ORIGINAL RESEARCH

Drinking Water Quality: Physical and Chemical Evaluation of Tap and Packaged Waters from Eight Local Government Areas in Lagos, Nigeria

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Abstract:

Introduction: The inadequacy of pipe borne water supplies in urban centers is a growing problem. In recent years, packaged waters became major sources of drinking water in the households and at work.

Aims: This study aimed at assessing drinking quality parameters of packaged water sold in some selected part of Lagos and compares them with the quality of tap water.

Materials and Methods: fifty seven packaged water samples from several commercial brands selected randomly and thirty tap water samples supplied by municipal pipelines were analysed for different chemical and physical parameters. Trace metals and major ions were analysed using atomic absorption spectrometry; Total hardness and chloride were measured titrimetically; pH and electrical conductivity were measured using a multi-purpose meter.

Results: The results showed that the concentrations of the water constituents in both tap and packaged water were below the drinking water threshold values stipulated by national and international agencies, with the exception of the nitrate (NO_3^-) content in packaged water, where 11 % and 20 % respectively of the bottled and sachet water samples investigated exceeded the United State Environmental Protection Agency (USEPA) standard of 10 mg L^{-1}. This finding may result from a number of different reasons including substances dissolving from either natural sources or from household plumbing systems.

Conclusion: This study concludes that the systematic monitoring by drinking water authorities of water quality is essential and that a uniform system for quality control and assurance is required by the enforcement agencies (National Agency for Foods and Drugs Administration and Control and the Ministry of Health) in the 'packaged water' industry.

Keywords: Packaged water; Drinking water quality; Tap water

All co-authors agreed to have their names listed as authors.

1. INTRODUCTION

The unwholesomeness of drinking water resulting from contaminants released from different anthropogenic sources has become a global concern [1,2]. Over at least the past two decades, there has been increased concern regarding the quality of tap water due to pollution and its undesirable taste and odor [3,4,5]. The pollution of tap water could originate from several sources, including contamination from water pipes and storage tanks [3,6], and in the absence of proper and periodic maintenance, from disinfectant by-products resulting from the treatment of water by ozonation and chlorination [3,7]. Thus, for the sake of safety and quality, people are switching from tap water to bottled water.

The Lagos Water Supply System comprising three (3) major waterworks (Adiyan, Iju and Isashi), twenty-seven (27) mini-waterworks and ten (10) micro-waterworks with a combined production capacity of 240 million gallons per day (MGD) meets about 40 % current demand and derive their water resources in the form surface water and groundwater [8]. Rapid population growth, coupled with accelerated industrialization and urbanization, corruption, climate change, unreliable electricity and seeming mismanagement of resources have hampered the capacity of government owned municipal water providers to meet the needs of the Lagos populace. The inadequate and lack of accessible drinking water have prompted the consume of packaged waters, thereby consumers rely upon their senses with packaged waters being perceived as pure, safe and of good taste, thus, their consumption is increasing despite the excessively high prices compared to tap water [9,10].

Packaged waters (PW) are drinking water packed in plastic bottles and for the low and middle income population, the packed water is also available in the form of relatively cheaper, machine sealed sachets and may be sold in shops, on the street, or delivered to homes. The volumes of sachet water (SW) consumed are often substantial relative to total daily drinking water consumption: a study of 137 PW users in Ibadan, Nigeria found that 58% consumed between two and four 50 cl sachets per day, while 28% consumed more than four sachets per day [11,12]. Bottled water (BW) are drinking water sealed in polyethylene terephthalate (PET) bottles and either drawn from natural springs, or deep boreholes and treated according to the specifications by passing through various filters and disinfected appropriately. They are available in 50 cl, 75 cl, and 150 cl bottles. These are relatively expensive (at the rate of Naira 50 to 150) and very popular among hotels and restaurants and people from higher socioeconomic strata. Sachet water (SW) are drinking water sealed in polyethylene pouches popularly called "pure water" which is manufactured by small scale industries with a registered name and supposed to have been prepared under Government stipulated hygienic quality regulations. According to the specifications, the water is passed through a series of activated charcoal or suitable filtering media and Millipore or equivalent filters of a specific pore size, and disinfected under ultraviolet radiation for a specific period. They are packed in 50 cl nylon / plastic film sachets, put in larger sacks in dozens and transported to various distribution points in open pick-up vehicles. The price is affordable (Naira 10) mostly for the low and middle income groups. They are popular at social gatherings and public places.

While a lot of studies have been done to assess the physicochemical quality of PW, relatively fewer studies have compared the physicochemical quality of PW to tap water [11]. Due to public concern about the perceived risks of tap water and the perceived safety packaged water, this study aims to (1) evaluate whether the quality of tap water in Lagos meets international standards for drinking water, (2) to examine the drinking quality parameters of packaged water sold on the Lagos metropolis, (3) compare the quality of the packaged waters with that of tap water. The results may be useful for improving the current legislation on packaged waters, and also to guide the consumers in the choice of different packaged water types.

2. MATERIAL AND METHODS

2.1 STUDY AREA

The study area is made up of eight local government areas. Lagos city lies on the longitude 3° 23' East of Greenwich meridian and latitude 6° 27' North of the Equator. Besides being the former capital of Nigeria, it is one of the fastest growing megacities and also one of the most populous urban agglomerations in the world. The city has a tropical climate with an average relative humidity of 79 %. Mean monthly temperature ranges from $23^{\circ}C – 32^{\circ}C$. Being located in a coastal area and influenced by strong sea-based disturbances, Lagos experiences an average wind speed of 4.3 km / h. However, the city is characterized by low level of environmental sanitation, poor housing, and lack of potable water and improper management of wastes.

