HEAVY METAL TOXICITY: A REVIEW

BY
J. O. JACOB, A.I. AJAI AND A. N. Amadi
DEPARTMENT OF CHEMISTRY,
FEDERAL UNIVERSITY OF TECHNOLOGY, P. M. B 65, MINNA, NIGERIA
E-MAIL: jacobasol@yahoo.com

ABSTRACTS
This paper reviews the literatures on both the human and plant toxicity of heavy metals, which has been for many years a global concern. It discusses the most common heavy metals viz-a-viz their sources and health effects. Historical cases of human toxicity of heavy metals were also highlighted as well as the synergetic and the antagonistic effects of these metals.
Keywords: *heavy metals, toxicity, human, plants, health effects*

INTRODUCTION
Metals are natural elements and components of the environment. They have been extracted from the earth and harnessed for human industry and products over many years. Metals are notable for their wide environmental dispersion due to such anthropogenic activities; their tendency to accumulate in selected tissues of the body; and their overall potential to be toxic even at relatively minor levels of exposure [1].

Heavy metals are metals with a specific gravity that is at least 5 times the specific gravity of water. There are different other definitions of the term 'heavy metal'. In environmental toxicology, any toxic metals may be called 'heavy metals' irrespective of their atomic mass or density, moreover, most environmentally toxic elements are the heavy metals [2]. Commonly encountered toxic heavy metals that are often measured in environmental surveys include aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, thallium, tin, titanium, vanadium and zinc. All toxic heavy metals can endanger human health on slight exposure; the critical organs they affect in the body differ from metal to metal [3]. They can directly or indirectly damage DNA increasing risk of cancer. A number of metals are said to be carcinogenic; these are, arsenic, beryllium, cadmium, nickel and hexavalent chromium. Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. As metals journey through the environmental and biological reservoirs, they can undergo chemical transformations that help to determine both their bioavailability and toxicity [4]. The major consequence of environmental contamination by heavy metals is their toxicity to humans, after entering the food chain. Unorganized dumping of solid waste is predominant in developing countries and causes adverse impacts to the environment. Sources such as electronic goods, electroplating waste, painting waste, used batteries, e.t.c, when dumped with municipal solid wastes, increase the heavy metal levels in the environment [5].

Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agriculture and in manufacturing, pharmaceutical, industrial, or residential settings. Industrial exposure accounts for a common route of exposure for adults. Ingestion is the most common route of exposure in children. Children may develop toxic levels from the normal hand to mouth activity of small children who come in contact with contaminated soil or by actually eating objects that are not food. Less common routes of exposure are during a radiological procedure, from inappropriate dosing or monitoring during intravenous nutrition, or from a suicide or homicide attempt [6]. As a rule, acute poisoning is more likely to result from inhalation or skin contact of dust, fumes or vapours, or materials in the workplace. However, lesser levels of contamination may occur in residential settings, particularly in older homes with lead paint or old plumbing [7].

The accumulation of metals in urban soils is caused by a wide range of industrial activities, automobile emissions, pestisides, use of lead paints and pipes and galvanized metals. Deposition of heavy metal pollutants as emissions, from gasoline and lubricating oils, along roadside soil and vegetation are known for copper, lead, and zinc. Advancement in technology has lead to high levels of industrialization leading to the discharge of effluents containing heavy metals into the environment. The extent of this widespread but general diffused contamination has caused concern about its possible hazards on plants, animals and humans generally. Significant amounts of metals, singly or in combination are introduced into the atmosphere from both natural and anthropogenic sources such as smelters/metallurgic processes, incineration of wastes as well as the combustion of fossil fuels [8].

Plants absorb metals from the soil through the roots which becomes incorporated in their tissues. Heavy metals are taken up by plants in their anionic and cationic forms. They are aspirated into plants together with water which constantly transpires. Thus the import of metals is directly dependent on the transpiration rate of plant. Metals have to be in an available form for plant to take up or plants must have mechanism to make the metals available [9].

BENEFITS OF HEAVY METALS IN BIOLOGICAL SYSTEM

Heavy metals are required in trace amounts by living organisms, some are essential for certain metabolic activities while others are essential components of enzymes and pigments in living systems. Such heavy metals include iron, cobalt, copper, manganese, molybdenum, vanadium, strontium and zinc. However, excessive levels of these metals can be detrimental to the organism [10].

Cobalt is essential for nitrogen fixation by rhizobium in legume noodles. In practice, it has the largest significance to animal nutrition and observed to be a component of vitamin B_{12} (cobalamine) molecule [11].

