The Synopsis of Environmental Heavy Metal Pollution

Anyiam N. Donald, Pene B. Raphael, Oluwole J. Olumide and Okoro F. Amarachukwu

Abstract: Heavy metal pollution continues to be a serious problem in the environment due to uncontrolled pesticide use, mining, foundry operations, smelting, fossil fuel burning and sewage sludge dumping. Mercury, lead, chromium, cadmium, copper and other heavy metals are non-biodegradable and remain in the environment in regions where human activity is prevalent. Heavy metal contamination is a serious hazard to all biota in the ecosystem because of its devastating consequences and their accumulation in soil and water has significant implications for food safety and security, the growth of plants and the survival of soil microorganisms that play significant roles in sustaining agricultural crop production. Even at low doses, these metals are toxic and can affect the food chain, posing serious public health risks. Hence, the purpose of this study is to present a concise but detailed potential source and impacts of heavy metals on the biotic segment of the ecosystems with a view to understanding and building long-term strategies for reducing their pollution and protecting public health.

Keywords: Heavy Metal, Environmental Pollution, Sources, Public Health, Ecosystem

Introduction

The term "heavy metal" refers to a class of metals and metalloids with atomic densities more than or equal to 4000 kg/m³ (Hawkes, 1997; Edelstein and Ben-Hur, 2018). Metal levels in soil can range from a few milligrams per kilogram to 100,000 milligrams per kilogram (Singh et al., 2011). Heavy metals are the most prevalent inorganic contaminants that have contaminated a vast region as a result of the usage of agrochemicals, municipal waste and sludge, pesticides, emissions from municipal waste incineration, mining residues, smelting industries, and other elements have contaminated a large area of the environment (Halima et al., 2003). Great amounts of various heavy metals, regardless of where they come from, can cause soil deterioration and reduction in crop yield leading to poor quality agricultural produce, all of which pose major health hazards. Gilbert and Weiss (2006) reported that "heavy metals have a strong tendency to accumulate in all media, including soil and water because they are not biodegradable and resistant to natural biodegradation". Bioconcentration explains the absorption of heavy metals from the environment into organisms, and it is the most essential phase in food chain contamination. When bioconcentration and bio-magnification levels exceed what is considered tolerable, they constitute a significant source of health concerns (Khan et al., 2008). Heavy metals build up in the food web owing to both natural and human activities (Zhang et al., 2017). Hence, the goal of this review is to present a concise but informative account of environmental heavy metal pollution in the environment and evaluate their impacts on various life forms. The findings of this study will probably serve as a reference tool for environmental scientists and health experts who work in ensuring environmental sustainability and improvement in public health.

Sources of Heavy Metal Pollution

The many sources of heavy metals around the world have been grouped into two categories: Natural and man-made sources (i.e., anthropogenic sources). Large swaths of human environment have been impaired by mining and smelting operations. To better understand the pressing issues of heavy metal pollution, the two main sources are illustrated in Fig. 1 and described in detail in subsequent sections.
Natural Sources of Heavy Metals

**Natural Sources**

Natural sources are those processes in nature that release heavy metals to the environment (without human intervention). Erosion, volcanic eruptions, and mineral weathering are examples of natural processes (Ayangbenro and Babalola, 2017). The primary and natural sources of heavy metals are weathering and pedogenesis from geologic parent material or rock outcroppings. Mineral ores such as arsenopyrite, galena, cerussite, and cassiterite are prone to dissolution by chemical weathering during which heavy metals bound within their structures are released (Abdu, 2010; Abdu et al., 2011a). The kind of rock and the surrounding environment determines the nature and the amount of heavy metals in an environment. Mercury (Hg), lead (Pb), nickel (Ni), manganese (Mn), cadmium (Cd), tin (Sn), zinc (Zn), Cobalt (Co), chromium (Cr), and copper (Cu) are typically found in high concentrations in geologic plant materials (Nagajyoti et al., 2010). As pointed by Rodríguez-Rodríguez et al. (2013) “many erosion characteristics, such as rainfall intensity, volume and frequency, vegetation and soil physical properties, influence the release and dispersion of heavy metals from rocks to varied environmental media”. Furthermore, volcanoes generate enormous levels of Al, Zn, Mn, Pb, Ni, Cu, and Hg, in addition to dangerous and hazardous gases (Nagajyoti et al., 2010). According to a study, “wind dust (i.e., atmospheric deposition) from desert regions contains high amounts of Fe but low levels of Pb, Zn, Mn, Ni and Cr, and the marine aerosols, as well as forest fires, play a role in the migration of some heavy metals in various ecosystems (Nagajyoti et al., 2010). In precise terms, (Zhang et al. 2017) are of the opinion that “natural sources of heavy metals include volcanic eruptions and continental weathering, which, when combined with anthropogenic sources, produce heavy metal accumulation in the food chain”.

