Heavy metals research in Nigeria: a review of studies and prioritization of research needs

Gideon Aina Idowu

Abstract
Nigeria is experiencing continuous economic and industrial transformations, typical of many developing nations. In addition to its well-established oil industry, which is infamous for exuding various kinds of pollutants, there are increased mining operations, indiscriminate disposal and burning of wastes, illegal oil refinery and terroristic insurgency, all poised to increase the levels of heavy metal contaminants in the Nigerian environment. A recent revelation indicates that about 2 million people in South-western Nigeria alone could potentially be poisoned by lead (Pb) and mercury (Hg), emanating from illegal mining operations. This further underscores the importance of investigations of toxic trace metal levels in the country. The current review of 148 research articles was conducted to provide an understanding of the scope of heavy metals research in Nigeria and to prioritize needed research. The review recognized that the scope of heavy metals studies has been wide, covering matrices such as cosmetics, human blood, hair, medicines, foods, beverages, water, air, soil and crude oil. However, important toxic metals, especially mercury (Hg), arsenic (As) and antimony (Sb), are largely under-investigated. Also, there is a need for more studies to be conducted in the northern part of the country. Furthermore, studies need to focus on marine environments rather than the freshwater ecosystems alone. Techniques such as the inductively coupled plasma-optical emission spectrometry (ICP-OES) and particle-induced X-ray emission (PIXE) analyses are herein recommended to bridge the data gap and to overcome limitations in trace metals analyses in the Nigerian total environment.

Keywords Heavy metals · Nigeria; Environment · Research scope · Research needs · Human exposure

Introduction
The term ‘heavy metals’ is used widely to refer to a group of metals and semimetals (metalloids) that have been associated with contamination and potential toxicity to the environment and to various species of organisms. They have specific gravities greater than 5 g/cm³ or specific gravity at least five times that of water and are known to exist naturally in the Earth’s crust (Duffus 2002). More recently, the definition has been broadened to include naturally occurring elements with atomic number greater than 20 (Ali and Khan 2018; Ali et al. 2019).

Heavy metals are broadly grouped into essential and non-essential elements. The essential ones include iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), cobalt (Co), nickel (Ni), molybdenum (Mo) and selenium (Se). They are so-called because they are required by living organisms for fundamental metabolic activities. Many of them serve as cofactors that are functionally and structurally important for enzymes and enzyme-catalysed biochemical reactions, and this is true for many life forms. However, presence of these ‘essential’ metals above certain levels in organisms results in deleterious physiological effects. The non-essential heavy metals have no known benefits to the living systems and many of them are toxic at low concentrations. Non-essential heavy metals include lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), tin (Sn), aluminium (Al), silver (Ag), gold (Au), antimony (Sb), bismuth (Bi), palladium (Pd), platinum (Pt), vanadium (V), strontium (Sr), tellurium (Te), titanium (Ti), Uranium (U) and chromium (Cr), particularly...
the hexavalent form (Cr VI) (Tchounwou et al. 2012). Concerns about heavy metals arise from the fact that they may find their ways into the food chain, through bioaccumulation in plants and animal species, or they may contaminate drinking water sources. The latter is particularly through of developing nations (e.g. Nigeria), where many rural communities depend on open and unprotected surface water sources for drinking, domestic and recreational purposes.

Toxicity effects of heavy metals manifest in various forms. For example, the ability of Cu to change between Cu(I) and Cu(II) oxidation states in living systems enables it to function as cofactor for many oxidative stress-related cuproenzymes such as superoxide dismutase, cytochrome oxidases and ferrooxidases. However, this ability to transit between oxidation states also makes Cu toxic, since the process may generate superoxide and hydroxyl radicals (Harvey and McArdle 2008; Stern 2010). Thus, excessive exposure to Cu causes cellular and tissue damages, resulting in Wilson disease in humans (Tchounwou et al. 2012). Pb exerts its toxicity effect by mimicking and inhibiting Ca ions and by interacting with proteins. It therefore affects the central nervous system and vitamin D metabolism and causes reproductive impairments, brain and kidney damages, as well as gastro-intestinal diseases (Flora et al. 2006; Wani et al. 2015).

The vast majority of heavy metals are present naturally in the environment. However, the public and environmental health concerns associated with them stem mainly from the levels introduced by anthropogenic activities. Heavy metals emanate from industrial effluents, mining, smelting of iron, combustion of fossil fuels, waste and biomass burning, manufacturing, use and disposal of electronic gadgets and a host of other human-initiated processes. While many of these activities also go on in the developed nations, as they do in the developing economies, the poor enforcement of environmental laws, coupled with the indiscriminate proliferation of small-scale manufacturing businesses and the lack of efficient recycling programme, makes the environment in developing nations particularly susceptible to heavy metals contamination.

In Nigeria, fairly recent cases of heavy metals poisoning and potential significant pollution by heavy metals make their continuous monitoring worthwhile. The largest known incidence of lead poisoning in history, killing 163 people (including 111 children), took place in Zamfara villages, Northern Nigeria in 2010 (CDC 2016). Unauthorized and illegal mining of gold ores, apparently containing high levels of Pb, caused widespread contamination of soil and drinking water sources with Pb. High concentration of Pb was detected in the blood of children, many of whom had suffered from headaches, vomiting, abdominal pains, seizures and death (Orisakwe et al. 2017). The Pb contamination spread across eight villages, namely Bagega, Dareta, Yargalma, Abare, Tungar Daji, Tungar Guru, Duza and Sunke. More recently, artisanal mining operations, similar to that in Zamfara State have been spreading across the country, and a recent investigation suggests that about two million people in South-western Nigeria may be at risk of Pb and Hg poisoning (Vanguard 2021). Beyond artisanal mining, there is potential for toxic metals emanating from various activities in the country to enter the food chain, leading to significant chronic/long-term human exposure. This necessitated numerous individual studies which determined heavy metals in all kinds of samples. In this review, an attempt is made to summarize investigations into heavy metals in Nigeria over the past 22 years, with a view to understanding the full scope of studies so far and to identify important research gaps.

Previous reviews on heavy metals studies in Nigeria have been limited in scope. Onakpa et al. (2018) reviewed heavy metals contamination of food crops in Nigeria. Musa et al. (2017) focussed their review on studies that reported the contamination of agricultural soils by heavy metals. Review of contamination of potable water sources and beverages were conducted by Izah et al. (2016) and Izah et al. (2017), respectively. While these reviews have focussed mostly on food items and water, understandably because they are obvious sources of exposure of humans to these toxic substances, they do not provide the full scope of research into heavy metals contamination in Nigeria. This is important to identify knowledge gaps in trace metal investigations in the country and to provide an understanding of the levels reported in other exposure sources (e.g. cosmetics, herbal medicines, orthodox medicines, air) and in human body/fluid samples, which are all covered in this review. The review therefore attempts to exhaustively summarize the investigations of heavy metals in all matrix types and environmental phases reported so far in Nigeria.

Methodology

Literature search

Literature search for studies on heavy metals in Nigeria was performed in Scopus, Google scholar, PubMed and ResearchGate databases in the month of November in year 2021. Key phrases used in the search were as follows: heavy metal research in Nigeria; heavy metals in the Nigerian environment; heavy metals in the atmosphere/air in Nigeria; heavy metals in cosmetics in Nigeria; heavy metals in human samples in Nigeria; heavy metals in water in Nigeria; heavy metals in foods in Nigeria; heavy metals in soil and sediments in Nigeria; heavy metals in medicine and drugs in Nigeria; heavy metals in aquatic biota in Nigeria; and heavy metals in all matrices in Nigeria. The search was also conducted with the phrase ‘heavy metals’ replaced with other...
similar terms such as ‘trace elements’, ‘toxic elements’ and ‘potentially toxic metals’, which are also commonly used in publications. The search was performed independently in each database and the results were compared and collated.

**Article selection criteria**

Articles that reported concentrations of heavy metals in various matrices in Nigeria were sought for. Article information such as title and abstracts were scrutinized and the irrelevant ones, such as those reporting on phytoremediation of heavy metals, were excluded. Only articles published within the last 22 years (i.e. from years 2000 to 2021) were retained from each database. Furthermore, in order for the final review to reflect the most up-to-date data and information, as well as the latest trend of research on heavy metals in the country, priority was given to articles published within the last three years (up to November, 2021). In instances where two or more papers reported on the same sample types, the latest of the publications was retained in order to keep the total number of the articles for review within a sizable/reasonable amount. After applying the selection criteria and eliminating irrelevant articles, a total of 148 were left from an initial 197 articles obtained via the database search.

The full scheme of selection of the 148 reviewed articles is shown in Fig. 1. The 148 articles were then read in sufficient details during the review and draft preparation (December 2021 to March 2022). Apart from the 148 articles that were actually reviewed and analysed, additional 36 articles were cited while discussing the findings of the review under the various subheadings.

**Results and discussion**

**Distribution of heavy metals research articles reviewed**

Distribution of articles reviewed is considered with respect to the year of publication and the geopolitical zone of Nigeria where the study was conducted. Figure 2 shows the distribution of the journal articles reviewed according to the years of publication. All articles that reported levels of heavy metals in Nigeria and published within the last 4 years (2019–2022) were retained to provide current data and current research trends.

The 78 articles in this category constitute 52.7% of the 148 articles reviewed. These 78 articles were all published
after the last review on the subject by Onakpa et al. (2018) which focussed on food contamination aspect only, thereby making this review an important update on heavy metal research in Nigeria. Articles published from years 2000–2004, 2005–2009, 2010–2015 and 2016–2018 represent 1.35%, 7.43%, 18.91% and 19.59% of the reviewed articles, respectively.

Nigeria is divided into six distinct geo-political zones for the purpose of governmental administration. Table 1 presents details of studies that reported heavy metals from the regions and shows a list of the heavy metals that were reported from each region. It should be noted that the summation of the number of articles from the regions shown in Table 1 exceed 148, because some studies determined heavy metals in samples obtained from more than one geo-political zones.

**Scope of heavy metals research in Nigeria**

**Heavy metals in cosmetics and personal care products**

Manufacturers of cosmetics and skin care products often incorporate substances that could impart substantial amount of heavy metals onto the products. Relevant items to which such substances are incorporated include lipsticks, body creams, sunscreen products, talcum and brown powder, eye shadow, shampoos and concealers. For example, zinc (as the oxide) is widely used in sunscreens, diaper ointments, moisturizers, shampoos and concealers; chromium is used in some products as a colorant; and iron oxides are commonly used as colorants in eye shadows, blushes and concealers (Odukudu et al. 2014).

Despite the prohibition of Pb, As, Cd, Co, Sn, Hg, Ni and Cr in cosmetics, many producers still include compounds that contain these metals at levels above the WHO permissible limits. Table 2 provides a summary of studies that have investigated levels of some heavy metals in cosmetics and personal care products (PCPs) marketed in Nigeria. Usman et al. (2021) determined concentrations of Pb, Co, Cu, Cr and Ni on various kinds of cosmetic products in Nigeria and found high concentrations of Co and Pb in face powders and eye shadows, respectively. The study also found that the concentrations of Cr in eyeshadow, lipstick and face powders were above the USEPA and USFDA permissible limits.

Odukudu et al. (2014) investigated the concentration of heavy metals in toothpaste, cosmetics, tissue papers and hair relaxers. Cd and Cr, which are not permitted to be used in personal care products, were present at high concentrations up to 0.68 and 0.76 mg/kg (or ppm), respectively, in the products. Oyekunle et al. (2021) worked on native black soaps and conventional soaps and reported high Hg concentrations of 273.6 and 55.12 µg/g maximum values, respectively, in the soaps. While noting that highly mercuric soaps are effective against fungi and bacteria, the authors cautioned that such products would only be safe if restricted to occasional use by adults and children. Cd, another very toxic metal, was also detected in the soaps, although at much lower concentrations compared to those of Hg. Despite the fact that Zn is an essential element, the study reported values for Zn that raise safety concerns, due to potential cumulative dermal exposure to such high concentrations of the metal.

In addition to studies that investigated the heavy metals directly in cosmetics and PCPs, Eneh (2021a) analysed urine and serum samples of female students in a selected Nigerian population to assess impacts of the use of cosmetics on trace metals absorption into the body. The study found that the mean concentration of Hg (25.9 µg/dL), Pb (17.3 µg/dL) and As (166.0 µg/L) in the urine of students who had consistently used make-up were higher than those who did not wear make-ups. The study points to the negative impact of the use of contaminated cosmetic products on body’s burden of these toxic metals.

