ZIBELINE INTERNATIONAL™
PUBLISHING

Earth Sciences Malaysia (ESMY)

DOI: http://doi.org/10.26480/esmy.02.2023.83.95

ISSN: 2521-5035 (Print)
ISSN: 2521-5043 (Online)
CODEN: ESMACU

REVIEW ARTICLE

ASSESSMENT AND EVALUATION OF STORAGE VESSEL'S IMPACT ON PHYSICOCHEMICAL PROPERTIES OF BOREHOLE WATER FOR IRRIGATION AND DOMESTIC USE SUITABILITY

Akpa Chibuike[a*], Njoku Chima[a], Mark Ngozi Nwoye[a], Agbo Blessing[b]

[a]Ebonyi State University, Abakaliki. Nigeria.
[b]Alex Ekwueme Federal University, Ndufu-Alike Ikwo. Ebonyi State, Nigeria
**Corresponding Author Email: akpachibuike@gmail.com*

ARTICLE DETAILS

Article History:

Received 04 January 2023
Revised 11 February 2023
Accepted 17 March 2023
Available online 20 March 2023

ABSTRACT

The impact of storage vessels on stored water quality changes and how it can influence plant growth, and human health through irrigation and domestic uses has been evaluated. The water was collected from the same borehole source at Ebonyi State University and stored in vessels made of plastic, metal, calabash, and clay pot. The samples were tested in the laboratory to ascertain the physiochemical quality of the water. The following ions Cd, Pb, Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, and Cl^{-} were identified in each of the storage vessels which vary from the values of the controlled sample and were below their respective WHO permissible limits, except Cd which is significantly higher than WHO limit (>0.0003mg/l). The variation in qualities (odour, taste, colour, and metal concentration) of stored samples implies a significant influence of storage vessels on water quality. The pH range changed to slight alkali and hardness ranges from 160 to 330 mg/l after storage. The non-uniformity of each of the tested parameters among the samples indicated that each vessel had a different degree of impact on water quality during storage. The irrigation parameter and domestic use assessment showed some level of the potential risk to crops and humans mostly indicated by the MAR of calabash and Cd concentration respectively. The significant decrease in Cl^{-} after storage suggests Cl decay, this enhances quality deterioration as microbial growth can be accelerated. The research conclusively noted that water quality deterioration is not an isotropic result of storage vessel influence but an integral impact of storage culture and geogenic factors' influence on the water before and during storage and varying environmental constraints.

KEYWORDS

Borehole, Storage Vessel, Water Quality, Irrigation Qualities, Domestic Use, Heath Risk.

1. INTRODUCTION

Water is known to be a very important and life-sustaining resource to humanity and their related activities which have been considered essential for the survival of all organisms and plants (Nwoke et al., 2019). This in conjunction with the characteristics of water as a solvent for many solutes needed in the body and environment contaminating elements exacerbates the risk associated with poor water quality, since water has been known to be vital in the metabolic processes of living things. Across the globe, groundwater has relatively turned out to be the most dependable source of water supply for both public and private usage (domestic and industrial daily requirements) (Obasi et al., 2022; Akpa et al., 2022). The non-availability of municipal water supply facilities by government agencies and the growing human population have enhanced water scarcity, which has occasioned water storage practice as an option to cushion the scourge (Obasi et al., 2022; Akpa et al., 2022).

Inconsistency in the power supply is a known challenge among developing countries such as Nigeria and has contributed to the poor water supply network in the study area (Kuma et al., 2014). These direct and indirect effects of water supply shortage to the populace, through water scheme outlets owned by governments, institutions, and/or individuals have accelerated the practice of storing water in the area as in other parts of the globe to meet up with daily needs of water usage. This practice is more in the remote rural communities where there is little or no portable water source, and areas face with the challenge of water schemes and borehole failures (like Abakaliki Urban), relegating the dwellers to source their water from ephemeral streams, ponds, and abandoned mine pits (in most villages). Therefore, it has become a common practice to store rainwater, borehole water, stream water, and other sources of water that can be fetched and stored in large containers to ensure continuity in supply during the period of scarcity. This practice spelled risk as recent findings by researchers, have shown that the quality of these stored water is usually not the same with time, indicating a possible influence of the storage vessel(s) in their deteriorating qualities (Manga et al., 2021; Nwoke et al., 2019; Njoku et al., 2018; Adeleke, 2012; Slavik et al., 2020; Packiyam et al., 2016).

The World Bank report, documented that the proportion of the world's population having access to securely managed drinking water services has been on increase, even before the adoption of SDG (goal six) 2030 (World Bank, 2019). Not with standing, these efforts has been influenced by anthropological and user practices which have underscored the attainment of sustainable quantity in water resources. These quality deteriorations arising from storage vessels and storage practices have contributed to the problems facing Sustainable Development Goal six (SDG), which focuses on addressing universal issues of poor water quality supplies, and equitable access to free and innocuous drinking water

Quick Response Code	Access this article online	
	Website: www.earthsciencesmalaysia.com	**DOI:** 10.26480/esmy.02.2023.83.95

Cite The Article: Akpa Chibuike, Njoku Chima, Mark Ngozi Nwoye, Agbo Blessing (2023). Assessment and Evaluation of Storage Vessel's Impact on Physicochemical Properties of Borehole Water for Irrigation and Domestic Use Suitability. *Earth Sciences Malaysia, 7(2): 83-95.*

resources. Such that the world still faces the visible crisis of poor water quality, which threatens the well-being of humanity, their productive capacity, and efficiency (World Bank, 2019). Human health and well-being require acceptable quality and quantity of water, as one of its critical dependent parameters (CDCP-NCEZID, 2020; WHO, 2011). For many years now, attention has drifted from just water availability to the availability of quality water and the anthropological activities which appear to have negatively influenced water quality hence engendering its deterioration more than proportionally to the population and economic growth (Manga et al., 2021; Boretti and Rosa, 2019). Perhaps the adoption of efficient storage practices/facilities may contribute to a reliable improvement in water quality assurance.

Good quality water must have acceptable chemical, physical, biological, and radiological characteristics, based on local and widely-acceptable international measuring standards, such as World Health Organization (WHO). Booker defined potable water as one in which the physiochemical and bacteriological characterizations are within the WHO-specified limits (Booker, 2014). Research had shown that the total percentage of available water in the globe which satisfy the definition of Booker's specification is miniature relative to the global water supply quotient (Nala and Jagals, 2013; Ogbozige et al., 2018). Because human activities coupled with the type and nature of the storage facility have further reduced the quality of the little available water when supplied, hence exposing the water to relative continuous contamination (Manga et al., 2021). This defines another focal point on water quality issues as the influence of the distribution systems and storage facilities on physical and chemical properties, stability, and/or alteration of the stored water over a while which depend on the purpose of usage (Eyankware et al., 2020; Obasi and Akudinobi, 2020; Nwoke et al., 2019; Njoku et al., 2018; Dodoo, et al., 2006).

The storage interval in storage facilities has been considered one of the most important factors affecting water quality degradation (Potgieter et al., 2021; Nwoke et al., 2019). Because the vessels can harbour debris accumulation, hence resulting in in-house microbial contamination within the storage facilities following the user practices such as where households do not clean up their storage tanks for a long interval (Manga et al., 2021; Akuffo et al., 2013). Though the storage vessels often are enclosed structures, there could be other numerous access points and user practices that can become entry pathways for debris and contaminants (USPEA, 2002). These pathways include but are not limited to; rooftop access of hatches and appurtenances, sidewall joints, unhygienic storage vessel, and vent and overflow piping, which are not from geogenic factors (Nwoke et al., 2019; Ogbozige et al., 2018).

The purpose of water storage could be for any of the following applications; irrigation agriculture, drinking water, fire suppression, agricultural farming (plants and livestock), food processing, and chemical manufacturing (Obianyo, 2020; Duru et al., 2013). Low-quality water plays a vital role as a mechanism for the spread of diseases, indicating the relationship between healthy living, water sanitation, and quality (according to a report on Water Tank-Lining) (Duer, 2006; Chalchisa et al., 2017). Across developing countries, high morbidity, increase in death numbers, disease outbreaks, and health problems have been attributed in many cases to poor water quality, limited water availability, sanitation, and/or poor hygiene practices (Obasi, and Akudinobi, 2019, 2020; Nwoke et al., 2019; Eyankware et al., 2016; Obasi et al., 2022).

An effort to mitigate the above pressing scourge has been ongoing to create an environment conducive to improving access to portable water. Others are providing relatively low-cost and effective household water treatment options, improvement and educating the masses on hygiene, sanitation, and proper use of storage facilities (Slavik, et al., 2020). Since water quality reappraisal has indicated that quality deterioration problems in stored water are not just characterized based on sanitation parameters only but as an integral function of microbiological, chemical, or/and physical qualities alterations which could be enhanced by storage vessels makeup (Adeleke, 2012; Raphael and Brown, 2011; Slavik et al., 2020; Packiyam et al., 2016).

In Ebonyi State, commonly used water storage containers are made of plastic, metal/steel, and clay. Some of these materials have been sanctioned with respect to their use for water storage by some standards organizations such as the Standard Organization of Nigeria (SON) (Scott, 2020; Philip and Efiong, 2013). Also, manufacturers of these storage vessels usually do not state the maximum retention and shelf life of water stored in them before it could experience quality change (Ogbozige et al., 2018). Relatively, water scarcity in Ebonyi State is eminent, as there has not been municipal water supply by government-owned water schemes in the past eight years within the entire state. This relegates the populace to depend on borehole water (groundwater sources) which sourcing has been challenging following rampant borehole failures in the area occasioned by underlying litho-units (geology) of the area dominated by indurated shale (Obasi et al., 2022; Akpa et al., 2023).

This amount to water supply shortage which has foisted the dwellers to adopt water storage approaches to manage the water scarcity challenge in the area. Since water storage and re-use of rainwater and other sources of water can reduce demand on the municipal water supply, and possibly make the resource (water) readily available, particularly for non-potable uses (toilets, laundry, and gardening) but the glaring question remains how safe stored water could be over a defined period of storage in correlation to storage culture and facilities. Therefore the fundamental aim of this work is to assess the storage vessels and user culture impact on borehole water suitability for domestic and agricultural purposes in the study area. This is a source of concern as many people are now opting to invest in water storage tanks to collect water from different sources for domestic use or commercial purposes and to cushion the impact of water scarcity ravaging the area.

2. REVIEW OF STORAGE VESSEL'S IMPACT ON WATER QUALITY

United Nations projected that nearly six (6) billion people globally are likely to face scarcity of clean water by 2050, this accentuates the critical need to reappraise sources of water contamination for the available healthy water (United Nations, 2018; Slavik et al., 2020; Boretti and Rosa 2019). Water storage facilities have been identified as one of the cardinal problems contributing to water contamination in the world; hence several studies have investigated the impact of storage systems on water quality. These impacts of storage material on water quality have been evaluated and correlated with certain user cultures on stored household water quality for consumption (Nnaji et al., 2019; Mohanan et al., 2017; Douhri et al., 2015; Lemke and DeBoer, 2012; Schafer, 2010; Agensi et al., 2019; Holt, 2005; Ziadat, 2005). The storage vessels can harbour several pathogens once the environmental condition and chemistry of the water are conducive for their breeding/replication, this can cause different diseases and illnesses. Hence increasing the household water contamination level with the corresponding risk of spreading waterborne diseases and many infectious outbreaks is a threat to humanity (Khan and Al-Madani, 2016).

