Expo Health (2016) 8:285–304
DOI 10.1007/s12403-016-0195-9

CrossMark

REVIEW PAPER

A Review on Heavy Metal Concentration in Potable Water Sources in Nigeria: Human Health Effects and Mitigating Measures

Sylvester Chibueze Izah[1] · Neelima Chakrabarty[2] · Arun Lal Srivastav[3]

Received: 26 December 2015 / Revised: 13 January 2016 / Accepted: 14 January 2016 / Published online: 27 February 2016

Abstract Nigeria is one of the most populated black nation in the world with a population of about 170 million. Over the years, potable water source which is one of the basic essential requirements for healthy living has been challenging due to inadequate controlled anthropogenic activities and by lesser extent natural conditions. This paper reviews the various potable water sources, heavy metal concentration, and its associated health effects in Nigeria. The study found that surface water such as stream, river, lake; ground water including borehole and hand-dug well; rain water; and packaged water such as bottled and sachet are the major source of potable water. The dominant heavy metals found in potable water include iron, zinc, copper, chromium, lead, and manganese. The concentration of heavy metals like mercury, lead, cadmium, iron, cobalt, manganese, chromium, nickel, zinc, and copper often exceed the maximum permissible limit recommended by standard organization of Nigeria and World Health Organization. The concentration of heavy metals fluctuates in most states/geographical coverage depending on the type of potable water sources. To a large extent, industrialization causes heavy metals concentration to exceed the permissible limits. The high concentration reported in most locations could cause various disease conditions depending on the type of metal and level of exposure. This study also suggest possible treatment and mitigating measures to avoid such harmful effects.

Keywords Contamination · Health impacts · Heavy metals · Nigeria · Potable water pollutants

✉ Sylvester Chibueze Izah
chivestizah@gmail.com

Neelima Chakrabarty
neelima.chakrabarty@gmail.com

Arun Lal Srivastav
arunitbhu2009@gmail.com

[1] Department of Biological Sciences, Faculty of Science, Niger Delta University, Wilberforce Island, Bayelsa State, Nigeria

[2] Traffic Engineering and Safety Division, Central Road Research Institute (CRRI-CSIR), New Delhi, India

[3] Department of Chemistry, Indian Institute of Technology (BHU), Varanasi, India

Introduction

Due to massive growth of population, industries, and urban infrastructures in Nigeria, an upsurge has occurred in environmental degradation. The discharge of wastewater from industries has led to a decline in potable water resource (Mogborukor 2012). Now efforts are being made by Nigerian Government to improve the environmental condition of the country especially to control the industrial pollution (Ebiare and Zejiao 2010). Water pollution occurs either by natural processes such as weathering, decomposition of plants and animals remains or anthropogenic activities such as untreated wastewater discharge from agriculture, industries etc. Moreover, pressure on water resource is a major challenge for supplying safe drinking water to the community. According to Izah and Ineyougha (2015) and Kolo and Waziri (2012), potable water for human consumption must be free from any kind of chemical and microbial contaminants. Typically, the quality of water bodies differs depending on the location and environmental factors (Hosseinifard and Aminiyan 2015).

In Nigeria, most potable water sources get contaminated through anthropogenic activities. For instance, effluents of manufacturing industries such as mining (Miller et al. 2004), textile, metal, dying chemicals, fertilizers, pesticides, cement, petrochemical, energy and power, leather, sugar processing, construction, steel, engineering, food processing etc. typically contain several types of toxic elements (Idris et al. 2013) that could contaminate the nearby surface water during runoff after rainfall. Surface water act as dump site in some communities aligning surface water (rivers, creeks) in Bayelsa state, central Niger Delta (Agedah et al. 2015). The discharge of untreated effluents may increase the concentration of heavy metals in the surface water systems. In Nigeria, increasing water pollution is found due to the discharge of sewage as well as waste materials into water bodies and its adverse impact have been observed on the health of flora and fauna (Galadima et al. 2011).

Water pollution has become one of the greatest challenge to Nigeria especially in rural areas with low income (Muta'aHellandendu 2012). Anthropogenic inputs are more substantial than natural sources to alter the natural flow biogeochemical cycles (Omotoriogun et al. 2012). Intake of water without proper sanitation has been recognized as the leading cause of water-borne diseases. Heavy metals found in several potable water sources are due the natural and anthropogenic activities and are toxic to both health and environment at concentration (Oehmen et al. 2006; Burke et al. 2011) above the permissible guideline.

Metals which have $\geq$5 cm^3 specific gravity are known as heavy metals (Idris et al. 2013). Heavy metals' monitoring in potable water sources has been a serious concern to environmental scientists in recent times (Muhammad et al. 2011). Common heavy metals found in effluents are iron, manganese, copper, lead, cadmium, chromium, mercury, cobalt, nickel etc. (Musa et al. 2013; Muhammad et al. 2011; Kelepertzis 2014). These heavy metals in water are toxic even at very low concentration and can accumulate in the human body (Elinge et al. 2011) depending on the type. These heavy metals have some adverse effects on the living beings when they exceed permissible limit in potable water sources.

Typically, heavy metals in water cannot be degraded easily due to their complex bioaccumulation properties (Idris et al. 2013). Mercury, lead, zinc, cadmium, iron, cobalt, manganese, and chromium are quietly studied and reported in the potable water sources of Nigeria (Elinge et al. 2011). When humans are exposed to heavy metals above the permissible limits, disease conditions may occur. According to Kolo and Waziri (2012), heavy metals are very toxic and are mostly carcinogenic in nature because of their ability to accumulate in visual and sensory organs. They also possess the tendency to affect the tissue and other organs and cause various types of diseases including cancer. For instance, a recent review by Izah and Srivastav (2015) shows that arsenic could cause several diseases including cardiovascular, hematological, neurological, respiratory, gastrointestinal and birth disorders, dermatitis, and cancer on exposure.

Therefore, this study provides an outlook about the heavy metal contamination in the aquatic resources of Nigeria. Potential health hazards on human beings associated with the drinking water consumption with reference to Standard Organization of Nigeria, SON (2007) and World Health Organization, WHO (2011), and their remedial measures are also discussed. Likewise suggestions are given to reduce the negative health impacts on society regarding heavy metal contamination of drinking water.

Potable Water Sources in Nigeria

The demand for drinking water is increasing due to population growth. Around 50 % Nigerian suffers from huge scarcity of potable water (Galadima et al. 2011), which implies that about 80 million Nigerian are at risk of water-related issues. Water which is a vital resource for humans utilized in diverse means including domestic and drinking purposes comes from various sources such as ponds, streams, rivers (surface water), borehole, and shallow wells (groundwater), hence monitoring is important (Ebiare and Zejiao 2010). Fresh water is only recommended safe for human consumptions because it fits with the regulatory guidelines of WHO and SON. SON is the regulatory body who approves the standards of water quality in Nigeria for drinking purpose. However, 75 % of all fresh water are present in the form of glaciers and ice caps, 24 % are found in groundwater, and 1 % found in lakes, rivers, soils (Elinge et al. 2011). Apart from drinking, fresh water is also required for other domestic, industrial, and agricultural applications and which can be obtained mainly from lakes, streams, rivers, wells, taps, boreholes etc. or from underground water reservoirs (Galadima et al. 2011; Eruola and Adedokun 2012).

Ground Water

Groundwater serves as the most significant source of drinking water and provides about 50 % potable water around the globe (Afolabi et al. 2012). Groundwater is also the source of wells, boreholes, and springs water (Ukpong and Okon 2013). Groundwater occurring as borehole water is mostly found in urban areas. Similarly, well water from the ground directly are gathered during raining season from roof of building and transported to underground tank is also potable water sources in some region of Nigeria especially during the dry season. However, the borehole which is pumped out using submergible pump is the most source of groundwater supply. Other groundwater supply such as well water take preference when borehole water availability is scarce especially in rural areas.

Groundwater has been indiscriminately exploited for domestic, agricultural as well as industrial uses (Musa et al. 2013). Generally, groundwater is considered free from any contamination, but due to the anthropogenic and natural conditions, the quality is being declined (Musa and Ahanonu 2013). However, it is believed that groundwater is more clean than surface water because of the natural purification properties of the soil (Oludare and Sikiru 2012; Adefemi 2013). Typically, ground water contamination takes place through discharge of industrial effluent on soil (Musa and Ahanonu 2013). Groundwater may also be contaminated by soil erosion through water runoff into streams or leaching processes (Adegbola and Adewoye 2012).

The degree of groundwater contamination depends on the size of affected area, concentration, solubility, toxicity, and density of the contaminant. Rainfall pattern, water table depth, rate of filtration, rocks, and hydraulic features of the soils such as texture and structure are also regulatory factors for the groundwater contamination level (Musa and Ahanonu 2013). In Nigeria, borehole is a major source of drinking water for the people. Therefore most sub-Saharan people (Africa) health could be affected by toxic heavy metals present in groundwater (Kolo and Waziri 2012).

Surface water

Normally, water sources such as rivers, streams, ponds, and lakes are often termed as the surface water reservoir. These surface water sources are potable water supplies especially in area where groundwater such as borehole is lacking or inadequate. Water quality problem has been linked to water crisis in many countries (Chukwuma et al. 2013). Nigeria is blessed to have good numbers of rivers, creeks, ponds, and lakes available in the country (Agedah et al. 2015). Due to urbanization, may people have migrated to the urban areas from the rural regions in search of better source of livelihood. Besides human, pollutants of surface water may affect the fish and other aquatic organisms present therein (Dabai et al. 2013).

Rain Water

Rain water is the purest form of natural water and it is an alternative source of potable water supply for huge Nigerian population due to inadequate sources of groundwater supply especially in rural areas (Ubuoh et al. 2012; Chukwuma et al. 2013) depending on geographical location. However, rain water contains weak carbonic acid due to dissolution of atmospheric carbon dioxide during rainfall (Chinedu et al. 2011). Like other sources of fresh water, rainwater which is harvested as roof catchment is also used for domestic, agricultural, industrial, and environmental purposes (Chukwuma et al. 2013). Due to the presence of weak acids that rain water may contain, its consumption have decline even among the rural dwellers.

Packaged Water

Packaged water are usually supplied in the form of bottled and sachet water. About 70 % of Nigerians consume sachet water, because it is affordable and easily available (Oguntona et al. 2012). This implies that over 120 million Nigerian consumes sachet water. Bottled water is also available, however, consumed by relatively lesser percentage of the Nigerian population. The water packaging business has become a profitable venture. Typically some manufacturing industries are responsible for water pollution, when their factory is located adjacent to groundwater sources such as borehole (Oguntona et al. 2012).

Sources of Heavy Metal Pollutant in Potable Water in Nigeria

Heavy metals are metallic elements that have relatively high atomic weight and are poisonous even at low concentrations (Butu and Iguisi 2013). Heavy metals may contaminate the drinking water sources through natural or anthropogenic activities. Foroughi et al. (2011) reported that heavy metals enter into the environment through emissions from the industries like electroplating, metal finishing, textile, storage batteries, lead smelting, mining, plating, ceramic, and glass industries. According to Azizullah et al. (2011) and Khan et al. (2013), heavy metals have been major contaminants of surface and groundwater through several human activities like large-scale use of chemicals in agriculture and improper disposal of industrial and municipal wastes as well. In automobile industries, bearing wear, engine part, brake emission (David et al. 2013), and mining process are among the major sources of copper in environment. Idris et al. (2013) reported that pharmaceutical and personal care product's industries are also releasing adequate effluents without treatment which contain recalcitrant substances such as antibiotics, antiepileptics, tranquilizers etc into the environment. Muhammad et al. (2014) stated that mining activities have also accounted for heavy metal contamination with diverse concentrations in potable water resources of Nigeria especially in Northern region. According to Butu and Iguisi (2013), rivers flowing through the populated areas are highly vulnerable to heavy metal pollution due to urbanization and industrialization activities. Also geologic process could also be a major contributor.

