Heavy Metals Toxicity to Indian Environment: A Review

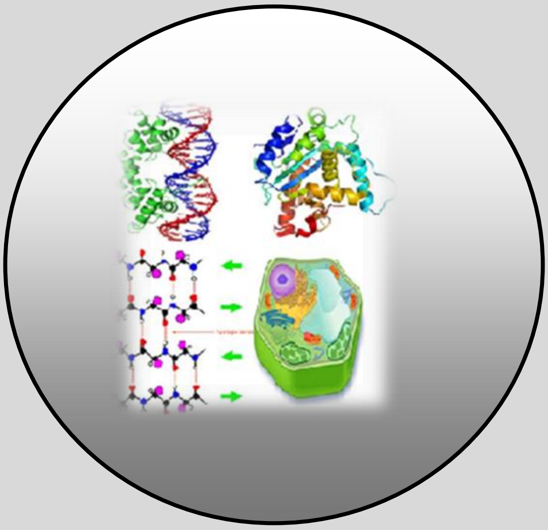
By

Ozair Aziz and Prerna Shukla

ISSN 0970-4973 Print
ISSN 2319-3077 Online/Electronic

Volume 28
No. 1 & 2 (2011)

J. Biol. Chem. Research
Volume 28 2011 Pages No: 103-108



Journal of Biological and Chemical Research

An International Peer reviewed Journal of Life Sciences and Chemistry

Published by Society for Advancement of Sciences®

J. Biol. Chem. Research. Vol. 28 (1 & 2), 103-108 (2011)
(An International Peer Reviewed Journal of Life Sciences and Chemistry)
ms 28/1-2/99/2011, All rights reserved
ISSN 0970-4973 (Print)
ISSN 2319-3077 (Online/Electronic)
Published by Society for Advancement of Science®

www.jbcr.in
jbiolchemres@gmail.com
info@jbcr.in

REVIEW ARTICLE

Received: 25/10/2011 Revised: 03/12/2011 Accepted: 04/12/2011

Heavy Metals Toxicity to Indian Environment: A Review

Ozair Aziz and Prerna Shukla
R. S. Government Degree College, Bairi – Shivrajpur, Kanpur Nagar – 209 205, India

ABSTRACT

Metallic pollution of the environment from anthropogenic sources constitutes a major health hazard of the century. This has led to the global concern over long term as well as immediately imperceptible effects of heavy metals. Among the international agencies the WHO, ILO, UNEP and FAO have been in the fore front in initiating action on monitoring, control and prevention of metal pollution of the environment. The development of metallurgical, heavy engineering and various types of chemical industries in India have given rise to new and complex problems of health hazards both for workers and the community at large.
Keywords: Metal Toxicity, Arsenic, Lead, Mercury, Cadmium and Chromium.

INTRODUCTION

Metals are found naturally in the earth's crust and their compositions vary among different localities, resulting in spatial variations of surrounding concentrations. The main objective of this review is to provide insight into the sources of heavy metals and their harmful effects on the environment and living organisms. The toxic effects of Heavy metals are generally referred to as those metals which possess a specific density of more than 5 g/cm^3 and adversely affect the environment and living organisms (Järup, 2003). The toxic effects of heavy metals particularly lead and mercury were not unknown to our ancestors. Thus an excerpt from *Bhava Prakasa Nighantu*, a 14^{th} century ayurvedic text, touches on toxic effects of lead and tin mentioned earlier in the *Samhita* and *Sutr* literature of pre Christian era.

The impact on human health of the biogeochemical cycling of a metal is determined by its physical, chemical and biological properties. In eliciting biological responses the following physical properties of metal appear to be significant.

a) Natural occurrence and availability
b) Volatility of metal and its salts

c) Adsorption and desorption by tissues
d) Transport and diffusion through biomembrane
e) Solubility in lipids
f) Particle size in the atmosphere

Following chemical properties of metals are of clinical importance

a) Speciation
b) Ease of formation, transport and stability of alkyls when such derivatives are formed
c) Redox properties
d) Stability and solubilization of sulphides
e) Ionic association and dissociation in aqueous media
f) Stability and persistence in the environment

Following biological properties of metals are largely derived from their above physicochemical properties

a) Toxicity to man
b) Bioaccumulation and bio magnification
c) Retention time in living organism
d) Biological transformation e.g. methylation

