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Investigating the effect of storage materials on the quality of potable water

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ABSTRACT

The quality of potable water can deteriorate significantly when stored in different types of containers, potentially posing health risks to consumers. Water storage containers, made from materials like plastic, clay, and aluminum, can interact with water both chemically and biologically, leading to contamination. Understanding how different storage materials affect water quality is crucial, especially in regions relying on extended storage. This study aims to evaluate the impact of different storage container materials (white plastic, blue plastic, clay, and aluminum) on the physio-chemical and bacteriological properties of potable water. Water samples were collected from a hand pump at FUTO Hostel C and subjected to laboratory tests both before and after storage in white plastic, blue plastic, clay, and aluminum containers. The parameters tested included pH, turbidity, conductivity, total dissolved solids, dissolved oxygen, total hardness, total chloride, manganese, iron, chromium, lead, and bacterial counts (heterotrophic and coliform). Water quality indices were calculated based on the Nigerian Industrial Standards (NIS 977:2017). The initial water quality was classified as "good" with a water quality index (WQI) of 34.98. However, after storage, significant deterioration was observed across all container types. Water stored in white plastic had a WQI of 91.69, while blue plastic resulted in a WQI of 78.87, both indicating "very poor" water quality. Clay storage also yielded a "very poor" WQI of 76.97, mainly due to increased turbidity and bacterial contamination. The most severe deterioration was seen in aluminum containers, with a WQI of 217.67, classifying the water as "unfit for consumption" due to excessive manganese (1.8 mg/L) and iron (0.51 mg/L) contamination. The study reveals that none of the materials tested is ideal for long-term potable water storage. Plastic and aluminum containers lead to significant chemical contamination, while clay containers promote bacterial growth.

Keywords: water quality index, potable water, storage containers, physio-chemical properties, bacteriological contamination, plastic storage, clay storage, aluminum contamination, water treatment

INTRODUCTION

Potable water is water that is safe for human consumption and is distinguished from general water sources by its absence of harmful contaminants and pathogens (Gokulanathan et al., 2021). While water in its broadest definition encompasses all forms, including surface water, groundwater, and even industrial wastewater, potable water specifically refers to water that has been treated and deemed fit for human consumption, adhering to regulatory standards set by entities such as the World Health Organization (CDC, 2024). The significance of potable water cannot be overstated, yet the quality of potable water is a global concern (Okafor et al., 2024). Access to safe drinking water is one of the most necessities for human health and survival. It directly impacts a population's public health, with access to clean water reducing the prevalence of waterborne diseases, which account for a significant portion of illness and death globally (Dinka, 2018; Hutton & Chase, 2017).

Globally, approximately 785 million people lack access to basic drinking water services, with the majority residing in low- and middle-income countries like Nigeria (Ekumah et al., 2020). Potable water is essential in preventing diseases such as cholera, dysentery, and typhoid, which are typically spread through contaminated water (Hutton & Chase, 2017). In regions with inadequate water treatment infrastructure, ensuring the safety of potable water remains a significant challenge. Common sources of potable water include surface water from rivers and lakes, as well as groundwater, often accessed via wells or boreholes (Edokpayi et al., 2018; Katsanou & Karapanagioti, 2017; Okafor et al., 2024). However, environmental contaminants, such as heavy metals, pesticides, industrial waste, agricultural runoff, untreated sewage, and organic pollutants, can infiltrate these water sources, exacerbating the difficulty of maintaining water quality as well as posing serious health risks (Bashir et al., 2020; Mishra et al., 2023; Wang et al., 2024). Nigeria in particular faces significant challenges in maintaining water quality due to infrastructural limitations, urbanization, and a rapidly growing population. These challenges often result in untreated or minimally treated water sources, leaving much of the population vulnerable to waterborne diseases. Improper storage practices, including inadequate cleaning and disinfection, further compound these challenges and impact the water quality (Adeoti et al., 2023; Isukuru et al., 2024).

Water quality degradation during storage is a critical issue in both urban and rural settings where potable water, once treated, is often stored in containers that can introduce contaminants or foster bacterial growth, thereby reversing the effects of initial purification processes (Balasooriya et al., 2023; Zhang et al., 2023). Storage practices and the materials used for water storage are pivotal in determining water quality, both in the short and long term. Materials used for water storage can have a direct impact on the physiochemical and bacteriological properties of the water; even after water is treated, its quality can degrade if stored improperly. Environmental contaminants, including airborne pollutants and dust, can infiltrate stored water, particularly in open or poorly sealed containers (Adesakin et al., 2022; Manga et al., 2021; Siddiqua et al., 2022).

Commonly used materials for water storage include plastic, stainless steel, clay, and glass (D et al., 2024). Plastics, metals, and earthenware all interact differently with water, potentially altering its pH, adding chemical compounds through leaching, or serving as a breeding ground for microorganisms (Aralappanavar et al., 2024; Barone et al., 2024; Issac & Kandasubramanian, 2021). Plastic storage containers, particularly polyethylene terephthalate (PET) and high-density polyethylene (HDPE), are commonly used in Nigeria for storing potable water in bottles and bags. PET and HDPE are preferred due to their lightweight nature, ease of transportation, and cost-effectiveness. However, both types of plastic are susceptible to leaching under certain conditions, such as prolonged exposure to sunlight or high temperatures (Egun & Evbayiro, 2020; Masry et al., 2021; Nayanathara Thathsarani Pilapitiya & Ratnayake, 2024). Plastic containers may leach chemicals such as bisphenol A and phthalates into the water, especially when exposed to high temperatures. These compounds not only affect the chemical composition of the water but also pose potential health risks, such as endocrine disruption (Palsania et al., 2024). The presence of microplastics in water stored in plastic containers is also a concern and studies have shown that even bottled water, often perceived as safer, can contain microplastic particles, which may pose health risks when ingested (Aralappanavar et al., 2024). In contrast, stainless steel and glass, although less commonly used in Nigeria due to their cost and fragility, offer more inert options for water storage with minimal chemical interactions with the stored water. Clay pots, which are more traditional in rural areas, provide a more natural, cost-effective alternative but are often more prone to microbial contamination due to their porous nature (Briffa et al., 2020; Ibrahim et al., 2024). The color of storage containers and their exposure to light further also complicate water storage practices (Manga et al., 2021). The color of a storage container can affect water temperature and, consequently, it’s quality. Dark-colored containers absorb more heat when exposed to sunlight, which can increase the water’s temperature, creating a more favorable environment for microbial growth. On the other hand, water stored in transparent or lightly colored containers exposed to direct sunlight is more likely to undergo chemical changes, such as the breakdown of chlorine used for disinfection, thereby increasing the risk of contamination (Clayton et al., 2013).