Heavy Metal Concentration in Potable Water in Nigeria and WHO, SON, and USEPA Limits

Heavy metals are basically classified into essential and non-essential based on their biological functions. Essential heavy metals including iron, zinc, copper, chromium, cobalt, and manganese (Prashanth et al. 2015) are required by human health at concentration which could be beneficial to the body metabolites (Table 1). According to Prashanth et al. (2015), the daily requirement of essential heavy metals include 2–5 mg/day (manganese), 0.005 mg/day (chromium), 0.0001 mg/day (cobalt), 15–20 mg/day of which 99 % is found intracellularly and 1 % in the plasma (zinc), 1–2 mg/day of which 75 % is found in the blood and the rest 25 % in the bone marrow, liver etc. (iron) and 2–5 mg/day of which 50 % is absorbed from the gastrointestinal tracks (copper). Generally, these essential trace elements are taken in indirectly through consumption of different types of food products. Non-essential heavy metals that are commonly found in potable water include cadmium, lead, nickel, and mercury. However, at a concentration above the threshold limit thus exceeding the permissible limit for potable water as stipulated by SON and WHO such water could be detrimental to the organ/tissues of the body. Duru et al. (2012) stated that heavy metal's concentration above permissible limits are generally not safe for human consumption.

Heavy metals have been reported in drinking water sources in Nigeria. This section of the paper discusses the concentration of frequently reported heavy metals in potable water sources in Nigeria as well as the regulatory limit specified by WHO, SON, and USEPA. Table 2 shows the level of heavy metals that have been reported in potable water sources in Nigeria. However, in Nigeria heavy metals found in potable water sources often exceed the concentration recommended by SON, USEPA, and WHO (Table 3).

Iron

Iron is found in natural fresh water, though at a low concentration. The presence of iron in water enhances the growth of iron reducing bacteria that aid in the conversion of iron II to Iron III via oxidation (WHO 2011). The level of iron recommended is 0.3 mg/l (WHO) (Azizullah et al. 2011), 0.3 mg/l (SON), and 0.02 mg/l (EU) (Table 3). Iron level have also been found to exceed the maximum permissible limit prescribed by SON in the potable water sources across the country such as the surface water of Imo state (Duru et al. 2012), ground and surface water at Ebonyi (Afiukwa 2013), stream at Abia (Eze and Madumere 2012) etc. Similarly, Northern Nigeria have been reported with high iron concentration in different potable water sources such as sachet water in Kano (Uwah et al. 2014), borehole water in Kebbi (Elinge et al. 2011), surface water in Sokoto (Dabai et al. 2013), well and stream water in Kogi (Musa et al. 2013) etc. Southern part of Nigeria is also suffering with high iron concentration problems which has been reported by various authors in rain, surface as well as ground waters (Ohimain et al. 2013; Nwankwoala et al. 2011; Ubuoh et al. 2012; Uffia et al. 2013; Ukpong and Okon 2013; Olorunfemi et al. 2013; Omotoriogun et al. 2012). However, iron in potable water sources ranged from 0.00 to 43.09 mg/l, the highest concentration was recorded in groundwater of Bayelsa state. Generally, iron concentration is higher in South–south region as compared to other geographical locations. High iron in water sources in the Niger Delta has been attributed to the geology of the area. Ocheri et al. (2014) reported that the geology of the environment is the main factor controlling groundwater hydrology.

Copper

The permissible of copper limit is 1 mg/l (SON) and 2 mg/l (EU and WHO) (Table 3). High concentration of copper in potable water could give rise to taste. Copper concentration in potable water sources in Nigeria is considerably high in some states. Sachet water in Lagos state (Oguntona et al. 2012), ground water in Lagos (Akoteyon 2012), ground/surface water in Osun (Ayantobo et al. 2014), and surface water in cross rivers state (Ekpo et al. 2013a, b) have found to have greater concentrations of copper. However, water sources such as rain, well, surface, and ground waters of various states including Kebbi (Elinge et al. 2011), Kano (Uwah et al. 2014), Anambra (Chukwuma et al. 2013), Abia (Eze and Madumere 2012), Imo (Duru et al. 2012), Edo (Olorunfemi et al. 2013; Omotoriogun et al. 2012), Akwa Ibom (Ukpong and Okon 2013), Ogun (Anake et al. 2014), Oyo (Adegbola and Adewoye 2012; Akinyemi et al. 2014), and Bayelsa (Ohimain et al. 2013; Agbalagba et al. 2011) are found safe in terms of copper concentration. Generally, copper concentration were in the order; South-west > South–south > Northern region > south-east. Again, the high concentration occurred in groundwater, hand-dug well, and surface water. The source of copper in water in Lagos is due to the industrial activities near to the potable water source. High concentration in surface water may be due to runoff. However, the copper concentration in potable water sources ranged from 0.00 to 8.71 mg/l. The highest concentration was recorded in ground water in Lagos state.

Table 1 Beneficial biological functions of some essential heavy metals to human body

Essential heavy metal	Function	References
Iron	Participates in several biochemical/metabolic processes including oxygen transport, deoxyribonucleic acid synthesis, electron transport chain, and regulation of cell growth and differentiation	Lieu et al. (2002), Abbaspour et al. (2014) and Beard (2001)
	Physiological functions, and formation of hemoglobin, transferrin, ferritin, and some iron-containing enzymes	Sevcikova et al. (2011)
Zinc	Essential for taste acuity, prostaglandin production, bone mineralization, proper thyroid function, blood clotting, cognitive functions, fetal growth, and sperm production	Chasapis et al. (2012)
	Essential for wound healing, immune system function	Chasapis et al. (2012), Osredkar and Sustar (2011) and Prashanth et al. (2015)
	Essential for cell growth, development, differentiation, homeostasis, connective tissue growth and maintenance, DNA synthesis, RNA transcription, cell division, and cell activation	Chasapis et al. (2012) and Osredkar and Sustar (2011)
	Essential regulatory, catalytic, co-catalytic and structural roles in enzyme molecules	Nriagu 2007, Roohani et al. (2013), Chasapis et al. (2012) and Osredkar and Sustar (2011)
	The function of zinc in cells and tissues is dependent on metalloproteinase and these enzymes are related to reproductive, neurological, immune, dermatological systems, and gastrointestinal track	Prashanth et al. (2015)
	Regulation of body fluid pH, formation of collagen for hair, skin for nails growth, enhancement of mental development, and sexual functions such as prostate functioning and secretion of testosterone	Bhowmik et al. (2010) and Chasapis et al. (2012)
	Vital for normal spermatogenesis and maturation, genomic integrity of sperm, for normal organogenesis, proper functioning of neurotransmitters, proper development of thymus, proper epithelialization in taste sensation, and secretion of pancreas and gastric enzymes	Watson (1998) and Prashanth et al. (2015)
Copper	Normal iron metabolism and the formation of red blood cells (hemoglobin) synthesis, connective tissue metabolism, and bone development	Angelova et al. (2011), Prashanth et al. (2015) and Osredkar and Sustar (2011)
	Cell metabolism, and is a part of various enzymes such as tyrosinase, uricase, and cytochrome oxidase	Prashanth et al. (2015)
	Vital for variety of biological processes including embryonic development, mitochondrial respiration, regulation of hemoglobin levels as well as hepatocyte and neuronal functions	Krupanidhi et al. (2008)
	Vital for maintaining the strength of the skin, blood vessels, epithelial; production of myelin, melanin, and effective functioning of the thyroid gland; antioxidant (scavenges or neutralize free radicals and may minimize or help avert some of the damage they cause) and a pro-oxidant	Osredkar and Sustar (2011)
Manganese	Vital for the activation of enzyme and as a component of metalloenzymes	Prashanth et al. (2015)
	Essential for oxidative phosphorylation, fatty acids and cholesterol metabolism, mucopolysaccharide metabolism	Rehnberg et al. (1982) cited in Prashanth et al. (2015)
Cobalt	Essential for in methionine metabolism where it controls the transfer of enzymes such as homocysteine methyltransferase	Prashanth et al. (2015)
Chromium	Biosynthesis of glucose tolerance factor	Prashanth et al. (2015)

Copper is one of the vital substance to human life in trace concentration (Muhammad et al. 2014; de Namor et al. 2012), but its high concentration is lethal for living beings. Copper also enters drinking water through corrosion by the copper leaching pipe used in the supply/distribution of water to the homes (WHO 2011).

Mercury

Mercury is one of the harmful metals that is not need in water. WHO and SON standards for mercury concentration in drinking water is 0.001 mg/l, while EU permissible limit is 0.006 mg/l (Table 3). Mercury concentrations in

Table 2 Heavy metal status in potable water sources in Nigeria

Water source	State	Fe	Zn	Cd	Cr	Pb	Hg	Cu	Co	Ni	Mn	References
Southwestern states												
Well	Lagos	0.139–0.151	0.311–0.410	–	0.009–0.026	0.098–0.116	–	0.027–0.47	–	0.721–0.951	–	Afolabi et al. (2012)
Borehole		0.171–1.804	0.111–0.213	–	0.011–0.021	0.121–0.140	–	0.051–0.064	–	0.814–0.953	–	
Surface water		0.140	0.270	–	0.016	0.102	–	0.146	–	1.021	–	
Sachet water	Lagos	0.1–0.2	4.01–4.21	–	0.10–0.21	0.05–0.08	–	1.30–1.35	1.3–1.6	–	–	Oguntona et al. (2012)
Ground water	Lagos	0.0–10.16	1.40–55.18	0.02–0.32	0.0–0.04	0.0–3.14	–	0.02–8.71	–	–	0.04–30.0	Akoteyon (2012)
Borehole	Ogun	0.46–1.41	0.09–0.65	–	–	0.00–0.3	–	0.06–0.17	–	0.02–0.11	0.02–0.08	Anake et al. (2014)
Bottled		0.11–1.24	0.04–0.15	–	–	–	–	0.06–0.08	–	0.03–0.08	0.03–0.07	
Sachet		0.42–0.43	0.05–0.11	–	–	–	–	0.07–0.15	–	0.07–0.10	0.04–0.05	
Well		0.41–0.51	0.09–0.12	–	–	–	–	0.04–0.07	–	0.07–0.18	0.02–0.05	
Potable (distilled, borehole, tap, bottled and sachet water)	Ogun	0.00–0.145	0.00–0.03	–	–	0.00–0.086	–	–	–	–	–	Chinedu et al. (2011)
Surface water(chlorinated and unchlorinated, rain and river water)		0.074–0.302	0.00–0.007	–	–	0.04–0.183	–	–	–	–	–	
Borehole	Ogun	0.17–0.71	0.50–0.88	–	–	0.03–0.95	–	–	–	0.17–0.86	–	Amori et al. (2013)
Hand-dug well		0.11–0.98	1.49–1.97	–	–	0.01–0.014	–	–	–	0.17–0.99	–	
Hand-dug wells	Ogun	0.00–8.406	–	0.00–0.018	–	0.196–0.317	–	–	–	–	–	Eruola and Adedokun (2012)
River	Ondo	–	–	–	–	0.10–0.30	–	–	0.00–0.40	0.00–1.40	0.90–6.50	Adewumi et al. (2014a)
River/dam	Ondo	1.577–2.710	<0.001–0.051	0.00–0.007	0.033–0.064	0.00–0.016	–	0.363–0.800		0.293–0.950	0.165–0.527	Oyhakilome et al. (2012)
Well	Ondo	0.1–5.3	5.5–9.2	0.0	0.00–0.4	0.00–0.2		0.00–0.4		0.0–0.1	–	Adefemi and Awokunmi (2010)
River	Oyo	–	0.026–0.214	0.009–0.085	0.013–0.068	0.241–0.349	–	0.001–0.164	–	0.018–0.076	–	Akinyemi et al. (2014)
Ground water	Oyo	0.1–0.5	0.01–0.05	–	–	0.00–0.03	–	0.1–0.3	–	–	0.01–0.05	Adegbola and Adewoye (2012)
Surface/ground water	Osun	–	0.49–29.90	–	0.80–34.80	0.09–8.30	–	0.09–4.30	–	0.05–9.60	–	Ayantobo et al. (2014)
Surface water	Osun	0.79– 1.31	0.006–0.144	–	–	–	–	–	–	–	–	Abdus–Salam et al. (2013)
Boreholes and hand-dug well	Osun	–	0.01–0.07	0.00	6.1–7.7	0.11–0.19	–	–	–	–	0.02–0.06	Jeje and Oladepo. (2014)
Well	Ekiti	0.34–4.18	0.29–1.32	–	–	0.0–1.49	–	–	–	–	0.0–1.01	Adefemi (2013)
Stream		0.53	0.28	–	–	0.0		–	–	–	0.0	
River	Ekiti	1.20 –3.52	0.062–0.40	–	–	0.08–0.11	–	–	–	–	0.12–0.30	Samuel (2013)
South–south states												
Rainwater	Akwa Ibom	0.1–0.90	–	0.00–0.05	–	0.01–0.90	–	–	–	–	0.01–2.10	Ubuoh et al. (2012)

