International Journal of Environment and Pollution Research, 13(1),48-69, 2025
Print ISSN: 2056-7537(pri5nt)
Online ISSN: 2056-7545(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Health Risk Assessment of Heavy Metals in Sachet Water in Federal Capital Territory of Nigeria

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doi: https://doi.org/10.37745/ijepr.13/vol13n14869 Published May 16, 2025

Citation: Makwe E. and Ukah C. (2025) Health Risk Assessment of Heavy Metals in Sachet Water in Federal Capital Territory of Nigeria, *International Journal of Environment and Pollution Research*, 13(1),48-69

Abstract: *The physical, chemical and bacteriological properties of fifteen (Groups A-O) selected sachet water brands sold in Gwagwalada, Nigeria, were analyzed and compared with WHO standard. Physical examination of the samples showed 100% compliance in term of product names, manufacturer's addresses and NAFDAC registration, but 0% compliance on manufacturing date, expiry date, batch number and mineral composition. Results showed that Fluoride (Groups B=1.53mg/l, N=1.51mg/l); Residual chlorine (Groups B=0.32mg/l, K=0.22mg/l, N=0.26mg/l, O=0.22mg/l); Fe (Groups B=0.4mg/l, F=2.5mg/l, H=2.6mg/l, I=3.2mg/l, J=1.3mg/l, L=0.4mg/l) and Pb (Groups F=0.013mg/l, I=0.012mg/l) had concentrations above the acceptable limits in some sachet water brands, while Ca concentration is high in all brands (Groups A-O). Cd, Total coliforms and faecal coliforms were not detected in any of the sachet water brands. ANOVA and student t-tests at significance level $P \leq 0.05$ indicates no statistically significant variation in concentration of tested parameters across the different water samples; also, there is no significant difference between concentration of parameters in individual Groups (A-O) of the water samples and WHO standard. Non-carcinogenic health risk assessment based on concentrations of HMs in the water samples ingested orally indicates that the CDI and HQ were higher in the children compared to adults exposed to the same sachet water brands. Hazard Index (HI) was in the order Ca>Na>Cu>Fe>Cr>Mg>Pb>Zn>Ni>Mn for both adult and children, with Ca, Na, Cu, Fe, Cr and Mg having HI>1 for adults while the children had HI>1 for Ca, Na, Cu, Fe, Cr, Mg and Pb. Cumulative HI of 1489.47 and 2478.48 were obtained for adults and children respectively, with Ca contributing most towards the exposure to non-cancer risks. These results indicate severe exposure to non-carcinogenic health risk for both populations, with the children being more disposed towards non-cancer risks. The result is quite worrisome and presents the need to further collect data for the assessed heavy metals especially for those with HI>1 as there could be likelihood of carcinogenic health risks.*

Keywords: hazard index, hazard quotient, health risk, heavy metals, sachet water

INTRODUCTION

Drinking water safety has become a global public health problem, as over two billion people use drinking water sources contaminated with faeces and other chemicals including arsenic, fluoride, nitrate as well as other emerging contaminants such as pharmaceuticals, pesticides, per- and polyfluoroalkyl substances (PFASs) and microplastics (WHO, 2022a). According to the World Health Organisation (2022b), contaminated water and poor sanitation are linked to transmission of diseases such as cholera, diarrhoea, dysentery, hepatitis A, typhoid and polio. Inadequate or inappropriately managed water and sanitation services expose individuals to preventable health risks.

The increase in human population has increased the demand for potable drinking water, and with the emergence of the sachet or packaged water companies and vendors, it has made access to "clean" drinking water relatively affordable and convenient. Sachet water has become widely accepted in Nigeria and many west African countries due to its affordability, accessibility and general perception of quality by the general public. In a layman's term, sachet water is mostly referred to as 'pure water', being a label it earned from the false perception that sachet packaged water is pure and free from any physicochemical and microbiological contaminants. However, the potability and suitability of sachet water for human consumption have been questioned over the years due to the working environment and unhygienic practices surrounding its production, transportation and storage. Investigations conducted in some major cities in Nigeria and some African countries including Wukari (Kusa & Joshua, 2023), Gboko (Akpen *et al*., 2018), Ibadan (Airaodion *et al*., 2019), Anambra (Emmanuel *et al*., 2022), Kaduna (Eke *et al*., 2022), Malawi (Manjaya *et al*., 2019) and Ghana (Addo *et al*., 2019) on the safety of drinking water has shown that the quality of some sachet water were noted to be doubtful. These observations were based on studies carried out on sachet water samples to ascertain the presence of indicators of faecal contamination, heavy metals and other chemical contaminants.

Drinking water that is fit and suitable for human consumption is expected to meet the World Health Organization standard and be free from physical and chemical substances as well as microorganisms in an amount that can be hazardous to health (Airaodion *et al*., 2019; Makwe *et al*., 2020). It is a known fact that no single method of purification can eliminate 100% contaminants from drinking water. However, water can and should be made safe for consumption within acceptable limits (Denloye, 2004).

Apart from the raw sources of water and the practices surrounding the production of sachet water, the materials (sachets) used for packaging of the water has also become a major source of contaminants in sachet water (Abdel-Rahman *et al*., 2019; Magaji, 2020). The impact of contaminants in drinking water as well as the attendant health risks are important factors that must be considered when evaluating drinking water quality (Onyele & Anyanwu, 2018; Saira *et al*., 2019). The health risk assessment is a tool for assessing the link between the environment and human health that can be expressed quantitatively in terms of hazard degree (Batayneh, 2012; Zhang *et al*., 2023). A proper health risk assessment involves establishing the capacity of a risk source to introduce contaminants into the environment, determining the quality of risk agents that came in contact with the consumer's environment boundaries, and then quantifying the health implications of the contact or exposure (Emmanuel *et al*., 2022). The potential health implications of contaminants in drinking water may be carcinogenic or non-carcinogenic (Masok *et al*., 2017; Kusa & Joshua, 2023) and these can be estimated by assessing the potential hazard risk involved.

Many studies carried out on sachet water in different parts of Nigeria only reported the water quality in comparison to national and international guidelines (Akpen *et al*., 2018; Manjaya *et al*., 2019; Magaji, 2020; Ibe *et al*., 2023) and failed to assess the health risks associated with the consumption of such water. Thus, this study evaluated the quality of some of the most consumed sachet water in Gwagwalada and the health risk associated with the oral exposure to adult and children.

Before the advent of sachet water, the residents of Gwagwalada sourced their drinking water from surface water, groundwater and harvested rainwater. This was due to the government's inability to provide adequate access to potable drinking water. These water sources were characterized by different kinds of pollutants which pose health threats to the people. The advent of sachet water therefore provided a relatively affordable and easy access to drinking water. It became popular, widely accepted and was perceived to be of higher quality. Over the years the number of sachet water companies in Gwagwalada has continued to increase with minimal or no supervision, after the first registration, by the regulatory authorities such as the National Agency for Food and Drug Administration and Control (NAFDAC), Standard Organization of Nigeria (SON) and other State regulatory agencies. With the minimal or absence of supervision of the sachet water production in Gwagwalada, there is the possibility that the different sachet water brands may contain pollutants which may pose health threats to the ignorant consumers.

