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THE QUALITY AND HEALTH RISK ASSESSMENT OF POLYETHYLENE-PACKAGED TABLE WATER SUNLIGHT EXPOSED AND UNEXPOSED DURING STORAGE

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ABSTRACT
Exposure of sachet water to sunlight by vendors is a common practice in Nigeria which could affect its quality. In this study, 80 sachets of branded table water divided equally into group 1 (exposed to sunlight) and group 2 (unexposed to sunlight); were stored for 16 days. At four days interval, microbiological, physicochemical properties, minerals, and heavy metals concentration of the stored sachet water samples were determined using standard methods. There was reduction in total heterotrophic bacterial count (THBC), total coliform count (TCC), and total fungal count (TFC) of sachet water exposed to sunlight. The THBC, TCC, and TFC of all the samples ranged from 3.70-5.04, 0.00-3.95, 0.00-4.36 log10CFU/ml, respectively. Bacterial species isolated from the stored sachet water were resistant to most antibiotics. Non-microbiological properties of the stored sachet water were within the World Health Organization (WHO) permissible limits, with the exception of pH. The concentration of metals in the sachet water fluctuated during storage, whereas Cd and Pb was below detection limit. The non-microbiological properties of the stored sachet water monitored at intervals were significantly different ($p<0.05$), with few exceptions. Although the parameters met the WHO limits, pathogens and potentially toxic metals present in the stored sachet water could have health implications.

Keywords: Antimicrobial Resistance, Heavy Metals, Potable Water, Public Health, Waterborne Pathogens

INTRODUCTION
Water is an essential natural resource that sustain all living things on earth (Ojekunle & Adeleke, 2017; Edegbene *et al.*, 2025). It is rated second with oxygen as the most essential need of human beings (Imam *et al.*, 2023; Ire *et al.*, 2024). In Nigeria, large scale production of drinking water sealed by machine in small size sachets (primary packaging) and subsequently wrapped in polyethylene bags (secondary packaging) for easy distribution to consumers started in 1990s. A popular material used by cottage industries for packaging drinking water in developing countries is high density polyethylene (HDPE) film sachet (Angnunavuri *et al.*, 2022). The unit cost of sachet drinking water is affordable to the masses because the cost of HDPE film sachet is cheaper than polyethylene terephthalate (PET) commonly used to produce bottled water. Also, the water treatment method used by some sachet water producers is cheaper than the method bottled water producers are using to purify water (Nwankwo & Odenigbo, 2022; Umoafia *et al.*, 2022).
Several factors responsible for high demand for sachet water in developing countries include lack of access to pipe-borne water by majority of Nigerian population (Chinenye & Amos, 2017; Balogun *et al.*, 2024), demographic and socioeconomic variables (Onosakponome, 2021), teeming population (Makwe & Ukah, 2025), and heavy snacking which is a modern lifestyle (Ahaotu *et al.*, 2022; Hammond *et al.*, 2023). Millions of rural and urban dwellers drink sachet water daily because it is readily available, portable, and affordable (Aroh *et al.*, 2013; Chiwetalu *et al.*, 2022; Amoo *et al.*, 2025). Estimated daily production of sachet water sold to Nigerians to drink is 60 million units (Umoafia *et al.*, 2023).
The standard recommended by international regulatory bodies for delivering safe water to people living in developed countries is very difficult to replicate in developing countries like Nigeria because of high cost, infrastructural deficit, weak policy implementation, among other factors (Dada, 2013; Isukuru *et al.*, 2024). Consequently, the quality of packaged and non-packaged drinking water supplied to large population of inhabitants in developing countries might not meet the international standard (Edegbene *et al.*, 2025). This prevailing condition is undesirable because the health of the general public is at risk. It is widely believed that the water packaged in polyethylene sachets popularly known as 'pure water' is safe for drinking (Balogun *et al.*, 2024), unlike water from other sources such as streams and rivers (Ire *et al.*, 2024). Water considered to be safe for drinking is colourless, odourless, tasteless, completely free from harmful physical, chemical, fecal matter, and pathogens (Aroh *et al.*, 2013; Chinenye & Amos, 2017; Umoafia *et al.*, 2023; Hammond *et al.*, 2024). The quality of water is influenced by physical, chemical, and biological factors (Some *et al.*, 2021; Ichu *et al.*, 2024). Cultural and behavioural factors also influence the quality of water consumed in developing countries (Jimoh *et al.*, 2025). Regular monitoring of the quality of packaged drinking water and factors that could affect its quality, especially in developing countries is important because the health of consumers is at risk when they drink contaminated and unsafe water (Okey-Wokeh *et al.*, 2021; Wogu *et al.*, 2023).
Several studies carried out by researchers have shown that the sachet water produced by different manufacturers and distributed to the general public exceeded the permissible limits for microbiological and physicochemical properties, minerals, and heavy metals concentration recommended by the World Health Organization (WHO), National Agency for Food and Drug Administration, and Control (NAFDAC), Nigeria Standard for Drinking Water Quality (NSDWQ), and other relevant regulatory bodies (Mberekpe & Ozi, 2014; Chinenye & Amos, 2017; Ezekiel *et al.*, 2020; Adesakin *et al.*, 2022). At different stages of production, packaging, and distribution of packaged drinking water, it could be contaminated by microbial, chemical, and physical agents. The presence of pathogenic bacteria in large population in sachet water for drinking purpose produced in commercial

quantity is a threat to healthiness of the general public (Angnunavuri *et al*., 2022). The detrimental health effect associated with drinking water contaminated by heavy metals above permissible limits recommended by relevant regulatory bodies were reported by Manne *et al*. (2022), Garba *et al*. (2023), and Ichu *et al*. (2024). The menace of rapid spread of antibiotic resistance in developing countries could be compounded by consumption of microbially contaminated packaged water which include sachet and bottled water, and other water sources (Alalade *et al*., 2020; Ahmed *et al*., 2022). Packaged drinking water unsafe for consumption could be attributed to the source of water, the quality of packaging materials used, hygienic condition while dispensing the water into sachets or bottles, sealing of the water, storage condition, and transportation of the product to consumers (Duwiejuah *et al*., 2013; Fadipe *et al*., 2020).

The storage conditions producers and vendors of sachet water expose their product could affect its quality before it is consumed. Few researchers considered storage conditions as one of the factors that could affect the quality of commercially available sachet water (Mberekpe & Eze 2014; Ezekiel *et al*., 2020; Fadipe *et al*., 2020; Umoafia *et al*., 2022; Adedire *et al*., 2021; Jacob *et al*., 2025). This study is intended to provide more information regarding the influence of two storage conditions on the quality of sachet water and health risks associated with it. In this part of the world, bags of sachet water produced in large quantity are either exposed under the sun or kept indoors away from sunlight (Osei *et al*., 2023; Umoafia *et al*., 2023; Hammond *et al*., 2024). Due to hot weather condition, sachet water stored inside refrigerators is on high demand (Duwiejuah *et al*., 2013).

According to Adedire *et al.* (2021), bags of sachet water exposed to sunlight for 5 days affected the physical, chemical, and bacteriological properties of the product. The researchers reported that the storage condition did not influence its organoleptic acceptability. Due to common practice of exposing drinking water packaged with polyethylene sachets/bags to direct sunlight by vendors, the temperature of the product is substantially increased. This storage condition usually increase the degradation reaction of the photosensitive material used in packaging the drinking water. Consequently, microplastic and metals potentially toxic to human health are released into the packaged drinking water (Umoafia *et al*., 2023). It has been reported that there is a high risk of chemicals such as limonene, polycyclic aromatic hydrocarbons, xylene, trichloromethane, benzene, toluene and 2-hexanone to be released into drinking water packaged with polyethylene pouches when the product is directly exposed to sunlight (Adedire *et al*., 2021). Health risk assessment of consuming different brands of drinking water packaged in sachets exposed and unexposed to sunlight was carried out by Umoafia *et al*. (2022). Mberekpe & Ozi (2014) reported that two brands of sachet water stored indoors for 8 weeks had no significant difference in terms of odour and taste, contrary to the product stored outdoors. The study revealed that the sachet water stored indoors had a relatively lower microbial count compared with the samples kept outdoors. The researchers reported that coliforms, *Escherichia coli, Cladosporium sphaerosperum* spp*, Curvularia lunata,* and *Cladosporium macrocarpum* were present in the stored sachet water.

The effect of exposing sachet water to sunlight for several hours on microbiological and physicochemical properties, total petroleum hydrocarbon, minerals, and heavy metals concentration have been reported (Duwiejuah *et al*., 2013; Chinenye & Amos, 2017; Fadipe *et al*., 2020; Onosakponome, 2021, Umoafia *et al*., 2022; Osei *et al*., 2023; Hammond *et al*., 2024). Although the researchers evaluated the effect of storage conditions on bacterial population in the sachet water, many of them did not go further to evaluate the antibiotic susceptibility of the bacterial isolates. There is limited information with regards to possible effects of sunlight on different batches of sachet water from one producer as it relates to microbiological and non-microbiological quality parameters. Different batches of sachet water from the same producer could be produced with different quality of polyethylene material and water without consumers being aware. Drinking sachet water contaminated with potential pathogens inhabiting antibiotic resistance genes could hamper the treatment of bacterial infections. Significantly reduced population or absence of pathogenic bacterial species in sachet drinking water could help in reducing the spread of antibiotic resistance genes. Therefore, this study determined the effect of exposing two batches of sachet water to sunlight for sixteen days on the microbiological and physicochemical properties, minerals, and heavy metals concentration of the product. A similar analysis was carried out using the same batch of sachet water unexposed to sunlight. The antibiotic susceptibility of the bacterial isolates from the stored sachet water samples was also evaluated.

