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Chemical Quality of Bottled Water in Nigeria: A Systematic Review

Ojatta, Dominic Oteino, PhD
The Federal Polytechnic Idah (FPI), 271001, Idah, Kogi State, Nigeria
E-mail: oteinoojatta@yahoo.com

Abstract
The global surge in bottled water consumption is attributed partly, to consumers perception that bottled water is superior than tap in terms of physical, microbial, and chemical qualities. However, a comprehensive study on the actual chemical quality parameters of bottled water, especially in developing countries like Nigeria, with less stringent monitoring, to justify this claim is lacking. This paper provides a synthesis of literature on chemical quality of bottled water in Nigeria. A systematic review of available peer-reviewed literatures was conducted using adapted Preferred Reporting Items for Systematic Reviews and Meta- Analysis (PRISMA) model. A total of seventeen peer-reviewed studies were descriptively analysed. The finding shows that most bottled water samples analyzed breached the chemical quality guidelines prescribed by Standards Organization of Nigeria (SON). This finding has implications for bottled water consumption, water and public health policies, and marketing strategy in developing countries.

Keywords: *Bottled water; Chemical parameters; Aluminium, Arsenic, Barium, Cadmium, Copper, Cyanide, Fluoride, Lead, Manganese, Nickel, Nitrate, Quality guidelines; Nigeria*

1 Introduction

The surge in the consumption of bottled drinking water is generally attributed to consumers underlying perception that bottled water is safer than tap (Prasetiawan et al. 2017), even as the bottled water sector promotes the product on the basis of purity and health (Platikanov et al. 2017). According to Spar and Benebek (2008) the Bottled Water market is built on "perception". In recent times, however, several studies have argued that bottled water may not necessarily be safer or better than tap water (Collins & Wright 2014; Pant et al. 2016; Dias & Bernardes 2016; Ferrier 2001; De Queiroz et al. 2013). Thus, the wholesomeness of bottled water products has become a contentious issue especially in developing countries like Nigeria, where adequate public water supply is lacking (Kaur et al. 2015), water quality is less monitored (Vorosmarty et al. 2005), and less than 20% of Nigerians have access to safely managed drinking water (World Bank 2018).

Different aspects of bottled water quality have been investigated in Nigeria: microbial (Igbeneghu & Lamikanra 2014; Akinnibosun & Ugbawa 2018; Sule et al. 2017); physical (Oluyege et al. 2014; Onoja et al. 2015); and chemical qualities (Adelana et al. 2002; Bolawa & Adelusi 2017; Abasiekong et al. 2016). In addition to individual studies on microbiological quality, a comprehensive literature on microbiological quality of bottled water, in the form of systematic literature review and meta-analysis exists (Odeyemi, 2015). However, despite that several studies on chemical quality of bottled water in Nigeria have been equally conducted, a synthesis of the literatures on the chemical quality of bottled water in Nigeria is still lacking. Besides, though guideline values (GVs) for trace and metal elements in drinking-water are established in Nigeria, an all-inclusive information on actual compliance with the GVs by operators is scarce.

Whereas this lack can limit bottled water research, policy, and marketing strategy, undertaking this study is needed to inform government drinking water policy, managers' marketing strategy, consumers' choice of drinking water alternatives, and enriching bottled water literatures in Nigeria. The objective of this paper is to conduct a systematic appraisal of peer-reviewed literatures on the chemical quality of bottled water in Nigeria, in order to describe the phenomenon. The ultimate aim is to collate and compare findings with guideline values for chemical parameters to determine the level of compliance with regulators' standards for chemical parameters. The question this study intends to answer is, "In the context of weak drinking water regulatory controls, what are the levels of compliance of bottled water samples, with the SON GVs for the chemical parameters in Nigeria?" The following section is a review of literature on the regulated chemicals the likely health and acceptability effects.

2 The Regulated Drinking Water Chemicals

Drinking water chemicals that are regulated by the World Health Organization (WHO 2017) and the Standards Organization of Nigeria (SON 2015) are sometimes loosely and broadly classified as heavy metals and trace metals, (Abasiekong et al. 2016), macro- and micro – nutrients (Prashanth et al. 2015), or micronutrients and heavy metals (Blum et al. 2009). Inappropriate composition of these elements constitutes chemical contamination - levels of various trace or metal elements outside the permitted drinking-water parameters. A recent study suggest heavy metals are harmful to human health

(Zhao et al. 2017). Trace and metal elements in drinking-water are regulated because of their potential influence on consumers' choice and health (WHO 2011). For the purpose of this study, we adopt the heavy metal and trace metal classifications to represent the normally toxic and the micronutrient categories.

2.1 The Heavy Metals and the Health significances

Heavy metals are elements having densities greater than 5.0 g cm^3 and denote metals and metalloids that are associated with pollution and toxicity but also include essential elements (Blum et al. 2009). Some of the most vital drinking water metals or elements are fluoride, nitrates, heavy metals (Doria 2010), Copper, Cadmium, Zinc, Arsenic and Chromium (Ikudayisi et al. 2015; Njinga & Tshivhase 2017). According to Maduka et al. (2014) the heavy metals comprise of cadmium, chromium, lead, copper, iron, aluminium, manganese, zinc, magnesium, and calcium, while the anions are fluoride, sulphate, chloride, and nitrate. Arsenic, barium, cadmium, chromium, copper, cyanide, fluoride, lead, manganese, mercury, nickel, and nitrate are considered to be potentially toxic to health (Marcussen et al. 2013). In particular, lead is recognized as one of the most damaging substances in human environment (DeAngelis et al. 2015).