The type of vessels used for storage highly influences the water quality over time. This follows their interaction and reactivity with mineral elements in the water hence degrading its quality. The obvious decline in the quality of water supplied can be credited to contamination at different stages of distribution and storage (Al-Bahry et al., 2011, 2009). This is in line with the observation of Raphael and Brown on plastic vessel, that its quality deterioration is relative to its exposure to the sun (Raphael and Brown, 2011). This storage facility influence suggests a threat to the projection of the world bank 2019 concerning SDG goal six of 2030. This heightened the need for storage vessels and user culture reappraisal. Manga et al. (2021) posits that to date, there is no single study documented in the literature, that comprehensively evaluates the tank features concerning user practices in accessing household water contamination factors. Providing such comprehensive knowledge will aid researchers and policy-making in mitigating the impact of storage vessels on household water quality and educative background for the citizenry on best storage practices. The three (3) problems captured by Manga et al., (2021) rose to the cardinal questions in environmental and storage water management practices across the globe (Manga et al., 2021).

- What is the correlation between the features of storage vessels and user practices' impact on household water quality?
- How do the features of storage vessels and user practices affect household water quality?
- Can anything be done to mitigate the effects of storage vessel features and use practices on water quality?

In a bid to answer the above questions they concluded; that a multivariate contamination prediction model should be developed that can combine all the vessel features, maintenance, and user practices to determine the best matrix for safe storage of water at the household level. This must consider the economic implications of chosen tank type(s) through life cycle costing and cost-benefit analysis. Ziadat reappraises the impact of storage tanks in residential homes on drinking water quality compared to it the water source, this study would have brought about a radical revolution in defining water quality and its storage effect but its inability to integrate analysis of major anions, cations, and certain PHEs limit the scope (Ziadat, 2005). However, they found that the water in storage tanks had higher ionic concentrations compared to the sources, perhaps rusting could be a possible cause since most of the tanks are vulnerable to rusting. A related observation made by Graham and VanDerslice, redefines the effectiveness of household large water storage vessels/tanks in safeguarding the quality of drinking water in El Paso County, Texas, which indicated that the water from the tanks was generally of poor quality (Graham and VanDerslice, 2007).

Schafer and Mihelcic disclosed that storage impacts on water quality are likely to be affiliated with water temperature differences inside the storage vessels (Schafer and Mihelcic, 2012). This suggests that vessel designs could be a factor in water quality alteration during storage. Though it may not wholesomely initiate all the quality change, user practice and cleanness culture may contribute viciously; mostly if the tanks are not completely emptied during use or cleaning (Schafer and Mihelcic, 2012). Apart from physical and chemical variations in water quality which result during storage, there are usually microbial content alterations. A group of researchers through examination of water stored in glass-reinforced-plastic, polyethylene, and galvanized iron showed that all water storage tanks affirmed microbial regrowth with high values of the microbial total count, but the regrowth varied with the type of the water storage vessels (Al-Bahry et al., 2013). He isolated Coliforms from all vessels but abundance in glass-reinforced plastic. A similar result was obtained by on the assessment of drinking water quality in storage tanks in Ethiopia being positive for total coliforms and fecal coliforms presence (Chalchisa et al., 2017).

Though some water samples might have been contaminated microbiologically from the sampling point, high temperature after storage up to 23.1 °C has been found to increase the number of fecal coliforms in storage tanks (Chalchisa et al., 2017). Certain storage tanks have indicated contamination with heterotrophic bacteria; with 80% of coliforms, and 30 % containing fecal coliforms, but indicated the absence of E. coli (Manga et al., 2021; Al-Ghanim et al., 2014). Elsewhere about 60 % of the tanks evaluated recorded algal counts exceeding 103 unit/l (Home Plus Water, 2022; Manga et al., 2021). The absence of some delicate microbes and the abundance of coliforms suggested that microbial growth in storage vessels is defined by environmental conditions that support the thriving and replication of such organisms during storage. This increase in microbial presence in water after a certain interval of storage results from water storage vessel surface interactions which usually encourage microbial growth differently, hence the influence of storage facilities on municipal water quality is crucial (Al-Ghanim et al., 2014). Contamination usually occurs as a result of the storage facility(ies) infrastructural deterioration; hence facilitating the entry of particulate matter or other non-potable substances into water (Chalchisa et al., 2017). Water stored in an unhygienic manner can be re-contaminated resulting in waterborne diseases. This clearly explains why the rate of water bore disease is alarming despite all concerted efforts by governmental, and non-governmental organizations and individuals to provide clean water to the masses.

However, none of the above workers have properly correlated their findings to the human health risk via domestic use and possible hazard faced by plants when such low-quality water are used for irrigation. Therefore, the main objective of this study is to assess the physicochemical qualities of borehole water in Ebonyi State University, Abakaliki stored in different water storage vessels, which are used by the University Community both for irrigation processes by the faculty of Agricultural science students of the institution. Such that this work focuses on identifying the physical and chemical properties of the water stored in different vessels and taking cognizance of whether water quality deteriorates in storage containers for a given time; and through that, determining which vessel is most suitable for water storage to preserve it from quality deterioration, the effect on soil and plant when used for irrigation purposes.

3. MATERIAL AND METHODS

The materials and methods adopted in this study followed certify scientific approach for analysis and research as discussed below. Apparatus used include; measuring cylinders, beakers, micro-pipette, burettes, volumetric flasks, funnel, test tubes, Stopwatch, thermometer, oven, plastic bottles, Erlenmeyer flask (different sizes), electronic mill, refrigerator, filter papers, stirrer; other are potentiometric digital pH meter and conductivity meter. The main reagent used are; Buffer solution, Pb $(NO_3)_2$, HCl, $KMnO_4$, Distilled water, and Nitric acid (HNO_3). The determination of electrical conductivity (EC) of water samples was achieved via a pocket-sized dissolved solids and conductivity meter with temperature compensation (TDS & EC hold, ±2%) made by Griffin Company, USA. The colour was determined using Lovibond (S1000) comparator made by Tinton LTD. The total solids were determined using a weighing balance (FA/JA series) a product of HANNA LTD, England, and a Steam bath (GA942-041) produced by Gallen Kamp Group of Companies Canada. A Pocket-sized pH meter (pH,) made by HANNA LTD, England respectively.

However, Atomic Absorption Spectrophotometer (AAS 500) made by Fredonia LTD, USA was used in determining the concentration of selected metals (heavy metals) after digesting the sample. These physicochemical parameters, which include pH, colour, odour, carbonate, total solid, and total dissolved solids (TDS), were analyzed following the standard method of the American Public Health Association (APHA, 2005, 2012; MacCrady, 2011). Potassium, Cadmium, Sodium, Magnesium, Chloride, and Lead, were determined by the atomic absorption spectrophotometer (AAS) method. The selection of sampled ions is due to their enrichment in the groundwater of the area and their associated health risk (for example Pb, Cd, and Mn) when their safe limit is exceeded.

3.1 Sampling and Laboratory Analysis

Water samples were collected from CAS Campus boreholes (Campus with Law Faculty, Agricultural Science Faculty, and Post Graduate School of Ebonyi State University Abakaliki). The students and Lecturers of these Faculties mostly Agriculture and Natural Resources Management, Ebonyi State University, Abakaliki source their water used for various experiments and irrigation of their crops, and other uses by resident staff and students for their domestic usage. The water was stored for 28 days (four weeks) in a calabash, clay pot, metal vessel, and plastic container. Twenty-eight days were chosen as a period of assessment as the water storage for irrigation and domestic uses usually do not exceed the said period in the study area.

The sample collection was done in the morning using disposable sterile hand gloves but before that storage vessel has been washed with distilled water and dried before sample collection, and rinsed during the same sample to be collected at the point of collection. Also, the control sample of water from the borehole was collected at the same time as those stored in the vessel for analysis which helps in determining whether there are parameter changes after the storage period. Water stored in all containers was placed outside. This was done to reflect actual field conditions as the practice is in most the farms where water is being used for a diverse purpose and also being common household practice in south-eastern Nigeria culture mostly among ruler dwellers. The correctness of the physiochemical results was assessed by applying the following relationship (equation 1) of the analyzed samples expressed in Mg/L.

$$\%\ \text{Parameter} = \frac{Individual\ Parameter}{Total\ Parameter} \times 100\% \qquad (1)$$

The contamination factor (CF) and pollution index (PLI) of the elements were calculated using the mathematical expressions given by Hakanson (1980) and Tomlinson et al. (1980) (equations 2 and 3) respectively.

$$CF = \frac{C_n}{C_b} \qquad (2)$$

$$PLI = \sqrt[n]{CF_1} + CF_2 + CF_3 +, \ldots.., + CF_n \qquad (3)$$

The assessment of the suitability of the water sample after the storage period were achieved through the application of the various mathematical simulations as presented in table 1 (equation 4 to 7), to appraise the impacts of these storage vessels on chemical properties and their effects on humans and plants. The result was later correlated to standard regulatory bodies/organizations such as the world health organization permissible limit standard for drinking water qualities (WHO, 2011).

Table 1: Equation for Assessing the Irrigation Indices Water (all calculated in Meq/L)

Parameters	Equation	Equation Number	Reference
Sodium percentage (Na%)	Na % = $\frac{Na \times 100}{Ca+Mg}$	4	Doneen, 1964)
Magnesium adsorption ratio (MAR)	MAR = $\frac{Mg \times 100}{Ca+Mg}$	5	Raghunath, 1987)
Soluble Sodium Percentage (SSP)	SSP = $\frac{Na+K \times 100}{Ca+Mg+Na+K}$	6	Richards, 1969), Todd, 1980)
Domestic Use (Mg/L)	$Ca^{2+} + Mg^{2+} - HCO_3^-$	7	Durfor and Becker, 1964)

4. Result and Discussion

The comprehensive result obtained from the laboratory analysis is presented in Table 2 as the effect of different storage materials on selected water physiochemical parameters (physical properties) for defining water qualities. Similarly, Table 3a shows the result arising from the effect of different storage materials on selected water chemical properties whereas Table 3b presented a summary of statistical values of chemical parameters evaluated from the stored samples.

4.1 Water Quality Alterations and Associated Health Risks

The total solid (TS) varies considerably for metal, clay pot, calabash, and plastic vessels as follows 0.061, 5.46, 8.20, and 0.04 mg/l respectively (Table 2). Since the water sample were all from the same source and collected at the same time, it implies that TS varies uniquely with a wide range relative to the storage vessel, in the following order calabash > clay pot > Metal > plastic (decrease order) or plastic > metal > clay pot > calabash (increasing order). The increase in metal vessel TS may have resulted from rusting of the material/vessel. A group researchers earlier reported non-improvement in TS concentration in uncoated steel metal tanks (Ogbozige et al., 2015; 2018). The samples in metal, plastic, and clay pots were all odourless whereas calabash has an objectionable odour (Table 2), which corresponds to alteration influenced by storage vessel and environment.

The groundwater source rock (Asu River Shale) in the study area is rich in sulfide minerals which can easily introduce sulphide compounds into the water (Obasi and Akudinobi, 2020; WHO, 2011; Kimbrough et al., 1999). Sulphide can enhance an objectionable odour in water during storage and can aggravate bacteria growth hence threatening human and plant health. The Asu River Group (AGR) shale is highly carbonaceous with high organic material content which usually enhances odour when the water source from the rock is stored for some time. The groundwater of the area is salty and has indicated an excess of the following mineral elements; Cl, Na, Mg, K, and/or S, presence of these metals can induce odour, colour, and taste change and accentuating microbial growth within the storage vessel relative to natural changing storage environmental condition(s) (Obasi and Akudinobi, 2020; Ukpai, 2018).