MATERIALS AND METHODS

Sample Collection

A total of four (4) bags of branded sachet water containing twenty (20) small sachets per bag were obtained directly from the production factory in Benin City. The volume of one sachet of water is 60 cl. Two (2) bags of sachet water from two batches (B1 and B2) were directly exposed to 9 hours sunlight per day between the hours of 8 am to 5 pm, whereas the remaining two (2) bags of sachet water from two batches (B1 and B2) were stored indoors away from sunlight. The study was carried out during dry season between October-November. Sachet water samples were collected from the lot exposed under the sun and the unexposed at Day 0, 4, 8, 12, and 16 for laboratory analyses. All the water samples were analyzed in the Microbiology and Biochemistry Laboratories, Wellspring University, Benin City, Nigeria.

Serial Dilution

One millilitre (1 ml) of water from each sachet was aseptically dispensed into 9 ml of distilled water (1:10) in sterile test tube to obtain the stock solution. From the stock, 1 ml was pipetted into 9 ml distilled water. Serial dilution was carried out by stepwise transfer of 1 ml dilution from the first test tube into subsequent tubes using sterile pipettes for each transfer.

Microbiological Analysis

Determination of Total Heterotrophic Bacterial Count

MacConkey and nutrient agar plates were prepared following manufacturer's instructions. Dilution 10^{-3} was inoculated into the Petri dish in duplicate using the pour plate technique. The Petri dishes were gently swirled for homogeneity. The inoculated plates were incubated at 37 ^{o}C for 24 hours. The colonies were counted and expressed as colony forming units per ml (CFU/ml) using the formula below.

$$\text{CFU/ml} = \text{no. of colonies} \times \frac{1}{dilution\ factor} \times \frac{1}{volume\ plated}$$

Determination of Total Fungal Count

Potato dextrose agar (PDA) plates were prepared following manufacturer's instructions. Dilution 10^{-3} was inoculated into the Petri dishes in duplicate using the pour plate technique. The Petri dishes were gently swirled for homogeneity. The medium was incubated at room temperature (25 ºC) for 5 days. The colonies were counted and expressed as colony forming units per ml (CFU/ml) using the formula below.

$$CFU/ml = \text{no. of colonies} \times \frac{1}{dilution\ factor} \times \frac{1}{volume\ plated}$$

Obtaining Pure Isolates

Discrete bacterial colonies that appeared on the culture plates were picked using a sterile wire loop and inoculated on freshly prepared nutrient agar plates. The inoculated plates were incubated for 24 hours at 37 °C. Similarly, discrete fungal isolates were also plated on potato dextrose agar and incubated at room temperature (25±2 ºC) for 5 days. The pure isolates obtained were stored in slants for further identification. Bergeys' Manual of Determinative Bacteriology was used to aid interpretation of the results.

Identification of Bacterial Isolates

The colonial morphology of the bacterial isolates in the Petri dishes were observed and noted. Gram staining of the bacterial isolates were carried out, followed by biochemical tests which include catalase, citrate, oxidase, motility, indole, methyl red Voges-Proskauer, triple sugar iron agar (TSIA), and sugar fermentation tests (Madigan *et al*., 2018).

Identification of Fungal Isolates

The morphological structures of fungi that appeared in the culture plates was noted. The microscopic features were noted after carrying out lactophenol-cotton blue stain using the procedure described by Ire *et al*. (2020). The fungal types were analyzed for each sampling exercise. The fungal isolates were identified using the methods described by Barnett & Hunter (1972).

Antimicrobial Susceptibility Testing

Antimicrobial susceptibility testing was carried out on each bacterial isolate obtained from the sachet water samples by the Kirby-Bauer disc diffusion method using the procedure described by Ehiaghe *et al.* (2020). The test isolates were grown on nutrient agar and incubated at 37 ºC for 24 hours. Thereafter, the colonies were suspended in a sterile normal saline and the inocula density was adjusted to 0.5 McFarland turbidity standards. A sterile swab stick was used to apply the broth medium containing the respective isolates onto the surface of a freshly prepared dried Mueller-Hinton agar plate. The antimicrobial discs (Oxoid) used were cefuroxime, gentamycin, cefotaxime, ceftriaxone, cefixime, levofloxacin, ciprofloxacin, imipenem, azithromycin, ofloxacin, erythromycin, amoxicillin-clavulanate, nitrofurantoin, nalidixic acid, and ampiclox. The manufacturer is Basingstoke, United Kingdom. The disc was aseptically placed on the surface of the inoculated Muller-Hinton agar plate and incubated at 37 °C for 24 hours. After incubation, the diameter of zone of inhibition around each antibiotic disc was measured using a vernier caliper. The result was interpreted as resistant (≤19 mm), sensitive (≥23 mm) and intermediate (20-22 mm) in accordance with standard specified by Clinical Laboratory Standard Institute (CLSI) (Olisaka *et al*., 2021).

Multiple Antibiotic Resistance (MAR) Index

The multiple antibiotic resistance (MAR) index was determined for each bacterial isolate by dividing the number of antibiotics the isolate was resistant to by the total number of antibiotics tested (Olisaka *et al*., 2021).

$$\text{MAR index} = \frac{a}{b}$$

Where: a - the number of antibiotics which the test isolate demonstrated resistance

b - the total number of antibiotics used in subjecting the isolates to susceptibility test

Determination of Physicochemical Parameters

The atomic absorption spectrometry (AAS) was also used to evaluate the levels of Na and K. The pH, total dissolved solids (TDS) and electrical conductivity (EC) were determined using Adwa multi-parameter meter (model AD8000). Total hardness was measured by ethylenediaminetetraacetic acid (EDTA) titrimetric method. Temperature of the water samples was determined using a mercury-in-glass thermometer. Turbidity, SO_4, total dissolved solids, and dissolved oxygen of the water samples was determined using standard methods as described by Chiwetalu *et al*. (2022). Total soluble solids, HCO_3 and NO_3 of the water sample were also determined using standard methods (APHA, 1998; 1999).

Determination of Minerals and Heavy Metals Concentration

The atomic absorption spectrophotometry (AAS) method was used for the rapid determination of heavy metals which included lead, cadmium, iron, copper, cobalt, chromium, manganese, and zinc in the stored sachet water samples. They were not pre-treated before the analysis. The water samples were analyzed for their various metallic contents using AAS. Minerals which include potassium, sodium, and calcium content of the samples was determined using standard methods (APHA, 1998; Odu *et al*., 2020).

Health Risk Assessment

The need to ascertain the potential health risk that will be faced by consumers of the sachet water exposed and unexposed to sunlight involves the parameters which include: average daily dose, hazard quotient, and carcinogenic risk.

Estimation of Average Daily Dose

The formula used to determine the average daily dose (ADD) of heavy metals potentially toxic to humans who consume the sachet water exposed and unexposed to sunlight is stated below (Umoafia *et al*., 2023).

$$ADD = \frac{Cwater\ x\ IR\ X\ EF\ x\ ED}{BW\ x\ AT}$$

Where: ADD = average daily dose of potential toxic metals exposure (mg/kg/day).

C_{water} = concentration of potential toxic metals in water (mg/L)

IR = water ingestion rate of adults: 2 L/day

EF = exposure frequency: 365 days/year

ED = duration of adult exposure: 64.4 years

BW = body weight of humans: 70 kg (adults)

AT = average time of adult exposure: 365 days/year. 64.4 years (23, 506 days)

Hazard Quotient (HQ)

The hazard quotient (HQ) as a result of consuming the sachet water containing potential toxic metals released into the drinking water from the polyethylene material used to package the water directly exposed to sunlight is calculated using the formula below (Umoafia *et al*., 2023).

$$HQ = \frac{ADD}{RFD}$$

Where: HQ – Hazard quotient through the ingestion of potential metals

ADD – Average daily dose

RFD – Reference doses for ingestion of potential toxic metals

Carcinogenic Risk (CR)
Based on lifespan of 64.4 years, the CR was calculated as prescribed by the USEPA using the formula below (Umoafia *et al*., 2023).
CR = ADD x CSF
Where: CR - Carcinogenic risk through the ingestion of potential toxic metals
CSF - Carcinogenic slope factor
ADD - Average daily dose

Statistical Analysis
The analysis were carried out in triplicates and the data generated were analyzed using one way ANOVA. IBM Statistical Package for the Social Sciences (SPSS) version 22 software was employed to carry out the statistical analysis. Significant difference at $p<0.05$ among a set of data was determined with the aid of the software. In order to separate the means, Duncan Multiple Range Test (DMRT) was performed.

RESULTS AND DISCUSSION
Figure 1 shows the total heterotrophic bacterial count (THBC) of batches 1 and 2 sachet water samples directly exposed to sunlight and the unexposed samples. The highest/lowest THBC among the batches 1 and 2 sachet water exposed to sunlight is 5.04/4.18 and 4.72/3.7 $\log_{10}$CFU/ml, while the values for the unexposed samples was 4.32/3.9 and 4.92/4.41 $\log_{10}$CFU/ml, respectively. The result obtained from this study showed that the THBC of the unexposed sachet water (batches 1 and 2) and sachet water samples exposed to sunlight (batches 1 and 2) steadily reduced during storage, with few exceptions. It could be attributed to daily exposure of the sachet water to sunlight and poor nutrients in the sachet water to favour increase in bacterial population. Our result is in agreement with the report by Adedire *et al*. (2021). Going by the reduction in the THBC of sachet water directly exposed to sunlight, it is possible that the radiation could not prevent the microbial cells from developing a biofilm complex induced by sunlight which is also responsible for the degradation of polyethylene packs. Batch 1 sachet water exposed to sunlight had higher THBC values than the batch 2 sachet water under the same storage condition. A contrary result involved the batch 2 sachet water samples unexposed to sunlight. This observation could be attributed to initial level of contamination of sachet water by bacterial species. Several factors which could be responsible for microbial contamination of sachet water include effectiveness of water treatment, microbial contamination of packaging material, poor environmental and personal hygiene of production workers. It is a source of concern that only batch 2 sachet water exposed to sunlight at day 12 and 16 met the NAFDAC permissible limit for drinking water in terms of THBC. According to the regulatory body, the THBC of drinking water should not exceed 4 $\log_{10}$CFU/ml (Ire *et al*., 2024).

