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Original Research Article

Assessment of the physical, chemical and microbiological quality of packaged water sold in Nnewi, South-East Nigeria: a population health risk assessment and preventive care study

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ABSTRACT

Background: Global statistics show that over 1.2 billion people do not have access to potable water and 70% of Nigerians lack access to potable water. Non-availability and/or lack of access to potable water predisposes people to preventable life-threatening conditions. This study assessed the physical, chemical, and microbiological quality of sachet and bottled water to generate evidence for planning, policy, and intervention.
Methods: The study was a cross-sectional analytic study of the quality of packaged (sachet and bottled) drinking water obtained from consumer households. The potability status of the water samples was assessed by means of qualitative assessments and quantitative laboratory tests. The results were compared to guideline values stipulated by the Nigerian Industrial Standard for Potable Water, NIS 306:2008. Data were analyzed using descriptive and inferential statistics. A p-value of <0.05 was considered statistically significant. The study period was from April 2016 to June 2016.
Results: Of the 35.0 bottled water samples, 18.0 (51.4%), 21.0 (60.0%) and 17.0 (48.6%) had their production dates, expiry dates and batch numbers. All 65.0 (100.0%) samples appeared colourless to the naked eye and visible particles were present in 3.0 (4.6%) of the total water samples. The lead content of 7.0 (23.3%) sachet and 1.0 (2.9%) bottled sample exceeded the guideline value for lead. The pH of 16.0 (53.3%) sachet samples and 27.0 (77.1%) bottled samples fell below the recommended limits for pH. *Escherichia coli* was found in 4.0 (13.3%) and 15.0 (42.9%) of sachet and bottled (water samples) respectively.
Conclusions: The study suggested that sachet and bottled water sold in Nnewi have good physical qualities, but poor chemical and microbiological qualities. More of the microbiological contaminant *(E. coli)* was present in the bottled water than the sachet water.

Keywords: Potable water, Quality, Public health, Packaged water, Disease prevention, Risk assessment, Nigeria

INTRODUCTION

Availability of potable water supply is essential for population health and sustainable development.[1] Studies have shown that 80% of diseases in the tropics are traceable to unsafe drinking water leading to more than 30% of associated preventable deaths.[2,3] In several West African countries including Nigeria, limited efforts have been made by the government in the provision of safe drinking water, prompting the growth of several private water-vending businesses to meet the demands of the teeming populace.[4] In Nigeria, drinking water is packaged for sale in plastic bottles (bottled water) or pouches (sachet water). The Nigerian Industrial Standard (NIS) for potable water was developed by the Standards Organization of Nigeria (SON) in 2003 in order to ensure that all packaged water (excluding mineral water) available to consumers is safe for consumption. The NIS 306:2008 is the second edition of the standard and draws on information from national, international and the World Health Organization (WHO) guidelines. The standard covers the quality (physical, organic and inorganic chemical, toxic chemical, microbiological, and disinfectants and their by-products), packaging, and transportation of the products. Other areas of coverage include the distribution, storage, sampling, and test requirements for packaged water in Nigeria.[6] In this standard, maximum permissible limits are set for the physical properties, chemical and microbiological constituents of packaged drinking water.

It also stipulates that the labeling on the packaged product should include the name of the product-packaged potable water, the brand name, and the net volume of water. Others include the factory name, location, batch number, manufacture, and best before dates, disposal information, and NIS mandatory conformity assessment (MANCAP) logo. The National Agency for Food and Drug Administration and Control (NAFDAC) registration number, is a mandatory requirement.[6] In Nigeria, the NAFDAC with the SON plays complementary roles in ensuring that all packaged drinking water sold in Nigeria is of the highest quality possible.[7,8] This study assessed the physical, chemical, and microbiological quality of sachet and bottled water to generate evidence for policy and intervention.

METHODS

Study location

The study was carried out in Nnewi, a commercial town in Anambra State Nigeria. According to the 2006 Nigerian census, Nnewi has a population of 155,443 inhabitants. Four villages make up the town- Otolo, Umudim, Uruagu, and Nnewichi. The town is known for her indigenous manufacturing industries and motorcycle spare-parts market; and houses several financial, educational and health institutions.

Study design

The study was a cross-sectional analytic study of the quality of packaged bottle and sachet drinking water sold in Nnewi.