2.1.1 Sampling of waters

For the packaged water analysis, 27 bottled water and 30 sachet water samples were purchased between the months of October and December 2015 from water vendors in the markets, food serving areas (Bukhas) and motor parks in eight Local Government Areas (Somolu, Ikeja, Surulere, Ojo, Yaba, Oshodi / Isolo, Alimosho and Mushin) of the Lagos metropolis as shown in Fig. 1. For the tap water analysis, 30 tap waters were collected from same Local Government Areas (LGAs). The samples were stored in a cool box and carried to the laboratory. The samples collected were immediately processed for physico-chemical analysis as described in Standard Methods [13].
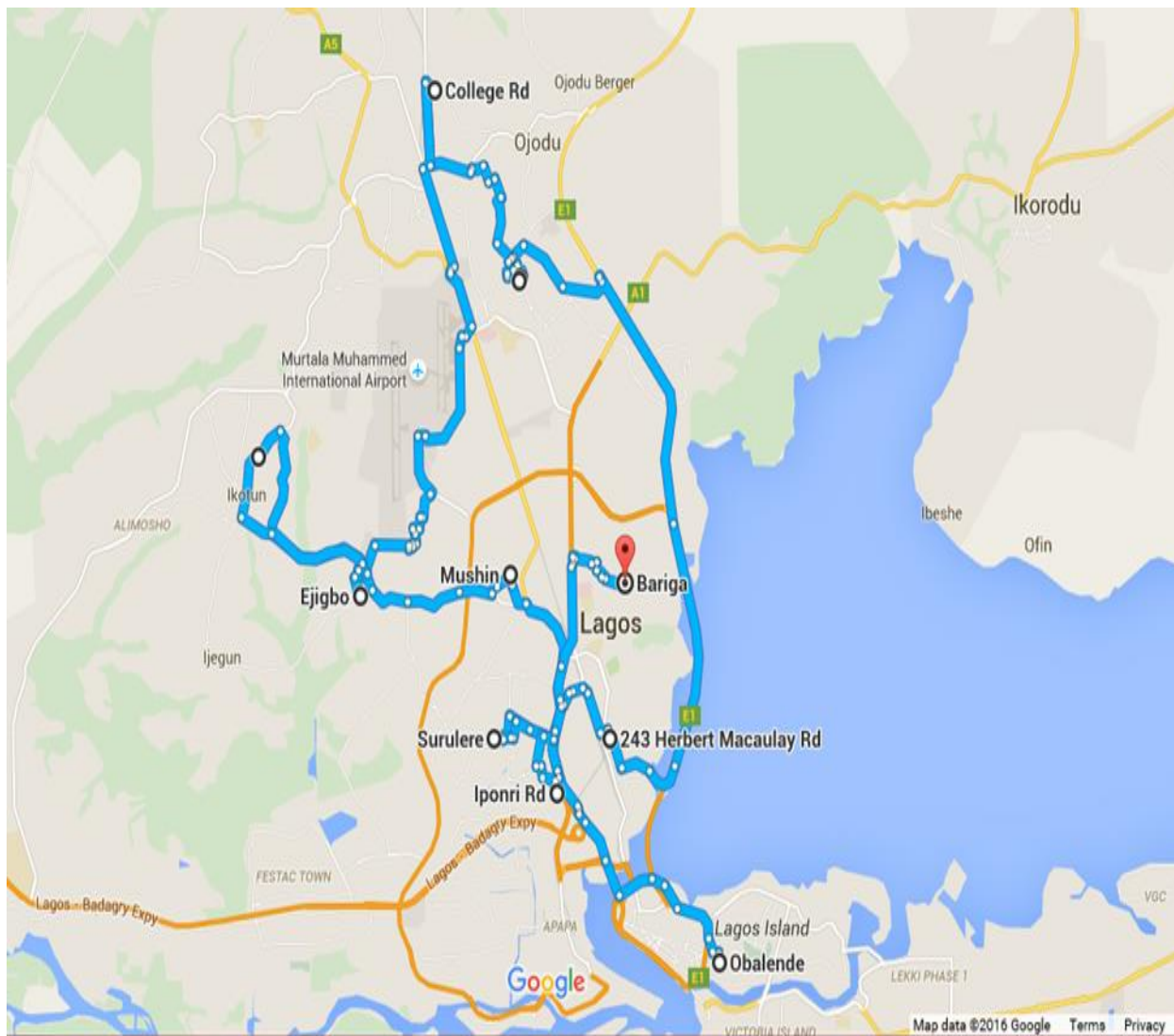
o   Fig. 1. Map showing the location of bottled, sachet and tap water samples considered in this study.

2.1.1.1 Physico-chemical Analysis

The electrical conductivity (EC) and pH were determined in situ using Jenway 470 Conductivity meter and Jenway 3505 pH meter respectively. Total hardness was determined by EDTA titration method using Eriochrome Blak T as indicator. Chloride was determined Mohr's method using potassium chromate as indicator. Nitrate and Sulphate were detemined using HACH DR-3900 spectrophotometer and chemical reagents supplied along with the kit were used for analyses. The determination of metals in drinking water samples were performed with a Solar Thermo Electron Corporation AA Series Spectrometer. All analyses were carried out in accordance with standard methods for the examination of water and wastewater [13].

All the plastics and glassware were washed and soaked with 5% nitric acid (HNO_3) for 24 hours and rinsed thoroughly with distilled water. The water samples were labeled acidified and non-acidified subsamples. The non-acidified sample was used to analyse all parameters with the exception of metals. For acidified samples, 5% HNO_3 was added to maintain pH 2. The samples were preserved at 4°C before analysis. Quality control and Quality Assurance were ascertained appropriately.

2.2 Statistical Analysis

2.2.1 Correlation Analysis (CA)

In the present study, "Pearson r correlation" was used to evaluate the linear relationships between various pairs of variables, with statistical significance set at $p<0.01$ and $p<0.05$. The value of correlation coefficient ranges between −1.0 and +1.0. The earlier value (-1.0) represents a perfect inverse relationship between the two variables, whereas the later one (+1.0) occurs when the two variables react in exactly the same way as their values change. A correlation coefficient of zero suggests that the two variables are independent of each other.

2.2.2 Principal Components Analysis (PCA)

PCA is used to reduce a large number of variable parameters (identified in water samples) to a small number of principal components [14-19]. Varimax normalized rotation was applied to the principal components in order to reduce the contribution of significantly minor variables. The number of PCs extracted (to explain the underlying data structure) is defined by using the "Kaiser criterion" [20] leaving for consideration only factors with eigenvalues greater than one.

2.2.3 Hierarchical Cluster Analysis (HCA)

The HCA [15,17,19,21] was used to determine if the drinking water samples can be grouped into statistically distinct groups (clusters). These water types were classified according to their major ion composition, for which the Ward's method was used as amalgamation rule to obtain the hierarchical associations. Classification results of the HCA are generally presented in a graphical form called "dendogram". The statistical analyses of data were performed using SPSS 16.0.

2.2.3 Linear Discriminant Analysis (LDA)

LDA was used to achieve maximum discrimination among known groups. Groups are forced to be as statistically different as possible by forming a weighted linear combination of the discriminating variables (i.e. the ion concentrations and the pH), the weights or canonical discriminant function coefficients ($βi$) are estimated so that they result in an optimal separation between the groups. Also, LDA provided better insight into the relationship between group membership and the variables used to predict group membership [22,23]. The Wilk's Lambda was used to catch the importance of the discriminating function. The Wilk's Lambda is an inverse measure of the functions discriminating power; the smaller the value of Wilk's Lambda the better the discriminating power of the function [16].

3. RESULTS AND DISCUSSION

The physical and chemical composition (pH, EC, TH, Na, K, Cl^-, NO_3^-, SO_4^{2-}) in packaged and tap waters were reported in Tables I - III together with recommended values established by regulatory bodies [24-26] for drinking water. The pH values ranged between 5.10 and 6.85 indicating slightly acidic nature. Recommended pH values for drinking water according to local and international standards should be 6.5 to 8.5. Based on Total Hardness [27] classification, 86 % of the water samples were classified as soft while 14 % were considered moderately soft.

Nitrate concentrations in the packaged and tap water samples were below the Nigerian and WHO recommended value for drinking water (i.e. 50 mg L^{-1} for short-term exposure). The primary health concern regarding nitrate is the formation of methemoglobinemia, so-called 'blue-baby syndrome': nitrate is reduced to nitrite in the stomach of infants, and nitrite is able to oxidize hemoglobin to methemoglobin, which is unable to transport oxygen around the body [9]. USEPA has set the primary drinking water standard (from public water supplies) for nitrate at 10 mg L^{-1}. Some packaged water samples considered in this study showed NO_3^- concentrations higher than USEPA guidelines of 10 mgL^{-1}. [Tables I and II]. Concentrations of $NO_3^- ≥10$ mg L^{-1} occur in 11 % and 20 % of bottled and sachet water samples, respectively.