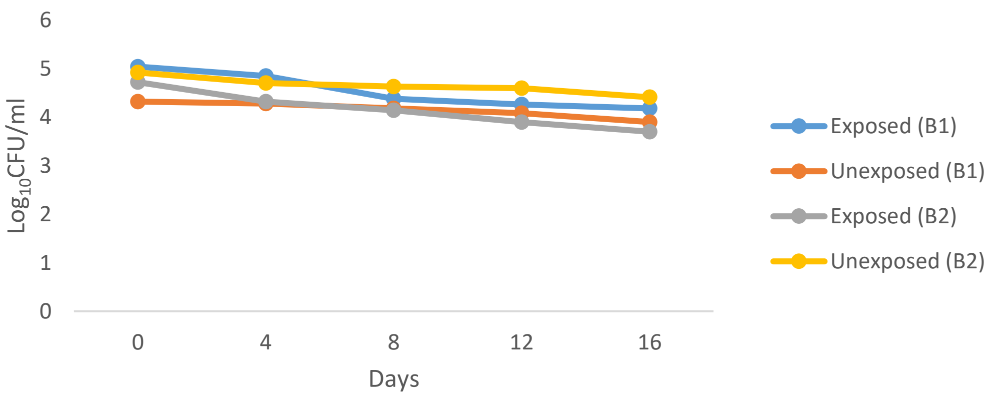

Figure 1: Total heterotrophic bacterial count of sachet water exposed and unexposed to sunlight for 16 days
Key: Exposed (B1) - Batch 1 sachet water exposed to sunlight; Exposed (B2) - Batch 2 sachet water exposed to sunlight; B1 (unexposed) - Batch 1 sachet water unexposed to sunlight; B2 (exposed) - Batch 2 sachet water exposed to sunlight; B2 (unexposed) - Batch 2 sachet water unexposed to sunlight.

Presented in Figure 2 is the total coliform count (TCC) of the sachet water samples exposed to sunlight and the unexposed samples. With regards to the batch 1 and batch 2 exposed sachet water samples, the highest/lowest TCC was 3.60/0.00 and 0.00/0.00 $\log_{10}$CFU/ml, while the values for the unexposed samples was 3.95/3.70 and 3.90/3.6 $\log_{10}$CFU/ml, respectively. No coliforms was detected in the batch 2 sachet water samples exposed to the sunlight. A similar result was reported in the batch 1 sachet water exposed to sunlight at day 16. Reduction in the total coliform count (TCC) of the sachet water samples exposed to sunlight and the unexposed samples occurred during storage, with few exceptions. Possible sources of contamination of the sachet water by coliforms include the environment, packaging material, and handlers (Fadipe *et al*., 2020). The presence of coliforms is an indication that water treatment employed by the producer is not effective or absent (Hammond *et al*., 2024).
For each batch of sachet water, it was reported that the TCC of the samples exposed to sunlight was lower than the sachet water unexposed to sunlight. There was no viable coliform count in batch 1 sachet water exposed to sunlight at day 16 contrary to the results reported earlier. These observations could be attributed to sunlight disinfection of sachet water during storage (Hammond *et al*., 2024). Remarkably, no viable coliform bacteria was reported in the batch 2 sachet water samples exposed to sunlight. Therefore, the sachet water samples met the standard stipulated by NAFDAC (Ire *et al*., 2024).
According to Akharame *et al*. (2018), 43-91% of coliforms exposed to sunlight for 6 hours die-off, while 51-100% of the coliforms exposed to room temperature for 48 hours also die off. Effective water treatment, high level environmental sanitation, personal hygiene of sachet water production workers, and sunlight disinfection of sachet water could be responsible for absence of coliforms in the product. In a related study, Mberekpe & Eze (2014) reported a steady increase in the coliform count of sachet water stored indoors and outdoors. The result is not in agreement with our research

findings. According to Fadipe *et al*. (2020), the population of coliform bacteria present in packaged water could be affected by temperature prevalent during storage of the product and the type of packaging material used by the producers. Polyethylene used in producing sachet water is more permeable to gases than glass or plastic bottles.

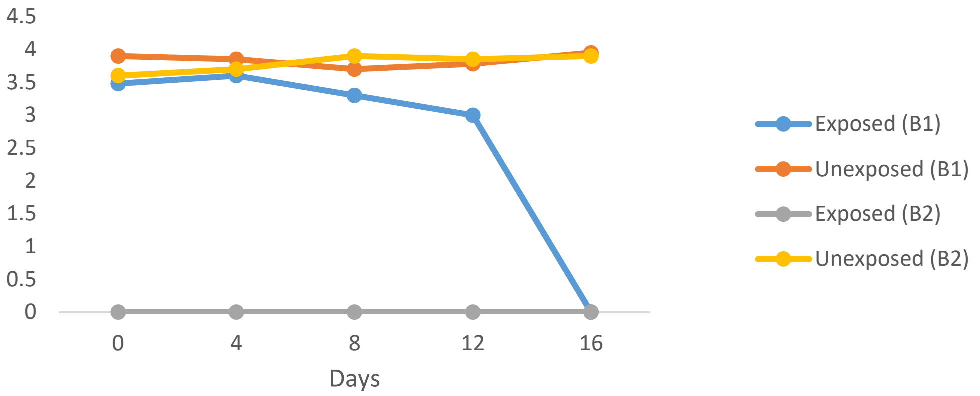

Figure 2: Total coliform count of sachet water exposed and unexposed to sunlight for 16 days
Key: Exposed (B1) - Batch 1 sachet water exposed to sunlight; Exposed (B2) - Batch 2 sachet water exposed to sunlight; B1 (unexposed) - Batch 1 sachet water unexposed to sunlight; B2 (exposed) - Batch 2 sachet water exposed to sunlight; B2 (unexposed) - Batch 2 sachet water unexposed to sunlight.

Figure 3 shows the total fungal count (TFC) of the sachet water samples exposed to sunlight and the samples that were not exposed. The highest/lowest TFC for batches 1 and 2 sachet water samples exposed to sunlight was 4.36/0.00 and 4.04/3.60 log_{10}CFU/ml, while the values for the samples unexposed to sunlight was 3.90/3.00 and 3.90/3.48 log_{10}CFU/ml, respectively. No viable fungi was detected in the batch 1 sachet water sample exposed to sunlight at day 12 and 16. In terms of the TFC of sachet water samples exposed and unexposed to sunlight, it was observed that the values decreased during storage, with few exceptions. This result corroborate the research findings by Akharame *et al*. (2018) from a related study. Furthermore, it was observed that the TFC of the water samples exposed to sunlight was lower than the unexposed sachet water. The effect of the solar radiation could be responsible for the reduction in TFC of stored sachet water samples directly exposed to sunlight.

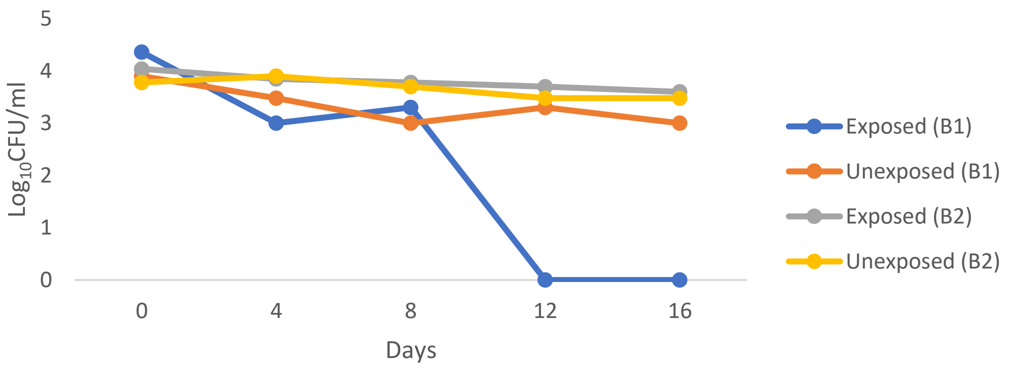

Figure 3: Total coliform count of sachet water exposed and unexposed to sunlight for 16 days
Key: Exposed (B1) - Batch 1 sachet water exposed to sunlight; Exposed (B2) - Batch 2 sachet water exposed to sunlight; B1 (unexposed) - Batch 1 sachet water unexposed to sunlight; B2 (exposed) - Batch 2 sachet water exposed to sunlight; B2 (unexposed) - Batch 2 sachet water unexposed to sunlight.

The bacteria isolated from the stored water samples and their frequency of occurrence include *Bacillus subtilis* (71.51 %), *Escherichia coli* (14.84 %), *Pseudomonas aeruginosa* (8.61 %), and *Staphylococcus aureus* (5.04 %), while the fungal isolates were *Rhizopus stolonifer* (55 %), *Aspergillus niger* (32 %), and *Fusarium* spp. (13 %). The bacterial species isolated from the unexposed and exposed sachet water to sunlight is in agreement with the report by Chinenye & Amos (2017); Umoafia *et al.* (2022). The presence of *Escherichia coli* and *Pseudomonas aeruginosa* in the sachet water imply that fecal contamination occurred (Forstinus *et al*., 2016). Drinking sachet water contaminated with *E. coli* predisposes the consumers to gastro-enteric disease (Some *et al*., 2021). The risk of immunocompromised individuals to experience gastrointestinal infections is high due to consumption of drinking water contaminated with high population of *Pseudomonas aeruginosa* (Maduka & Ugbogu, 2024). *Bacillus* species have been isolated from sachet water (Dibua *et al*., 2007). According to Olagoke *et al.* (2018), the presence of *Staphylococcus aureus* in drinking water predispose consumers to diarrhea associated with dehydration, electrolyte loss from the body system, and vomiting for extended period especially among elderly persons and children. The researchers reported the presence of *Shigella* sp., *Providencia* spp., *Salmonella* sp., *Enterobacteria faecalis, Citrobacter fruendi*, and *Providencia* spp. including the bacterial species isolated from this study. Adesakin *et al*. (2022) reported the presence of *Penicillium* spp., *Candida krusei, Aspergillus niger, A. fumigatus*, *A. nidulans* and many other microbial species in the sachet water stored on a wooden plank, floor, and inside a refrigerator for 3 months. The result is partly in agreement with our research findings. The presence of fungi in drinking water increases the risk of consumers to experience allergies, respiratory illness, meningitis which could be life threatening, mycoses, and other infections which are contagious and invasive. The ability of some of the fungal species in the sachet water to produce mycotoxins beyond permissible limit could lead to life threatening diseases. On a lesser note, the organoleptic properties of water which include smell and taste is affected by fungal contaminant in drinking water (Allaq *et al*., 2023).