Iron is an essential element in animals and plants, a micro-nutrient required in a relatively small amount. It has a major role in a host of biochemical reactions, particularly in connection with enzyme of the electron transport chain (cytochromes). Iron, although not part of the chlorophyll molecule is essential in plants for the synthesis of chlorophyll. Some of the enzymes and carriers that function in the respiratory and photosynthesis mechanisms of living cells are iron compounds, e.g. cytochromes and ferredoxin. The principal iron-containing pigments in animals are the red haemoglobin of vertebrate blood, the red erythrocruorin found in many annelids and mollusks, and the green chlorocruorin of certain polycheate worms. All these respiratory pigments form oxy-derivatives by the molecular union of oxygen with the metal atom; they serve for transport of oxygen in the body [12].

Chromium is required for normal carbohydrate, lipid and nucleic acid metabolism. Insufficient dietary chromium leads to impaired glucose and lipid metabolism and may ultimately lead to maturity onset diabetes, and /or cardiovascular diseases. The essentiality of chromium is seen in mice, chicken and sheep. In human, it acts as a defense mechanism against weight loss, glucose intolerance, and impaired energy metabolism. Nickel is required to maintain health in animals. Small amount of Nickel is probably essential for human, although lack of Nickel has not been found to have effect. Copper and zinc are micronutrients essential for the normal growth and development of the body. Copper is found to be essential in haemoglobin formation, production of RNA, cholesterol utilization among others. Zinc is essential for protein synthesis, carbon dioxide transport, and sexual function, among others. On the other hand, arsenic, lead, mercury and cadmium have no known beneficial importance in living organisms [13]. Table 1 shows some metals and their specific functions in the living system.

Table 1: Metals and their Specific Functions in Living System [13]

Metal	Functions
Calcium	Builds bones and teeth, muscle contraction, heart action, nerve impulses, blood clotting.
Magnesium	Liver, muscles, transfer of intercellular water, alkaline balance, neuromuscular activity
Sodium	Electrolyte balance, body fluid volume, nerve impulse condition
Potassium	Cell membrane potential, nerve impulse conduction, heart rhythm, acid base balance
Copper	Haemoglobin formation, production of RNA, elastic tissue formation, cholesterol utilisation, oxidase ezyme activator
Zinc	Protein synthesis, carbon dioxide transport, sexual function, insulin storage, carbohydrate metabolism wound healing
Iron	Haemoglobin formation, electron transport, oxygen transport, enzyme activator
Chromium	Glucose utilisation, insulin activity, heart muscle, cholesterol utilisation
Nickel	Activates some liver enzymes
Manganese	Carbohydrate metabolism, protein metabolism, connective tissue, joint fluid production, nerve tissue, vitamin B1 utilisation
Vanadium	Strengthens bones and teeth, lowers blood lipids, inhibits cholesterol synthesis
Tin	Essential growth, protein synthesis

HUMAN TOXICITY OF HEAVY METALS

As a rule, acute poisoning is more likely to result from inhalation or skin contact of dust, fumes or vapours, or materials in the workplace. However, lesser levels of contamination may occur in residential settings, particularly in older homes with lead paint or old plumbing [14]. Toxic substances emitted into the air change quantitative relations among elements occurring in the environment, as well as in the human body. Many workers are exposed to heavy metals in industry, particularly in the metal finishing industry or traditional glassworks. Thallium, cadmium, bismuth, and lead cause morphological and functional changes in the human body. The clinical course of such changes is determined by the amount of the heavy metal dose, duration of exposure to the toxic metal, and individual immunity of the patient [15]. Table 2 shows the sources and health effects of some highly toxic heavy metals while Table 3 shows some historical cases of heavy metal toxicity.

Table 2: Sources and Health Effects of Some Highly Toxic Heavy Metals [16]

S/N	Metal	Sources	Human Health Effects
1.	Arsenic	Smelting processes, manufacture of chemicals & glasses, paint, rat poisoning, fungicides and wood preservation	Target organs are the blood, kidneys & central nervous, digestive & skin systems. Causes nausea, anemia and cancer.
2.	Lead	Pipes, drains and soldering materials, paints, batteries, fuel additives, pesticides	Bones, brain, blood kidney and thyroid gland impairment and anxiety.
3.	Mercury	Degassing of the earth's crust, volcanic emissions and mining operations	Brain and kidney damage, anxiety, hearing loss, deafness and depression.
4.	Cadmium	Mining and smelting activities, batteries, PVC plastics, paint, insecticides, fertilizers, cigarettes, electroplating, motor oil	Damage to liver, placenta kidneys, lungs liver brain and bones. Hypertension anemia and cancer
5.	Nickel	Mining & smelting activities, nickel cadmium batteries, nickel plating	Chronic bronchitis, cancer, heart problem, liver damage and skin irritation
6.	Chromium	Volcanic emissions, mining & smelting activities, alloys, pigments furnace bricks, wood preservatives, burning of fossil fuels	Chronic exposure of Cr^{6+} is mutagenic. It can also lead to asthma & damage to the nasal and skin epithelia
7.	Copper	Mining, wielding, insecticides, birth control pills, dental alloys, copper cookware and pipes.	High level of accumulation in the body leads to nausea, vomiting, abdominal pain, breakdown of red blood cells and Wilson's disease in children