Twenty out of the hundred and five elements have been identified as normal constituents of biological tissues. Almost 96% of the total mass of any organism is made up of C, H, O, N, while Ca, P, S, K, Na, Cl and Mg make up about 3.6%. The remaining 0.4% is contributed by so called toxic elements or Heavy Metals. From the view point of health metals can be divided into following four groups

a) Metals essential to life processes e.g. Cu, Zn, Cr, Mn, Fe and Co
b) Metals probably not essential e.g. Ba, Al, Li, Zr
c) Metals toxic to some life processes e.g. As
d) Metals highly toxic to the system e.g. Hg, Cd, Pb

At present eleven metals are believed to be essential for life. These are Fe, Cu, Zn, Mn, Co, Mb, Se, Cr, Ni, Sn and V. Elements like As, Sb, An, Pb, Cd, Hg and Bi are known to be definitely toxic even at very low levels of intake. Food and water are the main sources of our daily requirements of essential metals. Metals ingested in excess are excreted by the body through urine and faeces, otherwise there may be a chance of their accumulation in various body tissues. At higher concentrations trace elements become toxic. Metals usually considered to be toxic at **'physiological dose'** may be stimulatory or essential in very minute doses depending upon the environment and state of the organism. The indispensability, deficiency or toxicity of metals is manifestations of dose-response effects. However, environment conditions, natural and biological factors such as age, sex, species differences, stress, relationship of one metal with the other and metal and metal-ion imbalances in biological systems in turn influence the toxicity of metals.

Heavy metals are significant environmental pollutants and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional and environmental reasons (Nagajyoti *et al.*, 2010). The most commonly found heavy metals in waste water include arsenic, cadmium, chromium, copper, lead, nickel, and zinc, all of which cause risks for human health and the environment (Lambert *et al.*, 2000). Heavy metals enter the surroundings by natural means and through human activities. Various sources of heavy metals include soil erosion, natural weathering of the earth's crust, mining, industrial effluents, urban runoff, sewage discharge, insect or disease control agents applied to crops, and many others.

Based on their adverse health effects, metal can be classified into highly toxic, moderately toxic, slightly toxic and nontoxic groups. As, Pu, Sr, Th and Ti are highly toxic; Cd, Cu, Hg, Pb, Sb and V are moderate toxic; Al Mo, Ta W, Zn and Zr are slightly toxic while Ca, Na, I, Rb and K are nontoxic.

The property of some metals to undergo biological methylation or complexation and to be accumulated in tissues are most important factors to be taken into account while assessing their health effects. Water hyacinth has a special affinity for mercury, lead and cadmium. Mercury is the only metal which is known to be biomagnified in the food chain. It is effectively transformed into its most toxic form, methyl mercury, in the aquatic environment. The extent to which human interference can modify the environment in regard to the biogeochemical cycles of metals depends on the following factors:

i. Production and diffusion of metals in quantities more than the background fluxes Residence time in various environmental sinks e.g. seas, lakes, forest, soil etc.,
ii. Active and passive bioaccumulations
iii. Physiochemical properties relevant to environmental integrity
iv. Toxicity to aquatic spp
v. Long term effects on ecosystem
vi. Biotransformation reactions

The main target organs of toxic metals and their carcinogenic potentials in man are Kidney, lung, liver, CNS, PNS and skin.

Whatever be the port of entry- the lung, the mouth, or the skin- the toxic metal must eventually reach its target organ, the brain, the liver, the kidney, the blood forming system and the reproductive system. The fate of metal within the body is determined by its inherent properties and the ability of the body to modify them.

Toxicity manifest as death is an acute effect and represent the eventual outcome of disturbances of a number of physiological processes possibly triggered by primary action of the toxic metal on a specified target tissue. Toxicity manifestation depend upon

a. Concentration and bioavailability, rate of absorption, storage, transport
b. Speciation
c. Target tissue affected
d. Route of entry
e. Interaction with other metals
f. Ligand binding with protein and nucleic acid
g. Biotransformation and bioaccumulation

Although these metals have crucial biological functions in plants and animals, sometimes their chemical coordination and oxidation-reduction properties have given them an additional benefit so that they can escape control mechanisms such as homeostasis, transport, compartmentalization and binding to required cell constituents. These metals bind with protein sites which are not made for them by displacing original metals from their natural binding sites causing malfunctioning of cells and ultimately toxicity. Previous research has found that oxidative deterioration of biological macromolecules is primarily due to binding of heavy metals to the DNA and nuclear proteins (Flora *et al.*, 2008).