Inclusion criteria

Included in the study were packaged water obtained from consumer households in Nnewi; all packaged water (sachet and bottle) produced by companies registered with the Association of Table Water Producers, Anambra State; other packaged water not produced by members of ATWAP, Anambra State, but enjoy a wide consumer base in Nnewi, was purposively included. To determine this, several packaged water vendors and distributors in each of the four villages that comprise Nnewi were asked for the brand names of packaged water often sold by them.

Exclusion criteria

Excluded from the study were packaged water not sold in Nnewi; packaged water already opened or found to have leaks.

Sampling technique

A preliminary investigation to identify popular brands among packaged water vendors and distributors to ensure representativeness of the samples was undertaken. Bottled and sachet water samples for analysis were obtained from the households selected for the study. Households were selected by means of a 2-stage sampling technique comprising stratified sampling and cluster sampling.

Study instruments

The physical parameters assessed were colour and turbidity. The colour and turbidity levels were determined using a bench-top multipurpose photometer. The chemical quality was assessed by measuring the values of certain chemicals that are of public health concern globally, and especially in the African region. They include fluoride, nitrate, lead, arsenic and cyanide.[11,12] Nitrate and fluoride contents were assayed by UV-Visible spectrophotometer, pH was determined by use of a digital bench-top pH meter; arsenic and lead were measured by flame atomic absorption spectrophotometer. Titrimetry was utilized for cyanide content assay. For microbiological quality, the *Escherichia coli* (*E. coli*) content was analysed using the membrane filtration method. *E. coli* was used as the indicator organism of choice in monitoring drinking water quality, as it is considered the most suitable indicator of fecal contamination of drinking water supplies.[7] The physical, chemical and microbiological parameters of all water samples were compared with their respective guideline values as stipulated in the Nigerian Industrial Standard for potable water, NIS 306:2008.

Data collection methods

All water samples found to have leaks were discarded. The ones intact were visually inspected for colour, particulate matter, and compliance with labeling instructions, after which they were kept in a cold box, transported to the laboratory, and analyzed. Analysis was done at Okeson and Chemical Associates, Onitsha; a laboratory approved and accredited by the Institute of Public Analysts of Nigeria (IPAN).

Study period

The study lasted from April 2016 to June 2016.

Data management

Data analysis

Frequency distributions of all relevant variables were developed. Relevant means, medians, and proportions were calculated. The means and medians of the measured water parameters were compared with the standard using the one-sample T-test and the Wilcoxon one sample signed rank test. A p-value of <0.05 was considered statistically significant.

Ethical considerations

The Nnamdi Azikiwe University Teaching Hospital Ethics Committee (NAUTHEC) gave ethical approval for the study.

RESULTS

A total of 65.0 packaged water samples (total population sample of 30.0 sachets and 35.0 bottled) were collected from households, visually inspected and further analysed in the laboratory. The compliance of all the packaged water samples with the required labeling was assessed. Table 1 show that sachet water fell below standard with respect to product labeling. Table 2 indicates that both the sachet and bottled water had good physical appearance. However, particulate matter was found in more of the bottled water samples.

Table 1: Packaged water compliance with labeling instructions.

Requirements	n (%)		
	Sachet	Bottled	Total
Production date			
Present	1.0 (5.3)	18.0 (94.7)	19.0 (100.0)
Absent	29.0 (63.0)	17.0 (37.0)	46.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Expiry Date			
Present	1.0 (4.5)	21.0 (95.5)	22.0 (100.0)
Absent	29.0 (67.4)	14.0 (32.6)	43.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Batch number			
Present	1.0 (5.6)	17.0 (94.4)	18.0 (100.0)
Absent	29.0 (61.7)	18.0 (38.3)	47.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Factory address			
Present	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Absent	0.0 (0)	0.0 (0.0)	0.0 (0.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
NAFDAC number			
Present	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Absent	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
NIS number/logo			
Present	0.0 (0.0)	9.0 (100.0)	9.0 (100.0)
Absent	30.0 (53.6)	26.0 (46.4)	56.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Metric volume			
Present	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Absent	0.0 (0.0)	0.0 (0)	0.0 (0.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)

Table 2: Visual inspection of packaged water samples.