Table 2 continued

Water source	State	Fe	Zn	Cd	Cr	Pb	Hg	Cu	Co	Ni	Mn	References
Ground water	Akwa Ibom	1.8–8.3	1.3–2.9	0.00–0.50	0.0–0.25	0.01–0.54	–	–	–	–	0.0–1.4	Uffia et al. (2013)
Borehole	Akwa Ibom	0.03–0.05	0.00–0.160	–	–	–	–	0.020–0.180	–	–	–	Ukpong and Okon (2013)
Rivers	Akwa Ibom	0.82–87	0.21–0.37	–	–	–		0.03– 0.42	0.01–0.04	0.42–0.64	0.18–0.37	Denise et al. (2014)
Groundwater	Edo	0.1–6.4	0.0–4.5	–	0.0–0.3	0.0–0.1	–	0.0–0.3	–	0.0–0.1	0.0 0.2	Olorunfemi et al. (2013)
Surface water	Edo	0.3–0.37	0.07–0.27	0.04	–	0.08	–	0.04	–	0.05	0.03	Omotoriogun et al. (2012)
Surface water	Cross River	12.4	9.7	1.3	1.8	6.3	–	3.7	–	–	–	Ekpo et al. (2013a)
Borehole	Cross Rivers	0.66–1.52	0.0–0.05	–	–	0.0–0.07		0.0–0.03		–	0.03–0.21	Ekpo et al. (2013b)
Rivers	Cross Rivers	0.95–5.11	0.04–2.97	0.0–0.0013	–	–		0.06–0.97		0.0–0.43	0.1–3.67	Ada et al. (2012)
River	Delta	–	–	0.56–1.20	0.18–0.89	0.36–1.0	–	–	–	–	–	Nduka, and Orisakwe (2009)
Shallow well		–	–	0.21–0.60	0.05–0.44	0.10–0.22	–	–	–	–	–	
Borehole		–	–	0.01–0.04	0.01–0.05	0.01–0.04	–	–	–	–	–	
Well	Delta	0.02–0.63	–	0.010–0.198	0.10–0.42	0.01–33.50	–	–	–	–	–	Mogborukor (2012)
River	Delta	0.03–5.02	0.00–0.63	0.00–0.05	0.00–0.06	0.00	–	0.00–0.26		0.00–0.32	0.02–0.68	Wogu and Okaka (2011)
Sachet water	Delta	0.00–0.003	–	0.00–0.002	0.00–0.001	0.00–0.003	–	–	–	–	–	Akpoborie and Ehwarimo (2012)
Bottle water		0.00– 0.02	–	0.00–0.001	0.00–0.001	0.00–0.001	–	–	–	–	–	
Borehole	Bayelsa	0.12–0.40	0.15–0.78	–	–	0.00–0.20	–	–	–	–	0.01–0.30	Ohwo and Abotutu (2014)
Borehole	Bayelsa	5.32–9.96	0.01–0.96	–	0.00	<0.01	<0.01	<0.01	–	–	–	Ohimain et al. (2013)
Ground water	Bayelsa	0.06–43.09	0.15–10.09	0.00–0.03	0.01–0.18	0.21–0.42	0.07–0.78	0.01–1.31	–	0.00–0.02	0.12–2.34	Nwankwoala et al. (2011)
Ground water	Bayelsa state	0.40–1.40	–	0.00	0.00	–	–	0.00		–	–	Agbalagba et al. (2011)
Stream and well	Rivers state	0.00	–	–	0.00	–	–	–	0.00–0.080	–	0.0–0.335	Obunwo and Opurum (2013)
Borehole water, drainage water, and C.way bottle water	Rivers state	0.088–3.396	0.065–0.159	0.006–0.013	–	0.014–0.047	–	–	–	0.015–0.140	–	Nte et al. (2013)
South Eastern states												
Surface water	Imo	0.14–1.12	0.30–2.01	–	–	0.00–0.005	–	0.03–0.19	–	–	0.03–0.07	Duru et al. (2012)
Ground water	Ebonyi	0.916	–	0.008	0.256	0.073	–	–	0.036	–	0.66	Afiukwa (2013)
Surface		2.58	–	0.007	0.352	0.568	–	–	0.044	–	1.2	
River	Ebonyi	4.85	0.56	0.19	–	0.44	–	0.45	–	0.48	–	Odoemelam et al. (2013)
Stream	Abia	3.20–6.60	1.3–2.45	–	–	0.04–0.08		0.08–0.18		–	–	Eze and Madumere (2012)

Table 2 continued

Water source	State	Fe	Zn	Cd	Cr	Pb	Hg	Cu	Co	Ni	Mn	References
Ground water	Abia	0.04–0.09	0.29–0.34	–	–	0.0	0.00	0.04–0.14		–	–	Adindu et al. (2012)
River	Abia	0.040–6.580	0.071–5.240	0.001–0.004	0.001–0.078	0.001–0.015		0.012–2.755		0.004–0.211	0.050–0.508	Amadi (2012)
Rain	Anambra	0.00	0.20	0.00	–	0.00	–	0.00	–	–	–	Chukwuma et al. (2013)
Northern states												
Sachet water	Kano	0.33–0.71	0.22–0.33	–	–	0.00–0.05	–	0.12–0.21	–	–	–	Uwah et al. (2014)
River	Nasarawa	0.10–0.20	0.30–1.3	–	0.13–0.20	0.10	–	–	0.002–0.014	0.30–0.50	0.16–0.24	Adewumi et al. (2014b)
Stream	Nasarawa	7.51	3.19	0.023	–	0.04	0.00	0/95	–	–	0.51	Opaluwa et al. (2012)
Hand-dug well	Kaduna	0.75–5.25	0.18–2.11	–	–	0.04–1.0	–	0.82–4.30	–	0.02–0.12	0.42–2.33	Yakubu (2013)
Groundwater	Benue	0.03–0.82	0.1–0.13	–	–	0.04–0.74	–	0.0–0.88	–	–	0.14–0.73	Idoko et al. (2012)
Borehole	Niger	0.0–1.29	0.029–0.380	0.00–0.020	0.00	0.00– 0.032	–	0.00–0.129	–	–	–	Nnaji and Omotugba (2014)
River	Adamawa	–	0.002–1.008	0.004–1.481	0.12–1.09	0.071–0.897	–	0.07–0.48	–	–	–	Maitera et al. (2011)
Groundwater	Adamawa	0.60–2.10	–	0.001–0.60	0.1–0.4	0.02–0.6	–	0.01–1.30	–	0.001–0.60	0.022–3.0	Hong et al. (2013)
Borehole	Kebbi	0.41–1.282	0.019–0.141	–	0.052–0.121	0.047–0.245	–	0.302–0.606	0.03–0.07	0.038–0.087	–	Elinge et al. (2011)
Surface water	Sokoto	2.05	0.04	0.66	0.38	–	2.85	–	–	–	–	Dabai et al. (2013)
Sachet water	Sokoto	0.41–0.65	0.18–0.24	–	0.63–0.86	0.27–0.35	–	0.22–0.28	0.32–0.37	0.26–0.36	0.51–0.72	Raji et al. (2010)
Well water		0.55–0.72	0.18–0.34	–	0.67–1.5	0.30–0.54	–	0.25–0.51	0.34–0.58	0.28–0.47	0.51–1.2	
Tap water		0.42–0.51	0.19–0.24	–	0.65–0.85	0.31–0.39	–	0.23–0.26	0.34– 0.44	0.29–0.46	0.51–0.80	
Hang dug well	Kogi	0.007–0.627	0.04–0.062	0.0–0.017	–	0.00–0.0012	–	–	–	–	–	Musa et al. (2013)
Borehole		0.012–0.014	0.043–0.066	0.00–0.004	–	0.00–0.003	–	–	–	–	–	
Stream		0.078–0.101	0.00–0.020	0.00–0.002	–	0.012–0.004	–	–	–	–	–	
Borehole	Borno	–	–	0.04–0.07	0.03–0.21	0.04–0.14	–	–	–	–	–	Kolo and Waziri (2012)

potable water sources in Nigeria have been scantly reported. However, Dabai et al. (2013) have reported mercury in drinking water source in Sokoto state, North West at a concentration of 2.85 mg/l, while Ohimain et al. (2013) have reported at concentration of <0.01 in ground water in Bayelsa state, South–South. However, in Bayelsa, a concentration of 0.07–0.78 mg/l has been detected in some part of the state (Nwankwoala et al. 2011). The concentration in the surface water may be due to runoff resulting from improper discharge of waste material containing mercury.

Mercury is used not only in thermometers, dental filling, batteries, but also used in producing chlorine gas and caustic soda (Muhammad et al. 2014). Generally, mercury enters the environment through mining activities, industries that uses mercury, and combustion of coal, volcanicity, and toxic waste disposal. It can accumulate in the human body and create lethal problems to the life.

Cadmium

The concentration of cadmium recommended is 0.003 mg/l (SON, WHO) and 0.005 mg/l (EU) (Table 3). The concentrations of cadmium in most potable source of water were observed higher than the permissible limit. However, the level of cadmium in drinking water in Nigeria ranged from 0.00 to 1.481 mg/l. The highest concentration was recorded in river in Adamawa state. The trend of cadmium was similar in all geographical location of the country but varies according source of water. Typically, during industrial activities, cadmium enters to the soil and can contaminate the ground water and surface water through the runoff after rain.

Generally, each of the heavy metals that are found in potable water sources in Nigeria including essential and non-essential are found in their elemental form. Cadmium is being used in the steel and plastics industries. Cadmium is released into the environment released by extractions of zinc, lead, and copper as well as from other sources like use of pesticides (Muhammad et al. 2014), tyre wear, fuel combustion, and batteries (David et al. 2013; Omotoriogun et al. 2012).