4.2 Total Dissolved Solid and Electrical Conductivity

Electrical conductivity (EC) values of the metal, clay pot, calabash, and plastic sample were 682 µS/cm, 692µS/cm, 638.2 µS/cm, and 590.10 µS/cm respectively (Table 2), which correspond to clay pot > metal > calabash > plastic. The high values of EC recorded here are also influenced by the geology of the aquifer (fractured indurated marine shale). All the storage vessels showed EC and TDS record values lesser than WHO standard (1000 µS/cm) and (500 mg/l) respectively (WHO, 2011). From the classifications of the EC, the stored water samples fall within excellent to good envelopes (Figure 1b and Table 4a) (Eyankware et al., 2020). The EC has a relatively proportional relationship with TDS in each of the water storage vessels (Table 2 and Figure 1a), though the TDS is controlled by the concentration of mineral elements in the water sample.

Table 2: Effect of Different Storage Materials on Selected Water Physical Properties.

Storage Materials	Color	Odour	Electrical Conductivity (EC)	TS	TDS (mg/l)
Metal	Amber color	Odourless	682	0.061	55.60
Clay pot	Colourless	Odourless	692	5.46	75.15
Calabash	Yellowish	Objectionable	638.2	8.20	62.70
Plastic	Colourless	Odourless	590.10	0.04	43.01
WHO	-	-	1000	500	1000
Control Sample	Colourless	Odourless	586	0.038	38.2

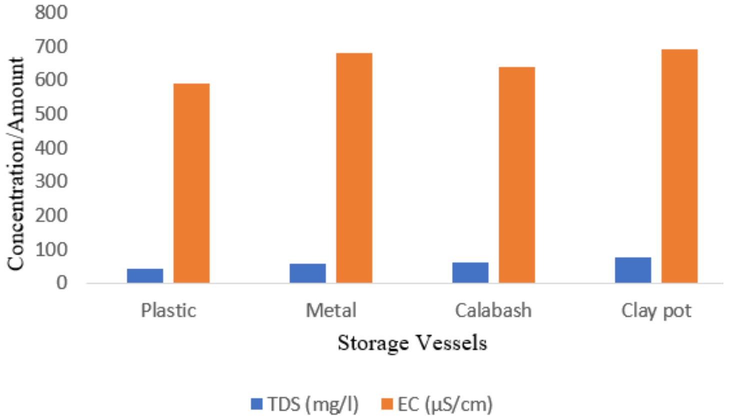

Figure 1a: The Correlation of TDS and EC in respective Storage Vessels

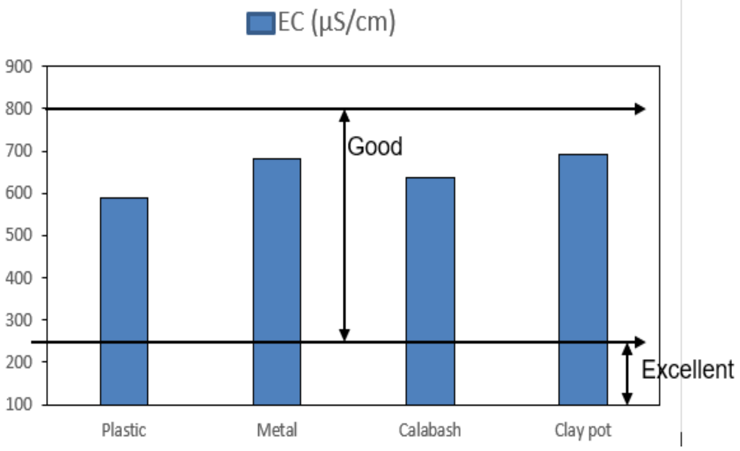

Figure 1b: Chart of EC against Storage Vessels

Relative to colour change, plastic, and clay pot samples do not change colour after the storage period, the metal vessel shows a slight colour change (Amber colour) while the calabash displayed a significant colour change (Yellowish, Table 2). Most times, the water and storage vessel age may affect water quality deterioration during storage such that the initial properties of the water will be altered; TS, TDS, EC, pH, colour, and ionic content of the water, however high levels of TDS in some tanks could more of the tanks being old (Al-Ghanim et al., 2014). Water hardness is a function of the Mg^{2+} and/or Ca^{2+} content of the water. The result obtained indicated hardness except for the clay pot sample which is very hard (Table 3a & b; Table 4a & b; Figure 2a & 2b), according to Sawyer and McCarty's hardness scheme (Sawyer and McCarty's, 1967). The total hardness (TH) classification scheme are; TH < 75 is soft water, 75 ≥ TH ≤ 150 is moderately hard, while TH value within 150 to 300 is hard, and TH > 300 is regarded as very hard (Sawyer and McCarty, 1967) (Table 2, 4(a-b) and Figure 2a&b). The interaction of the water with clay minerals present in the clay pot used for the storage might have led to an increase in the concentration of Mg^{2+} or Ca^{2+} ions hence the clay pot showing high hardness. The correlation of TH and TDS have a linear relationship (Table 4a, Figure 2a), an increase in TDS brings about a compensative increase in TH because both are controlled by the presence of dissolved ions.

Table 3a: Effect of Different Storage Materials on Selected Water Chemical Properties.

Storage Material	pH	Ca^{2+}(mg/l)	K^+ (mg/l)	Na^+(mg/l)	Mg^{2+}(mg/l)	Cl^-(mg/l)	Total hardness (TH)
Metal (M)	8.60	1.54	0.395	0.91	0.63	0.24	160.00
Clay pot (CP)	8.10	1.45	0.480	0.67	0.21	0.23	330.40
Calabash (CAL)	7.80	1.64	1.334	0.96	2.65	0.27	190.00
Plastic (P)	7.60	1.86	0.415	0.57	0.78	0.25	210.40
Control Sample	5.78	1.40	0.301	0.61	0.20	0.29	156
WHO	6.5-8.5	75	12	200	20	250	500

Table 3b: Statistics Description of Physicochemical Analysis of Water Samples of The Storage Vessels.

Parameter	Min	Max	Ave	WHO (2011)	
				DL	PL
pH	7.60	8.60	8.025	6.50	8.5
EC	590.10	692	650.58	N/A	1000
Cl	8.20	9.62	8.728	200	250
Na	0.57	0.96	0.778	N/A	200
Ca	1.45	1.86	1.623	N/A	12
Mg	0.2	2.65	1.068	20	100
Cd	0.039	0.18	0.082	0.001	0.003
K	0.395	1.334	0.656	N/A	12
Na%	13.01	32.91	23.33%	N/A	N/A
MAR	19.10	72.85	43.193	N/A	N/A
SSP	18.56	31.54	24.54	N/A	N/A

Where all values in mg/L except pH and EC (μS/cm), DL maximum desirable limit, PL permissible limit, and N/A not available

Table 4a: Irrigation Water Quality Characteristics Are Used to Categorize the Sampled Water Relative to Storage Vessels.

Parameter	Ranges	Classes	Storage Vessel	Reference
TH	< 75	Soft		Sawyer and McCarty, 1967
	75-150	Moderate		
	150-300	Hard	M, CAL, P	
	> 300	Very hard	CP	
MAR	< 50	Suitable	M, CP, P	Raghunath, 1987
	> 50	Unsuitable	CAL	
TDS	< 300	Excellent	M, CP, CAL, P	Freeze and Cherry, 1979
	300-600	Good		
	600-900	Fair		
EC	< 250	Excellent		Eyankware et al., 2020
	250-750	Good	M, CP, CAL, P	
SSP	< 50%	Suitable	M, CP. CAL, P	Eyankware et al., 2022
	> 50%	Unsuitable		
CF	< 1	Low Concentration		Hakanson, 1980
	1 ≤ CF < 3	Moderate Concentration		
	3 ≤ CF < 6	Considerable Concentration		
	CF ≥ 6	Very Concentration		
PLI	PLI < 1	No Pollution		Tomlinson et al., 1980
	1< PLI < 2	Moderate Pollution		Ganiyu et al., 2021
	2 < PLI < 3	Heavy Pollution		
	3 < PLI	Extremely Pollution		

Table 4b: The Summary of Percentage Difference in Concentrations of Analysed Parameter in each Vessel Sample Relative to that of Control Sample after Storage Period

Storage Vessels	Ca^{2+} (%)	K^+ (%)	Na^+ (%)	Mg^{2+} (%)	Cl^- (%)	pH (%)	Total Hardness (%)
Metal	10	31.23	49.18	215	-17.24	48.79	2.56
Clay pot	3.57	59.47	9.84	5	-20.69	40.14	111.54
Calabash	17.14	343.19	57.38	1225	-6.9	34.95	21.8
Plastic	32.86	37.87	-6.56	290	-13.79	31.49	34.62

CAL = calabash vessel, CP = clay pot vessel, P = plastic vessel, and M = metal vessel

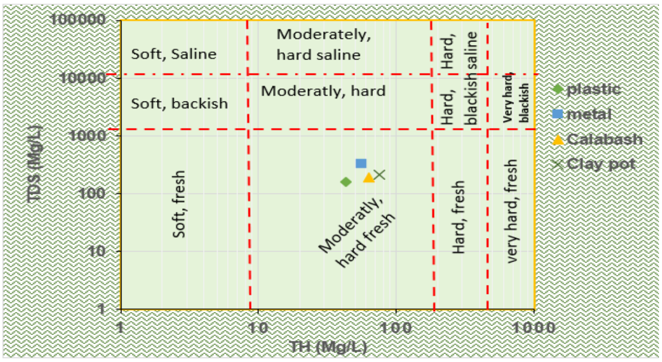

Figure 2a: Plot of TDS against TH for Water Quality Characterization

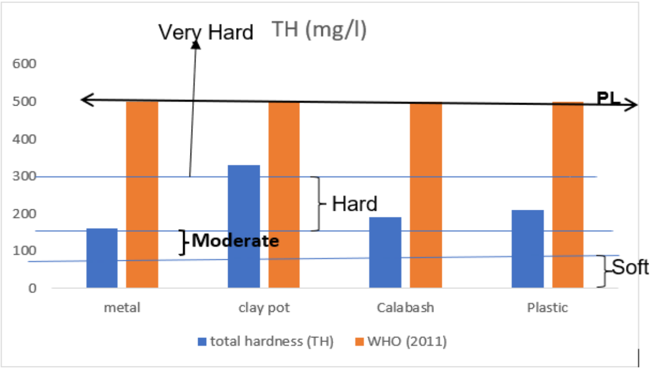

Figure 2b: Chart of TH and WHO against Storage Vessels

The pH was slightly alkaline with a range of 7.6 to 8.6. The lowest and highest pH values were recorded in plastic (7.6) and metal (8.6) respectively (Table 3a), and an average of 8.025 across the samples. The percentage (%) alkalinity of the samples trend follows; metal > Clay pot > Calabash > Plastic with corresponding values of 22.86%, 15.71%, 11.43 %, and 8.57% respectively (Table 4b). Abakaliki water has been reported to be mostly acidic, which is also reflected by the control sample before storage (Table 3a) (Obasi and Akudinobi, 2020; Obasi et al., 2022). Therefore the slight increase in pH observed results from storage vessel influence, which is most likely explained by alkaline hydrolysis caused by a reaction between water and the clay mineral surface interaction since the host rock, from which the borehole is being recharged is fractured indurated shale (rich in clay minerals).