Antibiotic susceptibility of Gram positive bacterial isolates from the sachet water against selected antibiotics is presented in Table 1. *Bacillus subtilis* was resistant to all the antibiotics tested except levofloxacin which the bacterium demonstrated intermediate susceptibility. Meanwhile, *Staphylococcus aureus* was resistant to all the antibiotics tested. Also presented in Table 2 is the antibiotic susceptibility of Gram negative bacterial isolates from the sachet water against selected antibiotics. *Escherichia coli* and *Pseudomonas aeruginosa* were resistant to all the antibiotics tested, with the exception of nitrofurantoin and ampiclox, respectively. Each of the Gram negative bacterium demonstrated intermediate susceptibility to 1 out of 12 antibiotics.

Table 1: Antibiotic Susceptibility of Gram-Positive Bacterial Isolates

Isolates	Antibiotics/Zone of inhibition (mm)											
	Cxm (30µg)	**Gn (10µg)**	**Ctx (25µg)**	**Cro (45µg)**	**Zem (5µg)**	**Lbc (5µg)**	**Cip (5µg)**	**Imp (5µg)**	**Azn (15µg)**	**Ofx (5µg)**	**Ery (15µg)**	**Aug (30µg)**
Bacillus subtilis	7 (R)	5 (R)	16 (R)	17 (R)	5 (R)	21(I)	3 (R)	4 (R)	7 (R)	2 (R)	6 (R)	4 (R)
Staphylococcus aureus	16 (R)	3 (R)	19 (R)	7 (R)	8 (R)	18 (R)	17(R)	16 (R)	6 (R)	5 (R)	7 (R)	18 (R)

Key: R - Resistant (≤19 mm); S - Sensitive (≥ 23 mm); I - Intermediate (20-22 mm); Cxm: cefuroxime; Gn: gentamycin; Ctx: cefotaxime; Cro: ceftriaxone; Zem: cefixime; Lbc: levofloxacin; Cip: ciprofloxacin; Imp: imipenem; Azn: azithromycin; Ofx: ofloxacin; Ery: erythromycin; Aug: amoxicillin-clavulanate.

Table 2: Antibiotic Susceptibility of Gram-Negative Bacterial Isolates

Isolates	Antibiotics/Zone of inhibition (mm)											
	Nf (300µg)	**Na (30µg)**	**Acx (10µg)**	**Aug (30µg)**	**Cxm (30µg)**	**Gn (10µg)**	**Ofx (5µg)**	**Imp (10µg)**	**Lbc (5µg)**	**Zem (5µg)**	**Ctx (25µg)**	**Cro (45µg)**
Escherichia coli	22 (I)	7 (R)	5 (R)	6 (R)	4 (R)	3 (R)	5 (R)	8 (R)	7 (R)	4 (R)	5 (R)	18 (R)
Pseudomonas aeruginosa	5 (R)	17 (R)	20 (I)	5 (R)	6 (R)	5 (R)	4 (R)	7 (R)	8 (R)	7 (R)	8 (R)	6 (R)

Key: R - Resistant (≤19 mm); S - Sensitive (≥ 23 mm); I - Intermediate (20-22 mm); Nf: nitrofurantoin; Na: nalidixic acid; Acx: ampiclox; Aug: amoxicillin-clavulanate; Cxm: cefuroxime; Gn: gentamycin; Ofx: ofloxacin; Imp: imipenem; Lbc: levofloxacin; Zem: cefixime; Ctx: cefotaxime; Cro: ceftriaxone.

Table 3 shows the multiple antibiotic resistance (MAR) index of bacterial isolates obtained from sachet water samples. The MAR indexes of *Staphylococcus aureus*, *Bacillus subtilis*, *Pseudomonas aeruginosa* and *Escherichia coli* were 1.00, 0.92, 0.92, and 0.92, respectively; indicating high risk.

Table 3: Multiple Antibiotic Resistant (MAR) Index of the Bacterial Isolates

Isolates	**MAR Index**	**Standard (≤0.2)**
Staphylococcus aureus	1.00	High risk
Bacillus subtilis	0.92	High risk
Pseudomonas aeruginosa	0.92	High risk
Escherichia coli	0.92	High risk

The result of antibiotic susceptibility test that involved the four bacterial isolates obtained from the sachet water samples is worrisome due to limited treatment options available for those who might fall sick after drinking the sachet water. *Escherichia coli*, *Pseudomonas aeruginosa,* and *Bacillus subtilis* isolated from the sachet water demonstrated an intermediate susceptibility to nitrofurantoin, ampiclox and levofloxacin, respectively. Sadly, the three bacterial isolates were resistant to other antibiotics tested. Each of them had a multiple antibiotic resistant (MAR) index of 0.92. Bacterial strain that demonstrated MAR that is above 0.2 is an indication that the bacterium was isolated from an environment where antibiotics have been misused or extensively used (Olisaka *et al*., 2021). In a related study, Alalade *et al*. (2020), reported that three isolates of *E. coli* from sachet water and pipe-borne water were resistant to seven antibiotics used in carrying out antibiotic susceptibility test. The MAR of the isolates were within the range of 0.2-0.7. *Staphylococcus aureus* also isolated from the sachet water was resistant to all the antibiotics tested, while the MAR index is 1.00. This result is not in agreement with the report by Umoafia *et al*. (2023) from a related study. According to the researchers, *S. aureus* isolated from stored sachet water is resistant to 1 out of 10 antibiotics tested. As for *P. aeruginosa* and *E. coli*, the researchers reported that each of the bacterial specie is resistant to 3 out of 10 antibiotics. This result is not in agreement with our research findings. It could be attributed to the antibiotics selected for the antibiotic susceptibility test and the strains of *S. aureus* isolated from the sachet water.

Table 4 shows the physicochemical properties of batch 1 sachet water unexposed to sunlight. There was significant differences ($p<0.05$) in the values of each of the parameters monitored at 4 days interval, with the exception of total dissolved solids. Total soluble solids (TSS), colour, and turbidity was not detected in the sachet water unexposed to sunlight (Table 4). The physicochemical properties of batch 1 sachet water exposed to sunlight is presented in Table 5. There was significant differences ($p<0.05$) in the values of each of the parameters monitored at 4 days interval. Colour, TSS, and turbidity was not detected in the batch 1 sachet water exposed to sunlight (Table 5).

Presented in Table 6 is the physicochemical properties of batch 2 sachet water unexposed to sunlight. There was significant differences ($p<0.05$) in the values of each of the parameters monitored at 4 days interval, with the exception of salinity and dissolved oxygen (DO). Total soluble solids (TSS), colour, and turbidity was not detected in the sachet water unexposed to sunlight (Table 6). The physicochemical properties of batch 2 sachet water exposed to sunlight is presented in Table 7. There was significant differences ($p<0.05$) in the values of each of the parameters monitored at 4 days interval, with the exception of DO, salinity, NO_3, and total hardness. Colour, TSS, and turbidity was not detected in the sachet water exposed to sunlight (Table 7).

The value of each physicochemical property of stored sachet water samples exposed and unexposed to sunlight were within the WHO permissible limit, with the exception of pH of some samples that were slightly acidic (4.50-5.70). This result corroborate the research findings by Fadipe *et al*. (2020). According to Akharame *et al.* (2018), Benin City have underground water that is slightly acidic. This factor could influence the pH of sachet water produced in the city. Umoafia *et al*. (2023) reported that the pH values of sachet water exposed to sunlight did not meet the WHO, NAFDAC, and NSDWQ specifications. Slightly acidic pH of the stored sachet water exposed to sunlight and the unexposed sachet water could be attributed to chemicals released into the product from the polyethylene used as a packaging material. Since the physicochemical properties of the stored sachet water were within the WHO limits excluding the samples that had a slightly acidic pH, the consequences on the health of consumers is expected to be minimal.

There was a reduction in the electrical conductivity (EC), salinity, total dissolved solids (TDS), HCO_3^-, and NO_3^- in the batch 1 sachet water unexposed to sunlight contrary to the DO and total hardness of the samples. As for the batch 2 sachet water stored under the same condition, there was increase in the EC, TDS, and salinity of the samples, whereas the NO_3^- and HCO_3^- of the samples reduced. Total hardness and DO of batch 1 and 2 sachet water unexposed to sunlight increased during storage, whereas the pH reduced. In a related study, Adedire *et al*. (2021) reported that total hardness of sachet water exposed to sunlight within the range 0.00-30.00 mg/l increased during the period of storage.

There was reduction in the EC, NO_3^-, HCO_3^-, pH, TDS, salinity, and total hardness of the batch 1 sachet water directly exposed to sunlight contrary to the DO and temperature of the water samples. With regards to batch 2 sachet water also exposed directly to sunlight, the EC, salinity, TDS, HCO_3^-, NO_3^-, DO, and total hardness of the samples decreased, whereas the SO_4^{2-} and temperature of the sachet water increased.

