AJBCPS African Journal of Biological, Chemical and Physical Sciences
Jozac Publishers
Vol 4, Issue 1, 2025

ISSN: 2790-9522 (Print) ǀ 2790-9530 (Online)
Website: https://journals.jozacpublishers.com/ajbcps/index
https://doi.org/10.5281/zenodo.15851060
OPEN ACCESS

Impact of water treatment and storage on the deterioration of packaged water before shelf-life expiration

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Received: February 16, 2025 ǀ **Accepted:** April 04, 2025 ǀ **Published:** July 09, 2025

Abstract
Certain phases of treatment, processing, and storage may render packaged drinking water unfit for human consumption, even prior to its expiration date. The underlying factors contributing to their deterioration are examined and analyzed in this study. Following the standard protocols outlined by the World Health Organization, the Physico-chemical and microbiological characteristics of ten sachet water products and two bottled waters were examined. Nevertheless, the microbiological evaluation of some samples' total coliform count prior to storage revealed no coliform, whilst Pws 1, 2, 5, 7, and 10 showed a high total coliform count of 70–780 CFU/ml. Further investigation on the research showed that the purifying methods employed in water production, such as carbon filtration, reverse osmosis, and ultraviolet light sterilization, correlated with the degradation of water samples over time. In samples Pw (1, 2, 3, 7, 8, & 10), high amounts of some elements, including Fe and Pb, were found. here were also increasing turbidity values of Pw3 with 7.75NTU, 10.31NTU, and 14.05NTU monthly during the shelf period, and Pw8 with 11.74NTU in the third month, and Pw8's turbidity values increased from 11.74NTU in the third month, which both exceeded the permissible limits of 5NTU. The colour of the samples (Pw2, Pw3, Pw8, and Pw10) changed from 5Hu to 10Hu, which corresponded with their unpleasant taste. According to the study, the varied values of different parameters are caused by the chemical, physical, and biochemical processes that take place in the packaged water. These processes include the respiratory and metabolic activities of the total coliforms on nutrients, temperature, and the degree of light penetration.

Keywords: Deterioration of Packaged water, Impact of storage conditions, Shelf life, Water quality monitoring, Water treatment

Introduction
Packaged pure water is a purified, treated, and sealed water to ensure that the water is safe, protected, clean, and potable for the customers' or consumers' consumption. The pure water is generally

packaged for consumption in vessels such as cans, plastics, sachets, glasses, pouches, laminated boxes, and as ice prepared for customer use or for consumption. In Nigeria, sachet water has steadily risen to the top of the packaged water consumption list among both the wealthy and the underprivileged. An aided statistics carried out in Jos showed that 93% of sachet water is consumed compared to others (Miner et al., 2016). Sachet water happens to win the choice of consumers amongst other packaged pure water products because it is cheaper. It is also considered to be acceptable even for affluence, purity, hygiene, and, most importantly, for safety. This acceptance is probably one of the dynamic reasons why sachet water is mostly consumed. Unfortunately, adverse concerns with its purity and potential health conditions have started to emerge (Oladipo et al., 2009).

Packaged drinking water is a consumable, and as such, it is subject to laws requiring expiration dates on all consumables (*Food Safety Authority of Ireland,* 2017). Packaged water may not be completely sterilized, and that depends on the treatment methods and water production facilities available. As a result, physical, microbiological, and chemical water standards are not attained even after such treatment. The need, therefore, arises for regular investigation of water quality standards of packaged water. The need for regular quality checks is essential to save energy and reduce waste.

Generally, the characteristic properties of water are significantly influenced by physical activities (such as filtration, dispersion/dilution, and gas movement), biochemical activities (such as microbial respiration, cell synthesis and decay,) and geochemical activities (such as acid-base reactions, adsorption-desorption precipitation solution, oxidation-reduction, and complexation).

2. Aim and objectives

Aim*:*

Assessing the effects of water treatment processing and storage on the degradation of packaged water prior to its shelf-life expiration is the goal of this project.

Objectives:

1. To evaluate the physical, microbiological, and chemical qualities of packaged drinking water brands available in the area.
2. To observe and study the variance in the changes and deterioration of the sachet and bottled water after production, even before its expiry date.
3. To investigate when the produced packaged drinking water is most suitable for consumption even before its expiry date.
4. To investigate the common sources and reasons for possible deterioration.
5. To make consumers aware of the reliability of packaged water even before its shelf life expires.

3. Statement of the problem

The problem statement regarding the "Impact of water treatment and storage on the deterioration of packaged water before shelf-life expiration" highlights the vulnerabilities of treated water during storage and distribution. Packaged water, while initially safe, can experience quality degradation due to various factors, including microbial growth and environmental conditions. This deterioration can occur even before the indicated shelf-life expiration, necessitating a deeper understanding of the underlying mechanisms.

a) **Vulnerability of Packaged Water**
   a. Packaged water is susceptible to contamination post-treatment, as residual nutrients can support microbial growth (Robertson *et al.,* 2003). Studies indicate that bacterial regrowth can occur within a month of storage, with significant increases in Total Coliform counts observed (Hammond et al., 2024).

b) **Impact of Storage Conditions**
   a. Storage temperature plays a critical role; higher temperatures accelerate microbial growth and chemical degradation (Sevostyanova et al., 2019). Research shows that water stored at elevated temperatures can lead to significant quality deterioration, affecting both microbiological and physicochemical properties (Sevostyanova et al., 2019).

c) **Quality Monitoring and Management**
   a. Regular monitoring of water quality during storage is essential to ensure safety, as prolonged storage can lead to increased bacterial counts and other quality issues (Nnaji *et al*., 2019*)*. Implementing effective storage practices and cleaning protocols can mitigate quality deterioration (Nnaji *et al*., *2019).*

Natural and human activities affect our environment due to industrialization and development, and these create adverse conditions that may affect human life. These activities expose this same water to environmental challenges, and these challenges are in various dimensions, as the potable water is being distributed in order to reach the target of consumers, thus the problem of this research lies on the fact that the treatment, exposure, storage conditions and the packaging itself may affect the quality of water being distributed. And therefore, at certain stages of its storage, even before its stipulated expiry date, it becomes unfit for human consumption.

Conversely, while the focus is on deterioration, some studies suggest that certain storage conditions can be optimized to extend shelf life, indicating a potential for improving packaged water quality through better management practices.

4. Literature review

An important factor in preserving human health is water. It is clear that a man has a fundamental right to safe drinking water. Approximately 2.5 billion people lack acceptable environmental balance, with 780 million people lacking enough access to clean and safe drinking water (Citifmoline, 2011). As a result of this degradation, Water-related diseases claim the lives of 6 to 8 million people annually such as Typhoid cholera and many of such diseases are often generated from water related disasters and outbreaks such as food and water pollution; which are mostly influenced by the activities of man (UNDESA and UNECE, in association with UNESCO, 2013). Therefore, the aim of controlling and achieving an optimum quality of water is of the principal policy agenda in many nations worldwide at the moment (World Health Organisation (WHO), 2022).

