Contamination of Heavy Metals in India

Health Effects and Remediation Measures
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HEAVY METALS CONTAMINATION IN INDIA

HEALTH EFFECTS AND REMEDIATION MEASURES

HIGHLIGHTS

- Heavy metals have a persistent and bio-accumulative nature.
- Humans get exposed to the heavy metals through different sources and routes, and since these heavy metals are toxic and non-degradable, they have serious health effects on humans.
- Due to their toxic nature, these heavy metals can affect all body parts of humans including lungs, kidneys, liver, skin, muscles, reproductive system, and immune system.
- To prevent contamination and exposure, thus, there is a need of expanding scope of current standards and statutory restrictions and policies.
- The exposure to heavy metals in humans and exposure pathways in environment should be monitored regularly.
- Various natural and technological practices known as mitigation measures facilitate reduction of already exposed environmental compartments.

RECOMMENDATIONS

The heavy metals have constantly caused a great havoc in the environment, both due to their effect on ecology and human health. These metals are bio-persistent and thus, accumulate in the environment resulting in prevalence of different diseases in India. The following are the recommendations:

- Need to develop zonal maps of environmental contaminants in the country to highlight the high risk geographical locations in order to protect public health.
- Initiate bio-marker assessments of environmental contaminants in the population on priority basis.
- Conduct regular monitoring of hazardous contaminants in different environmental compartments including soil, water, crops, and marine produce.
- Develop feedback mechanisms to transfer time-stamped, geo-tagged environment status information to various government departments for developing actionable policies and mitigation measures.
- Formulate provisional Indian standards for contaminant/heavy metal concentrations in irrigation water, agricultural soil, aqua-culture ponds, and agri-produce.
- Promote customized agricultural practices, agricultural produce, and variant of crop to minimize pathways of contamination through food chain.
- Build capacities to conduct analyses of environmental contaminants through skill training and network of laboratories.

INTRODUCTION

Heavy metal pollution is a great concern for the environment and human health, especially in developing countries like India. Owing to their toxic, non-degradable and bio-accumulative nature, health burden on the population has increased significantly.

Heavy metals are naturally occurring hazardous metals with density greater than 4 g/cm³ (Tchounwou et al. 2012). These metals are used in several industries and agricultural activities leading to increased environmental contamination and human exposure. Due to anthropogenic activities, deep buried heavy metals in the earth’s crust have now been exposed in the air, agricultural soil and drinking water.

Various metals like chromium, aluminium and iron, are essential for various biochemical and physiological processes in plants and animals, but they can become toxic when ingested in large amounts. Heavy metals such as arsenic, lead, mercury, cadmium and uranium play no significant role in metabolism in human body and are thus toxic. Their exposure in high concentration can cause acute toxicity resulting acute health conditions, which is easy to observe and regulate while similar is not visible for immediate action when their exposure is in trace amounts over the years.
Environmental Exposure
Contamination of water, air and soil with heavy metals

Natural sources such as seepage from rocks, volcanic activities and forest fires

Anthropogenic sources like coal mining, smelting, leather tanning, and many more

Routes of human exposure

Inhalation  Ingestion  Dermal

Figure 1: Sources and modes of exposure to heavy metals
Contamination of heavy metals in India has been observed across the nation. Nearly 718 districts have contaminated groundwater with arsenic, cadmium, chromium, and lead (Mohan V 2018). Arsenic-contaminated groundwater covers major states such as Bihar, West Bengal, Uttar Pradesh, Jharkhand, Assam, Manipur, and Chhattisgarh (WHO 2019). On the other hand, polluted air and crop fields have also been reported, especially selenium toxicity, in 9% of people in Hoshiarpur and Nawansahar districts of Punjab (Jamwal 2015). Industrialization is one of the major contributors of contamination to sites like Vadodara (Gujarat), Ranipet (Tamil Nadu), Talcher (Orissa), Ratlam (Madhya Pradesh), Ganjam (Orissa), Singrauli (Madhya Pradesh), Balai (Uttar Pradesh) and Malanjkhand (Madhya Pradesh) (Dotaniya and Jayanta 2016). Ganga, the national river of India, is polluted with chromium, copper, nickel, lead, and iron (Pandey, et al. 2019). The Ministry of Environment, Forest and Climate Change (MoEF&CC) has identified 320 locations of high probability of contamination with heavy metals (Cr, Pb, Hg, As, and Cu) and pesticides in India, as represented in Figure 2.

![Figure 2: Location of the 320 probably contaminated sites in India (MoEF&CC 2015)](image)
HEALTH EFFECTS OF HEAVY METALS IN HUMANS

Heavy metals affect human health in various ways. The organ affected and the levels of severity of health conditions depend on the nature and concentration of heavy metal, duration of exposure, and route of exposure (Jaishankar, et al. 2014). The organs likely to be affected by various heavy metals are shown in Figure 3. The research studies done in India for health effects of these heavy metals are discussed in subsequent sections.