Chromium

Chromium is one of the most naturally existing element in the earth crust. For drinking water SON, EU, WHO described its maximum allowable concentration at 0.05 mg/L (Table 3). Potable water with high chromium found in Nigeria states includes sachet water in Lagos (Oguntona et al. 2012), rivers in Oyo (Akinyemi et al. 2014), surface/ground water in Osun (Ayantobo et al. 2014), ground water in Akwa Ibom (Uffia et al. 2013), Edo (Olorunfemi et al. 2013), surface water in cross Rivers (Ekpo et al. 2013a, b), river and well in Delta (Nduka, and Orisakwe 2009), well in Delta (Mogborukor 2012), ground and surface water in Ebonyi (Afiukwa 2013), river in Nasarawa (Adewumi et al. 2014b), borehole in Kebbi (Elinge et al. 2011), surface water in Sokoto (Dabai et al. 2013), and borehole in Borno (Kolo and Waziri 2012) etc. The concentration of chromium in Nigeria potable water sources ranged from 0.00 to 34.80 mg/l. However, the highest concentration was found in ground/surface water in Osun state, which authors attributes to industrial activities such as mining. Generally, the occurrence of chromium in potable water sources shows similar trend across the various geographical location according to the source of the water. Higher concentration occasionally observed across the various potable water sources could be due to anthropogenic activities close to the source of such water.

Chromium occurs in free-state as a mineral in several oxidative form (Muhammad et al. 2014). Sevcikova et al. (2011) reported the most common biologically essential oxidative state of chromium are trivalent (Cr III) and hexavalent (Cr VI). Chromium enters in the water through the discharge of effluent water containing chromium including tanning, electroplating, pigment production, refractory technologies (de Namor et al. 2012), ferrochrome production etc.

Lead

When lead is ingested by human they are mostly removed through urination (Adegbola and Adewoye 2012) but in children, it could wreak havoc and making them more vulnerable than adult (Muhammad et al. 2014). The safe standard set by WHO, SON, and EU for lead in drinking water is 0.01 mg/L (Table 3). Its concentration is reported from 0.00 to 33.50 mg/l in drinking water sources (surface and ground water and packaged water) (Table 2). Besides Sachet and bottle water in Delta state (Akpoborie and Ehwarimo 2012), river in Delta state (Wogu and Okaka 2011), well borehole and stream in Kogi state (Musa et al. 2013), stream in Ekiti (Adefemi 2013), ground water in Abia (Adindu et al. 2012), ground water in Bayelsa state (Ohimain et al. 2013), rain water in Anambra (Chukwuma et al. 2013), it was generally above the permissible limit (Table 3). The concentration of lead shows similar trend according to the water source in all the geographical locations. Higher concentration occurred in areas with high industrial activities such as quarry, sewage disposal system.

Lead is a bluish-gray metal present as a trace element in the earth's crust and mainly comes into the environment through the combustion of fossil fuels (Omotoriogun et al. 2012; Muhammad et al. 2014), mining, and manufacturing

Table 3 Guideline for drinking water quality

Limits	Fe	Zn	Cd	Cr	Pb	Hg	Cu	Co	Ni	Mn	References
SON	0.3	3	0.003	0.05	0.01	0.001	1	–	0.02	0.2	SON (2007)
WHO	–	–	0.003	0.05	0.01	0.006	2	–	0.07	–	WHO (2011)
WHO	0.3	3	0.003	0.05	0.01	0.001	2	–	0.02	0.5	Azizullah et al. (2011)
European Union (EU)	0.2	0.02	0.005	0.05	0.01	0.001	2	–	0.02	0.05	Lenntech (2014)

industries (Muhammad et al. 2014) such as paint and leaded gasoline (Adegbola and Adewoye 2012), tyre wear, lubricating oil, grease (David et al. 2013), batteries production and ceramics (Butu and Bichi 2013), remains of batteries, cosmetics, medicine/pharmaceutical, food supplements etc. The high concentration is also attributable to anthropogenic activities especially petroleum products (i.e., sales, spill and combustion), mining activities, and paint making.

Manganese

The concentration of manganese in potable water sources in Nigeria ranged from 0.00 to 30.0 mg/l. The permissible limit for manganese is 0.5 mg/l (WHO) (Azizullah et al. 2011), 0.05 (EU), and 0.2 mg/l (SON) (Table 3). Generally, a concentration of manganese (>0.1 mg/l) could be detrimental to the taste of the water resulting to an impact in the use of the water in beverages and laundry (WHO 2011). However, high concentration of manganese has been reported in the groundwater of Lagos (Akoteyon 2012; Uffia et al. 2013), river waters of Ondo and Nasarawa (Adewumi et al. 2014b), wells of Ekiti (Adefemi 2013), rainwater (Ubuoh et al. 2012), borehole in Bayelsa (Ohwo and Abotutu 2014), surface and ground waters of Ebonyi (Afiukwa 2013), rive/dam in Ondo (Oyhakilome et al. 2012), surface water in Akwa Ibom (Denise et al. 2014), ground water in Bayelsa (Nwankwoala et al. 2011), ground water in Adamawa (Hong et al. 2013), etc. The highest concentration was found in ground water in Lagos state. Manganese is found in the Earth's crust, and most likely associated with iron (WHO 2011; Nwaichi et al. 2013).

Manganese trend was similar in all the geographical locations according to the water type. The extreme high concentration is attributed to anthropogenic activities close to such water source. Typically, manganese occurs naturally with iron and is used as an oxidant for cleaning, bleaching, disinfection process, and in the production of iron and steel alloys (WHO 2011). Manganese can exist in eleven oxidative states with low concentrations (0.02 mg/l) (Shortt et al. 2003; Nwaichi et al. 2013). It enters into potable water source through both natural and man-made activities. Unsustainable discharge of wastes could be due to the source of manganese in the surface water.

Nickel

Nickel enters into the human body through inhalation, water and food consumption, and its high concentration may pose threat to human health. The permissible guideline for nickel in drinking water is 0.02 mg/L (WHO) (Azizullah et al. 2011), SON, EU, and WHO (2011) stated a higher concentration of 0.07 mg/l (Table 3). Generally, the level of nickel in potable water source in Nigeria ranged from 0.0 to 9.6 mg/l. The concentration is high in most states that nickel have been reported. Nickel concentration is found highest in some states including well, borehole, and surface water of Lagos (Afolabi et al. 2012), well, borehole, sachet, and bottled waters of Ogun (Amori et al. 2013; Anake et al. 2014), rivers of in Ondo, Oyo, Nasarawa (Adewumi et al. 2014a, b; Akinyemi et al. 2014), ground and surface waters of Osun (Ayantobo et al. 2014), surface water of Edo (Omotoriogun et al. 2012), and borehole of Kebbi (Elinge et al. 2011) etc. (Table 2). Like most other heavy metals, the concentration of nickel show similar trend among the various geographical locations. However, the occasional increase in nickel concentration could be attributed to human interference such as mining activities.

Nickel is mostly used in stainless steel and nickel alloys production companies. Elemental nickel and its compounds are noxious agent and used in industries, known to have adverse effects for individuals (Boustani et al. 2012). Major sources are diesel and gasoline, lubricating oil, and brake emission (David et al. 2013).

Zinc

Zinc is one essential element of human body, and it can exist in nature either independently or as the oxide of other compounds. Regulatory bodies have recommended permissible limits for zinc as 3 mg/L (WHO) (Azizullah et al. 2011), SON, while EU gave a stricter limit of 0.02 mg/l (Table 3). Zinc concentration was detected about 3–5 mg/l, a severe taste as well as opalescent and greasy film may develop upon heating (WHO 2011). Zinc is a commonly reached to water through leaching. The concentration of zinc from drinking water sources in Nigeria have been reported in the range of 0.00–55.18 mg/l. Only few places such as sachet waters of Lagos (Oguntona et al. 2012), ground water (Akoteyon 2012), and surface water in Cross River (Ekpo et al. 2013a, b) were found contaminated with zinc based on the limit specified by WHO and SON. But highly contaminated based on the EU permissible limit. The higher concentration of Zinc in the water could be due to leaching effects from several sources. The zinc concentration appears to be same trend for different potable water sources across the various geographical locations in Nigeria. However, concentration above the permissible limits for various water sources could be due to discharge from anthropogenic affects.

Cobalt

Cobalt is one of the heavy metal found in potable water sources of Nigeria. Like other metals, high concentration of cobalt is also toxic to human beings. However, Oguntona et al. (2012) reported 1.6 mg/l of cobalt in sachet water of Lagos state. No maximum permissible limit has been set for cobalt by SON, WHO, and EU. In some of the potable water sources, cobalt concentrations have been reported in borehole of Kebbi (Elinge et al. 2011), river water of Nasarawa (Adewumi et al. 2014b), ground and surface waters of Ebonyi (Afiukwa, 2013), and river waters of Ondo (Adewumi et al. 2014a) etc. (Table 2). Cobalt enters the water through combustion of coal or oil and use of cobalt-related chemicals. Based on geographical coverage, cobalt shows similar trend in various potable water sources and occasional increase may be due to industrial activities.

Most of the heavy metals evaluated in the drinking water sources such as packaged, surface, and groundwater display a wide disparity between the heavy metal concentration and their permissible limit guideline like WHO and SON. The concentration of the heavy metals fluctuates among the various states of the federation and geographical coverage, with most metals exceeding far beyond the limit. The high heavy metal found in potable water sources have been widely attributed to anthropogenic activities including disposal of industrial, municipal, and domestic wastes (Azizullah et al. 2011) and other industrial activities.

Generally, the high concentration of heavy metals could be detrimental to both human life as well as to the environment. Table 4 presents some of the negative impact of heavy metals, and the effects may be directly or indirectly affect human.

Heavy Metals Pollution in Potable Water in Nigeria and its Effects on Human

Water plays an essential role in supporting life and has the tendency of spreading diseases following contamination (Omotoriogun et al. 2012). Heavy metals such as lead, mercury, cadmium etc. are very toxic and have been reported in potable water sources in Nigeria. Generally, heavy metals may become hazardous when their concentration exceeds the permissible limit (Elinge et al. 2011). Drinking water supply is one of the vital resource for the sustenance of a healthy life (Elinge et al. 2011). Most of the drinking water sources contain heavy metals and have crossed the permissible limits prescribed by SON.

The presence of heavy metal in potable water more than desirable limits can cause damage even at cellular level through the production of dangerous free radicals inside the body. These free radicals can cause diseases such as cancer, damaged to mental, immune system and central nervous function, intestinal tract, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other essential organs (Oguntona et al. 2012; Erah et al. 2002). Other acute human health symptoms include skin rashes, vomiting, dizziness, birth defects, and sometimes death (Erah et al. 2002). Moreover, redox active metals may undergo redox cycling reactions due to their ability to produce reactive radicals including superoxide anion

Table 4 Some common harmful effects of heavy metals on biological diversity and water use

Indicators	Effects
Living organisms	Cause mutation leading to chromosomal changes
	Disruption of cell mechanisms due to empathy with amino acids, proteins, and even carboxylic acids
	Bio-accumulate in the body and organs of biological diversity
	Hinder respiration in aquatic organisms such as fishes through the precipitation of mucous secretion
Water use	In obstruct the use of water for critical domestic and industrial uses
	Excess heavy metals on long-time exposure could affect atmospheric oxygen, contaminate and affect aquatic biota
Cost effectiveness	Treatment of water with heavy metal could pose extra cost on the products in which water is used for
	High cost of treating water containing heavy metals could lead to high price of good and service since is used in the production of several products

radical and nitric oxide in biological systems. Other numerous diseases like cancer, cardiovascular, diabetes, atherosclerosis, neurological disorders, chronic inflammation are linked with high heavy metal concentrations (Jomova and Valko 2011). In addition, muscles cramp, vomiting, pain, sweating, headache, suffocation, speaking problems, convulsions, nervousness, emotional instability, insomnia, nausea, lethargy, and ill filling could also be caused due to heavy metal toxicity (Oguntona et al. 2012). There is also a possibility of gastrointestinal tract problems due to the exposure of heavy metal-contaminated food as well as water (Maduabuchi et al. 2007). Rowel (2012) stated that the exposure to heavy metals, such as lead, mercury, copper, cadmium, and chromium, could cause cardiovascular disease, certain types of cancers, developmental defects in children, and neurological effects such as memory loss and behavioral changes.