This study therefore evaluates the physicochemical and biological quality of selected sachet water brands in Gwagwalada, their suitability for consumption as well as the health risks associated with oral exposure to the assessed pollutants.

MATERIALS AND METHODS

Study Area

Gwagwalada is one of the six Area Councils of the Federal Capital Territory (FCT) of Nigeria. It is located between latitude 8°50'N and 9°00'N and between longitude 6°50''and 7°00'E, with an altitude of about 400m - 600m and a total land area of 1,043km^2. Being part of the Federal Capital Territory (FCT), Gwagwalada falls under the tropical sub-humid climate with distinct dry and wet season with high temperature throughout the year. The wet season commences in late March or early April and lasts to mid-October while dry season starts from late October to March. The mean annual rainfall varies from 1145mm to 1631mm (Hassan, 2002), with 60% of the annual rainfall received during the months of July, August and September.Temperature in Gwagwalada records its highest value during the month of March which is between 39°C and 40.1°C and its lowest in December which ranges from 17.2°C to 19.1°C (Madaki & Jibrin, 2014).

Gwagwalada is well drained through a series of small streams that convey water from all parts of the town to River Usman, a tributary of River Gurara, the largest river within Gwagwalada (Adakayi, 2000). For most part of the year, except in the peak of the rainy season, the rivers around Gwagwalada are shallow. The water of the rivers around the Gwagwalada area is heavily polluted due to several domestic, industrial and farming activities around them (Balogun, 2001). The population of Gwagwalada area is heterogeneous in nature comprising of people from various parts of Nigeria. According to National Population Commission (2006), the population of Gwagwalada area council was 157,770, it was projected to 221,209 in 2019 at 3% annual growth rate

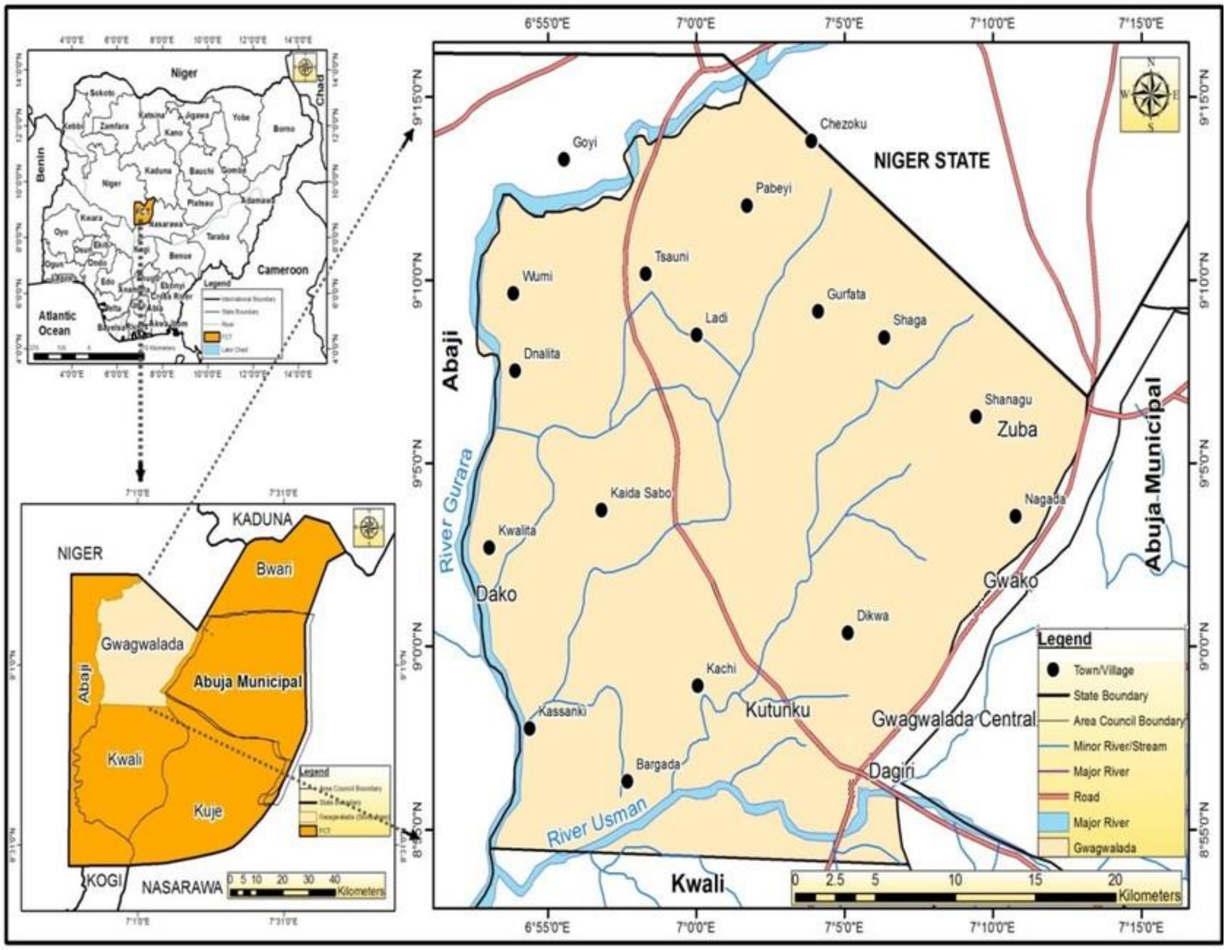

Figure 1: Map of the Federal Capital Territory showing Gwagwalada Area Council

Survey and Questionnaire Administration

Information on the different sachet water brands sold in the study area, the preferred brands, and the quality perceptions of the consumers were collected using a well-structured questionnaire. The study adopted the survey procedures and practical guidelines for designing surveys (Sandelowski, 1995). The questionnaire was made of two sections. Section 1 was for the collection of data on the respondents' demographic data while section 2 was for data on the respondents' perception/preference of sachet water consumed. It was designed using simple language to avoid ambiguity or misconceptions. The questionnaire was tested through a pilot survey with a small number of participants in the Department of Geography and Environmental Management, University of Abuja. This was so as to verify the questionnaire's content, its viability and completion time.

The study drew a sample size from the 2023 projected population of the study area. The sample size was determined using the formula for sample size determination as given by Yamane (1967).

$n = \frac{N}{1+N(e)^2}$ …………eq. (1)

Where: n is the sample size
N is the population size, which is 507,000 (NPC, 2006)
e is the level of precision or margin of error, which is 0.05
Substituting these values in the formula above, the sample size is approximately 400.
A purposive sampling technique was used in the study as described in Sim *et al*. (2018) to reach the target population.