Even today, the majority of people in Nigeria's major cities lack access to quality water sources, particularly drinking water, which was formerly distributed by the Water Board under the Ministry of Water Resources. As a result of the lack or insufficiency of potable drinking water, many have turned to more expensive options, such as purchasing water from water vendors, which has led to the development of sachet or bottled water which has become a major source of drinking water to date (Omalu et al., 2010).

Water can be said to be pure when the impurities are removed or purified by carbon filtration, micro-porous filtration, and ultraviolet oxidation. And this is a category of water available for sale and distribution to customers and consumers.

There are uncertainties in our reliability regarding the overall quality of drinking water distributed for consumption due to producers', consumers', and customers' ignorance of and disregard for caution and information regarding the need to know about pathogenic or parasitic organisms and other influences that may arise from environmental and human impacts associated with drinking water. Bacteria like Pseudomonas sp., Bacillus sp., Klebsiella sp., oocysts of Cryptosporidia spp., and Streptococcus sp. have been found in some sachet waters, among other things. These bacteria may be made possible by unsuitable storage conditions and environmental pollutants, which could seriously endanger and be of concern to consumers' health (Omalu et al., 2011).

The presence of contaminants in water is dangerous and undoubtedly impacts the quality of the water, which in turn impacts human health. Human activities related to agriculture, industry, and water treatment facilities during production are the possible causes of contaminated water. Geological conditions can also be naturally occurring sources of contamination. Inorganics, radionuclides, organics, disinfectants, and microorganisms are other classifications for these contaminants (Nollet, 2000). The majority of the contaminants found in drinking water are inorganic substances rather than organic compounds (Azrina, 2011).

Faecal contaminants, which include pathogens including Shigella species, Salmonella species, Vibrio cholera, and Escherichia coli, are the most hazardous source of drinking water pollution. They enter groundwater and other channeled sources of drinking water as a result of poorly treated sewage water systems.

Different microorganisms have different minimum infectious doses, which indicate the lowest number of ingested pathogens that can cause illness in an average healthy adult. Shigella Flexneri can cause dysentery with several hundred organisms, Salmonella Typhi can cause typhoid with only a few hundred organisms, Vibrio cholerae can cause cholera with a hundred million cells, and Salmonella Typhi serotypes can cause Gastroenteritis with several million cells (World Health Organization, 2022).

The minimum infectious dose also varies with age, nutritional and health status (this includes the ability of the immune system to attack or defend the body of the infected individual). For those individuals weakened in strength, like the sick, the elderly, just a very small dose would infect them compared to the active adult persons (World Health Organization, 2022).

Drinking water quality is also assessed based on its chemical composition. These can be achieved by assessing parameters like its pH, dissolved oxygen, heavy metals, total hardness, total alkalinity, and organic constituents. Water quality and its assurance for human consumption are measured based on its colour, taste, odour, and concentration of organic and inorganic materials (Dissmeyer, 2000; Nollet, 2000). Several scientific methods have been developed and implemented to evaluate these contaminants, including the analysis of various parameters such as total suspended solids (TSS), turbidity, pH, TDS, conductivity, heavy metals, and total organic carbon (TOC) (Dissmeyer, 2000). If the tested values obtained are of higher concentrations in the water samples more than the safe, permissible limits recommended by recognized health and drugs regulatory bodies in the world (World Health Organization (WHO), 2024). These parameters may affect or change the quality of water and may even deteriorate with time during storage. Hence, it is imperative that scientists, researchers, and government health and consumer regulatory agencies continue to constantly examine the quality of drinking water globally, particularly in developing countries (Treacy, 2019).

4.1. Physical quality

Apparently the most crucial attribute of a good drinking water rating by the consumers would be after the water's colour appearance, the odour, the taste and its freshness. Some examples of parameters that particularly contribute to the storage and shelf characteristics of drinking water most specifically includes colour, turbidity, total dissolved solids, pH, temperature, dissolved oxygen, free chlorine, and many more.

4.2. Chemical quality

The presence of chemical in water or any use of chemicals to treat water is surely of great concern to the human health because if there are no proper handling of chemical during treatment such as chlorination, chemicals injected for the stabilization of the pH, these naturally occurring inorganic or organic chemical may be toxic, and develop more associations in the water of which, while on storage and when consumed, they will be harm to the human health depending on the concentrations present in the drinking water. These related effects generally affect the aesthetic quality of the treated drinking water. Chemicals present in water are inorganic or organic as discussed below.

4.3. Inorganic chemicals

Generally, inorganic substances in drinking water are dissolved salts, such as carbonates and chlorides, which are attached to other suspended solids or dissolved solids, such as particles of clay, or they can combine with organic compounds that are prevalent in nature to form complexes.

Inorganic chemical present in water due the following reasons;

- Leaching and corrosion in pipelines and fittings.
- Mineral deposits that are naturally leached in water sources.
- Land activities that may involve the excavation from the natural occurrences like that of the mineral and salts beds.
- Small amounts of treatment chemicals are carried over.
- Chemicals like fluoride and chlorine are added.

4.4. Organic chemicals

Organic elements or compounds are usually present in drinking water as naturally occurring or from human activities especially during water treatment of which are present in very low concentrations. The effects from back washing, the filters and adsorption resins, by-products of disinfection, introducing chemicals to control the pH are generally traced to be the reasons for organic contamination of the drinking water.

your manuscript.

5. Research methodology

5.1. Scope of research

Sachet and bottled water were obtained from water treatment companies who employ most of the treatment's methods used in the production of packaged pure water such as Chlorination, Filtration, Ultraviolet light, Reverse Osmosis and Ozonation. Twelve (12) water samples were investigated in all which included Ten (10) sachets of water samples were obtained from Zaria local government areas and two (2) bottled water samples collected from Iza Bottled Water Company and Ahmadu Bello University service drinking water outlet.

The Physico-chemical and microbiological tests for each of the twelve (12) water samples were carried out on the day of collection before being stored in an open facility (green house) to investigate the impact of the storage system on water quality. The Physico-chemical parameters such as pH, turbidity, total hardness, electrical conductivity, taste, dissolved oxygen and the microbiological total coliform count of the water samples evaluated were used to make assessment. These evaluations were repeated on the twelve water samples at monthly intervals, for three consecutive months.

The results obtained were used in the evaluation of the effect of water treatment methods on water quality over time and also the impact of storage techniques or weather conditions on the quality of water samples over a period of time.

6. Data analysis

6.1. Materials and methods

The study was conducted in Zaria Local Government Area, with samples obtained from Bassawa, Samaru, Sabon Gari, and Giwa local areas in Kaduna State, North Central Area of Nigeria. The materials used which consist of consumables and equipment are as follows:

Consumables

Distilled Water, Buffer solution, Nitric Acid, Petri dishes, Eosin Methylene Blue Agar, Cotton wool, Foil, Glass rod, Boric acid, Methyl red, Magnesium oxide (MgO), Devarda's alloy, Ammonia solution, Sodium Cyanide (2%), Sodium EDTA, Indicator (Eriochrome Black T), Reagents Solochrome Black T(Calcom), Sodium hydroxide (1 Normal) and Samples of packaged pure water.