Table 4: Physicochemical Properties of Batch 1 Sachet Water Unexposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
pH	6.53±0.15[b]	6.60±0.51[b]	5.47±0.23[a]	5.70±0.26[a]	5.27±0.32[a]	6.50-8.00
Temperature (°C)	25.90±0.40[a]	26.80±0.26[b]	25.70±0.40[a]	25.67±0.32[a]	25.65±0.44[a]	25– 30
EC (µS/cm)	46.00±1.00[d]	38.67±0.58[a]	46.67±0.58[d]	42.33±0.58[b]	44.00±1.00[c]	70
Salinity (mg/l)	0.022±0.001[b]	0.017±0.00[a]	0.022±0.001[b]	0.020±0.001[b]	0.021±0.001[b]	200-500
Colour (Pt. Co)	ND	ND	ND	ND	ND	15
Turbidity (NTU)	ND	ND	ND	ND	ND	5.0
TSS (mg/l)	ND	ND	ND	ND	ND	NA
DO (mg/l)	1.00±0.03[a]	1.60±0.11[c]	1.27±0.09[b]	1.38±0.11[b]	1.26±0.12[b]	≥4
TDS (mg/l)	23±1.00[a]	19±3.60[a]	23±2.65[a]	21±3.61[a]	22±2.00[a]	500
HCO_3^- (mg/l)	61±1.73[c]	57.61±1.32[a]	54.7±1.25[a]	59.88±1.43[ab]	57.40±1.26[b]	NA
NO_3^- (mg/l)	0.91±0.06[c]	0.50±0.05[a]	0.51±0.05[a]	0.71±0.08[b]	0.62±0.08[ab]	50.00
SO_4^{2-} (mg/l)	0.034±0.004[a]	0.029±0.003[a]	0.199±0.010[c]	0.030±0.005[a]	0.115±0.005[b]	100.00
Total hardness (mg/l)	2.43±0.21[a]	2.87±0.35[a]	4.60±0.21[c]	2.60±0.15[a]	3.60±0.19[b]	500

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: EC: Electrical conductivity; TSS: Total soluble solids; DO: Dissolved oxygen; TDS: Total dissolved solids; ND: Not detected; NS: Not available

Table 5: Physicochemical Properties of Batch 1 Sachet Water Exposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
pH	7.53±0.23[c]	6.23±0.51[b]	6.70±0.26[b]	6.03±0.47[b]	5.10±0.30[a]	6.50-8.00
Temperature (°C)	28.63±0.40[c]	26.50±0.36[a]	27.78±0.38[b]	29.71±0.37[d]	29.57±0.21[d]	25 – 30
EC (µS/cm)	64.67±1.15[c]	40.00±1.00[a]	40.67±0.58[ab]	52.33±0.58[bc]	46.67±0.58[bc]	70
Salinity (mg/l)	0.03±0.00[d]	0.018±0.001[a]	0.018±0.001[a]	0.024±0.001[c]	0.021±0.000[b]	200-500
Colour (Pt. Co)	ND	ND	ND	ND	ND	15
Turbidity (NTU)	ND	ND	ND	ND	ND	5.0
TSS (mg/l)	ND	ND	ND	ND	ND	NA
DO (mg/l)	0.85±0.03[a]	2.14±0.15[c]	1.60±0.16[b]	1.56±0.22[b]	1.57±0.20[b]	≥4
TDS (mg/l)	32±1.00[c]	20±3.21[a]	20±3.46[a]	26±2.00[b]	23±0.00[ab]	500
HCO_3^- (mg/l)	67.17±1.19[e]	62.23±1.18[c]	36.6±1.47[a]	64.82±1.02[d]	50.47±1.22[b]	NA
NO_3^- (mg/l)	1.17±0.05[c]	1.05±0.13[c]	0.39±0.05[a]	1.14±0.08[c]	0.76±0.06[b]	11.3
SO_4^{2-} (mg/l)	0.042±0.006[c]	0.003±0.000[a]	0.155±0.009[e]	0.023±0.004[b]	0.090±0.004[d]	250-500
Total hardness(mg/l)	3.90±0.26[b]	3.40±0.26[ab]	3.23±0.35[a]	3.62±0.19[ab]	3.42±0.24[ab]	500

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: EC: Electrical conductivity; TSS: Total soluble solids; DO: Dissolved oxygen; TDS: Total dissolved solids; ND: Not detected; NA: Not available

Table 6: Physicochemical Properties of Batch 2 Sachet Water Unexposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
pH	5.6±0.26[b]	6.60±0.30[c]	4.50±0.55[a]	4.71±0.43[a]	4.22±0.38[a]	6.50-8.00
Temperature (°C)	24.50±0.66[a]	25.23±0.49[ab]	25.50±0.26[b]	24.70±0.50[ab]	25.30±0.50[ab]	25 – 30
EC (µS/cm)	42.8±1.76[b]	40.0±1.37[a]	43.0±0.70[b]	42.0±0.93[ab]	43.4±0.57[b]	70
Salinity (g/l)	0.019±0.004[a]	0.018±0.003[a]	0.020±0.002[a]	0.019±0.004[a]	0.020±0.003[a]	200-500
Colour (Pt. Co)	ND	ND	ND	ND	ND	15
Turbidity (NTU)	ND	ND	ND	ND	ND	5.0
TSS (mg/l)	ND	ND	ND	ND	ND	NA
DO (mg/l)	1.3±0.10[a]	1.4±0.17[a]	1.3±0.20[a]	1.3±0.1[a]	1.3±0.17[a]	≥4
TDS (mg/l)	21.2±0.53[a]	24.3±0.95[b]	24.4±0.62[b]	23.2±0.4[b]	23.4±0.56[b]	500
HCO_3^- (mg/l)	59.30±0.46[c]	56.6±0.46[a]	57.12±0.77[a]	58.24±0.37[b]	57.78±0.43[b]	NA
NO_3^- (mg/l)	0.95±0.19[b]	0.74±0.20[ab]	0.61±0.15[a]	0.68±0.11[ab]	0.63±0.14[a]	11.3
SO_4^{2-} (mg/l)	0.031±0.005[a]	0.030±0.009[a]	0.029±0.008[a]	0.080±0.004[b]	0.097±0.010[c]	250-500
Total hardness (mg/l)	2.60±0.2[a]	2.72±0.21[ab]	3.60±0.22[d]	3.10±0.28[bc]	3.41±0.12[cd]	500

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: EC: Electrical conductivity; TSS: Total soluble solids; DO: Dissolved oxygen; TDS: Total dissolved solids; ND: Not detected; NA: Not available

Table 7: Physicochemical Properties of Batch 2 Sachet Water Exposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
pH	5.70±0.18[ab]	5.30±0.62[a]	6.52±0.84[b]	6.09±0.54[ab]	5.00±0.47[a]	6.50-8.00
Temperature (°C)	25.52±0.49[a]	25.57±0.58[a]	26.40±0.46[ab]	27.70±0.44[c]	27.20±0.36[bc]	25 – 30
EC (µS/cm)	52.0±0.20[e]	46.0±0.45[b]	43.1±0.62[a]	48.2±0.31[c]	47.2±0.40[d]	70
Salinity (mg/l)	0.024±0.003[a]	0.018±0.006[a]	0.018±0.002[a]	0.021±0.003[a]	0.021±0.005[a]	200-500
Colour (Pt. Co)	ND	ND	ND	ND	ND	15
Turbidity (NTU)	ND	ND	ND	ND	ND	5.0
TSS (mg/l)	ND	ND	ND	ND	ND	NA
DO (mg/l)	1.93±0.15[a]	2.00±0.36[a]	1.70±0.26[a]	1.60±0.17[a]	1.60±0.26[a]	≥4
TDS (mg/l)	26.1±0.78[c]	20.1±0.64[a]	20.3±0.50[a]	23.4±0.66[a]	23.4±0.56[b]	500
HCO_3^- (mg/l)	64.67±0.42[e]	49.30±0.50[a]	50.61±0.94[b]	57.60±0.44[d]	54.10±0.29[c]	NA
NO_3^- (mg/l)	1.16±0.50[a]	1.16±0.31[a]	0.78±0.20[a]	0.96±0.18[a]	0.85±0.22[a]	11.3
SO_4^{2-} (mg/l)	0.023±0.008[a]	0.013±0.005[a]	0.084±0.010[c]	0.054±0.001[b]	0.072±0.011[c]	250-500
Total hardness (mg/l)	3.60±0.2[a]	3.50±0.28[a]	3.41±0.22[a]	3.61±0.24[a]	3.50±0.20[a]	500

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: EC: Electrical conductivity; TSS: Total soluble solids; DO: Dissolved oxygen; TDS: Total dissolved solids; ND: Not detected; NA: Not available

Table 8 shows the minerals and heavy metals content of batch 1 sachet water unexposed to sunlight. Also presented in Table 9 is the concentration of minerals and heavy metals in the batch 1 sachet water exposed to sunlight. Lead and cadmium in the batch 1 sachet water exposed to sunlight (Table 9) and unexposed sachet water (Table 8) were below detection limits (BDL) throughout the storage period. At some intervals, chromium and cobalt earlier detected in the stored sachet water exposed to sunlight (Table 9) and unexposed sachet water samples (Table 8) were later BDL. There was significant differences ($p<0.05$) in the values of other parameters monitored at 4 days interval in the batch 1 sachet water exposed to sunlight (Table 9) and unexposed batch 1 sachet water (Table 8).

Depicted in Table 10 is the minerals and heavy metals content of batch 2 sachet water unexposed to sunlight. There is significant differences ($p<0.05$) in the values of the parameters monitored at 4 days interval. The minerals and heavy metals content of batch 2 sachet water exposed to sunlight is presented in Table 11. There is significant differences ($p<0.05$) in the values of the parameters monitored at 4 days interval. Lead and cadmium in the batch 2 sachet water exposed to sunlight (Table 11) and unexposed sachet water (Table 10) were BDL throughout the storage period.

