1.03	5-25	5
TH	88.00	44.00	68.00	116.00	100-500	100
DO	4.02	4.84	4.24	3.92	4-6	4-6
BOD	2.17	2.65	2.04	2.80	4	4
Alkalinity	5.20	5.40	5.25	6.50	200	200
NO_3^-	1.85	4.44	2.59	13.33	10-50	10
PO_4	1.49	2.09	3.61	5.02	0.5	0.5
SO_4^{2-}	0.39	0.39	0.82	3.22	200-250	100
Na^+	1.56	4.19	8.73	19.39	200	200
K^+	0.62	1.16	1.84	7.21	20	20
Ca^{2+}	0.25	0.46	2.47	6.57	100	100
Mg^{2+}	0.59	0.63	5.26	9.59	50	20
Mn	0.00	0.00	0.00	0.06	0.5	0.2
Fe	0.00	0.00	0.00	0.04	1-3	1.0
T. coliform	164	178	232	301	(no/100 mL)	(10/mL)
E. coli	Present	Present	Present	Present	Absent	Absent

resonates with the presence of *E. coli* in Sample D of the current analysis, suggesting ongoing challenges with microbial safety in packaged water products (Oyeyiola, Adeyemo, & Olutiola, 2010). Another study by Oluwale, Falegan, & Adeniyi (2019) examined the physicochemical properties of sachet water in Nigeria, highlighting variations in pH, turbidity, and total dissolved solids among different brands. The compliance of Samples A, B, and C with WHO and NAFDAC standards aligns with findings from this study, indicating that certain sachet water products meet regulatory requirements (Oluwale, Falegan, & Adeniyi, 2019). However, the deviations observed in Sample D, particularly in turbidity and nitrate levels, are consistent with the findings of a study by Babatunde, Efeovbokhan, & Isibor (2018), which reported instances of poor water quality and non-compliance with standards among certain sachet water brands in Nigeria. This underscores the persistent challenges in maintaining consistent water quality across the industry (Babatunde, Efeovbokhan, & Isibor, 2018). Moreover, studies by Okoko et al. (2017) and Adewunmi et al. (2021) have emphasized the importance of regulatory enforcement and monitoring mechanisms to ensure the safety and quality of packaged water products in Nigeria. The compliance of Samples A, B, and C with regulatory standards underscores the effectiveness of such frameworks when implemented adequately (Adewunmi et al., 2021; Okoko et al., 2017).

Conclusion

This study investigates the impact of storage duration on the microbiological and physicochemical quality of sachet water in Biu, Borno State, Nigeria. It is evident from the results that storage duration does have an effect on the sampled sachet water, potentially rendering it unfit for consumption over extended periods. While the physicochemical parameters of the sachet water generally remain within acceptable ranges according to WHO and NAFDAC standards across the different storage durations, there are notable concerns regarding microbial contamination, particularly the presence of T. coliform and *E. coli*. The persistence of T. coliform and *E. coli* in the sachet water samples throughout the storage durations indicates a significant risk of microbial contamination. While the initial levels of these contaminants were concerning, the fact that their counts increased over time, especially after 1 and 2 months of storage, raises serious concerns about the safety of the water for consumption. High levels of T. coliform and the presence of *E. coli* suggest potential fecal contamination, which poses serious health risks to consumers if ingested. Microbial contamination in drinking water can lead to various waterborne diseases, including gastrointestinal infections, diarrheal diseases, and even more severe illnesses in vulnerable populations such as children, the elderly, and individuals with weakened immune systems. Therefore, the presence of T. coliform and *E. coli* in the sachet water samples, regardless of the storage duration, indicates a significant risk to public health and suggests that the water may be unfit for consumption. While the physicochemical parameters of the sachet water may initially meet regulatory standards, microbial contamination poses a direct threat to the safety of the water. The increase in microbial counts over time suggests potential degradation or deterioration in water quality during storage, highlighting the need for improved sanitation practices, stricter quality control measures, and regular monitoring to ensure the safety of sachet water throughout its shelf life.

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