**Anthropogenic Sources**

Although heavy metals are discharged into the environment via natural phenomena, the most common and dangerous type of environmental pollution is caused by human activity. This is most likely due to their instability and solubility, as well as their bioavailability (Abdu et al., 2011b). Among the anthropogenic sources of heavy metals are alloy (steel) production, discharge from automobile exhaust, battery manufacturing, biosolids and sewage sludge, coating, cement and explosive manufacturing, processing of electronic waste, fossil-fuel burning, mining, improper stacking of industrial solid wastes, leather tanning, use of agrochemicals (fertilizers and pesticides), textiles and dyes, farmland irrigation, photographic materials, steel printing pigments, electroplating and smelting (Bi et al., 2006; Walter et al., 2006; Navarro et al., 2008; Fulekar et al., 2009; Atafar et al., 2010; Luo et al., 2011; Zhang et al., 2012; Ogunkunle and Fatoba, 2013; Boussen et al., 2013; Armah, 2014; Dixit et al., 2015; Balkhair et al., 2016; Noli and Tsamos, 2016; Chaoua et al., 2019).

**Impacts of Heavy Metals on the Ecosystem**

Large amounts of toxic wastes, heavy metals, metalloids (elements possessing the properties of nonmetals and typical metal, e.g., arsenic and antimony), and organic contaminants are consistently released as a result of industrialization and technological advancement, all of which have caused problems in the natural environment. Ayangbenro and Babalola (2017) are of the firm believe that "heavy metals and metalloids continue to build up in soils and rivers, creating serious global health hazards owing to their inability to be converted into harmless forms and hence persist in the environment". This is validated by the report that "the amount of heavy metal contamination in the environment has reached an unacceptably high level, posing a hazard to all living things (Tak et al., 2013; Gaur et al., 2014; Dixit et al., 2015)". The permissible limits of several heavy metals in

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*Fig 1: Natural and anthropogenic sources of heavy metals, adapted from Kanwar et al. (2020)*
water, according to the United States Comprehensive Environmental Response Compensation and Liability Act (CERCLA), are 0.05, 0.002, 0.015, 0.01, 0.05, 0.015, 0.002 and 0.05 mg/L for Ag, Hg, Pb, Cr, Cd, and As., respectively (Chaturvedi et al., 2015). For Zn, Pb, Ni, Cu, and Cd, the standards for soil are 300-600, 250-500, 75-150, 135-270, and 3-6 mg/kg, respectively, based on the Indian heavy metals standards (Nagajyoti et al., 2010). These metals are substantial pollutants in the environment and their effects are becoming more worrisome. Humans and plants are usually exposed and are susceptible to heavy metal toxicity. Being naturally phytotoxic, heavy metals have an adverse effect on plant growth even at low concentrations. This means that when heavy metal concentrations are high, plant development is significantly impeded (Donald et al., 2022). Because of the health implications associated with these metals, regulatory agencies such as the Food and Agriculture Organisation (FAO), World Health Organization (WHO), and the United Nations Environmental Agency (USEPA) have set the acceptable heavy metal limits in drinking water, soil as well as plants. For drinking water, the maximum permissible and desirable limits have been presented in Table 1a, while the maximum permissible limits for soil and plants are shown in Table 1b. In addition, the summary of the sources and impacts of heavy metals on different life forms is presented in Table 2.