The heavy metals in the sachet water directly exposed to the sun and the unexposed samples were within the WHO permissible limits. Among the heavy metals monitored in the sachet water samples, zinc, copper, and iron ingested in the right amount is beneficial to the human body. According to Odu *et al*. (2020), copper is an essential component of diet required by humans. As such, it ought not to be toxic to human health except the concentration exceed the WHO permissible limit. Copper is required for boosting the immune system, brain development, and formation of foetus. Ingestion of high concentration of copper is associated with liver damage, kidney diseases, and stomach cramp. Iron is responsible for the reddish colour blood is well-known for. However, excess intake of iron is associated with genetic and metabolic disease conditions. Intake of little quantity of zinc boost the immune system, whereas excess quantity is associated with diarrhea (Odu *et al*., 2020).

It is worthy to note that Pb and Cd in the sachet water samples were below detection limit (BDL) throughout the storage period. This result is not in agreement with a similar study carried out by Balogun *et al.* (2024). The researchers reported that Pb was not detected in sachet water before storing it. After one month of storage, Pb (0.0010-0.0020 mg/L) was detected in the sachet water. Another study carried out by Umoafia *et al*. (2023) reported that Cd and Pb in 2 out of 3 brands of sachet water unexposed to sunlight was BDL, whereas the two heavy metals within the range of 0.001-0.06 and 0.01-0.33 mg/L was detected in all the brands of sachet water exposed to sunlight for 42 days, respectively. Lead and cadmium are very dangerous heavy metals to human health (Chinyere *et al*., 2023; Kopdorah *et al*., 2023). Drinking water containing a high quantity of Cd increases the risk of cardiovascular diseases, cancer, hypertension, and normal functioning of the kidney. Pb is associated with cancer, anemia, and kidney diseases (Odu *et al*., 2020). Chiwetalu *et al*. (2022) reported that the concentration of copper in sachet water sold in Enugu metropolis by producers located in the city is insignificant. In a related study, Akharame *et al*. (2018) also reported that the Pb and Cd detected in bottled water directly exposed to sunlight was below detection limit of 0.05 and 0.005 mg/l, respectively.

During the period of storing the sachet water samples, there was reduction in the mineral content which include potassium, sodium, and calcium. Among the three minerals evaluated, only calcium in batch 2 sachet water unexposed to sunlight reduced in quantity to the extent of BDL. Reduction in quantity of sodium content in the stored sachet water packaged with polyethylene was reported by Balogun *et al*. (2024). Possible reason for the reduction in sodium content is the complexation of sodium with some other elements which makes it difficult to detect the concentration of sodium.

Table 8: Minerals and Heavy Metals Content (mg/L) of Batch 1 Sachet Water Unexposed to Sunlight

Para-meters	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
Fe	0.007±0.00078^{b}	0.002±0.0004^{a}	BDL	0.002±0.0004^{a}	BDL	0.3
K	1.78±0.140^{d}	0.58±0.070^{c}	0.36±0.062^{b}	0.58±0.009^{a}	0.19±0.082^{a}	100
Mn	0.046±0.0050^{c}	0.014±0.0040^{b}	0.005±0.0020^{a}	0.013±0.0035^{b}	0.009±0.0026^{ab}	1.0
Na	0.392±0.015^{d}	0.142±0.011^{c}	0.086±0.010^{b}	0.143±0.009^{c}	0.046±0.010^{a}	200.00
Ca	0.189±0.006^{d}	0.063±0.005^{c}	0.046±0.009^{b}	0.062±0.005^{c}	0.023±0.005^{a}	75
Zn	0.1060±0.0045^{c}	0.0070±0.005^{b}	0.0031±0.0003^{a}	0.0072±0.0004^{a}	0.0022±0.0004^{a}	5.0
Pb	BDL	BDL	BDL	BDL	BDL	0.01
Cd	BDL	BDL	BDL	BDL	BDL	0.003
Cr	0.011±0.0036^{b}	BDL	BDL	BDL	BDL	0.05
Co	0.029±0.00260^{b}	0.002±0.00040^{a}	BDL	0.0022±0.00034^{a}	0.0021±0.00047^{a}	NA
Cu	0.074±0.03700^{c}	0.0130±0.00150^{b}	0.0071±0.00035^{a}	0.0130±0.00210^{b}	0.0150±0.00260^{b}	0.05

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: BDL: Below detection limit; NA: Not available

Table 9: Minerals and Heavy Metals Content (mg/L) of Batch 1 Sachet Water Exposed to Sunlight

Para-meters	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
Fe	0.012±0.004[b]	0.0025±0.0005[a]	0.004±0.0004[a]	0.003±0.0008[a]	0.003±0.0007[a]	0.3
K	1.40±0.072[c]	0.42±0.11[b]	0.24±0.046[a]	0.21±0.026[a]	0.12±0.053[a]	100
Mn	0.032±0.007[b]	0.009±0.004[a]	0.0031±0.0050[a]	0.004±0.0004[a]	0.0031±0.00031[a]	1.0
Na	0.388±0.013[c]	0.046±0.008[b]	0.043±0.005[a]	0.053±0.005[a]	0.041±0.009[a]	200.00
Ca	0.154±0.008[c]	0.048±0.006[b]	0.027±0.008[a]	0.028±0.005[a]	0.016±0.001[a]	75
Zn	0.098±0.0057[b]	0.004±0.00[a]	BDL	0.005±0.000[a]	BDL	5.0
Pb	BDL	BDL	BDL	BDL	BDL	0.01
Cd	BDL	BDL	BDL	BDL	BDL	0.003
Cr	0.008±0.0026[b]	BDL	BDL	BDL	BDL	0.05
Co	0.033±0.0021[c]	0.002±0.00021[b]	BDL	0.003±0.00035[b]	BDL	NA
Cu	0.046±0.0075[c]	0.009±0.00026[b]	0.0021±0.0002[a]	0.005±0.00026[ab]	0.002±0.00035[a]	0.05

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: BDL: Below detection limit; NA: Not available

Table 10: Minerals and Heavy Metals Content (mg/L) of Batch 2 Sachet Water Unexposed to Sunlight

Para-meters	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
Fe	0.026±0.00260[c]	0.010±0.00260[b]	0.005±0.00036[a]	0.008±0.00046[ab]	0.0061±0.00025[a]	0.3
K	0.055±0.0021[a]	0.012±0.0046[b]	0.006±0.00061[a]	0.010±0.0038[a]	0.010±0.0026[a]	100
Mn	0.080±0.0040[c]	0.009±0.0004[b]	0.005±0.00026[a]	0.009±0.0004[b]	0.006±0.00026[ab]	1.0
Na	0.135±0.0036[e]	0.036±0.00021[a]	0.021±0.0036[c]	0.036±0.0026[d]	0.012±0.0036[b]	20
Ca	0.006±0.0004[c]	0.002±0.0003[b]	BDL	0.002±0.00026[b]	BDL	75
Zn	0.95±0.036[d]	0.31±0.044[c]	0.19±0.026[b]	0.31±0.046[c]	0.10±0.026[a]	5.0
Cd	BDL	BDL	BDL	BDL	BDL	0.003
Cu	0.019±0.0020[d]	0.008±0.00035[c]	BDL	0.002±0.00032[b]	0.002±0.00035[b]	0.05
Pb	BDL	BDL	BDL	BDL	BDL	0.01
Cr	0.014±0.0017[bc]	0.015±0.0010[c]	0.012±0.0030[bc]	0.011±0.0026[b]	BDL	0.05
Co	0.020±0.0053[a]	0.074±0.0036[c]	0.069±0.0046[bc]	0.065±0.0052[b]	0.074±0.0030[c]	NA

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: BDL: Below detection limit; NA: Not available

Table 11: Minerals and Heavy Metals Content (mg/L) of Batch 2 Sachet Water Exposed to Sunlight

Properties	Day 0	Day 4	Day 8	Day 12	Day 16	WHO permissible limit
Fe	0.030±0.0036[c]	0.007±0.00053[b]	0.004±0.0003[ab]	0.004±0.00036[ab]	0.003±0.00036[a]	0.3
K	0.038±0.0004[b]	0.009±0.00021[c]	0.003±0.00035[a]	0.004±0.00026[b]	0.003±0.00026[a]	100
Mn	0.069±0.00400[c]	0.008±0.00036[b]	BDL	0.005±0.00035[b]	BDL	1.0
Na	0.110±0.004[d]	0.027±0.003[b]	0.015±0.0026[a]	0.016±0.0026[a]	0.009±0.026[c]	20
Ca	0.022±0.0034[b]	0.002±0.00026[a]	0.004±0.00036[a]	0.003±0.00035[a]	0.003±0.00038[a]	75
Zn	0.75±0.036[d]	0.22±0.04[c]	0.13±0.026[b]	0.11±0.044[ab]	0.06±0.01[a]	5.0
Cd	BDL	BDL	BDL	BDL	BDL	0.003
Cu	0.028±0.0035[c]	0.005±0.00032[b]	BDL	0.003±0.00021[b]	BDL	0.05
Pb	BDL	BDL	BDL	BDL	BDL	0.01
Cr	0.038±0.0026[c]	0.014±0.0026[b]	0.015±0.0026[b]	BDL	BDL	0.05
Co	0.038±0.0026[a]	0.054±0.0036[b]	0.085±0.0036[c]	0.081±0.002[c]	0.053±0.0026[b]	NA

The values show the means of triplicate analysis (±SD). Means with different superscript along the row are significantly different ($p<0.05$). Key: BDL: Below detection limit; NA: Not available

Presented in Tables 12 and 13 is the average daily dose (ADD) of batch1 sachet water unexposed and exposed to sunlight, respectively. The ADD of Pb and Cd in the sachet water monitored during the storage period (exposed and unexposed to sunlight) could not be determined because the concentration of both heavy metals in the water were below detection limit (BDL). A similar result was reported for Fe, Cr, and Co at various intervals of storing the sachet water unexposed to sunlight, while the samples exposed to sunlight involved Zn, Cr, and Co. Taking other metals detected in the sachet water into consideration, the ADD values ranged from 6.3×10^{-5} - 1.0×10^{-2} mg/kg/day for the sachet water unexposed to sunlight, while the samples exposed to sunlight is 8.9×10^{-5} – 1.1×10^{-2} mg/kg/day.