**Heavy metals in the atmosphere**

Heavy metal presence in atmospheric air may result from combustion of fossil fuel. They could also emanate from non-exhaust sources like wear and tear of vehicle brakes and tyres and from a host of other anthropogenic activities (Anake et al. 2017). Metals may exist in form of vapour in the air, thereby increasing the chance of being inhaled by humans. Studies which investigated toxic metals in air in Nigeria have done so relative to metals bound to particulate matters (PM). Uzoekwe et al. (2021) investigated heavy metal presence and levels in particulate matters (PM$_{10}$)
| Zone           | Number of articles | Metals reported              | References                                                                 |
|---------------|--------------------|------------------------------|----------------------------------------------------------------------------|
| North-east    | 6                  | Pb, Cr, As, Cd, Fe, Cu and Zn | Amadi et al. (2020); Bawuro et al. (2018); Nduka et al. (2020); Lawal et al. (2021); Usman et al. (2021); Akan et al. (2014) |
| North-west    | 7                  | Ti, Fe, Nb, Pb, Rb, Sr, Y, Cu, Cd, Cr, Ni, Mo, Mn, Zn and Zr | Haruna et al. (2009); Abdu et al. (2011); Tukura et al. (2011); Gaya and Ikechukwu (2016); Amadi et al. (2020); Datti and Mukhtar (2020); Usman et al. (2021) |
| North-central | 20                 | Zn, Pb, Cr, Cu, Fe, Rb, Zr, Ni, Cd, Co, As, Mn | Adekola et al. (2001); Akande et al. (2021); Barau et al. (2018); Opaluwa et al. (2012); Mafuyai et al. (2014); Amoo et al. (2005); Isinkaye (2018); Ramadan and Haruna (2019); Abalaka et al. (2020); Amadi et al. (2020); Aya et al. (2020); Emurutu (2020); Olotuna and Daniel (2020); Orosun et al. (2020); Abdulraheem et al. (2021); Denkok et al. (2021); Oluwasola et al. (2021); Orisakwe et al. (2018); Samuel and Babatunde (2021); Usman et al. (2021) |
| South-south   | 40                 | Cd, Cr, Fe, Zn, Ni, Cu, Pb, Co, Mn, V, Cu | Osuji and Onojake (2004); Hart et al. (2005); Akaninwor et al. (2006); Wegwu and Akaninwor (2006); Wegwu and Wigwe (2006); Iwegbue et al. (2007); Obasohan and Eguavoen (2008); Iwegbue (2010); Wegwu and Omecud (2010); Iwegbue et al. (2012); Ighariemu et al. (2019); Joseph et al. (2021); Udousoro et al. (2013); Vincent-Akpu and Babatunde (2013); Amos -Tautua and Onigbinde (2014); Bassey et al. (2014); Iwegbue et al. (2014); Adebiyi and Adebiyi (2015); Ebong et al. (2015); Adams et al. (2016); Benson et al. (2016); Anani and Olomukoro (2017); Omole (2017); Anani and Olomukoro (2018); Ebong et al. (2018); Enuneku et al. (2018); Aigberua and Izah (2019); Ebong et al. (2019); Kalagbor et al. (2019); Aigberua et al. (2020); Amadi et al. (2020); Izah and Aigberua (2020); Ohiagu et al. (2020); Akinlua et al. (2020); Odigie and Olomukoro (2021); Ogamba et al. (2021); Usman et al. (2021); Uwah et al. (2021); Uzoekwe et al. (2021); Nwaichi et al. (2016) |
| South-east    | 33                 | Pb, As, Cr, Cd, Hg, Fe, Zn, Cu, Ni, Se, Co, I, Mo | Wegwu and Wigwe (2006); Olife et al. (2007); Obasohan (2008); Orisakwe et al. (2019); Ohanu et al. (2020); Ekere and Ukoha (2013); Ezeh and Chukwu (2011); Ekere et al. (2014); Ekwere et al. (2014); Emerereiboe et al. (2017); Anyanwu and onyele (2018); Azi et al. (2018); Ekwere (2019); Ibe et al. (2018); Ugochukwu (2019); Verla et al. (2019); Amadi et al. (2020); Anyanwu et al. (2020); Anukwuorji et al. (2020); Anyanwu and Nwachukwu (2020); Eze et al. (2020); Obaasi and Akudinobi (2020); Verla et al. (2020); Duru et al. (2022); Enhe (2021b); Njoga et al. (2021); Nnamonu et al. (2021); Onome and Igwe (2021); Orji et al. (2021); Ugochukwu et al. (2021); Ugochukwu et al. (2021); Ugwu and Olomotai (2021); Ugbede et al. (2021); Usman et al. (2021) |
suspended in air around a gas flaring facility in Bayelsa State. Maximum concentrations of the metals were 0.197, 0.060, 1.280, 0.170, 0.310 and 8.233 µg/m^3 for Co, As, Cr, Cd, Cu and Fe, respectively. The study concluded that gas production and flaring did not contribute significantly to atmospheric metal loads within the study area. On the other hand, Anake et al. (2017) determined PM_{2.5}-bound trace metals in an industrial estate in Ogun State and reported

### Table 1

| Zone     | Number of articles | Metals reported | References |
|----------|--------------------|-----------------|------------|
| South-west | 54                 | Cd, Co, Cu, Ni, Pb, Zn, Fe, Cr, Mn, Ti, Fe, Ga, As, Hg, Rb, Sr, Se, Zr, Nb, V, Sc, Th, U and ^{40}K | Adekola et al. (2001); Adeogun et al. (2020); Adesewa and Morenikeji (2017); Olabanji and Adeniyi (2005); Wegwu and Wigwe (2006); Otitoloju et al. (2007); Oladejo et al. (2021); Aiyesannmi et al. (2010); Aiyesannmi and Idowu (2012); Olutona et al. (2012); Olutona et al. (2013); Obedunmi et al. (2014); Odukudu et al. (2014); Ofudje et al. (2014); Olutona et al. (2014); Tomori and Onibon (2015); Onojake et al. (2016); Anake et al. (2017); Ogugua and Ikegwu (2017); Ogundele et al. (2017); Oyebamiji et al. (2018); Aduwo and Adeniyi (2018); Alolayan (2018); Olutona and Adedokun (2018); Maduwuchi et al. (2019); Ogundele et al. (2019); Oputola and Aderemi (2019); Adebiyi and Ore (2020); Aiyesannmi et al. (2020); Amadi et al. (2020); Amusan and Adu (2020); Laniyan and Adepu et al. (2020); Ogunlade et al. (2020); Oguntade et al. (2020); Olusegun et al. (2021); Oluwafemi et al. (2021); Adewumi et al. (2021); Achi et al. (2021); Adeyemi and Ojekunle (2021); Ayodele et al. (2021); Ganiyu et al. (2021); Idowu et al. (2020); Nnanemene (2021); Ogundele et al. (2021); Oyekunle et al. (2021); Oyetibo et al. (2021); Taiwo et al. (2021); Usikalu et al. (2021); Usman et al. (2021) |

### Table 2

| Sample type               | Pb     | Cd     | Cr     | Fe     | Cu     | Co     | Zn     | Ni     | References |
|---------------------------|--------|--------|--------|--------|--------|--------|--------|--------|------------|
| Toothpaste                | 0.04   | 0.07   | 0.03   | 0.70   | 0.31   | -      | 0.41   | 0.05   | Odukudu et al. (2014) |
| Disinfectants             | 0.38   | 0.38   | 0.76   | 0.92   | 0.65   | -      | 0.61   | 0.12   | Odukudu et al. (2014) |
| Tissue paper              | 0.06   | 0.16   | 0.09   | 0.71   | 0.73   | -      | 0.14   | 0.18   | Odukudu et al. (2014) |
| Hair relaxer              | 0.03   | 0.68   | 0.60   | 1.03   | 0.63   | -      | 0.79   | 0.08   | Odukudu et al. (2014) |
| Cosmetics                 | 0.17   | 0.09   | 0.47   | 6.65   | 1.03   | -      | 0.88   | 0.08   | Odukudu et al. (2014) |
| Cocoa pods soap           | 22.6   | 4.72   | -      | -      | 20.71  | -      | 42.6   | 171    | Oyekunle et al. (2021) |
| Palm bunch soap           | 15.0   | 4.51   | -      | -      | 260    | -      | 66.1   | 143.1  | Oyekunle et al. (2021) |
| Lux soap                  | 3.37   | 5.20   | -      | -      | 9.82   | -      | 17.5   | 55.1   | Oyekunle et al. (2021) |
| Joy soap                  | 5.29   | 2.88   | -      | -      | 3.10   | -      | 32.3   | 46.3   | Oyekunle et al. (2021) |
| Lipstick                  | 7.80   | 4.31   | -      | -      | 1.79   | 5.76   | -      | 0.90   | Usman et al. (2021) |
| Face powder               | 2.02   | 2.08   | -      | -      | 2.14   | 8.15   | -      | 8.95   | Usman et al. (2021) |
| Eye shadow                | 13.6   | -      | 5.28   | -      | 6.07   | 2.09   | -      | 2.80   | Usman et al. (2021) |
| Eyeliner                  | 6.12   | -      | 0.01   | -      | 1.20   | 7.87   | -      | 5.17   | Usman et al. (2021) |
| Foundation                | 1.80   | -      | 1.52   | -      | 1.28   | 4.02   | -      | 4.81   | Usman et al. (2021) |
| Primer                    | 2.95   | -      | 1.87   | -      | 2.49   | 6.51   | -      | 7.26   | Usman et al. (2021) |
| Lip gloss                 | 6.12   | -      | 0.13   | -      | 4.89   | 2.87   | -      | 7.00   | Usman et al. (2021) |

All recorded values are mean or maximum concentrations determined by the authors; '-' are metals not determined by the authors or below the quantitation limit.
which were well above the acceptable range of $10^{-6}$ to $10^{-4}$, indicating significant contribution of the industrial activities to the levels of suspended metals in air. The study also reported that Cu and Cr exist in the exchangeable form and would be readily transferred to the human system if the particulate matters were inhaled. Ogundele et al. (2017) investigated nine heavy metals (Pb, Mn, Cd, Zn, Cr, As, Ni, Cu and Fe) in air PM around iron and smelting companies in Ile-Ife, Osun State. Concentrations of Cd, Pb, Mn and Ni in the samples were found to exceed both WHO and USEPA guideline safety limits, resulting in the deterioration status confirmed by various pollution indices. Following months of black soot enveloping the atmosphere in Port-Harcourt, the city of oil and refineries in Southern Nigeria, Kalagbor et al. (2019) determined heavy metals in the soot samples collected from residential areas. Concentrations of all the metals were higher than those in unpolluted control samples, while also exceeding WHO standard limits. In particular, Cd and Pb levels were significantly high and cancer risk assessments suggested that children in the city were at risk of developing various types of cancers (Kalagbor et al. 2019).

There have also been reports of heavy metal presence in the atmosphere in Northern Nigeria. Mafuyai et al. (2014) determined heavy metals (Pb, Cr, Fe, Mn, Cd, Zn, Cu and Ni) in respirable dusts from seven locations within Jos metropolis, Plateau State, over a period of 3 months. Concentrations of Cd, Ni and Mn were found to greatly exceed the WHO recommended limits for the metals in respirable dusts. The study attributed the presence of the metals in the samples to vehicular traffic and wastes incineration in the city (Mafuyai et al. 2014). Ayua et al. (2020) also investigated heavy metals in respirable dust and PM around industrial sites in Kano, Kaduna and Jos. Concentrations of Cd, Ni and Pb were found to be above the WHO set standard limits in some of the areas studied. The study reported strong correlation between PM and the heavy metals, thereby confirming that the contaminants indeed originated from the industrial activities. This finding also gives credence to the use of sampled air-suspended PM for the evaluation of heavy metal levels in air, as reported by most of the studies.

**Heavy metals in ground waters, surface waters and aquatic biota species**

The review revealed that water is one of the most studied environmental phases, with respect to investigations of heavy metals contamination in Nigeria. Numerous studies have considered this phase from various perspectives and motivated by different reasons. For instance, only about 10% of Nigerians have access to centrally managed clean pipe-borne water; the majority of Nigerian homes depend on underground waters, accessed via hand-dug wells and mechanically drilled borehole facilities (Idowu et al. 2022). Many rural populations also depend on water abstracted from unprotected surface sources such as streams and rivers. This situation, coupled with poor enforcement of environmental laws, which potentially exposes these water resources to contamination by various industrial and municipal wastes, has formed part of the motivation for many studies investigating levels of heavy metals in water samples. Additionally, unprotected and unmanaged streams and rivers often serve as means of recreation (i.e. swimming) to people in rural Nigeria, with the potential hazard of ingesting waters contaminated with toxic metals.