Table 1a: Maximum permissible and desirable limits of some heavy metals in drinking water (USEPA, 2009; Abdullahi et al., 2016; WHO, 2017; Kumar et al., 2019; Joseph et al., 2019)

<table>
<thead>
<tr>
<th>Heavy metals (mg/L)</th>
<th>WHO MPL</th>
<th>WHO MDL</th>
<th>USEPA max. perm. limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium, Cr</td>
<td>0.005</td>
<td>0.003</td>
<td>0.100</td>
</tr>
<tr>
<td>Manganese, Mn</td>
<td>1.000</td>
<td>2.00</td>
<td>0.050</td>
</tr>
<tr>
<td>Iron, Fe</td>
<td>1.000</td>
<td>0.10</td>
<td>3.000</td>
</tr>
<tr>
<td>Cobalt, Co</td>
<td>0.100</td>
<td>0.04</td>
<td>0.110</td>
</tr>
<tr>
<td>Nickel, Ni</td>
<td>0.070</td>
<td>NA</td>
<td>0.015</td>
</tr>
<tr>
<td>Lead, Pb</td>
<td>0.010</td>
<td>NA</td>
<td>0.015</td>
</tr>
<tr>
<td>Copper, Cu</td>
<td>3.000</td>
<td>0.05</td>
<td>1.300</td>
</tr>
<tr>
<td>Cadmium, Cd</td>
<td>0.100</td>
<td>0.50</td>
<td>0.005</td>
</tr>
<tr>
<td>Zinc, Zn</td>
<td>5.000</td>
<td>3.00</td>
<td>5.000</td>
</tr>
<tr>
<td>Arsenic, As</td>
<td>0.050</td>
<td>0.01</td>
<td>0.010</td>
</tr>
<tr>
<td>Mercury, Hg</td>
<td>0.001</td>
<td>NA</td>
<td>0.002</td>
</tr>
</tbody>
</table>

NA= Not available. MPL= Maximum Permissible Limit. MDL= Maximum Desirable Limit. USEPA= United States Environmental Protection Agency

Table 1b: Maximum Permissible Limits of Heavy Metals in Soil and Plants/Vegetables (WHO/FAO, 2007; WHO, 2011; Mensah et al., 2009; Taber, 2009; FAO/WHO, 2001; Chiroma et al., 2014; Adagunodo et al., 2018; Fosu-Mensah et al., 2018; Iyama et al., 2021; Alkhattib et al., 2022)

<table>
<thead>
<tr>
<th>Heavy metals (mg/kg)</th>
<th>MPL in Soil</th>
<th>MPL in Plants/Vegetables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium, Cd</td>
<td>3</td>
<td>0.20</td>
</tr>
<tr>
<td>Iron, Fe</td>
<td>300</td>
<td>425.50</td>
</tr>
<tr>
<td>Zinc, Zn</td>
<td>300</td>
<td>99.40</td>
</tr>
<tr>
<td>Chromium, Cr</td>
<td>300</td>
<td>1.30</td>
</tr>
<tr>
<td>Lead, Pb</td>
<td>50</td>
<td>0.43</td>
</tr>
<tr>
<td>Copper, Cu</td>
<td>100</td>
<td>40.00</td>
</tr>
<tr>
<td>Arsenic, As</td>
<td>20</td>
<td>0.15</td>
</tr>
<tr>
<td>Mercury, Hg</td>
<td>2</td>
<td>NA.00</td>
</tr>
<tr>
<td>Manganese, Mn</td>
<td>2000</td>
<td>500.00</td>
</tr>
<tr>
<td>Cobalt, Co</td>
<td>100</td>
<td>50.00</td>
</tr>
<tr>
<td>Nickel, Ni</td>
<td>50</td>
<td>67.90</td>
</tr>
<tr>
<td>Selenium, Se</td>
<td>10</td>
<td>NA.00</td>
</tr>
</tbody>
</table>