Water Sample Collection

Fifteen (15) sachet drinking water brands from different manufacturers were used for this study. These were the most popular and consumed brands in the area (derived from the survey results). The samples were collected within 24 hours of supply so as to ensure that the validity of the results is not affected by prolonged number of days. Three samples were collected for each of the selected sachet water brands, making a total of forty-five samples. These were labelled as Groups A to O. The samples were examined physically and the information on the packages were recorded. The water samples were carefully transferred into pretreated (with 0.05M HCl) sample bottles, which were rinsed with distilled water and re-rinsed three times with the sachet water. They were transported to the laboratory in ice-packed coolers so as to maintain a temperature of 4^{o}C (Makwe *et al*., 2020, Makwe & Madu 2021; Kusa & Joshua, 2023)

Physicochemical Analysis

On-site analyses of temperature, pH, turbidity and conductivity were carried out at the site of sample collection following the standard protocols and methods of American Public Health Organization (APHA, 2005). Temperature of the different samples were measured using a glass thermometer. The pH of the samples was measured using a pH meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.). The pH meter was calibrated with three standard solutions (pH 4.0, 7.0, and 10.0) before taking the measurements. Electrical conductivity of the samples was measured using a conductivity meter (model HI 98130 HANNA, Mauritius, Iramac Sdn. Bhd.). The probe was calibrated using a standard solution with a known conductivity. The probe was submerged in the water sample and the reading was recorded after the disappearance of stability indicator. Turbidity was determined using a portable turbidity meter (Model: TN-100/T-100) according to standard methods as described in the manual. The meter was calibrated by standardizing with distilled water and the sample placed inside the cell holder. The read/enter key was then pressed and the value of turbidity was read directly in Nephelometric Turbidity Unit (NTU).

Other parameters were analysed in the laboratory as follows: Total dissolved solids (TDS) were determined using the gravimetric method by evaporating the water samples in an oven at103^o-105^{o}C. The TDS was then computed by taking the difference between the mass of the dried beaker and that of the beaker containing the residue in mg/L (APHA, 2005; Makwe & Chup, 2013a; Makwe & Ishaya, 2014). Total hardness was determined using Standard Method 2340 C: EDTA Titrimetric Method and expressed in mg/L.; Residual chlorine was determined using oxidation reduction titration standard method (APHA 4500-Cl) in mg/L. These were as detailed in Standard Methods for the Examination of Water and Wastewater (APHA, 2005). Nitrate was determined using Hydrazine reduction and colour intensity measurement with a spectrophotometer at an absorbance of 520nm (APHA, 1998). Total ionic strength adjusting buffer II

(TISAB II) was prepared as specified in Whitford (2014) and Metrohm lnc. NO.82/3e and used for the determination of fluoride in the water samples.

The determination of metals such as Fe, Pb, Zn, Cr, Cu, Ca, Mg, Cd, Na, Mn and Ni were carried out using Atomic Absorption Spectrophotometer (AAS, Perkin Elmer Analyst 400). 100 ml of each of the water sample was measured with a measuring cylinder and 5 ml of concentrated hydrochloric acid was added to it. The solution was then transferred into a conical flask and heated on the hot plate for two hours at 105°C to 25 ml. it was then transferred into 100ml volumetric flask and distill water was added to fill up to the mark where it was filtered and transferred into the pre-cleaned sample bottle and taken for further Atomic Adsorption Spectrophotometer (AAS) analysis. The results were recorded automatically on a computer connected with the AAS system (Makwe, 2019).

Bacteriological Analysis

The water samples were analysed for Total coliform and faecal coliform organisms. Membrane filtration technique was conducted for enumeration of total viable and coliform counts (Makwe & Chup, 2013b; Vunain *et al.,* 2019; Morka, 2022). A pore sized 0.45 µm of a sterile membrane filter (small enough to retain the indicator bacteria to be counted) was employed for the filtration of 100 ml of each of the harvested rainwater samples. The paper filter was mounted on an already prepared or solidified Membrane Lactose Glucuronide agar plate in inverted form. The plates were then incubated at 37°C for 20 hrs and at 44.5°C for 24 hrs respectively for the counts of total coliform and thermo tolerant faecal coliforms. The Green and yellow clusters were recorded as total coliform whereas plates observed as green and yellow clusters were recorded as thermo-tolerant faecal coliforms using a colony counter and reported as Colony Forming Units (CFU) per 100ml. Gram staining reactions, morphological test, and relevant biochemical techniques were employed for identification.

Quality Assurance and Control

To ensure quality assurance and control, the possibility of background contamination during laboratory analysis was eliminated. This was done by using a blank sample after every group of samples (3 samples) were analysed. This was so as to ensure the accuracy of the data. Also, the analyses were performed in duplicates and the average was recorded as the final result. For the survey, a pilot survey was carried out at the Department of Geography and Environmental Management, University of Abuja, to test for reliability, viability, clarity and completion time of the questionnaire.

Statistical Analysis

Data obtained from the survey and laboratory analyses were subjected to statistical analysis. One-way Analysis of Variance (ANOVA) was used to test for significant variation (at $p=0.05$) in the concentration of the analysed parameters across the groups (A-O) of sachet water brands. The t-test analysis was also used to test for significant differences (at $p=0.05$) between the experimental means for each sachet water group (A-O) and WHO standard values.

Human Health Risk Assessment

The data obtained from the survey and laboratory analyses were also used to assess the health risk of the consumers (adult and children) of the sachet water brands. Human health risk assessment is the process used to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future (USEPA, 2023). It is a key tool in appraising water quality even when the concentration of contaminants is within stipulated standard limits. For this study, the health risk assessment was done only for the consumption of the analysed heavy metals in the sachet water brands.

To assess the human health risk for adults and children, based on the oral pathway of consumption of heavy metal contaminants in the sachet water brands, the chronic daily intake (CDI) was computed according to USEPA (2014) using the equation,

$$\boldsymbol{HRI = CDI = \frac{C\ X\ IR\ X\ ED\ X\ EF}{ABW\ X\ AET}} \quad \textbf{............eq. (2)}$$

Where: CDI = chronic daily intake (mg/kg/day); C = concentration of a particular contaminant (mg/L); IR = ingestion rate with assigned values of 2.5L for adults and 0.78L for children; ED = exposure duration with values of 26years and 6years for adult and children respectively; EF = exposure frequency, which is taken as 365 days; ABW = average body weight taken as 80kg and 15kg for adults and children respectively; AET = average exposure time is ED x 365days, which is 9,490 for adults and 2,190 for children.

Next is the computation of the non-Cancer risks Hazard Quotient (HQ).