Denkok et al. (2021) determined heavy metals in various water samples, including ground water and factory-packaged satchet water, in Jos, Plateau State. The authors found that the levels of Pb, Cd, Cr and Cu were higher than their respective WHO allowable limits in drinking water. Adeyemi and Ojekunle investigated heavy metal concentrations in underground waters (which provide drinking water to people) around industrial estates in Ogun State. High concentrations of Pb, Fe, Ni and Cr were measured in the samples, with the total hazard index (HI) showing high risk across different age groups and particularly for infants. On the other hand, Enuneku et al. (2018) worked on water samples from boreholes sited close to some dumpsites in Benin City, Nigeria. Based on the metals pollution indices and the estimated daily dosage through drinking, it was established that the levels of metals in the boreholes posed no threat to the health of the people.

Afolayan (2018) reported heavy pollution of surface waters in Ibadan with Pb, Cd and Fe, due to the presence of a battery waste dumpsite from which these metals leach to the surface water. Odebunmi et al. (2014) worked on various ground and surface water samples from different locations in Osun State and found that the toxic metals (Pb, Hg, As and Cd) were all higher than WHO permissible limit for drinking water. Because many Nigerian homes harvest rainwater for drinking during the rainy season, Olabanji and Adeniyi (2005) investigated heavy metals content of rain water, comparing levels in free-fall rain water to those harvested via roof tops. The study found that the metal concentrations were higher in roof-harvested rain water, with the metals content reflecting the metallic composition of the roofing material. However, levels in both water types were within safe limits and were lower than those determined for the neighbouring surface waters, packaged table waters and vegetation-intercepted rainwater.

Ekere et al. (2014) determined levels of As, Cd, Hg, Pb, Cr, Fe and Cu in water samples from streams, lakes/ponds and hand-dug wells in rural parts of South-eastern Nigeria. The result showed that except for Hg, other showed above the permissible limit of drinking water. The total hazard index of the metals, assessed through human oral water...
consumption, indicated that the water sources were mostly of high risk. As an example of studies that sought to determine seasonal variation of heavy metals in environmental matrices, Achi et al. (2021) investigated levels of Fe, Mn, Zn, Cu, Cd, Cr, Pb and Ni in water samples from Ogberere River, in Ibadan South-western Nigeria. Significant variation was observed for Mn, Fe, Pb, Cr and Cd, with concentrations higher in the dry season samples than in the wet season samples.

Closely related to studies on surface waters are those examining concentrations of heavy metals in fish and other aquatic fauna. Such studies are important because they reveal the level of exposure of the organisms to toxic trace metals, which may also be passed on to humans through the food chain. Indeed, Nigerians in rural areas freely obtain food resources from many rivers and streams. Also, the use of contaminated waters for fish cultivation may result in the presence of heavy metals in fish species sold and consumed locally. Abalaka et al. (2020) determined concentrations of heavy metals in samples of *Clarias gariepinus* (common catfish) and *Synodontis clarias* (mandi) obtained at Kado fish market Abuja (north central) Nigeria. Concentrations of Cr, Fe, Cd and Cu exceeded their permissible limits, while evidence of bioaccumulation in liver was obtained for Zn, Cr, Fe and Cu. Obasohan and Eguavoen (2008) studied heavy metal levels in *Erpetoichthys calabaricus* (freshwater reed fish) in Ogbere River, Benin City. The authors determined and compared dry and rainy season concentrations of Cu, Mn, Zn, Cr, Ni and Pb in the fish. Concentrations of the metals in the fish were all higher than in the river water, pointing to a bioaccumulation effect of metals in this fish species. The study also reported that both dry and rainy season levels of Cu, Mn and Ni exceeded their WHO permissible limits for the metals in food. Bawuro et al. (2018) investigated levels of Zn, Pb, Cd and Cu in fish species from Geriyo Lake in Adamawa State and found high concentrations of Pb, above permissible limit, in *Clarias anguillaris* and *Heterotis niloticus* species. Similar studies were conducted by Wegwu and Akaninwor (2006), Oguguah and Ikegwu (2017) and Olayinka-Olagunju et al. (2021) on fish resources in new Calabar River, Lagos Lagoon and Ogbese River (Ondo State), respectively. Wegwu and Akaninwor (2006) further demonstrated that heavy metal presence, even at concentrations below those determined in the Nigerian rivers, caused death of fishes and inhibited hatching of their eggs. A number of studies (for example Aiyeyami et al. 2010; Anani and Olomukoro 2017; Adowo and Adeniyi 2018; Ogundele et al. 2019; and Aigberua et al. 2020) have also reported levels of heavy metals in river sediments, the bottom layer comprising soil, dead and decayed plant and animal materials, onto which metals are significantly adsorbed and may be resuspended into the water column.

### Heavy metals in foods and beverages

Plants growing on contaminated soils may bioaccumulate heavy metals from the soil and translocate it from the root to other parts of the plant. This principle is employed in phytoremediation of lands contaminated with heavy metals. In Nigeria, edible crop plants are sometimes grown on river floodplains, which receive deposits of wastes and contaminants (including heavy metals) during flooding events (Madauwuchi et al. 2019). Metals from the soil may then transfer to vegetables and food crops growing on the floodplains. Additionally, edible crops and vegetables are found growing around waste dumpsites and factories, with the tendency of toxic metals being transferred from the soil into various plant parts. Apart from these routes, there are other potential routes through which food items may be contaminated by trace metals, and a number of studies have focussed on this subject (Table 3). Akaninwor et al. (2006) compared trace metal concentrations in Nigerian staple food crops (both raw and cooked) from farmlands in Rivers State, an oil-producing area of Nigeria, to those from farmlands in non-oil producing (Ebonyi) state. Metal concentrations were found to be significantly higher in the food crops from the oil-rich region than in the same crops from the non-oil state. This result was attributed to the nature of the soil in the oil-producing area, being high in organic matter content that could chelate metals in the soil and facilitate their transfer into the crop plants. Similar report of comparatively high heavy metals content in crops from oil-producing area was made by Wegwu and Omeodu (2010).

Olutona and Daniel (2020) worked on melon seeds obtained from northern and south-western parts of Nigeria. Heavy metals determined in the samples were of the following order: Pb > Zn > Ni > Co > Cd, with all values higher in seeds from the north than in the south-west. Concentrations of Pb, Cd and Ni were found to be above the WHO permissible limits in samples where they were detected. Samuel and Babatunde (2021) performed health risk assessment, following the determination of heavy metals in food crops grown around an abandoned lead–zinc mining site in Tse-Faga, Benue State. High hazard quotients of 1714 and 1.143 were determined for Pb in *Zea mays* and *Manihot esculenta*, respectively. The study indeed indicated that the consumption of food crops growing in the vicinity of the abandoned mining site may cause lead poisoning in humans.

Taiwo et al. (2021) investigated heavy metals in sixty samples of snacks and ‘fast foods’ in Ijebu-ode, South-western Nigeria. The authors found that Fe was most abundant in the samples at concentrations up to 71.3 mg/kg (in cashew nuts). Cancer risk for Co in all the food samples exceeded the acceptable limit of 0.0001, suggesting the possibility of development of cancer by individuals who consume the foods on regular basis. Gaya and Ikechukwu (2016)
investigated levels of ten heavy metals in different types of plant-derived spices (seeds, leaves, bulbs, fruit pods and rhizomes), obtained from a market in Kano, Northern Nigeria. The spices all had excessive amounts of Fe and Cu, with maximum levels in ginger (19.4 mg/kg) and African nutmeg (15.3 mg/kg), respectively. Estimated daily intakes of the metals in onion, ginger, alligator pepper, utazi, Ashanti leaves, garlic, castor seeds and shallot were all above the tolerable limits set by FAO/WHO.

Apart from plant-based foods, other types of food materials produced in the country have also been investigated. For instance, environmental contamination with toxic metals affects fodder plants, pastures and drinking water sources used for livestock production. In particular, nomadic cattle roaming and rearing in Nigeria depend on waters from unprotected rivers and streams as sources of drinking water for cattle, with the animals directly ingesting water contaminated with toxic metals and other chemical substances. Heavy metal levels in tissues of food animals may therefore provide indication of the degree of meat toxicological safety and the extent of environmental contamination by the metals. Ihedioha and Okoye (2013) investigated heavy metals in various edible organs of cattle and reported high levels of Cr (19.9 ± 2.92 mg/kg) and Zn (529.4 ± 155.3 mg/kg) in the samples. This finding is highly significant, given the huge amount of beef consumed annually in Nigeria, estimated at 360,000 tonnes (Vanguard 2019). Njoga et al. (2021) also determined levels of As, Cd and Pb in 450 edible samples of goat meat, comprising the kidney, liver and muscle, obtained from regular slaughter houses in Enugu State. The study detected at least one toxic metal in 56% of the samples, with the highest mean concentrations of 0.57, 0.82 and 0.06 mg/kg recorded for As, Pb and Cd, respectively. Estimated daily intake for all the metals exceeded recommended safety limits. Because goat meat is commonly consumed in delicacies in eastern part of Nigeria, this study highlighted the significant public health risks that the consumption of goat meats poses to humans in the region. Wegwu and Wigwe (2006) worked on edible meat/flesh of the African giant snail (Archachatina marginata), sourced from three geopolitical zones of Nigeria — south-east, south-west and south-south. The study quantified Cu, Fe, Zn, Ni, Pb and Cd in the snail samples and reported that the heavy metal concentrations were above the WHO limits.

Table 3 Heavy metal concentrations reported in foods (mg/kg) and drinks (mg/L) in Nigeria

| Sample type         | Pb   | Cd   | Cr   | Fe   | Cu   | Co   | Zn   | Mn   | Ni   | As   | References                  |
|---------------------|------|------|------|------|------|------|------|------|------|-----|-----------------------------|
| Fish                | 0.12 | 0.19 | 0.73 | 146  | 3.28 | -    | 67.1 | -    | -    | -   | Abalaka et al. (2020)        |
| Vegetables          | 180  | 24.9 | 46.0 | 894  | 5.50 | 144  | 189  | -    | -    | -   | Aiyesanmi and Idowu (2012)  |
| Cooked foods        | -    | 0.28 | 52.8 | 5.83 | 38.3 | 4.50 | -    | -    | -    | -   | Akinrinor et al. (2006)      |
| Vegetables          | 4.31 | 0.22 | 0.02 | -    | -    | 28.6 | -    | -    | 2.12 | -   | Barau et al. (2018)          |
| Fish species        | 0.05 | 0.01 | 0.017| 1.75 | 0.65 | 0.45 | 0.15 | 0.01 | -    | -   | Bassey et al. (2014)         |
| Vegetable           | 0.08 | 0.73 | 13.8 | -    | -    | 252  | 26.8 | -    | -    | -   | Benson et al. (2016)         |
| Spices              | 4.72 | 7.8  | 4.07 | 19.4 | 15.3 | 10.6 | 14.9 | 8.33 | 4.12 | -   | Gaya and Ikechukwu (2016)    |
| Farm crops          | 9.10 | -    | 650  | 23.0 | -    | 240  | -    | -    | -    | -   | Hart et al. (2005)           |
| Cattle meats        | -    | 19.9 | -    | -    | -    | 529  | 1.72 | -    | -    | -   | Ihedioha and Okoye (2013)    |
| Alcoholic drinks    | 0.19 | 0.05 | 0.15 | 10.3 | 0.60 | 0.08 | 3.84 | 3.97 | 0.11 | -   | Iwegbue et al. (2014)        |
| Canned beers        | 0.047| 0.01 | 0.40 | 0.73 | 0.10 | 0.01 | 0.15 | -    | 0.10 | -   | Iwegbue (2010)               |
| Tomatoes            | -    | -    | 0.896| -    | 2.43 | 2.05 | 1.77 | -    | -    | -   | Izah and Aigberua (2020)      |
| Goat meats          | 0.82 | 0.06 | -    | -    | -    | 2.94 | -    | 0.57 | -    | -   | Njoga et al. (2021)          |
| Vegetables          | 0.67 | 0.07 | 0.18 | 13.2 | 0.05 | 6.54 | 0.38 | -    | -    | -   | Odum et al. (2021)           |
| Legumes             | 1.45 | -    | 44.7 | 179  | 8.23 | 59.6 | -    | -    | -    | -   | Olotuna and Aderemi (2019)   |
| Melon               | 19.8 | 1.35 | -    | -    | 2.58 | 16.9 | 3.56 | -    | -    | -   | Olotuna and Daniel (2020)    |
| Malt drinks         | 1.12 | -    | 0.698| 0.102| -    | 0.65 | 0.48 | -    | -    | -   | Olotuna and Livingstone (2018)|
| Vegetables          | 14.8 | -    | 20.4 | -    | 112  | 106  | -    | -    | -    | -   | Olotuna et al. (2021)        |
| Food crops          | 2.03 | 4.71 | -    | 16.7 | -    | 7.65 | 0.61 | -    | -    | -   | Omeke and Ighwe (2021)        |
| Snacks              | -    | -    | 71.3 | 20.9 | 3.99 | 13.5 | -    | -    | -    | -   | Taiwo et al. (2021)          |
| Rice plants         | 20.0 | -    | 45   | -    | 80.0 | 2.00 | -    | -    | -    | -   | Udousoro et al. (2013)       |
| Seeds/vegetables    | 0.23 | 0.14 | -    | 26.2 | 16.8 | 5.27 | 202  | 199  | -    | -   | Wegwu and Omeodu (2010)      |
| Giant snail         | 5.00 | 1.70 | -    | 34.8 | 9.60 | 20.4 | 10.2 | -    | -    | -   | Wegwu and Wigwe (2006)        |

All recorded values are mean or maximum concentrations determined by the authors. Mercury (Hg) 7.5 and 0.01 mg/kg were reported by Azi et al. (2018) and Bassey et al. (2014), respectively; 0.004 mg/kg of Al was reported by Iwegbue (2010); ‘-’ are metals not determined by the authors or below the quantitation limit.
particularly in samples gotten from highly industrialized environments.