Table l: Physico-chemical characteristics of Packaged (Bottled Water) water and the standard   limits recommended by Nigerian and international regulations for drinking water

Parameters Sample	pH	EC (mS/cm)	TH (mg/L)	Cl$^-$ (mg/L)	NO$_3^-$ (mg/L)	SO$_4^{2-}$ (mg/L)
BW1	6.20	0.17	60.00	27.00	6.80	3.67
BW2	5.90	1.00	31.50	24.00	21.35	8.05
BW3	5.43	0.34	16.00	15.00	6.40	2.33
BW4	5.67	0.27	13.33	9.00	9.43	2.67
BW5	5.33	0.56	32.00	19.67	9.40	7.37
BW6	5.97	0.16	13.33	15.00	5.60	10.67
BW7	6.17	0.14	na	13.00	5.27	2.17
BW8	6.41	0.09	na	4.67	3.27	5.33
BW9	6.70	0.30	na	20.67	7.67	9.00
WHO, 2011	6.5- 8.5		500.00	250.00	50.00	500.00
NSDWQ, 2007	6.5- 8.5		150.00	250.00	50.00	100.00
USEPA, 2011	6.5- 8.5			250.00	10.00	250.00

na = not available; NSDWQ: Nigerian Standards for Drinking Water Quality [24]; WHO: World Health Organization for Drinking Water [26]; USEPA: United State Environmental Protection Agency [25]

Table ll: Physico-chemical characteristics of packaged (Sachet Water) water and the standard limits recommended by Nigerian and international regulations for drinking water

Parameters Sample	pH	EC mS/cm	TH mg/L	Cl$^-$ mg/L	NO$_3^-$ mg/L	SO$_4^{2-}$ mg/L
SW1	6.60	0.08	13.00	6.00	6.17	8.37
SW2	6.37	0.27	44.00	10.00	3.50	8.33
SW3	6.60	0.55	49.00	14.00	10.75	8.33
SW4	6.40	0.15	0.00	11.00	3.47	3.67
SW5	6.53	0.23	12.67	10.00	9.07	1.67
SW6	6.67	0.90	32.00	21.33	24.13	3.33
SW7	5.93	0.20	4.00	11.33	6.03	9.67
SW8	6.47	0.20	14.00	11.67	7.23	11.00
SW9	6.27	0.10	18.00	11.00	4.60	7.67
SW10	6.40	0.57	16.67	11.67	5.73	7.33
WHO, 2011	6.5-8.5		500.00	250.00	50.00	500.00
NSDWQ, 2007	6.5-8.5		150.00	250.00	50.00	100.00
USEPA, 2011	6.5-8.5			250.00	10.00	250.00

na = not available; NSDWQ: Nigerian Standards for Drinking Water Quality [24]; WHO: World Health Organization for Drinking Water [26]; USEPA: United State Environmental Protection Agency [25]

Table lll: Physico-chemical characteristics of tap (TW) water and the standard limits recommended by Nigerian and international regulations for drinking water.

Parameters Sample	pH	EC mScm	TH mg/L	Cl⁻ mg/L	NO₃⁻ mg/L	SO₄²⁻ mg/L
TW1	5.65	0.32	42.00	11.00	3.60	25.00
TW2	5.10	0.29	10.90	23.00	9.50	3.00
TW3	5.80	1.70	35.00	7.50	2.27	4.90
TW4	6.30	5.80	50.00	9.00	1.70	14.00
TW5	5.90	1.21	32.00	7.00	3.60	7.00
TW6	6.20	0.37	52.00	8.00	2.40	na
TW7	6.15	0.25	48.00	5.00	1.45	na
TW8	6.05	0.28	na	11.00	3.50	na
TW9	6.25	0.47	na	11.00	3.50	na
TW10	6.85	0.62	50.00	1.00	3.20	na
WHO, 2011	6.5-8.5		500.00	250.00	50.00	500.00
NSDWQ 2007	6.5-8.5		150.00	250.00	50.00	100.00
USEPA, 2011	6.5-8.5			250.00	10.00	250.00

na = not available; NSDWQ: Nigerian Standards for Drinking Water Quality [24]; WHO: World Health Organization for Drinking Water [26]; USEPA: United State Environmental Protection Agency [25]

The trace metals (Zn, Mn, Fe, Ni, Cd and Pb) in packaged waters were found at median and maximum concentrations significantly higher than the corresponding median and maximum concentrations in tap waters (Figs. lla-llh),
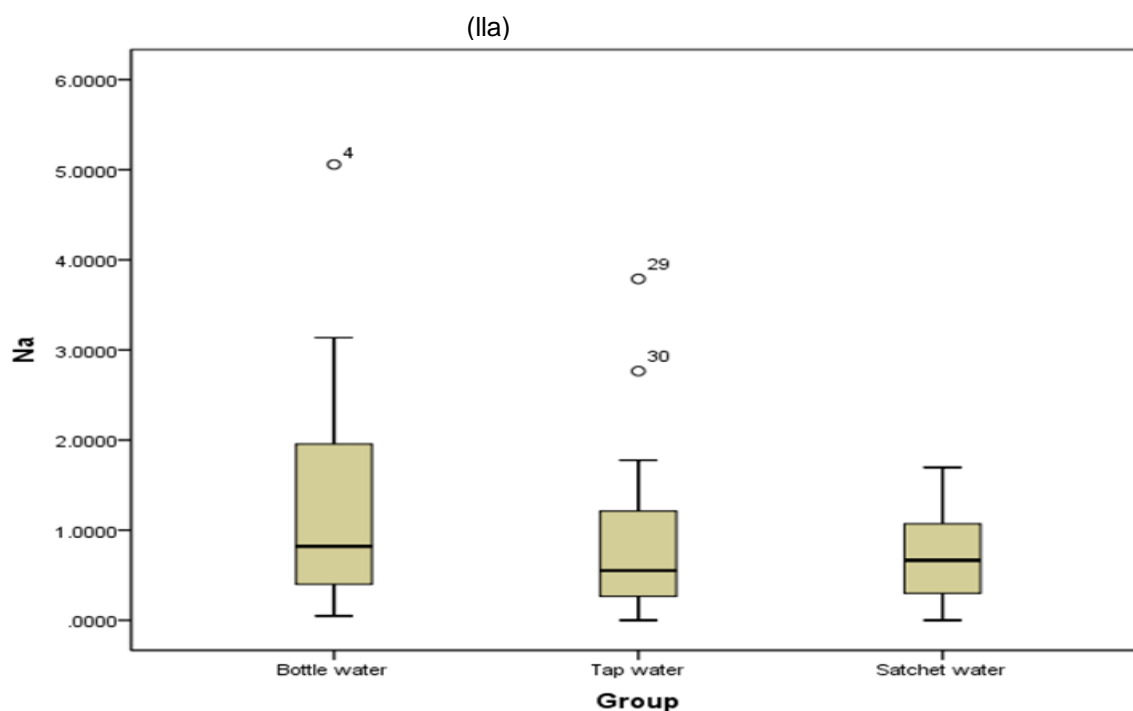