These heavy metals which also include mercury do not easily break down once they are in the environment and have toxic effects on humans (Bolawa & Adelusi 2017). Specifically, since barium has been linked to nephropathy in laboratory animals, it has been selected as the toxicological end-point of concern for the current guideline (World Health Organization 2017). Epidemiological studies have indicated a strong connection between incidence of cardiovascular diseases, kidney related disorder, neurocognitive effect, and cancer, on one part and metals such as cadmium, mercury, and lead, according to Saleh and Al-Doush, (1998) as cited by Abasiekong et al. (2016). Arsenic has been associated with cancer and cardiovascular diseases (Phung et al. 2017). Chronic arsenic toxicity (arsenicosis) in humans has been linked to incidences of chronic lung disease, liver fibrosis (non-cirrhotic portal fibrosis), polyneuropathy, peripheral vascular disease, hypertension, non-pitting oedema of limbs, conjunctival congestion, weakness, and anaemia. (Guha Mazumder 2017). Njinga and Tshivhase (2017) investigated Pb, Cd, and Cr in drinking water in Nigeria and report high risk of adverse health outcomes emanating from Pb, Cd, and Cr.

2.2 The Trace Metals and the Health and Acceptability significances

Trace elements mostly denote "elements that occur in natural and perturbed environments in small amounts and that when present in excessive bioavailable concentrations, are toxic to living organisms. Micronutrients are those elements essential in biological processes (Blum et al. 2009 p.56). The extreme levels of trace metals or elements, usually toxic to human body health have been associated with numerous deadly ailments, such as cancers (Al-Fartusie & Mohssan 2017). Some elements identified as trace metals are Ca, Mg, Fe, Mn, Se, and Zn (Islam et al. 2018).

These elements are vital because of their likely effect on human health (Swaine 2000). In fact, it has been suggested that imbalance in trace element metabolism and homeostasis may have important role in a diversity of diseases and disorders (Zhang 2017). Although small amounts of trace metals are essential for metabolic activities of the human body, they can constitute adverse health effects at high levels of concentrations (Bolawa & Adelusi 2017). Evidence of an inverse relationship between coronary heart disease mortality, and magnesium and calcium in water exists (WHO 2005). It has also been posited that protracted consumption of demineralized water relates to micronutrient deficiencies, especially in calcium and magnesium. Such deficiencies have been linked to high incidences of dieresis, hypertension, and coronary heart disease (Akpoborie & Ehwarimo 2012).

In addition to the health consequences, inappropriate levels of the micronutrients in drinking water, can affect the aesthetic perceptions of the water, thus making acceptability an issue. For example, high concentrations of Manganese, Nitrate (NO3), magnesium (Mg+2), chloride, sodium (Na), sulphate (SO4), zinc (ZN), and the total dissolved solids (TDS) can, and do affect the taste of drinking water. Iron (Fe+2) and chlorine affect both taste and odour, pH - taste and appearance, and Aluminium - colouration. Acceptability of drinking-water organoleptic attributes is crucial because according to World Health Organization (2017 p.219), “water that is aesthetically unacceptable can lead to the use of water from sources that are aesthetically more acceptable, but potentially less safe”. From the foregoing, it is evident that compliance with Guideline Values for chemical parameters is imperative. In the context of Nigeria, extant literature on chemical qualities have made differing conclusions on the level of compliance of bottled water products with the GVs. The detail of chemical parameters investigated, samples in the studies, and the relevant studies are profiled in Table 1.

3 Methods

This study is a systematic review of literatures that examined the chemical quality of bottled water in Nigeria. This methodology is justifiable because systematic reviews are considered as ideal method for chemical risk assessments (Phung et al. 2017). The present study does not include a meta-analysis, nor does it have a review protocol, because the since the studies are not experimental, the effect sizes (f^2) were not reported. The preferred reporting items for systematic reviews and meta- analysis (PRISMA) statement guided the review.

3.1 Criteria for inclusion of materials

For any study that was included, it must have been a peer-reviewed material, assessed chemical quality of bottled water and analysed bottled water samples collected from any part of Nigeria. Such study must also have identifiable number of samples analysed and clear objective(s), methods, and results.

3.2 Search strategy

For literature search, online databases, journal home pages and search engines were used. These include ProQuest, Web of Science, Scopus, Emerald, Springer, Francis, Taylor online, and Google scholar. For Web of Science, ProQuest and Scopus, the search term(s) were “Bottled water OR packaged water OR mineral water OR table water AND chemical quality OR trace elements AND Nigeria” while for others, it was "bottled water" "packaged water" “mineral water” "chemical quality" "trace metals" "heavy metals", depending on which is most amenable to the databases. The limiter used in some cases included “scholarly articles”. As shown in Figure 1, down from 1077 peer-reviewed articles found, only seventeen met the inclusion criteria and were thus included.