Benthic invertebrates such as periwinkle (\textit{Tymanotonus fuscatus}), mudskipper (\textit{Periophthalmus barbarus}) and sesarmid crab (\textit{Guinearma alberti}) constitute an important food (soup) ingredient in Southern parts of the country. Odigie and Olomukoro (2021) determined heavy metals content of these benthic fauna species, collected monthly from a wetland area in Delta State, over a period of 18 months. Apart from assessing the toxicological safety of their consumption, the species are bioindicators that could reveal levels of bioavailable toxic metals or other pollutants present in the rivers and sediments. Notable maximum mean concentrations of the metals measured in the species were 349.8, 3.46, 2.09, 0.41 and 0.19 mg/kg for Fe, Cu, Cd, Pb and Cr, respectively. Such levels of the metals are a cause for concern, given the widespread consumption of the invertebrate species in special delicacies in the area. Study by Azi et al. (2018) provide evidence that heavy metals are leached from raw foods into the cooking water, which is often consumed together with meals in soup preparations.

Few studies have investigated levels of toxic metals in beverages. Iwegbue (2010) analysed various brands of canned beers in Nigeria and reported that Pb, Cd, Cr and Ni were above permissible maximum levels for the metals in drinking water, while Co, Al, Cu and Zn were within the limits. Iwegbue et al. (2014) investigated heavy metal concentrations in locally produced alcoholic beverages, including raphia palm wine, oil palm wine, ogogoro, pito and burukutu, mostly consumed in rural communities in Southern Nigeria. In contrast to the result obtained for canned alcoholic (beer) drinks, the concentrations of all the metals were below permissible limits. The high concentrations of toxic trace metals in canned beers may be due to the industrial nature of the production process, which typically involves the intermediate liquors and finished products coming in contact with metallic equipment and machineries, unlike the production of traditional alcoholic drinks, which employs local wooden utensils. The packaging and storage of beers in metallic cans may also be contributing to the impartation of trace metals onto the drinks. Olutona and Livingstone (2018) investigated heavy metal concentration of non-alcoholic (malt) drinks obtained from various markets in Ibadan, South-western Nigeria. Concentrations of Pb, Ni and Cr were found to be above their respective WHO limits for drinking water.

**Heavy metals in medicine and human fluid samples**

Medicines, being substances ingested to cure or lessen the effects of diseases and ailments, are normally manufactured under hygienic conditions. They are also expected to be of high-purity standards, with the absence or non-detectable levels of extraneous chemical substances. In Nigeria, as it is in many developing African nations, people use orthodox/modern medicines as well as local medicines, produced from herbs and made in form of tablets or mixed bottle concoctions. Aigberrua and Izah (2019) investigated levels of heavy metals in some liquid herbal medicines sold in Portharcourt, Southern Nigeria. Ni, Zn, Co and Fe were determined in the concoctions at maximum concentrations of 0.07, 0.03, 0.18 and 27.1 mg/L, respectively (Fe was found in 100% of the samples). The study noted that some of the herbal medicines were not approved by the government agency regulating the production and sales of foods and drugs in Nigeria. This points to the inadequacy of surveillance and inadequacy of enforcement of relevant laws by the concerned national agencies. Similarly, Nduka et al. (2020) determined carcinogenic heavy metals (Cd, Hg, As, Cr, Pb and Ni) in 30 brands of locally manufactured painkiller medicines, randomly sourced from pharmaceutical stores in Anambra State. The metals were detected in various combinations in the samples, while Ni was found in all the painkiller samples. The study estimated total cancer risk (TCR) and total non-cancer risk (TNCR) for the heavy metals to range from $7.21 \times 10^{-13}$ to $1.25 \times 10^{-10}$ and $1.51 \times 10^{-7}$ to $5.56 \times 10^{-5}$, respectively, noting that the continuous consumption of these painkiller medicines puts people at risk of heavy metal toxicity. Nnanem (2021) worked on orthodox analgesic syrups from pharmaceutical shops in Ibadan, Oyo State. The mean maximum concentrations reported by the study were 4.12, 3.5, 0.49, 0.67, 0.7 and 0.91 mg/L for Ni, Cd, Cr, Zn, Pb and Hg, respectively (Table 4). These values are highly worrisome and cast some doubts on the correctness of the analytical procedure and processing of the ensuing data. For instance, the maximum values reported for Ni and Cd in the syrups are 58 times and 1166 times higher than the authentic WHO guideline limits for these metals (WHO 2017). On the other hand (though very unlikely), the results may mean that the pharmaceutical syrups indeed contain such high levels of toxic trace metals, raising even more concerns for the health and safety of the Nigerian unsuspecting public.

The presence of heavy metals in medicines and in other samples such as cosmetics, foods and water (as discussed in ‘Heavy metals in cosmetics and personal care products’, ‘Heavy metals in foods and beverages’ and ‘Heavy metals in ground waters, surface waters and aquatic biota species’, respectively) provide good premise and justification for studies, which investigated toxic trace metals in human samples. Adekola et al. (2001) investigated heavy metals (Cd, Pb, Zn and Cu) in scalp hair samples of 900 individuals aged between 1 and 40 years, living in Ibadan or Ilorin, Nigeria. Varying concentrations of the metals were detected in the hair samples. The values range from 28 mg/kg for Cu to 1047 mg/kg for Zn. However, a most profound outcome of the study is the generally higher concentrations of Pb and
Cd, found in hair samples of older people (16–40 years) than in hair samples of younger ones, irrespective of the location.

This result provides strong indication of bioaccumulation of heavy metals in human body, through ingestion and other exposure routes. The fact that the hair samples were thoroughly and repeatedly washed with solvents and water prior digestion (Adekola et al., 2001) excludes the possibility that the heavy metals were merely adsorbed on the surface of the hair samples. Accumulation of toxic trace metals in human body systems in Nigeria was also corroborated by findings of Akan et al. (2014), who determined Ni, Cd, Pb and As in blood and urine of patients at the University of Maiduguri Teaching Hospital (UMTH), Borno State. The authors found that the concentrations of metals increased with the age of people, being lowest in the 1–10-year group and highest in the 51–60-year age group. Furthermore, levels of the metals in blood and urine were above those in drinking water sources in Maiduguri Metropolis, where the patients reside (Akan et al. 2014). Verla et al. (2019) also investigated levels of heavy metals in urine and blood samples of 60 children in Owerri Metropolis, Eastern Nigeria. The study found Pb, Cd, Ni, Mn and Cr in both the urine and blood samples, with concentrations in blood being higher than those of urine samples. Indeed, the authors noted that the maximum concentrations of the metals in blood were higher than the maximum values specified by the American Academy of Pediatrics. Mn levels up to 16.2 and 4.57 mg/kg were measured in the blood and urine samples, respectively (Verla et al. 2019). Eneh (2021b) investigated toxic heavy metal concentrations in blood and urine samples of a cohort of 100 hairdressers in Enugu, believed to have been exposed to the metals through regular use of hairdressing cosmetics. Exposure to Pb was implied from a high mean blood Pb concentration of 17.47 µg/dL. The study also reported mean blood Hg level of 25.06 ng/mL, which was above the expected normal range of 10–20 ng/mL. Mean concentration of Ni (0.49 µg/dL) was found to be above the reliable value of 0.2 µg/dL. These Ni levels were noted to be possibly responsible for carcinogenic effects, which impaired the quality of life of the subjects, as indicated by the rates of dizziness, nausea, vomiting, sleeplessness and headaches that were recorded among the workers (Eneh 2021b).

### Heavy metals in soils

Soil could be imparted with trace metals through weathering and mineralization of parent rock materials, as well as anthropogenic influences such as industrialization, mining, indiscriminate waste dumping and automobile emissions. Particular areas of soil prone to receiving high concentrations of heavy metals in Nigeria are the waste dumpsites, serving as receptacle for all forms of solid and liquid wastes and are mostly unregulated by the authorities. The majority of studies investigating heavy metals in soil have focussed on dumpsite soils (Table 5). Aiyemami and Idowu (2012) reported high concentrations of heavy metals in soils of three dumpsites in Akure, South-western Nigeria. Order of concentration of the metals was the same in the three dumpsite soils and followed the pattern: Cu > Ni > Pb > Zn > Cr > Cd > Co. High concentrations of all the metals were also detected in edible leafy vegetables (Amaranthus spinosus and Talinum triangulare) found

| Sample type       | Pb   | Cd   | Cr   | Zn   | Ni   | Hg   | As   | References               |
|-------------------|------|------|------|------|------|------|------|--------------------------|
| **Herbal medicines** |      |      |      |      |      |      |      | Aigberua and Izah (2019)  |
| Local painkiller* | 2.47 | 0.14 | 6.64 |      |      |      |      | Nduka et al. (2020)       |
| Panadol syrup     | 0.10 | 1.80 | 0.49 | 0.67 | 0.94 | 0.91 |      | Nnaneme (2021)            |
| Bonabe syrup      | 0.20 | 1.10 | 0.04 | 0.04 | 0.49 | 0.55 |      | Nnaneme (2021)            |
| Paracetamol syrup | 0.70 | 1.30 | 0.24 | 0.15 | 4.12 | 0.23 |      | Nnaneme (2021)            |
| Ibuprofen suspension | 0.30 | 3.50 | 0.18 | 0.15 | 0.60 | 0.36 |      | Nnaneme (2021)            |
| Rexifen suspension | 0.20 | 1.70 | 0.31 | 0.48 | 2.60 | 0.54 |      | Nnaneme (2021)            |
| Herbal medicines  | 3.01 |      |      | 0.07 |      |      |      | Izah et al. (2022)        |
| Blood             | 0.34 | 0.17 |      |      | 0.60 | 0.53 |      | Akan et al. (2014)        |
| Urine             | 0.30 | 0.27 |      |      | 0.62 | 1.2  |      | Akan et al. (2014)        |
| Blood             | 7.61 | 2.51 | 1.06 |      | 8.06 |      |      | Verla et al. (2019)       |
| Urine             | 4.20 | 0.62 | 36.3 |      | 6.84 |      |      | Verla et al. (2019)       |
| Hair*             | 78.8 | 31.3 | 1047 |      |      |      |      | Adekola et al. (2001)     |