Table 12: Average Daily Dose (mg/kg/day) of Batch 1 Sachet Water Unexposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	2.0×10^{-4}	5.7×10^{-5}	-	5.7×10^{-5}	-
K	5.1×10^{-2}	1.7×10^{-2}	1.0×10^{-2}	1.7×10^{-2}	5.4×10^{-3}
Mn	1.3×10^{-3}	4.0×10^{-4}	1.4×10^{-4}	3.7×10^{-4}	2.6×10^{-4}
Na	1.1×10^{-2}	4.1×10^{-3}	2.5×10^{-3}	4.1×10^{-3}	1.3×10^{-3}
Ca	5.4×10^{-3}	1.8×10^{-3}	1.3×10^{-3}	1.8×10^{-3}	6.6×10^{-4}
Zn	3.0×10^{-3}	2.0×10^{-4}	8.9×10^{-5}	2.1×10^{-4}	6.3×10^{-5}
Pb	-	-	-	-	-
Cd	-	-	-	-	-
Cr	3.1×10^{-4}	-	-	-	-
Co	8.3×10^{-4}	5.7×10^{-5}	-	6.3×10^{-5}	6.0×10^{-5}
Cu	2.1×10^{-3}	3.7×10^{-4}	2.0×10^{-4}	3.7×10^{-4}	4.3×10^{-4}

Reference dose (Rfd) for ingestion of potential toxic metals which include Na, Ca, Fe, Mn, Zn, Pb, Cd, Cr, Co, and Cu is 0.03, 0.001, 0.07, 0.14, 0.3, 0.0035, 0.001, 0.003, 0.003, and 0.04 mg/kg/day, respectively (Makwe & Ukah, 2025). The Rfd of K is not specified.

Table 13: Average Daily Dose (mg/kg/day) of Batch 1 Sachet Water Exposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	3.4×10^{-4}	7.1×10^{-5}	1.1×10^{-4}	8.6×10^{-5}	8.6×10^{-5}
K	4.0×10^{-2}	1.2×10^{-2}	6.9×10^{-3}	6.0×10^{-3}	3.4×10^{-3}
Mn	9.1×10^{-4}	2.6×10^{-4}	8.9×10^{-5}	1.1×10^{-4}	8.9×10^{-5}
Na	1.1×10^{-2}	1.3×10^{-3}	1.2×10^{-3}	1.5×10^{-3}	1.1×10^{-3}
Ca	4.4×10^{-3}	1.4×10^{-3}	7.7×10^{-4}	8.0×10^{-4}	4.6×10^{-4}
Zn	2.8×10^{-3}	1.1×10^{-4}	-	1.4×10^{-4}	-
Pb	-	-	-	-	-
Cd	-	-	-	-	-
Cr	2.3×10^{-4}	-	-	-	-
Co	9.4×10^{-4}	5.7×10^{-5}	-	8.6×10^{-5}	-
Cu	1.3×10^{-3}	2.6×10^{-4}	6.0×10^{-5}	1.4×10^{-4}	5.7×10^{-5}

Reference dose (Rfd) for ingestion of potential toxic metals which include Na, Ca, Fe, Mn, Zn, Pb, Cd, Cr, Co, and Cu is 0.03, 0.001, 0.07, 0.14, 0.3, 0.0035, 0.001, 0.003, 0.003, and 0.04 mg/kg/day, respectively (Makwe & Ukah, 2025). The Rfd of K is not specified

Depicted in Tables 14 and 15 is the average daily dose (ADD) of batch 2 sachet water unexposed and exposed to sunlight during storage, respectively. The result shows that the ADD of Cd and Pb in the sachet water unexposed/exposed to sunlight for 16 days could not be determined because the concentration of both heavy metals in the water were below detection limit (BDL). A similar result was reported for Ca, Cu, and Cr at various intervals of storing the sachet water unexposed to sunlight, while the samples exposed to sunlight involved Mn, Cr, and Co. As for other metals monitored at various intervals, the ADD values ranged from 5.7×10^{-5} - 2.7×10^{-2} mg/kg/day for the sachet water unexposed to sunlight, while the samples exposed to sunlight is 8.6×10^{-5} – 2.1×10^{-2} mg/kg/day.

Table 14: Average daily dose (mg/kg/day) of batch 2 sachet water unexposed to sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	7.4×10^{-4}	2.9×10^{-4}	1.4×10^{-4}	2.3×10^{-4}	1.7×10^{-4}
K	1.6×10^{-3}	3.4×10^{-4}	1.7×10^{-4}	2.9×10^{-4}	2.9×10^{-4}
Mn	2.3×10^{-3}	2.6×10^{-4}	1.4×10^{-4}	2.6×10^{-4}	1.7×10^{-4}
Na	3.9×10^{-9}	1.0×10^{-3}	6.0×10^{-4}	1.0×10^{-3}	3.4×10^{-4}
Ca	1.7×10^{-4}	5.7×10^{-5}	-	5.7×10^{-5}	-
Zn	2.7×10^{-2}	8.9×10^{-3}	5.4×10^{-3}	8.9×10^{-3}	2.9×10^{-3}
Cd	-	-	-	-	-
Cu	5.4×10^{-4}	4.3×10^{-4}	-	5.7×10^{-5}	5.7×10^{-5}
Pb	-	-	-	-	-
Cr	4.0×10^{-4}	4.3×10^{-4}	3.4×10^{-4}	3.1×10^{-4}	-
Co	5.7×10^{-4}	2.1×10^{-3}	2.0×10^{-3}	1.9×10^{-3}	2.1×10^{-3}

Reference dose (Rfd) for ingestion of potential toxic metals which include Na, Ca, Fe, Mn, Zn, Pb, Cd, Cr, Co, and Cu is 0.03, 0.001, 0.07, 0.14, 0.3, 0.0035, 0.001, 0.003, 0.003, and 0.04 mg/kg/day, respectively (Makwe & Ukah, 2025). The Rfd of K is not specified

Table 15: Average daily dose (mg/kg/day) of batch 2 sachet water exposed to sunlight

Properties	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	8.6 x 10^{-4}	2.0 x 10^{-4}	1.1 x 10^{-4}	1.1 x 10^{-4}	8.6 x 10^{-5}
K	1.1 x 10^{-3}	2.6 x 10^{-4}	8.6 x 10^{-5}	1.1 x 10^{-4}	8.6 x 10^{-5}
Mn	2.0 x 10^{-3}	2.3 x 10^{-4}	-	1.4 x 10^{-4}	-
Na	3.1 x 10^{-3}	7.7 x 10^{-4}	4.3 x 10^{-4}	4.6 x 10^{-4}	2.6 x 10^{-4}
Ca	6.3 x 10^{-4}	5.7 x 10^{-5}	1.1 x 10^{-4}	8.6 x 10^{-5}	8.6 x 10^{-5}
Zn	2.1 x 10^{-2}	6.3 x 10^{3}	3.7 x 10^{-3}	3.1 x 10^{-3}	1.7 x 10^{-3}
Cd	-	-	-	-	-
Cu	8.0 x 10^{-4}	1.4 x 10^{-4}	-	8.6 x 10^{-5}	-
Pb	-	-	-	-	-
Cr	1.1 x 10^{-3}	4.0 x 10^{-4}	4.3 x 10^{-4}	-	-
Co	1.1 x 10^{-3}	1.5 x 10^{-3}	2.4 x 10^{-3}	2.3 x 10^{-3}	1.5 x 10^{-3}

Reference dose (Rfd) for ingestion of potential toxic metals which include Na, Ca, Fe, Mn, Zn, Pb, Cd, Cr, Co, and Cu is 0.03, 0.001, 0.07, 0.14, 0.3, 0.0035, 0.001, 0.003, 0.003, and 0.04 mg/kg/day, respectively (Makwe & Ukah, 2025). The Rfd of K is not specified.

Presented in Tables 16 and 17 is the hazard quotient (HQ) of batch 1 sachet water unexposed and exposed to sunlight, respectively. The result shows that the HQ of Cd and Pb in the sachet water unexposed/exposed to sunlight for 16 days could not be determined because the concentration of both heavy metals in the water were below detection limit (BDL). A similar result was reported for Fe, Cu, and Cr at various intervals of storing the sachet water unexposed to sunlight, while the samples exposed to sunlight involved Zn, Cr, and Co. The HQ of other metals monitored in the unexposed sachet water is within the range of 8.1 x 10^{-4} – 1.3 x 10^{0}, while the exposed sachet water is 6.4 x 10^{-4} – 1.4 x 10^{-1}.