However, the water quality index (WQI) is a valuable tool for assessing the overall quality of water based on various physiochemical and biological parameters, such as pH, turbidity, dissolved oxygen (DO), total dissolved solids (TDS), and microbial presence (Uddin et al., 2021). These indices made use of different kinds and numbers of water quality parameters. Every criterion has weight based on standards, and the weight allocated to it shows how important it is and how it affects the index (Chidiac et al., 2023). A usual WQI method follows three steps, which include selection of parameters, determination of quality function for each parameter, and aggregation through mathematical equation. The index makes it possible to compare data from various sampling locations (Uddin et al., 2021). WQI simplifies the process of determining water quality by providing a single score that represents the overall condition of the water, making it easier to communicate and understand. It is particularly useful in evaluating water quality before and after storage, as it can highlight how different storage materials and practices affect water over time (Akhtar et al., 2021). WQI is calculated by averaging the individual index values of some or all of the parameters within five water quality parameter categories:

1. Water clarity: Turbidity (nephelometric turbidity unit [NTU])
2. DO: DO concentration (mg/l)
3. Oxygen demand: Biochemical oxygen demand (BOD) (mg/l) and chemical oxygen demand (mg/l)
4. Nutrients: Total nitrogen (mg/l) and/or total phosphorus (mg/l)
5. Bacteria: Total coliform (per mg/l) and/or fecal coliform (per mg/l)

A ‘confidence value’ of 1-5 indicates how many of the above categories were incorporated into the index. The standard rating is shown in **Table 1** (Adelagun et al., 2021; Chidiac et al., 2023).

Table 1. Water quality rating

WQI	Water quality rating
0-25	Excellent water quality
26-50	Good water quality
51-75	Poor water quality
76-100	Very poor water quality
Above 100	Unsuitable for drinking purposes

Research on the impact of storage materials on water quality has gained increasing attention, as it is now widely recognized that the type of material used for storing water can significantly alter its quality (Clayton et al., 2013; D et al., 2024; Issac & Kandasubramanian, 2021; Kelechi et al., 2013; Manga et al., 2021). Studies show that plastic containers have become prevalent for water storage in many regions, particularly in developing nations such as Nigeria (Adelagun et al., 2021; Isukuru et al., 2024). However, several studies have raised concerns over the leaching of chemicals from these plastics, especially when exposed to environmental stressors such as heat or light. In a study by Xu et al. (2020), it was demonstrated that PET bottles, commonly used for water storage, can release substances such as antimony and phthalates into the water under certain conditions. Such leaching may not only affect the taste and odor of water but can also pose serious health risks. Similarly, polyethylene-based storage materials have been shown to leach additives, such as stabilizers and plasticizers, which degrade water quality over time (Maddela et al., 2023). In contrast, studies have suggested that stainless steel and glass containers are more inert, with a lower propensity to leach harmful substances into the water. These materials tend to be non-reactive and are preferred in environments where water quality must remain uncontaminated for long periods (Nunamaker et al., 2013). However, clay containers, despite their traditional use in many communities, have a dual role. While they often maintain cooler water temperatures and thus inhibit microbial growth, they can also introduce natural contaminants such as heavy metals, depending on the clay's composition (Amalina et al., 2022)

Water quality is often assessed based on a series of physicochemical and bacteriological parameters. Parameters such as pH, turbidity, TDS, and the presence of microbial contaminants (e.g., coliforms) provide insight into the health implications of stored water. Research indicates that storage materials can alter these parameters (Kalavari et al., 2022; Some et al., 2021). In a review by Kye et al. (2023), it was found that plastic containers, especially those exposed to prolonged sunlight, experienced an increase in water turbidity and pH fluctuations due to chemical interactions between the plastic material and water. This was attributed to the breakdown of the polymer structure under ultraviolet (UV) radiation, leading to the release of microplastics into the water. Bacteriological quality, particularly the presence of coliform bacteria, is another critical measure of water safety. Storage conditions, including the choice of container material, play a significant role in microbial growth (Aram et al., 2021). Studies have found that water stored in plastic containers tends to have higher bacterial counts compared to stainless steel or glass containers (Radha & Palanisami, 2015). Di Pippo et al. (2023) highlighted that porous surfaces in certain plastic containers create favorable environments for microbial colonization. Furthermore, the lack of proper cleaning and sanitization of storage containers exacerbates the proliferation of bacteria (Joy Chinenye, 2017).

Temperature, light exposure, and container color are storage conditions that significantly affect water quality. Light, particularly UV radiation, can degrade water quality by promoting the growth of algae and bacteria, especially in transparent plastic containers (Some et al., 2021). Research has shown that water stored in unclear PET bottles can experience increased microbial proliferation when exposed to sunlight, a phenomenon attributed to the greenhouse effect within the container (Bach et al., 2014). Cai et al. (2023) showed that higher storage temperatures accelerate chemical leaching from plastic materials and promote the growth of harmful bacteria, such as E. coli. In a study conducted in rural Nigeria, water stored in black polyethylene bags under direct sunlight showed a significant increase in bacterial count, along with noticeable changes in physicochemical properties like DO and TDS (Ikechukwu & Shabangu, 2021). Thus, the combination of material type, temperature, and light exposure forms a complex interplay that directly influences the safety and quality of stored potable water.

While there has been extensive research into the impact of storage materials on water quality, gaps remain, particularly in the context of developing nations like Nigeria, where informal storage practices are prevalent. Many studies have focused on individual materials or specific physicochemical properties without holistically examining the combined effect of material type, storage conditions, and container design on water quality. Furthermore, research on the role of container color and exposure to environmental factors like light and temperature remains limited.