Non-Cancer Risks

A non-cancer risk hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected. It is computed using the equation,

$$\boldsymbol{HQ = \frac{CDI}{RfD}} \textbf{...........eq. (3)}$$

Where: HQ is the hazard quotient; CDI = chronic daily intake (mg/kg/day); RfD is the reference dose of a specific contaminant (mg/kg/day). A reference dose (RfD) is an estimate of a daily exposure to the human population (including sensitive subpopulations) that is likely to be without an appreciable risk of deleterious effects during a lifetime. It is the maximum acceptable oral dose of a toxic substance, below which no adverse non-cancer health effects should result from a lifetime of exposure. The RfD values for assessed parameters are as shown in Table 1.

Table 1: Oral Reference Dose of the Metals Assessed in Sachet Water

Chemical	Oral reference dose RfD (mg/kg/day)
Fe	0.007
Pb	0.0035
Zn	0.3
Cr	0.003
Cu	0.04
Ca	0.001
Mg**	4.625 for adult and 5.0 children
Na	0.03
Mn	0.14
Cd	0.0005
Ni	0.02

****RfD for Mg was based on 420mg and 320mg allowable daily intake for men and women respectively /80kg body weight; and 80mg for children /15kg body weight.**
Source: USEPA IRIS, 2011, 2017; Zheng *et al.*, 2015; Emmanuel *et al.*, 2022; Kusa & Joshua, 2023

The hazard index (HI) was computed as the sum of HQ values of each of the contaminant (Li *et al*., 2013; Emmanuel *et al*., 2022).

$$HI = \sum HQ \quad \text{............eq. (4)}$$

The classification of the non-carcinogenic risk was based on the USEPA (1991) guideline as shown in Table 2.

Table 2: Chronic Non-carcinogenic Health Risk Classification

Risk Level	HI	Chronic Risk Description
1	<0.1	Negligible
2	≥0.1 to <1	Low
3	≥1 to <4	Medium
4	≥4	High or severe

RESULTS AND DISCUSSION

Demographically, about 51.2% of the respondents were male while the remaining 48.8% were female. The majority of the respondents (58%) were students from tertiary educational institutions; 3% were staff of the university of Abuja while the remaining 39% includes bike riders, business owners, civil servants and the unemployed. For age distribution, 61.5% of the respondents were between the ages of 15-25 years, while the rest were older; 69.2% earn 30,000 Naira and below; 63%, who were mostly students, use 1-3 bags of sachet water per week.

There are variations in the preference among the fifteen (15) different sachet water brands from the study area, with the first five Groups in Table 3 accounting for 73.6% that is preferred/consumed. These are Group B (PR = 20.5%), Group E (EW = 16.2%), Group A (JR = 13.0%), Group D (ZR = 12.5) and Group C (RH = 11.4%). The rest of the sachet water brands were preferred by 26.4% of the respondents. These preferences were overwhelmingly due to the perceived quality (no taste and odour) of the sachet water brands, followed by their registration with NAFDAC, the national regulatory agency. Cost and availability were the least considered factors in the choice of sachet water brands among the respondents. This result is similar to those obtained by Kusa & Joshua (2023).

Table 3: Sachet Water Brands and Preferences

Group	Name of Sachet Water	Abbreviation	Preferences (%)
A	Jimrose table water	JR	13.0
B	Presido table water	PR	20.5
C	Rhoda table water	RH	11.4
D	0^{o} table water	ZR	12.5
E	Ero Water	EW	16.2
F	Doremi table water	DR	5.0
G	Beru table water	BR	7.2
H	Minash water	MN	4.5
I	Kinkin table water	KK	1.5
J	Fari table water	FR	0.8
K	Auta table water	AU	0.5
L	Hauwa table water	HW	1.7
M	Bridgewit table water	BW	2.4
N	ABC crystal aqua	AB	1.0
O	Al-Ahad table water	AA	1.8

Source: Field survey, 2024

The National Agency for Food, Drug Administration and Control (NAFDAC), the agency responsible for regulating drugs, foods and chemicals in Nigeria, requires that all the labelling of food and drugs must be informative and accurate. The information required on labels include manufacturer's name, contact information, batch number, nutritional information, manufacturing date, expiration date (best before date) and NAFDAC registration number (Airaodion *et al*., 2019). The result of the physical examination of the sachet water brands used for this study is presented in Table 4.

Table 4: Physical Examination of Sachet Water Brands used in Gwagwalada

Group	Product Name	Manufacturer's contact	Batch Number	Manufacturing Date	Expiry Date	NAFDAC Number	Mineral Composition
A	+	+	-	-	-	+	-
B	+	+	-	-	-	+	-
C	+	+	-	-	-	+	-
D	+	+	-	-	-	+	-
E	+	+	-	-	-	+	-
F	+	+	-	-	-	+	-
G	+	+	-	-	-	+	-
H	+	+	-	-	-	+	-
I	+	+	-	-	-	+	-
J	+	+	-	-	-	+	-
K	+	+	-	-	-	+	-
L	+	+	-	-	-	+	-
M	+	+	-	-	-	+	-
N	+	+	-	-	-	+	-
O	+	+	-	-	-	+	-

(+) indicates present while (–) indicates absent

Physical examination of the different sachet water brands showed that all the sachet water studied had 100% compliance in term of the product names, manufacturer's addresses, and NAFDAC registration number. However, none of them had manufacturing and expiry dates (Table 4). This information is very important because it tells the consumer whether or not the sachet water is still within its shelf life. Furthermore, all the sachet water used for this study were observed to be without batch number on their labels. Information on Batch number is essential for any product, especially when there is the need to recall such product from the market (Airaodion *et al.*, 2019). There is also the absence of information about mineral composition on all the sachet water that were examined (Groups A-O). These observations clearly indicate the non-compliance by the sachet water companies and it is very worrisome. With the absence of these information on the sachet water labels, it sends the signal that the sachet water which are sold to the general public in Gwagwalada and its environs may pose serious health risk when consumed.

The results of physical, chemical and bacteriological assessments of the sachet water samples are presented in Table 5. The results were compared with the recommended World Health Organisation standards for drinking water quality (WHO, 2011). The result shows that the temperature of the assessed water samples ranged from 21.8 – 23.9ºC and is within the WHO recommended values of <40ºC. Similarly, the values for pH (6.7 - 7.6), Electrical conductivity (73 - 236 µs/cm), turbidity (0.23 - 1.3NTU), Total dissolved solids (36 - 78mg/l) and Nitrates (10.8 - 23.5mg/l) across the Groups (A-O) of the assessed water samples were within the recommended WHO standards (see Table 5).

However, the concentration of fluoride in the sachet water samples in Group B (1.53mg/l) and Group N (1.51mg/l) has mean values which were higher than the WHO recommended limit of 1.5mg/l. The rest of the samples had their fluoride concentrations withing the recommended limit. Although adding fluoride to drinking water helps to reduce the incidence of tooth decay, however, too much fluoride can lead to dental fluorosis or skeletal fluorosis, which can damage bones and joints. It has also been linked to thyroid and neurological problems (Solanki *et al.,* 2022).