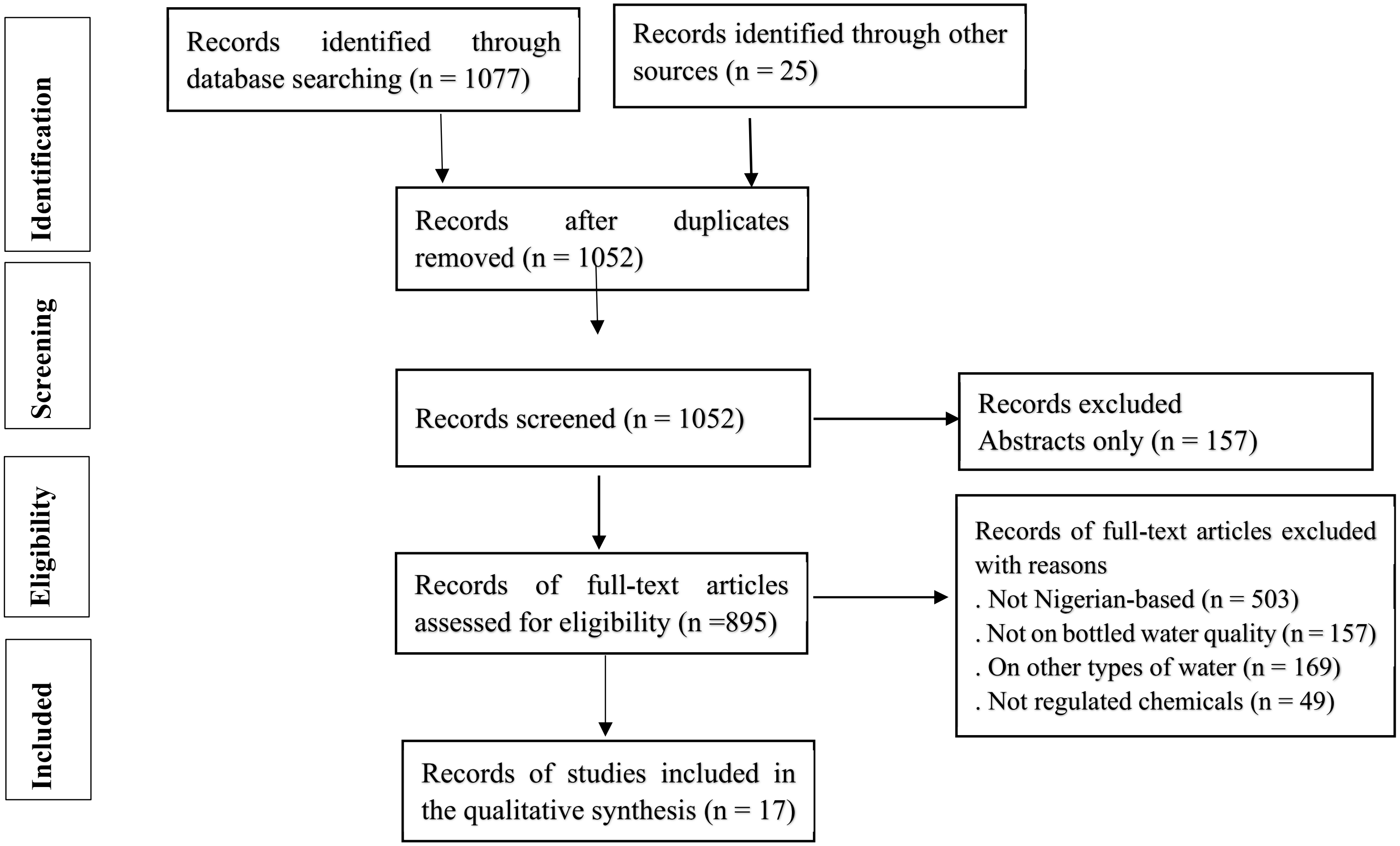

Figure 1: PRISMA Flow chart of information through the different phases of the systematic review.
Source: doi: 10.1371/journal.pmed. 1000097.g001(Moher et al. 2009)

3.3 Data extraction

Data on the study characteristics such as chemical parameters and number of bottled water samples analysed by each study were extracted. This study focuses on the chemical parameters because it is regulated by the drinking water quality guidelines in Nigeria, can influence consumers' choice of drinking water option, and increase the consumers overall health-risk ratio. The information on the results of the analyses - whether contaminants were detected or not, and the proportion of samples that tested positive (+) and negative (-) were extracted.

3.4 Analysis

Data extracted were analysed descriptively in tables and charts using SPSS software. Specifically, the number of each of the studies done on chemical quality, percentage of positive and negative occurrence of contaminants (level of compliance with the GVs) were tabulated and charted.

3.5 Profile of parameters and studies in the review

Overall, twenty-three chemical constituents were investigated in the seventeen studies included in this review. Table 1 shows the chemicals investigated, the number of studies and the total sample sizes. Majority of the chemicals were investigated by at least five studies. Sample sizes for seven and eight of the elements are above hundred and fifty, respectively. The least numbers of study that investigated an element (Arsenic, Barium, Cyanide, and Fluoride) is one – Inam et al. (2010) and Ajayi et al. (2008), while the most investigated are Iron, (10 studies), Chloride (10 studies), and pH (10 studies). Mercury is the only regulated metal that was not investigated by any of the studies, thus indicating the need to include it in future studies. The results of these studies were collated and compared with SON's guideline values.

Table 1: The regulated drinking water chemicals and the existing studies in Nigeria

S/No.	Chemicals	Studies	Number of studies	Total sample
1.	Aluminium (Al)	(Maduka et al. 2014; Inam et al. 2010; Ajayi et al. 2008)	4	57
2.	Arsenic (As)	(Inam et al. 2010)	1	40
3.	Barium	Inam et al. 2010)	1	40
4.	Cadmium	(Abasiekong et al. 2016; Akpoborie & Ehwarimo 2012; Ogunfowokan et al. 2008; Inam et al. 2010; Nkono & Asubiojo 1997; Bolawa & Adelusi 2017)	6	108
5.	Chromium	(Ogunfowokan et al. 2008; Nkono & Asubiojo 1997; Akpoborie & Ehwarimo 2012; Inam et al. 2010; Ajayi et al. 2008; Bolawa & Adelusi 2017)	6	83
6.	Copper	(Abasiekong et al. 2016; Okoli et al. 2007; Njoku et al. 2015; Duru & Ike 2017)	4	60
7.	Cyanide	(Ajayi et al. 2008)	1	10
8.	Fluoride	(Ajayi et al. 2008)	1	10
9.	Lead (Pb)	(Nkono & Asubiojo 1997; Njoku et al. 2015; Akpoborie & Ehwarimo 2012; Inam et al. 2010; Ogunfowokan et al. 2008; Bolawa & Adelusi 2017)	6	102
10.	Manganese (Mn)	(Nkono & Asubiojo 1997; Njoku et al. 2015; Inam et al. 2010; Bolawa & Adelusi 2017)	5	89
11.	Mercury (Hg)	Nil	Nil	Nil
12.	Nickel (Ni)	(Ogunfowokan et al. 2008; Nkono & Asubiojo 1997; Inam et al. 2010; Bolawa & Adelusi 2017)	4	85