This study seeks to address these gaps by comprehensively evaluating the impact of various storage materials and conditions on both the physicochemical and bacteriological quality of potable water. The research aims to investigate the impact of storage materials on potable water quality. This is a significant topic due to the critical role potable water plays in public health and well-being. Contamination can lead to various diseases, including gastrointestinal illnesses, typhoid, and cholera. Thus, understanding how storage materials can influence water quality is essential for ensuring safe and accessible drinking water. We will provide new insights into the cumulative effects of storage practices on water safety. The aim is to advance the current understanding of storage-related water contamination and propose practical solutions to improve water safety in regions with similar challenges.

MATERIALS AND METHODS

Materials and Apparatus

Water samples were collected from a hand pump located at FUTO Hostel C (5.38845° N, 6.99897° E), ensuring that the source remained uncontaminated throughout the collection process. The storage materials used for the experiment consisted of containers made from different materials, including plastic (in both white and blue variants), aluminum, and clay. Each material was selected for its common use in water storage across different contexts, with the color variation in plastic specifically chosen to assess the potential impact of container color on water quality.

The apparatus employed in the analysis included a Sac Tech turbidity meter, used to measure the clarity and turbidity levels of the water samples before and after storage. A UV-visible spectrophotometer was used to determine various physiochemical properties, including the presence of potential contaminants. The water samples were also subjected to bacteriological analysis using a thermostat incubator (Search Instruments, British Standard) to monitor microbial growth under controlled temperature conditions.

To assess oxygen demand and related water quality parameters, BOD bottles were used to measure oxygen concentration changes over time. Conical flasks and measuring cylinders facilitated the preparation and measurement of reagents and water samples during the analysis. Burets were employed for titration, and deionized water served as the solvent for the preparation of the reagents used in the chemical analysis.

Several indicators, including Mordant Black, potassium chromate, and zincon, were utilized to detect changes in water quality based on various chemical reactions. The experimental procedure also required the use of acids and bases to adjust the pH of the samples, ensuring the accuracy of specific tests related to the water's physicochemical properties. All materials were carefully calibrated and cleaned before and after each use to maintain the precision of the experiments.

Experimental Procedures

Water sample collection

Water samples were collected from a borehole source at FUTO Hostel C. To ensure the integrity of the samples, the taps fitted in the storage vessels were allowed to run for several minutes before collection. This helped to flush out any stagnant water and reduce the risk of contamination. Sterile sample bottles were used to collect the water, and proper labelling was employed to avoid errors during analysis.

Physiochemical and bacteriological analysis

The collected water samples were analyzed for various physicochemical and bacteriological parameters based on Nigerian industry standards. The following procedures were, as follows.

Temperature: Temperature was measured by transferring the sample from the storage container to a test tube. A thermometer was immediately inserted, and the temperature was recorded at the point where the thermometric fluid stabilized.

Turbidity: Turbidity was determined using the HACH 2100N Turbidimeter, calibrated to 0.14 NTU. The water sample was shaken and transferred into a clean cell, wiped to remove fingerprints, and placed in the device. The turbidity reading was then taken directly from the display.

Electrical conductivity: Electrical conductivity was measured using an EC/TDS/NaCl meter. After shaking the sample thoroughly, 50 mL was transferred to a test tube, and the electrode was fully immersed. Air bubbles were avoided, and the conductivity reading was taken from the device's LCD in µS/cm.

Total hardness: To determine the total hardness, 50 mL of the sample was mixed with an equal volume of deionized water and 4 mL of buffer solution. Six drops of the indicator were added to produce a mordant blank, followed by the addition of 2 mL of magnesium chloride solution, which turned the mixture pink. The sample was titrated with 0.01 M EDTA until the pink color disappeared, and the volume of EDTA used was recorded to calculate the total hardness in ppm.

Zinc concentration: Zinc concentration was analyzed by transferring 0.5 mL of the sample into a test tube and adding 5 mL of zincon reagent. The solution's absorbance was measured using a UV-visible spectrometer and compared with a blank solution made of deionized water and zincon reagent to determine zinc levels.

Manganese concentration: For manganese, 10 mL of the sample was mixed with 5 mL of a special reagent and one drop of hydrogen peroxide. The solution was heated to reduce the volume to 9 mL, followed by the addition of 1 g of ammonium persulfate. The sample and a distilled water blank were analyzed using a UV-visible spectrometer at 525 nm, and the manganese concentration was calculated using the absorbance values.

Biochemical oxygen demand & dissolved oxygen: BOD and DO were measured by adding 100 mL of manganese sulfate to a DO bottle, followed by 1 mL of alkaline iodide azide and 1 mL of concentrated sulfuric acid. The mixture was titrated with 0.025 M sodium thiosulphate after adding 2% starch solution to complete the test.

Total heterotrophic bacteria: The total heterotrophic bacterial count was determined using the total viable count method with nutrient agar as the culture medium. The agar and apparatus were sterilized, and after preparation, the sample was transferred to a petri dish using a sterile glass-bent rod. The dish was inverted and incubated to allow for bacterial growth.

Salinity: Salinity was inferred by adding 1 mL of potassium chromate indicator to 100 mL of the sample and incubating it in a petri dish. After 24 hours, bacterial colonies were counted, and salinity was estimated based on the number of colonies, with higher salinity inhibiting growth.

Total solids: Total solids were measured by weighing an empty petri dish and adding 100 mL of the agitated sample. The dish was heated to dryness in a steam bath, further dried in an oven, and then cooled in a desiccator before reweighing to determine the total solids content.

Evaluation of the Effect of the Different Types of Storage Material on the Quality of the Drinking Water

To determine how different types of storage containers affect water quality, comparisons were made with the Nigerian Industrial Standards (NIS) of the water samples obtained from the borehole source before and after storage. Charts were developed showing the details of just how much each parameter considered changed over time in each of the storage materials.