The concentration of residual chlorine in the water samples from Group B (0.32mg/l), Group K (0.22mg/l), Group N (0.26mg/l) and Group O (0.22mg/l) are higher than the recommended limit of 0.2mg/l (WHO, 2011). The rest of the water sample groups has residual chlorine concentration within the recommended limits. The presence of residual chlorine in drinking water is as a result of chlorination, a process which disinfects drinking water. A number of different by-products can be produced from the process of chlorination including chloroform, dibromochloromethane, trihalomethanes and halo acetic acids. These by-products, especially trihalomethanes are carcinogens and have been a topic of concern in chlorinated water due to a number of adverse health effects associated with long term exposure to them. They include shortness of breath, vomiting colon, bladder and rectal cancer (Helte *et al.,* 2023; Shi *et al.*, 2024).

The total hardness of sachet water samples in this study ranged from 79.65mg/l (Group L) to 123.15mg/l (Group O). These values are within the 150mg/l WHO recommended standard limits for drinking water.

Table 5: Mean Concentration of Analysed Physico-Chemical and Biological Parameters in Sachet Water Samples

Parameters	GROUPS															WHO
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
Temp. ºC	23.5	23.9	22.0	21.9	22.9	23.4	23.6	22.7	23.2	23.5	21.8	22.6	23.4	22.2	23.0	<40
pH	7.2	6.8	6.8	7.0	6.7	7.3	7.6	6.7	6.8	7.1	7.5	6.9	6.7	7.0	6.8	6.5-8.5
E.C (µs/cm)	76	182	73	89	90	95	102	152	88	137	190	94	117	203	236	1000
Turbidity	0.99	1.30	0.56	0.50	0.23	0.80	0.58	1.10	1.0	0.89	0.60	0.32	0.64	1.20	1.10	5
TDS	39	78	40	60	43	54	38	36	53	68	56	38	42	66	72	1000
Nitrate	12.2	15.3	18.6	22.8	16.4	13.2	19.6	14.7	11.4	10.8	21.7	16.2	15.5	16.3	23.5	50
Fluoride	1.40	1.53	1.30	1.25	1.21	1.48	1.42	1.32	1.28	1.39	1.44	0.98	1.00	1.51	1.42	1.5
R. Chl.	0.15	0.32	0.18	0.20	0.10	0.20	0.12	0.16	0.14	0.18	0.22	0.12	0.11	0.26	0.22	0.2
T. Hard.	112.75	102.5	110.3	119.15	99.50	94.85	118.20	115.50	83.60	92.15	88.50	79.65	96.55	121.20	123.15	150
Fe	0.20	0.40	0.20	0.10	0.30	2.50	0.30	2.60	3.20	1.30	0.20	0.40	0.10	0.10	0.20	0.3
Pb	0.002	0.005	0.003	0.003	0.002	0.013	0.002	0.007	0.012	0.004	0.010	0.010	0.007	0.003	0.002	0.01
Zn	0.33	0.65	0.24	0.42	0.28	0.76	0.38	0.21	0.63	0.28	0.33	0.41	0.19	0.16	0.37	3
Cd	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.003
Cr	0.02	0.03	0.01	0.01	0.01	0.03	0.01	0.01	0.03	0.01	0.01	0.02	0.03	0.01	0.01	0.05
Cu	0.19	0.62	1.23	0.19	0.11	1.09	1.18	0.88	1.58	1.00	0.92	1.23	1.43	0.74	1.11	2
Ca	3.31	1.14	3.65	3.02	2.11	4.03	2.35	3.54	4.41	2.22	2.86	1.86	3.30	0.98	2.88	0.5
Mg	18.27	26.22	9.95	16.15	15.22	21.25	19.55	11.34	14.33	23.20	21.42	17.17	13.22	10.47	18,87	50
Na	7.22	4.54	3.15	9.60	6.12	23.11	4.55	19.43	21.32	16.75	11.25	6.14	5.32	8.44	10.20	200
Mn	0.03	0.08	0.03	0.06	0.08	0.02	0.05	0.07	0.01	0.02	0.07	0.01	0.05	0.03	0.06	0.5
Ni	0.02	0.03	0.02	0.01	0.04	0.01	0.02	0.01	0.02	0.02	0.01	0.03	0.02	0.01	0.03	0.08
TCC (cfu/100ml)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
E.coli(cfu/100ml)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0

Note: E.C = Electrical conductivity; TDS = Total dissolved solids; R. Chl = Residual chlorine; T.Hard. = Total hardness; Parameters are presented in mg/l except where stated; Turbidity is measured in NTU;

The concentration of Fe in the sachet water samples exceeded the WHO (2011) recommended limit of 0.3mg/l in Groups B (0.4mg/l), F (2.5mg/l), H (2.6mg/l), I (3.2mg/l), J (1.3mg/l) and L (0.4mg/l), with Groups F, H and I exceeding the recommended value by 8 to 10 times. Although Fe is an essential mineral which the body needs to transport oxygen in the blood, However, high levels of iron in drinking water can have several noticeable effects on the appearance, smell and taste of the water. Iron can also affect the skin by making it dry and itchy. It also provides ideal breeding grounds for certain bacteria. In addition, high iron in water content leads to an overload which can cause diabetes, hemochromatosis, stomach problems, and nausea. It can also damage the liver, pancreas, and heart (McDowell *et al*., 2024).

Lead (Pb) concentration in the different groups of water samples were within the recommended limit of 0.01mg/l except for those in Groups F (0.013mg/l) and I (0.012mg/l). Lead is a toxic metal that can be harmful to human health even at low exposure levels. Lead is persistent, and it can bioaccumulate in the body over time. Even moderate to low levels of lead exposure, which might cause subtle symptoms, can still produce serious harm such as hearing loss, anemia, hypertension, kidney impairment, immune system dysfunction, and toxicity to the reproductive organs. Low levels of exposure can interfere with thought processes and lower children's IQ and also cause attention and behavioral problems (WHO, 2023; USEPA, 2024).

The concentration of Zn, Cr, Cu, Mg, Na, Mn and Ni across the groups of sachet water samples were all within the WHO recommended limit values. However, the concentration of Ca in all the sachet water groups (A-O) were higher than the recommended value of 0.5mg/l. The presence of cadmium (Cd) was not detected in all the analysed water samples.

Results obtained in this study indicated that the analysed sachet water samples were free from microbiological contaminants, as shown in (Table 5). Total coliforms and Faecal coliforms were not isolated in any of the groups of sampled water. The presence of coliforms in treated drinking water is usually an indication of its general sanitary quality.

The Analysis of Variance test was conducted to test for significant variation in the concentration of the tested parameters across the Groups (A to O). of sachet water samples. The results showed an F-value of 0.1736, which is much smaller than the critical F-value (F crit) of 1.7286; and a P-value of 0.9997, which is significantly higher than the standard significance level of $P \leq 0.05$. Hence there is no statistically significant variation in the concentration of the tested parameters across the different water sample groups.