Equipment

- **a.** pH: HANNA INSTRUMENTS pH meter, PH-2601 model
- **b.** Colour: Lovibond 1000 comparator.
- **c.** Turbidity: 4200 series HACH instruments turbidimeter.
- **d.** Total Dissolved Solids: Search Tech Instruments DDS-307A/DDS-307/DDS-11A England.
- **e.** Conductivity: Search Tech Instruments DDS-307A/DDS-307/DDS-11A England.
- **f.** Total Hardness: EDTA Titrimetric Method.
- **g.** Temperature: HANNA INSTRUMENTS pH meter, PH-2601 model
- **h.** Dissolved Oxygen: (model: JPB-607A Search Tech Instruments England).
- **i.** Nitrate: Kjeltec ™ 8200 Auto distillation assembly, An electric muffle furnace, A desiccator
- **j.** Metals: PG instruments England PG 990 model Atomic Absorption spectrophotometer.
- **k.** Total Coliform Count: Air oven, colony counter, Incubator.

6.2. Identifications and treatment processes of packaged water samples

The water samples from the randomly selected production factories were identified with their characteristic mode of treatment processes involved in the treatment of water which is shown the Table below:

Table 1: Identifications and Treatment Processes of the Water Samples

S/N	Pure Water	Source	Treatment Processes Employed
1	Pw1	Borehole	Sand and Activated Carbon Filtration, U.V light Packaging
2	Pw2	Well	Sand Filtration
3	Pw3	Borehole	Filtration, U.V light Packaging
4	Pw4	Borehole	Sand Filtration, Activated Carbon Filtration, U.V Light Sterilization, Reverse Osmosis, Ozonation, U.V Light packaging
5	Pw5	Well	Filtration
6	Pw6	Borehole	Sand Filtration, Activated Carbon Filtration, U.V Light Packaging, Reverse Osmosis, Ozonation, U.V Light Packaging
7	Pw7	Well	Filtration, Reverse Osmosis U.V Light Packaging,
8	Pw8	Well	Filtration, U.V Light Sterilization
9	Pw9	Borehole	Sand Filtration, U.V Light Sterilization, Chlorination, U.V light packaging, Ozonation
10	Pw10	Borehole	Sand Filtration
11	Bw11	Dam	Filtration, Chlorination, U.V Light Sterilization, Activated Carbon Filtration, U.V Light, Sterilization, Ozonation
12	Bw12	Borehole	Sand Filtering, Activated Carbon Filtration, U.V Light Sterilization, Reverse Osmosis, Ozonation, U.V Light Packaging.

7. Results and discussions

7.1. Standard deviation of individual pure water of the Monthly Mean Values

Table 2, displays the packaged water samples' monthly pH mean values below

Table 2: Standard deviation of individual pure water samples.

Water Samples		pH	Coliforms	Total Hardness	Conductivity	Turbidity	T.D. S	D.O_2
Pw1	Mean	7.8975	505.0000	94.0550	44.6775	.3475	22.9667	6.2000
	Std. Deviation	.08170	503.23499	22.64336	1.43623	.01055	.43762	.04264
	Minimum	7.82	.00	77.32	42.23	.33	22.30	6.10
	Maximum	8.05	1300.00	132.95	47.48	.37	23.60	6.30
Pw2	Mean	8.0725	118.3333	88.2050	162.8133	.6558	82.1000	6.2000
	Std. Deviation	.27173	92.62175	11.47242	13.87100	.06501	4.94718	.12792
	Minimum	7.84	.00	69.28	141.77	.55	75.10	5.90
	Maximum	8.53	290.00	101.24	178.45	.73	87.10	6.30
Pw3	Mean	8.4800	.0000	85.8850	143.0317	8.1950	74.0333	6.1750
	Std. Deviation	.81959	.00000	9.19623	1.74199	5.10581	2.44553	.15448
	Minimum	7.71	.00	79.95	140.79	.67	69.80	6.10
	Maximum	9.74	.00	101.67	145.39	14.14	77.70	6.60
Pw4	Mean	8.1750	.0000	60.7917	15.5667	.4350	8.0292	6.2750
	Std. Deviation	.55874	.00000	10.77227	.95281	.08980	.55988	.11382

	Minimum	7.24	.00	50.02	13.99	.35	7.19	6.10
	Maximum	8.52	.00	74.51	16.77	.55	8.87	6.40
Pw5	Mean	7.7850	1092.5000	102.0392	53.8017	.7125	25.9250	6.1167
	Std. Deviation	.08898	953.67352	55.27869	1.47777	.10306	1.21963	.12673
	Minimum	7.67	30.00	58.99	51.09	.63	23.80	5.90
	Maximum	7.91	2550.00	194.04	56.73	.92	27.70	6.30
Pw6	Mean	7.1425	.0000	41.9233	14.6575	.4350	7.9100	6.4500
	Std. Deviation	.10738	.00000	2.45025	.67078	.13460	.12534	.17321
	Minimum	7.03	.00	39.68	14.03	.29	7.75	6.20
	Maximum	7.31	.00	46.16	16.37	.65	8.23	6.60
Pw7	Mean	7.5225	147.5000	62.7175	179.4258	.6742	88.3583	6.2333
	Std. Deviation	.10567	125.41748	3.41528	6.30021	.10068	4.94322	.14355
	Minimum	7.35	40.00	60.07	168.22	.57	82.10	6.10
	Maximum	7.63	360.00	70.53	186.48	.85	93.40	6.50
Pw8	Mean	8.3775	.0000	105.9942	186.9408	3.4142	64.0000	6.0667
	Std. Deviation	.59794	.00000	18.40878	2.46341	5.03688	7.10122	.14355
	Minimum	7.73	.00	87.71	183.94	.17	56.10	5.90
	Maximum	9.35	.00	132.88	190.61	12.44	75.30	6.30

Pw9	Mean	7.9600	.0000	83.3575	148.2242	.7092	69.4000	6.1250
	Std. Deviation	.17776	.00000	13.72052	24.57868	.18258	.38612	.37929
	Minimum	7.71	.00	60.13	126.66	.51	68.70	5.50
	Maximum	8.19	.00	91.71	189.52	.91	70.30	6.40
Pw10	Mean	8.2558	669.1667	95.6125	139.8342	.7592	71.3667	6.6083
	Std. Deviation	.04907	691.67068	8.85343	6.88970	.08174	3.75144	.18809
	Minimum	8.19	30.00	89.76	131.11	.62	67.10	6.40
	Maximum	8.34	1850.00	112.62	150.16	.87	77.50	7.10
Bw11	Mean	7.7150	.0000	90.9100	155.2425	.4400	59.9925	6.5250
	Std. Deviation	.10715	.00000	.08528	1.28955	.07628	31.51233	.22613
	Minimum	7.63	.00	90.71	153.33	.40	7.75	6.40
	Maximum	7.91	.00	91.11	157.34	.68	79.80	6.90
Bw12	Mean	6.9625	.0000	40.7358	14.5225	.4283	8.8425	6.5000
	Std. Deviation	.02927	.00000	.48861	.23398	.12350	.08781	.00000
	Minimum	6.93	.00	40.04	14.25	.34	8.75	6.50
	Maximum	7.01	.00	41.79	15.14	.68	8.99	6.50
Total	Mean	7.8622	211.0417	79.3522	104.8949	1.4338	48.5770	6.2896
	Std. Deviation	.56466	495.37683	28.43645	67.36581	2.96480	31.39149	.24372

	Minimum	6.93	.00	39.68	13.99	.17	7.19	5.50
	Maximum	9.74	2550.00	194.04	190.61	14.14	93.40	7.10

7.2. pH Results of the Monthly Mean Values.