Determination of the Initial Water Quality Index Before and After Storage

The weighted arithmetic water quality index method was used. WQI was calculated by averaging the individual index values of all of the parameters tested. The Federal Ministry of Environment standards were used in this study to determine and grade water quality. **Table 2** was used as a sample to tabulate the calculated values. Relative weight (RW) can be calculated using Eq. (1), as follows:

Table 2. Sample table for WQI

Parameters	CI	SI	AW	RW	QI	IS

Table 3. Laboratory test results obtained for plastic, clay, and aluminum containers after storage period

Parameters	White plastic	Blue plastic	Clay	Aluminum	Unit	Initial reading	NIS 977:2017
pH	5.10	5.10	5.20	4.90	-	6.47	6.50-8.50
Turbidity	1.60	2.60	4.00	2.40	NTU	ND	5.00
Conductivity	118.00	117.00	141.00	115.00	S/cm	139.50	1,000.00
Chromium	2.85	2.38	0.51	0.80	mg/l Cr	0.64	0.01
Lead	1.85	2.01	1.03	1.41	mg/l Pb	0.15	0.01
Zinc	N/A	N/A	N/A	N/A	mg/l Zn	ND	5.00
Manganese	0.26	0.16	0.07	1.80	mg/l Mn	0.01	0.10
Iron	1.76	0.52	0.42	0.51	mg/l Fe	0.28	0.30
TDS	76.70	76.05	91.65	74.43	mg/l	90.68	500.00
DO	5.35	6.50	4.30	4.85	mg/l O^2	6.10	> 7.50
Total hardness	44.03	38.26	68.64	73.82	mg/l Ca & $MgCO^3$	38.85	100.00
Total chloride	22.5	22.40	22.99	21.99	mg/l Cl	23.99	100.00
Heterotrophic bacteria	76	82	91	11	cfu/100ml	8	30
Total coliform count	96	45	81	8	cfu/100ml	3	10

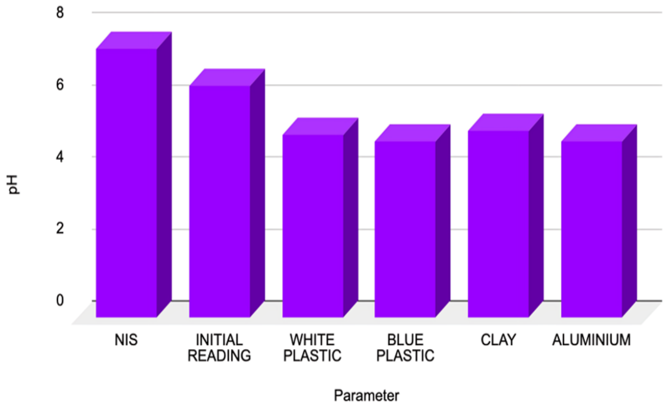

Figure 1. pH variations for selected containers (Source: Authors' own elaboration)

$$RW = \frac{AW}{\sum AW'} \tag{1}$$

where AW is assumed weight.

Quality rating (QI) can be calculated using Eq. (2) and Eq. (3), as follows:

$$QI = \frac{CI}{SI} \times 100. \tag{2}$$

$$QI = \frac{CI-VI}{SI-VI} \times 100, \tag{3}$$

where CI is the measured values, SI is the standard values, VI is 7.0 for pH and VI is 14.6 for DO. Eq. (3) was used for QI of pH and DO while Eq. (2) was used for every other parameters.

Sub-index (IS) can be calculated using Eq. (4), as follows:

$$IS = RW \times QI. \tag{4}$$

Finally, WQI can be calculated using Eq. (5), as follows:

$$WQI = \sum IS. \tag{5}$$

After computing the water quality, the index values were corroborated with the water quality grading in **Table 1**.

RESULTS AND DISCUSSION

The results of the laboratory tests conducted on water stored in white plastic, blue plastic, clay, and aluminum containers, as shown in **Table 3**, reveal significant changes in the physiochemical and bacteriological properties of the water compared to the initial readings. These variations in parameters reflect the impact of storage materials and conditions on water quality, with important health and regulatory implications.

Physicochemical Parameters

pH values

Based on the data, the pH values of all samples decreased after storage, with readings below the acceptable NIS (NIS 977:2017) range of 6.50-8.50. The water stored in aluminum containers had the lowest pH at 4.90, while the clay container showed a slightly higher pH of 5.20, as shown in **Figure 1**. Acidic water can have corrosive effects, potentially leading to the leaching of metals from containers, as reflected in the elevated levels of heavy metals like chromium and lead. This deviation from the standard may have implications for consumer health, particularly in prolonged exposure to acidic water, as it can cause irritation of the gastrointestinal tract and increase the likelihood of contamination from leached substances.

Turbidity

Turbidity increased after storage in all container types. **Figure 2** shows that water stored in the clay container exhibited the highest turbidity at 4.00 NTU, approaching the NIS limit of 5.00 NTU, while water in white plastic and aluminum containers displayed relatively lower turbidity at 1.60 NTU and 2.40 NTU, respectively. Turbidity is a key indicator of water clarity. Increased turbidity often indicates the presence of suspended particles, which may harbor microorganisms or organic matter. The high turbidity in clay containers could be attributed to the porous nature of clay, which may allow particulates to seep into the water.

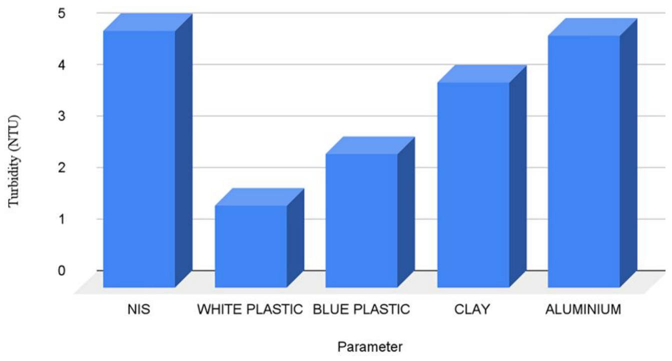

Figure 2. Turbidity variations for selected containers (Source: Authors' own elaboration)