The student t-tests were also conducted to test for significant difference between the concentration of the parameter in the individual groups (A-O) and the WHO standard. The result of the tests showed no significant difference as the P-values from the t-tests are greater than the standard significance level of $P \leq 0.05$.

The results for the chronic daily intake (CDI) for the ingestion pathway of metals in the different sachet water types in the study area are summarised in Table 6. The results showed that the CDI values for Fe has a wide range of 0.0003-0.01mg/kg/day for adults and 0.0005-0.0166mg/kg/day for children in the different sachet water types, with sachet water in Groups F, H and I (for both adult and children) having CDI values above the recommended oral reference dose (RfD) of 0.007mg/kg/day (USEPA/IRIS, 2011). Sachet water in Group I has the highest mean CDI value for Fe (0.01mg/kg/day and 0.0166mg/kg/day) for both adult and children population.

Print ISSN: 2056-7537(pri5nt)

Online ISSN: 2056-7545(online)

Website: https://www.eajournals.org/

Publication of the European Centre for Research Training and Development -UK

Table 6: Chronic Daily Intake (CDI) of Metals in Different Sachet Water Brands (mg/kg/day)

Metals	GROUPS														
	A	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**	**O**
								ADULTS							
Fe	0.0006	0.0013	0.0006	0.0003	0.0009	0.0078	0.0009	0.0081	0.0100	0.0041	0.0006	0.0013	0.0003	0.0009	0.0006
Pb	0.0001	0.0002	0.0001	0.0001	0.0001	0.0004	0.0001	0.0002	0.0004	0.0001	0.0003	0.0003	0.0002	0.0001	0.0001
Zn	0.0103	0.0203	0.0075	0.0131	0.0088	0.0238	0.0119	0.0066	0.0197	0.0088	0.0103	0.0128	0.0059	0.0050	0.0116
Cr	0.0006	0.0009	0.0003	0.0003	0.0003	0.0009	0.0003	0.0003	0.0009	0.0003	0.0003	0.0006	0.0009	0.0003	0.0003
Cu	0.0372	0.0506	0.0384	0.0059	0.0034	0.0341	0.0369	0.0275	0.0494	0.0313	0.0288	0.0384	0.0447	0.0231	0.0347
Ca	0.1034	0.0356	0.1141	0.0944	0.0659	0.1259	0.0734	0.1106	0.1378	0.0694	0.0894	0.0581	0.1031	0.0306	0.0900
Mg	0.5709	0.8194	0.3109	0.5047	0.4756	0.6641	0.6109	0.3544	0.4478	0.7250	0.6694	0.5366	0.4131	0.3272	0.5897
Na	0.2256	0.1419	0.0984	0.3000	0.1913	0.7222	0.1422	0.6072	0.6663	0.5234	0.3516	0.1919	0.1663	0.2638	0.3188
Mn	0.0009	0.0025	0.0009	0.0019	0.0025	0.0006	0.0016	0.0022	0.0003	0.0006	0.0022	0.0003	0.0016	0.0009	0.0019
Ni	0.0006	0.0009	0.0006	0.0003	0.0013	0.0003	0.0006	0.0003	0.0006	0.0006	0.0003	0.0009	0.0006	0.0003	0.0009
								CHILDREN							
Fe	0.0010	0.0021	0.0010	0.0005	0.0016	0.0130	0.0016	0.0135	0.0166	0.0068	0.0010	0.0021	0.0005	0.0016	0.0010
Pb	0.0001	0.0003	0.0002	0.0002	0.0001	0.0007	0.0001	0.0004	0.0006	0.0002	0.0005	0.0005	0.0004	0.0002	0.0001
Zn	0.0172	0.0338	0.0125	0.0218	0.0146	0.0395	0.0198	0.0109	0.0328	0.0146	0.0172	0.0213	0.0099	0.0083	0.0192
Cr	0.0010	0.0016	0.0005	0.0005	0.0005	0.0016	0.0005	0.0005	0.0016	0.0005	0.0005	0.0010	0.0016	0.0005	0.0005
Cu	0.0619	0.0842	0.0640	0.0099	0.0057	0.0567	0.0614	0.0458	0.0822	0.0520	0.0478	0.0640	0.0744	0.0385	0.0577
Ca	0.1721	0.0593	0.1898	0.1570	0.1097	0.2096	0.1222	0.1841	0.2293	0.1154	0.1487	0.0967	0.1716	0.0510	0.1498
Mg	0.9500	1.3634	0.5174	0.8398	0.7914	1.1050	1.0166	0.5897	0.7452	1.2064	1.1138	0.8928	0.6874	0.5444	0.9812
Na	0.3754	0.2361	0.1638	0.4992	0.3182	1.2017	0.2366	1.0104	1.1086	0.8710	0.5850	0.3193	0.2766	0.4389	0.5304
Mn	0.0016	0.0042	0.0016	0.0031	0.0042	0.0010	0.0026	0.0036	0.0005	0.0010	0.0036	0.0005	0.0026	0.0016	0.0031
Ni	0.0010	0.0016	0.0010	0.0005	0.0021	0.0005	0.0010	0.0005	0.0010	0.0010	0.0005	0.0016	0.0010	0.0005	0.0016

The CDI values for Pb, Zn and Cr showed the following ranges for the different sachet water types; Pb (Adults: 0.0001-0.0004mg/kg/day; Children: 0.0001-0.0007mg/kg/day); Zn (Adults 0.005-0.0238mg/kg/day; Children: 0.0083-0.0395mg/kg/day) and Cr (Adults: 0.0003-0.0009mg/kg/day; Children: 0.0005-0.0016mg/kg/day). These CDI values are within the acceptable oral reference dose for Pb(0.0035mg/kg/day), Zn(0.3mg/kg/day) and Cr(0.003mg/kg/day) as recommended by USEPA/IRIS (2017).

The oral reference dose for Cu as recommended by USEPA/IRIS (2011) is 0.04mg/kg/day. The CDI values for Cu in the different sachet water samples ranged from 0.0034-0.0506mg/kg/day for adults and 0.0057-0.0842mg/kg/day for children, with sachet water Groups B, I and M having CDI values that are higher than the oral RfD for both the adults and children population. Furthermore, all the remaining Groups, except for Groups D, E and N also have elevated CDI values that are higher than the oral RfD for the children population. Group B had the highest mean CDI values for Cu (0.0506mg/kg/day and 0.0842mg/kg/day) for both populations.