Fig lla: Box-plot showing Na concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)
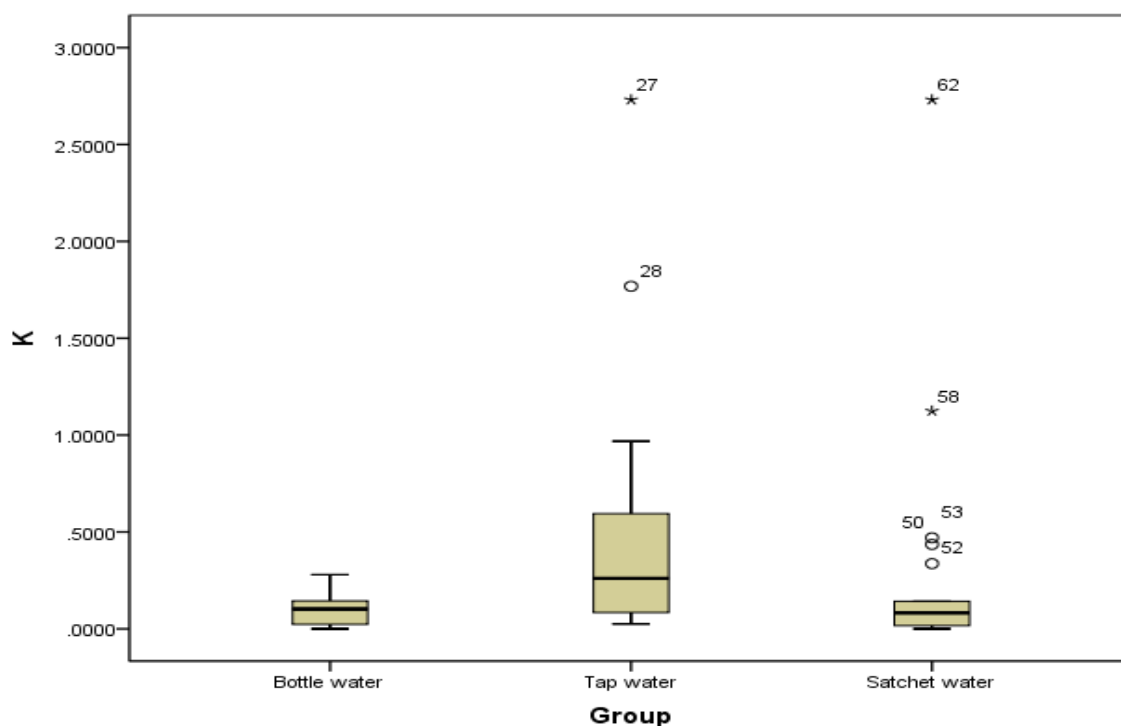
(llb)

Fig llb: Box-plot showing K concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)
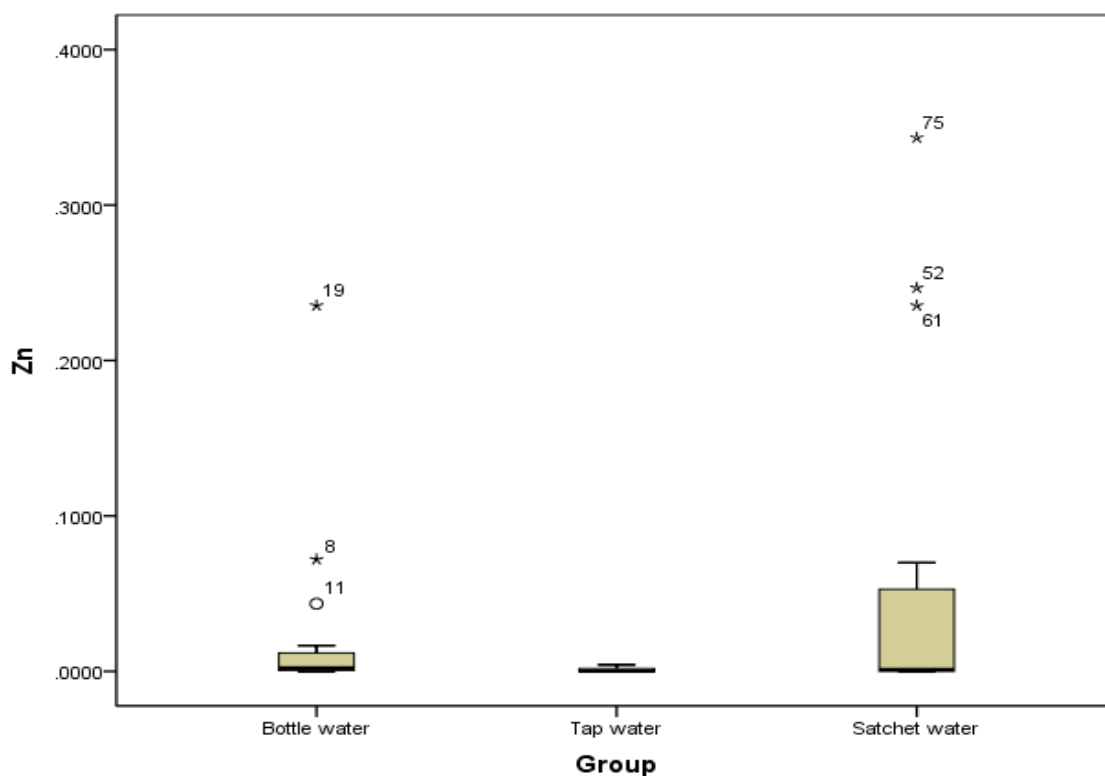
llc

Fig llc: Box-plot showing Zn concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)
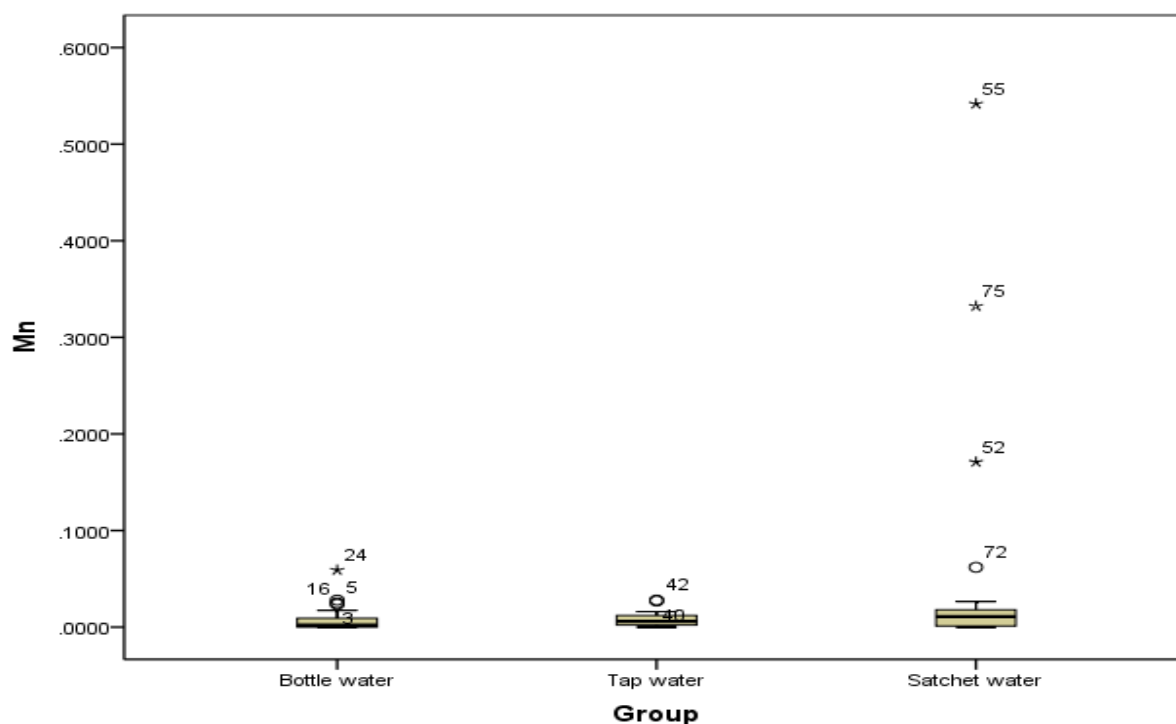
(lld)