Table 2: Summary of heavy metal sources and impacts on living things

<table>
<thead>
<tr>
<th>Heavy metals Sources</th>
<th>Humans</th>
<th>Plants</th>
<th>Microbes</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cd</td>
<td>Bronchitis, renal malfunction, bone disease, cancer, hypertension, emphysema, lung disease, prostate cancer, ictus, testicular atrophy, gastrointestinal disorder, microcytosis, hypochromic anemia, kidney diseases, headache, lymphocytosis, vomiting, and high blood pressure and cough.</td>
<td>Chlorosis, seed germination retardation, decrease in nutrient uptake, root and shoot growth inhibition</td>
<td>Protein denature, cell division inhibition, decrease in carbon and nitrogen release, mutagenic acid defects.</td>
<td>Iyama et al., 2018; Chiroma et al., 2014; Fosu-Mensah et al., 2018; Fosu-Mensah et al., 2018; Fosu-Mensah et al., 2018; Iyama et al., 2021; Alkhattib et al., 2022</td>
</tr>
<tr>
<td>Plastic, Pigments, Ni batteries, agrochemical application, coal combustion, mining, coating of metal, weathering of ingenious rocks, welding/metallurgy smelting, refining, combustion of fossil fuel, sewage/sludge, electroplating, nuclear plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The contamination of the environment by heavy metals has become a major concern to public health owing to man’s reliance on industry. Agricultural practices, mining, fossil fuel combustion, wastewater irrigation, sewage sludge dumping, smelting, corrosion, weathering, volcanic eruption, and atmospheric deposition, among other anthropogenic activities and natural phenomena, have all contributed to heavy metal pollution of land and water bodies. Anthropogenic activities such as automobile use and mixed industrial activity also contribute to heavy
metal contamination. These metals enter the human system via ingestion of contaminated foods and water and are nephrotoxic, carcinogenic, immunotoxic, genotoxic, and reproductive organ disruptors, according to experts and scholars in many research and review publications. Heavy metals are regarded as persistent pollutants, because they continue to be detected in different life forms, in addition to being present in every segment of the environment, including foods owing to their chemical stability, biomagnification tendency, large production and high intake. And heavy metal hazardous effects on plants, animals, and microorganisms start to manifest beyond a specific threshold. Analysis of the effects of heavy metal pollution on many living things has been presented in this review. However, the lack of integrated analysis globally limits research on the risk assessment of micropollutants, especially heavy metals in all environmental systems. Sometimes, residue analysis simply examines a single compound and excludes related matrices, like the constituents of aquatic ecosystem. Another issue is the restriction on undertaking a quick analysis of a single substance under controlled circumstances. Hence, the following data gaps should be considered so as to carry out a thorough risk assessment of heavy metals: (i) The human accumulation parameters for heavy metals, especially in groups with high exposure rates, like young women of reproductive age, inhabitants of coastal cities, who consume crops that may have accumulated these metals and people who live close to chemical process industries, (ii) heavy metal contamination screening for edible goods and environmental components and (iii) hazard characterization based on the permissible limits set by USEPA, WHO and other environmental protection agencies. Therefore, to keep the ecological balance of the earth, it is imperative to strengthen scientific studies to look into the effects of heavy metal toxicity on different life forms. In addition, it is crucial to concentrate on risk assessment and research on the concentrations and distribution of these persistent environmental toxins in the environment.

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Authors’ Contributions

Anyiam N. Donald: Study conception and design, critical review of relevant literature, writing of the first and final draft.

Pene B. Raphael: Data collection, critical review of relevant literature and writing of the first draft.

Oluwole J. Olumide: Critical review of relevant literature, revision of the final draft for scientific errors.

Okoro F. Amarakchunu: Data collection, checking/revision of the final draft for grammatical errors.

Ethics

This scientific article is original and has neither been published nor being considered for publication in any other journal. The corresponding author attests that all other authors have read and approved the manuscript and that no ethical principles were violated.

References