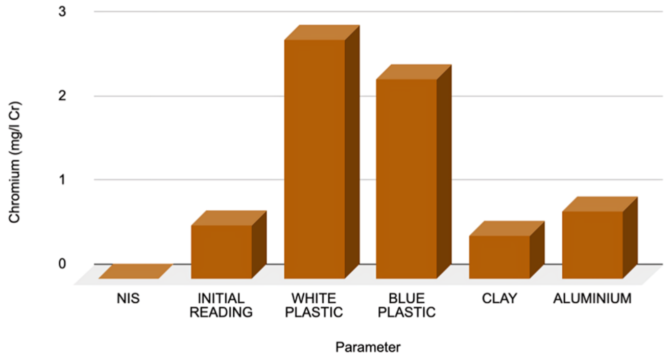

Figure 4. Chromium variations for selected containers (Source: Authors' own elaboration)

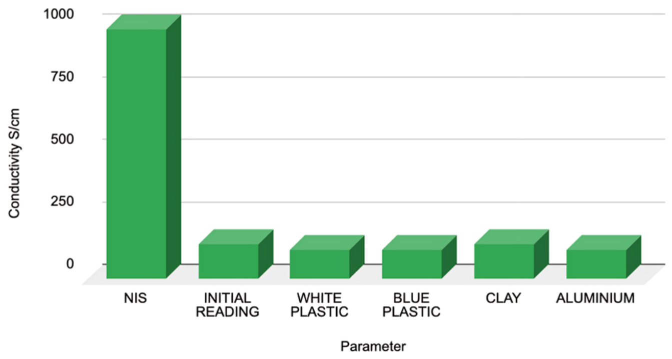

Figure 3. Conductivity variations for selected containers (Source: Authors' own elaboration)

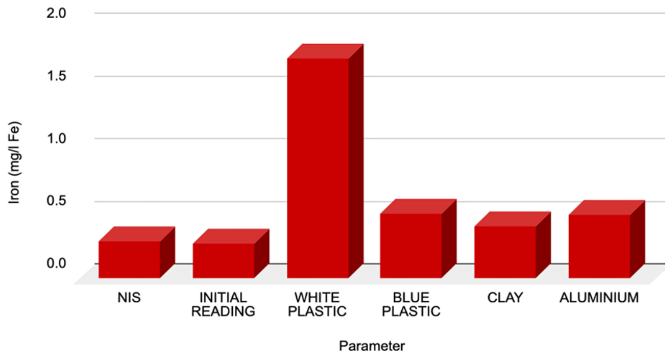

Figure 5. Iron variations for selected containers (Source: Authors' own elaboration)

Conductivity

The results showed that conductivity levels increased marginally in the clay container (141 µS/cm), reflecting a higher concentration of dissolved ions in the water. This contrasts with the slight decrease in conductivity for water stored in aluminum containers (115 µS/cm) in **Figure 3**. While all values remained well within the NIS limit of 1,000 µS/cm, the differences indicate that storage materials like clay may contribute to the dissolution of additional salts or minerals into the water, potentially altering its chemical composition over time.

Metal

The heavy metal analysis revealed the levels of chromium and lead, particularly in plastic containers. Chromium concentrations were highest in the white plastic container (2.85 mg/L), significantly exceeding the NIS limit of 0.01 mg/L, as shown in **Figure 4**. Lead levels were also high, particularly in blue plastic (2.01 mg/L), surpassing the NIS threshold of 0.01 mg/L. These findings highlight the potential for chemical leaching from plastic materials, especially when exposed to environmental factors such as temperature fluctuations or UV radiation.

Chronic exposure to elevated levels of chromium and lead poses serious health risks, including kidney damage, neurological effects, and increased cancer risk.

Zinc was not detected in any of the samples, which indicates that the storage materials did not leach significant amounts of this metal into the water. Manganese concentrations, however, were higher in water stored in aluminum containers (1.8 mg/L), far exceeding the NIS limit of 0.1 mg/L. This could be due to interaction between aluminum and stored water, resulting in the dissolution of manganese. Elevated manganese levels in drinking water are associated with adverse neurological effects, especially in children.

Iron concentrations exceeded the NIS limit of 0.3 mg/L in all containers except the clay container, where iron levels were just below the threshold at 0.42 mg/L. The highest iron concentration was found in white plastic containers (1.76 mg/L), as shown in **Figure 5**.

Iron in drinking water can cause discoloration and a metallic taste and may stain household fixtures and clothing, though it is generally not considered a direct health risk at these levels.

Total dissolved solids

TDS were within acceptable limits across all storage containers, with the clay container showing the highest TDS level at 91.65 mg/L, while the aluminum container had the lowest at 74.43 mg/L, as shown in **Figure 6**. The slight increase in TDS in the clay container further suggests the dissolution of minerals or salts from the porous material, although these levels remain well below the NIS guideline of 500 mg/L.

Dissolved oxygen

Figure 7 shows that DO levels were lower in clay and aluminum containers, with the clay container exhibiting the lowest DO at 4.30 mg/L. The aluminum container also had a relatively low DO value at 4.85 mg/L. While DO levels below

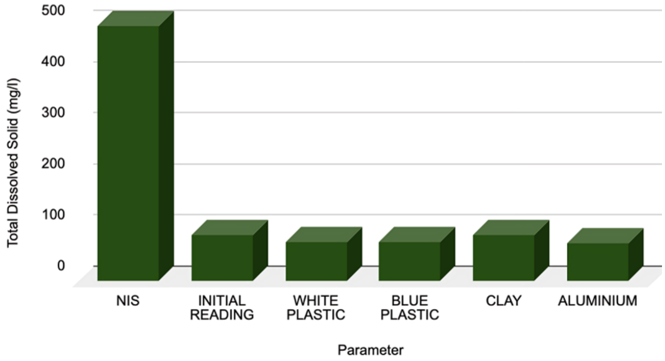

Figure 6. TDS variations for selected containers (Source: Authors' own elaboration)