Heavy metals are harmful to the human body because they can accumulate inside the body and may create lethal problems even at low concentration. These effects may be carcinogenic, teratogenic, phytotoxic, or synergistic. Trace metal concentration can also lead to damage of cell membrane by interfering with cytoplasmic and nuclear functions (Chinedu et al. 2011). According to Oguntona et al. (2012), the chronic symptoms of heavy metal toxicity may take several months or years to develop. Table 5 presents the adverse human health symptoms heavy metals present in drinking water.

Low concentrations of iron are necessary for human body, because its deficiency could lead to anemia, causing tiredness, headaches, and loss of concentration (Muhammad et al. 2014). However, a concentration above the permissible limit may lead to adverse health problem of gastrointestinal irritation (Musa et al. 2013). High concentration of iron could cause conjunctivitis, choroiditis, and retinitis, and chronic inhalation could lead to benign pneumoconiosis (Lenntech 2014).

Mercury is highly toxic to life when consumed by human through the intake of contaminated water or food (Muhammad et al. 2014). On long- and short-term exposure mercury compounds can accumulate in the kidney causing disease conditions. Similarly, Fu and Wang (2011) stated that mercury is neurotoxic and can impairs with the central nervous system. Mercury is a harmful metal to the environment and its living components. Being a potential cellular toxin, it can adversely affects various important processes within nerve cells (Azizullah et al. 2011). Lenntech (2014) presented the health effect of mercury to include disruption of the brain, chromosomal number, nervous system, allergy, and reproductive system. Other potential health problems associated with mercury include abdominal pain, headache, diarrhea, chest pain, hemolysis etc (Table 5).

According to Paulino et al. (2006), excess intake of copper causes toxicological distresses including vomiting, cramps, convulsions, and worst still death. Lenntech (2014) stated that long-term exposures of copper intake lead the problems in nose, mouth and eyes irritation, headaches, stomach upset, dizziness, vomiting, and diarrhea. Authors further asserted that high uptakes of copper may cause damage to the liver and kidney and reduces intelligence quotient in young adolescents (Table 5).

Like other heavy metals, cadmium can enter the body through water intake (Sevcikova et al. 2011). Cadmium causes acute and chronic toxicity in humans on exposure (Azizullah et al. 2011). Cadmium can lead to growth retardation, diarrhea, bone deformation, kidney damage, anemia, central nervous system disorder, hypertension, liver damage etc. (Dabai et al. 2013).

Chromium is very toxic due to strong oxidation properties (Dabai et al. 2013), hence, it can cause disease like gastrointestinal, central nervous system disorder, cancer etc. Fu and Wang (2011) also stated prolonged contact with chromium could lead to dysfunctions of the kidney and even death. Generally, the oxidative state of chromium that is found in the water will determine the nature of disease condition that could follow. Lenntech (2014) also reported that chromium (III) is a vital nutrient for humans and its deficiency increases the chance of heart diseases, disruption of metabolisms, diabetes, over-ingestion, skin rashes etc. Chromium (VI) causes allergic reactions including skin rash, nose irritations and bleeds, stomach upset, ulcers, respiratory disorders, lower immune system, kidney, lung, liver disorders, and mutation.

Excess manganese concentration increases the growth of bacteria in water and can cause hypertension in patients older than 40 years (Adegbola and Adewoye 2012) and neurological disorders on protracted patients (WHO 2011). Lenntech (2014) reported that the adsorption of excess manganese will deposit in the liver, kidneys, pancreas, and endocrine glands through the blood vessels and can also cause respiratory system and brains disorder.

Cobalt is another, trace metal found in water, its high concentration may create problems like diarrhea, bone deformation etc. Nickel has potential adverse effects on human health and which could have a long-term damage for body tissue (Boustani et al. 2012). Nickel are require in small quantity, however, excess could lead to serious health implications such as nickel dermatitis, nausea, diarrhea, headache, vomiting, and chest pain (de Namor et al. 2012).

Lead is a very toxic element which can accumulate in the skeletal structures of both man and animal (Musa et al. 2013). Lead enters the body through ingestion and inhalation of lead containing compounds, and causes multiple body and nervous systems disorders especially in

Table 5 Pathological effect of heavy metal water pollution on human

Metals	Pathological effects/symptoms	References
Lead	Damage to liver and brain, miscarriage in women and death	Idris et al. (2013) and Muhammad et al. (2014)
	Damage to reproductive system	Idris et al. (2013), Nwaichi and James (2012) and Fu and Wang (2011)
	Damage to kidney	Idris et al. (2013), Duru et al. (2012), Muhammad et al. (2014), Vivien et al. (2012), Fu and Wang (2011) and SON (2007)
	Damage to nervous system	Dabai et al. (2013), Idris et al. (2013), Nwaichi and James (2012), Muhammad et al. (2014), Fu and Wang (2011) and SON (2007)
	Reduction in birth weights and premature birth	Henson and Chedrese (2004)
	High concentration causes cerebral edema, anemia	Duru et al. (2012)
	Damage or poisoning of cardiovascular system	Azab et al. (2010) and Nwaichi and James (2012)
	Hair loss, lung fibrosis, skin allergies, outbreak of eczema, and variable degrees of kidney	Azab et al. (2010)
	Damage to renal system	Nwaichi and James (2012) and Erah et al. (2002)
	Gastrointestinal, neuromuscular disorder with symptoms including anorexia, headache, malaise, diarrhea, lead-palsy, encephalopathy, insomnia	Erah et al. (2002)
	Increases blood pressure, anemia, and weakness in fingers, wrists, or ankles	Muhammad et al. (2014)
	Impairment of neurological development, suppression of the hematological system	Vivien et al. (2012)
Chromium	Damage to kidney, liver and blood cells through oxidation reactions, resulting into hemolysis, renal and liver failure	Dabai et al. (2013)
	Damages the kidneys, liver	Lokeshappa et al. (2012) and Muhammad et al. (2014)
	Circulatory and nerve disorders, and skin irritation	Lokeshappa et al. (2012)
	Cancer, high breathing rate, irritation to the lining of the nose; nose ulcers; running nose; and breathing problems including asthma, cough, shortness of breath	Muhammad et al. (2014)
	Cancer	SON (2007)
Cadmium	Liver and kidney damage, bone demineralization	Erah et al. (2002), Dabai et al. (2013), Barbier et al. (2005), Muhammad et al. (2014), Fu and Wang (2011), SON (2007) and Bernard (2008)
	Internal hemorrhage, and respiratory disorders	Erah et al. (2002)
Cobalt	Increases incidence of goiter	Duru et al. (2012)
	Vomiting and nausea, optical, cardiovascular, and thyroid damage	Lenntech (2014)
Manganese	Interfere with absorption of dietary iron which can result in iron deficiency anemia.	Adegbola and Adewoye (2012)
	Neurological disorder	SON (2007)
Copper	Abdominal pains, nausea, vomiting, diarrhea, headache, and dizziness	Chinedu et al. (2011)
	Anemia, acne, adrenal hyperactivity and insufficiency, allergies, hair loss, arthritis, autism, cancer, depression, elevated cholesterol, depression, diabetes, dyslexia, failure to thrive, fatigue, fears, fractures of the bones, headaches, heart attacks, hyperactivity, hypertension, infections, inflammation, kidney and liver dysfunction, panic attacks, strokes, tooth decay	Lokeshappa et al. (2012) and Muhammad et al. (2014)
	Gastrointestinal disorder	SON (2007)
Zinc	Diarrhea	Osibanjo and Majolagbe (2012)
Iron	Genetic and metabolic diseases	Fraga and Oteiza (2002)
	Lung disease, development of a benign pneumoconiosis, called siderosis	Muhammad et al. (2014)

Table 5 continued

Metals	Pathological effects/symptoms	References
Mercury	Respiratory failure and death, damage the brain, and developing fetus. Symptom includes irritability, shyness, tremors, changes in vision or hearing, and memory problems, nausea, vomiting, diarrhea, increased blood pressure, skin rashes, and eye irritation	Muhammad et al. (2014)
	Damage to central nervous system and kidney	Muhammad et al. (2014) and SON (2007)
	Gastrointestinal disorders, respiratory tract irritation, renal failure, and neurotoxicity	Vivien et al. (2012)
Nickel	Poisonous and carcinogenic	Fu and Wang (2011) and SON (2007)
	Gastrointestinal distress, pulmonary fibrosis/cardiovascular diseases and skin dermatitis, and impairment of the lung and kidney.	Seilkop and Oller (2003), Borba et al. (2006), McGregor et al. (2000) and Oller et al. (1997)
	Hematotoxic, immunotoxic, neurotoxic, genotoxic, reproductive toxic, pulmonary toxic, nephrotoxic, hepatotoxic, and carcinogenic agent	Das et al. (2008)

children (Muhammad et al. 2014). Moreover, in children it also boost problems like inattention, hallucinations, and delusions manifesting as poor memory and irritability (Adegbola and Adewoye 2012; Naseem and Tahir 2001), decreased mental ability, learning difficulties, reduced growth, blood anemia, severe stomachache, muscle weakness, and brain damage (Muhammad et al. 2014; Naseem and Tahir 2001). Premature birth by pregnant women may also be occurring due to lead poisoning (Muhammad et al. 2014). Fu and Wang (2011) stated that lead damages the cellular activities leading to brain, central nervous system, kidney, liver, and reproductive system disorder. Other pathological effects of lead include vomiting, loss of appetite, central nervous system defects, liver problems, kidney damage etc.

Zinc is essential for physiological and metabolic process for human life (Fu and Wang 2011; Adegbola and Adewoye 2012). However, its over concentration in food and potable water may cause vomiting, muscle cramp, and renal damage. Like zinc, copper is essential in numerous metabolic processes occurring in water and soil (Sevcikova et al. 2011). Omotoriogun et al. (2012) reported the over-ingestion of zinc, copper, and lead-laden water could result the cause of nausea, vomiting, and diarrhea.

Excess concentration of these essential and non-essential heavy metals found in potable water sources can be harmful to human. de Namor et al. (2012) have summarized the target organs of some heavy metals found in potable water including Cu^{29} (liver, gastrointestinal tracts), Cd^{48} (lungs, gastrointestinal tracts, heart, bone, kidney), Ni ^{28} (lungs, skin, heart), Pb 82 (eye, kidney, heart, gastrointestinal tracts, muscular and skeletal system and bone), Co^{27} (heart and lungs), Cr ^{28} (kidney, lungs), Zn ^{30} (gastrointestinal tracts, lungs), Hg ^{80} (bone, eye, lungs and kidney). A number of these heavy metals are carcinogenic and could also affect the children even at low level of exposure. However in Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC) has already mandated the enforcement of rules in compliance with international drinking water guidelines (Uwah et al. 2014).

Heavy Metal Quality Legislation in Potable Water and Their Effectiveness in Nigeria

In Nigeria, the National Council on Water Resources (NCWR) in 2005 recognized the importance to establish a regulatory body for drinking water known as Nigerian Standard for Drinking Water Quality. Table 6 presents the regulatory framework in Nigeria that was considered in establishing drinking water quality.

The prescribed limit for drinking water has been variously stated with the consultation of WHO guidelines. The regulations were aimed to provide safe drinking water for the country teaming population. Due to inadequate water supply, significant number of resorts in Nigeria installed personal water supply system in their houses. The Nigerian drinking water quality guidelines tend to favor groundwater, and a significant number of the population is still getting their drinking water from stream, rivers, lake, and even rainwater. Therefore, the surveillance of water sources has significant importance especially in the coastal regions were pollution occurs due to flooding.