*Values in these rows are in mg/kg. All recorded values are mean or maximum concentrations determined by the authors. '-' are values not determined or below the quantitation limit. Izah et al. (2022) also reported levels up to 0.03, 0.27, 6.94, 19.4 mg/L for Cu, Co, Mn and Fe, respectively.
Table 5  Heavy metals concentrations (mg/kg) reported in various soil types in Nigeria

| Soil type                  | Pb   | Cd    | Cr   | Fe   | Cu   | Co   | Zn   | Mn   | Ni   | As   | References                  |
|----------------------------|------|-------|------|------|------|------|------|------|------|------|----------------------------|
| Battery waste site         | 157  | 2.20  | 976  | -    | -    | -    | -    | -    | -    | -    | Afolayan (2018)             |
| Dumpsite                   | 233  | 23.5  | 61.2 | 714  | 12.1 | 199  | 840  | -    | -    | -    | Aiyessanmi et al. (2012)    |
| River floodplain           | 4.75 | -     | 250  | 6413 | 29.3 | 79.7 | -    | -    | -    | -    | Aiyessanmi et al. (2020)    |
| Old automechanic site      | 568.1| 12.6  | 365.8| 79,422| 821  | 1276 | 2263 | 479  | 1011 | 44.7 | Duru et al. (2022)          |
| Dumpsite                   | 32.4 | 9.94  | -    | 1761 | 42.2 | -    | -    | -    | 14.6 | -    | Ebong et al. (2018)         |
| Dumpsite                   | 202  | 1.19  | -    | 2215 | 44.3 | -    | -    | -    | 50.2 | -    | Ebong et al. (2019)         |
| Dumpsite                   | 76.5 | 156   | -    | 926  | 43.5 | -    | 867  | -    | 11.5 | -    | Emereleboe et al. (2017)    |
| Farmland                   | 41.9 | 83.0  | -    | -    | 74.5 | 48.6 | 84.3 | -    | 73.2 | -    | Emurotu (2020)              |
| Dumpsite                   | 2165 | 0.60  | 146  | 63,245| 6180 | 843  | 2498 | 603  | 513.6| 309  | Eze et al. (2020)           |
| Old iron ore mine          | 17.4 | 30.2  | 105  | 438  | 223  | 105  | 405  | 112  | 24.6 | 17.9 | Isinkaye (2018)             |
| River floodplain           | 22.0 | 26.0  | -    | -    | 10.5 | -    | -    | -    | -    | -    | Maduawuchi et al. (2019)    |
| E-waste dumpsite           | 328  | 31.4  | 30.8 | -    | -    | 306  | -    | 64.8 | -    | -    | Ofudje et al. (2014)        |
| Dumpsite                   | 3.79 | 4.31  | 8.36 | -    | 7.77 | 3.07 | 7.5 | 3.09 | -    | -    | Ogundele et al. (2019)      |
| Artisanal gold mine        | 72.9 | 58.3  | 42.8 | -    | -    | -    | 33.7 | 24.1 | 23.9 | -    | Ogundele et al. (2021)      |
| Dumpsite                   | 2.54 | 7.54  | -    | -    | 14.8 | 8.17 | 16.5 | 13.9 | 12   | -    | Ohiagui et al. (2020)       |
| Around cement factory      | 1.41 | 0.76  | 11.9 | -    | -    | 2.06 | -    | 1.82 | -    | -    | Olatunde et al. (2020)      |
| Battery recycling site     | 3.41 | 0.22  | -    | 12.5 | -    | 9.23 | 3.79 | 2.08 | -    | -    | Oluruntoba et al. (2021)    |
| Roadside soil              | 0.41 | 0.89  | -    | 173  | -    | 51.6 | 104  | -    | -    | -    | Olutona et al. (2012)       |
| Mining community           | 24.1 | 0.004 | 117  | -    | -    | 29.8 | 85.8 | 51.4 | 1.92 | -    | Oluwasola et al. (2021)     |
| Abandoned mine             | 5.60 | 3.95  | -    | 1304 | -    | 56.5 | 37.9 | -    | -    | -    | Omeka and Igwe (2021)       |
| Car spare parts market     | 28.8 | 10.1  | 108  | 378  | 22.6 | 154  | 66.7 | 42.5 | -    | -    | Orosun et al. (2020)        |
| Farmland                   | 0.02 | 0.002 | 0.17 | -    | -    | -    | -    | 0.084| -    | -    | Ugbede et al. (2021)        |
| Residential area           | 18.5 | 3.10  | 57.5 | -    | 23.4 | 78.2 | -    | -    | -    | -    | Ugochukwu (2019)            |
| Children playground        | -    | -     | 60.2 | 9.61 | 172  | 99.1 | 55.1 | -    | -    | -    | Verla et al. (2019)         |

All recorded values are mean or maximum concentrations determined by the authors. Silver (Ag) 2.45 and 3.50 mg/kg were reported by Duru et al. (2022) and Orosun et al. (2020), respectively; 21.9 mg/kg of Sn was reported by Oluwasola et al. (2021); 0.18 mg/kg of Sb and 0.03 mg/kg of Se were reported by Oloruntoba et al. (2021); ‘-‘ are metals not determined by the authors or below the quantitation limit.
observed by Olatunde et al. (2020) for soil samples around Ibese cement factory. In addition to the proximal soil pollution with heavy metals at the Ewekoro factory, Laniyan and Adewumi (2020) detected Cu, Pb, Cr, Co and Ni in vegetables and root crops, at concentrations above international maximum safe limits. Ogundele et al. (2021) worked on soil samples from both active and abandoned artisanal gold mining sites in Ile-Ife, South-western Nigeria. While various metals were detected in the samples, concentration of Pb was particularly high and an assessment of contamination status via geoaccumulation indices revealed that the soils were indeed contaminated with Pb. In Northern Nigeria, Orisakwe et al. (2018) investigated the concentrations of Cu, Cr, Cd, Zn, Ni and Se in soil and edible vegetable samples in Dilimi, Bukuru and Barkin Ladi communities, where artisanal mining activities are prevalent. Estimated total hazard quotient and hazard index, based on metal concentration in the vegetables, were both above unity, indicating potential health risk from consumption of the vegetables.

Floodplain soils (adjacent to rivers) are commonly used in Nigeria for cultivation of food crops and vegetables, due to their alluvial nature and the availability of water for irrigation purposes. A number of recent studies have been focussing on the metals content of floodplain soils, which potentially derive from materials deposited by overflowing rivers, themselves contaminated with toxic trace metals. Maduwuchi et al. (2019) investigated levels of Pb, Co and Cr in three floodplains in South-western Nigeria. The study found that fluvial deposition contributed more significantly to Pb and Co contents of the floodplains, with percentage contribution ranging from 79.3–99% and 67.2–85.7%, respectively. These two metals were also detected in an edible vegetable (Amaranthus hydridus) harvested from the floodplains. Another study by Aiyesanmi et al. (2020) determined the speciation of metals in the floodplain of Onunkun River, Ondo State. Cu was found to be associated with the soil organic fraction; Pb and Zn exists in reducible fractions, while Cr and Fe are associated with the residual fraction. The findings suggest that Cu, Pb and Zn were mostly contributed by fluvial deposition to the floodplains, whereas Cr and Fe determined in the soils were more of geogenic or lithologic origin. Association of Pb with reducible soil fraction and attribution to anthropogenic activities was also reported by Ebong et al. (2019). In relation to agriculture, soils of vegetable farms irrigated with wastewater have showed higher levels of heavy metals than similar soils with no wastewater applied (Abdu et al. 2011). A recent investigation of heavy metals in floodplain soils and edible vegetables by Oguntade et al. (2020) found dangerous levels of accumulation of Cd (0.46 mg/kg) and Pb (49.30 mg/kg) in Celosia argentea and Corchorus olitorius, respectively.

Heavy metals in crude oil and oil-contaminated sites

Hydrocarbons and various heavy metals are common components of crude oil, bitumen, oil-bearing rocks and other valuable earth resources. A number of studies have determined heavy metals in crude oil in Nigeria, to provide indication of the suitability of crude for refining, in terms of the tendency to cause corrosion or poison catalysts used in refinery operations (Onojake et al. 2016; Adebiyi and Adebiyi 2015). The heavy metals present in Nigerian crude oil are mainly Cu, Mn, Fe, Zn, Pb, Co, Ni, Cd and Cr (Chinedu and Chukwuekwa 2018). Of greater relevance to this review, however, are studies which examined heavy metals in oil sands and oil-spillage sites. An estimated 3.1 million barrels of crude oil is believed to have spilled in the Niger Delta, the oil-endowed region of Nigeria, from 1976 to 2014 (Chinedu and Chukwuekwa 2018). Osuji and Onojake (2004) worked on soil samples from oil-polluted lands in Obiobi and Obrikom, Niger Delta. The study confirmed higher levels of Pb, Ni and Cu in all surface soils (0–15 cm) from oil-contaminated lands, compared to nearby ones which did not receive oil spills. Similarly, Nwaichi et al. (2016) determined heavy metals in farm soils and crops grown on 4-year-old crude oil-impacted lands in Uduwukwo and Ekore, Delta State, compared to non-oil-impacted lands in the same area. The study found much higher levels of Cd and Cr in oil-impacted farmlands than in the controls. Also, edible cassava tubers grown on the contaminated lands contained Cd and Cr at average concentrations of 0.24 and 1.33 mg/kg, respectively, exceeding WHO set limits for these metals in food, whereas the same metals were not detected in cassava from non-oil-impacted farmlands. This study exemplifies the exposure of humans in Nigeria to heavy metals, through consumption of food crops cultivated on contaminated soil environments. Similar results of elevated metals content in crops from oil-prospecting areas of Rivers State were earlier reported by Hart et al. (2005). Adebiyi and Ore (2020) determined heavy metals in sand residues (tailings) of the Nigerian bituminous sand field. Various heavy metals, including Cu, Fe, Sc, Nb, As, V, Mn, Ti, Sr and Ni, were detected at high concentrations, ranging from 81.75 µg/g (As) to 9453 µg/g (Fe). Indeed, assessment of contamination revealed very high ecological risks by the level of metals present in the tailings.

Identified gaps and recommendations for research priority

The review revealed that very few studies have been conducted in the northern part of Nigeria, especially, the north-eastern and north-western geopolitical zones, with only 5 and 7 published articles, respectively (Table 1). The fact that these zones are educationally and technically less developed
may have contributed to the little research being conducted in the region. The over-a-decade-long terroristic insurgency and associated violent activities in the north-east, which in itself may contribute to high environmental levels of heavy metals, have also limited scientific studies in the region. To avoid incidents similar to the Zamfara Pb poisoning in 2010 (Orisakwe et al. 2017), there is the need for Researchers in the north to collaborate more with their southern counterparts on heavy metal investigations in Northern Nigeria.

One of the key reasons for investigating heavy metal concentrations in matrices is to identify sources of toxic elements that may potentially injure the health of humans and affect animals and biodiversity. This review revealed that some important toxic metals are not being investigated in most studies. For instance, the summary presented in Table 1 showed that less toxic metals such as iron (Fe) and zinc (Zn) are being investigated and reported in all the six geopolitical zones, whereas the more toxic elements such as arsenic (As) and mercury (Hg) are scarcely investigated. From the set of studies reviewed (the bulk of which were conducted in the last ten years), As has been reported by mainly three studies (Ekere et al. 2014; Eneh 2021) out five that include Hg in their investigations. It is noteworthy that only one study from the region (Akan et al. 2014) determined this metal. Furthermore, it could be seen from summaries provided in Table 3 (For foods) and Table 5 (for soil samples) that little attention is being given to As, compared to Zn and Fe. This same pattern is prevalent in studies of heavy metals in the entire sub-Saharan Africa. A compilation of 35 studies (Anyanwu et al. 2018), cutting across 11 countries in the sub-Sahara, showed that As was reported by only 4 of the studies, while Hg was not determined by all. The poor reportage of Hg may be due to the special requirement of a cold vapour atomic absorption spectrometry (CVAAS), which is needed for its accurate detection and quantification. Although the majority of the studies in the current review employed the AAS instrumentation for analyses, the cold vapour facility is lacking in the laboratories from which the studies emanated; hence, the inability of these studies to include Hg in their investigations. It is noteworthy that only three studies (Ekere et al. 2014; Eneh 2021) out five that reported Hg levels in the south-eastern zone employed the CVAAS variant, while the remaining three studies used the flame AAS technique. This implies that the levels reported for Hg by some of the studies may be lower than are actually present in the samples. The gap in data availability for Hg (and the perceived inaccuracy in the concentrations being reported) can be effectively remedied by turning to the inductively coupled plasma-optical emission spectrometry/mass spectrometry (ICP-OES and ICP-MS), capable of providing limits of detection up to 0.001 µg/L for the metal (Passariello et al. 1996), while determining it alongside other heavy metals. Similar to Hg, researchers in Nigeria may also deploy ICP versatility and sensitivity to bridge the data gap for As. Indeed, there is a need to investigate Hg and As levels of many environmental matrices in Nigeria, including phases and ecosystems for which levels of other heavy metals were previously reported.

This review recognized that investigations of heavy metals in Nigeria have been broad in scope, in terms of the different sample matrices studied. However, the scope is limited from the perspective of the various heavy metals being investigated. Apart from data gap relating to Hg and As levels highlighted above, there are other elements categorized as toxic metals, but are not regularly investigated and monitored by Researchers in Nigeria. As an indication, the WHO (2017) guideline for drinking water quality provides maximum limit for 13 metals and metalloids (Table 6). This review indicates that five of the elements (Ba, Se, U, Sb and Mo) are not routinely investigated in environmental studies in Nigeria. Indeed, some of these elements have confirmed toxicity effects, just as others (e.g. Cd, Pb) that are often investigated and reported. For instance, Ba is a potent non-specific inhibitor of the inward rectifier channel (IRCs), causing blockade of potassium conducting pores. Exposure manifests in the form of gastrointestinal diarrhea, cardiac arrhythmias, hypokalemia, muscle weakness and paralysis (Bhoelan et al. 2014). Also, exposure to high levels of molybdenum (although an essential nutrient metal) may cause kidney damage, decreases in sperm count, anemia and loss of body weight in animals and humans (Todd 2020). Implication of non-investigation of these metals/metalloids is that they may be present at dangerous levels

### Table 6 Heavy metals included in the latest guideline for drinking water (WHO 2017)

| Metals and metalloids | Guideline value (mg/L) |
|-----------------------|------------------------|
| Antimony (Sb)         | 0.02                   |
| Arsenic (As)          | 0.01                   |
| Barium (Ba)           | 1.3                    |
| Cadmium (Cd)          | 0.003                  |
| Chromium (Cr)         | 0.05                   |
| Copper (Cu)           | 2                      |
| Lead (Pb)             | 0.01                   |
| Manganese (Mn)        | 0.4                    |
| Mercury (Hg)          | 0.006                  |
| Molybdenum (Mo)       | 0.07                   |
| Nickel (Ni)           | 0.07                   |
| Selenium (Se)         | 0.04                   |
| Uranium (U)           | 0.03                   |

*Have not been commonly reported in environmental studies in Nigeria*
in the environment and in the food chain, while attention is not yet given to their determination. The ICP facilities and the proton/particle-induced X-ray emission (PIXE) analyses (Ishii 2019), now available in the country, may be effectively deployed for the determination of these elements.

