HUMAN HEALTH RISK ASSESSMENT OF SOME HEAVY METALS IN COSMETI C PRODUCTS

Abstract

Many cosmetic products contain heavy metals such as lead, cadmium, chromium, arsenic, mercury, cobalt, and nickel as ingredients or impurities. Recent research has reported that these metals can easily cause many types of skin problems. The investigated fairness creams varied in their metal concentrations, and the estimated amounts of lead and cadmium were lower than the respective maximum allowable concentration (MAC), according to the WHO/EU standard. The concentrations of lead and cadmium are presented in Table 1. The level of lead in the samples used ranged from 0.001±0.00 to 0.0827±0.00. The lowest value of lead was obtained in sample A while the highest value was obtained in sample C. Two of the fairness creams used have cadmium below the detection level while the highest value (0.0347±0.00) and the lowest value (0.0017±0.00) were obtained in sample F and sample C, respectively. All the values obtained are below the WHO allowable concentration of lead and cadmium in cosmetics. This study recommends continuous monitoring of this field including other items of cosmetics and the agencies that control the safety of cosmetic products will have to work hard to ensure safety of the consumers of these products. None of the metals were found to be considered as potential health hazards for humans.

CHAPTER ONE

1.1 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 specifi c gravity at least five times that of water, and are known to exist naturally in the earth 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-catalyzed biochemical reactions, and this is true for many life forms. However, the 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), pall adium (Pd), platinum (Pt), vanadium (V), strontium (Sr), tellurium (Te), titanium (Ti), Uranium (U), and chromium (Cr), particularly the hexavalent form (Cr VI) (Tchoun wou *et al.*, 2012). Concerns about heavy metals arise from the fact that they may fin d their way into the food chain, through bioaccumulation in plants and Page 2/34an imal species, or they may contaminate drinking water sources. The latter is particul arly through developing nations (e.g. Nigeria), where many rural communities depen d on open and unprotected surface water sources for drinking, domestic and recreat ional purposes. Toxicity effects of heavy metals manifest in various forms. For exa mple, the ability of Cu to change between Cu(I) and Cu (II) oxidation states in living s ystems enables it to function as cofactor for many oxidative stress - related cuproen zymes such as superoxide dismutase, cytochrome oxidases and ferroxidases. Howe ver, this ability to transit between oxidation states also makes Cu toxic, since the pro cess may generate superoxide and hydroxyl radicals (Harvey and McArdle, 2008; Stern, 2010). Thus, excessive exposure to Cu cause cellular and tissue damages, res ulting in Wilson disease in humans (Tchounwou *et al.*, 2012). Pb exerts its toxicity eff ect by mimicking and inhibiting Ca ions, and by interacting with proteins. It therefore affects the central nervous system and vitamin D metabolism, and causes reproduct ive impairments, brain and kidney damages, as well as gastro-intestinal diseases (Fl ora *et al.*, 2006; Wani *et al.*, 2015). The vast majority of heavy metals are present na turally 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). 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 Southwestern Nigeria may be at risk of Pb and Hg poisoning (Vanguard, 2021). Beyond artisanal mining, there is potential for toxic metals emanatin g 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.

1.2 Statement of problem

With many new products released into the market every season, it is hard to keep tra ck of the safety of every product and some products may carry carcinogenic conta minants (Peter and Viraraghavan 2005). There are concerns regarding the presenc e of harmful chemicals, including heavy metals, in these products. Many cosmetic p roducts contain heavy metals such as lead, cadmium, chromium, arsenic, mercury, cobalt, and nickel as ingredients or impurities. Recent research has reported that the se metals can easily cause many types of skin problems (Nesterenko and Jones 1997; Sainio *et al.* 2000).

1.3 Aims and Objectives

The aims of this research is to assess human health risk of some heavy metals in cos metic products.

The specific objectives are:

1. To determine the level of lead in some selected cosmetic products.
2. To determine the level of cadmium in some selected cosmetic products.
3. To compare the values of lead and cadmium in some selected cosmetic pr oducts with WHO-recommended values.