Heavy Metal Treatment Strategies for Potable Water

Treatment of the waters prior to drinking using heavy metal removal techniques including chemical precipitation, ion-exchange, adsorption, membrane filtration, coagulation-

Table 6 Regulatory framework in Nigeria participated in drinking water quality standard

Regulatory framework	Act/Act N°/Cap/NIS	Years
Consumer Protection Council	Act 66	1992
Council for Regulation of Engineering in Nigeria	Act 55	1972
Federal Environmental Protection Agency	Retained as Cap 131	–
Food and Drugs	Retained as Cap 150	
Food and Drugs (FD) Changed to National Agency for Food and Drug administration and Control (NAFDAC)	FD No.19 changed to NAFDAC Act 11	1999
Institute of Chartered Chemist of Nigeria	Act N°91	1993
Institute of Public Analyst of Nigeria	Act N°100	1992
National Water Resources Institute Act	Retained as Cap 284	–
Public Health Act	–	1958
Standards Organization of Nigeria (SON)	Retained as Cap 412	–
Water Resources Act	Act N° 101	1993
International standard Organization (ISO) in relation to drinking water management, National Guidelines and standards for Water Quality in Nigeria	–	–
Nigerian Industrial Standards for Natural Mineral Water	NIS 345	2003
Nigerian Industrial Standards for Potable Water	NIS 306	2004

Adapted from SON (2007)

flocculation, flotation, electrodialysis, photocatalysis and electrochemical methods (Hashim et al. 2011; Barakat 2011; de Namor et al. 2012; Fu and Wang 2011; Cheung et al. 1997; Sternberg and Dom 2002), and trickling filter method (Ohimain et al. 2013) have been comprehensively covered in literature.

Fu and Wang (2011) stated that chemical precipitation method is inexpensive but ineffective for low levels of heavy metal present in water; ion exchange is an expensive treatment option. Membrane filtration technology is complex, costly with low fouling problems. Coagulation-flocculation consumes a lot of chemicals and generates heavy sludge. The adsorptive materials such as activated carbon, carbon nanotubes, low cost adsorbent, and bio-have commonly been used in removing heavy metals from water (Fu and Wang 2011).

Other treatment technologies have been widely employed for the treatment of potable and waste water in some developed and developing countries including chemical precipitation, ion-exchange, adsorption, membrane filtration, coagulation-flocculation, flotation, electrodialysis, photocatalysis, and electrochemical methods is not popular as a treatment technology in Nigeria. Due to high cost and pinpoint treatment efficiency, the traditional techniques of heavy metal removal have become impractical (Foroughi et al. 2011). Bio-adsorption is a promising technology for heavy metal removal from water (Fu and Wang 2011), due to of its lower cost (Volesky 2003). But in some region of Nigeria, the use of single and double trickling treatment technology have widely employed. Typical double trickling water treatment technologies consist of two treatment tank in addition to the reservoir tank. Each of the treatment tanks contains gravel, sand, and water (Ohimain et al. 2013). Each of the components is separated by rubber net or foam or like materials. Ohimain et al. (2013) reported that double trickling water treatment technology reduces iron from initial of 5.32–9.82 to 1.67–2.02 mg/l in single trickling method and finally to 0.05–0.31 mg/l using double trickling method. Generally, reduction in heavy metal concentration such as zinc, chromium, arsenic, and selenium has been reported using double trickling water treatment techniques (Ohimain et al. 2013).

Typically, heavy metal removal efficiency of each of the techniques/approach may vary and depends on the operation, cost, flexibility, reliability of the plants, concentration of heavy metal in the water as well as the concentration of competitive ions (Kurniawan et al. 2006). de Namor et al. (2012) have stated that coagulation, sand filtration, ion exchange, activated carbon, alumina, and reverse osmosis can be used to remove lead (II) and diatomite from the aqueous solutions.

In addition, biomass can be used to treat waste and potable water. Besides macrophytes and sea organisms such as shells from sea animals, terrestrial plants such as plantain leaves can bio-accumulate heavy metals from water. Rowel (2012) reported that banana peel have the potentials of heavy metal removal such as copper, lead from water. The author reported that even in the presence of nitrogen, sulfur, and carboxylic acids, banana peels make it possible to bind the toxic metals and remove them from the water. Ohimain et al. (2014) also reported that banana leaf, bract, and trunk could be used for water treatment especially water containing high iron content. Banana peel can be used up to 11 times during water treatment without replacement (Rowel 2012). Richard (2009) reported that due to the presence of aragonite (a form of calcium carbonate), sea shells are able to remove toxic metals like cadmium, zinc, lead, and iron through the swapping out of calcium atoms into a solid form. Aquatic plants such as *Eichhornia crassipes* found in some surface water could aid in the purification of heavy metals contaminant (Ogamba et al. 2015a, b, c, d).

Constraints and Strategies for the Implementations of Cost Effective Heavy Metal Treatment Options in Nigeria

The study found that double trickling technology is widely used for the treatment of potable water in Nigeria. This technology is mostly applied for groundwater. In surface water, heavy metal removal occurs through natural techniques. This could be due to the presence of macrophytes such as *Eichhornia crassipes* that found in most aquatic ecosystem especially in the Niger Delta Nigeria (Ogamba et al. 2015a, b, c, d). The use of plantain tissues is also promising technology but research on its efficiency appears to be deficient in literature.

This low cost promising technology for heavy metal removal in potable water sources could be constrains in several ways. For instance, the use of double trickling method for purification implies that not less than three tanks and a surface pump are required for this process. This increases the cost of potable water production. In addition, the cost management of the sludge could also be high. If aquatic plants such as *Eichhornia crassipes* are encouraged for the remediation of heavy metals from surface water, it could block canals and channels, impede navigation, halt fishing activities due to its high growth rate (Ndimele et al. 2010a, b, 2011; Ndimele 2012). This is because *Eichhornia crassipes* have been described as worst invasive aquatic plant and are found in most Nigerian water ways (Ogamba et al. 2015e). The use of plantain tissues could pose challenge of taste or odor in the potable water hence it could be more appropriate for the treatment of municipal waste water.

This pitfall in the various heavy metal remediation technologies such as double trickling method and use of biomass for water treatment could be overcome through the following:

- Effective management of sludge because, when the sludge film is too thick, it affects the porosity and permeability of the water flow.
- The end product needs to be chlorinated since it passes through sand.
- The plantain tissues should be used for treating waste water due to challenge of odor, color.

Conclusion and Suggested Mitigation Measures

Potable water source often gets contaminated or polluted due to the anthropogenic activities and some extent of natural conditions. Some of the anthropogenic activities increase the release of heavy metals into water like burning of fossil fuels, mining, use of fertilizers and pesticides such as herbicides, insecticides, and fungicides. The heavy metals find its way in surface water runoff and or soil erosion. The concentration of heavy metals such as lead, chromium, cadmium, manganese, and iron exceeded the limit prescribed by WHO and SON in most of the Nigerian states, while copper, mercury, zinc, manganese were found in high concentration among few potable water sources. Human health disorders that can be caused by heavy metals include cardiovascular, respiratory, cancer, organ damage, poisoning, neurological, hematological etc. depending on their exposure. Based on the aforementioned literature review on heavy metal-related human health problems, we are recommending some suggestions for the conservation of water sources in Nigeria as follows:

- Packaged water factories should be planted far from industrial areas.
- Industrial wastes, especially effluents should not be discharged without proper treatment (Erah et al. 2002).
- Intensive monitoring of sachets water should be carried out by appropriate national agency to assure the quality for drinking purpose (Uwah et al. 2014).
- Renovation or change of pipelines will be good initiatives to reduce the water contamination.
- Research works should be encouraged regarding the removal of heavy metals from water.

References

Abbaspour N, Hurrel R, Kelishadi R (2014) Review on iron and its importance for human health. J Res Med Sci 19(2):164–174

Abdus-Salam N, Bale RB, Taorid R, Adeniyi OO (2013) Studies of water and sediment quality of Owalla Dam, Osun State, Nigeria. Fountain J Nat Appl Sci 2(2):22–31

Ada FB, Ayotunde EO, Offem BO (2012) Surface and ground waters concentrations of metal elements in central Cross River State, Nigeria, and their suitability for fish culture. Int J Environ Sustain 1(2):9–20

Adefemi SO (2013) Physicochemical and microbiological assessment of groundwater from Ijan-Ekiti South Western Nigeria. SWISS J Appl Sci 2(5):13–21

Adefemi SO, Awokunmi EE (2010) Determination of physico-chemical parameters and heavy metals in water samples from