Table 3: displays the packaged water samples monthly pH mean values below.

Table 3: The monthly mean values in pH (Mg/l).

S/N	Initial	M1	M2	M3
Pw1	7.86	7.86	7.84	8.03
Pw2	7.85	7.91	8.02	8.51
Pw3	7.71	7.93	9.73	9.55
Pw4	7.52	8.49	8.44	7.25
Pw5	7.91	7.81	7.73	7.69
Pw6	6.99	7.12	7.11	7.05
Pw7	7.62	7.36	7.59	7.52
Pw8	7.82	8.11	8.25	9.33
Pw9	7.71	7.98	8.19	7.96
Pw10	8.21	8.23	8.26	8.33
Bw11	7.64	7.65	7.68	7.89
Bw12	6.95	6.94	6.95	7.01

M1= (1st Month), M2= (2nd Month), and M3= (3rd Mont**h)**

Discussion of pH limit result

The initial readings of the water samples were within the W.H.O acceptable pH limit of 6.5-8.5. The initial readings of the pH values taken on the day of samples collected showed that all the packaged drinking water represented ranged from 6.95 - 8.21 as represented in Table 4.1, which falls within the W.H.O, *2017* acceptable limit. Samples Bw12 and Pw6 which were both treated with reverse osmosis and Ozonation had the lowest pH values of 6.95 and 6.99 respectively, and Pw10 had the highest pH values.

The pH values of sample Pw8 progressively increased through the period of storage. This may be due to the dissolved solids, nitrate levels and any other metal contaminants present.

Sample Pw3 was above W.H.O, 2017 permissible drinking water limit by the second month (M2). This may be due to metal contamination, algae formation and leaching of nutrients like nitrates.

The fluctuations in the pH values of some other water samples such P9 (7.71 – 7.9) and Pw6 (6.99 – 7.05) were influenced by the chemical, physical, and biochemical activities occurring in the packaged water.

There were observed increases in pH values from during the period of storage which were higher than the permissible limits on M2 (In Pw3 which increased to 9.73) and on M3 (in Pw3 which increased to 9.55, and Pw8 also increased to 9.33), thereby becoming more alkaline.

The changes in the pH of samples Pw3, and Pw8 correlated the results of colour change from 5 to 10 Hazen units, objectionable taste in, and the increase in the turbidity values observed in the water samples.

Results of the monthly mean values of total dissolved solids

The monthly Total Dissolved Solids mean values of the pure water samples are presented in Table 4.

Table 4: The monthly mean values in Total Dissolved Solids (48.6 ± 31.4) Mg/l

S/N	Initial	M1	M2	M3
Pw1	23.1	23.1	22.9	22.7
Pw2	86.9	86.2	79.7	75.6
Pw3	76.9	74.7	73.5	70.7
Pw4	8.86	8.03	7.81	7.42
Pw5	24.7	25.1	26.8	27.1
Pw6	7.88	7.88	7.89	7.99
Pw7	93.1	92.9	84.8	82.6
Pw8	56.3	60.7	64.5	74.4
Pw9	69.3	69.5	69.5	69.3
Pw10	67.3	77.1	70.9	70.2
Bw11	77.2	77.4	77.7	77.6

M1= (1^{st} Month), M2= (2^{nd} Month), and M3= (3^{rd} Month)

Discussion of total dissolved solids result.

Table 4 shows the values for the total dissolved solids (TDS) in each of the twelve drinking water samples. The standard or maximum value of the TDS set by World Health Organization (WHO), 2022. is 259-500 mg/L.

All through the period of investigation, the TDS values of all the samples were low in dissolved solids ranging between (8.03-93.1) mg/l, this implies that all the obtained packaged water samples were low in dissolved solids basically due to efficient filtration practices in the treatment of the water samples.

All the Reverse Osmosis (RO) treated water (Pw4, Pw6, Pw12) showed very low values of TDS of about 7.88mg/l, 8.03mg/l and 8.91mg/l except for sample 7, which had 93.1mg/l. this may be due to the source of water, or error from the RO equipment.

Results of the monthly mean values of temperature (^{0}C).

The monthly pH mean values of the pure water samples are presented in table 5:

Table 5: The monthly mean values of Temperature (^{0}C)

S/N	Initial	M1	M2	M3
Pw1	25.3	24.5	25.1	24.7
Pw2	25.1	24.6	25.1	24.7
Pw3	24.9	24.5	24.8	24.9
Pw4	24.8	24.7	24.6	24.7
Pw5	24.3	24.9	24.9	24.7
Pw6	24.8	24.5	24.6	24.8
Pw7	24.6	24.6	24.8	24.8
Pw8	24.6	24.5	24.6	24.8
Pw9	24.7	24.6	24.7	25.1
Pw10	24.8	24.5	24.9	24.8
Bw11	24.4	24.6	24.7	24.6
Bw12	24.7	24.8	24.7	24.8

M1= (1st Month), M2= (2nd Month), and M3= (3rd Month)

Discussion of temperature results.

According to the above table, the temperature results of the water samples under investigation ranged from 24.5 ^{0} C to 25.3 ^{0} C during the study period, all of which fell within the acceptable limit of W.H.O. standards. For mesophilic bacteria and human diseases, the temperature values recorded during the course of the shelf period are within the ideal range for growth. The World Health Organization (2022) states that drinking water temperatures should not exceed 24.5 to 39.7 degrees Celsius.

Results of the monthly mean values of total hardness

The monthly total Hardness mean values of the pure water samples as presented in table 4.0.

Table 6: Monthly mean values of Total Hardness (79.4 $\pm$ 28.4) Mg/**l)**

S/N	Initial	M1	M2	M3
Pw1	80.48	78.91	131.31	85.52
Pw2	90.89	90.51	101.01	70.71
Pw3	80.81	80.81	80.81	101.11
Pw4	50.54	50.54	70.71	71.71
Pw5	112.26	144.21	192.91	60.63
Pw6	45.89	40.94	40.45	40.41
Pw7	67.89	60.62	60.65	60.61
Pw8	89.34	90.91	111.11	132.62
Pw9	90.99	92.99	111.11	60.62
Pw10	90.45	90.89	90.91	110.11
Bw11	90.91	90.91	90.91	90.91
Bw12	40.47	40.67	40.81	40.99

M1= (1st Month), M2= (2nd Month), and M3= (3rd Month)

Discussion of total hardness result.