13.	Nitrate (NO^3)	(Anyanwu & Nwigwe 2015; Onoja et al. 2015; Taiwo et al. 2010; Okoli et al. 2007; Njoku et al. 2015; Akpoborie & Ehwarimo 2012; Ajayi et al. 2008; Duru & Ike 2017)	8	92
14.	Hardness	(Anyanwu & Nwigwe 2015; Taiwo et al. 2010; Onweluzo & Akuagbazie 2010; Ajayi et al. 2008; Sule et al. 2017)	5	72

Table 1 continued

S/No.	Chemical	Studies	Number of studies	Total sample
15.	Iron (Fe^{+2})	(Abasiekong et al. 2016; Taiwo et al. 2010; Adelana et al. 2002; Okoli et al. 2007; Onweluzo & Akuagbazie 2010; Njoku et al. 2015; Inam et al. 2010; Ajayi et al. 2008; Bolawa & Adelusi 2017; Duru & Ike 2017)	10	167
16.	Magnesium (Mg^{+2})	(Abasiekong et al. 2016; Adelana et al. 2002; Njoku et al. 2015; Akpoborie & Ehwarimo 2012; Ajayi et al. 2008; Bolawa & Adelusi 2017)	6	81
17.	Chloride	(Onoja et al. 2015; Abasiekong et al. 2016; Anyanwu & Nwigwe 2015; Taiwo et al. 2010; Adelana et al. 2002; Onweluzo & Akuagbazie 2010; Akpoborie & Ehwarimo 2012; Ajayi et al. 2008; Duru & Ike 2017; Sule et al. 2017)	10	169
18.	Chlorine	(Taiwo et al. 2010; Ajayi et al. 2008)	2	31
19.	pH	(Ogunfowokan et al. 2008; Anyanwu & Nwigwe 2015; Abasiekong et al. 2016; Taiwo et al. 2010; Adelana et al. 2002; Okoli et al. 2007; Onweluzo & Akuagbazie 2010; Njoku et al. 2015; Akpoborie & Ehwarimo 2012; Ajayi et al. 2008)	10	122
20.	Sodium (Na)	(Adelana et al. 2002; Onweluzo & Akuagbazie 2010; Bolawa & Adelusi 2017)	3	47
21.	Sulphate (SO^4)	(Maduka et al. 2014; Anyanwu & Nwigwe 2015; Onoja et al. 2015; Taiwo et al. 2010; Adelana et al. 2002; Okoli et al. 2007; Onweluzo & Akuagbazie 2010; Njoku et al. 2015)	8	104
22.	TDS	(Ogunfowokan et al. 2008; Anyanwu & Nwigwe 2015; Abasiekong et al. 2016; Taiwo et al. 2010; Adelana et al. 2002; Akpoborie & Ehwarimo 2012; Ajayi et al. 2008; Duru & Ike 2017)	8	108
23.	Zinc (Zn)	(Ogunfowokan et al. 2008; Nkono & Asubiojo 1997; Abasiekong et al. 2016; Okoli et al. 2007; Njoku et al. 2015; Inam et al. 2010; Ajayi et al. 2008; Bolawa & Adelusi 2017; Duru & Ike 2017)	9	104

4 Assessment of Chemical Parameters of Bottled Water in Nigeria

According to the World Health Organization (2011 p.26) “Assessment of the adequacy of the chemical quality of drinking-water relies on comparison of the results of water quality analysis with guideline values”. That makes it imperative to look at the guideline values for chemical parameters in Nigeria (Table 2). Chemical contaminants that have been associated with some illnesses are aluminium, arsenic, barium, cadmium, and chromium. Others are copper, cyanide, fluoride, lead, etc. As mentioned before, GVs were established for these chemicals both by the WHO (2011) and Standard Organization of Nigeria (SON) because of their health significances. Table 2 shows the list of chemicals regulated by SON. The table also indicates the GVs, and health and acceptability implications. The GVs are the maximum limit outside which drinking-water should be declared unfit for human consumption in Nigeria. Thirteen of the chemicals (S/Nos. 1-13) could have serious health impacts if GVs are exceeded in drinking water. The chemical elements which could have effect on the aesthetic properties of drinking water, when present at certain quantities, include Iron (Fe^{+2}), Magnesium (Mg^{+2}), Chloride, and chlorine. (S/No. 14 to 23).

Table 2: The regulated chemicals, health/acceptability significances, & guideline values in Nigeria

S/No.	Chemical	Health significance	Guideline value (Maximum) mg/l	Acceptability significance
1.	Aluminium (Al)	Potential neuro-degenerative disorders	0.2	Colouration
2.	Arsenic (As)	Cancer	0.01	
3.	Barium	Hypertension	0.7	
4.	Cadmium	Toxic to kidney	0.003	
5.	Chromium	Cancer	0.05	
6.	Copper	Gastrointestinal disorders	1	
7.	Cyanide	Very toxic to thyroid and nervous system	0.01	
8.	Fluoride	Fluorosis, skeletal morbidity	1.5	
9.	Lead (Pb)	Cancer, interference with vitamin D, toxi to peripheral nervous system, affect mental development	0.01	
10.	Manganese (Mn)	Neurological disorder	0.2	Taste
11.	Mercury (Hg)	Kidney and central nervous system	0.001	
12.	Nickel (Ni)	Possibly carcinogenic	0.02	
13.	Nitrate (NO^3)	Cyanosis, asphyxia	50	
14.	Hardness		150	Taste
15.	Iron (Fe^{+2})		0.3	Taste, colour
16.	Magnesium (Mg^{+2})		20	Taste
17.	Chloride		250	Taste
18.	Chlorine		0.2 - 0.25	Taste, odour
19.	pH		6.5- 8.5	Taste, appearance
20.	Sodium (Na)		200	Taste
21.	Sulphate (SO^4)		100	Taste
22.	Total dissolved solids		500	Taste
23.	Zinc (Zn)		3	Taste