Fig lld: Box-plot showing Mn concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)
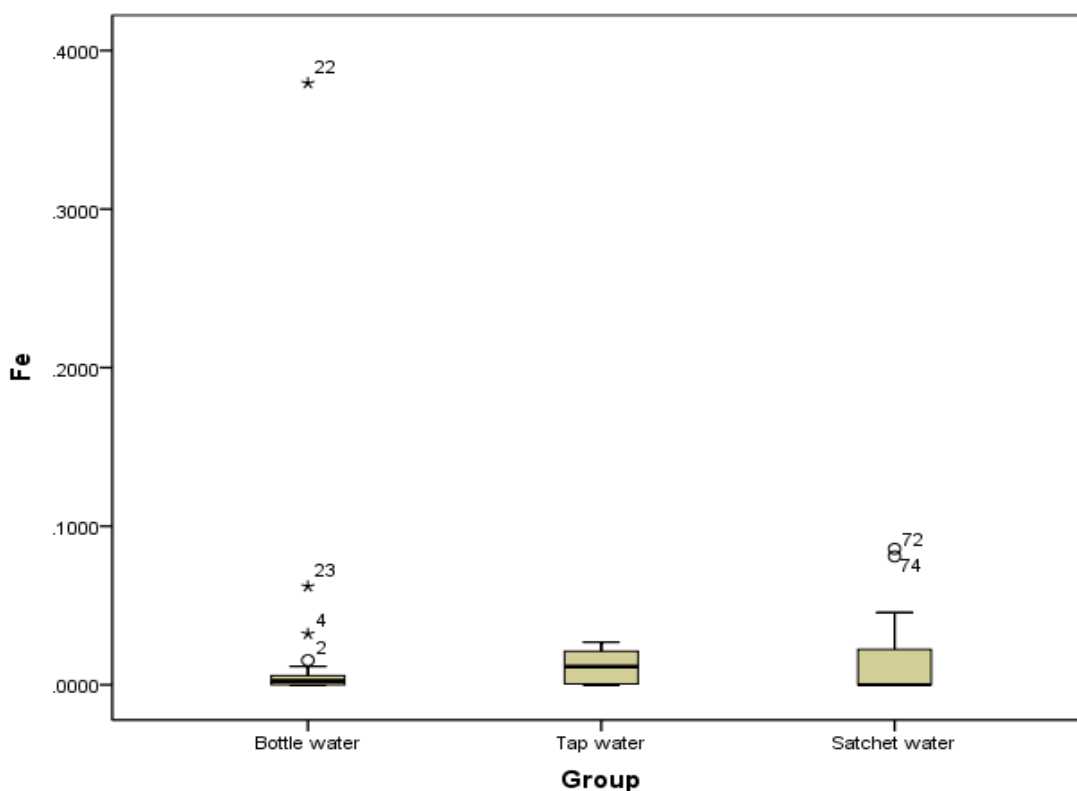
(lle)

Fig lle: Box-plot showing Fe concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)

(llf)

Fig llf: Box-plot showing Ni concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)
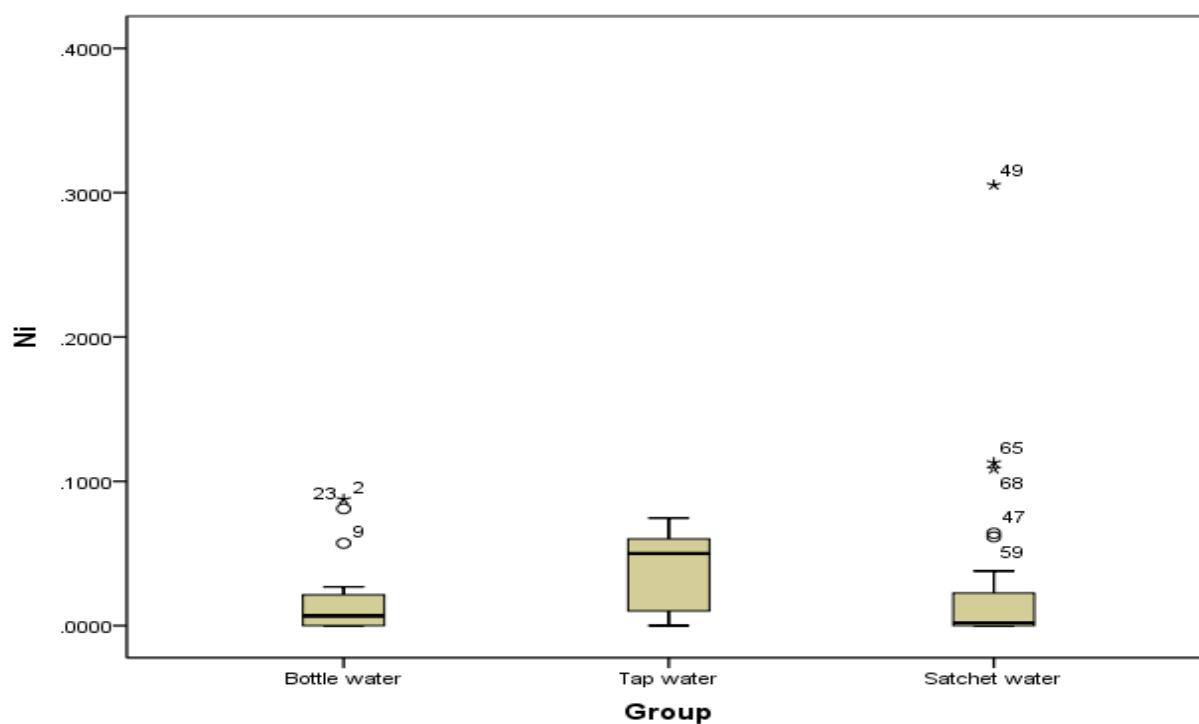
(llg)
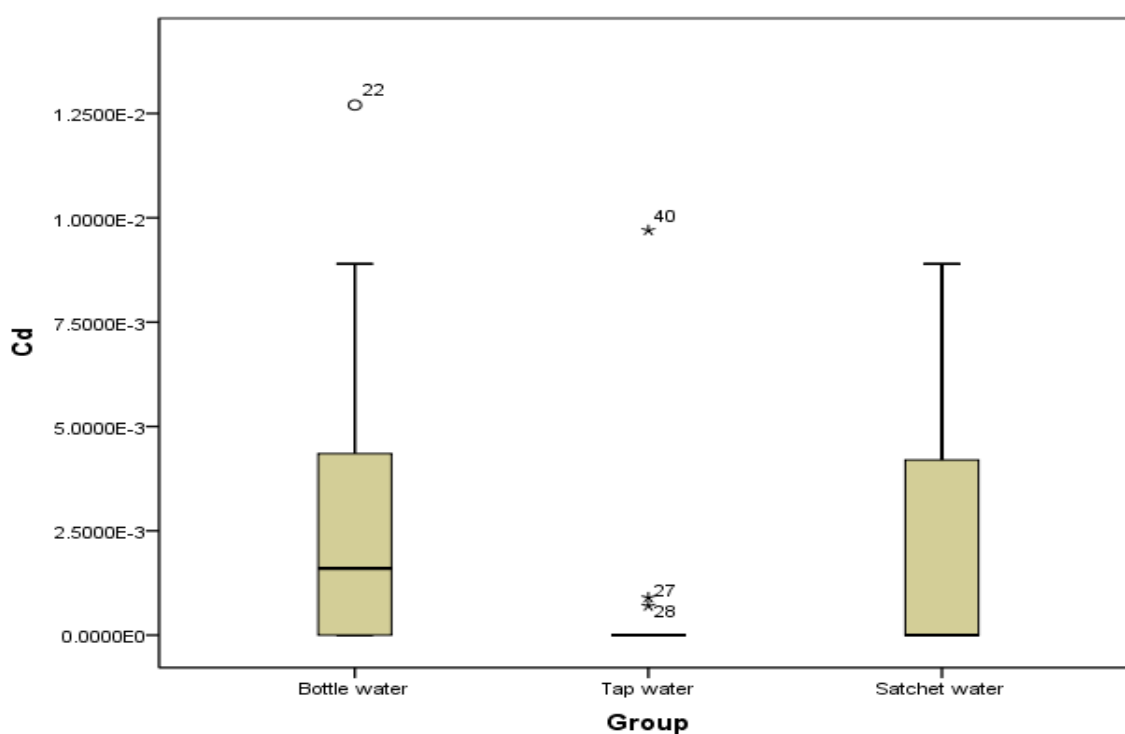
Fig llg: Box-plot showing Cd concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)