1.4 Significance of the study

The use of some heavy metals in cosmetics has been controversial due to the biological accumulation of those metals and their toxicity in the human body. In most countries, it is legally prohibited to use lead, arsenic, and mercury in skin cosmetic products. It is also reported that these metals can cause allergic contact dermatitis or other skin problems. Since the issue of heavy metals as deliberate cosmetic ingredients has been addressed, attention is turned to the presence of these substances as impurities. As the use of cosmetic products is increasing rapidly in Nigeria and various chemicals including the heavy metals are used in the cosmetics which pose health risk to consumers, the aim of the present study is to assess toxic metals like lead, cadmium, chromium, and mercury in some fairness creams highly used by the people and their effect on human health.

CHAPTER TWO

2.0 LITERATURE REVIEW

Heavy metals have harmful effects on human health, and exposure to these metals has been increased by industrial and anthropogenic activities and modern industrialization. Contamination of water and air by toxic metals is an environmental concern and hundreds of millions of people are being affected around the world. Food contamination with heavy metals is another concern for human and animal health. Concentration of heavy metals in water resources, air, and food is assessed with this regard (Mousavi *et al.*, 2013; Ghorani-Azam *et al.*, 2016; Luo *et al.*, 2020). Metals among the other environmental pollutants may also occur naturally and remain in the environment. Hence, human exposure to metals is inevitable, and some studies have reported gender differences in the toxicity of metals (Vahter *et al.*, 2007; Tchounwou *et al.*, 2012). They may frequently react with biological systems by losing one or more electrons and forming metal cations which have affinity to the nucleophilic sites of vital macromolecules. Several acute and chronic toxic effects of heavy metals affect different body organs. Gastrointestinal and kidney dysfunction, nervous system disorders, skin lesions, vascular damage, immune system dysfunction, birth defects, and cancer are examples of the complications of heavy metals toxic effects. Simultaneous exposure to two or more metals may have cumulative effects (Fernandes Azevedo *et al.*, 2012; Cobbina *et al.*, 2015; Costa, 2019; Gazwi *et al.*, 2020). High-dose heavy metals exposure, particularly mercury and lead, may induce severe complicatio ns such as abdominal colic pain, bloody diarrhea, and kidney failure (Bernhoft, 2012; Tsai *et al.*, 2017). On the other hand, low-dose exposure is a subtle and hidden threat, unless repeated regularly, which may then be diagnosed by its complications, e.g., neuropsychiatric disorders including fatigue, anxiety, and detrimental impacts on intelligence quotient (IQ) and intellectual function in children (Mazumdar *et al.*, 2011). The fact that several metals have emerged as human carcinogens is another important aspect of the chronic exposure. While the exact mechanism is unclear, aberrant changes in genome and gene expression are suggested as an underlying process. Carcinogenic metals such as arsenic, cadmium, and chromium can disrupt DNA synthesis and repair (Clancy *et al.*, 2012; Koedrith *et al.*, 2013). The toxicity and carcinogenicity of heavy metals are dose dependent. High-dose exposure leads to sever responses in animal and human which causes more DNA damage and neuropsychiatric disorders (Gorini *et al.*, 2014). The toxic mechanism of heavy metals functions in similar pathways usually via reactive oxygen species (ROS) generation, enzyme inactivation, and suppression of the antioxidant defense. However, some of them cause toxicities in a particular pattern and bind selectively to specific macromolecules. Different toxic mechanisms of heavy metals increase our knowledge on their harmful effects on the body organs, leading to better management of animal and human poisonings. We aimed to review the literature on the toxicity mechanisms associated with heavy metals, which will increase our knowledge on their toxic effects on the body organs, leading to better management of the metal poisonings.