Notice: *SON* Standard Organization of Nigeria
Source: (Standards Organization of Nigeria, 2007, 2015)

5 Results

Figure 2 is the composite bar chart showing details of the number of samples analysed for each of the chemicals on the SON list of regulated trace and metal elements. Only the thirteen chemicals that have health significances are included in the chart. Immediately below the charts are the names of the thirteen chemicals of interest. Next after that are the figures for total number of samples analysed by the 17 studies reviewed. Followed by that are the number of sample found to have complied with the GVs and those that failed compliance tests, respectively. The number of samples, number within and outside the GVs for each of the elements are clearly shown in figures and charts. The guideline value for aluminium (Al) set by SON is 0.2 mg/l of drinking-water. The total number of samples from four studies that profiled aluminium in bottled water is fifty-seven (57) (Figure 2). Based on the GV of 0.2, all samples

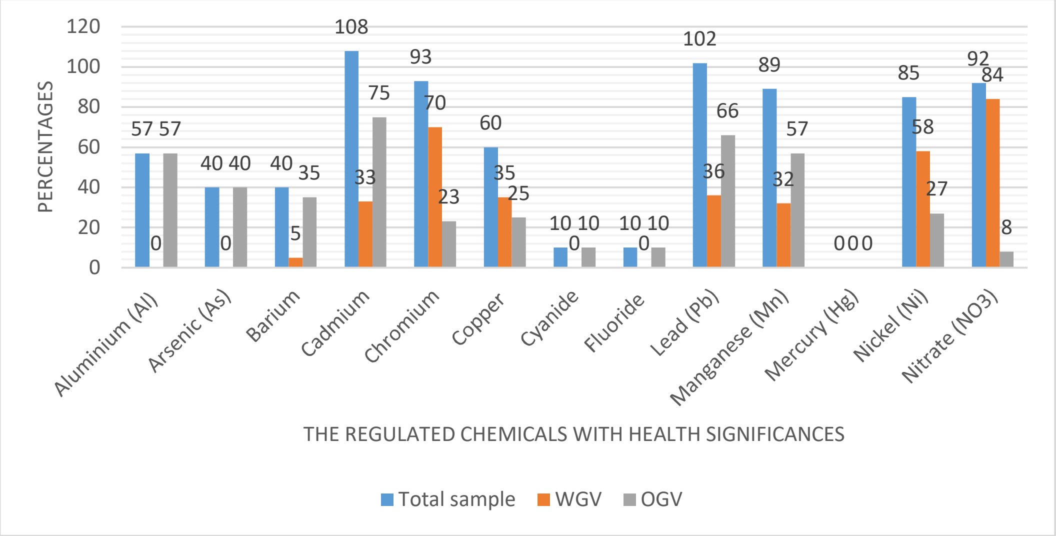

Figure 2: Chemical parameters: Sample size, % of samples within (WGV) and outside (OGV) based on SON Guideline Values, 2015

(100%) were found to be in violation. Prolonged ingestion of Al above the recommended by GV has been associated with a disease known as neuro-degenerative disorders (SON, 2015). For arsenic (As), forty samples were analysed by Inam et al. (2010). All the samples (100%) breached the GV is 0.01 mg/l established by SON. Again, this element is associated with cancer. Like all other chemicals in water, the effect of ingestion of high doses above the recommended parameters may not be immediate. For barium, cadmium, chromium, and copper, the GVs were 0.7, 0.003, 0.05 and 1.

Of the forty (40) samples analysed for Barium, thirty-five (87.5%) were in violation while only five (5) samples complied. The figures for cadmium, chromium and copper were 108, 93, and 60 for number of samples; 33, 70, and 25 for numbers in compliance with the GVs; and 75, 23, 25, for the samples whose values were higher than the GVs. This means 33%, 70%, and 35% levels of compliance for cadmium, chromium, and copper, respectively. As usual, cadmium, chromium and copper are associated with kidney toxicity, cancer, and gastrointestinal disorders, respectively (SON 2015). In particular, Que et al. (2010) suggest that cadmium affects the DNA damage-repair ability of lymphocytes. These are potential health risks consumers of bottled water in Nigeria are exposed to as a result of violation of GVs by stakeholders. While the GV for cyanide, a causative element for toxicity of the thyroid and the nervous system, is set at 0.01, the actual values of the ten (10) samples analysed in the studies were higher (Ajayi et al. 2008). Thus hundred percent (100%) of the samples were in violation of the GV. For fluoride, ten samples were analysed and found to be hundred percent (100%) in violation of the limits. Fluoride deficiency is associated with fluorosis and skeletal tissue morbidity (SON 2015). Although mercury has health significances in the context of kidney and central nervous system, none of the studies investigated it.

Lead and manganese had total number samples 102 and 89, number within GVs, 36 and 32, and numbers outside GVS of 66 and 57, respectively. For these two elements, this means about sixty-five percent (65%) of the samples had lead and manganese constituents higher than the GVs for drinking-water in Nigeria. In a study on heavy metals in Oman, Yaghi (2007) had found 80% of the samples in certain parts exceeded safe levels specified for lead and chromium. The areas of health impact of these elements in drinking water include cancer, mental under-development in children, toxicity to both central and peripheral nervous systems as well as neurological disorders (SON 2015). The last two elements analysed in the studies are nickel (Ni) and nitrate (No^3). With samples of 85 and 92, respectively, compliance with the GVs are highest for these elements. Fifty-eight (58) and eighty-four (84) samples, representing 68% and 91% complied with the set GVs, in that order. Nitrate is considered to be a causative element for asphyxia in children while nickel is considered to be possibly carcinogenic in nature (SON 2015).