(llh)

Fig llh: Box-plot showing Pb concentrations in packaged (Bottled and Sachet) and tap water samples. Each box includes the 25th and 75th percentiles with the median as thick line; bottom and upper whiskers respectively show the smallest and largest values and the circles indicate the extreme values (outliers)

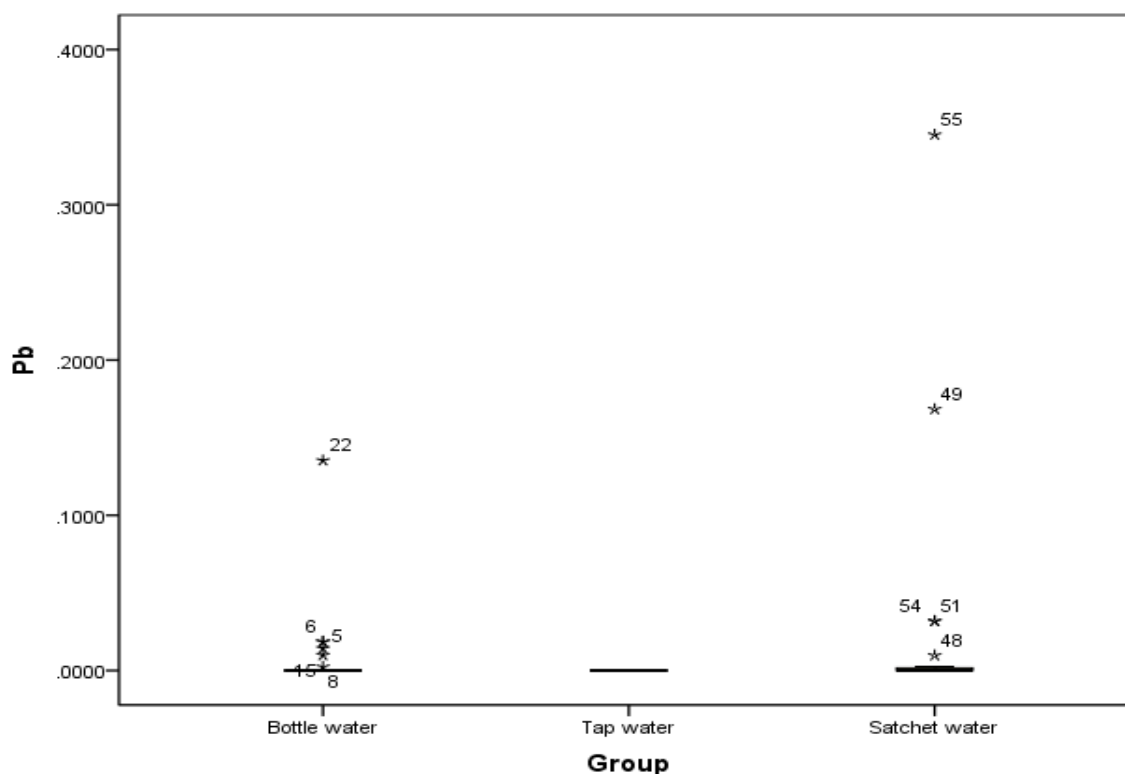This could be attributed to natural environment from which the water is taken (geological setting, climate, topography, etc.), source water composition and type of treatments applied during their production. Additional changes in the water chemistry may also occur during storage and transportation, especially when bottles and nylon become exposed to direct sunlight [28].

The chemical compositions (Cl^-, NO_3^-, SO_4^{2-}, Fe, Zn, Mn, Ni, Cd and Pb) in packaged and tap water samples in this study were compared with the Turkish, Malaysian and Italian studies, as shown in Table IV the concentrations of trace metals such as Fe, Zn, Mn, and other heavy metals in the studied packaged samples were higher than values reported by Azlan et al. [29] and G¨uler and Alpaslan [30]. A study by Naddeo et al. [31] showed that bottled water in Italy had higher mean concentrations in Fe, Mn, Pb, Cl^- and SO_4^{2-} than the studied bottled samples.

The studied tap water samples had lower Cl^-, SO_4^{2-} and heavy metal concentrations compared to Malaysian's and Egypt's tap water samples, except for the concentration of Ni and Cd.

3.1 Statistical analysis

Pearson's correlation coefficients among the contents of different ions are presented in Table V. The Zn and Mn (r = 0.35), Fe and Cd (r = 0.49), Mn and Pb (r = 0.68) pairs are positively correlated with each other significantly at the 99 % confidence level, which may

suggest a common source or a similar geochemical behavior for these metals.

The results of the ANOVA showed that no significant differences were observed between the packaged (sachet and bottled) and tap waters for EC, TH, SO_4^{2-}, Na, K, Fe, Mn, Ni, Cd and Pb. The Cl^- $F_{(2, 26)}$ = 3.78, p = 0.036 had concentrations in the sachet (11.80 mg/L) and bottled (16.45 mg/L) water samples respectively to be 1.21 and 1.76 times higher than in the tap water (9.35 mg / L). The Tukey post- hoc tests indicated that Cl^- concentration in bottled water differed significantly from tap water (p < 0.05). The NO_3^- content $F_{(2, 26)}$ = 3.79, p = 0.036 had concentrations in the sachet (8.07 mg/L) and bottled (8.35 mg/L) water samples respectively to be 2.32 and 2.41 times higher than in the tap water (3.47 mg/L). The Tukey post- hoc tests indicated that NO_3^- concentration in tap water differed significantly from sachet water (p < 0.05).

The Principal Component Analysis (PCA) of the water quality variables extracts four components with eigenvalue >1.0, which account 74.82 % of the total variance in the dataset (Table VI). The Kaiser-Meyer-Olkim (KMO) criterium for sampling adequacy (KMO=0.439). However, the correlation matrix and the Barlett's test of sphericity (χ^2(107.21) ≈ 55; p<0.00), both indicated that correlations between items were sufficiently large for PCA [22].