Parameter	n (%)		
	Sachet	Bottled	Total
Visible colour			
Present	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Absent	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Presence of particles			
Present	0.0 (0.0)	3.0 (100.0)	3.0 (100.0)
Absent	30.0 (48.4)	32.0 (51.6)	62.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Location of company			
Nnewi	24.0 (64.9)	13.0 (35.1)	37.0 (100.0)
Within Anambra	4.0 (23.5)	13.0 (76.5)	17.0 (100.0)
Outside Anambra	2.0 (18.2)	9.0 (81.8)	11.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)
Was the sample expired?			
Yes	1.0 (33.3)	2.0 (66.7)	3.0 (100.0)
No	0.0 (0.0)	18.0 (100.0)	18.0 (100.0)
Indeterminate	29.0 (65.9)	15.0 (34.1)	44.0 (100.0)
Total	30.0 (46.2)	35.0 (53.8)	65.0 (100.0)

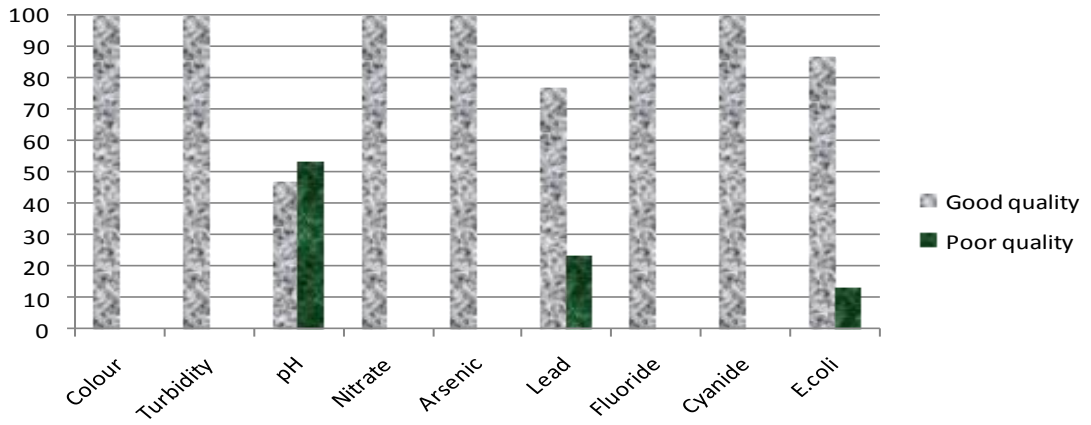

Figure 1: Bar chart showing quality of sachet water samples by percentage of measured characteristic.

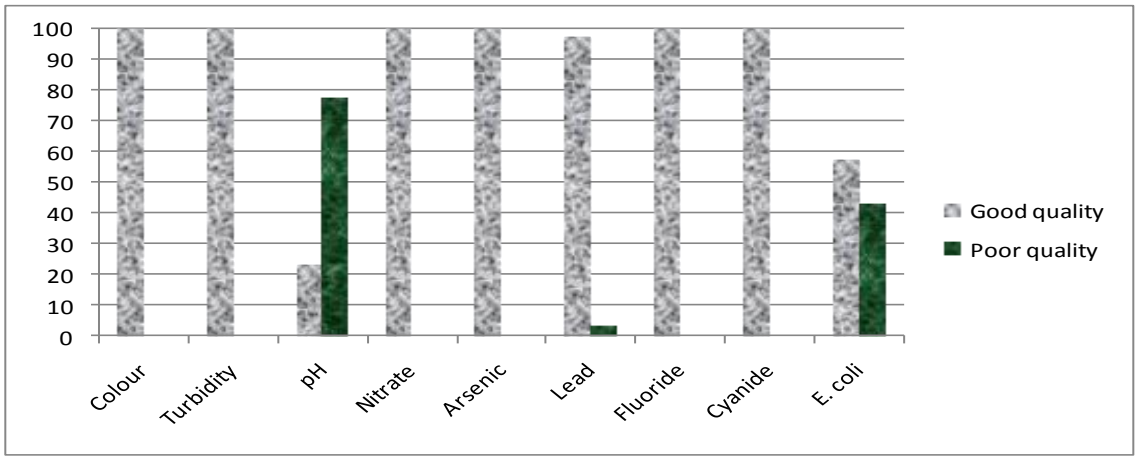

Figure 2: Bar chart showing quality of bottled water samples by percentage of measured characteristic.

Table 3: Comparison of packaged water parameters with standard guideline values.