Hem stresses the importance of water pH as an indication of water quality and usually provides important information regarding its geochemical equilibrium (Hem, 1985). Though Subba and Krishna assert that pH has no direct effect on human health, but (Subba and Krishna, 1991) noted that all biochemical reactions are sensitive to variations in pH (Subba and Krishna, 1991). Though there is a health-based guideline for pH, however, its variations can enhance quality deterioration relatively such as odour, colour, and taste (NIS, 2007; WHO, 2017; Egbueri and Mgbenu, 2020). Also, water pH and TDS does not have any significant correlation with the heavy metals in water and this usually suggests differences in the origins /source of aquifer unit(s) (Mgbenu and Egbueri, 2019; Barzegar et al., 2018; Ukah et al., 2019). They (pH and TDS) are influenced by geogenic processes rather than anthropogenic point sources which characterized the level of heavy metal concentration in an environment (Ukah et al., 2019; Egbueri 2019; Obasi et al., 2023). Therefore, pH does not determine metals present in water except for those of HCO_3 where the pH variation can induce the conversion of dissolved CO_2 to bicarbonate ion (McDonald 2006; Barzegar et al. 2018; Egbueri 2019).

The pH alteration during storage was the result of carbonic oxide interaction and fluctuation relative to the respiration activities of microbe in the storage vessels and water sample temperature variations. So, the possible decomposition of this unstable compound HCO_3 (highly volatile) in the water is changing environmental conditions, and microbial activities during the storage period contribute to pH fluctuations and hence influence the CO_2 levels of the stored water (Fondriest Environmental, 2013). The inference of metal, clay pot, calabash, and plastic to heat trap under the same environmental condition is not uniform or isotropic as each of the vessels has a different makeup and this may impact pH alteration. Once CO_2 content is altered, the pH value will change depending on the extremity of the change hence, defining the alkalinity or acidity of any stored water. Also, CO_2 is susceptible to daily diurnal variations coupled with the presence of dissolved oxygen. Under normal conditions; when carbon dioxide reacts with water it forms weak carbonic acid which is a volatile and reversible reaction mostly in an enclosed system (see the reaction equation below).

$$H_2O + CO_2 \rightleftharpoons H_2CO_3$$

Also, the carbonaceous enrichment of the fractured indurate Albian Asu River Group shale in Lower Benue Trough provides extra carbon and its oxidizes some elements in the groundwater of the area through the fluid (water) and rock interaction. Perhaps during the reaction when hydrogen ion is being lost (due to its high reactiveness and very light nature), the slight change in equilibrium condition (heat and energy change of the system) will lead to the formation of more $CaCO_2$ which will not just increase the hardness but also affect the pH level. The concentration of these dissolved ions (Ca^{2+}, K^+, Na^+, $Mg^{2+,}$ and Cl^-) ranges from 1.45 – 1.86, 0.395 – 1.334, 0.57 – 0.96, 0.21 – 2.65 and 0.23 – 0.27 mg/l respectively (Table 3a, 3b 4a and 4b). They were all below WHO's permissible limit (Table 3a&b 4a and Fig. 3a-f) (WHO's, 2011).

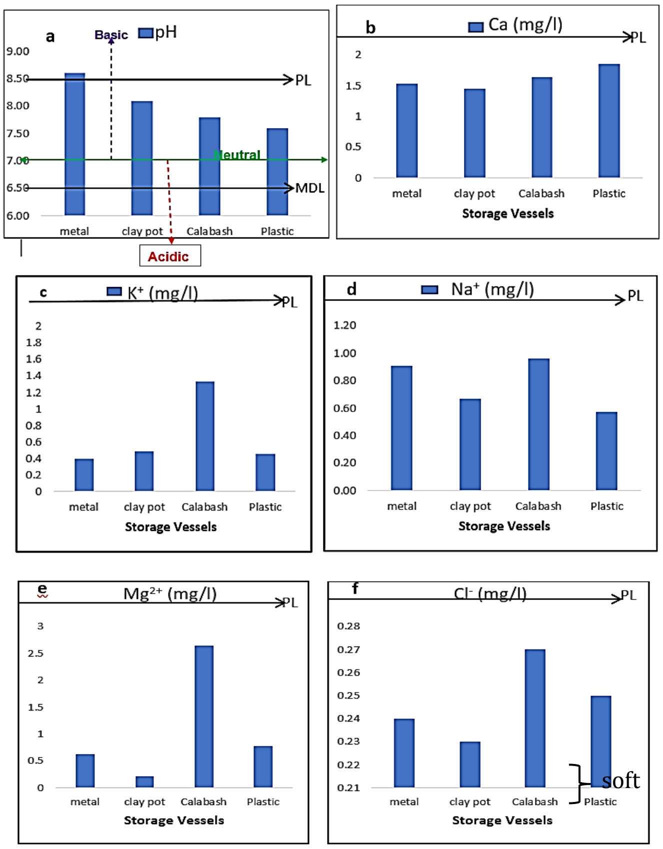

Figure 3: a–f Chart of pH, Ca^{2+}, K^+, Na^+ Mg^{2+}, Cl^-, versus Storage Vessels, respectively. Where MDL is the Maximum Desirable limit, PL is the Permissible limit.

All the vessels' samples show a reasonable percentage (%) increase in concentrations of Ca^{2+}, K^+, Na^+, Mg^{2+}, and Cl^- after the storage period, except for the Na^+ content of the plastic vessel sample which has a negative value (-6.56%). The negative value implies a reduction in Na^+ from the initial concentration before storage (Table 1b & 2b) in the vessel. The variation trend follows; P > CAL > CP > M; CAL > CAL > P > M; CAL > M > CAL > P; CAL > P > M > CP and CAL > P > M > CP for Ca^{2+}, K^+, Na^+, Mg^{2+}, and Cl^- respectively. The elements (Ca^{2+}, K^+, Na^+, Mg^{2+}, and Cl^-) have average concentrations of 1.623, 0.656, 0.778, 1.068, and 8.728 respectively all in Mg/l, and their respective minimum and maximum values are presented in Table 3b. Relatively, Fig. 3a–f shows the significant corelative concentration variation of these ions relative to the storage vessel and their respective permissible limits (Table 3b) after (WHO, 2011). The difference in metal concentration in each of the vessels from that of the control sample is regarded as the integral effect of the storage vessel, environment, and storage culture since the stored samples were from the same source and collected at the same time using the same sampling approach.

The Cl^- concentration unlike other mineral elements revealed appreciable decay in concentration among all the storage vessels. It implies that storage reduces chlorine concentration in the water (Table 4b, Fig. 4). The metal and clay pot samples showed greater Cl^- decay than calabash and plastic samples after storage. The decay in the vessels follows the order of CAL < P < M < CP (Fig. 4a and Table 4b). This further gives an overview of what influences water quality deteriorates, since chlorine which would aid in checkmating microbial activities is on a decline. The microbe and sulphide compounds are the major causes of odour, and colour change outside pH variations, they also influence some of the chemical reactions in the water (Obasi et al., 2022). The reduction in the chlorine content of the stored water is an indication that chlorine decays in water with storage.

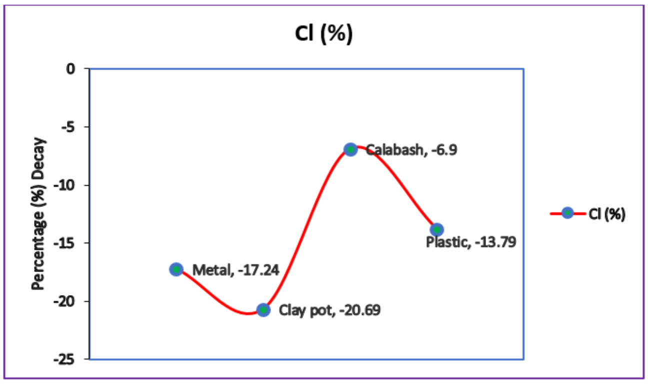

Figure 4: Percentage Chlorine Decay of in the Vessels

According to the factors upon which chlorine decay rates are defined as an integral function of water temperature, nature, and concentration of organic matter in the water, this extends to initial chlorine concentration (and where applicable the number of chlorination) (Powell et al., 2000). But among these factors, the temperature remains the most influential decay factor due to its easy variation relative to environmental changes as well as changes within water supply systems (Karadirek et al., 2016; Laura et al., 2017). This by extension explains why the quality of sealed treated water (bottle and sachet but mostly sachet water) deteriorates after a few weeks of storage even when chlorinated especially when it is exposed to the sun (varying temperature).

These decays are usually accompanied by microbial growth (such as algae and coliforms); this contributes to the general deterioration of water health quality and this can lead to bioaccumulation of toxins in insensitive organs and tissues of humans, animals and when such water is used for irrigation it fouled the food chain with these excess harmful metals and when ingested it double the associated health risk exposure (Lake and Driver, 2002; Melgar et al., 2009 Nowrouzi et al., 2012; Karadirek et al., 2016; Laura et al., 2017; Obasi et al., 2023). Algae breakdown in treated water with high total organic carbon is a nutritional source for coliform regrowth even in the presence of high Cl^- concentration (Lake and Driver, 2002). All of these amount to public health challenges/risks that can lead to waterborne diseases outbreak, suggesting that the direct and indirect impact of storage vessels and storage cultures is a threat to quality water security.

Cadmium (Cd) and lead (Pb) has been listed as part of the most health concerned heavy metals (Obasi et al., 2023). The Pb was below the detection limit in plastic and clay pot vessels whereas its trace was found in the metal vessel while calabash indicated the highest concentration (0.003 mg/l). Similarly, Cadmium(Cd) concentration in the vessels ranges from 0.039 – 0.18 mg/l, in the following sequence calabash > plastic > metal > clay pot. Clay pot and calabash vessels have the lowest and highest Cd concentrations respectively (Table 5 and Fig. 5).

The average Cadmium (Cd) from the four storage vessels is 0.082 mg/l, which is beyond the WHO permissible limit (PL) guideline value of 0.003 mg/L for drinking water (Table 5 and Fig. 5) (WHO, 2011). There is a non-uniformity of Cd concentration among the samples, hence implying that storage vessels, storage culture, environmental storage condition, and/or ion interactions have an impact on its concentration. Though, the natural/geogenic factor usually contributes to Cd concentration in an environment (Obasi and Akudinaobi, 2020; Obasi et al., 2023). Defining the hazard level for the Cd using the following expression (equation 8); When the $H_L < 1$; it implies that such sample does not have any foreseeable health hazard when taken by an individual and its concentration is below the specific WHO permissible limit for safe use, but when $H_L > 1$ it indicates that the consumer of such water will face health risk.

$$\text{Hazard Level } (H_L) = \frac{M_C - W_C}{W_C} \tag{8}$$

Where H_L = Hazard level of the sample, M_C = Cadmium concentration in the sample, and W_C = world Health permissible of cadmium, all in mg/l.

The H_L values of the sample among the vessels after the storage period follow; CAL > P > M > CP (Table 5)., the The cadmium hazard level is at high-risk scope in the analysed sample ranging from 12 to 59, with clay pot and calabash having the least and highest impact respectively (Table 5 and Fig. 5).

Table 5: Effect of Different Storage Materials on Selected Heavy Metals.