Table IV: Concentrations of chemical parameters in packaged (BW and SW) and tap (TW) water Samples from Lagos, Nigeria and other countries.

Parameters	Fe mg/L	Zn mg/L	Mn mg/L	Ni mg/L	Cd mg/L	Pb mg/L	Cl^- mg/L	NO_3^- mg/L	SO_4^{2-} mg/L
Country									
[a]Present study(SW)	0.02	0.05	0.04	0.03	0.002	0.02	11.8	8.07	6.94
[a]Present study(BW)	0.02	0.02	0.009	0.02	0.003	0.008	16.5	8.35	5.7
[b]Malaysia	0.011	0.0048	0.031	0.0015	0.00036	0.00026	34.46	1.16	9.35
[c]Turkey	0.0023	0.01	0.00009	0.00005	0.000037	0.000021	3.23	3.01	6.46
[d]Italy	0.182	0.045	0.627	0	0.000038	0.35	96.95	5.51	113.82
[a]Present study(TW)	0.003	0.009	0.02	0.03	0.001	nd	9.35	3.47	10.8
[b]Malaysia	0.058	0.034	0.025	0.00009	0.000041	0.000028	20.2	1.39	10.2
[e]Egypt	0.073	0.083	0.0052	0.0025	0.00004	0.00018	45.3	0.03	69.1

Sources: [a]Present study; [b]Azlan et al. [29]; [c]G¨uler and Alpaslan [30]; [d]Naddeo et al. [31]; [e]Saleh et al. [5].

Table V: Pearson's correlation coefficients between metals in drinking water samples

	Na	K	Zn	Mn	Fe	Ni	Cd	Pb
Na	1	0.082	-0.055	-0.095	-0.063	-0.081	-0.146	-0.142
K	0.082	1	-0.05	-0.09	-0.079	-0.146	-0.121	-0.106
Zn	-0.055	-0.05	1	0.353**	-0.027	-0.17	-0.146	-0.077
Mn	-0.095	-0.09	0.353**	1	-0.001	-0.09	-0.001	0.678**
Fe	-0.063	-0.079	-0.027	-0.001	1	0.044	492**	0.249*
Ni	-0.081	-0.146	-0.17	-0.09	0.044	1	-0.138	0.226
Cd	-0.146	-0.121	0.146	-0.001	0.492**	-0.138	1	0.194
Pb	-0.142	-0.106	-0.077	0.678**	0.249*	0.226	0.194	1

*Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table VI: Total variance explained and component matrix for parameters

Variable	Factor			
	component 1	component 2	component 3	component 4
EC			0.831	
TH			0.788	
Cl^-	0.865			
NO_3^-	0.845			
Na	0.724			
K	0.574			
Zn				0.965
Ni		0.884		
Pb		0.936		
Eigenvalue	2.357	1.828	1.527	1.022
Explained variance (%)	26.185	20.313	16.968	11.355
Cumulative % of variance	26.185	46.498	63.466	74.821

The first Principal Component (PC1) accounted for 26.85 % of the total variance and contains most of the information on the monovalent ions Cl^-, NO_3^-, K and Na (with loadings 0.86, 0.84, 0.57 and 0.72 respectively). The first principal component (PC1) can therefore be considered as a measure for the water saltiness [32]. The second Principal Component (PC2) explained 20.31 % of the total variance and is characterized by positive loadings in Mn and Pb (with loadings 0.88 and 0.94 respectively). This principal component can be considered as a measure of the anthropogenic inputs. The third Principal Component (PC3) explained 16.97 % of the total variance and contains information on the EC and TH (with loading 0.82 and 0.81 respectively) and mostly contains information on the water hardness. The fourth Principal Component (PC4) was mainly related to Zn which could be due to mineralization.

Hierarchical Cluster Analysis (HCA) using ward's method was performed to detect similarity group among the water samples (bottled, sachet and tap waters). The resulting dendrogram (Fig. III) has four clusters based on a similarity of nine parameters. The first cluster was predominant and characterized by
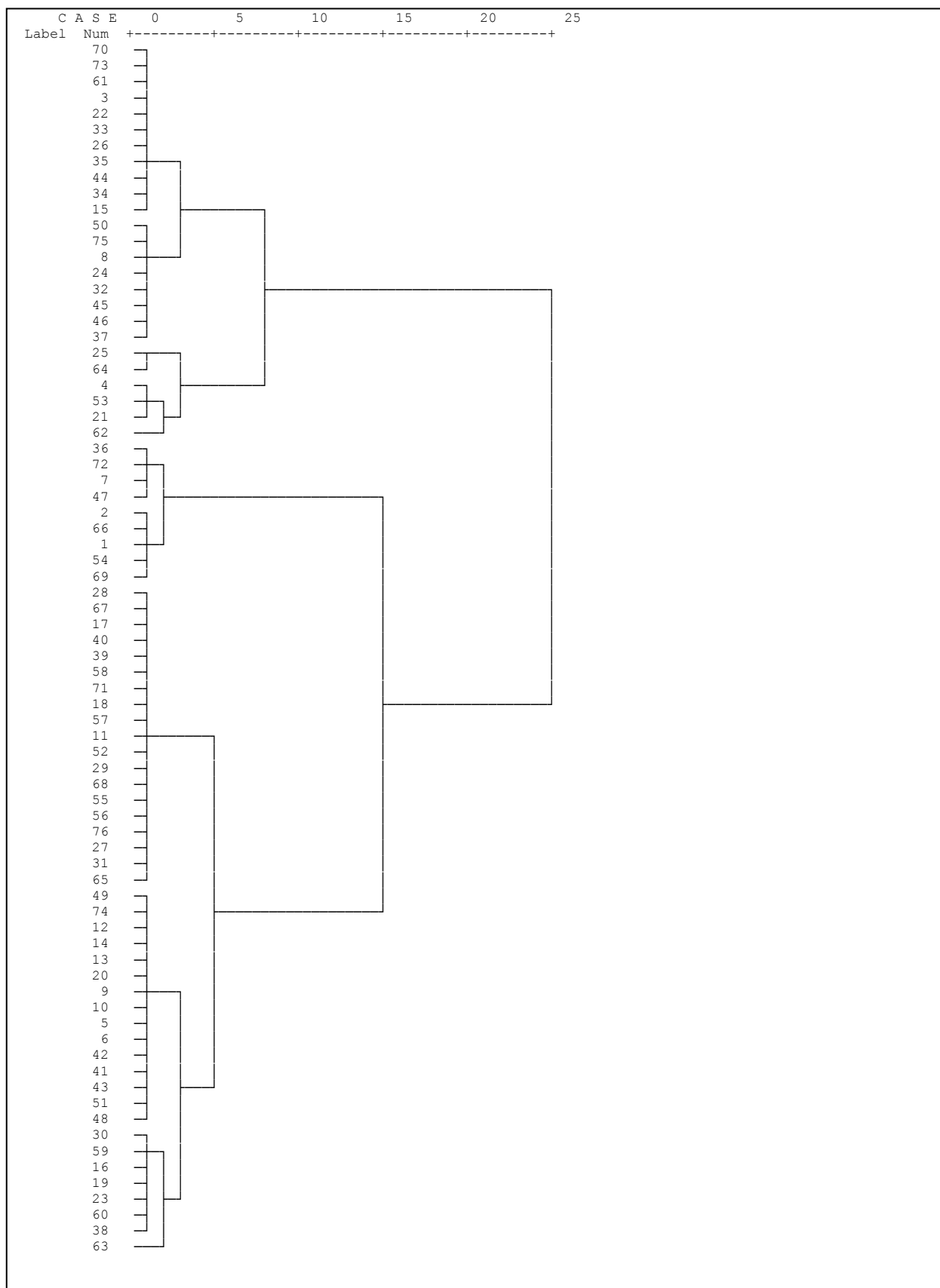
Fig. III: Heierarchical Dendrogram using Ward's method

high Cl^-, NO_3^-, Na and K. The second group represents the water brands Mn and Pb. The third cluster was essentially high EC and TH while the fourth group had high Zn. The results of HCA coincide with those obtained from PCA.