2.1 Toxic Effects of Heavy Metals

2.1.1 Mercury (Hg)

Mercury (Hg) is found in air, water, and soil and exists in three forms: elemental or metallic mercury (Hg^0), inorganic mercury (Hg^+, Hg^{2+}), and organic mercury (commonly methyl or ethyl mercury) (Li R. *et al.*, 2017). Elemental mercury is liquid at room temperature and can be readily evaporated to produce vapor. Mercury vapor is more hazardous than the liquid form. Container breakage causes Hg^0 spills and inhaling large amounts of Hg vapor can be fatal. Organic mercury compounds such as methyl mercury (Me-Hg) or ethyl mercury (Et-Hg) are more toxic than the inorganic compounds. The order of increasing toxicity related to different forms of mercury is defined as $Hg^0 < Hg^{2+}, Hg^+ < CH_3\text{-}Hg$ (Kungolos *et al.*, 1999). Mercury compounds have many applications in mining for example extraction of gold and some industrial processes. In lamp producing factories, Hg is used in the production of fluorescent light bulbs. Me-Hg and Et-Hg have been used as fungicides to protect plants against infections. Moreover, mercury has had medicinal uses in the past, but such drugs have been replaced by safer pharmaceutical medicines. Some examples are chlormerodrin, merbaphen, and mercurophylline (all diuretics) and phenylmercury nitrate (disinfectant). Besides, some skin lightening creams and some soaps are mercury polluted. Mercury chloride ($HgCl_2$) is one of the active ingredients of skin brightening creams which are used to remove freckles and spots of the skin due to excessive accumulation of melanin. $HgCl_2$ inhibits tyrosinase activity irreversibly, an enzyme which functions in melanin formation, by replacing the copper cofactor (Chen *et al.*, 2020). Further, a mercury-containing organic compound called thimerosal has been use d as a preservative in multidose vials of vaccines. Hg^0 (vapor) is readily absorbed from lungs (80%) and distributed throughout the body. Hg^0 can pass the blood brain barrier (BBB) and placenta: thus, its neurotoxicity is higher than inorganic Hg which passes through membranes at a slower rate. Hg^0 is oxidized in the body to produce divalent Hg (Hg^{2+}). Hg^0 (liquid) is slightly absorbed from the gastrointestinal (GI) tract and does not appear to be toxic. Inorganic Hg is concentrated in the kidneys—reabsorbed from proximal tubules as Cys-S-Hg-S-Cys or basolateral membrane by organic anions transporters. Inorganic Hg cannot pass the BBB and placenta. Organic Hg is easily absorbed from the GI tract (95%) and distributed throughout the body. CH_3-Hg is bound to thiol-containing molecules such as cysteine (CH_3-Hg-Cys) so that it can pass the BBB. Hair is considered as an index of Hg exposure since CH_3-Hg is accumulated there. Other than hair, Hg is excreted in urine and feces. CH_3CH_2-Hg follows similar pharmacokinetics to CH_3-Hg (Bridges and Zalups, 2017).

2.1.2 Lead (Pb)

Lead is a harmful environmental pollutant which has high toxic effects to many body organs. Even though Pb can be absorbed from the skin, it is mostly absorbed from respiratory and digestive systems. Pb exposure can induce neurological, respiratory, urinary, and cardiovascular disorders due to immune-modulation, oxidative, and inflammatory mechanisms. Furthermore, Pb could disturb the balance of the oxidant–antioxidant system and induce inflammatory responses in various organs. Exposure to Pb can produce alteration in physiological functions of the body and is associated with many diseases (Joseph *et al.*, 2005; Jacobs *et al.*, 2009; Kianoush *et al.*, 20

12). Pb is highly toxic which has adverse effects on the neurological, biological, and cognitive functions in the bodies. The international level-of-concern for Pb poisoning is 10 μg/dl in the blood (Burki, 2012; Kianoush *et al.*, 2013). Adulteration of opium with Pb has been considered as a threat to human health in recent years (Kianoush *et al.*, 2015).