As well as investigating heavy metal presence and levels in foods, beverages, drugs, cosmetics and other commodities that are of direct use to humans, there is clear evidence of awareness of the potential impacts of toxic heavy metal levels to the natural environment. A good number of the studies reviewed (74 out of 148) investigated and reported metal concentrations in natural environments such as streams, lakes, rivers and soil, which serve as habitats for species of organisms. However, such studies appear to be limited to the freshwater ecosystems alone and data are scarce regarding trace metal concentrations of the Nigerian marine ecosystems, which is very important to the country’s fish resources. The situation also obscures the understanding of the nation’s contribution to toxic metal levels in the world’s interconnected ocean system. Possible reason for the dearth of studies on heavy metal levels in the Nigerian marine environment may be the more difficult logistics of obtaining samples from such environments, compared to the fresh water areas which are readily accessible. This review serves to recognize the need for groups of researchers in the country to pool resources together, to investigate and monitor levels of toxic heavy metals in the Nigerian marine ecosystems.

Also important for the marine environment is the association of heavy metals with plastic pollution. Heavy metals have been demonstrated to adsorb on plastic fragments (Oz et al. 2019; Cao et al. 2021), which may then carry them to far locations and into the bellies of organisms in water environments. Nigeria is one of the five countries in Africa, estimated to contribute the most to global marine plastic pollution, the other countries being Algeria, Egypt, Morocco and South Africa (Babayemi et al. 2019). In addition to serving as vectors for toxic heavy metal transport, plastics themselves are sources of metals in the aquatic environment. This is because their production processes involve the incorporation of certain metals, especially lead (Pb), cadmium (Cd), mercury (Hg), tin (Sn), antimony (Sb) and arsenic (As), to function as catalysts, biocides and heat stabilizers (Hahladakis et al. 2018), and during plastic degradation processes, these metals are also released into the environment. As plastics and microplastic research are starting to develop in Nigeria (Alimi et al. 2021), the extent of association of toxic heavy metals with plastic pollutants (both as vectors and as sources) need to be studied, especially under the prevailing tropical environmental conditions.

As governments now seek to diversify the economy through solid mineral development, resulting in increased mining activities across the country, there is a need to monitor levels of toxic metals, particularly Cd, Pb, Hg, As, Co, Ni, Cr, Se, Ba and U which are usually associated with geogenic sources (WHO, 2017; Ungureanu et al. 2017; Horvart and Kotnik 2019; Sodango et al. 2021) and will potentially be released more into the environment, particularly surface waters, as mining activities increase.

**Concluding notes**

This review has provided a state-of-the-art summary of heavy metals research in Nigeria. It reports on the levels of various metals determined for all sample types, including human body fluids, cosmetics, medicines, beverages, foods, drinking water, surface water, biota, soil and atmosphere. Identified sources of human exposure to heavy metals include the use cosmetics and personal care products (PCPs), consumption of food crops grown on lands with history of oil-spillage, consumption of crops grown in industrialized areas, consumption of aquatic resources from contaminated rivers, irrigation of farmlands with wastewaters, as well as the use of locally made herbal medicines. This review revealed that heavy metal concentrations in human body are increasing with age of individuals in Nigeria. As these toxic elements can typically induce organ damage and cancers, it remains to be demonstrated whether there is correlation between metal level in human body and increasing number of deaths from non-communicable kidney/heart failure and cancers in Nigeria (Olanrewaju et al. 2020; Idris et al. 2020). In the meantime, the review underscores the need for relevant food and drug agencies to pay more attention to locally made medicines in the country, with a view to prohibiting the sales and distribution of heavy metal–laden concoctions. The proliferation of such local medicines as well as cosmetics also calls for the establishment of trace metals limits, upon which such products could be benchmarked.

The review reveals that the scope of heavy metals studies has been sufficiently wide, with respect to various kinds of samples and matrices analysed. It shows that the latest trend in heavy metal research in Nigeria is the focus on cosmetics, electronic waste sites, herbal medicines, air samples and artisanal mining sites. However, it recognized the dearth of data regarding levels of some metals and metalloids, especially Hg, As, Ba, Se, U and Sb. There is also a general lack of data on heavy metals contamination of the marine ecosystems in Nigeria. Reduction of toxic metals’ entrance into the food chain may be achieved by locating farmlands away from industrial areas and dumpsites and from oil-contaminated sites. Policies should be put in place to eradicate street hawking and display of food items, acts that expose the materials to air-borne toxic metals, emanating from diverse anthropogenic sources.
Acknowledgements Prof. A. F. Aiyesanmi and Prof. O. O. Ajayi of the Federal University of Technology Akure are acknowledged for inspiring the writing of this review.

Author contribution The single author conceptualized and designed the study, performed literature search and the review, collated and analysed results, wrote the original draft, revised and prepared the final manuscript.

Data availability Not applicable.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The author declares no competing interests.