Table 3: Some Historical Cases of Heavy Metal Toxicity [17, 18]

Metal	Place	Date	Health Effects
Arsenic	Bradford, England	1858	Intense abdominal pains, nausea, vomiting, diarrhea, coma and death
Cadmium	Juntsu, Japan	1955	*Itai-itai* disease, characterized by severe bone pain, waddling gait, pathological fractures, renal impairment, etc
Mercury	Britain	1940 - 1950	The pink disease: characterized by poor health, high BP and poor memory.
	Minamata, Japan Niigata, Japan Iraq Iraq Ghana Canada	1956 1965 1956 1960 1967 1970	Minamata disease; a neurological syndrome. Symptoms include numbness in hands and feet, damage to hearing and speech, insanity, paralysis, coma and death
Lead	Ancient Greek & Arabs Devonshire & several other places	- 1700s-1800s	Physiological & neurological effects which include weariness, nausea, abdominal pain, uncoordinated body movements, inflammation of the brain, IQ defects, coma and death, especially children.
	Chinna	2009	
	Some mining villages of Zamfara State, Nigeria	2010	
Polonium ($^{210}P_o$)	Russia (The poisoning of Alexander Litvinenko)	2006	Hair loss, damage to peripheral nerves, coma and death

PHYTOTOXICITY OF HEAVY METALS

The term phytotoxicity has normally been associated with phenomenon whereby a potentially harmful substance has accumulated in the plant tissue to a level affecting optimal group and the development of the plant. It is important to note that plants absorb heavy metal from the soil as well as from surface deposits on parts of plants exposed to polluted air. The presence of heavy metals in fertilizers and wastewaters contribute to additional sources of metal pollution for cultivated vegetables [19].

Leafy vegetables have greater potential of accumulating heavy metals in their edible parts than grain or fruit crops. Studies on the uptake of heavy metals by plants have shown that heavy metals can be transported passively from roots to shoots through the xylem vessels. In addition, plant organs such as fruits and seeds that have low transpiration rates do not accumulate heavy metals because the storage organs are largely phloem-loaded and heavy metals are generally poorly mobile in the phloem. Zheljarzkov and Nielsen, found that the concentration of heavy metals in vegetables per unit dry matter generally followed the order; leaves > fresh fruits > seed [20].

JOINT OR COMBINED TOXICITY OF HEAVY METALS

The recent trends in heavy metal studies are to analyze and predict lethal and sub-lethal toxicity levels of metal mixtures. Several studies have stressed the importance of mixed toxicities in determining water quality criteria. Interactions between metal may increase (synergetic) or decrease (antagonistic) the degree of toxicity, depending on the nature of individual pollutants. Information on metals interactions provides a more realistic assessment of their toxicity to organisms than observations with individual metal, since they usually occur as mixtures in the environment. Several workers have studied the toxicity of metal mixtures, and a few have considered possible reasons for increased or decreased toxicities of metal mixtures. Barnes and Stanbury [21] found that mixtures of copper sulphate and mercury chloride were far more toxic to the copepod, *Nitocra spinipes*, than either of the salts alone. Machines and Calabrese [22], reported the interaction of metals to be temperature dependent. Antagonism and less than additive interactions have also been documented for Hg and Cu mixtures [23].

REMEDIATION OF HEAVY METALS

In general, it is very difficult to eliminate metals from the environment. Once metals are introduced and contaminate the environment, they will remain. Metals do not degrade like carbon-based (organic) molecules. The only exceptions are Mercury and Selenium, which can be transformed and volatilized by microorganism. Traditional treatments for metal contamination in soils are expensive and cost prohibitive when large areas of soil are contaminated. Treatments can be done *in situ* (on-site) or *ex situ* (remove and treated off-site). Different methods exist for the remediation of heavy metals in the environment. These include mechanical, chemical and bioremediation methods [24].

CONCLUSION

The toxicity of heavy metals cannot be over emphasized, however, one thing is needful there must be a continuous monitoring of heavy metals accumulation in the environment. Development of Nigerian standards or maximum permissive limits for heavy metals in soils, water, ambient air and food stuffs is paramount. The lead poisoning in Zamfara state in 2010, shows that Nigeria is not spared of the toxic effects of heavy metals in the environment.