2.1.3 Chromium (Cr)

Chromium (Cr) is found in the earth's crust and seawater and is a naturally occurring heavy metal in industrial processes (Tchounwou *et al.*, 2012). Cr has multiple oxidation states ranging from −2 to + 6, in which the trivalent and hexavalent forms are the most common stable forms (Shekhawat *et al.*, 2015). Cr (VI) is related to a series of diseases and pathologies while Cr (III) is required in trace amounts for natural lipid and protein metabolism and also as a cofactor for insulin action (Cefalu and Hu, 2004; Achmad *et al.*, 2017; Vincent, 2017; Vincent, 2019). Based on the International Agency for Research on Cancer (IARC) report (2018), hexavalent chromium has been classified as a group I occupational carcinogen (Loomis *et al.*, 2018). In this context, a meta-analysis of 973,697 workers involving 17 standardized incidence ratios (SIRs) from seven countries and four kinds of occupations found that 11,564 of them had cancer (Deng *et al.*, 2019). The primary route of exposure for nonoccupational human populations occurs via ingestion of chromium containing food and water or dermal contact with products containing chromium (Nickens *et al.*, 2010). Furthermore, metallurgical, refractory, and chemical industries release a large amount of Cr into soil, ground water, and air which causes health issues in humans, animals, and mari ne life (Fang *et al.*, 2014). Cr can cause a variety of diseases through bioaccumulation in human body. This ranges from dermal, renal, neurological, and GI diseases to the development of several cancers including lungs, larynx, bladder, kidneys, testicles, bone, and thyroid (Fang *et al.*, 2014).

2.1.4 Cadmium (Cd)

Cadmium (Cd), although rare, occurs naturally in soil and minerals such as sulfide, sulfate, carbonate, chloride, and hydroxide salts as well as in water. High levels of Cd in water, air, and soil can occur following industrial activities which could be a substantial human exposure to Cd. Moreover, the ingestion of contaminated food will cause major exposure to Cd. Cd exposure may also occur through smoking, which is capable of elevating blood and urine Cd concentrations. Presence of Cd in contaminated water could disturb the necessary mechanisms in the body, possibly resulting in short-term or long-term disorders (Jiang *et al.*, 2015; Richter *et al.*, 2017; Cao *et al.*, 2018). Cd is classified by the International Agency for Research on Cancer (IARC) as carcinogenic to humans (Group 1) (Kim *et al.*, 2020). Occupational exposure to Cd may occur in alloy, battery, and glass production and in electroplating industries. Due to the importance of the subject, Cd level in the air is routinely monitored in some countries (Cancer, 1993). Rice, grains, and sea food have been found to be polluted by Cd (Chunhabundit, 2016); nonetheless, after oral intake, a small portion of Cd is absorbed. Tragically, the outbreak of Itai-itai disease in Japan was due to the mass Cd contamination of food and water supplies. The patients suffered from painful degenerative bone disease, kidney failure, and the GI and lungs diseases (Nishijo *et al.*, 201

7). Unlike low GI absorption, Cd is more efficiently taken from the lungs via industrial dust. Acute or chronic inhalation of Cd in industrial areas might lead to renal tubular dysfunction and lung injuries. Cd blood concentration in smokers is almost twice higher than that of nonsmokers. Batáriová *et al*. (2006) found Cd blood levels of 0.4 against 1.3 μg/L for nonsmokers vs. smokers in adult population (Batáriová *et al*., 2006). This seems to be related to the nature of tobacco plants to accumulate relatively high Cd concentrations in tissues especially in the leaves (Proshad *et al*., 2020).

2.1.5 Arsenic (As)

Arsenic as a harmful heavy metal is one of the main risk factors for the public health. Sources of As exposure are occupational or via the contaminated food and water. As has a long history of use, either as a metalloid substance or as a medicinal product. It is notoriously known as the king of poisons and poison of kings (Gupta *et al*., 2017). As is present as a contaminant in food, water, and environment. Arsenic exists in the forms of metalloid (As^0), inorganic (As^{3+} and As^{5+}), organic, and arsine (AsH_3). The order of increasing toxicity of As compounds is defined as organic arsenicals < As^0 < inorganic species (As^{5+} < As^{3+}) < arsine (Shah *et al*., 2010; Sattar *et al*., 2016; Kuivenhoven and Mason, 2019). Primary As absorption is from the small intestine. Other routes of exposure are from the skin contact and by inhalation. Following distribution to many tissues and organs in the body including the lungs, heart, kidneys, liver, muscles, and neural tissue, As is metabolized to monomethylarsonic acid (MMA) and dimethylarsinic acid (DMA) in which the latter is the predominant form in the urina ry excretion of As (Del Razo *et al.*, 1997; Ratnaike, 2003). Acute and chronic As toxicity is related to the dysfunctions of numerous vital enzymes. Similar to the other heavy metals, As can inhibit sulfhydryl group containing enzymes which leads to their dysfunction. Moreover, As inhibits the pyruvate dehydrogenase by binding to the lipoic acid moiety of the enzyme. Pyruvate dehydrogenase inactivation can block the Krebs cycle and inhibits oxidative phosphorylation. As a result, ATP production decreases, resulting in cell damage (Shen *et al.*, 2013). Furthermore, the damage of capillary endothelium by As increases vascular permeability, leading to vasodilation and circulatory collapse (Jolliffe *et al.*, 1991).