From the results of total hardness in table 6; above, the initial Total hardness Concentration ranged between 40.47 – 122.26 mg/L and 40.47-192.91 mg/L throughout the window of investigation.

a) Initial total hardness values for samples Pw12 and Pw6 are 40.47 mg/L and 45.89 mg/L, respectively, while sample Pw5 has the highest total hardness value of 112.26 mg/l. The high hardness levels of these samples may be due to deposits of calcium and magnesium, which are primarily found in minerals such as dolomite, chalk, and limestone.

b) Initial readings of all samples conformed with the W.H.O standards of permissible limit of 150 mg/L. During the period of investigation Pw5 had increased to 192.91mg/L in the second month (M2). which may be due to very higher concentration of calcium and magnesium compare to other samples, these sharp changes observed may also be due the growth of Total Coliforms which involves the excretion of metabolic waste Pw5 have its highest peak of CFU/100 units in the second month (M2) with about 2500 CFU/100ml.

c) Samples Pw1, Pw2, and Pw5, exhibited a similar pattern in the values of total hardness with their highest values in the second month. These changes may be due to the growth and death phase contributed by the biochemical activities of the total coliforms in the packaged water.

d) The total hardness values of sample Pw8 which has no coliform count increased progressively, even so, Pw8 was also observed to have higher nitrate level of 0.14mg/l and a high concentration of Fe of 0.109mg/l which exceeds the allowable limit of 0.03mg/l. this may be responsible for the sharp deterioration of the Pw8 water sample.

Results of the monthly mean values of electrical conductivity; Table 7: displays the pure water samples' monthly mean electrical conductivity values.

Table 7: The monthly mean values of Electrical Conductivity

(104.90 $\pm$ 67.37) μS/cm

S/N	Initial	M1	M2	M3
Pw1	44.62	44.54	44.44	45.11
Pw2	178.22	170.65	159.36	143.09
Pw3	144.23	144.64	142.22	141.16
Pw4	16.55	15.71	15.02	14.98
Pw5	53.34	53.66	53.52	54.22
Pw6	14.36	14.35	14.33	15.59
Pw7	179.47	182.55	185.52	169.83
Pw8	188.88	184.33	185.33	189.22
Pw49	188.11	138.82	138.69	127.17
Pw10	134.67	146.81	145.44	132.55
Bw11	154.12	154.11	156.11	156.53
Bw12	14.38	14.44	14.55	14.72

M1= (1^{st} Month), M2= (2^{nd} Month), and M3= (3^{rd} Month)

Discussion of electrical conductivity result

The Electrical Conductivity (EC) of some samples decreased with time except for some fluctuations found in Samples (Pw1, Pw2, Pw6, Pw5, Bw11, and Bw12) Table 7; illustrates this. This could be because of different dissolved substances and their concentrations of metal ions and the microbial activities ongoing in some of the samples. The highest conductivity level that is permitted for portable drinking water is 500μS/cm (W.H.O, Geneva, Switzerland, 2011). According to the findings, all water samples had initial conductivity values between 14.38 and 188.88 μS/cm, and the conductivity values acquired throughout the course of investigation varied from (14.38-189.22) μS/cm which is within permissible limit. Pw4, Pw6, and Pw12 samples treated with Reverse Osmosis had the lowest conductivity of 14.38 μS/cm -16.55 μS/cm, which corresponds with the level of Total Dissolved Solids values. This may be due to the efficient absorption of dissolved solids by the Reverse Osmosis water treatment processes.

Samples Pw2, Pw7, Pw9, and Pw8 recorded the highest electrical conductivity values in Table 7: ranging between 178.22 μS/cm -189.22 μS/cm which is still in conformity to the W.H.O, *2017* permissible limit of 500 μS/cm. Higher Conductivity can give water a mineral taste, which might reduce its aesthetic value. (Rahmanian N. *et al,* 2015).

Sample Pw7 had the highest conductivity values of 188.11 μS/cm even though it was treated by Reverse Osmosis, while the sample Pw4, Pw6, and Bw12 have the lowest values.

The fluctuation in the electrical conductivity values partly depends on the chemical, physical activities taking place in the water**.**

Results of the monthly mean values of turbidity; The monthly Electrical Conductivity mean values of the pure water samples are presented in table 8 below:

Table 8: Results showing the monthly mean values of Turbidity (1.43 $\pm$ 2.97) mg/l

S/N	Initial	M1	M2	M3
Pw1	0.35	0.34	0.34	0.36
Pw2	0.56	0.68	0.72	0.66
Pw3	0.67	7.75	10.31	14.05
Pw4	0.35	0.35	0.52	0.52
Pw5	0.66	0.64	0.67	0.88
Pw6	0.36	0.31	0.42	0.46
Pw7	0.56	0.64	0.67	0.82
Pw8	0.81	0.87	0.96	11.74
Pw9	0.91	0.51	0.52	0.84
Pw10	0.78	0.84	0.82	0.65
Bw11	0.43	0.41	0.41	0.41
Bw12	0.36	0.35	0.34	0.35

M1= (1st Month), M2= (2nd Month), and M3= (3rd Month)

Discussion of turbidity result.

The initial test readings ranged from (0.34-0.91) NTU which was below the maximum standard limit of 5NTU. Generally, the turbidity progressively increased across the months.

Pw4, Pw6 and Pw12 water samples treated with Reverse Osmosis have lowest values ranging from 0.35-0.36NTU, due to its effective elimination of undesirable organisms and solids from water. These samples maintained the same range of lower values pattern during storage. Pw5 which is also treated by reverse osmosis process has 0.66 NTU which indicates inefficiency in the treatment process of Pw5 sample.

The turbidity values of samples throughout the period investigated varied between 0.31-14.05 NTU which shows that some water samples were at certain point in time during the storage, above the permissible limit for consumption. These samples include Pw3 (10.31, and 14.05) NTU in the second (M2) and the third (M3) months of the investigation) and also Pw8 (11.74 NTU) in the third month (M3) of the investigation.

Pw9 and Bw11 samples which were treated with the chlorination process had their highest turbid values at their initial readings. This may be due to the effect of chlorination.

The turbid value of Pw3 was above the W.H.O acceptable limit of 5NTU, at the end of the first month. This makes it not permissible for consumption.

Results of the monthly mean values of colour (Hazen units)

The monthly Colour mean values of the pure water samples are presented in Table 9.

Table 9: Results showing the monthly mean values of colour (Hazen Units)

S/N	Initial	M1	M2	M3
Pw1	5	5	5	5
Pw2	5	10	10	10
Pw3	5	10	10	10
Pw4	5	5	5	5
Pw5	5	5	5	5
Pw6	5	5	5	5
Pw7	5	5	5	5
Pw8	5	5	10	10
Pw9	5	5	5	5
Pw10	5	5	5	10
Bw11	5	5	5	5
Bw12	5	5	5	5

M1= (1st Month), M2= (2nd Month), and M3= (3rd Month)

Discussion of colour result

From the results in table 9; All sample maintain a clear colour of 5 Hazen Units all through the investigation except for Samples Pw2 and Pw3, (whose colour both changed to 10HU in the first month (M1) and Pw8 (in the second (M2), and Pw10 in the third month (M3). Sample Pw3, physically exhibited/showed a greenish colour which could indicate leaching copper plumbing or Algae this may be due to the high concentration of metals such as Tannins Cu, Fe, Mn, and many more. and natural deposits.