In Table VII the canonical discriminant function coefficients for the different variables are presented for the performed discriminant analysis. The eigenvalues of the discriminant functions are presented as well. Fig. IV presented the canonical discriminant functions for the different water types.

It can be seen that there are two discriminant functions. The Wilk's Lambda is statistically significant for one of the functions at a significance level $p < 0.05$. The first discriminant function (DF1) accounted for 70.2 %. The eigenvalue (2.09) and canonical correlation ($rc = 0.823$) values with small Lambda (0.171), a chi-square of 38.833 and $p = 0.003$. The second discriminant function (DF2) accounted for 29.8 %. The eigenvalue (0.890) and canonical correlation ($rc = 0.686$) values with a large Lambda (0.529), a chi-square of 14.00 and $p = 0.082$. Thus only one of the two functions explains the variation. The variables NO_3^- and Cl^- are strongly correlated with DF1, confirming previous findings: NO_3^- and Cl^- are the main discriminating factors between the packaged and tap water. 'Bottled water' (i.e group 1) has the highest mean, while 'tap water' (i.e group 3) has the lowest as shown in Fig. IV. In total 25 out of 29 water types were classified correctly. This corresponds with 86.2 % of the water types. This indicates that a considerable amount of discriminatory information was accounted for by the discriminatory variables.

Table VII: Canonical discriminant function coefficient (βi) for the different original variables and eigenvalues of the discriminant functions

Variable Function		
	1	2
EC	-0.321	-0.141
TH	-0.057	-0.11
Cl^-	1.037	-0.714
NO_3^-	0.564	0.42
Na	-0.536	-0.317
K	-0.753	0.659
Zn	0.89	0.27
Mn	-1.015	0.84
Pb	1.15	-0.238
Eigenvalue	2.092	0.89
% of Explained variance	70.2	29.8

4. CONCLUSION

In this study, the drinking quality of tap and packaged water in selected part of Lagos was investigated. In terms of the drinking quality, tap water is closely matching the bottled water. Therefore, tap water drinking quality should not pose any serious public threat. The results show that the concentrations of water constituents in both tap and packaged waters were within or below the threshold levels set for drinking water by the national and international standard. The only concern was the nitrate (NO_3^-) content, as 11 % and 20 % of bottled and sachet water respectively exceeded the USEPA standard of 10 mg L^{-1}.

The application of different multivariate statistical techniques, such as Correlation Analysis (CA), Principal Component Analysis (PCA), Hierarchical Cluster Analysis (HCA) and discriminant analysis were used to provide information on the composition of water and characterized them according to their sources. PCA identified four factors, which carry ~75 % of the total variance of the dataset. HCA classified the water samples into four different groups based on the similarity of water quality characteristics. Analysis of variance concluded that there exists a significant difference in NO_3^- and Cl^- concentrations between the packaged and tap water. The discriminant analysis revealed NO_3^- and Cl^- ions as the main discriminating factor.

One main recommendation of this study is that water supply and public health authorities should address the high level of chemicals present in an individual water supply that may pose a public health risk from long-term exposure. To protect human health, proper drinking water monitoring systems should be implemented to ensure that the physiochemical parameters of drinking water match acceptable national standards. A moderate use of packaged waters is also recommended. A reduced consume of bottled and sachet waters would also help to decrease the impact of plastic and nylon packaging on the environment, especially in Nigeria where recycling of plastic materials is very low at present.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

AUTHORS' CONTRIBUTIONS

Author 1' designed the experiment, and interprets the data using statistical analysis.
Authors 2 and 3 contributed to sampling, literature searches and references.
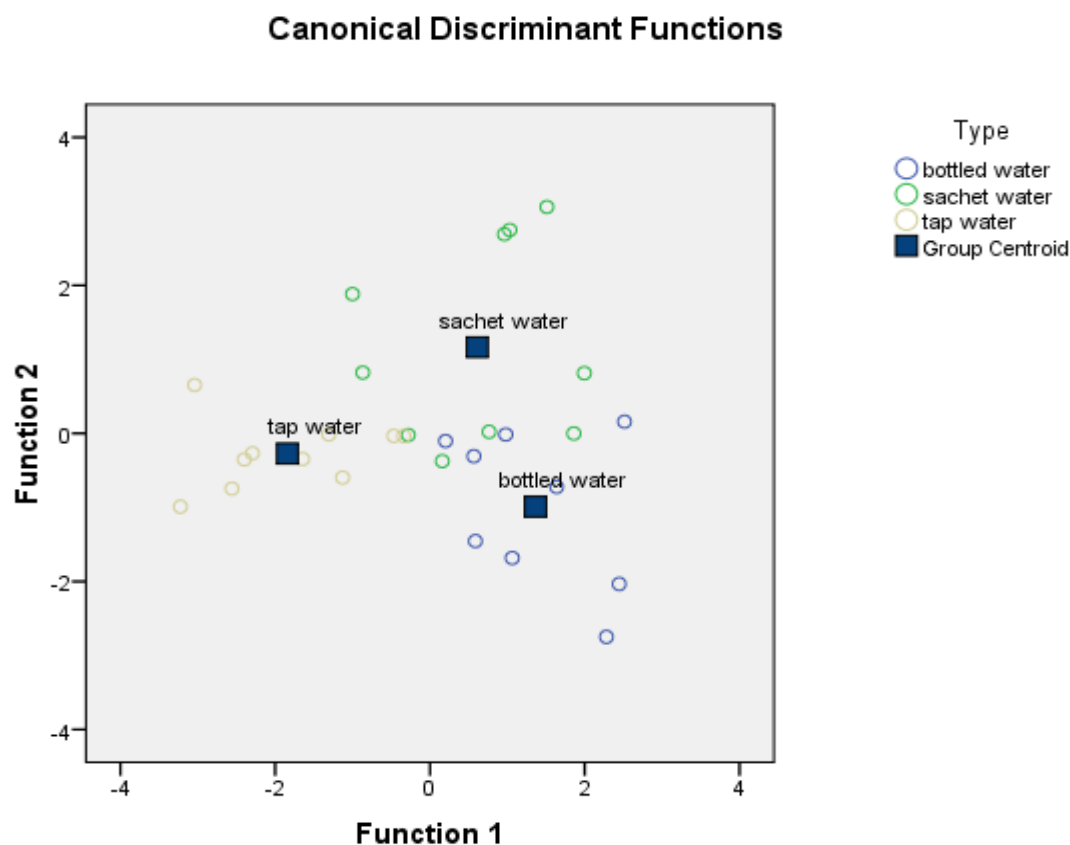All authors read and approved the final manuscript.

Canonical Discriminant Functions

Fig. IV: The canonical discriminant functions for the different water types: bottled water (o), sachet water (o) and tap water (o).

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