6 Discussion of findings

Adequate knowledge of compliance with drinking water guidelines for chemical parameters is desirable. However, a comprehensive synthesis of peer-reviewed articles revealing the actual chemical quality parameters of bottled water products in Nigeria is arguably not available. This systematic review of available peer-reviewed literatures on bottled water chemical quality was conducted using adapted Preferred Reporting Items for Systematic Reviews and Meta- Analysis (PRISMA) model. A total of 17 peer-reviewed studies of bottled water samples in Nigeria were descriptively analysed. The finding suggests an exacerbated levels of breach of the guideline values established by the regulator (SON, 2015).

All samples analyzed for Aluminium breached the guideline values established by SON. The health implication is that folks that engaged in protracted use of bottled water in Nigeria are exposed more to incidences of potential neuro-degenerative disorders. Reduced visuo-motor coordination, poor long-term memory, and increased sensitivity to flicker among the elderly persons have been connected to elevated aluminium serum levels (Bowdler et al. 1979). Further, epidemiological research indicates that imbalance of aluminium in drinking water may aid the start and progression of Alzheimer's disease (Bondy 2016). Similarly, all samples of water analyzed for Arsenic (AS) violated the guideline values. This has a serious implication for disease incidence and control. Arsenic has been associated with cancer and cardiovascular diseases (Phung et al. 2017). Chronic arsenic toxicity (arsenicosis) in humans has been linked to incidences of chronic lung disease, liver fibrosis (non-cirrhotic portal fibrosis), polyneuropathy, peripheral vascular disease, hypertension, non-pitting oedema of limbs, conjunctival congestion, weakness, and anaemia. (Guha Mazumder 2017).

Abasiekong et al. (2016) referring to Al Saleh and Al-Doush, (1998) suggests a relationship between incidences of cardiovascular diseases, kidney related disorder, neurocognitive effect, and cancers, and the presence of cadmium, mercury, and lead. This connotes a higher incidence of these disease among consumers of bottled water in Nigeria. In other words, the risk-level of these ailments will be higher among bottled water consumers than otherwise. Given that the rates of violation of the GVs for lead and Cadmium are 69 and 65 percent respectively, the potential risk-level for these ailments calls for urgent regulatory actions.

Other than the health significances of the heavy drinking-water chemicals, violation of the GVs for other regulated trace elements that have acceptability significances should be of concern to consumers, managers, and drinking-water policymakers. Elevated levels of some of the trace elements can convey “water hardness” to the consumers. Although “hard water is good because it contains nutrients valuable in themselves and because these nutrients can decrease impact of toxic elements in the environment” (WHO 2005 p.95), the danger is that consumers can actually abandon drinking water that are regarded as “hard” without adequate health education. This has implications for health policy design and implementation in Nigeria and other developing countries of similar attributes.

In summary, all bottled water samples tested for Aluminium, Arsenic, cyanide, and fluoride were in violation of the GVs. In addition, majority of samples tested for barium, chromium, nickel, and Nitrate complied with the GVs while majority of samples tested for cadmium, lead and manganese breached the GVs. Therefore, it can be said that compliance with chemical quality guideline values has been grossly jeopardized, due in part, to the weak regulatory mechanisms found generally in developing countries. As consumption of bottled water surges in Nigeria, the long-run effects of chemical quality standard violations will be a heightened incidence of diseases and heavier disease burden on individuals, families, and the country in general. It is glaring that the rate of violation of guideline standards in relation to chemicals in bottled water in Nigeria is higher than the rate of compliance. Since this is unsustainable and is an impediment to the actualization of the UN SDG of universal access to safe and affordable water by the year 2030, the Nigerian Government and those of other developing nations should ensure adequate policy design and implementation. Managers should admit it is their responsibility to ensure safe and sustainable consumption through socially-responsive strategies, and where breaches are found, adequate sanctions and remedial actions should be enforced.

References

Abasiekong, K.S., Dim, F.A. & Azubike-Izah, F.O., 2016. Quality Evaluation of Sachet and Bottled Water in Isuochi Town of Abia State - South East Nigeria. *Food Science and Quality Management*, 50, pp.65–72.

Adelana, S.M.A., Olasehinde, P.I. & Vrbka, P., 2002. An assessment of chemical quality of bottled drinking water in Nigeria. *Water Resources – Journal of Nigerian Association of Hydrogeologist (NAH)*, 13(November), pp.12–18.

Ajayi, A.A., Sridhar, M.K.C., Adekunle Lola, V., & Oluwande, P.A., 2008. Quality of packaged waters sold in Ibadan, Nigeria. *African Journal Biomedical Research*, 11(3), pp.251–258.

Akinnibosun, F.I. & Ugbawa, I.A., 2018. Comparative Analysis of Bottled and Sachet Water sold in Urban and Rural Areas of Edo State, Nigeria. *Sierra Leone Journal of Biomedical Research*, 9(2), pp.19–27.

Akpoborie, I.A. & Ehwarimo, A., 2012. Quality of packaged drinking water produced in Warri Metropolis and potential implications for public health. *Journal of Environmental Chemistry and Ecotoxicology*, 4(11), pp.195–202.

Al-Fartusie, F.S. & Mohssan, S.N., 2017. Essential Trace Elements and Their Vital Roles in Human Body. *Indian Journal of Advances in Chemical Science*, 5(3), pp.127–136.