Storage Material	Pb (Mg/L)	Cd (Mg/L)	H_L
Metal (M)	Trace	0.054	17.00
Clay pot (CP)	ND	0.039	12.00
Calabash (CAL)	0.003	0.180	59.00
Plastic (P)	ND	0.055	17.33
WHO	0.01	0.003	0.00

ND = Not Detected

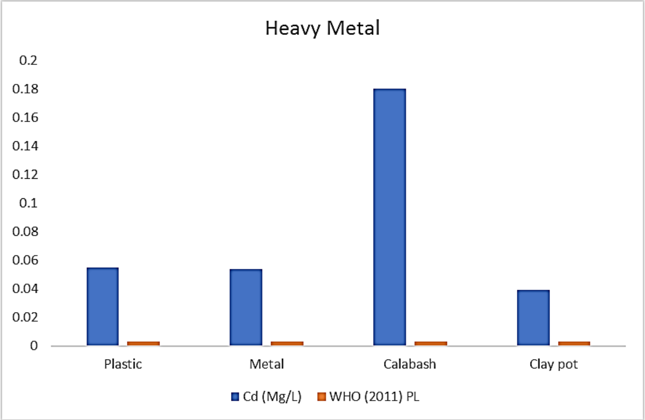

Figure 5: Cd Content and its Correlation to WHO (2011) Permissible Limit

Cadmium has been known to occur naturally in the environment with some notable anthropogenic sources such as the combustion of fossil fuel, incineration of municipal or industrial wastes, or land application of sewage sludge or fertilizer (EPA, 1985; Abdu et al., 2011; Obasi and Akudinaobi., 2020; Obasi et al., 2023). Cadmium mobility in water is an integral interplay of several factors such as pH and organic matter content (Potential for Human Exposure P280). However, the ability of Cd to bind strongly to organic matter affords it the characteristics of being immobilized in most cases, this explains why the calabash sample has the highest concentration and its potent effect on human health (Autier and White, 2004; Obasi et al., 2023). Cadmium in water tends to be more vulnerable following the low pH, Elinder noted that the mobility of Cd decreases with pH (acidic) (Elinder, 1992).

On the horizon of health impact, high Cd intrigues lots of health risks in human organs and jeopardizes some body biochemical activities (Jarup et al., 1998). The health effects resulting from Cd exposure are exacerbated

Cite The Article: Akpa Chibuike, Njoku Chima, Mark Ngozi Nwoye, Agbo Blessing (2023). Assessment and Evaluation of Storage Vessel's Impact on Physicochemical Properties of Borehole Water for Irrigation and Domestic Use Suitability. *Earth Sciences Malaysia, 7(2): 83-95.*

following the inability of the human body to excrete it, leading to reabsorption by the kidney hence, limiting its excretion quotient (Obasi and Akudinaobi, 2020; Obasi et al., 2023; Pendias-Kabata and Pendias 1984; Davies et al., 2005). Obasi and Akudinaobi, (2020) concluded that cadmium exposure can cause renal dysfunction and kidney disease, and excess exposure can even cause disturbances in calcium metabolism, as well as the formation of renal stones and hypercalciuria (Jarup et al., 1998; Jungers et al., 2008). Today Cd is classified to be a group 1 carcinogen element and one of the troubling potential health risk elements to humans by the International Agency for Research on Cancer (Chen et al., 2022).

From the result obtained, exposure of the populace and plants (through irrigation) to lead (Pb) through water storage in metal, plastic, and clay pot is relatively insignificant, as Pb was not detected except for calabash which has 0.003mg/l and is below WHO permissible guideline value of 0.01mg/l (Table 5) (WHO, 2011). This result shows that the Pb content in groundwater is more related to the water source and anthropogenic interference with the environment rather than the storage vessel and culture except in special cases, like activities undertaken during storage can introduce Pb into the water. The traces of lead in metal vessels could be the result of metal content, oxidation, and/or storage culture. Apart from the natural composition of Pb, low pH, salinity, and presence of CO_2 in the water sources cause faster dissolution of lead in water, which will result in high motivity of lead in water especially, at low pH (Obasi and Akudinaobi, 2020; ATSDR, 2007).

The contamination factor (CF) used suggests risks associated with storing water in different vessels. The result indicated different echelons (low-high) of contamination quotient relative to assessed metals (Mg, Cl, K, Ca, Cd, and Pb). Generally, Cadmium (Cd) indicated a very high degree of contamination (CF ≥ 6) in all the vessels which are pelt risk of Cd. The contamination factor (CF) of Mg, Cl, K, Ca, and Pb was of low contamination class (CF < 1) in all the storage vessels sampled according to Hakanson's (1980) classification (Tables 4a & 6 and Fig. 6). The PLI was all very high across the storage vessels (PLI > 3) influenced by high PLI values of Cd (Tables 4a & 5 and 6). The integral high level of CF and PLI resulted from the excess concentration of Cd in the water generally (Tables 3 & 4, Fig. 6).

Table 6: Contamination Factor and Pollution Index of Respective Metals in Each Storage Vessel

	Contamination Factor (CF)			
Elements	Metal	Clay pot	Calash	Plastic
Na	0.00455	0.00335	0.0048	0.00285
Mg	0.0315	0.0105	0.1325	0.039
Cl	0.00096	0.00092	0.00108	0.001
K	0.032917	0.04	0.0375	0.0375
Ca	0.020533	0.019333	0.021867	0.0248
Pb	0	0	0.3	0
Cd	18	13	60	18.33333
	Pollution Index (PLI)			
PLI	29.77	25.11	54.45	30.01

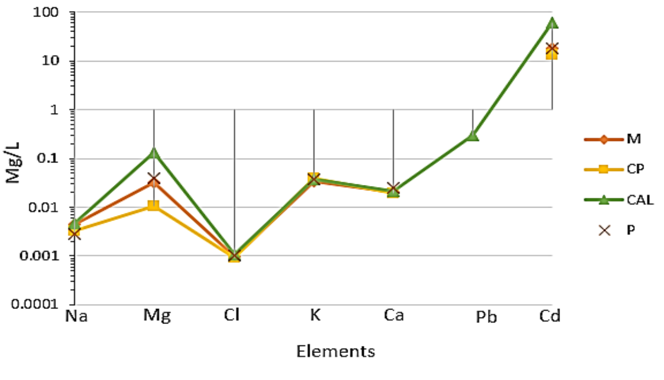

Figure 6: Schoeller plot of Contamination factor of each of the elements in respective storage Vessels

4.3 Impact of Stored Water Quality Alteration on Domestic Utility

The major factors that define the quality of stored water for domestic uses are; suggestive vessel material, the retention time of water in the vessels, user storage practice, and environmental condition of storage. For instance, deterioration noticed in some of the parameters such as pH, TDS, total solids, EC, TH, cadmium, magnesium, sodium, and chloride concentrations are combined effects of the above-listened factors. The above results and discussion showed that storage facilities affect water quality over time. From the TH and EC of the water, it was observed that the water sample analyzed for each of the vessels is moderately hard to hard (See Table 2 – 6 and Fig. 2). Relative to odour, samples in metal, clay pot, and plastics were all odourless after storage period but calabash sample has objectionable odour. The Colour of the clay pot and plastic sample remained unchanged, metal and calabash showed amber and yellowish colour respectively (Table 2). Cadmium content is very high and was above the WHO permissible limit of 0.003mg/l (Table 6 and Fig. 8) impacting high CF (WHO, 2011).

Its health impact has been discussed in section 4.5.1. This high Cd content gives an overview of the possible contributing sources to the prevalence of cancer records and its continuous increase in the state (Heyes, 1997). Since this water is also used for irrigation, it contributes also to heavy metal accumulation in soils and crops, alteration of soil structure, and mineral element concentration, a process that kept on encircling (Obasi et al., 2023). On a general note, water storage tanks affect domestic water quality due to vessel/material, colour, design, location, the elemental composition of the water, and retention time. According to the WHO, most of these metals found in drinking water might be of human health concern after years of continuous exposure (WHO, 2011). And since storage vessels' impact on their quality change implies that the longer the storage of household water, the more the risk matrix due to deterioration hence water stored for a longer time is potentially harmful, and increases the health hazard quotient of the end user.

4.4 Causes of Water Quality Variations

The variation in the physical properties of the water was found to be evident in storage vessels occasioned changing by conditions of the water within the storage vessels. Resultant internal interaction settings such as oxygen, and temperature variation; combined, aggravate the growth of microbes and brought about distinguishable physical and chemical changes in stored water (Goldberg et al., 1994). These variations in the chemical, the physical, and heavy metal content of the samples stored in respective vessels result from the impact of storage materials on the water relative to prevalent environmental storage conditions and geogenic content of the water rather than the vessel effect alone. This follows the fact that water sample stored in the vessels (metal, plastic, clay pot, and calabash) was collected from the same source. The storage vessels play a vital role in water quality defilement, but it's an integral interplay among environmental conditions, storage culture, and composition of storage vessels while keeping in mind that microbes are ubiquitous (Victor, 2019). This explains why the sample in calabash has the most deterioration in quality after the storage period because it was most prone to the above influencing conditions of quality changes.

However, the effect of detention time (that is storage period) cannot be ruled out as a factor that affects the quality of the water, the detention times, might result in excessive water age which can be conducive to microbial growth and chemical changes vis-z-vi extend to physical property change such colour and odour (Chalchisa et al., 2017; Sommer et al., 2017; Purohit, 2017). This increases the contamination factor risk and favours chlorine volatilization within the storage vessels (Graham and VanDerslice, 2007). Excess water age can be caused by underutilization, space interaction, and short-circuiting within the storage vessels (Chalchisa et al., 2017; Nwoke et al., 2019). Accordingly, poor mixing (and stratification) might aggravate the water quality deterioration by creating zones within the storage vessels where the water age will significantly exceed the average water age throughout (Nwoke et al., 2019; Sommer et al., 2017; Purohit, 2017; Rokade and Ganeshwade, 2005).

Hence the distribution systems within the storage facilities where water moves from one facility to another result in exceedingly long water age in the most distant tanks and reservoirs (Nwoke et al., 2019). This indicated that in most cases water quality degradation may not be the consequential result of the type of storage vessel alone but an integral interplay of storage practices by the household (such as the material used in cleaning the vessels before storage and exposure of the stored water to external influence and length of storage period). For example, on one occasion a woman was observed cleaning the drinking-water container with hypo another used an improperly washed and cleaned sacolux paint rubber container which the ruler dwellers use to store water for household use could be dangerous. This practice has serious potential health risks as far as the stored water is concerned and its quality stability.

4.5 Assessment of the Water Quality and its impact on the plant when used for Irrigation Purposes

The percentage sodium content (Na%), Soluble Sodium Percentage (SSP) were calculated alongside with magnesium absorption ratio with equation 4 presented in table 1.

4.5.1 Sodium Percentage (Na%)

The application of Na % in water quality assessment has become an important parameter in evaluating the suitability of surface and groundwater quality for irrigation and other related uses (Mohammed et al., 2017; Eyankware et al., 2022). The value of Na% for plastic, metal, calabash, and clay pots is 15.82 %, 31.01 %, 13.91 %, and 32.58 % respectively which are all suitable with an average of 23.33 % as shown in Tables 3b & 4a. A high concentration of Na% may influence the exchange of Mg^{2+} and Ca^{2+} ions, hence reducing the soil permeability and thereby damaging the drainage system (Eyankware et al., 2020). When Na % excess it creates physiographic drought for the plants, introducing a condition where there will be the presence of water in the soil but the plant couldn't be able to absorb it. The correlation of Na % and EC showed that water samples stored in Plastic fell into the good to permissible class whereas others (Metal, Calabash, and Clay pot) fall within the permissible to doubtful classification (Fig. 7a). From TDS, EC, and SSP results, the waters are good for irrigation purpose despite little alteration of the property arising from the storage culture (Figs. 7a&b and Tables 4a).