Itaogbolu area of Ondo-State, Nigeria. Afr J Environ Sci Technol 4(3):145–148
Adegbola AA, Adewoye AO (2012) Impact assessment of selected pollution sources on groundwater quality in wells in Gambari Community, Ogbomoso, Nigeria. Int J Mod Eng Res 2(5):3118–3122
Adewumi DF, Daniyan IA, Adeodu AO (2014a) Physico-chemical properties of Ala-River, Akure Ondo State, Nigeria (a case study Ofala River in Akure, South Western Nigeria). J Phys Chem Sci 1(2):1–6
Adewumi DF, Daniyan IA, Adeodu AO (2014b) Determination of heavy metals in water, fish and soil samples from Antau River in Keffi, Nasarawa State, Nigeria: a case study of Antau River in Keffi, Nasarawa North Central Nigeria. Int J Sci Res 3(3):701–705
Adindu RU, Igboekwe MU, Lebe N (2012) Groundwater mineralization analysis of Osisioma Local Government Area of Aba, Abia State, Nigeria. Am J Chem 2(3):121–125
Afiukwa JN (2013) Evaluation and correlation study of heavy metals load in drinking water and update of water-related disease cases in Ebonyi State from 2001–2011. Am J Sci Ind Res 4(2):221–225
Afolabi TA, Ogbuneke CC, Ogunkunle OA, Bamiro FO (2012) Comparative assessment of the potable quality of water from industrial, urban and rural parts of Lagos, Nigeria. Ife J Sci 14(2):221–232
Agbalagba OE, Agbalagba OH, Ononugbo CP, Alao AA (2011) Investigation into the physico-chemical properties and hydrochemical processes of groundwater from commercial boreholes in Yenagoa, Bayelsa State, Nigeria. Afr J Environ Sci Technol 5(7):473–481
Agedah EC, Ineyougha ER, Izah SC, Orutugu LA (2015) Enumeration of total heterotrophic bacteria and some physico-chemical characteristics of surface water used for drinking sources in Wilberforce Island, Nigeria. J Environ Treat Tech 3(1):28–34
Akinyemi LP, Odunaike RK, Daniel DE, Alausa SK (2014) Physico-chemical parameters and heavy metals concentrations in Eleyele River in Oyo State South-West of Nigeria. Int J Environ Sci Toxicol 2(1):1–5
Akoteyon IS (2012). Evaluation of groundwater quality using contamination index in parts of Alimosho, Lagos–Nigeria. Am Acad Sch Res J, vol 4(4)
Akpoborie IA, Ehwarimo A (2012) Quality of packaged drinking water produced in Warri Metropolis and potential implications for public health. J Environ Chem Ecotoxicol 4(11):195–202
Amadi AN (2012) Quality assessment of Aba River using heavy metal pollution index. Am J Environ Eng 2(1):45–49
Amori AA, Oduntan OO, Okeyode IC, Ojo SO (2013) Heavy metal concentration of groundwater deposits in Odeda region, Ogun state, Nigeria. E3 J Environ Res Manage 4(5):0253–0259
Anake WU, Benson NU, Akinsiku AA, Ehi-Eromosele CO, Adeniyi IO (2014) Assessment of trace metals in drinking water and groundwater sources in Ota, Nigeria. Int J Sci Res Publ 4(5):1–4
Angelova M, Asenova S, Nedkova V, Koleva-Kolarova R (2011) Copper in the human organism. Trakia J Sci 9(1):88–98
Ayantobo OO, Awomeso JA, Oluwasanya GO, Bada BS, Taiwo AM (2014) Mining in Igun-ijesha, southwest Nigeria: impacts and implications for water quality. Am J Environ Sci 10(3):289–300
Azab YA, Mandour RA, Ibrahim W, Kenawy I, El-Menshawy A, El-Zyat M (2010) Chemical evaluation of some heavy metals in surface drinking water in Dakahlyia Governorate and warning from their toxicity. Mansoura. J Forensic Med Clin Toxicol XVIII 2:69–80
Azizullah A, Khattak MNK, Richter P, Häder D-P (2011) Water pollution in Pakistan and its impact on public health: a review. Environ Int 37:479–497
Barakat MA (2011) New trends in removing heavy metals from industrial wastewater. Arab J Chem 4:361–377
Barbier O, Jacquillet G, Tauc M, Cougnon M, Poujeol P (2005) Effect of heavy metals on, and handling by, the kidney. Nephron Physiol 99:105–110
Beard JL (2001) Iron biology in immune function, muscle metabolism and neuronal functioning. J Nutr 131(2):568S–580S
Bernard A (2008) Cadmium & its adverse effects on human health. Indian J Med Res 128(4):557–564
Bhowmik D, Chiranjib KP, Kumar KPS (2010) A potential medicinal importance of zinc in human health and chronic disease. Int J Pharm Biomed Sci 1(1):05–11
Borba CE, Guirardello R, Silva EA, Veit MT, Tavares CRG (2006) Removal of nickel (II) ions from aqueous solution by biosorption in a fixed bed column: experimental and theoretical breakthrough curves. Biochem Eng J 30:184–191
Boustani F, Hojati M, Ebrahimzadeh S (2012) Assessment of nickel concentration in surface and groundwater of the Kowsar Dam Basin. World Acad Sci Eng Technol 6(3):16–19
Burke DM, O'Byrne JP, Fleming PG, Borah D, Morris MA, Holmes JD (2011) Carbon nanocages as heavy metal ion adsorbents. Desalination 280:87–94
Butu AW, Bichi AA (2013) Assessment of some heavy elements in Galma dam, Zaria, Nigeria. Int J Dev Sustain 2(2):686–696
Butu AW, Iguisi EO (2013) Concentration of heavy metals in sediment of river Kubanni, Zaria, Nigeria. Compr J Environ Earth Sci 2(1):10–17
Chasapis CT, Loutsidou AC, Spiliopoulou CA, Stefanidou ME (2012) Zinc and human health: an update. Arch Toxicol 86(4):521–534
Cheung CW, Porter CF, McKay G (1997) Sorption kinetics for the removal of copper and zinc from effluents using bone char. Sep Purif Technol 19:55–64
Chinedu SN, Nwinyi OC, Oluwadamisi AY, Eze VN (2011) Assessment of water quality in Canaanland, Ota, Southwest Nigeria. Agric Biol J North Am 4:577–583
Chukwuma EC, Ogbu KN, Okonkwo IF (2013) Quality assessment of direct harvested rainwater in parts of Anambra State, Nigeria. Int J Agric Biosci 2(3):120–123
Dabai MU, Bagudo BU, Jodi LM, Ocheni L (2013) Evaluation of some trace metal levels in the water, fish and aquatic plant in River Sokoto, North-Western Nigeria. Asian J Appl Sci 1(5):195–199
Das KK, Das SN, Dhundasin SA (2008) Nickel, its adverse health effects & oxidative stress. Indian J Med Res 128:412–425
David TW, Awoh DK, Essa GA (2013) Investigation of heavy metals in drinking water (sachet and bottled) in ago-Iwoye and environs, Ijebu North lga, Ogun state, Nigeria. Sch J Biotechnol 2(1):1–6
de Namor AFD, Gamouz AEI, Frangie S, Martinez V, Valiente L, Webb OA (2012) Turning the volume down on heavy metals using tuned diatomite. A review of diatomite and modified diatomite for the extraction of heavy metals from water. J Hazard Mater 241–242:14–31
Denise EM, Udoh EI, Idada I (2014) Comparative study of heavy metals concentration in some water bodies of EKET and NSIT Ubium local government area of Akwa Ibom state, Nigeria. Adv Appl Sci Res 5(3):1–4
Duru MKC, Nwanekwu KE, Adindu EA, Odika PC (2012) Heavy metal and bioload levels of Otamiri River, Owerri, Imo State, Nigeria. Arch Appl Sci Res 4(2):1002–1006
Ebiare E, Zejiao L (2010) Water quality monitoring in Nigeria; Case Study of Nigeria's industrial cities. J Am Sci 6(4):22–28
Ekpo FE, Agu NN, Udoakpan UI (2013a) Influence of heavy metals concentration in three common fish, sediment and water collected within quarry environment, Akamkpa L.G. Area, Cross River State, Nigeria. Eur J Toxicol Sci 3:1–11

Ekpo IA, Agbor RB, Ekanem AP, Okpako EC, Inyang PI (2013b) Assessment of heavy metal status and bacteria population in municipal borehole water in landfill and non-landfill areas in Calabar municipality, cross river state, Nigeria. Int J Eng Appl Sci 2(4):31–41

Elinge CM, Itodo AU, Peni IJ, Birnin-Yauri UA, Mbongo AN (2011) Assessment of heavy metals concentrations in bore-hole waters in Aliero community of Kebbi State. Adv Appl Sci Res 2(4):279–282

Erah PO, Akujieze CN, Oteze GE (2002) The Quality of groundwater in Benin City: a baseline study on inorganic chemicals and microbial contaminants of health importance in boreholes and open wells. Trop J Pharm Res 1(2):75–82

Eruola AO, Adedokun NA (2012) Analytical assessment of cadmium, lead and iron in hand dug wells of Ilaro, South-Western Nigeria. Glob J Sci Front Res Chem 12(6):39–43

Eze SO, Madumere IC (2012) Physicochemical and microbiological analysis of water bodies in Uturu, Abia State-Nigeria. Asian J Nat Appl Sci 1(4):58–65

Foroughi M, Najafi P, Toghiani S (2011) Trace elements removal from waste water by *Ceratophyllum demersum*. J Appl Sci Environ Manag 15(1):197–201

Fraga CG, Oteiza PI (2002) Iron toxicity and antioxidant nutrients. Toxicology 180(1):23–32

Fu F, Wang Q (2011) Removal of heavy metal ions from wastewaters: a review. J Environ Manag 92:407–418

Galadima A, Garba ZN, Leke L, Almustapha MN, Adam IK (2011) Domestic water pollution among local communities in Nigeria-causes and consequences. Eur J Sci Res 52(4):592–603

Hashim MA, Mukhopadhyay S, Sahu JN, Sengupta B (2011) Remediation technologies for heavy metal contaminated groundwater. J Environ Manag 92:2355–2388

Henson MC, Chedrese PJ (2004) Endocrine disruption by cadmium, a common environmental toxicant with paradoxical effects on reproduction. Exp Biol Med 229:383–392

Hong AH, Law PL, Onni SS, Mboh ABS (2013) Groundwater quality assessment for domestic and irrigation purposes in Yola, Adamawa State Northeastern Nigeria. Am J Eng Res 02(6):34–41

Hosseinifard SJ, Aminiyan MM (2015) Hydrochemical characterization of groundwater quality for drinking and agricultural purpose: a case study in Rafsanjan plain, Iran. Water Qual Expo Health 7:531–544

Idoko OM, Ologunorisa TE, Okoya AA (2012) Temporal variability of heavy metals concentration in rural groundwater of Benue State, Middle Belt, Nigeria. J Sustain Dev 5(2):2–16

Idris MA, Kolo BG, Garba ST, Waziri I (2013) Pharmaceutical industrial effluent: heavy metal contamination of surface water in Minna, Niger State, Nigeria. Bull Environ Pharm Life Sci 2(3):40–44

Izah SC, Ineyougha ER (2015) A review of the microbial quality of potable water sources in Nigeria. J Adv Biol Basic Res 1(1):12–19

Izah SC, Srivastav AL (2015) Level of arsenic in potable water sources in Nigeria and their potential health impacts: a review. J Environ Treat Tech 3(1):15–24

Jeje JO, Oladepo KT (2014) Assessment of heavy metals of boreholes and hand dug wells in Ife North Local Government Area of Osun State, Nigeria. Int J Sci Technol 3(4):209–214

Jomova K, Valko M (2011) Advances in metal-induced oxidative stress and human disease. Toxicology 283:65–87

Kelepertzis E (2014) Investigating the sources and potential health risks of environmental contaminants in the soils and drinking waters from the rural clusters in Thiva area (Greece). Ecotoxicol Environ Saf 100:258–265

Khan K, Lu Y, Khan H, Zakir S, Ihsanullah, Khan S, Khan AA, Wei L, Wang T (2013) Health risks associated with heavy metals in the drinking water of Swat, northern Pakistan. J Environ Sci 25(10):2003–2013

Kolo BG, Waziri M (2012) Determination of some heavy metals in borehole water samples of selected motor parks in Maiduguri, Nigeria. Int J Basic Appl Chem Sci 2(3):18–20

Krupanidhi S, Sreekumar A, Sanjeevi CB (2008) Copper & biological health. Indian J Med Res 128:448–461

Kurniawan TA, Chan GYS, Lo WH, Babel S (2006) Physico-chemical treatment techniques for wastewater laden with heavy metals. Chem Eng J 118:83–98

Lenntech (2014) EU's drinking water standards. Council Directive 98/83/EC on the quality of water intended for human consumption. Adopted by the Council, on 3 November 1998: http://www.lenntech.com/periodic/elements/. Accessed 14 July 2014

Lieu PT, Heiskala M, Peterson PA, Yang Y (2002) The roles of iron in health and disease. Mol Aspects Med 22(1–2):1–87

Lokeshappa B, Kandarp S, Vivek T, Anil KD (2012) Assessment of toxic metals in agricultural produce. Food Public Health 2(1):24–29

Maduabuchi J-MU, Adigba EO, Nzegwu CN, Oragwu CI, Okonkwo IP, Orisakwe OE (2007) Arsenic and chromium in canned and non-canned beverages in Nigeria: a potential public health concern. Int J Environ Res Public Health 4(1):28–33

Maitera ON, Barminas JT, Magili ST (2011) Determination of heavy metal levels in water and sediments of river Gongola in Adamawa State, Nigeria. J Emerg Trends Eng Appl Sci 2(5):891–896

McGregor DB, Baan RA, Partensky C, Rice JM, Wilbourn JD (2000) Evaluation of the carcinogenic risks to humans associated with surgical implants and other foreign bodies: a report of an IARC monographs programme meeting. Eur J Cancer 36:307–313

Miller JR, Hudson-Edwards KA, Lechler PJ, Preston D, Macklin MG (2004) Heavy metal contamination of water, soil and produce within riverine communities of the Rıo Pilcomayo basin, Bolivia. Sci Total Environ 320:189–209

Mogborukor JOA (2012) Domestic sewage disposal and quality of water from hand dug wells in Ughelli, Nigeria. AFRREV STECH Int J Sci Technol 1(3):112–125

Muhammad S, Shah MT, Khan S (2011) Health risk assessment of heavy metals and their source apportionment in drinking water of Kohistan region, northern Pakistan. Microchem J 98:334–343

Muhammad I, Ashiru S, Ibrahim ID, Salawu K, Muhammad DT, Muhammad NA (2014) Determination of some heavy metals in wastewater and sediment of artisanal gold local mining site of Abare Area in Nigeria. J Environ Treat Tech 1(3):174–182