Anyanwu, E.D. & Nwigwe, N.C., 2015. Assessment of bottled water quality using physico-chemical indicators. *Applied Science Research Journal*, 3(1), pp.1–12.

Blum, W.E.H., Horak, O., Mentler, A., & Puschenreiter, M., 2009. Trace elements. In A. Sabljic, ed. *Environmental and Ecological Chemistry*. Singapore, pp. 156–164.

Bolawa, O.E. & Adelusi, O.S., 2017. Determination of Heavy Metal Profile in Bottled Water and Sachet Water Samples Obtained From Various Markets in Lagos , Nigeria. *Environment Pollution and Climate Change*, 1(2), pp.1–5.

Bondy, S.C., 2016. Low levels of aluminum can lead to behavioral and morphological changes associated with {Alzheimer}'s disease and age-related neurodegeneration. *NeuroToxicology*, 52, pp.222–229.

Bowdler, N.C., Beasley, D.S., Fritze, E.C., Goulette, A.M., Hatton, J.D., Hession, J., … Schmittdiel, C. J, 1979. Behavioral effects of aluminum ingestion on animal and human subjects. *Pharmacology, biochemistry, and behavior*, 10(4), pp.505–512.

Collins, H. & Wright, A., 2014. Still Sparkling : The Phenomenon of Bottled Water — An Irish Context. *Journal of Marketing Management*, 2(1), pp.15–31.

DeAngelis, K., Sanaie-Movahed, B. & Reibstein, R., 2015. Research note: low awareness of lead law. *International Journal of Sustainable Society*, 7(1), pp.86–95.

Dias, P. & Bernardes, A.M., 2016. Carbon emissions and embodied energy as tools for evaluating environmental aspects of tap water and bottled water in Brazil. *Desalination and Water Treatment*, 57(28), pp.13020–13029.

Doria, M.F., 2010. Factors influencing public perception of drinking water quality. *Water Policy*, 12(SUPPL. 1), pp.1–7.

Duru, C.E. & Ike, E.M., 2017. Quality Assessment of Popular Bottled Water Brands Sold in Owerri Municipal , Imo State , Nigeria. *International Journal of Chemical, Material and Environmental Research*, 4(2), pp.118–122.

Ferrier, C., 2001. Water Bottled: Understanding a social phenomenon. *AMBIO: A Journal of the Human Environment*, 30(2), pp.118–119.

Guha Mazumder, D.N., 2017. Health Impact of Bacteriological and Chemical Contamination of Drinking Water with Special Reference to Arsenic. In K. Nath & V. Sharma, eds. *Water and Sanitation in the New Millennium*. New Delhi: Springer, New Delhi, pp. 197–206.

Igbeneghu, O.A. & Lamikanra, A., 2014. The bacteriological quality of different brands of bottled water available to consumers in Ile-Ife, south-western Nigeria. *BMC research notes*, 7, p.859.

Ikudayisi, A., Adeyemo, F. & Adeyemo, J., 2015. Chemical and Hydro-Geologic Analysis of Ikogosi Warm Spring Water in Nigeria. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering*, 9(9), pp.1110–1114.

Inam, E., Kim, K.-W., Ebong, G., & Eduok, U., 2010. Trace Elements in Ground and Packaged Water in Akwa Ibom State, Nigeria. *Geosystem Engineering*, 13(2), pp.57–68.

Islam, M.R., Islam, M.R., Shalahuddin Qusar, M.M.A., Islam, M.S., Kabir, M.H., Mustafizur-Rahman, G.K.M., … Hasnat, A., 2018. Alterations of serum macro-minerals and trace elements are associated with major depressive disorder: a case-control study. *BMC Psychiatry*, 18(1), p.94.

Kaur, S., Tarannum, N. & Negi, A., 2015. Branded Bottled Water as Evidence of Product Tampering. *International Journal of Innovative Research*, 4(13), pp.17–19.

Maduka, H.C., Chukwu, .N.C., Ugwu, C.E., Dike, C.C., Okpogba, A.N., Ogueche, P.N., & Maduka, A. A., 2014. Assessment Of Commercial Bottled Table And Sachet Water Commonly Consumed In Federal University Of Technology,\nOwerri (FUTO), Imo State, Nigeria Using Microbiological Indices.\n. *IOSR Journal of Dental and Medical Sciences (IOSR-JDMS)*, 13(1), pp.86–89.

Marcussen, H., Holm, P.E. & Hansen, H.C.B., 2013. Composition, Flavor, Chemical Foodsafety, and Consumer Preferences of Bottled Water. *Comprehensive Reviews in Food Science and Food Safety*, 12(4), pp.333–352.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., & PRISMA Group, 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement (Reprinted from Annals of Internal Medicine). *PLoS Medicine*, 6(7), pp.1–6.

Njinga, R.L. & Tshivhase, V.M., 2017. Major Chemical Carcinogens in Drinking Water Sources : Health Implications Due to Illegal Gold Mining Activities in Zamfara State-. *Exposure and Health*, pp.1–11.

Njoku, C., Okoro, G.C., Igwe, T.S., Ngene, P.N., & Ajana, A.J, 2015. Evaluation of Water Sources in Abakaliki Southeastern Nigeria for Domestic Uses. *Journal of Agriculture and Ecology Research International*, 2(1), pp.87–91.

Nkono, N. A & Asubiojo, O.I., 1997. Trace elements in bottled and soft drinks in Nigeria--a preliminary study. *The Science of the total environment*, 208(3), pp.161–163.

Odeyemi, O.A., 2015. *Bacteriological safety of packaged drinking water sold in Nigeria: public health implications.*, Springer International Publishing.