		Sachet samples		Bottled samples	
Parameter	**Recommended max. limit**	**Median value**	**p value**	**Median value**	**p value**
Nitrate	10.00	1.10	0.000*	0.80	0.000*
Arsenic	0.01	0.00	0.000*	0.00	0.000*
Lead	0.01	0.00	0.160	0.00	0.000*
Fluoride	1.00	0.06	0.000*	0.01	0.000*
Cyanide	0.01	0.01	0.000*	0.00	0.000*
E. coli	0.00	0.00	0.059	0.00	0.001*
pH	6.5[a]	6.38**	0.337	6.06**	0.003*

*Statistically significant, ** Mean values, [a] NIS lower range standard.

Table 4: Comparison of differences between sachet and bottled water parameters.

Parameter	Mean rank		Test statistics	Significance
	Sachet (N=30)	**Bottle (N=35)**		
Nitrate	34.32	31.87	485.50[u]	0.603
Arsenic	34.75	31.50	472.50[u]	0.057
Lead	37.67	29.00	385.00[u]	0.003*
Fluoride	39.83	27.14	320.00[u]	0.007*
Cyanide	42.32	25.01	245.50[u]	0.000*
E. coli	27.57	37.66	362.00[u]	0.008*
pH	6.38	6.07	1.173[t]	0.092

*Statistically significant, [u] Mann-Whitney U test statistic, [t] T-test statistic.

Laboratory analysis showed that both the sachet and bottled water were in keeping with the stipulated NIS guideline values for colour, turbidity, nitrate, arsenic, fluoride and cyanide as observed in Figures 1 and 2. Table 3 compared packaged water parameters with standard guideline values using the Wilcoxon one sample signed rank test. It showed that the median values of nitrate, arsenic, fluoride and cyanide for both sachet and bottled water were lower than their respective guideline limits. This difference was statistically significant. There was also a statistically significant difference between the sachet and bottled water for lead, fluoride, cyanide, and *E. coli* as shown in Table 4.

DISCUSSION

Compliance with labeling instructions is a basic requirement for packaged water for consumption. Regulatory and enforcement agencies expect compliance with the fundamental parameters as shown in Table 1. However, sachet water fell below standard with respect to product labeling probably due to its lower cost compared to bottled water. Visual assessment was carried out for physical characteristics namely colour and presence of particulate matter, as shown in Table 2. Laboratory analysis of the colour and turbidity of the samples showed that these parameters in all the packaged water samples were in keeping with the regulatory guideline values. This is similar to findings from several other studies done in Nigeria.[6,13-16] Studies in Ghana and Ethiopia had similar findings.[17,18] While colour and turbidity play a role in the acceptability of water to consumers, turbidity determines the efficiency and effectiveness of the disinfection process. It signals the presence of contaminants that may pose a threat to health, especially when water is inadequately treated.[7] The conformity of the samples with guideline values for colour and turbidity may be due to the attention given to these parameters by the production companies; consumers can easily detect abnormalities in these parameters, which may decrease patronage of the brand.

The chemical parameters analyzed in this study were pH, nitrate, lead, arsenic, fluoride, and cyanide. The results of the pH analysis showed deranged values for 53.3% of the sachet and 77.1% of bottled water samples, which were statistically significantly below the lower reference limit. Some other studies carried out in Lebanon, Ethiopia and Nigeria had similar finding.[19-21] However, others done in Saudi-Arabia and Ghana had different finding.[18,22] The pH of drinking water determines the degree of corrosion of the metals which came in contact with the water, and the efficacy of the water treatment disinfection process.[7] The study indicated a significant variation of these key elements with reference standards. Table 3 shows some elements of key importance in the determination of water potability compared with their standard values. Contamination of water supplies with nitrate is often due to agricultural activities that involve the use of fertilizers. The health effects of nitrate stem from its ability to cause methaemoglobinaemia in humans, especially in infants fed with milk or water containing high levels of this compound.[7] This study showed that the nitrate level in all the samples studied was significantly lower than the

maximum recommended limit. The study done by Onweluzo and Akuagbazie in Nsukka, Enugu State, South-Eastern Nigeria, also reported normal levels of nitrate for both sachet and bottled water brands.[23] Arsenic, a toxic, naturally occurring chemical in the earth's crust, was significantly lower than the recommended maximum concentration in all the water samples studied. Chronic exposure to arsenic has been shown to cause dermal lesions, neuropathies, cancers of the skin, bladder and lung and peripheral vascular disease.[7] These results indicate that the water supply from which the samples were produced are free from these chemicals as reported by Asubiojo et al, or the water factories were diligent in the treatment process.[24]

Lead is a heavy metal used in the automotive industry for the manufacture of batteries, lubricating agents and other alloys. When taken in excess, it adversely affects the reproductive, renal, gastrointestinal, central and peripheral nervous systems, and upsets the activities of several other organs of the body.[7] In this study, the lead content of 12.3% (7 sachet and 1 bottled) of the 65 water samples was above the guideline limit. This result coincides with that obtained from a study carried out in South Eastern Nigeria by Orisakwe and colleagues.[7,35] The affected water samples were produced by factories located in Nnewi. This finding could be explained in either of two ways: water production factories in Nnewi use lead pipe systems leading to corrosion by acidic water or the lead produced by industries in Nnewi might have leached into the water source.