Arsenic

Arsenic is one of the most important heavy metals causing disquiet from both ecological and individual health standpoints. It has a semi metallic property, is prominently toxic and carcinogenic, and is extensively available in the form of oxides or sulfides or as a salt of iron, sodium, calcium, copper, *etc.* (Singh *et al.*, 2007). Arsenic is the twentieth most abundant element on earth and its inorganic forms such as arsenite and arsenate compounds are lethal to the environment and living creatures. Humans may encounter arsenic by natural means, industrial source, or from unintended sources. Drinking water may get contaminated by use of arsenical pesticides, natural mineral deposits or inappropriate disposal of arsenical chemicals.

Mechanism of arsenic toxicity

In arsenic biotransformation, harmful inorganic arsenic compounds get methylated by bacteria, algae, fungi and humans to give mono methyl arsenic acid (MMA) and di methyl arsenic acid (DMA). In this biotransformation process, these inorganic arsenic species are converted enzymatically to methylated arsenicals which are the end metabolites and the biomarker of chronic arsenic exposure.

Lead

Lead is a highly toxic metal whose widespread use has caused extensive environmental contamination and health problems in many parts of the world. Lead is a bright silvery metal, slightly bluish in a dry atmosphere. It begins to tarnish on contact with air, thereby forming a complex mixture of compounds, depending on the given conditions (Sharma & Dubey, 2005). The sources of lead exposure include mainly industrial processes, food and smoking, drinking water and domestic sources. The sources of lead were gasoline and house paint, which has been extended to lead bullets, plumbing pipes, storage batteries, toys and faucets . In the US, more than 100 to 200,000 tons of lead per year is being released from vehicle exhausts. Some is taken up by plants, fixation to soil and flow into water bodies, hence human exposure of lead in the general population is either due to food or drinking water (Goyer, 1990). Lead is an extremely toxic heavy metal that disturbs various plant physiological processes and unlike other metals, such as zinc, copper and manganese, it does not play any biological functions. A plant with high lead concentration fastens the production of reactive oxygen species (ROS), causing lipid membrane damage that ultimately leads to damage of chlorophyll and photosynthetic processes and suppresses the overall growth of the plant. Some research revealed that lead is capable of inhibiting the growth of tea plant by reducing biomass and debases the tea quality by changing the quality of its components. Even at low concentrations, lead treatment was found to cause huge instability in ion uptake by plants, which in turn leads to significant metabolic changes in photosynthetic capacity and ultimately in a strong inhibition of plant growth

Lead metal causes toxicity in living cells by following ionic mechanism and that of oxidative stress. Many researchers have shown that oxidative stress in living cells is caused by the imbalance between the production of free radicals and the generation of antioxidants to detoxify the reactive intermediates or to repair the resulting damage.

Mercury

The metallic mercury is a naturally occurring metal which is a shiny silver-white, odorless liquid and becomes colorless and odorless gas when heated. Mercury is very toxic and exceedingly bioaccumulative. Its presence adversely affects the marine environment and hence many studies are directed towards the distribution of mercury in water environment. Major sources of mercury pollution include anthropogenic activities such as agriculture, municipal wastewater discharges, mining, incineration, and discharges of industrial wastewater.

Mechanism of mercury toxicity

Mercury is well known as a hazardous metal and its toxicity is a common cause of acute heavy metal poisoning with cases of 3,596 in 1997 by the American Association of Poison Control Centers. Methylmercury is a neurotoxic compound which is responsible for microtubule destruction, mitochondrial damage, lipid peroxidation and accumulation of neurotoxic molecules such as serotonin, aspartate, and glutamate (Patrick, 2002). The brain remains the target organ for mercury, yet it can impair any organ and lead to malfunctioning of nerves, kidneys and muscles. It can cause disruption to the membrane potential and interrupt with intracellular calcium homeostasis

Cadmium

Cadmium is the seventh most toxic heavy metal. It is a by-product of zinc production which humans or animals may get exposed to at work or in the environment. Once this metal gets absorbed by humans, it will accumulate inside the body throughout life. This metal was first used in World War I as a substitute for tin and in paint industries as a pigment. In today's scenario, it is also being used in rechargeable batteries, for special alloys production and also present in tobacco smoke. Cadmium distributed in the environment will remain in soils and sediments for several decades. Plants gradually take up these metals which get accumulated in them and concentrate along the food chain, reaching ultimately the human body.