REFERENCES

1. Hu, H. (2002). Human Health and Heavy Metals Exposure, In; Life Support: The environment and human Health, Michael McCally (ed), MIT press.
2. Duffus, J. H. (2002). Heavy Metal-A Meaningless Term?, *Pure and Applied Chemistry*, 74(5): 793-807.
3. Chen, T. B. Wong, J. W. C., Zhou, H. Y. and Wong, M. H. (1997). Assessment of Trace Metal Distribution and Contamination in Surface Soils of Hong Kong, *Environmental Pollution*, 96(1): 61 – 68.
4. Adeniyi, A. A. (1996). Determination of Cadmium, Copper, Iron, Lead, Manganese and Zinc in Water Leaf in Dumpsites, Environment International, 22: 259-262.
5. Esakku, S., Palanivelu, K. and Joseph, K. (2003). Assessment of Heavy Metals in Municipal Solid Waste Dumpsite, Workshop on Sustainable Landfill Management, Chennai, India, pp 139-144.
6. Trueby, P. (2003). Impact of Heavy Metals on Forest Trees from Mining Areas, International Conference on Mining and the Environment III, Sudbury, Ontario, Canada.
7. Hussein, E. M. (1994). Radioactivity of Phosphate Ore, Superphosphate and Phosphogypsum, *Health Physics*, 67(3): 280 – 282.
8. Oyewale, A. O. and Funtua, I. I. (2002). Lead, Copper and Zinc Levels in Soils Along Kaduna-Zaria Highway, Nigeria, Global J. Env. Sci., Vol. 1, No.1, 7-13.
9. McCluggage, D. (1991). Heavy Metal Poisoning, NCS Magazine, Published by the Bird Hospital, CO, USA. www.cockatiel.org/articles/diseases/metals
10. Harada, M. (1994). Environmental Contamination and Human Rights, Case of Minamata Disease, *Ind. Environ. Crisis and Quality*, 8:141-154.
11. Macrae, R. R., Rabinson, R. K. and Sadler, M. J. (1999). Encyclopedia of Food Science and Technology: Trace Elements, 7: 4593 – 4600.
12. Adeniyi, A. A. (1996): "Determination of Cadmium, Copper, Iron, Lead, Manganese and Zinc in Water Leaf, in Dumpsites", *Environmental International*, 22(2): 259 – 262.
13. Prasad, M. N. V. (2004). *Heavy Metal Stress in Plants*, Second Edition, Springer, U. K., 484 – 487.
14. ASTDR TOXFAQs (1999). International Occupational Safety and Health Information Centre, U. S. A.
15. Bachanek, T., Staroslawska, E., Wolanska, E., Jarmolinska, K. (2000). Heavy Metal Poisoning in Glass Worker Characterised By Severe Dental Changes, Ann Agric Environ Med., 7:51–53
16. Wong, J. W. C. (1996). Heavy Metal Contents in Vegetables and Market Garden Soil in Hong Kong, *Environmental Technology*, 17: 407 – 410.
17. McCluggage, D. (1991). Heavy Metal Poisoning, NCS Magazine, Published by the Bird Hospital, CO, USA. www.cockatiel.org/articles/diseases/metals
18. RSC (2009). Heavy metal poisoning sparks protests in China, Advancing the Chemical Sciences, 25th August 2009.
19. Adamo, P. S., Dudka, M. J. and Mchardy, W. J. (2000). Chemical and Mineralogical Forms of cu and Ni in Contaminated Soil from the Sudbury Mining and Smelting Region, Canada, *Environment Pollution*, 91: 11 – 19.

20. Heal, M. R., Hibbs, L. R., Agius, R. M. and Berverland, I. J. (2005). Total and Water-Soluble Trace Metal Content of Urban Background and Black Smoke in Endiburg, U. K., *Atmos. Environ.*, 39(8): 1417 – 1430.

21. Jensen, P. E., Ottosen, L. M. and Pedersen, A. J. (2006). Speciation of Pb in Industrially Polluted Soils", *Water, Air and Soil*, 68:167 – 182.

22. Mench, M. J., Didier, V. L., Loffler, M., Gomez, A. and Masson, P. (1994). A Mimicked *In-Situ* Remediation Study of Metal Contaminated Soils with Emphasis on Cadmium and Lead", *Journal of Environmental Quality*, 23:58 – 63.

23. Tuber D., Maynard, B. and Standalone, J. (2001). Heavy Metal Contamination in Soils of Urban Highways: Comparison between Runoff and Soil Concentration at Cincinnati, Ohio, *Water, Air and Soil Pollution*, 132: 293 – 314.

24. USDA-NRCS (2000). *Heavy Metal Soil Contamination*, Soil Quality – Urban Technical Note, No. 3, A Publication of United State Department of Agriculture and Natural Resources Conservation Service, pp. 3 – 4.