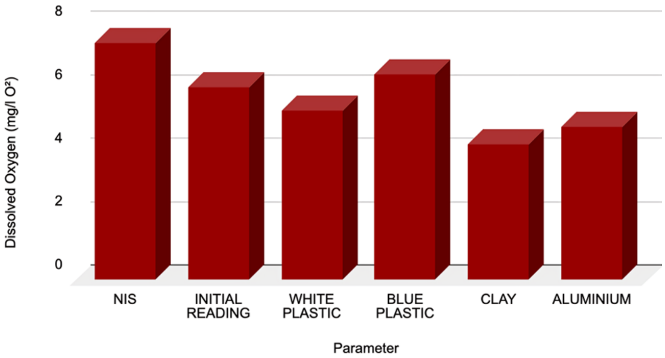

Figure 7. DO variations for selected containers (Source: Authors' own elaboration)

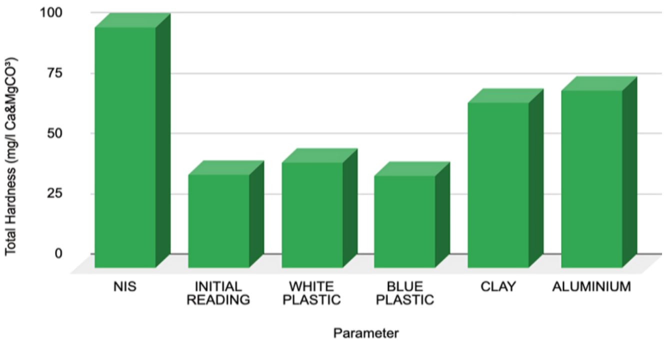

Figure 8. Total hardness variations for selected containers (Source: Authors' own elaboration)

the ideal range (> 7.50 mg/L) can promote anaerobic bacterial growth, the implications for long-term water storage may be of greater concern in terms of taste and odor, as well as the potential for biofilm formation.

Total hardness

The total hardness increased in the clay (68.64 mg/L) and aluminum (73.82 mg/L) containers, compared to the initial reading of 38.85 mg/L, as shown in **Figure 8**. While still below the NIS limit of 100 mg/L, the significant increase in hardness in these materials suggests the leaching of minerals into the water. Hard water can contribute to scaling in plumbing and appliances, but it is generally not a health concern.

The total chloride content of the water remained relatively stable after storage, suggesting that the materials did not significantly affect chloride levels.

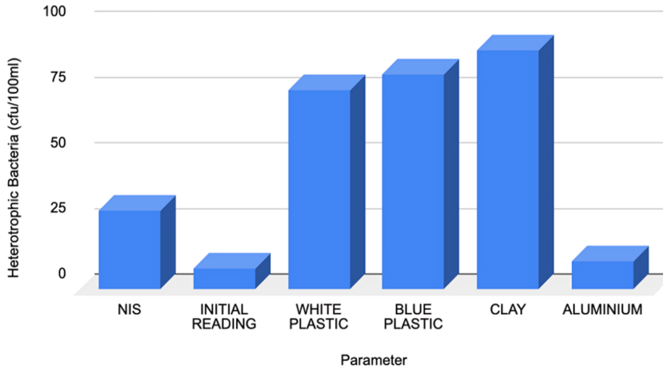

Figure 9. Heterotrophic bacteria for selected containers (Source: Authors' own elaboration)

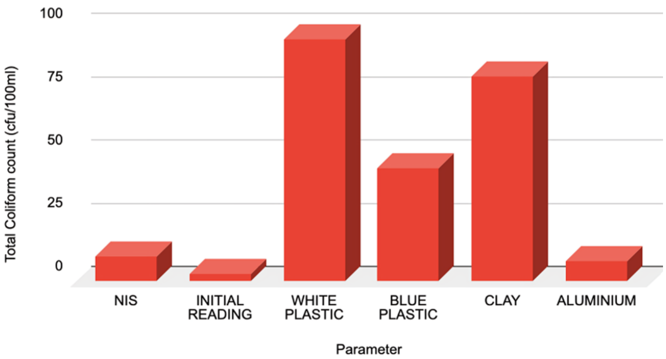

Figure 10. Total coliform count for selected containers (Source: Authors' own elaboration)

Bacteriological Parameters

Heterotrophic bacteria

Bacteriological analysis revealed substantial growth of heterotrophic bacteria, particularly in the clay container (91 cfu/100 mL), followed by the blue plastic (82 cfu/100 mL) and white plastic (76 cfu/100 mL) containers. The aluminum container had the lowest bacterial count at 11 cfu/100 mL, as shown in **Figure 9**.

Total coliform count

Similarly, total coliform counts were highest in the clay container (81 cfu/100 mL), while the aluminum container showed the lowest contamination (8 cfu/100 mL), as shown in **Figure 10**.

The results of this study expose the potential risks associated with the use of certain storage materials for potable water. Clay containers, in particular, were found to be more prone to the leaching of contaminants and microbial growth. This could be attributed to the porosity of the clay containers.

Aluminum containers also showed evidence of metal leaching and microbial proliferation. While plastic containers generally performed better in terms of contaminant release, they still exhibited increases in turbidity, conductivity, and microbial counts. These findings suggest that careful consideration should be given to the choice of storage materials, particularly in regions with limited access to treated water.

Table 4. WQI (before storing)

Parameters	CI	SI	AW	RW	VI	QI (CI/SI)	QI × 100	IS (RW × QI)
pH	6.47	8.50	4	0.173913	7	0.35330	35.330	6.144348
Turbidity, NTU	0	5	1	0.043478	0	0	0	0
Conductivity, S/cm	139.50	1,000	2	0.086957	0	0.13950	13.950	1.213043
Zinc, ng/IZn	0	5	2	0.086957	0	0	0	0
Manganese, mg/1 Mn	0.01	0.10	2	0.086957	0	0.10000	10	0.869565
Iron, mg/1 FE	0.28	0.30	1	0.043478	0	0.93333	93.333	4.057971
TDS, mg/1	90.28	500	3	0.130435	0	0.18136	18.136	2.365565
DO, mg/1 O_2	6.10	5	4	0.173913	14.6	0.88540	88.540	15.398260
Total hardness, mg/1	38.85	100	1	0.043478	0	0.38850	38.850	1.689130
Total chloride, mg/1 Cl	23.99	100	2	0.086957	0	0.23990	23.990	2.086087
Heterotrophic bacteria	8	30	1	0.043478	0	0.26666	26.666	1.159420
Total			23	1				34.983390