References

Abalaka SE, Enem SI, Idoko IS, Sani NA, Teneuche OZ, Ejeh SA, Sambo WK (2020) Heavy metals bioaccumulation and health risks with associated histopathological changes in Clarias gariepinus from the Kado fish market, Abuja, Nigeria. J Health Pollut 10(26):1–12. https://doi.org/10.5696/2156-9614-10.26.200602
Abdu N, Aghben JO, Buervert A (2011) Geochemical assessment, distribution, and dynamics of trace elements in urban agricultural soils under long-term wastewater irrigation in Kano, northern Nigeria. J Plant Nutr Soil Sci 174(3):447–458. https://doi.org/10.1007/jpn.20100033
Abdurraheem KA, Aremu AS, Adeniran JA (2021) Ecological risk and sources of metals in open-burned grasses in Guinea savanna of Nigeria. Environ Qual Manag 1-15. https://doi.org/10.1002/qem.21787
Achi CG, Omoniyi AM, Coker AO (2021) Distribution of selected toxic elements in water phases of River Ogbere, Ibadan, Nigeria. J Environ Prot 12:429–437. https://doi.org/10.4236/jep.2021.127026
Adams GO, Ogedegbe PE, Tawari-Fufeyin P (2016) Assessment of presence of heavy metals and other pollution in urban agricultural soils and their effect on water quality in Benin City, Edo State. Environ Qual Manag 65–87. https://doi.org/10.1002/qem
Adebiyi FM, Adebiyi AY (2015) Evaluation of trace metals and physiological properties of Nigerian crude oil saturated fraction. Pet Sci Technol 33(12):1322–1330. https://doi.org/10.1080/10916466.2015.1065277
Adebiyi, FM, Ore, OT (2020) EDXRF analysis and risks assessment of potentially toxic elements in sand fraction (tailing) of Nigerian oil sands. Energy Ecol Environ 1-13 https://doi.org/10.1007/s40974-020-00175-1
Adekola FA, Dosumu OO, Olaleye GA (2001) Comparative study of the age and location dependence of some heavy metals in hair of residents from two cities in Nigeria. Biosci Res Commun 13(2):101–105
Adeogun AO, Ibor OR, Omiwole R, Chukwuka AV, Adewale AH, Kumuyi O, Arukwe A (2020) Sex-differences in physiological and oxidative stress responses and heavy metals burden in the black jaw tilapia, Sarotherodon melanotain from a tropical freshwater dam (Nigeria). Comp Biochem Physiol C: Toxicol Pharmacol 229:108676. https://doi.org/10.1016/j.cbpc.2019.108676
Adesewa A, Morenikjeji O (2017) Helminths and heavy metals in soils from a dumpsite in Ibadan city, Nigeria. J Prev Med Hyg 58(4):E328–E333. https://doi.org/10.15167/24214248/jpmh2017.58.4.608
Ademy AA, Ojekunle ZO (2021) Concentrations and health risk assessment of industrial heavy metals pollution in groundwater in Ogun state, Nigeria. Sci Afr 11:1–11. https://doi.org/10.1016/j.sciaf.2020.e00666
Aduwo AI, Adejini IF (2018) The heavy metals/trace elements content of sediments from Owalla Reservoir, Osun State, South-west Nigeria. Adv Oceanogr Limnol 9(2):68–78. https://doi.org/10.4081/aol.2018.7576
Afolayan AO (2018) Accumulation of heavy metals from battery waste in topsoil, surface water, and garden grown maize at Omilende area, Oloado, Nigeria. Global Chall 17:0090:1–12. https://doi.org/10.1007/gch2.20170090
Aigberua AO, Izah SC (2019) pH variation, mineral composition and selected trace metal concentration in some liquid herbal products sold in Nigeria. Int J Res Stud Biosc 7(1):1–8. https://doi.org/10.20431/b2349-0365.0701001
Aigberua AO, Ogbuta AA, Izah SC (2020) Selected heavy metals in sediment of Taylor creek due to anthropogenic activities in the Niger Delta region of Nigeria: geochemical spreading and evaluation of environmental risk. Biodivers Int J 4(2):67–80
Aiyesanmi AF, Idowu GA (2012) Levels of heavy metals in leafy vegetables grown around waste dumpsites in Akure, south-western Nigeria. FUTA J Res Sci 8(2):27–35
Aiyesanmi AF, Oguntuase AA, Idowu GA (2010) Investigation on speciation and pollution index of heavy metals in River Ala sediment, Akure, Nigeria. Int J Biol Chem Sci 4(6):2348–2359. https://doi.org/10.4314/ibjc.v4i6.64980
Aiyesanmi AF, Oladele MF, Adelodun AA, Idowu GA (2020) Speciation and bioavailability studies of toxic metals in the alluvial soil of Onukun River floodplain in Okitipupa, South-western Nigeria. Environ Qual Manag 1-13. https://doi.org/10.1002/qem.21720
Akan JC, Sodipo OA, Liman Y, Chellube ZM (2014) Determination of heavy metals in blood, urine and water samples by inductively coupled plasma atomic emission spectrophotometer and fluoridase using ion-selective electrode. J Anal Bioanal Tech 5(6):1000217. https://doi.org/10.5539/jabt.v5n6p217
Akande MG, Sanni FS, Enene NG (2021) Assessment of the concentrations and health risk of some heavy metals in cowpea (Vigna unguiculata) in Gwagwalada, Nigeria. Drug Chem Toxicol 44(5):518–523. https://doi.org/10.1080/100840545.2019.1621334
Akaninwori JO, Onyeike EN, Ijeme JC (2006) Trace metal levels in raw and heat processed Nigerian staple foods from oil producing areas of Rivers and Bayelsa states. J Appl Sci Environ 10(2):23–27
Akinlua A, Adedeji AO, Fatokun VT (2020) A green approach of leaching trace metals from petroleum source rock. Anal Chem Lett 11(1):102–111. https://doi.org/10.1080/22297928.2021.1885487
Ali H, Khan E (2018) What are heavy metals? Long-standing controversy over the scientific use of the term ‘heavy metals’ - proposal of a comprehensive definition. Toxicol Environ Chem 100(1):6–19
Ali H, Khan E, Ilahi I (2019) Environmental chemistry and ecotoxicology of hazardous heavy metals: environmental persistence, toxicity, and bioaccumulation. J Chem 2019:6730305. https://doi.org/10.1155/2019/6730305
Alimi OS, Fadare OO, Okoffo ED (2021) Microplastics in African ecosystems: current knowledge, abundance, associated
contaminants, techniques, and research needs. Sci Total Environ 755(1):142422. https://doi.org/10.1016/j.scitotenv.2020.142422
Amadi CN, Frazzoli C, Orisakwe OE (2020) Sentinel species for bio-monitoring and biosurveillance of environmental heavy metals in Nigeria. J Environ Sci Health 38(1):21–60. https://doi.org/10.1080/26896583.2020.1714370
Amoo IA, Adebayo OT, Lateef AJ (2005) Evaluation of heavy metal load in fish, water and sediments of Lake Kainji, Nigeria. J Food Agric Environ 3(1):209–212
Amos-Tautua BMW, Onigbinde AO (2014) Estimation of iron, copper and zinc in some vegetables commonly consumed in Amassoma, Niger Delta, Nigeria. Pak J Nutr 13(12):742–745. https://doi.org/10.3923/pjn.2014.742.745
Amusan BO, Adu BW (2020) Trace metal pollution and its impacts on the macroinvertebrate community assemblage in a tropical reservoir. Afr J Ecol 59(2):424–435. https://doi.org/10.1111/aje.12828
Anake Wu, AnaGREE, Williams AB, Fred-Aduhmu OD, Benson NU (2017) Chemical speciation and health risk assessment of fine particulate bound trace metals emitted from Iita industrial estate. Nigeria. Earth Environ Sci 68:1–7. https://doi.org/10.1088/1755-1315/68/1/012005
Anani OA, Olomukoro JO (2017) The evaluation of heavy metal load in benthic sediment using some pollution indices in Ossiomo River, Benin city, Nigeria. FUNAI J Sci Technol 3(2):103–119
Anani OA, Olomukoro JO (2018) Trace metal residues in a tropical watercourse sediment in Nigeria: health risk implications. Earth Environ Sci 210:1–18. https://doi.org/10.1088/1755-1315/210/1/012005
Anukwuoru CI, Okigbo RN, Chikwendu AE, Orisakwe OE (2018) Heavy metals contamination of some food materials from markets in South Eastern Nigeria. Eur J Nutr Food Saf 12(2):94–101. http://doi.org/10.9734/EJNFS/2020/v12i2s019
Anyanwu BO, Ezejiofor AN, Igweze ZN, Orisakwe OE (2018) Heavy metal mixture exposure and effects in developing nations: an update. Toxics 6:65. https://doi.org/10.3390/toxics6040065
Anyanwu ED, Adetenji OG, David Nwachukwu ED (2020) Application of pollution indices and health risk assessment of heavy metals in the waters of a South-eastern Nigeria River. Pollution 6(4):909–922. https://doi.org/10.22050/POLL.2020.303140.820
Anyanwu ED, Nwachukwu ED (2020) Heavy metal content and health risk assessment of a South-western Nigeria River. Appl Water Sci 10:210. https://doi.org/10.1007/s12201-020-01296-y
Anyanwu ED, Onyele OG (2018) Occurrence and concentration of heavy metals in a rural spring in South-eastern Nigeria, J Appl Sci Environ Manag 22(9):1473–1478. https://doi.org/10.4314/jasem.v22i9.19
Ayodele OS, Madakwe HY, Adelodun AA (2021) Geoenvironmental evaluation of toxic metals in the sediments of Araromi coastal area, South-western Nigeria. Environ Qual Manag 1-19 https://doi.org/10.1002/tqem.21757
Ayua TJ, Tyondena AA, Sombo T, Tikaya EV, Igbawua T (2020) Fine particulate matter and heavy metals pollution status in ambient air of some selected industrial sites in Northern Nigeria. J Geosci Environ Protect 8(8):1–13. https://doi.org/10.4236/gep.2020.88001
Azi F, Odou MO, Okorie AP, Njoku HA, Nwobasi VN, David E, Onu TC (2018) Heavy metal and microbial safety assessment of raw and cooked pumpkin and Anuranthus viridis leaves grown in Abakaliki, Nigeria. Food Sci Nutr 6(6):1537–1544. https://doi.org/10.1002/fsn3.739
Babayemi JO, Nnorom IC, Osibanjo O, Weber R (2019) Ensuring sustainability in plastics use in Africa: consumption, waste generation, and projections. Environ Sci Eur 31:60
Barau BW, Abdulhameed A, Ezra AG, Muhammad M, Kyari EM, Bawa U, Yugo DA (2018) Heavy metal contamination of some vegetables from pesticides and the potential health risk in Bauchi, Northern Nigeria. Int J Sci Technol 7(1):1–11. https://doi.org/10.4314/stech.v7i1.1
Bassey FI, Oguntunde FC, Iweegbe CMA, Osabor VN, Edem CA (2014) Effects of processing on the proximate and metal contents in three fish species from Nigerian coastal waters. Food Sci Nutr 2(3):272–281. https://doi.org/10.1002/fsn3.102
Bawuro AA, Voeborgo RB, Adimado AA (2018) Bioaccumulation of heavy metals in some tissues of fish in Lake Geriyo, Adamawa State, Nigeria. J Environ Public Health 1854892. https://doi.org/10.1155/2018/1854892
Benson NU, Enyang PA, Fred-Aduhmu OU (2016) Trace metal contamination characteristics and health risks assessment of Commelina africana L. and Psammotic sandflats in the Niger Delta, Nigeria. Appl Environ Soil Sci 2016:8178901. https://doi.org/10.1155/2016/8178901
Bhoelan BS, Stevery CH, Van der Boog ATJ, Van der Heyden MAG (2014) Barium toxicity and the role of the potassium inward rectifier current. Clin Toxicol 52(6):584–593
Cao Y, Zhao M, Ma X, Song Y, Zuo S, Li H, Deng W (2021) A critical review on the interactions of microplastics with heavy metals: mechanism and their combined effect on organisms and humans. Sci Total Environ 788(20):147620. https://doi.org/10.1016/j.scitotenv.2021.147620
CDC (Centre for disease control and prevention) (2016) Lead poisoning investigation in Northern Nigeria. https://www.cdc.gov/onehealth/in-action/lead-poisoning.html. Accessed 14 November 2021
Chinedu E, Chukwuemeka CK (2018) Oil spillage and heavy metals toxicity risk in the Niger Delta, Nigeria. J Health Pollut 8(19):180905
Datti Y, Mukhtar B (2020) Determination of the concentrations of Cu, Zn and Fe in five selected leafy vegetables used as relish in Kano state, Nigeria. World J Adv Res Rev 07(02):056–062. https://doi.org/10.3057/wjarr.2020.7.2.0269
Denkoy Y, Adesina O, Gurumnet I, Kopdora SW (2021) An evaluative study on metallic concentration in different ground and industrial water sources in Jos south local government area of Plateau state, Nigeria. Asian J Biochem, Genet Mol Biol 7(1):25–33. https://doi.org/10.9734/AJBGBM/2021/v7i130165
Dufus JH (2002) “Heavy metals” a meaningless term? (IUPAC Technical Report). Pure Appl Chem 74(5):793–807. https://doi.org/10.1351/pac200274050793
Duru CE, Enejoh CE, Enedoh MC, Duru IA, Ibe FC, Verla AW, Isiku BO (2022) Assessment of heavy metals in soils from reclaimed section of Nekede mechanic village, Owerri, South-eastern, Nigeria. Che Afr 4:429–441. https://doi.org/10.1007/s42250-020-00216-6
Ebong GA, Etuk HS, Dan EU (2019) Distribution, pollution index and associated health risk of trace metals in waste-impacted soils within Akwa Ibom State, Nigeria. Geosystem Eng 21(3):121–134. https://doi.org/10.1080/12269328.2017.1376291
Ebong GA, Ofliong OE, Ekpo BO (2015) Pollution indices of trace metals in urban dumpsite soils within Akwa Ibom state, Nigeria. Int Res J Pure Appl Chem 6(2):84–94. https://doi.org/10.9734/IRJPAC/2015/15331
Ebong GA, Dan EU, Inam E, Ofliong NO (2019) Total concentration, speciation, and source identification and associated health implications of trace metals in Lemu dumpsite soil, Calabar, Nigeria. J King Saud Univ - Sci 31:886–897. https://doi.org/10.1016/j.jsus.2018.01.005
Ekere NR, Ihediora JN, Eze IS, Agbashue VE (2014) Health risk assessment in relation to heavy metals in water sources in rural regions of south east, Nigeria. Int J Phys Sci 9(6):109–116. https://doi.org/10.5897/IPS2014.4125
Musa JJ, Mustapha HI, Bala JD, Ibrahim YY, Akos MP, Daniel Maduawuchi CO, Idowu GA, Aiyesanmi AF (2019) Impact of fluvial 

Laniyan TA, Adewumi AJ (2020) Evaluation of contamination and ecological risk of heavy metals associated with cement production in Ewekoro, Southwest Nigeria. J Health Pollut 10(25):1–13

Lawal A, Tijani MN, D’Alessio M, Maigari AS (2021) Application of geographical information system to geoelectrical data for evaluation of the vulnerability of aquifers in parts of Bauchi, North-Eastern Nigeria. Environ Earth Sci 80(16):11–18. https://doi.org/10.1007/s12665-020-09308-5

Maduawuchi CO, Idowu GA, Aiyesamifi AM (2019) Impact of fluvial deposition on potential toxic metals burden of selected floodplains in Southwestern Nigeria. Environ Earth Sci 78(561):1–13. https://doi.org/10.1007/s12665-019-8574-8

Mafuyai GM, Enejii IS, Sha‘Ato R (2014) Concentration of heavy metals in respirable dust in Jos Metropolitan Area, Nigeria. Open J Air Pollut 3:10–19. https://doi.org/10.4236/ojap.2014.31002

Masu JI, Mustapha HI, Bala JD, Ibrahim YY, Akos MP, Daniel ES, Oguche FM, Kutu IA (2017) Heavy metals in agricultural soils in Nigeria: a review. Arid Zone J Eng, Technol Environ 13(5):593–603

Nduka JK, Kelle HI, Ogoko EC (2020) Hazards and risk assessment of heavy metals from consumption of locally manufactured pain-killer drugs in Nigeria. Toxicol Rep 7:1066–1074. https://doi.org/10.1016/j.toxrep.2020.08.009

Njoga EO, Ezenduka EV, Ogboro CG, Ogbonna CU, Jaja IF, Ofomata AC, Okpala COR (2021) Detection, distribution and health risk assessment of toxic heavy metals/metalloids, arsenic, cadmium, and lead in goat carcasses processed for human consumption in south-eastern Nigeria. Food 10(798):1–17. https://doi.org/10.27161/foods10040798

Nnamou EL, Odo GE, Ajuzie IO, Nwani CD (2021) Proximate composition and bioaccumulation of heavy metals in edible Achatina spp in some rural agro-settlements, south-east Nigeria. J Basic Appl Zool 82:62. https://doi.org/10.1186/s41936-021-00259-2

Nnanneme FO (2021) Heavy metals analysis of selected analgesic syrups in Ibadan, Nigeria. Asian J Appl Chem Res 8(3):1–8. https://doi.org/10.9734/AJACJR/2021/v8i33

Nwaichi E, Chukwu I, Ighoavwogan E (2016) Polycyclic aromatic hydrocarbons and selected heavy metals in some oil polluted sites in Delta State Nigeria. J Environ Prot 7:1389–1410. https://doi.org/10.4236/jep.2016.710120

Obasi PN, Akudinobi BB (2020) Potential health risk and levels of heavy metals in water resources of lead–zinc mining communities of Abakaliki, southeast Nigeria. Appl Water Sci 10(184):1–23. https://doi.org/10.1007/s13201-020-01233-z

Obasohan EE, Eguavoen OI (2008) Seasonal variations of bioaccumulation of heavy metals in a freshwater fish (Erpetoichthys calabaricus) from Ogba River, Benin City, Nigeria. Afr J General Agric 4(3):153–163

Odebunni EO, Olutona GO, Akinbunde EA, Faboro EO, Balogun OS, Oluwaniyi OO (2014) Trace metal levels of drinking water sources in parts of Osun state, Nigeria. Ethiop J Environ Stud Manag 7(6):635–644. https://doi.org/10.4314/ejems.v7i6.6

Odgbemi F, Idowu GA, Adebayo AO (2021) Nickel recovery from spent nickel-metal hydride batteries using LIX-84 impregnated activated charcoal. Environ Nanotechnol, Monit Manag 15:100452

Odigie O, Olomukoro JO (2021) Bioaccumulated trace metal profiles of Typanotus fasciatus, Periophthalmus barbarous and Guin-earma (Sesarma) albertii collected from a perturbed freshwater mangrove swamp in Warri, Nigeria. J Appl Sci Environ Manag 25(3):439–444. https://doi.org/10.4314/jasem.v25i3.20

Odokudu FB, Ayenimo JS, Adekunle AS, Yusuff AM, Mamba BB (2014) Safety evaluation of heavy metals exposure from consumer products. Int J Consum Stud 38:25–34. https://doi.org/10.1111/jics.12061

Odum PU, Ekere NR, Abubu HO, Ibedioha JN, Nwoke SU, Ezike CC, Eze SI (2021) Potential toxic elements load and their health risk assessment in vegetables grown in Nsukka area of South-eastern Nigeria. Toxicol Int 28(2):103–114. https://doi.org/10.18311/ti.2021v28i220674