The CDI values for Ca and Na in the assessed water samples are higher than the recommended oral RfD of 0.001mg/kg/day and 0.03mg/kg/day for Ca and Na respectively. CDI for Ca in the different sachet water groups ranged from 0.0306-0.1378mg/kg/day and 0.051-0.2293mg/kg/day for the adult and children population respectively; while those of Na ranged from 0.0984-0.7222mg/kg/day and 0.1638-1.2017mg/kg/day for the adult and children population respectively (Table 6). Group I had the highest mean CDI values for Ca (adult:0.1378mg/kg/day; children: 0.2293mg/kg/day); while the highest mean CDI values for Na are found in Group F (adult: 0.7222mg/kg/day; children: 1.2017mg/kg/day)

Mg, Mn and Ni in the different sachet water brands have CDI values that are within their recommended oral RfD of 4.6mg/kg/day, 0.14mg/kg/day and 0.02mg/kg/day respectively for both the adults and children population.

The CDI indices for the heavy metals in the different sachet water types (Groups A-O) as presented in Table 6, were found to be in the order Mg>Na>Ca>Cu>Zn>Mn>Fe=Cr=Ni>Pb for Group A for the adult and children population. Group B heavy metals CDI indices were found to be in the order Mg>Na>Cu> Ca>Zn>Mn>Fe>Cr=Ni>Pb, while those for Groups C, D and E had the following order: Group C (Mg>Ca>Na>Cu>Zn>Mn>Fe=Ni>Cr>Pb); Group D (Mg>Na>Ca>Zn>Cu>Mn>Fe=Cr=Ni>Pb); Group E (Mg>Na>Ca>Zn>Cu>Mn>Ni>Fe>Cr>Pb) for the adult and children population. In these Groups (A-E), Mg had the highest CDI values while Pb had the least. For Group F water samples, the heavy metal CDI indices were in the order Na>Mg>Ca>Cu>Zn>Fe>Cr>Mn>Pb>Ni, while those for Groups G, H and I are in the following order: Group G (Mg>Na>Ca>Cu>Zn>Mn>Fe>Ni>Cr>Pb); Group H (Na>Mg>Ca>Cu>Fe>Zn>Mn>Cr=Ni>Pb); Group I (Na>Mg>Ca>Cu>Zn>Fe>Cr>Ni>Pb>Mn) for both adult and children population. Note that in Groups F, H and I, Na had the highest CDI values followed by Mg. Furthermore, Groups F and I had their least CDI values as Ni and Mn respectively. In Groups J, K and L, the CDI indices were in the following order: Group J (Mg>Na>Ca>Cu>Zn>Fe>Mn=Ni>Cr>Pb); Group K (Mg>Na>Ca>Cu>Zn>Mn>Fe>Pb=Cr=Ni) and Group L (Mg>Na>Ca>Cu>Zn>Fe>Ni>Cr>Pb=Mn) in varying amounts for both adult and children population. In addition, the CDI indices for Groups M, N and O were in the following order: Group M (Mg>Na>Ca>Cu>Zn>Mn>Cr>Ni>Fe>Pb); Group N (Mg>Na>Ca>Cu>Zn>Fe=Mn>Cr=Ni>Pb); Group O (Mg>Na>Ca>Cu>Zn>Mn>Ni>Fe>Cr>Pb). In Groups J-O, Mg had the highest CDI values while Pb had the least, except for Groups K and L where Ni and Mn respectively had the least CDI values for both adult and children population.

The order for the heavy metals CDI indices in the different sachet water groups (A-O) for the adult and children population is the same. However, the values are different for individual heavy metals for each population. This is due to difference in water ingestion rate (IR), exposure duration (ED) and average body weight between the adult and children population.

The hazard quotient (HQ) and hazard index (HI) for the heavy metals in the different sachet water types are presented in Table 7. The HQ values for the heavy metals in the different sachet water Groups (A-O) were higher in children compared to the adult's population. The values for the HQ for adults as calculated for Fe was in the order, I>H>F>J>B=L>E=G=N>A=C=K=O>D=M, with Groups I, H and F having HQ>1. The HQ calculated for Cu in the adult's population was in the order B>I>M>C=L>A>G>O>E>J>K>H>N>D>E, with Groups B, I and M having HQ>1. For Ca and Na, the calculated HQ were in the order Ca (I>F>C>H>A>M>D>O>K>G>J>E>L>B>N) and Na (F>I>H>J>K>O>D>N>A>L>E>M>G>B>C), with all the sachet water Groups (A-O) having HQ>1 for both metals (Ca and Na). The order for the calculated HQ for Pb, Zn and Cr in the adults population were as follows: Pb (F>I>K=L>H=M>B>J>C=D=N>A=E=G=O), Zn (F>B>I>D>L>G>O>A=K>E=J>C>H>M>N), Cr (B=F=I=M>A=L>C=D=E=G=H=J=K=N=O), with the three metals having HQ values <1. Similarly, the calculated HQ values for Mg, Mn and Ni were in the order, Mg (B>J>K>F>G>O>A>L>D>E>I>M>H>N>C), Mn (B=E>H=K>D=O>G=M>A=C=N>F=J>I=L) and Ni (E>B=L=O>A=C=G=I=J=M>D=F=H=K=N), with all the sachet water groups (A-O) having HQ<1. These orders for the calculated heavy metals HQ were the same for both the adult and children population, although the values were higher for the children population.

The Hazard Index (HI) values as calculated for the different heavy metals across the groups of sachet water types was in the order Ca>Na>Cu>Fe>Cr>Mg>Pb>Zn>Ni>Mn for the adult and children population, with Ca, Na, Cu, Fe, Cr and Mg having HI >1 for the adult population while the children population had HI>1 for Ca, Na, Cu, Fe, Cr, Mg and Pb. The HI>1 calculated for these heavy metals in the water samples presents an unacceptable risk for non-carcinogenic adverse effect. Calcium contributed most towards the exposure to non-cancer risks in the exposed population (adult and children), while Mg and Pb contributed the least. It is worthy to note that Pb, Zn, Ni and Mn had HI<1 in the adult population while only Zn, Ni and Mn had HI<1 in the children population. The Cumulative Hazard Index (∑HI) is 1489.47 and 2478.48 for the adults and children population respectively. These results show severe exposure to non-carcinogenic health risk. The ∑HI for children were higher compared to those of the adults. This implies that children in the study area could be more disposed to non-cancer risks than adults. The result from this study is in tandem with that obtained by Emmanuel *et al.* (2022) in their assessment of the human health risk of heavy metals in drinking water sources from three senatorial districts of Anambra State, Nigeria.