The comparisons made between sachet and bottled water suggested significant variations in lead, fluoride, cyanide, and *E. coli* as shown in Table 4. The content of fluoride in all the water samples was significantly lower than the recommended limit. Fluoride is a naturally occurring chemical in drinking water, which protects against dental caries in humans, and which, in excess leads to dental and skeletal fluorosis. The protective effect of fluoride is achieved at a minimum concentration of 0.5mg/l in drinking water.[7] The concentration of fluoride in the drinking water was so low that none of the samples had up to 0.5 mg/L of fluoride, thus offering no protection from dental caries whatsoever. The study done in Ibadan, Nigeria also found low levels of fluoride in sachet water samples.[15] The reason for the observed result in this study may be related to the low fluoride content in the groundwater in South Eastern Nigeria.[24] Cyanide has toxic effects on the function of the thyroid gland and exacerbates Vitamin B12 deficiency. While no sample exceeded the maximum limit, more than three-fourths of the sachet samples had the maximum permissible concentration of cyanide. This was also the case for about a quarter of the bottled samples. This does not give enough room for errors, in view of its toxicity. This is dissimilar to findings by Ajayi et al in Ibadan, Nigeria where high levels of cyanide were observed in sachet water samples.[15]

The microbiological characteristics of the packaged water varied. This study showed that both sachet and bottled water were contaminated with *E coli*. The presence of *E coli* indicates recent faecal contamination and provides evidence of inadequacy of the treatment process, or a breach in the integrity of the distribution system. The finding is similar to that from some studies in Maiduguri, North Eastern Nigeria and in Dhaka, Bangladesh that have demonstrated *E. coli* and other faecal coliforms in drinking water.[13,27] Microbial contamination by faecal coliforms has been attributed to poor compliance of packaged water vendors with standard operational procedures, poor hygienic conditions, and inadequate pipeline maintenance.[28,29] Water contaminated by faecal coliforms are a potential route of transmission of infectious pathogens which makes it an issue of public health concern.[30-32] However, two studies carried out in Nigeria and Ghana did not detect any pathogenic organisms in sachet and bottled water.[18, 27] Results demonstrated a statistically significant proportion of bottled water containing *E. coli* than sachet water, indicating that sachet water sold in Nnewi is safer than its bottled water counterpart. This does not agree with findings from some other studies, which seem to place bottled water on a higher safety pedestal than sachet water; citing the production process and packaging for bottled water as being better than that of sachet water.[15,23]

This study shows that all water, whether sachet or bottle, can be unsafe for human consumption if the basic principles of proper hygiene, treatment and quality monitoring are not followed. Since it is difficult to contaminate bottled water after packaging and there is yet no substantial evidence that *E.coli* multiplies appreciably in drinking water, the bottled samples may have been contaminated at some point during the production process, thus pointing to poor quality assurance process of the factories.[7,35] The sachet water contamination might have occurred at any point during the production, distribution, or storage process by virtue of its packaging. The presence of E coli in the packaged water samples indicates that the population of Nnewi is at risk of water-borne diarrheal diseases, especially in the absence of any further treatment of this drinking water source.[34,35]

CONCLUSION

The study suggested that not all packaged water marketed in Nnewi is safe for human consumption, as certain parameters of public health importance were not in keeping with the Nigerian standard for packaged drinking water. The sachet and bottled water have good physical qualities, but poor chemical and microbiological qualities. Lead was in excess of its recommended guideline value in both sachet and bottled water, but more in sachet than bottled water. The fluoride content in both sachet and bottled water was in keeping with the NIS guideline value, but it was too low to provide any protection from dental caries. More of the

microbiological contaminant *(E. coli)* was found in the bottled water than the sachet water. The Nigerian drinking water regulating agencies should improve on the monitoring and evaluation process of packaged water to ensure strict adherence to the stipulated standards.

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Ethical approval: The study was approved by the Institutional Ethics Committee

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