2.2 The Carcinogenicity of Heavy Metals

The mechanism of carcinogenicity of heavy metals is unclear and complicated. Carcinogenicity of some heavy metals is assumed to be due to their bonding to regulatory proteins that are involved in cell cycle regulation, DNA synthesis and repair, and apoptosis (Kim *et al.*, 2015). Besides, toxicogenomic investigations highlight the characterization of gene expressions after metal toxicity. Transcription factors such as Activator Protein 1 (AP-1), Nuclear Factor-kappa B (NF-κB), and p53 are targets for Cd and As. As a result, controlling the expression of protective genes failed, leading to uncontrolled cell growth and division (Valko *et al.*, 2005). A few studies have examined Ras proteins mutations or increased activation in carcinogenic heavy metals exposure. Ngalame *et al.* (2014) showed overexpression of Ras in human prostate epithelial cells following As exposure. In another study, the elevation of the level of ERK 1/2, as well as transcription factors jun and fos, was observed *in vitro* by Cd. Cr

(VI) also induced overexpression of jun in cultured cells. The mutated Ras protein loses its ability to be inactivated and the kinase cascade is not turned off. Besides, intensified jun and fos or activated ERK 1/2 continues repeatedly the gene expression. Thus, a permanently activated signaling pathway results in continuously activated proliferation, leading to increased tumor formation (Zuo *et al.*, 2012; Ngalame *et al.*, 2014; Ataei *et al.*, 2019).

Arsenic is shown to inhibit DNA repair by inhibiting poly ADP-ribose polymerase 1 (PARP-1), a responsible enzyme for DNA break repair processes (Ding *et al.*, 2009). Resistance to apoptosis due to heavy metals exposure breaks down a basic cell defense. It has been shown that Cd can induce malignant transformation of the prostate epithelial cell line through increased apoptotic resistance. Apoptotic resistance is attributed to the overexpression of Bcl-2 and disruption of a specific pathway of apoptosis known as the JNK pathway (Qu *et al.*, 2007). Altered expression of genes involved in apoptosis and DNA repair is proposed for resistance to apoptosis induced by Cr^{6+} (Pritchard *et al.*, 2005). Moreover, hexavalent Cr causes DNA damage by inactivation of DNA ligase, DNA polymerase β, and PARP-1. Deficient DNA repair due to Cr leads to chromosome instability which is a key mechanism of Cr^{6+}-induced carcinogenesis (Wise *et al.*, 2018).

2.3 Epigenetic Mechanisms of Heavy Metals

Heavy metals can promote epigenetic alterations, including DNA methylation and histone modification. Hg, Pb, Cr, Cd, and As are capable of DNA methylation. Besides, Hg, Pb, Cr, and As can make histone alterations. However, there are no data availa ble for Cd to induce histone modifications. On the other hand, only Cd and As are reported to mediate expression of noncoding RNAs, another molecular mechanism of epigenetic regulation. The exact mechanism of epigenetic changes due to heavy metals exposure is not fully determined. It seems that increased expression of protooncogenes and silencing of tumor suppresser genes via intracellular ROS production are the underlying causes (Cheng *et al.*, 2012). DNA methylation is well known to inhibit the expression of some tumor suppressors. As a result, changes in gene expression result in the alteration of the cellular division process and facilitation of malignant transformation of cells (Li and Chen, 2016). Epigenetic dysregulations in human bronchial epithelial cells were reported following Cr^{6+} exposure. Wang Z. *et al.* (2018) found increased levels of histone H3 methylation marks (H3K9me2 and H3K27me3) and histone methyltransferases (HMTases) (Wang Z. *et al.*, 2018). Hu *et al.* reported Cr-induced methylation of the p16 gene, a tumor suppressor gene, in the same cell line (Hu *et al.*, 2016). Similarly, epigenetic changes may attribute to the Cd and As toxic and carcinogenic effects. DNA methylation as well as specific histone modification marks are associated with exposure to Cd and As (Bailey *et al.*, 2013; Sanders *et al.*, 2014; Xiao *et al.*, 2015; Ma *et al.*, 2016).