4.5.2 Soluble Sodium Percentage (SSP)

The assessment of sodium hazard is highly related to Na^+ concentration which can easily be determined using equation 5 for SSP (Table 1). In the study, SSP ranges from 18.56 to 31.54 % with an average of 24.54% (Table 3b & 4a and Fig. 7b), which can be classified as being good for irrigation purposes (Richards,1969; Todd, 1980; and Eyankware et al., 2022). The result indicated that the storage vessel does not alter the natural chemical composition of water to a significant level that can cause viscous growth impediment for the crops when used for irrigation.

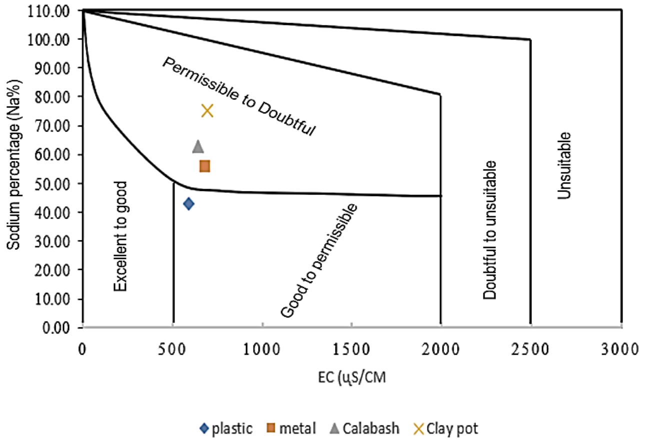

Figure 7a: Samples Classification based on EC and Na % (after Wilcox 1955)

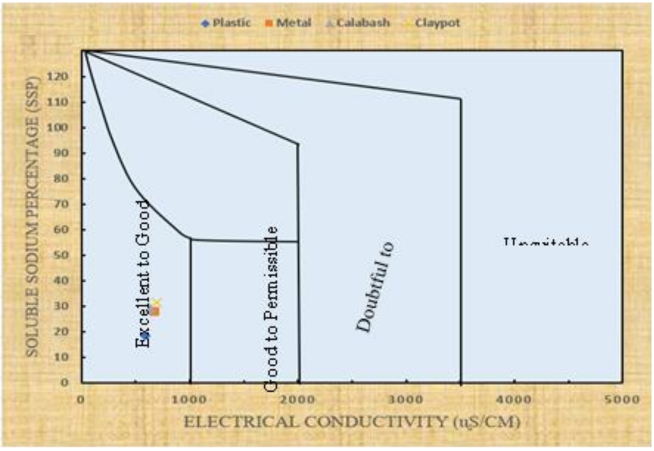

Figure 7b: Wilcox Diagram for Each of the Storage Vessel Samples Irrigation Quality Assessment

The cross-examining ratio of Na^+ and Cl^- (Fig. 8a) indicated calabash and clay pot samples are in an equal line of 1:1, whereas plastic and metal do not have such a relationship implying that ion exchange is a major process influencing water quality under storage and not just storage vessels and environmental influence. However, Fig. 8b indicated that on the points of a 1:1 ratio relationship, the storage vessel influences the water differently, indicating contributing factors of sodium and potassium are not from the same source (no linear relationship) and also not uniform in the storage vessels even though the samples were kept under similar environmental condition; this change suggests the influence of internal condition created within the storage vessel following nature of storage vessels and external environmental changes. It then means that if the condition could be maintained such that ion exchange processes are negligible it can be sure that stored water will likely maintain its quality irrespective of the vessel material used for the storage.

Na^+ versus Cl^- (Fig. 8a) plot indicates that the samples of plastic and metal are below and above the equal relationship line respectively. The high concentration of Na^+ in metal and calabash can be attributed to evaporation as those vessels are more susceptible to heat influence. It is relatively hard to say for sure the parameter that influences the variation of Na + K against the total cation as presented in Fig. 8b, following the lack of relationship co-existing at 1:1 among the storage vessels. However, it indicated that each storage vessel has an impact of non-linear correlation on the water despite the water being collected from the same. This entails that Na^+ concentration relative to total cation content in the storage vessel does not have a linear relationship of rising or decreasing rather the storage vessels have a unique way of altering the concentration based on its makeup and changing conditions.

The SSP together with Na % is an important factor to study sodium hazards and mostly in clayey soil where permeability is decreasing with high sodium concentration. Such permeability decrease in the soil can destroy the soil structure, which will affect the soil drainage and leads to hampering crop growth and reduction in crop production (Omo-Irabor et al., 2018; Eyankware et al., 2022). By extension, the process will amount to physiographic drought even when the water is available at the soil/top layer it could not permeate to the lower layer easily for plant/crop absorption. This will lead to the death of crops and plants that cannot withstand such adverse conditions. Because the local geology of the area also enhances the release of Na^+ aided by the solubility of sodium. Significant sodium content in the sample results could have come from saline water intrusion, and the occurrence of halite, gypsum, and sulphide mineral (sulphide ores) which characterized the Abakaliki area (Kogbe, 1976; Olade and Morton, 1985; Nwajide, 2013). When these minerals come in contact with groundwater they are dissolved and these enhance sodium richness in a water sample and oxidation of sulphide.

4.5.3 Magnesium Absorption Ratio

The magnesium absorption ratio (MAR) was used to assess the interaction of Mg^{2+} and Ca^{2+}, an interaction that could influence the hardness of water which by extension affects plant growth and nutrient absorption relative to soil properties and composition. MAR value for this study was determined using Eq. 6 as shown in Table 1. The value of MAR ranges from 19.10 to 72.85% with an average value of 43.193% as shown in Table 3b.

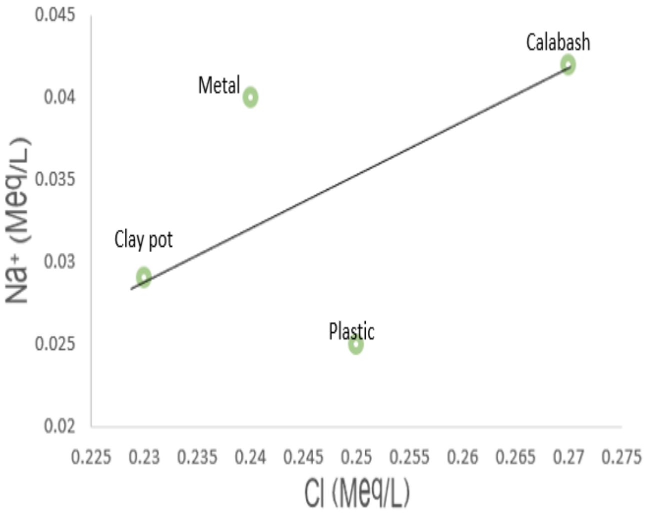

Figure 8a: Correlation between Na^+ and Cl^-

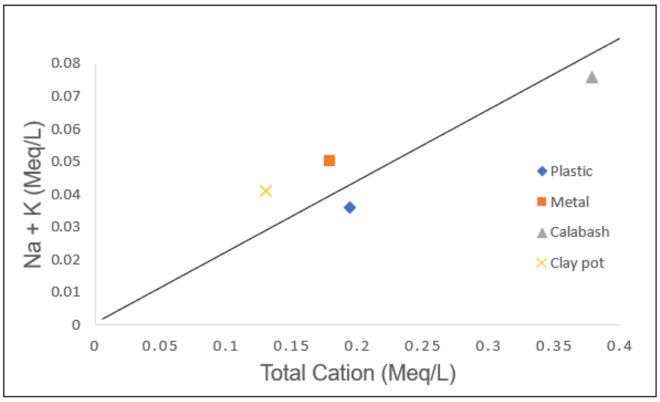

Figure 8b: Correlation between $Na^+ + K^+$ and total cation.

The water sample stored in plastic, metal, and clay pot was below the set limit of 50, hence considered suitable for irrigation, whereas water stored in calabash > 50% hence unsuitable (Table 4a). The MAR helps in predicting, understanding, and determining the significant effect of magnesium content in irrigation water (Fig. 9). Raghunath, (1987) documented that water is considered unsuitable for irrigation if the value of MAR (Mg^+) exceeds 50%. Magnesium and calcium usually maintain a state of equilibrium in groundwater, once this equilibrium relation is altered by an increase of Mg^+, it will accentuate negative effect on plants depending on the percentage of the alteration (See Table 4a and Fig. 9) (Eyankware et al., 2018; 2022). Mg^{2+} and Ca^{2+} are considered an essential tool for water hardness which relatively contributes to water/soil acidity and alkalinity ratio, for instance, a higher concentration of Mg^{2+} in water can affect the soil quality changing it into alkaline nature.

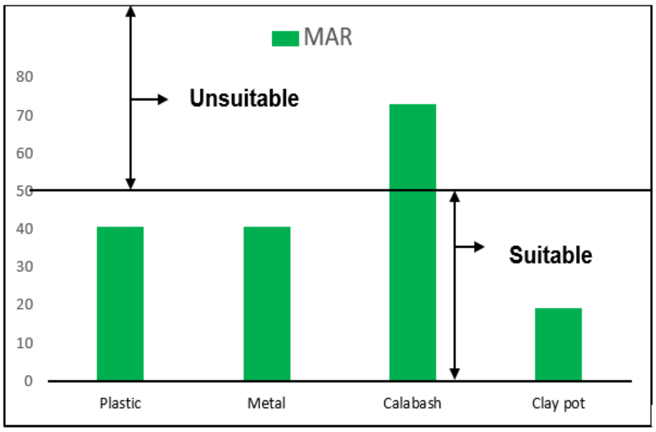

Figure 9: Plot of MAR against Storage Vessels

5. CONCLUSION

The water storage vessels, environment, groundwater source, and storage user practices all contribute to the alteration of stored water quality. Their impact on parameters for domestic and irrigation water suitability for diverse purposes indicated health concerns due to observed water quality alteration. The alternative use of small containers, clay pots, and calabash that can easily be transported from the water sources to their respective homes for water supplies and storage has been indicated to be unsafe. This study conclusively establishes that there is an influence of storage vessels on the quality of water stored in them, noting that stored water quality deterioration is an integral function of many factors rather than storage vessel impact only. Water quality deterioration was accentuated by the interplay of water storage tanks/vessel material, storage period, storage environment, and initial ionic content of the water. Nevertheless, the use of proper cleaning methods and tools; can enhance the reduction of the influence of storage vessels and associate parameters on water quality degradation. However, the problem of water quality may remain intractable if intermittent water supply problems are not addressed, especially in developing countries and rural communities with water scarcity must be provided with accessible water supply points such that SDGs goal six on water sanity could be achieved.

REFERENCES

Abdu, N., Agbenin, J.O., Buerkert, A., 2011. Phytoavailability, human risk assessment and transfer characteristics of cadmium and zinc contamination from urban gardens in Kano Nigeria. J Sci Food Agric., 91, Pp. 2722–2730.

Adeleke, N.B., 2012. Water Storage Pattern in Nigeria. Journal of Public Health and Environmental Research, 8 (3), Pp. 69-78.