Ojudje EA, Alayande SO, Oladipo GO, Williams OD, Akioke OK (2014) Heavy metals concentration at electronic-waste dismantling sites and dumpsites in Lagos, Nigeria. Int Res J Pure Appl Chem 4(6):678–690

Ogamba EN, Charles EE, Izah SC (2021) Distributions, pollution evaluation and health risk of selected heavy metal in surface water of Taylor creek, Bayelsa State, Nigeria. Toxicol Environ Heal Sci 13:109–121. https://doi.org/10.1007/s13530-020-00076-0

Ogugah NM, Ikegwu MOJ (2017) Concentration and human health implications of trace metals in fish of economic importance in Lagos lagoon, Nigeria. J Health Pollut 7(13):66–72

Ogundele LT, Owoade OK, Hopke PK, Olise FS (2017) Heavy metals in industrially emitted particulate matter in Ile-Ife, Nigeria. Environ Res 156:320–325

Ogundele LT, Adejoro IA, Ayeku PO (2019) Health risk assessment of heavy metals in soil samples from an abandoned industrial waste dumpsite in Ibadan, Nigeria. Environ Monit Assess 191(290):1–10. https://doi.org/10.1007/s10661-019-7454-8

Ogundele LT, Oladejo OF, Akinola AC (2020) Concentrations, source identification and human health risk of heavy metals in the road dust collected from busy junctions in Osogbo Southwest, Nigeria. EQA – Int J Environ Qual 38:24–36. https://doi.org/10.6092/issn.2281-4485/9953

Ogundele LT, Oluwajana OA, Ogunyce AC, Inuymo SO (2021) Heavy metals, radionuclides activity and mineralogy of soil samples from an artisanal gold mining site in Ile-Ife, Nigeria: implications on human and environmental health. Environ Earth Sci 80(202):1–15. https://doi.org/10.1007/s12665-021-09494-w

Oguntade OA, Adegbuyi AA, Nassir AL, Olagunju SO, Salami WA, Adewale RO (2020) Geoassessment of heavy metals in rural and urban floodplain soils: health implications for consumers of Celosia argentea and Corchorus olitorius vegetables in Sagamu, Nigeria. Environ Monit Assess 192(3):164. https://doi.org/10.1007/s10661-020-08779-9

Ohanu CM, Ekeh FN, Ohanu IB, Aguzie ION, Ivoke N (2020) Evaluation of some heavy metals and physicochemical properties of public refuse dumpsites in Nsukka metropolis, Nigeria. Environ Monit Assess 192(7):477. https://doi.org/10.1007/s10661-020-08450-8

Ohiagu FO, Lele KC, Chikezie PC, Verla AW, Enyoh CE (2020) Pollution profile and ecological risk assessment of heavy metals from dumpsites in Onne, Rivers State, Nigeria. Chem Africa 4:207–216. https://doi.org/10.4172/242250-020-00198-5

Olabanji IO, Adeniyi IF (2005) Trace metals in bulk free fall and roof intercepted rainwater at Ile-Ife, Southwest Nigeria. Chem Ecol 21(3):167–179. https://doi.org/10.1080/0275754050151648
Oladejo OF, Ogundele LT, Inuyomi SO, Olukotun SF, Fakunle MA, Alabi OO (2021) Heavy metals concentrations and naturally occurring radionuclides in soils affected by and around a solid waste dumpsite in Osogbo metropolis, Nigeria. Environ Monit Assess 193(11):730. https://doi.org/10.1007/s10661-021-09480-6

Olaniyi SR, Popoola SO (2021) Trace metal concentrations of surface sediments and total organic carbon of sediment core recovered from Lagos coastal waters, south western Nigeria. Sch Int J Chem Mater Sci 4(5):92–102. https://doi.org/10.3634/jicscms.2021.v04i05.007

Olanrewaju TO, Adetibigbe A, Popoola AA, Braimoh KT, Buhari MO, Adesoyin OT, Kuranga SA, Biliaminu SA, Chijioke A, Ajapa AA, Grobbée DE, Blankestijn PJ, Klijnstein-Grobusch K (2020) Prevalence of chronic kidney disease and risk factors in North-Central Nigeria: a population-based survey. BMC Nephrol 21:467

Olatunde KA, Osanya PA, Badaa BS, Ojekunle ZO, Abdussalaam SA (2020) Distribution and ecological risk assessment of heavy metals in soils around a major cement factory, Ibeje, Nigeria. Sci Afr 9:e00496. https://doi.org/10.1515/sijcms-2020-03067

Olayinka-Olagunju JO, Dosumu AA, Olatunji-Ojo AM (2021) Bioaccumulation of heavy metals in pelagic and benthic fishes of Ogbes River, Ondo state, South-western Nigeria. Water, Air Soil Pollut 232:44. https://doi.org/10.1007/s11270-021-04987-7

Olife IF, Okana AN, Dioka CE, Meludu SC, Oirisakwe OE (2007) Iodine status and the effect of soil erosion on trace elements in Nanka and Oba towns of Anambra state, Nigeria. Società Chimica Italiana 97:895–901

Olontonta E, Gurus O, Omokhodion F, Foh J, Basu N, Arko Mensah J, Robin TB (2021) Spatial distribution of heavy metals and pollution of environmental media around a used lead-acid battery recycling centre in Ibadan, Nigeria. J Health Pollut 11(29):210304. https://doi.org/10.5696/2156-9614.11.29.210304

Olusogun OA, Osuntogun B, Eluwole TA (2021) Assessment of heavy metals concentration in soils and plants from electronic waste dumpsites in Lagos metropolis. Environ Monit Assess 193(9):582. https://doi.org/10.1007/s10661-021-09307-4

Olutona GO, Aderemi MA (2019) Organochlorine pesticide residue and heavy metals in leguminous food crops from selected market sites in Ibadan, Nigeria. Legum Sci 1:e3. https://doi.org/10.1002/leg.2.3

Olutona GO, Alagbe OA, Oyekunle JAO, Ogfunwokan AO (2014) Trace metals assessment of groundwater in parts of Iwo south western Nigeria using flame atomic absorption spectrometry and very low frequency electromagnetic Methods. Chem Sci Trans 3(3):885–896. https://doi.org/10.7597/cst.2014.598

Olutona GO, Aribisala GO, Akintunde EA, Obimakinde SO (2012) Chemical speciation and distribution of trace metals in roadside soil from major roads in Iwo, a semi-urban city, south western Nigeria. Terr Aquat Environ Toxicol 6(2):116–126

Olutona GO, Daniel OO (2020) Investigation on organochlorine pesticides residues and trace metals in melon (Cucumis melo L.): a survey. Iranian (Iranica) J Energy Environ 11(1):26–32. https://doi.org/10.5829/ijee.2020.11.01.05

Olutona GO, Dawodu MO, Ajaelu JC (2013) Trace metal level and speciation pattern in surface water of Alba reservoir, after sorption on ambersite XAD-16 resin. Bioremediation, Biodiversity and Bioavailability 7(1):85–90

Olutona GO, Livingstone ST (2018) Detection of organochlorine pesticide (OCPs) residues and trace metals in some selected malt drinks in Nigeria. Beverages 4(3):65. https://doi.org/10.3390/beverages04030065

Olutona GO, Fakunle IA, Adegbola RA (2021) Detection of organochlorine pesticides residue and trace metals in vegetables obtained from Iwo market, Iwo, Nigeria. Int J Environ Sci Technol. https://doi.org/10.1007/s13762-021-03431-x

Olusosina HO, Oluoye O, Bashir SM, Odewale OA, Abihuo HO, Akporomie KG, David MK, Fagorite VI, Umar MA (2021) Geochemical and health risk assessment of heavy metals concentration in soils around Oke-Ere mining area in Kogi State, Nigeria. Int J Environ Anal Chem. https://doi.org/10.1080/03067319.2020.1862817

Omeke ME, Igwe O (2021) Heavy metals concentration in soils and crop plants within the vicinity of abandoned mine sites in Nigeria: an integrated indetexical and chemometric approach. Int J Environ Anal Chem. https://doi.org/10.1080/03067319.2021.1922683

Omkopariola DO, Omkopariola PL (2021) Health and exposure risk assessment of heavy metals in rainwater samples from selected locations in Rivers State, Nigeria. Phys Sci Rev. https://doi.org/10.1515/prs-2020-0090

Omole IA (2017) Concentration of heavy metals in fish (Synodontis clarius) of Benin river, Delta state, Nigeria. J Energy, Environ Chem Eng 2(1):6–9. https://doi.org/10.11648/j.jeece.20170201.12

Onakpa MM, Njan AA, Kalu OC (2018) A review of heavy metal contamination of food crops in Nigeria. Ann Glob Health 84(3):488–494. https://doi.org/10.29024/aogh.2314

Onojake MC, Osuji LC, Ndubuka CO (2016) Characterization of bitumen samples from four deposits in southwest, Nigeria using trace metals. Egypt J Pet 26(2):547–552. https://doi.org/10.1016/j.ejpe.2016.08.002

Opalawa OD, Aremu MO, Ogbo LO, Magaji JJ, Odiwa IE, Ekpo EO (2012) Assessment of heavy metals in water, fish and sediments from UKE stream, Nasarawa state, Nigeria. Curr World Environ 7(2):213–220

Orisakwe OE, Tagbo EA, Mbawwu HO, Udowelle NA, Ofor SJ (2018) Levels of some heavy metals in vegetables from artisanal mining sites of Dilimi River, Bukuru and Barkin Ladi North Central Nigeria: any public health concern? Rocz Panstw Zakl Hig 69(4):335–345. https://doi.org/10.32394/rrpz.2018.0038

Orisakwe OE, Oladipo OO, Ajaezi GC, Udowelle NA (2017) Horizontal and vertical distribution of heavy metals in farm produce and livestock around lead-contaminated goldmine in Daretata and Abare, Zamfara State, Northern Nigeria. J Environ Public Health 2017:1–10. https://doi.org/10.1155/2017/5306949

Orisakwe OE, Ozoani HA, Nwaogazie IL, Ezejiofor AN, Orisakwe OE, Aderemi MA, Ajaezi GC, Udowelle NA, Offor SJ, Dagor EA, Mbagwu HO, Udowelle NA, Ofor SJ (2018) Levels of some heavy metals in vegetables from artisanal mining sites of Dilimi River, Bukuru and Barkin Ladi North Central Nigeria: any public health concern? Rocz Panstw Zakl Hig 69(4):335–345. https://doi.org/10.32394/rrpz.2018.0038

Orisakwe OE, Oladipo OO, Ajaezi GC, Udowelle NA (2017) Horizontal and vertical distribution of heavy metals in farm produce and livestock around lead-contaminated goldmine in Daretata and Abare, Zamfara State, Northern Nigeria. J Environ Public Health 2017:1–10. https://doi.org/10.1155/2017/5306949

Orisakwe OE, Ozanji HA, Nwaogazie IL, Ezejiofor AN (2019) Probabilistic health risk assessment of heavy metals in honey, Manihot esculenta, and Vernonio amygdalina consumed in Enugu State, Nigeria. Environ Monit Assess 191(7):424. https://doi.org/10.1007/s10661-019-7549-2

Orji OU, Awoke JN, Aja PM, Aloe C, Obasi OD, Alum EU, Udubiam OE, Oka GO (2021) Halotolerant and metalotolerant bacteria strains with heavy metals bio restoration possibilities isolated from Uburu Salt Lake, Southeastern, Nigeria. Heliyon 7(7):E07512. https://doi.org/10.1016/j.heliyon.2021.e07512

Orosun MM, Adewuyi AD, Salawu NB, Isinkaye MO, Orosun OR, Onikuj AS (2020) Monte Carlo approach to risks assessment of heavy metals at automobile spare part and recycling market in Ilorin, Nigeria. Sci Rep 10:22084. https://doi.org/10.1038/s41598-020-79141-0

Osuji LC, Onojake CM (2004) Trace heavy metals associated with crude oil: a case study of ebocha-8 oil-spill-polluted site in Niger Delta, Nigeria. Chem Biodivers 1(11):1708–1715. https://doi.org/10.1002/cbdi.200490129
Wegwu MO, Omeodu SI (2010) Trace metal contents of selected seeds and vegetables from oil producing areas of Nigeria. Chem Biodivers 7:1737–1744. https://doi.org/10.1002/cbdv.200900425
Wegwu MO, Wigwe IA (2006) Trace metal contamination of the African giant land snail Archachatina marginata from Southern Nigeria. Chem Biodivers 3:88–93. https://doi.org/10.1002/cbdv.200690011
World Health Organization (2017) Guidelines for drinking-water quality, 4th edn. (Incorporating the first addendum). World Health Organization, Geneva.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.