Ogunfowokan, A.O., Oyekunle, J.A. O., Durosinmi, L.M., Amusa, N.A., Bbarinde, N.A., Akinyemi, A.J., & Onijamah, K.A., 2008. Quality of Some Commonly Consumed “Pure” and Bottled Waters in Ago Iwoye, Ogun State, Nigeria-A Comparative Study. *Ife Joumal of Science*, 10(l), pp.45–51.

Okoli, C.G., Ohiaeri, U.C., Obiekezie, S.O., Emereole, C.O., & Abanobi, O.C., 2007. Quality characteristics of commercial bottled water sold in Owerri, Nigeria. *International Journal of Tropical Agriculture and Food Systems*, 1(1), p.2007.

Oluyege, J.O., Olowomofe, T.. & Abiodun, O., 2014. Microbial Contamination of Packaged Drinking Water in Ado-Ekiti Metropolis, South Western Nigeria. *American Journal of Research Communication*, 2(10), pp.231–246.

Onoja, U.S., Nweze, I.E., Agbo, M.O., Nnamani, P.O., Eke, F.N., Ivoke, N., Ejere, V.C., 2015. Evaluation of bacteriological quality and essential elements in commercially bottled / packaged water produced and marketed in Southeastern Nigeria. *African Journal of Microbiology Research*, 9(28), pp.1728–1737.

Onweluzo, J.C. & Akuagbazie, C.A., 2010. Assessment of the quality of Bottled and Sachet Water Sold in Nsukka town. *tropical Agriculture, food and Environment*, 9(2), pp.104–110.

Pant, N.D., Poudyal, N. & Bhattacharya, S.K., 2016. Bacteriological quality of bottled drinking water versus municipal tap water in Dharan municipality , Nepal. *Journal of Health, Population and Nutrition*, pp.1–6.

Phung, D., Connell, D., Rutherford, S., & Chu, C., 2017. Cardiovascular risk from water arsenic exposure in Vietnam: Application of systematic review and meta-regression analysis in chemical health risk assessment. *Chemosphere*, 177, pp.167–175.

Platikanov, S., Hernández, A., González, S., Luis Cortina, J., Tauler, R., & Devesa, R., 2017. Predicting consumer preferences for mineral composition of bottled and tap water. *Talanta*, 162(September 2016), pp.1–9.

Prasetiawan, T., Nastiti, A. & Muntalif, B.S., 2017. 'Bad' piped water and other perceptual drivers of bottled water consumption in Indonesia. *Wiley Interdisciplinary Reviews: Water*, 4(4), p.e1219.

Prashanth, L., Kattapagari, K.K., Chitturi, R.T., Baddam, V.R.R., & Prasad, L.K, 2015. A review on role of essential trace elements in health and disease. *Journal of Dr. NTR University of Health Sciences*, 4(2), p.75.

Que, T., Anh, N.T.K., Trang, N.T.P., & Chuong, P.V. Que, T., Anh, N.T.K., Trang, N.T.P., & Chuong, P.V., 2010. The double action of Cd2+ in the types and frequencies of chromosomal aberrations induced in human lymphocytes exposed to gamma rays. *International Journal of Low Radiation*, 7(2), pp.149–156.

De Queiroz, J.T.M., Doria, M.F., Rosenberg, M.W., Heller, L., & Zhouri, A, 2013. Perceptions of bottled water consumers in three Brazilian Municipalities. *Journal of Water and Health*, 11(3), pp.520–531.

Spar, D. & Bebenek, K., 2008. Profitable springs : the rise, sources, and structure of the bottled water business. *Entreprises et histoire*, 7(1), pp.100–118.

Standards Organization of Nigeria, 2015. *Nigerian Standard for Drinking Water Quality*, Abuja.

Sule, I.O., Agbabiaka, T.O., Saliu, B.K., Bello, A.B., & Adeboye, A.B., 2017. Bacteriological and Physicochemical Assessment of Selected Brands of Bottled Water in Ilorin , Nigeria. *Al-Hikmah Journal of Pure & Applied Sciences*, 4(August), pp.15–22.

Swaine, D.J., 2000. Why trace elements are important. *Fuel Processing Technology*, 65–66(10), pp.21–33.

Taiwo, A.M., Gbadebo, A.M. & Awomeso, J.A., 2010. Potability assessment of selected brands of bottled water in Abeokuta, Nigeria. *J. Appl. Sci. Environ. Mange.*, 14(3), pp.47–52.

Vorosmarty, C.J., Leveque, C. & Revenga, C., 2005. Fresh Water. In F. Rijsberman, R. Costanza, & P. Jacobi, eds. *Ecosystems and Human and Human well-being: Current State and Trends*. pp. 165–207.

WHO, 2005. *Nutrients in Drinking Water*, Geneva.

World Bank, 2018. Health Nutrition and Population Statistics. *Data and Statistics*, p.5. Available at: https://data.worldbank.org/indicator/SH.H2O.SMDW.ZS?end=2015&locations=NG-GH&start=2000&view=chart.

World Health Organization, 2017. Acceptability aspects: Taste, odour and appearance. In *Guidelines for Drinking-water Quality*. Geneva, pp. 1–631.

World Health Organization, 2011. *Guidelines for Drinking-water Quality.*, Geneva.

Yaghi, B., 2007. Heavy metal levels in tap water in Batina Region, Oman. *International Journal of Environment and Pollution*, 31(1–2), pp.219–229.

Zhang, Y., 2017. Trace Elements and Healthcare: A Bioinformatics Perspective. In S. B, ed. *Advances in Experimental Medicine and Biology*. Singapore: Springer, pp. 63–98.

Zhao, C.-P., Zhou, X.-J., Dong, K., Fu, J., Zhu, D.-D., An, S.-Q., & Zhu, H.-L, 2017. Potential ecological risk and speciation analysis of heavy metals in sediments from the Jialu River, China. *International Journal of Environment and Pollution*, 61(1), pp.72–88.