Agency for Toxic Substances and Disease Registry (ATSDR) 2007. U.S. Department of Health and Human Services, Public Health Service, Division of Toxicology 1600, Atlanta, GA 30333.

Agensi, A., Tibyangye, J., Tamale, A., Agwu, E., Amongi, C., 2019. Contamination Potentials of Household Water Handling and Storage Practices in Kirundo Subcounty, Kisoro District, Uganda. Journal of Environmental and Public Health, Pp. 1–8.

Akpa, C., Chukwu, C.A., Kelechi, K.O., 2022. Efficiency and limitation of vertical electrical sounding in evaluation of groundwater potential in fractured shale terrain: a case study of Abakaliki Area Lower Benue Trough Nigeria. Environ Monit Assess 195, 158. https://doi.org/10.1007/s10661-022-10700-w

Akpa, C., Nnabo, P.N,. Ani, C.C., Obasi, A.I., Obasi, P.N., Nworie, C.D., 2023. Application of Ground Magnetic Method for Delineation Subsurface Structural Control on Sulphide Ore Deposit in Benue Trough; A Case Study of Ikenyi Izzi. Earth Sciences Malaysia, 7(1), Pp. 07-19. DOI: http://doi.org/10.26480/esmy.01.2023.07.19

Akuffo, I., Cobbina, S., Alhassan, E., Nkoom, M., 2013. Assessment of the quality of water before and after storage. Ghana Int J Sci Technol Res 2(2), Pp. 221–227.

Al-Bahry, S.N., Al-Hinai, J., Mahmoud, I., Al-Musharafi, S., 2013. Opportunistic and microbial pathogens in municipal water distribution systems. APCBEE Proc., 5, Pp. 339–343.

Al-Bahry, S.N., Elshafie, A.E., Victor, R., Mahmoud, I.Y., Al Hinai, J.A., 2011. Opportunistic pathogens relative to physicochemical factors in water storage tank. J Water Health Issue, 9, Pp. 382–393.

Al-Bahry, S.N., Mahmoud, I.Y., Al-Khaifi, A., Elshafie, A.E., Al-Harthy, A., 2009. Viability of multiple antibiotic-resistant bacteria in distribution lines of treated sewage effluent used for irrigation. Water Sci Technol Issue, Water Sci Technol., 60, Pp. 2939–2948.

Al-Ghanim, K., El-Sala, A., Mahboob, S., 2014. Assessment of water quality for some roof tanks in Alkharj governorate. KSA Pakistan J Zool 46(4), Pp. 1003–1012.

APHA 2005. Standard Method for Examination of Water and Wastewater.21thedn. American Public Health Association. Washington D

APHA 2012. Standard Methods for Examination of Water and Wastewater (25th Edition). American Public Health Association, Washington DC, USA.

Autier, V., White, D. 2004. Examination of cadmium sorption characteristics for aboreal soil near Fairbanks, Alaska. J Hazard Mater 106B, Pp. 149–155.

Barzegar, R., Moghaddam, A.A., Adamowski, J., Nazemi, A.M., 2018. Assessing the potential origins and human health risks of trace elements in groundwater: a case study in the Khoy plain, Iran. Environ Geochem Health. https ://doi.org/10.1007/s10653-018-0194-9

Boca, R.P.S.S., Efiong, D.A., 2013. Standard Organisation of Nigeria (SON): A tool for National Development. Daily Trust News Paper, Kaduna, Nigeria. March 17th, Pp. 13-16.

Booker, F.D., 2014. Necessity of Potable Water Storage Facilities. Asian Journal of Water Quality Monitoring, 11(4), Pp. 426-431.

Boretti, A., Rosa, L., 2019. Reassessing the projections of the World Water Development Report. Clean Water 2, Pp. 1

CDCP-NCEZID, 2020. Centers for Disease Control and Prevention, National Center for Emerging and Zoonotic Infectious Diseases, Importance of Water Quality and Testing (https://www.cdc.gov/healthywater/drinking/public/water_quality.html, Accessed on 1st September 2022)

Chalchisa, D., Megersa, M., Beyen, A., 2017. Assessment of the quality of drinking water in storage tanks and its implication on the safety of urban water supply in developing countries. Environ Syst Res 6(12), 1-6. DOI 10.1186/s40068-017-0089-2.

Chen, X.X., Xu, Y.M., Lau, A.T.Y., 2022. Metabolic effects of long-term cadmium exposure: an overview. Environ Sci Pollut Res 29, 89874–89888. https://doi.org/10.1007/s11356-022-23620-6

Davies, B.E., Bowman, C., Davies, T.C., Sellinus, O., 2005. Medical geology: perspectives and prospects. Essent Med Geol, Elsevier Inc., pp 649

Dodoo, S., Neden, D., Jones, R., Smith, J., Kirmeyer, G., Foust, G., 2006. "Comparing Chlorination and Chloramination for Controlling Bacterial Regrowth." J. Am. Water Works Association, 73(7), 80-881–14.

Doneen, L.D., 1964. Water quality for agriculture. Department of irrigation, University of California. Davis. Pp. 48

Douhri, H., Raissouni, I., Tazi, S., Badia, D., 2015. Effect of house storage on water's quality in rural areas of Tangier- Tetuan Region (Morocco). Larhyss J., 24, Pp. 301–314.

Duer, G., 2006. Drinking water quality management through correlation studies among various physicochemical parameters: A case study, International Journal of Environmental Sciences, 1(2), Pp. 253-259

Durfor, C.N., Becker, E., 1964. Public water supplies of the 100 largest cities in the United States. Geological survey water supply, vol. 1812. U.S. Government Printing Office, Washington, p 364.

Duru, M., Amadi, C., Amadi, B., Nsofor, C., Nze, H., 2013. Effect of Different Storage Vessels on Water Quality. Global Research Journal of Science 2(2), Pp. 9-13.

Egbueri, J.C., 2019. Water quality appraisal of selected farm provinces using integrated hydrogeochemical, multivariate statistical, and microbiological technique. Model Earth Syst Environ. https ://doi.org/10.1007/s4080 8-019-00585 -z.

Egbueri, J.C., Mgbenu, C.N., 2020. Chemometric analysis for pollution source identification and human health risk assessment of water resources in Ojoto Province, southeast Nigeria. Applied Water Science, 10, 98. https://doi.org/10.1007/s13201-020-01180-9.

Elinder, C.G., 1992. Cadmium as an environmental hazard. IARC Sci Publ., 118, Pp. 123–132.

Environmental Protection Agency (EPA) 1985. Chemical identity—manganese, tricarbonyl methylcyclopentadienyl. U.S. Environmental Protection Agency, Office of Toxic Substances, Cincinnati

Eyankware, M.O., Akakuru, O.C., Ulakpa, R.O.E., Eyankware, E.O., 2022. Hydrogeochemical approach in the assessment of coastal aquifer for domestic, industrial, and agricultural utilities in Port Harcourt urban, Southern Nigeria. International Journal of Energy and Water Resources.

Eyankware, M.O., Nnabo, P.N., Omo-Irabor, O.O., Selemo, O.I., 2016. Assessment of the effect of anthropogenic activities on hydrogeochemical quality of water resources of Ekaeru Inyimagu and its environs, southeastern, Nigeria. Sky J Soil Sci Environ Manag Nigeria. 5(5), Pp. 33–43.

Eyankware, M.O., Nnajieze, V.S., Aleke, C.G., 2018. Geochemical assessment of water quality for irrigation in abandoned limestone quarry pit at Nkalagu area, southern Benue Trough, Nigeria. Environ Earth Sci 77, 66 https://doi.org/10.1007/s12665-018-7232-x.

Eyankware, M.O., Obasi, P.N., Omo-Irabor, O.O., Akakuru, O.C., 2020. Hydrochemical Characterization of abandoned quarry and mine waters for domestic and irrigation uses in Abakaliki, Southeast Nigeria". Springer – Modelling Earth Systems and Environment. https://doi.org/10.1007/s42108-022-00184-2.

Freeze, R.A., Cherry, J.A., 1979. Groundwater. Prentice Hall, Englewood Cliffs Fondriest Environmental, Inc. "pH of Water." Fundamentals of Environmental Measurements. (2013). Web. < https://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/ > (Accessed on 8 August 2022).

Ganiyu, S.A., Oyadeyi, A.T., Adeyem, A.A., 2021. Assessment of heavy metals contamination and associated risks in shallow groundwater sources from three different residential areas within Ibadan metropolis, southwest Nigeria. Applied Water Science 11:81 https://doi.org/10.1007/s13201-021-01414-4.

Goldberg, J.J., Bramley, A.J., Sjogren, R.E., Pankey, J.W., 1994. Effects of Temperature and Oxygen Tension on Growth of Escherichia coli in Milk, Journal of Dairy Science, 77(11), 3338–3346. doi:10.3168/jds.S0022-0302(94)77275-1

Graham, J.P., VanDerslice, J., 2007. The effectiveness of large household water storage tanks for protecting the quality of drinking water. J Water Health 5(2), Pp. 307–313.

Hakanson, L., 1980. An ecological risk index for aquatic pollution control-a sedimentological approach. Water Res 14:975–1001. https:// doi. org/ 10. 1016/ 0043- 1354(80) 90143-8

Hem, J.D., 1985. Study and interpretation of the chemical characteristics of natural water. Geological Survey Water-Supply Paper, 1473. (http:// www. nativefshl ab. net/ library/ text pdf/ 16621. pdf. Accessed 27 April 2022).

Heyes, R.B., 1997. The carcinogenicity of metals in humans. Cancer Causes Control, 8, Pp. 371–385.

Holt, S., 2005. A survey of water storage practices and beliefs in households in Bonao, Dominican Republic in 2005. Springer, Berlin

Jarup, L., Berglund, N., Elinder, C.,G., Nordberg, G., Vanter, M., 1998. Health effects of cadmium exposure – a review of the literature and a risk estimate. Scandinavian Journal of Work, Environment & Health, 24(1) 1-51.

Jungers, P., Joly, D., Blanchard, A., Courbebaisse, M., Knebelmann, B., Daudon, C., 2008. Inherited monogenic kidney stone diseases: recent diagnostic and therapeutic advances Nephrol Ther. 4(4), Pp. 231-55. doi: 70010.1016/j.nephro.2007.12.005.

Karadirek, I.E., Kara, S., Muhammetoglu, A., Muhammetoglu, H., Soyupak, S., 2016. Management of chlorine dosing rates in urban water distribution networks using online continuous monitoring and modeling. Urban Water Journal, 13 (4), 345–359. https://doi.org/10.1080/1573062X.2014.992916.

Khan, M., Al-Madani, A., 2016. Assessment of microbial quality in household water tanks in Dubai. United Arab Emirates Environ Eng Res 22(1), Pp. 55–60.

Kogbe, C.A., 1976. Paleographic history of Nigeria from Albian Times. In: Kogbe CA (ed) Geology of Nigeria. Elizabethan Publishers, Lagos.

Kuma, D.D., Oruari, A.O., Olatunji, T.Y., 2014. Basic Amenities in Developing Countries. Royaleth Publishers, Jos- Nigeria. Pp. 56-57.

Lake, R., Driver, S., 2002. The role of algae in causing coliform problems within the distribution system. Water Science and Technology: Water Supply 2(4): 105–110 https://doi.org/10.2166/ws.2002.0127

Laura, M., David, F., Dídia, C., José, M., 2017. Integrating water temperature in chlorine decay modelling: a case study, Urban Water Journal, DOI: 10.1080/1573062X.2017.1363249.