Musa JJ, Ahanonu JJ (2013) Quality assessment of shallow groundwater in some selected agrarian communities in Patigi Local Government Area, Nigeria. Int J Basic Appl Sci 01(03):548–563

Musa OK, Shaibu MM, Kudamnya EA (2013) Heavy metal concentration in groundwater around Obajana and Its environs, Kogi State, North Central Nigeria. Am Int J Contemp Res 3(8):170–177

Muta'aHellandendu J (2012) Health implications of water scarcity in Nigeria. Eur Sci J 8(18):111–117

Naseem R, Tahir SS (2001) Removal of Pb(II) from aqueous solution by using bentonite as an adsorbent. Water Res 35:3982–3986

Ndimele PE (2012) The effects of water hyacinth (*Eichhornia crassipes* [Mart.] Solms) infestation on the physico-chemistry, nutrient and heavy metal content of Badagry Creek and Ologe Lagoon, Lagos, Nigeria. J Environ Sci Technol 5:128–136

Ndimele PE, Jenyo-Oni A, Jibuike CC (2010a) Comparative toxicity of crude oil, dispersant and crude oil-plus-dispersant to *Tilapia guineensis*. Res J Environ Toxicol 4:13–22

Ndimele PE, Jenyo-Oni A, Ayodele AI, Jimoh AA (2010b) The phytoremediation of crude oil-polluted aquatic environment by water hyacinth (*Eichhornia crassipes* [Mart.] Solms). Afr J Livest Ext 8:48–52

Ndimele PE, Kumolu-Johnson CA, Anetekhai MA (2011) The invasive aquatic macrophyte, water hyacinth {*Eichhornia crassipes* (Mart.) solm-Laubach: Pontedericeae}: problems and prospects. Res J Environ Sci 5:509–520

Nduka JK, Orisakwe OE (2009) Effect of effluents from warri refinery petrochemical company WRPC on water and soil qualities of "contiguous host" and "impacted on communities" of Delta State, Nigeria. Open Environ Pollut Toxicol J 1:11–17

Nnaji JC, Omotugba S (2014) Physico-chemical quality of drinking water in New Bussa, Niger State, Nigeria. Int Res J Pure Appl Chem 4(4):437–446

Nriagu J (2007) Zinc toxicity in humans. Elsevier, Ann Arbor, pp 1–7

Nte FU, Esi EO, Edomi O (2013) Determination of water quality at orwell international oil and gas Nigeria limited, Rivers State, Nigeria. Int J Environ Monit Anal 1(6):302–306

Nwaichi EO, James IO (2012) Groundwater quality assessment in selected Niger Delta communities in Nigeria. J. Environ Anal Toxicol 2:133. doi:10.4172/2161-0525.1000133

Nwaichi EO, Monanu MO, Njoku OC (2013) Water quality assessment of rumuodomaya stream: chemical and biological studies. Res J Eng Appl Sci 2(1):29–34

Nwankwoala HO, Udom GJ, Ugwu SA (2011) Some heavy metal investigations in groundwater sources in Yenagoa, Bayelsa state, Nigeria. J Appl Technol Environ Sanit 1(2):163–170

Obunwo CC, Opurum IJ (2013) Evaluation and comparison of water quality parameters from fresh water surface streams and hand-dug wells in Isiokpo Community, Rivers State, Nigeria. J Nat Sci Res 3(13):42–45

Ocheri MI, Odoma LA, Umar ND (2014) Groundwater quality in Nigerian urban areas: a review. Glob J Sci Front Res 14(3):35–46

Odoemelam SA, Okorie DO, Oko IO (2013) Physicochemical parameters and heavy metal content of water, fish and sediments from cross river at Afikpo north local Government area of Ebonyi state, Nigeria. Biores Bull, No vol, pp 010–015

Oehmen A, Viegas R, Velizarov S, Reis MAM, Crespo JG (2006) Removal of heavy metals from drinking water supplies through the ion exchange membrane bioreactor. Desalination 199:405–407

Ogamba EN, Izah SC, Ogbogu MJ (2015a) Cadmium and Lead level in *Eichhornia crassipes* from River Nun, Niger Delta, Nigeria. J Adv Biol Basic Res 1(1):53–56

Ogamba EN, Izah SC, Oribu T (2015b) Water quality and proximate analysis of *Eichhornia crassipes* from River Nun, Amassoma Axis, Nigeria. Res J Phytomed 1(1):43–48

Ogamba EN, Izah SC, Toikumo BP (2015c) Water quality and levels of lead and mercury in *Eichhornia crassipes* from a tidal creek receiving abattoir effluent, in the Niger Delta, Nigeria. Cont J Environ Sci 9(1):13–25

Ogamba EN, Seiyaboh EI, Izah SC, Ogbugo I, Demedongha FK (2015d) Water quality, phytochemistry and proximate constituents of *Eichhornia crassipes* from Kolo creek, Niger Delta, Nigeria. Int J Appl Res Technol 4(9):77–84

Ogamba EN, Izah SC, Emaviwe D (2015e) Phytochemical assessment of *Eichhornia crassipes* from River Nun, Nigeria. Res J Phytomed 1(1):24–25

Oguntona TS, Adedeji OO, Martins OC (2012) Contamination of sachet water produced within industrial area of Ikeja, Lagos Nigeria. Transnatl J Sci Technol 2(10):69–74

Ohimain EI, Angaye TNC, Okiongbo KS (2013) Removal of iron, coliforms and acidity from ground water obtained from shallow aquifer using trickling filter method. J Environ Sci Eng A2:349–355

Ohimain EI, Angaye TNC, Oduah AA (2014) Biotreatment of acidic and high iron containing groundwater for aquaculture using plantain (*Musa paradisiaca*) tissues. Int J Eng Sci Innov Technol 3(5):121–126

Ohwo O, Abotutu A (2014) Access to potable water supply in nigerian cities evidence from Yenagoa Metropolis. Am J Water Resour 2(2):31–36

Oller AR, Costa M, Oberdörster G (1997) Carcinogenicity assessment of selected nickel compounds. Toxicol Appl Pharmacol 143:152–166

Olorunfemi DI, Ofomata CR, Alimba CG (2013) Cytogenotoxicity assessment of a university borehole water supply using the *Allium cepa* test. J Sci Res Dev 14:25–34

Oludare A, Sikiru S (2012) Microbiological, physicochemical and mineral quality of borehole water in Ijebu land, Ogun state, Nigeria. Int J Sci Adv Technol 2(1):23–30

Omotoriogun TC, Uyi OO, Egbon IN (2012) The physicochemical characteristics of Ibiekuma River Ekpoma, Nigeria. J Wetl Ecol 6:01–06

Opaluwa OD, Aremu MO, Ogbo LO, Magaji JI, Odiba IE, Ekpo ER (2012) Assessment of heavy metals in water, fish and sediments from UKE Stream, Nasarawa State, Nigeria. Curr World Environ 7(2):213–220

Osibanjo O, Majolagbe AO (2012) Physicochemical quality assessment of groundwater based on land use in Lagos city, Southwest, Nigeria. Chem J 2(2):79–86

Osredkar J, Sustar N (2011) Clinical toxicology copper and zinc, biological role and significance of copper/zinc imbalance. J Clinic Toxicol S:3. doi:10.4172/2161-0495.S3-001

Oyhakilome GI, Aiyesanmi AF, Akharaiyi FC (2012) Water quality assessment of the Owena multi-purpose dam, Ondo State, Southwestern Nigeria. J Environ Prot 3:14–25

Paulino AT, Minasse FAS, Guilherme MR, Reis AV, Muniz EC, Nozaki J (2006) Novel adsorbent based on silkworm chrysalides for removal of heavy metals from wastewaters. J Colloid Interface Sci 301:479–487

Prashanth L, Kattapagari KK, Chitturi RT, Baddam VRR, Prasad LK (2015) A review on role of essential trace elements in health and disease. J Dr NTR Univ Health Sci 4(2):75–78

Raji MIO, Ibrahim YKE, Ehinmidu JO (2010) Physico-chemical characteristics and heavy metal levels in drinking water sources in Sokoto metropolis in North-western Nigeria. J Appl Sci Environ Manag 14(3):81–85

Rehnberg GL, Hein JF, Carter SD, Linko RS, Laskey JW (1982) Chronic ingestion of Mn_3O_4 by rats: tissue accumulation and distribution of manganese in two generations. J Toxicol Environ Health 9:175–188

Richard MG (2009) Using sea shells to remove heavy metals from water. http://www.treehugger.com/natural-sciences/using-sea-shells-to-remove-heavy-metals-from-water.html. Accessed 28 July 2014

Roohani N, Hurrell R, Kelishadi R, Schulin R (2013) Zinc and its importance for human health: an integrative review. J Res Med Sci 18(2):144–157

Rowel C (2012) Using banana to remove metals from polluted water: an apeeling option. http://www.mindthesciencegap.org/2012/03/19/using-banana-peels-to-remove-metals-from-polluted-water-an-apeeling-option/. Accessed 28 July 2014

Samuel AO (2013) Level of selected metals in water, sediment and fish samples from Itapaji Dam, South-Western, Nigeria. Am Chem Sci J 3(4):459–467

Seilkop SK, Oller AR (2003) Respiratory cancer risks associated with low-level nickel exposure: an integrated assessment based on animal, epidemiological, and mechanistic data. Regul Toxicol Pharmacol 37:173–190

Sevcikova M, Modra H, Slaninova A, Svobodova Z (2011) Metals as a cause of oxidative stress in fish: a review. Vet Med 56(11):537–546

Shortt R, Boelee E, Matsuno Y, Faubert G, Madramootoo C, van der Hoek W (2003) Evaluation of thermotolerant coliforms and

salinity in the four available water sources of an irrigated region of Southern Sri Lanka. Irrig Drain 52:133–146
Standard organization of Nigeria (SON) (2007) Nigerian standard for drinking water quality. Nigerian industrial standard, Lagos
Sternberg SPK, Dom RW (2002) Cadmium removal using Cladophora in batch, semi-batch and flow reactors. Bioresour Technol 81:249–255
Ubuoh EA, Akhionbare WN, Akhionbare SMO, Ikhile CI (2012) Evaluation of the spatial variation of rainwater quality in parts of Akwa Ibom State of Nigeria using Chloropleth Map. http://www.abrj.org, vol 1(2), pp 10–28
Uffia ID, Ekpo FE, Etim DE (2013) Influence of heavy metals pollution in borehole water collected within abandoned battery industry, Essien Udim, Nigeria. J Environ Sci Water Resour 2(1):022–026
Ukpong EC, Okon BB (2013) Comparative analysis of public and private borehole water supply sources in Uruan Local Government Area of Akwa Ibom State. Int J Appl Sci Technol 3(1):76–91
Uwah EI, Busari WR, Sayi A (2014) Physicochemical and bacteriological analyses of sachets water samples in Kano Metropolis, Nigeria. IOSR J Appl Chem 6(6):52–56
Vivien C, Caleb AB, Lekwot VE (2012) Public health effects of effluent discharge of Kaduna Refinery into River Romi. Greener J Med Sci 2(3):064–069
Volesky B (2003) Sorption and biosorption. BV Sorbex Inc., St. Lambert
Watson TD (1998) Diet and skin disease in dogs and cats. J Nutr 128(12 Suppl):2783S–2789S
Wogu MD, Okaka CE (2011) Pollution studies on Nigerian rivers: heavy metals in surface water of Warri river, Delta State. J Biodivers Environ Sci 1(3):7–12
World Health Organization (WHO) (2011) Guideline for drinking water quality, 4th edn. World Health Organization, Geneva
Yakubu S (2013) Assessment of water quality of hand-dug wells in Zaria LGA of Kaduna State, Nigeria. Int J Eng Sci 2(11):01–04