Results of the monthly mean values of dissolved oxygen; The monthly Dissolved Oxygen mean values of the pure water samples are presented in table 10.

Table 10: The monthly mean values of dissolved oxygen (6.3 $\pm$ 0.24) Mg/l

S/N	Initial	M1	M2	M3
Pw1	6.2	6.2	6.2	6.2
Pw2	6.3	6.2	6.2	6.1
Pw3	6.4	6.1	6.1	6.1
Pw4	6.4	6.3	6.3	6.1
Pw5	6.2	6.1	6.1	6.1
Pw6	6.6	6.6	6.4	6.2
Pw7	6.4	6.3	6.1	6.1
Pw8	5.9	6.1	6.1	6.2
Pw9	6.4	6.3	6.3	5.5
Pw10	6.6	6.7	6.6	6.5
Bw11	6.9	6.4	6.4	6.4
Bw12	6.5	6.5	6.5	6.5

M1= (1st Month), M2= (2nd Month), and M3= (3rd Month)

Discussion of dissolved oxygen result

From the result in Table 4.10, the value of the dissolved oxygen levels varied from 5.9 mg/l-6.9 mg/l throughout the period of investigation.

Sample (Bw11) which had chlorination as one its treatment processes involved, showed to have the highest initial reading of Dissolved Oxygen level of 6.9 mg/l.

All values of the samples tested conformed to the W.H.O permissible limit of 7.5mg/l as presented in Table 10.

The fluctuation in values in the dissolved oxygen was dependent on the interactive (synergistic and antagonistic) engaging activities in the packaged drinking water, such as respiration and total coliform metabolism.

Results of the monthly mean values of total coliforms count

The monthly Total Coliforms Count mean values of the pure water samples are presented in table 11.

Table 11: The monthly mean values of total coliforms (21.04 $\pm$ 495.38 CFU Units)

S/N	Initial	M1	M2	M3
Pw1	100	700	1200	30
Pw2	80	130	250	10
Pw3	0	0	0	0
Pw4	0	0	0	0
Pw5	650	1200	2500	30
Pw6	0	0	0	0

Pw7	70	120	350	60
Pw8	0	0	0	0
Pw9	0	0	0	0
Pw10	170	780	1700	50
Bw11	0	0	0	0
Bw12	0	0	0	0

M1= (1st Month), M2= (2nd Month), and M3= (3rd Month)

Discussion of coliform result

From the result, five samples analysed from the different sachet water revealed the presence of total coliform count. Table 11 showed Pw1, Pw2, Pw5. Pw7, Pw10 initial readings gave (70-650) CFU/100ml and (10-2500) mg/l throughout the time of investigation.

The total coliform count multiplied during the early to mid-period of storage. The highest Peak at which the coliform multiplied in all the samples as represented in the table 11 and in figure 1 was in the second (M2) month. This is so because the rate of multiplication still will depend on the nutrient level in the water. Total coliform bacteria count declined towards death, having lower values of (10 mg/l-50 mg/l) in the third month (M3). So, this is highly harmful to the consumer.

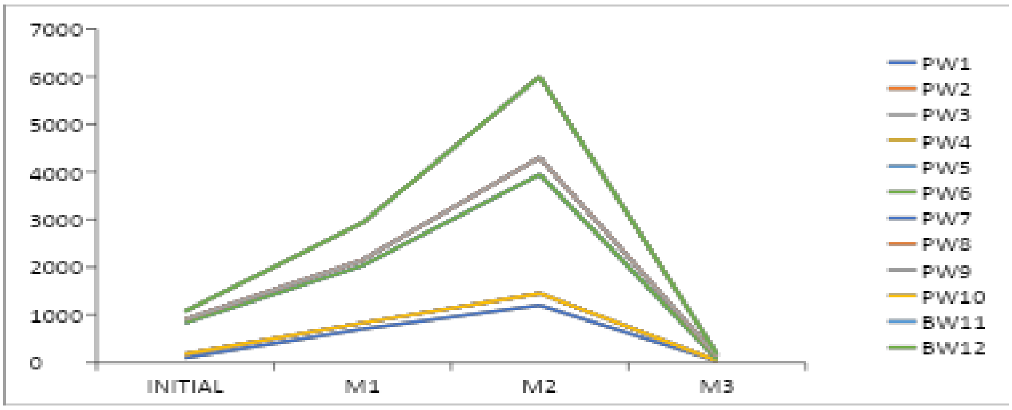


Figure 1: Graphic representation of the heavy metals observed through the investigation.

Results of the mean range variation of taste at two weeks interval

The monthly Taste mean values of the pure water samples are presented in table 12

Table 12: The mean range variation of the test for Taste in (2 Weeks Intervals)

S/N	Initial	W2	W4	W6	W8	W10	W12
Pw1	N	N	N	N	N	N	N
Pw2	N	N	X	X	X	X	X
Pw3	N	X	X	X	X	X	X
Pw4	N	N	N	N	N	N	N
Pw5	N	N	N	N	N	N	N
Pw6	N	N	N	N	N	N	N
Pw7	N	N	N	N	N	N	N

Pw8	N	N	X	X	X	X	X
Pw9	N	N	N	N	N	N	N
Pw10	N	N	N	N	X	X	X
Bw11	N	N	N	N	N	N	N
Bw12	N	N	N	N	N	N	N

X=Objectionable. N= Unobjectionable.

Discussion of taste result

From the result shown in Table 12, Pw2: was objectionable from the 4th week, Pw3: was objectionable from the 2nd week, Pw8: was objectionable from the 4th week, and Pw10: was objectionable from the 8th week of shelf storage. This does not conform to the W.H.O standard of drinking water. This implies the water may be unsafe for consumption before its expiry date.

Total dissolved solids and metals like iron, copper, manganese, or zinc can cause taste issues in water.

Results of the analysis of metals and nitrate.

The monthly Total mean values of the pure water samples are presented in table 13.0 below.

Table 13: Result of the values of Metals and Nitrate.