Table 16: Hazard Quotient of Batch 1 Sachet Water Unexposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	2.9 x 10^{-2}	8.1 x 10^{-4}	-	8.1 x 10^{-4}	-
Mn	9.3 x 10^{-3}	2.9 x 10^{-3}	1.8 x 10^{-2}	2.6 x 10^{-3}	1.9 x 10^{-3}
Na	3.7 x 10^{-1}	1.4 x 10^{-1}	8.3 x 10^{-2}	1.4 x 10^{-1}	4.3 x 10^{-2}
Ca	5.4 x 10^{0}	1.8 x 10^{0}	1.3 x 10^{o}	1.8 x 10^{0}	6.6 x 10^{-1}
Zn	1.0 x 10^{-2}	6.7 x 10^{-4}	3.0 x 10^{-4}	7.0 x 10^{-4}	2.1 x 10^{-4}
Pb	-	-	-	-	-
Cd	-	-	-	-	-
Cr	1.0 x 10^{-1}	-	-	-	-
Co	2.8 x 10^{-1}	1.9 x 10^{-2}	-	2.1 x 10^{-2}	2.0 x 10^{-2}
Cu	5.3 x 10^{-2}	9.3 x 10^{-3}	6.0 x 10^{-3}	9.3 x 10^{-3}	1.1 x 10^{-2}

Table 17: Hazard Quotient of Batch 1 Sachet Water Exposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	4.9 x 10^{-3}	1.0 x 10^{-3}	1.6 x 10^{-3}	1.2 x 10^{-3}	1.2 x 10^{-3}
Mn	6.5 x 10^{-3}	1.9 x 10^{-3}	6.4 x 10^{-4}	7.9 x 10^{-4}	6.4 x 10^{-4}
Na	3.7 x 10^{-1}	4.3 x 10^{-2}	4.0 x 10^{-2}	5.0 x 10^{-2}	3.7 x 10^{-2}
Ca	4.4 x 10^{-1}	1.4x 10^{-1}	7.7 x 10^{-1}	8.0 x 10^{-1}	4.6 x 10^{-1}
Zn	9.3 x 10^{-3}	3.7 x 10^{-4}	-	4.7 x 10^{-4}	-
Pb	-	-	-	-	-
Cd	-	-	-	-	-
Cr	7.7 x 10^{-2}	-	-	-	-
Co	3.1 x 10^{-1}	1.9 x 10^{-2}	-	2.9 x 10^{-2}	-
Cu	3.3 x 10^{-2}	6.5 x 10^{-3}	1.5 x 10^{-3}	3.5 x 10^{-3}	1.4 x 10^{-3}

As for the batch 2 sachet water unexposed and exposed to sunlight, the hazard quotient (HQ) of the samples are presented in Tables 18 and 19, respectively. The result shows that the HQ of Cd and Pb in the sachet water unexposed/exposed to sunlight for 16 days could not be determined because the concentration of both heavy metals in the water were below detection limit (BDL). A similar result was reported for Ca and Cr at various intervals of storing the sachet water unexposed to sunlight, while the samples exposed to sunlight involved Mn and Cr. The HQ of other metals monitored in the unexposed sachet water is within the range of 1.3 x 10^{-7}-1.0 x 10^{-1}, while the exposed sachet water is 8.7 x 10^{-3} - 1.0 x 10^{-1}.

Table 18: Hazard quotient of batch 2 sachet water unexposed to sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	7.4×10^{-4}	4.1×10^{-3}	2.0×10^{-3}	3.3×10^{-3}	2.4×10^{-3}
Mn	1.6×10^{-2}	1.9×10^{-3}	1.0×10^{-3}	1.9×10^{-3}	1.2×10^{-3}
Na	1.3×10^{-7}	3.3×10^{-2}	2.0×10^{-2}	3.3×10^{-2}	1.1×10^{-2}
Ca	1.7×10^{-1}	5.7×10^{-2}	-	5.7×10^{-2}	-
Zn	9.0×10^{-2}	3.0×10^{-2}	1.8×10^{-2}	3.0×10^{-2}	9.7×10^{-3}
Cd	-	-	-	-	-
Cu	1.4×10^{-2}	1.1×10^{-2}	-	1.4×10^{-3}	1.4×10^{-3}
Pb	-	-	-	-	-
Cr	1.3×10^{-1}	1.4×10^{-1}	1.1×10^{-1}	1.0×10^{-1}	-
Co	1.9×10^{-1}	7.0×10^{-1}	6.7×10^{-1}	6.3×10^{-1}	7.0×10^{-1}

Table 19: Hazard quotient of batch 2 sachet water exposed to sunlight

Properties	Day 0	Day 4	Day 8	Day 12	Day 16
Fe	1.2×10^{-2}	2.9×10^{-3}	1.6×10^{-3}	1.6×10^{-3}	1.2×10^{-3}
Mn	1.4×10^{-2}	1.6×10^{-3}	-	1.0×10^{-3}	-
Na	1.0×10^{-1}	2.6×10^{-2}	1.4×10^{-2}	1.5×10^{-2}	8.7×10^{-3}
Ca	6.3×10^{-1}	5.7×10^{-2}	1.1×10^{-1}	8.6×10^{-2}	8.6×10^{-2}
Zn	7.0×10^{-2}	2.1×10^{-2}	1.2×10^{-2}	1.0×10^{-2}	5.7×10^{-3}
Cd	-	-	-	-	-
Cu	8.0×10^{-1}	1.4×10^{-1}	-	8.6×10^{-2}	-
Pb	-	-	-	-	-
Cr	3.7×10^{-1}	1.3×10^{-1}	1.4×10^{-2}	-	-
Co	3.7×10^{-1}	5.0×10^{-1}	8.0×10^{-1}	7.7×10^{-1}	5.0×10^{-1}

Presented in Tables 20 and 21 is the carcinogenic risk (CR) of batch 1 sachet water unexposed and exposed to sunlight, respectively. The result shows that the CR of the sachet water based on its Cr content was determined at day 0, whereas the values in subsequent days could not be determined. The values for the sachet water unexposed and exposed to sunlight is within the range of 6.3×10^{-5} - 3.6×10^{-3} and 9.7×10^{-5} - 2.2×10^{-3}, respectively.

Tables 22 and 23 show the CR of batch 2 sachet water unexposed and exposed to sunlight, respectively. The result shows that the CR of the sachet water based on its Zn content was determined at intervals during the storage period, whereas the values dependent on the concentration of other potentially toxic metals could not be determined at various intervals. The values for the sachet water unexposed and exposed to sunlight is within the range of 9.7×10^{-5} - 8.1×10^{-3} and 9.3×10^{-4} – 1.1×10^{-3}, respectively.

Table 20: Carcinogenic Risk of Batch 1 Sachet Water Unexposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Zn	9.0×10^{-4}	6.0×10^{-5}	2.7×10^{-5}	6.3×10^{-5}	1.9×10^{-5}
Cr	1.6×10^{-4}	-	-	-	-
Cu	3.6×10^{-3}	6.3×10^{-4}	3.4×10^{-4}	6.3×10^{-4}	7.3×10^{-4}

The carcinogenic slope factor (CSF) of Zn, Cu, and Cr is 0.3, 1.7, and 0.5 mg/kg/day, respectively

Table 21: Carcinogenic Risk of Batch 1 Sachet Water Exposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Zn	8.4×10^{-4}	3.3×10^{-5}	-	4.2×10^{-5}	-
Cr	1.2×10^{-4}	-	-	-	-
Cu	2.2×10^{-3}	4.4×10^{-4}	1.0×10^{-4}	2.4×10^{-4}	9.7×10^{-5}

The carcinogenic slope factor (CSF) of Zn, Cu, and Cr is 0.3, 1.7, and 0.5 mg/kg/day, respectively

Table 22: Carcinogenic Risk of Batch 2 Sachet Water Unexposed to Sunlight

Parameters	Day 0	Day 4	Day 8	Day 12	Day 16
Zn	8.1×10^{-3}	2.7×10^{-3}	1.6×10^{-3}	2.7×10^{-3}	8.7×10^{-4}
Cr	2.0×10^{-4}	2.2×10^{-4}	1.7×10^{-4}	1.6×10^{-4}	-
Cu	9.2×10^{-4}	7.3×10^{-3}	-	9.7×10^{-5}	9.7×10^{-5}

The carcinogenic slope factor (CSF) of Zn, Cu, and Cr is 0.3, 1.7, and 0.5 mg/kg/day, respectively

Table 23: Carcinogenic Risk of Batch 2 Sachet Water Exposed to Sunlight

Properties	Day 0	Day 4	Day 8	Day 12	Day 16
Zn	6.3×10^{-3}	1.9×10^{-3}	1.1×10^{-3}	9.3×10^{-4}	5.1×10^{-4}
Cu	1.4×10^{-3}	2.4×10^{-4}	-	1.5×10^{-4}	-
Cr	5.5×10^{-4}	2.0×10^{-4}	2.2×10^{-4}	-	-

The carcinogenic slope factor (CSF) of Zn, Cu, and Cr is 0.3, 1.7, and 0.5 mg/kg/day, respectively

The average daily dose (ADD) of Fe, Mn, Zn, Pb, Cd, Cr, Co, and Cu in the batch 1 and 2 sachet water exposed and unexposed to sunlight were lower than their respective reference dose (Rfd) for ingestion of the potential toxic metals. This result contradicts the research findings by Umoafia *et al*. (2023). The researchers reported that the ADD of Zn, Cr, Cd, and Pb exceeded their Rfd. This study shows that K and Zn had the highest ADD among the metals monitored in the stored batch 1 and 2 sachet water, respectively.

The HQ for each metal in the stored sachet water samples exposed and unexposed to sunlight, monitored at 4 days intervals during the period of storage is below 1. This result implies that consuming the sachet water stored for 16 days does not pose any impending danger to human health.

However, the carcinogenic risk of the sachet water exposed and unexposed to sunlight during storage for 16 days is a source of concern. Going by the results obtained from this study, people who consume the stored sachet water are exposed to cancer risk. According to Umoafia *et al*. (2023), CR values above 10^{-6} to 10^{-4} is an indication that consumers of the product could experience cancer over a 64.4 years lifetime. In a related study, Makwe & Ukah (2025) reported that children are most likely to experience greater non-cancer risk than adults when both populations drink sachet water contaminated with heavy metals.

CONCLUSION

Sachet water exposed to sunlight experienced reduction in the total heterotrophic bacterial count, total coliform count, and total fungal count over a period of 16 days. The values for the microbiological parameters were lower compared with the sachet water samples unexposed to sunlight, with few exceptions. *Pseudomonas aeruginosa, Escherichia coli,* and *Bacillus subtilis* encountered in the sachet water were resistant to almost all the antibiotics tested, while *Staphylococcus aureus* was observed in all. During storage of the sachet water exposed to sunlight, there was reduction in the physicochemical properties, minerals, and heavy metals concentrations, with some exceptions. A similar result was noticed for sachet water samples unexposed to sunlight. Non-microbiological parameters of the stored sachet water samples were largely within the WHO permissible limits contrary to the microbiological parameters. Although sachet water exposed to sunlight had better microbiological quality than the unexposed samples, this storage condition could affect the quality of the product to the extent that it poses a greater health risk to consumers compare with sachet water unexposed to sunlight. Health risk assessment of the sachet water indicate that consumers might not face an immediate health danger, but could face cancer risk in the future.

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