2.4 Comparison of the Mechanistic Action

Since there are multiple cellular targets, the mechanism underlying the toxicity of toxic heavy metals is complicated. It is understood that Hg, Pb, Cr, Cd, and As commonly exert their toxicity through similar pathways including ROS generation, weakening of the antioxidant defense, enzyme inactivation, and multiple organ toxicity. For i nstance, glutathione peroxidase and reductase are known enzymes which are inactivated by these five metals. However, some metals selectively bind to a specific protein as a unique mechanism of that metal. For example, Pb-induced anemia occurs via the inhibition of two enzymes of heme biosynthesis: ALAD and ferrochelatase (Figure 1). The interaction of protein phosphatases (PP) with Cd can be mentioned as another example. Examination of protein phosphatases 1 (PP1) metal inhibitors showed that Cd^{2+} and Hg^{2+} both have inhibitory effects on PP1 enzyme. However, Cd^{2+} is likely a potent and competitive inhibitor of the enzyme (Pan *et al.*, 2013). Heavy metals can disrupt endocrine systems by interfering mainly with steroid and thyroid hormones in human and animals. As an example, Cd, Pb, and Cr are known to induce thyrotoxicosis (Qureshi and Mahmood, 2010). The mechanism of toxicity of these heavy metals and the organ toxicity are presented in Table 1.

While different types of mercury compounds are found in the environment, the organic forms of Hg are more toxic than the inorganic species. Hg can cause cognitive impairment and CNS injury. Besides, Hg causes renal dysfunction especially in the proximal tubules due to its preferential accumulation in the kidneys. It has also harmful effects on liver and the intestine (Kim *et al.*, 1995; Cheng *et al.*, 2006).

The effect of proinflammatory cytokines in the brain following Pb exposure is inflammation in the CNS which in turn causes neurotoxicity (Struzynska *et al.*, 2007). Pb has also shown to have hematotoxic and hepatotoxic effects. Moreover, it poses renal and respiratory harmful effects. Pb-induced renal toxicity might lead to necrosis. Apoptosis in lead toxicity takes place via the inhibition of Bcl-2 and the activation of caspase-3 following mitochondrial cytochrome C release (Liu *et al.*, 2012). Lead neurotoxicity and cognitive impairment might be promoted via the inhibition of NMDA receptor and the blockage of neurotransmitter release (Neal and Guilarte, 2010).

Hexavalent chromium has been classified as a carcinogen. Cr toxicity can cause the lungs and upper respiratory cancers. Mechanisms of Cr toxicity and carcinogenicity are considered as DNA damage, genomic instability, and ROS generation. Following exposure and bioaccumulation of Cr, a variety of diseases appeared. Skin, hepatic, renal, reproductive, and neurological disorders can be mentioned (Fang *et al.*, 2014). Moreover, many other cellular injuries and cell death as both apoptosis and necrosis may occur (De Flora *et al.*, 2008).

Like Cr, Cd is also classified as a carcinogen. Consequences of Cd poisoning might be painful degenerative bone disease, kidney failure, and the GI and lungs diseases (Nishijo *et al.*, 2017). Cd can bind to MT and other metal transporters in the small intestine and accumulates in the GI tract (Ohta and Ohba, 2020). Altered miRNA expression due to Cd exposure may play a role in Cd-induced nephrotoxicity (Fay *et al.*, 2018). Apoptosis is associated with the cytochrome C release into the cytosol due to Cd exposure (Pham *et al.*, 2006).

Like chromium and cadmium, arsenic is considered a human carcinogen. Chronic arsenic toxicity or arsenicosis causes skin manifestations such as pigmentation and keratosis. Arsenic poisoning may exert obstructive and restrictive pulmonary diseases. Arsenic has been linked to cognitive dysfunction and neurological problems such as pricking sensation in hands and legs (Lee *et al.*, 2006; Wasserman *et al.*, 2011).