International Journal of Environment and Pollution Research, 13(1),48-69, 2025
Print ISSN: 2056-7537(pri5nt)
Online ISSN: 2056-7545(online)
Website: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

Table 7: Hazard Quotient and Hazard Index in Different Sachet Water

Metals	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	H.Index
								ADULTS								
Fe	0.0893	0.1786	0.0893	0.0446	0.1339	1.1161	0.1339	1.1607	1.4286	0.5804	0.0893	0.1786	0.0446	0.1339	0.0893	**5.49**
Pb	0.0179	0.0446	0.0268	0.0268	0.0179	0.1161	0.0179	0.0625	0.1071	0.0357	0.0893	0.0893	0.0625	0.0268	0.0179	**0.76**
Zn	0.0344	0.0677	0.0250	0.0438	0.0292	0.0792	0.0396	0.0219	0.0656	0.0292	0.0344	0.0427	0.0198	0.0167	0.0385	**0.59**
Cr	0.2083	0.3125	0.1042	0.1042	0.1042	0.3125	0.1042	0.1042	0.3125	0.1042	0.1042	0.2083	0.3125	0.1042	0.1042	**2.60**
Cu	0.9297	1.2656	0.9609	0.1484	0.0859	0.8516	0.9219	0.6875	1.2344	0.7813	0.7188	0.9609	1.1172	0.5781	0.8672	**12.11**
Ca	103.4375	35.6250	114.0625	94.3750	65.9375	125.9375	73.4375	110.6250	137.8125	69.3750	89.3750	58.1250	103.1250	30.6250	90.0000	**1301.88**
Mg	0.1234	0.1772	0.0672	0.1091	0.1028	0.1436	0.1321	0.0766	0.0968	0.1568	0.1447	0.1160	0.0893	0.0707	0.1275	**1.73**
Na	7.5208	4.7292	3.2813	10.0000	6.3750	24.0729	4.7396	20.2396	22.2083	17.4479	11.7188	6.3958	5.5417	8.7917	10.6250	**163.69**
Mn	0.0067	0.0179	0.0067	0.0134	0.0179	0.0045	0.0112	0.0156	0.0022	0.0045	0.0156	0.0022	0.0112	0.0067	0.0134	**0.15**
Ni	0.0313	0.0469	0.0313	0.0156	0.0625	0.0156	0.0313	0.0156	0.0313	0.0313	0.0156	0.0469	0.0313	0.0156	0.0469	**0.47**
∑(HI) = 1489.47																
								CHILDREN								
Fe	0.1486	0.2971	0.1486	0.0743	0.2229	1.8571	0.2229	1.9314	2.3771	0.9657	0.1486	0.2971	0.0743	0.2229	0.1486	**9.14**
Pb	0.0297	0.0743	0.0446	0.0446	0.0297	0.1931	0.0297	0.1040	0.1783	0.0594	0.1486	0.1486	0.1040	0.0446	0.0297	**1.26**
Zn	0.0572	0.1127	0.0416	0.0728	0.0485	0.1317	0.0659	0.0364	0.1092	0.0485	0.0572	0.0711	0.0329	0.0277	0.0641	**0.98**
Cr	0.3467	0.5200	0.1733	0.1733	0.1733	0.5200	0.1733	0.1733	0.5200	0.1733	0.1733	0.3467	0.5200	0.1733	0.1733	**4.33**
Cu	1.5470	2.1060	1.5990	0.2470	0.1430	1.4170	1.5340	1.1440	2.0540	1.3000	1.1960	1.5990	1.8590	0.9620	1.4430	**20.15**
Ca	172.1200	59.2800	189.8000	157.0400	109.7200	209.5600	122.2000	184.0800	229.3200	115.4400	148.7200	96.7200	171.6000	50.9600	149.7600	**2166.32**
Mg	0.2054	0.2948	0.1119	0.1816	0.1711	0.2389	0.2198	0.1275	0.1611	0.2608	0.2408	0.1930	0.1486	0.1177	0.2122	**2.89**
Na	12.5147	7.8693	5.4600	16.6400	10.6080	40.0573	7.8867	33.6787	36.9547	29.0333	19.5000	10.6427	9.2213	14.6293	17.6800	**272.38**
Mn	0.0111	0.0297	0.0111	0.0223	0.0297	0.0074	0.0186	0.0260	0.0037	0.0074	0.0260	0.0037	0.0186	0.0111	0.0223	**0.25**
Ni	0.0520	0.0780	0.0520	0.0260	0.1040	0.0260	0.0520	0.0260	0.0520	0.0520	0.0260	0.0780	0.0520	0.0260	0.0780	**0.78**
∑ (HI) = 2478.48																

The results from this study indicate that there is a need to further collect data for the assessed heavy metals especially for those whose HI is >1. It also shows that the health risk on long-term consumption of the analyzed sachet water and exposure to the studied heavy metals is high and the non-cancer adverse effect is equally of great concern.

CONCLUSION

The physical, chemical and bacteriological properties of fifteen selected sachet water brands sold in Gwagwalada were analyzed and compared with the WHO standard. Physical examination of the samples indicated that all the sampled water had 100% compliance in term of the product names, manufacturer's addresses, and NAFDAC registration number. However, none of them had information on manufacturing date, expiry date, batch number and mineral composition. The results of the physico-chemical and bacteriological analysis showed that parameters such as Fluoride, Residual chlorine, Fe and Pb have concentrations above the acceptable limits in some of the sachet water brands, while Ca concentration is high in all the assessed brands. Cd, Total coliforms and faecal coliforms were not detected in any of the sachet water brands. The ANOVA and student t-tests at significance level of P=0.05 indicates that there is no statistically significant variation in the concentration of the tested parameters across the different groups of sachet water samples; also, there is no significant difference between the concentration of the parameters in the individual Groups (A-O) of the water samples and the WHO standard.

The non-carcinogenic human health risk of heavy metals for both adults and children were assessed based on the concentrations of HMs in the water samples ingested orally. The result indicates that the CDI and HQ were higher in the children population compared to adults exposed to the same sachet water brands. The Hazard Index (HI) as calculated for heavy metals across the different sachet water brands was in the order Ca>Na>Cu>Fe>Cr>Mg>Pb>Zn>Ni>Mn for the adult and children population, with Ca, Na, Cu, Fe, Cr and Mg having HI >1 for the adult population while the children population had HI>1 for Ca, Na, Cu, Fe, Cr, Mg and Pb. The Cumulative Hazard Index (∑HI) was 1489.47 and 2478.48 for the adults and children population respectively, with Ca contributing most towards the exposure to non-cancer risks in the exposed population. These results indicate severe exposure to non-carcinogenic health risk for both populations, with the children in the study area being more disposed towards non-cancer risks than the adults. The result is quite worrisome and presents the need to further collect data for the assessed heavy metals especially for those whose HI is >1 as there could be the likelihood of carcinogenic health risks.

Acknowledgement

The authors would like to express heartfelt gratitude to the management and staff of Zabson Laboratories Limited, Abuja.

Conflict of interest
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors

Authors' contribution

Conceptualization, Edith Makwe;
Data curation, Edith Makwe and Chinomso Ukah;
Formal analysis, Chinomso Ukah;
Investigation, Edith Makwe;
Methodology, Edith Makwe and Chinomso Ukah;
Resources, Edith Makwe and Chinomso Ukah;
Software, Chinomso Ukah;
Supervision, Edith Makwe;
Validation, Edith Makwe;
Visualization, Edith Makwe and Chinomso Ukah;
Writing – original draft, Edith Makwe;
Writing – review & editing, Edith Makwe.

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