Lemke, A., DeBoer, D.E., 2012. Effect of Storage Tank Mixing on Water Quality http://sdarws.com/assets/impactsofmixingonstoragetankwaterquality.pdf).

Manga, M., Timothy, G.N., Lawrence, O., Pamela, A., Hidaya, N., Elizabeth, K., Irene, N., Nathan, K., 2021. The effect of household storage tanks/ vessels and user practices on the quality of water: a systematic review of literature. Environ Syst Res 10(18) 1-26. https://doi.org/10.1186/s40068-021-00221-9.

McCrady, M.H., 2011. Standard methods for the examination of water and waste-water (12th ed.)." American Journal of Public Health and the Nations Health, 56(4), p. 684.

McDonald, J., 2006. Alkalinity & pH relationships. CSTN, pp 392–394

Melgar, M.J., Alonso, J., García, M.A., 2009. Mercury in edible mushroom sand underlying soil: bioconcentration factor sand toxicological risk. Sci Total Environ., 407(20), Pp. 5328–5334.

Mgbenu, C.N., Egbueri, J.C., 2019. The hydrogeochemical signatures, quality indices and health risk assessment of water resources in Umunya district, southeast Nigeria. Appl Water Sci 9(1):22. https ://doi.org/10.1007/s1320 1-019-0900-5 Mohanan, N., Manju, E., Sonia, J., 2017. The effect of different types of storage vessels on water quality. Int J Innov Res Sci Eng Technol 6(10), Pp. 20362–20368.

Mohammed, M.M., Murad, A., Chowdhury, R., 2017. Evaluation of groundwater quality in the Eastern District of Abu Dhabi Emirate, UAE. Bulletin of Environmental Contamination and Toxicology, 98, Pp. 1–7.

Nala, N., Jagals, P., 2013. The Effect of a Water-Hygiene educational Programme on the Microbiological Quality of Container-Stored Water in Households. Water SA 29 (2), Pp. 171-.182.

NIS (Nigerian Industrial Standard). 2007. Nigerian standard for drinking water quality. Nigerian Industrial Standard, 554, Pp. 13–14.

Njoku, C., Alu, M.O., Okoro, M.K., Agwu, J.O., Ngene, P.N., 2018. Evaluation of Selected Physio-chemical Properties and Heavy metal Content of Ebonyi River for Demestic use in Abakaliki Southeastern Nigeria. International Journal of Development and Sustainability, 7 (4), Pp. 1495-1502.

Nnaji, C., Nnaji, I., Ekwule, R., 2019. Storage-induced deterioration of domestic water quality. J Water Sanit Hyg Dev., 9 (2), Pp. 329–337.

Nowrouzi, M., Pourkhabbaz, A., Rezaei, M., 2012. Bioaccumulation and distribution of metals in sediments and Avicenna marina tissues in the Hara Biosphere Reserve, Iran. Bull. Environ. Contam. Toxicol., 89 (4), Pp. 799–804.

Nwajide, C.S., 2013. Geology of Nigeria's sedimentary basins. CSS Press, Lagos.

Nwoke, H.U., Obi, L.E., Quakers, I.I., 2019. Comparative Analysis of Water Quality of Water Stored in Concrete, Steel and Plastic Storage Facilities. International Journal of Scientific Engineering and Science; 3 (6), Pp. 34-38.

Obasi, P., Ekinya, A., Akpa, C., Edene, E., 2022, Characterization of subsurface lithology and aquifer parameters using vertical electrical sounding (VES) for groundwater development in Igbo-Imabana, Southern Nigeria. Advances in Geological and Geotechnical Engineering Research, 4 (3), Pp. 12–31. https:// doi. org/ 10. 30564/ agger. v4i3. 4939.

Obasi, P.N., Akudinobi, B.E.B., 2019. Pollution status of arable soil and stream sediment in the mining areas of Abakaliki, Lower Benue Trough. Springer—Int J Environ Sci Technol. https ://doi.org/10.1007/s1376 2- 019-02337 -z.

Obasi, P.N., Akudinobi, B.E.B., 2020. Potential Health Risk and Levels of Heavy Metals in Water Resources of Lead- zinc Mining Communities of Abakaliki, Southeast Nigeria. Springer- Applied Water Science https //doi.org/ 10.1007/s40808-020-00800-2.

Obasi, P.N., Chibuike, A., Immaculate, N., 2023. Contamination levels and health risk assessment of heavy metals in food crops in Ishiagu area, lower Benue trough South‑eastern Nigeria. International Journal of Environmental Science and Technology, https://doi.org/10.1007/s13762-022-04748-x

Obianyo, J.I., 2020. Effect of storage containers on water quality. Tropical Journal of Science and Technology, 1 (1), Pp. 66 – 73.

Ogbozige, F.J., Adie, D.B., Ibrahim, F.B., 2015. Chemistry of Potable Water During Storage: The North-Western Nigeria Perspective. International Journal of Scientific and Engineering Research, 6 (6), Pp. 549-563.

Ogbozige, F.J., Ibrahim, F.B., Adie, D.B., 2018. Effect of storage time and container material on potable water quality. Ife Journal of Science and Technology, 1 (2), Pp. 59-71.

Olade, M.A., Morton, R.D., 1985. Origin of lead-zinc mineralization in the southern Benue Trough, Nigeria - Fluid inclusion and trace element studies. Mineralium Deposita, 20, Pp. 76 – 80.

Omo-Irabor, O.O., Eyankware, M.O., Ogwah, C., 2018. Integration of hydrogeochemical analytical methods and irrigation parameters in the evaluation of groundwater quality at Ibinta, Southern Benue Trough Nigeria. FUPRE Journal of Scientific and Industrial Research, 2 (1), Pp. 38–49.

Packiyam, R., Kananan, S., Pachaiyappan, S., Narayanan, U., 2016. Effect of storage containers on coliforms in household drinking water. Int J Curr Microbiol Appl Sci., 5 (1), Pp. 461–477.

Pendias-Kabata, A., Pendias, H., 1984. Trace elements in soil and plants, 3rd edn. CRC Press.

Potential for Human Exposure (https://www.atsdr.cdc.gov/ToxProfiles/tp5-c6.pdf) Chapter fiv, Pp. 280.

Potgieter, N., Vanderloo, C., Barnard, T.G., 2021. Co-Existence of Free-Living Amoebae and Potential Human Pathogenic Bacteria Isolated from Rural Household Water Storage Containers. Biology, 10 (12), Pp. 12-28. https://doi.org/10.3390/ biology10121228.

Powell, J.C., Hallam, N.B., West, J.R., Forster, C.F., Simms, J., 2000. Factors which control bulk chlorine decay rates. Water Research, 34 (1), Pp. 117–126. doi:10.1016/S0043-1354(99)00097-4.

Purohit, M.P., 2017. Lake Water Mixing: The Might of The Microorganism? (https://www.dovemed.com/current- medical-news/lake-water-mixing-might-tcan-microorganisms-cause-lake-water Accessed on 30th August 2022).

Raghunath, I.I.M., 1987. Groundwater (2nd ed., pp. 344–369). Wiley.

Raphael, C.M., Brown, L.D., 2011. Oncology of Consuming Overstayed Sachet Water and Bottled Water. Khartoum Medical Journal, 4 (6), Pp. 17-28.

Richards, L.A., 1969. Diagnosis and improvement of saline and alkali soils. In: United States salinity Laboratory Staff Agricultural Handbook No. 60. The United States Government Printing Office, Washington DC

Rokade, H., Ganeshwade, E., 2005. Role of chlorine and chloramines in corrosion of lead bearing plumbing materials. Journal of the American Water Works Association, 96 (10), Pp. 64-82.

Sawyer, C.N., McCarty, P.L., 1967. Chemistry for sanitary engineers (2nd ed., p. 518). McGraw-Hill.

Schafer, C., 2010. Impact of tank material on water quality in household water storage systems in Cochabamba, Bolivia. Springer, Berlin.

Schafer, C., Mihelcic, J., 2012. Effect of storage tank material and maintenance on household water quality. J Am Water Work Assoc., 104 (9), Pp. 521–529.

Scott, 2020. 10 Best Water Storage Containers (Update 2022) Buyer's Guide (https://bestsurvival.org/best-water- storage-containers/)

Slavik, I., Oliveira, R.K., Cheung, P.B., Uhl, W., 2020. Water quality aspects related to domestic drinking water storage tanks and consideration in current standards and guidelines throughout the world – A review, Journal of Water and Health, 18 (4), Pp. 439–463. doi: 10.2166/wh.2020.052.

Sommer, T., Danza, F., Berg, J., Sengupta, A., Constantinescu, G., Tokyay, T., Bürgmann, H., Dressler, Y., Steiner, S,O., Schubert, C.J., Tonolla, M., Wüest, A., 2017. Bacteria-induced mixing in natural waters. Geophysical 779 Research Letters. DOI: 10.1002/2017GL074868.

Subba, R.N., Krishna, R.G., 1991. Groundwater quality in Vishakhapatnam urban area, Andhra Pradesh. Indian Journal of Environmental Health, 33 (1), Pp. 25–30.

Todd, D.K., 1980. Groundwater hydrology, 2nd edn. Wiley, New York, Pp.

516.

Tomlinson, D.L., Wilson, J.G., Harris, C.R., Jeffrey, D.W., 1980. Problems in the assessment of heavy metal levels in estuaries and the formation of a pollution index. Helgol Wiss Meeresunters, 33 (1–4), Pp. 566–575.

Ukah, B.U., Egbueri, J.C., Unigwe, C.O., Ubido, O.E., 2019. Extent of heavy metals pollution and health risk assessment of groundwater in a densely populated industrial area, Lagos, Nigeria. Int J Energ Water Res. https ://doi.org/10.1007/s4210 8-019-00039 -3

United Nations 2018. Water-related diseases. http://www.who.int/water_sanitation_health/diseases/en/. Accessed December, 2022).

USEPA, 2002. Finished Water Storage Facilities; Office of Water (4601M), Office of Ground Water and Drinking Water, Distribution System Issue Paper (https://www.epa.gov/sites/default/files/2015-09/documents/2007_05_18_disinfection_tcr_whitepaper_tcr_storage.pdf, Accessed on September, 4th 2022).

Victor Lage de Araujo, 2019. The Ubiquity of Microorganisms in Earth's' Ecology. Acta Scientific Microbiology, 2 (6), Pp. 158-160.

Water Tank Lining, 2022. (https://gtekresources.com/water-tank-lining Accessed on 28th August 2022).

WHO, 2011. Guideline for drinking water quality recommendations, 4th edn, vol 1. World Health Organization, Pp. 308–39.

WHO, 2017. Guidelines for drinking water quality, 3rd edn. World Health Organization, Geneva

Wilcox, L.V., 1955. Classification and use of irrigation water, Pp. 96. USDA, Circular.

World Bank, 2019. Worsening Water Quality Reducing Economic Growth by a Third in Some Countries: World Bank. https ://www.world bank.org/ en/news/press -relea se/2019/08/20/worse ning-water -quali ty-reduc ingecono mic-growt h-by-a-third -in-some-count ries. Accessed 27th April 2022).

Ziadat, A., 2005. Impact of storage tanks on drinking water quality in Al-Karak Province-Jordan. J Appl Sci., 5 (4), Pp. 634–638.