Note. WQI = 34.983390 (good)

Table 5. Plastic (white) WQI after storage

Parameters	CI	SI	AW	RW	VI	QI (CI/SI)	QI × 100	IS (RW × QI)
pH	5.10	8.50	4	0.173913	7	1.26667	126.667	22.029040
Turbidity, NTU	1.60	5	1	0.043478	0	0.32000	32	1.391304
Conductivity, S/cm	118	1,000	2	0.086957	0	0.11800	11.800	1.026087
Zinc, ng/IZn	0	5	2	0.086957	0	0	0	0
Manganese, mg/1 Mn	0.26	0.10	2	0.086957	0	2.60000	260	22.608700
Iron, mg/1 FE	0.76	0.30	1	0.043478	0	2.53333	253.333	11.014490
TDS, mg/1	76.70	500	3	0.130435	0	0.15340	15.340	2.000870
DO, mg/1 O_2	5.35	5	4	0.173913	14.6	0.96454	96.454	16.774610
Total hardness, mg/1	44.03	100	1	0.043478	0	0.44030	44.030	1.914348
Total chloride, mg/1 Cl	22	100	2	0.086957	0	0.22000	22	1.913043
Heterotrophic bacteria	76	30	1	0.043478	0	2.53333	253.333	11.014490
Total			23	1				91.686990

Note. WQI = 91.686990 (very poor)

Water Quality Index Before and After Storage

WQI provided an important approach to assess overall water quality. This helped to gauge how the water measures against standard values and offers a clear indication of its suitability for consumption. We present WQI data for water before and after storage in different materials (plastic, clay, and aluminum), showing significant differences across the various containers and timeframes.

Water quality index before storage

Before storage, WQI of the water was 34.98, indicating "good" water quality. This initial value reflects compliance with most NIS (NIS 977:2017), with only a few deviations. For instance, the initial iron content (0.28 mg/L) was near the threshold limit (0.3 mg/L), but this was not enough to negatively impact the overall WQI. Additionally, the water displayed low bacterial contamination, with heterotrophic bacterial counts of 8 cfu/100mL and total coliform counts within acceptable limits, as shown in **Table 4**. This initial reading serves as the baseline against which the impact of different storage containers can be assessed.

Plastic containers (white and blue)

After storage in white plastic, WQI increased dramatically to 91.69. According to WQI, this is "very poor" water quality. This shift is primarily due to substantial increases in several key parameters. The pH dropped to 5.1, which is significantly below the NIS minimum of 6.5. Manganese concentrations spiked to 0.26 mg/L, far exceeding the acceptable limit of 0.1 mg/L. Iron levels reached 0.76 mg/L, more than twice the NIS limit, further contributing to the degradation of water quality. Also, heterotrophic bacteria counts increased to 76 cfu/100 mL, as shown in **Table 5**.

For blue plastic, a similar trend was observed with a WQI of 78.87, also classified as "very poor." The key differences compared to white plastic are slightly elevated turbidity and a higher bacterial load (82 cfu/100 mL), as seen in **Table 6**. These results suggest that color may not significantly impact the overall water quality, but the plastic material itself likely contributes to both chemical leaching and bacterial proliferation.

The "very poor" WQI for both plastic containers implies that storing potable water in plastic, particularly over extended periods, results in significant degradation in water quality. The leaching of metals like manganese and iron, along with bacterial growth, raises concerns about the suitability of plastic containers for water storage, particularly in regions where alternative storage methods are unavailable. These conditions are detrimental to human health, as prolonged consumption of contaminated water can lead to various health complications.

Clay container

WQI for water stored in the clay container was 76.97, which is also classified as "very poor." The key factors that contributed to this low rating included the turbidity that increased to 4 NTU, nearing the NIS limit of 5 NTU. Iron levels reached 0.42 mg/L, again exceeding the NIS limit. The

Table 6. Plastic (blue) WQI after storage

Parameters	CI	SI	AW	RW	VI	QI (CI/SI)	QI × 100	IS (RW × QI)
pH	5.10	8.50	4	0.173913	7	1.26666	126.666	22.028990
Turbidity, NTU	2.60	5	1	0.043478	0	0.52000	52	2.260870
Conductivity, S/cm	117	1,000	2	0.086957	0	0.11700	11.700	1.017391
Zinc, ng/IZn	0	5	2	0.086957	0	0	0	0
Manganese, mg/1 Mn	0.16	0.10	2	0.086957	0	1.60000	160	13.913040
Iron, mg/1 FE	0.52	0.30	1	0.043478	0	1.73333	173.333	7.536232
TDS, mg/1	76.05	500	3	0.130435	0	0.15210	15.210	1.983913
DO, mg/1 O_2	6.50	5	4	0.173913	14.6	0.84375	84.375	14.673910
Total hardness, mg/1	38.26	100	1	0.043478	0	0.38260	38.260	1.663478
Total chloride, mg/1 Cl	22	100	2	0.086957	0	0.22000	22	1.913043
Heterotrophic bacteria	82	30	1	0.043478	0	2.73333	273.333	11.884060
Total			23	1				78.874930

Note. WQI = 78.874930 (very poor)

Table 7. Clay container WQI after storage

Parameters	CI	SI	AW	RW	VI	QI (CI/SI)	QI × 100	IS (RW × QI)
pH	5.20	8.50	4	0.173913	7	1.2000	120	20.869570
Turbidity, NTU	4	5	1	0.043478	0	0.80000	80	3.478261
Conductivity, S/cm	141	1,000	2	0.086957	0	0.14100	14.100	1.226087
Zinc, ng/IZn	0	5	2	0.086957	0	0	0	0
Manganese, mg/1 Mn	0.07	0.10	2	0.086957	0	0.70000	70	6.086957
Iron, mg/1 FE	0.42	0.30	1	0.043478	0	1.40000	140	6.086957
TDS, mg/1	91.65	500	3	0.130435	0	0.18330	18.330	2.390870
DO, mg/1 O_2	4.30	5	4	0.173913	14.6	1.07290	107.290	18.659130
Total hardness, mg/1	68.64	100	1	0.043478	0	0.68640	68.640	2.984348
Total chloride, mg/1 Cl	22.99	100	2	0.086957	0	0.22990	22.990	1.999130
Heterotrophic bacteria	91	30	1	0.043478	0	3.03333	303.333	13.188410
Total			23	1				76.969710