2.5 Heavy metals in cosmetics and personal care products (PCP)

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 lip sticks, 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, Sb, Hg, Ni and Cr in cosmetics, many producers still include compounds that contain these metals at levels above the WHO permissible limits. 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. Eneh (2021) analysed urine 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, Pb and As in the urine of students who had consistently used make-up were higher than those who did not wear make-ups. 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 pers onal care products, were present at high concentrations up to 0.467 and 0.435 µg/g (or ppm), respectively, in the products. Despite the fact that Zn is an essential elemen t, the study reported values for Zn that raise safety concerns due to potential cumula tive dermal exposure to such high concentrations of the metal. Oyekunle *et al* (2021) worked on native black soaps and conventional soaps, and reported high Hg conce ntrations 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 autho rs 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, alt hough at much lower concentrations compared to those of Hg.

2.6 Heavy metals in the atmosphere

Heavy metals presence in atmospheric air may result from combustion of fossil fue l. 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.*, 20 17). Metals may exist in form of vapour in the air, thereby increasing the chance of b eing inhaled by humans. Studies which investigated toxic metals in air in Nigeria ha ve done so relative to metals bound to particulate matters (PM). Uzoekwe *et al.* (202 1) investigated heavy metals presence and levels in particulate matters (PM10) suspe nded 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/m3 for Co, As, Cr, C d, 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 PM2.5 – bound trace metals in an industrial estate in Ogun state and reported inhalation exposure cancer risks for adults and children, that 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 metals 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 ex ceed 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.

2.7 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 metals 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 se ason, 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 metals 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 neighboring 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 Ogbere River, in Ibadan Southwestern 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 contamin ated 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 Ogba 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. Similar studies were conducted by Wegwu and Akaninwor (2006), Oguguah and Ikegwu (2017) and 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 metals 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 Aiyesanmi *et al.*, 2010: Anani and Olomukoro, 2017: Aduwo 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 re-suspended into the water colum n.

2.8 Heavy metals in foods and beverages

Plants growing on contaminated soils may bio-accumulate 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 (Maduawuchi *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 focused on this subject. Akaninwor *et al.* (2006) compared trace metals 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. Metals 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-pro ducing area was made by Wegwu and Omeodu (2010). Olutona and Daniel (2020) worked on melon seeds obtained from Northern and Southwestern part of Nigeria. Heavy metals determined in the samples were of the order: Pb > Zn > Ni > Co > Cd, with all values higher in seeds from the North than in the Southwest. 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 quotient 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, Southwestern Nigeria. The authors found that Fe was most abundant in the samples at concentrations up to 71.25 mg/kg (in cashew nuts). Cancer risk for Co in all the food samples exceeded the acceptable limit of 0.0001, suggesting possible 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 Co and Cu, with maximum levels in ginger (11.1 mg/kg) and African nutmeg (15.3 mg/kg), respectively. Estimated daily intake 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. Njoga *et al.* (2021) determined levels of As, Cd and Pb in 450 edible samples of meat, comprising goat's 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 - Southeast, Southwest and South-south. The study quantified Cu, Fe, Zn, Ni, Pb and Cd in the snail samples and reported that the heavy metals concentrations were above the WHO limits, particularly in samples gotten from highly industrialised environ ments.

Benthic invertebrates such as periwinkle (*Tympanotonus fuscatus)*, mudskipper (*Periophthalmus barbarous*) and Sesarmid crab (*Guinearma alberti*) constitute an important food (soup) ingredient in Southern parts of the country. Odigie and Olumokuro (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, Ni and Fe 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 metals 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 metals concentration of non-alcoholic (malt) drinks obtained from various market in Ibadan, Southwestern Nigeria. Concentration of Pb, Ni and Cr were found to be above their respective WHO limits for drinking water.