Samples	Nitrate (Mg/l)	Ca (Mg/l)	Mg (Mg/l)	Fe (Mg/l)	Zn (Mg/l)	Pb (Mg/l)
Pw1	0.03	0.20	0.06	0.090	0.020	0.057
Pw2	0.05	0.70	0.21	0.030	0.096	0.634
Pw3	0.07	0.60	0.18	BDLV	BDLV	0.152
Pw4	<0.01	0.40	0.12	BDLV	BDLV	0.147
Pw5	0.06	0.90	0.27	BDLV	BDLV	0.181
Pw6	<0.01	0.33	0.13	BDLV	0.003	BDLV
Pw7	0.37	1.00	0.28	0.150	0.024	0.259
Pw8	0.14	0.50	0.15	0.109	0.024	BDLV
Pw9	0.08	1.00	0.30	BDLV	BDLV	BDLV
Pw10	0.04	0.65	0.37	0.118	BDLV	0.228
Bw11	0.07	0.70	0.18	BDLV	BDLV	BDLV
Bw12	<0.0I	0.30	0.11	BDLV	0.004	BDLV

Note: BDLV= Below Detectable Limit

Discussion of nitrate result

Nitrates values measured of all the twelve (12) samples were between (<0.01mg/l-0.37mg/l) which is within the permissible limit of nitrate level in drinking water. Laboratory reports nitrate results either as Nitrate nitrogen or as nitrate, when reported as Nitrate nitrogen (NO_3N), the acceptable level is level than 10 mg/l (less than 2 mg/l is preferred). When reported simply as nitrate (NO_3) the acceptable level is less than 45 mg/l. all the samples of water treated by Reverse Osmosis (Pw4, Pw6, Pw12) correspond with lowest values of result of <0.01mg/l) except for sample Pw 7, which appeared to have the highest nitrate level value of 0.37mg/l. If other nutrients are present in the water (plant nutrients such as nitrogen, phosphorus, carbon, potassium, magnesium, and calcium and other micronutrient), Nitrate level as low as 0.50mg/L may result in significant growth of algae (Westminster College 2020).

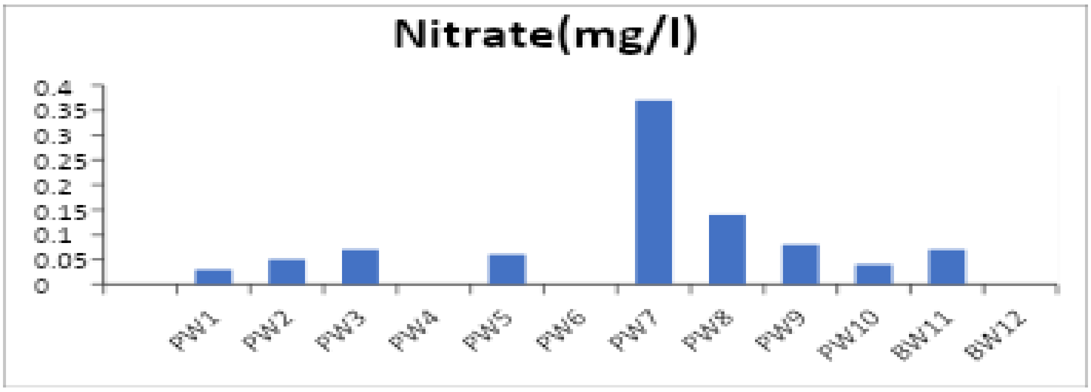
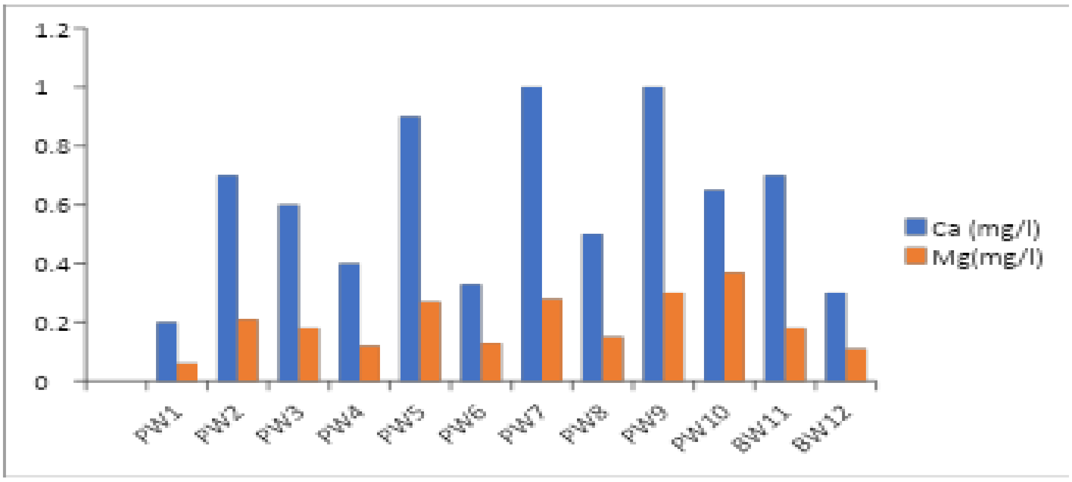


Figure 2: Graphic representation of the Nitrate levels

Discussion of Calcium and Magnesium result

The value for Calcium ranges between 0.20mg/l to 1.00 mg/while that of Magnesium ranges from (0.06-0.37) mg/l. This shows that the water samples are soft. Pw7, Pw9 both showed the highest value Ca^{2+} of 1.00mg/l. Reverse Osmosis and activated carbon showed their lowest ranges.



Figures 3: Graphic representation of the Calcium and Magnesium levels

Metals

The value of Iron (Fe) ranges between (-0.026mg/l-0.150mgl), which implies that some the samples (Pw1, Pw7, Pw8 and Pw10) are above the World health Organization (WHO) with Pw7 having the highest values of 0.150mg/l.

Observations of metal result

- **a.** Fe: Samples Pw1, Pw2, Pw7, Pw8 and Pw10 were above the limit of Fe 0.03mg/l
- **b.** Pb: Samples Pw (2, 3, 4, 5,7 and 10) were higher than the W.H.O acceptable limit of 0.05mg/l.
- **c.** Some samples like Pw9 were below the detectable limit.

Discussion of metal test result

The values of all the samples ranged between -0.082mg/l-0.096mgl) indicating that Zinc is low in the area when compare with the permissible limit of 5.0mg/l by the World Health Organization (W.H.O) Geneva, Switzerland, 2011.

It has been found that at many places higher concentration of lead are present in drinking water Zaria area has showed not to be an exception .The lead (Pb) concentrations in this samples were ranged between (-0.772mg/l-0.634mg/l) which shows some sample were much greater than the permitted limit of 0.05mg/l as recommended by WHO, as shown in table 4.2 The Iron(Fe) and Lead (Pb) concentration in some waters samples (such as Pw1,Pw2,Pw3,Pw5,Pw7,Pw10) especially for those that did not employ more/added treatment process such as Chlorination, Reverse Osmosis, sterilization using UV Light and Ozonation were high above the permissible standard. This corresponds to the fact stipulated by (Manahan 1994) that Activated carbon that is softer in water can significantly reduce lead, and so also, filtration can also reduce lead to a certain extent. 94% to 98% of the lead in drinking water can be eliminated at the time of use via reverse osmosis (Manahan, 1994).

Statistical interpretation of analytical results using Pearsons's correlation

The Pearson's product-moment correlation coefficient, '*r*-value' shows the relationship between two variables (x and y) for the specific equation used. The correlation coefficient value is $-1 \leq r \leq 1$. The sign of the correlation coefficient indicates how the variable behaves; more specifically, if the r-value is positive, the value of y rises as x rises, and if the r-value is negative, the value of y falls as x rises. Based on the above Table 4.13 result, the analysis of the relationship between coliform versus the other variables, showed that the Pearson's correlation coefficient (*r*-value < -0.5 at p-value > 0.05 level of significance) is a weak negative relationship that exist with the other variables, viz: colour, conductivity and dissolved oxygen, total dissolved solids and turbidity. A moderate positive relationship exists with the total hardness of the water (r= 0.554, $p < 0.001$); meanwhile, a weak positive relationship exists with total dissolved solids and the pH ($r < -0.5$, and $p > 0.05$).