Chromium

Chromium is the seventh most abundant element on earth. Chromium occurs in several oxidation states in the environment ranging from Cr^{2+} to Cr^{6+}. The most commonly occurring forms of Cr are trivalent- Cr^{+3} and hexavalent- Cr^{+6}, with both states being toxic to animals, humans and plants. Chromium occurs naturally by the burning of oil and coal, petroleum from ferrocromate refractory material, pigment oxidants, catalyst, chromium steel, fertilizers, oil well drilling and metal plating tanneries. Anthropogenically, chromium is released into the environment through sewage and fertilizers. Cr(III) is immobile in its reduced form and is insoluble in water whereas Cr(VI) in its oxidized state is highly soluble in water and thus mobile . Pollution of the environment by chromium, particularly hexavalent chromium, has been the greatest concern in recent years (Zayed & Terry, 2003). Tanneries discharge numerous polluting heavy metals and compounds into the water streams (Nath *et al.*, 2008). Due to the presence of excess oxygen in the environment, Cr (III) is oxidized to Cr (VI), which is extremely toxic and highly soluble in water (Cervantes *et al.*, 2001).

Mechanism of chromium toxicity

In the environment, trivalent chromium Cr(III) is generally harmless due to its weak membrane permeability. Hexavalent chromium Cr(VI), on the other hand, is more active in penetrating the cell membrane through passages for isoelectric and isostructural anions such as SO_4^{2-} and HPO_4^{2-} channels and these chromates are taken up through phagocytosis.

ACKNOWLEDGEMENTS

The authors thank Dr. Indu Saxena, Principal, R.S. Government Degree College, Bairi-Shivrajpur, Kanpur Nagar, for providing the necessary facilities and helpful critical suggestions.

REFERENCES

Cervantes, C., Campos-García, J., Devars, S., Gutiérrez-Corona, F., Loza-Tavera, H., Torres-Guzmán, J.C.and Moreno-Sánchez, R. (2001). Interactions of chromium with microorganisms and plants. *FEMS Microbiol Rev*.; 25(3):335–347. .

Flora, S.J.S., Mittal, M.and Mehta, A. (2008). Heavy metal induced oxidative stress & its possible reversal by chelation therapy. *Indian J Med Res.*; 128:501–523.

Goyer, R.A. (1990). Lead toxicity: from overt to subclinical to subtle health effects. *Environ Health Perspect.*; 86:177–181.

Järup, L. (2003). Hazards of heavy metal contamination. *Br Med Bull.*; 68(1):167–182.

Lambert, M., Leven, B.A.and Green, R.M. (2000). New methods of cleaning up heavy metal in soils and water; Environmental science and technology briefs for citizens; Manhattan, KS: Kansas State University.

Nagajyoti, P.C., Lee, K.D.and Sreekanth, T.V.M. (2010). Heavy metals, occurrence and toxicity for plants: a review. *Environ Chem Lett*; 8(3):199–216.

Nath, K., Shyam, S., Singh, D.and Shanna, Y.K. (2008). Effect of chromium and tannery effluent toxicity on metabolism and growth in cowpea (*Vigna sinensis* L. Saviex Hassk) seedling.*Res Environ Life Sci.*; 1:91–94.

Patrick, L. (2002). Mercury toxicity and antioxidants: Part 1: role of glutathione and alpha-lipoic acid in the treatment of mercury toxicity. *Altern Med Rev*; 7(6):456–471.

Sharma, P. and Dubey, R.S. (2005). Lead toxicity in plants. *Brazilian Journal of Plant Physiology*; 17(1):35–52.

Singh, N., Kumar, D.and Sahu, A. (2007). Arsenic in the environment: effects on human health and possible prevention. *J Environ Biol.*; 28 (2 Suppl): 359–365.

Zayed, A.M. and Terry, N. (2003). Chromium in the environment: factors affecting biological remediation. *Plant Soil.*; 249 (1):139–156.

Corresponding author: Dr. Ozair Aziz, R. S. Government Degree College, Bairi – Shivrajpur, Kanpur Nagar – 209 205, India
Email id: ozairaziz12@gmail.com