2.9 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. Aigberua and Izah (2019) investigated levels of heavy metals in some liquid herbal medicines sold in Port harcout, Southern Nigeria. Ni, Zn, Co and Fe were determined in the concoctions at maximum concentrations of 0.068, 0.024, 0.177 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 fo

ods 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
$7.21 \times 10^{-13} - 1.25 \times 10^{-10}$ and $1.51 \times 10^{-7} - 5.56 \times 10^{-5}$ respectively, noting that the continuous consumption of these painkiller medicines puts people at the risk of heavy metal toxicity. Nnaneme *et al.* (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. 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 1,166 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, f oods and water 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. 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 systems, through ingestion and other means. The fact that the hair samples were thoroughly and repeatedly washed with solvents and water prior digestion (Adekola *et al.*, 2021) exclude 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 years group and highest in the 51–60 years 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 con centrations 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 USA Academy of paediatrics (Verla *et al.*, 2019). Eneh (2021b) investigated toxic heavy metals 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 that impaired the quality of life of the subjects, as indicated by the rate of dizziness, nausea, vomiting, sleeplessness and headaches (Eneh, 2021b).

2.10 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 industrialisation, 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 authorities. Aiyesanmi and Idowu (2012) reported high concentrations of heavy metals in soils of three dumpsites in Akure, Southwestern Nigeria. Order of concentration of the metals was the same in the three dumpsite soils and follo wed 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 triangulae*) found growing around the waste dumpsites. Eze *et al*. (2020) investigated heavy metals levels in four major dumpsites in South-eastern Nigeria and performed an assessment of human health risks associated with metals at the dumpsites. The study revealed that children were at the highest risk of exposure to As, Pb and Ni, with the ingestion exposure pathway being the major contributor to both the cancer and non-cancer risks. Electronic wastes, particularly the cathode and anode of batteries used in many portable devices, contain substantial amount of heavy metals and rare earth elements after their useful life (Odegbemi *et al*, 2021).

Study by Ofudje *et al*. (2014) and Ibe *et al*. (2018) on electronics workshops and electronic wastes dumpsites in Nigeria have demonstrated the release of heavy metals from these materials. Investigation of heavy metals in soil near a battery wastes dumpsite in Ibadan, Oyo state by Afolayan (2018) revealed soil contamination factor above 6.0 for Cd, Pb and Fe, indicating excessive and severe pollution of the soil with the metals. Furthermore, the toxic metals, Cd and Pb, were found at concentrations above 2.80 and 40.0 mg/kg, respectively, in maize plants grown near the battery dumpsite. Accumulation of metals in vegetables growing around dumpsites is a major cause for concern, as unsuspecting individuals may fetch them for consumption or for sales in open markets.

Soils in the proximity of industrial sites have also attracted some attention. Two recent studies (Olatunde *et al*., 2020; Laniyan and Adewumi, 2020) investigated heavy metals levels of soils around different cement factories in Southwestern Nigeria. Heavy metals concentrations were higher in the soil samples, compared to the appropriate reference samples analysed in the studies. Considerable pollution and potential ecological risk from Cd, Cr, Ni and Pb were 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, 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.

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 focusing on the metals content of fl oodplain soils, which potentially derive from materials deposited by overflowing rivers, themselves contaminated with toxic trace metals. Maduawuchi *et al.* (2019) investigated levels of Pb, Co and Cr in three floodplains in Southwestern 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 Onukun 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, soil of vegetable farms irrigated with wastewater have showed higher levels of heavy metals, than similar soils with no wastewater applied (Abdu *et al.*, 2011).

2.11 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 Chukwuemeka, 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 Chukwuem eka, 2018). Osuji and Onajake (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 Uduvwoku 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.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Collection of samples

Fairness cosmetic products were purchased from markets in Ilorin.

3.2 Materials

Kjeldahl distillation glass, Nitric acid, Oxochlorate, Calibrated sample bottle, flam e Atomic Absorption Spectrophotometer, Samples, and distilled water.

3.2 Method

3.2.1 Digestion of sample

One gram of sample was weighed in a 250 ml Kjeldahl distillation glass and was w et digested using 20 ml of HNO_3-$HClO_4$ acid solution (2:1 volume) on a hot digestion system, heated until the samples turn colorless solution.

3.2.2 Heavy metals Analysis

After digestion was complete, the solution of each sample was transferred into a 100 ml calibrated sample bottle and the solution was diluted to the mark with distilled w ater. Minerals in the samples were determined by flame Atomic Absorption Spectro photometer (VARIAN model AA240FS, United State).