For the relationship between pH with the other variables; there is a moderate positive association ($r \geq 0.5$) with the colour, turbidity and total hardness of the water samples. A weak negative relationship was observed with pH and the amount of dissolved oxygen in water ($r = -0.235$) at $p = 0.005$ level of significance.

The colour values of the water samples and the other variables have a weakly positive correlation. Viz: total hardness, conductivity and total dissolved solids at ($r < 0.5$ and $p < 0.001$) shows that there would be increase in these variables as the colour of the water increases, although at a statistical significantly weak progression.

The analysis of the relationship of the total hardness of water with other variables shows that it has a strong positive relationship with the total dissolved solids present in the water, although not at statistically significant level ($r = 0.64$, $p > 0.05$). This implies that as total dissolved solids in the water increases, the hardness of the water increases. The other variables had weak positive and weak negative relationships with the total hardness of the water respectively ($-0.5 < r < 0.5$).

The statistically significantly strong degree of positive relationship between the conductivity and total dissolved solids ($r = 0.916$, $p < 0.001$), suggests that conductivity increases with increase in the concentration of dissolved solutes. A weak negative relationship exists between conductivity and dissolved oxygen in the water samples.

The correlation coefficient ($r < -0.5$) shows weak negative relationship between dissolved oxygen and all other variables; which is statistically significant for pH, colour, and turbidity ($p < 0.01$). This suggests that there is a slight increase in dissolved oxygen concentration with the decrease in other variables.

The correlated relationship between the total dissolved solids and the turbidity is a statistically significantly weak positive relationship ($r = 0.260$, $p = 0.002$). Also, there is a statistically significantly moderate positive correlation coefficient between the turbidity and the colour of the water samples ($r =0.624$, p = <0.001). This implies that the colour of the water increases with increase in turbidity.

Statistical interpretation of analytical results using Pearson's correlation

- **a.** Total Coliforms count had a significant relationship with Total hardness this implies that the increase or decrease in Total Coliforms directly influenced the increase and decrease in Total hardness.
- **b.** Total Coliforms count showed to have negative relationship with Colour, Total Dissolved Solid, Conductivity, Turbidity and Dissolved Oxygen, which implies that whilst coliforms increased the parameters mentioned decreased or when there is a decrease in Total coliform all other parameters remain within values and as well maintained or increased, depending on the strength (the many other factors of the deteriorations) as recorded in the correlation table. This brought about the fluctuations in values of the parameters.
- **c.** pH values have significant relationships with the changes of Colour, Total hardness, Dissolved oxygen, and Total Dissolved Solid, Turbidity, in the sample stored throughout the investigation. For example, Pearson's correlation relationship between pH and Dissolved oxygen (DO) shows negative (-235) implying that while there is an increase in pH level the Dissolved Oxygen level decreases with .005 significant strength.
- **d.** Total hardness had significance with all other parameters except that of Dissolved oxygen (DO) which showed negative -.155, this implies that every parameter investigated in this research are in one way or another have effects on the hardness of the water during the period of investigation.

- **e.** Conductivity values showed negative relationships with Coliforms and Dissolved Oxygen (DO) and positively significant with pH, Colour, Total hardness, Turbidity. The Conductivity and Total Dissolved Solids showed a high Pearson's relationship value of .916 which corresponds to the fact that the Total dissolved solids can be calculated by determining the water's specific conductance.
- **f.** The dissolved oxygen (DO) showed a negative relationship with all the other parameters, which means that while the Dissolved Oxygen decreased all throughout the investigation there were increases in all the parameters, and more significantly, with pH, Turbidity and Colour.
- **g.** Turbidity showed that there was a positive Pearson's correlation relationship with pH (.568), and Colour (.624), significance. This implies that the increase in pH, and Colour increased turbidity also.

8. Contribution to knowledge

1. This study creates the awareness of any consumer, and government regulatory bodies to be conscious of the kind of treatment process employed on the produced packaged drinking water and intended to be consumed because this research work has shown that the expiration dates or due dates do not eventually guarantee the quality of the water to be consumed.
2. All the different kinds of treatment employed solve the associated problems in the water differently, such that if not fully employed, it is not safe to say that the quality of water is excellent.
3. This study has shown that no matter the time of shelf life the water is consumed, the water may not be safe for consumption.

9. Recommendations

The following Recommendations were made based on the results obtained in this study.

- **a.** Packaged water is no longer safe for consumption even before its expiry dates or after the first three months of production; hence people should be discouraged from consuming them.
- **b.** Storage keepers, Retailers and Consumers should be mindful of production dates, Consumption, and keeping water safe properly away from any harsh environmental influence like polluted environment or chemicals.
- **c.** SON, NAFDAC, and other regulatory agencies ought to regulate packaged water factories.to ensure that registered water producing factories,
- **d.** Have concrete information on the source of their water so as to be cautioned on the best approach for the treatment. For example, knowing the Nitrate level, and other contaminants, like Fe, Mn, Cu, and Pb heavy metal ions which are efficiently traced to the history of the activities on their field of source such as Agricultural, Mining activities and also from acidic rain on open tanks.
- **e.** To ensure that all water production firms have effectively working ultraviolet light Sterilization equipment to kill microorganisms in water

f. The public should have access to information about the mineral makeup of bottled or packaged water in order to properly guide consumers and prevent illnesses. Companies should print the production and expiration dates of their water on their sachets.

10. Conclusion

Unanticipated changes in the quality of the water could indicate major contamination issues that could be harmful to one's health. Such alterations should be looked at right away using nitrate and coliform laboratory testing. In Nigeria, periodic water analysis remains the most effective strategy for achieving high water quality. Thus, this study adds to our understanding that.

1. All treated packaged water of either sachet or bottle, may not necessarily achieved its best before dates due to contamination.
2. Contamination (such from microbial chemical, and radiological materials) of a treated packaged water for period of time is mostly depends on the constituent of the water, and therefore the synergistic and antagonistic interaction and relationship in the (system) packaged water will differ with the others which includes exposure to the environment.
3. The different treatment processes have their different contribution to the deterioration, for example, this research showed that water treated by reverse osmosis reduced in TDS, Nitrate level, which in turn reduces its conductivity and total hardness and yet does not kill microorganisms.

The different treatment processes have their different contribution to the deterioration, for example, this research showed that water treated by reverse osmosis reduced in TDS, Nitrate Level, which in turn reduces its conductivity and total hardness and yet does not kill microorganisms.

The changes that occurred in the samples during the period of investigation showed that water quality, environmental exposures, impacts and improves deterioration in the various physico-chemical and microbiological parameters individually, Consequently, the best way to maintain good water quality in Nigeria is to periodically conduct more consistent quality control analyses of drinking water.

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