Note. WQI = 76.969710 (very poor)

Table 8. Aluminum container WQI after storage

Parameters	CI	SI	AW	RW	VI	QI (CI/SI)	QI × 100	IS (RW × QI)
pH	4.90	8.50	4	0.173913	7	1.40000	140	24.347830
Turbidity, NTU	2.40	5	1	0.043478	0	0.48000	48	2.086957
Conductivity, S/cm	115	1,000	2	0.086957	0	0.11500	11.500	1
Zinc, ng/IZn	0	5	2	0.086957	0	0	0	0
Manganese, mg/1 Mn	1.80	0.10	2	0.086957	0	18	1,800	156.521700
Iron, mg/1 FE	0.51	0.30	1	0.043478	0	1.70000	170	7.391304
TDS, mg/1	74.43	500	3	0.130435	0	0.14886	14.886	1.941652
DO, mg/1 O_2	4.85	5	4	0.173913	14.6	1.01560	101.560	17.662610
Total hardness, mg/1	73.82	100	1	0.043478	0	0.73820	73.820	3.209565
Total chloride, mg/1 Cl	21.99	100	2	0.086957	0	0.21990	21.990	1.912174
Heterotrophic bacteria	11	30	1	0.043478	0	0.36666	36.666	1.594203
Total			23	1				217.668000

Note. WQI = 217.668000 (unfit for consumption)

heterotrophic bacteria count increased to 91 cfu/100 mL, indicating significant microbial growth during storage, as captured in **Table 7**.

The use of clay containers for water storage presents mixed outcomes. While clay may not leach harmful chemicals as seen in plastic, its porous nature fosters microbial growth, which presents a health risk. Additionally, higher turbidity levels could reduce water clarity and contribute to the buildup of organic matter and pathogens. Clay containers, though traditional in some regions, may require additional treatment, such as filtration, to ensure safer drinking water.

Aluminum container

The aluminum container showed the most alarming results, with a WQI of 217.67, categorizing the water as "unfit for consumption." The primary contributors to this dismal quality were the manganese levels, which skyrocketed to 1.8 mg/L, far above the acceptable limit of 0.1 mg/L. This is a clear indication of metal leaching from the aluminum container itself, suggesting that prolonged storage in aluminum could release hazardous metals into the water. Heterotrophic bacteria remained low at 11 cfu/100 mL, indicating minimal bacterial contamination.

However, the severe chemical contamination, especially with manganese, outweighs the relatively lower microbial content. However, as shown in **Table 8**, the Iron levels also exceeded the limit at 0.51 mg/L, further degrading water quality.

Water stored in aluminum containers should be avoided for human consumption, as the significant leaching of metals like

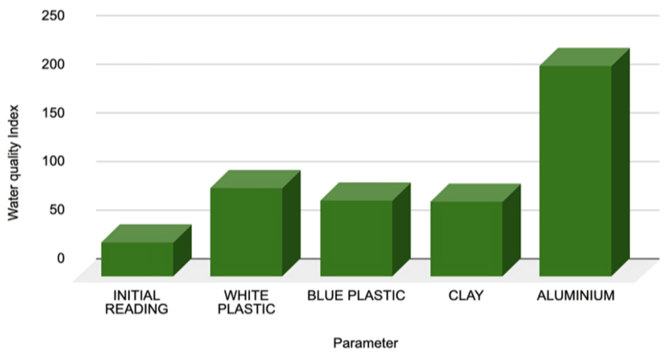

Figure 11. Summary of WQI results (Source: Authors' own elaboration)

manganese poses serious health risks, including neurological damage and other toxic effects, especially in sensitive populations such as children and pregnant women. Despite its relatively lower bacterial contamination, the chemical composition of water stored in aluminum containers renders it unsafe. **Figure 11** shows the summary of WQI results.

CONCLUSION

This study reveals critical insights into a pressing public health concern. With increasing global demand for safe drinking water, the manner in which containers affect water quality is of paramount concern. In this work, the effects of storage materials–white plastic, blue plastic, clay, and aluminum–were carefully analyzed for their influence on the three most important water quality measurements, including total hardness, BOD, and microbial contamination. Based on the results obtained from the research, it can be concluded that the aluminum container has the highest WQI value (217.668), indicating the poorest water quality among the tested containers. This suggests that water stored in aluminum containers may pose a higher risk to human health due to poor water quality parameters. Both white and blue plastic containers yielded "very poor" water quality after storage, with chemical leaching (manganese, iron) and microbial contamination (high bacterial counts) being the primary concerns. While both of these containers have lower WQI values compared to aluminum, they still indicate water quality concerns that should be addressed. These containers are unsuitable for long-term potable water storage without additional treatment. The clay container has the lowest WQI value (**76.96971**), suggesting relatively better water quality compared to the other containers. While chemical contamination was less severe compared to plastic, the microbial risks make this an unsuitable option for storing water intended for direct consumption. The total hardness, alkalinity, BOD, and nitrate decreased over the storage period in the plastic container, while the total coliform count significantly increased over the storage period. Studies from other scholars show that with increasing time of storage, the total coliform count will decline in value due to the absence of food required for biodegradation. However, the deviations in physio-chemical properties such as pH, turbidity, and heavy metal concentrations indicate that certain materials (plastic and aluminum) may not be ideal for prolonged water storage due to chemical leaching. The consequences of this work reach out beyond academicism into practice in public health and in environmental policy. The evidence offered warrants a reassessing of current water storage strategies, especially in areas where drinking safety water is not readily available. Stakeholders, including policymakers, health officials, and community leaders, must prioritize the adoption of safer storage materials to mitigate health risks associated with contaminated water. Further research is needed to explore the long-term impacts of storage materials on water quality and to develop strategies for mitigating the risks associated with the use of certain materials. Additionally, promoting public awareness about the importance of safe water storage practices can help to reduce the risk of waterborne diseases.

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