Figure 3: Health effects or organs likely to be affected by human exposure to heavy metals
INDIAN CONTEXT FOR HEALTH EFFECTS OF HEAVY METALS AND METALLOIDS IN HUMANS

I. Heavy metals

**Hexavalent Chromium (Cr (VI))**
A study was conducted in Kanpur, India, on people exposed and non-exposed to chromium-contaminated groundwater (Sharma, et al. 2012). The major health impacts among exposed people:

- gastrointestinal distress: 19.1% in controls and 39.3% in exposed population
- skin abnormalities: 6.5% in controls and 24.7% in exposed population
- eyes complaints: 7.8% in controls and 18.2% in exposed populations

**Lead (Pb)**
A study was done on 14 lead-exposed patients referred in National Referral Centre for lead poisoning in India (D’souza, et al. 2011). The study showed:

- Weakness: 93% in patients and 35.7% in controls
- signs of anxiety: 64.3% in patients and 35.7% in controls
- loss of appetite: 92.9% in patients and 42.9% in controls
- high systolic blood pressure: 57.1% in patients and 7.1% in controls
- abdominal pain: 85.7% in patients and 64.3% in controls

The Yamuna river water is contaminated with heavy metals due to discharge of treated and untreated industrial wastewaters from different sources. Thus, a study was done to estimate the lead levels in blood samples of mothers and children representing the local resident of the region. High levels of lead were observed in blood of mothers and 23% of children had blood lead levels above 10 microg/dl (limit by Centre for Disease Control) (Sehgal, et al. 2014).

**Mercury (Hg)**
Madhya Pradesh’s Singrauli, has a major site of thermal power generation, showed more than 1 µg/mg mercury in hair is 47.9% of the exposed subjects compared to 24.5% in controls of the city (Srivastava 2008). The health effects observed included:

- tremors: 8%
- abdominal pain: 41%
- respiratory problems: 38%
- gums problem: 16.8%
**Arsenic (As)**

In West Bengal’s Nadia district, water from public tube wells was reported to be contaminated with arsenic. Of the total exposed population, 15.44% had arsenicosis with skin lesions (cases) while 84.56% had no lesions (controls). Average arsenic exposure from groundwater was found to be 87.56 µg/l in cases and 64.98 µg/l in controls (Mazumder et al., 2010). The results showed:

- arsenicosis: 15.4%
- chronic lung diseases: 12.8% in cases and 0.78% in controls
- peripheral neuropathy: 15.9% in cases and 4.15% in controls

**Cadmium (Cd)**

A study on workers in jewellery workshops using cadmium and referent jewellery sales staff in Kolkata, West Bengal showed ten times higher urinary cadmium levels in exposed workers. Around 75% of the exposed workers reported respiratory tract symptoms, compared to 33% in controls. The exposed workers showed lower FVC and FEV1, thus reported a deficit in lung function than controls (Moitra, Blanc, and Sahu 2013).

**Uranium (U)**

In a study done in Malwa region, Punjab, the uranium concentration was found to be higher in the cancer patients compared to the healthy individuals (Blaurock-Busch, et al. 2014). The mean concentration of uranium in hair from breast cancer patients was 0.63 µg/g, which is six times higher than the reference range of 0.1 µg/g. Thus, uranium may be a leading factor in development of breast cancer among women in Punjab.

**II. Metals and Metalloids**

**Barium (Ba)**

The soil and dust samples in an informal e-waste recycling sector of Chandigarh and Ludhiana, India showed high levels of barium of 976 mg/kg and 529 mg/kg respectively compared to a Dutch standard value of 160 mg/kg(Singh, Thind, and John 2018). Another case study done on 27 patients admitted in hospital for barium toxicity in Chittagong Hill, Bangladesh reported stomach inflammation as a common symptom (Ghose et al. 2009). Other health effects include:

- rapid respiration: 81%
- muscle spasms and hypertension: 18%
- potassium deficiency in blood: 37%
- reduced blood supply to heart: 3%

**Aluminium (Al)**
A study done in Delhi investigated the trace elements’ levels in people with epilepsy on conventional and newer antiepileptic drugs (AEDs) (Sarangi et al. 2014).

- The aluminium levels were higher than controls in all the monotherapy groups.
- Aluminium levels were higher in all the people treated with conventional or new AEDs.
- These levels could result in aluminium accumulation and toxicity as it may interact with phosphate containing molecules and enzymes in body.

**Selenium (Se)**

Selenium toxicity was reported in 43% of subjects on soil selenium exposure in Punjab, India (Chawla, et al. 2016). Other effects include:

- dystrophic changes in nails: 42.2%
- hair loss: 40%
- garlicky odour in breath: 4.2%
- impaired organ function tests:
  - Liver: controls 6%; cases 8.5%
  - Kidneys: controls 10%; cases 14.7%
  - Pancreas: controls 4%; cases 15.7%

**Iron (Fe)**

In a study done on villagers living in close proximity to iron ore mines in Keonjhar district, Odisha, India, higher incidences of acute respiratory infections and malaria were observed (Pradhan and Patra 2014). The diseases reported in the study include the following:

- acute respiratory infection: 28.9%
- malaria: 40.9%
- water-borne disease: 14.2%
- fever: 9.5%
- typhoid: 4.1%
- blood pressure: 1.2%

**Silver (Ag)**

In e-waste recycling sites in Bengaluru, India, high concentration (61 µg/g dry wt.) of silver was found in the hair of a person engaged in silver extraction from the e-waste in backyard recycling sites in the slum areas (Ha, Agusa, and Ramu 2009).

**BIOMARKERS AND HUMAN BIO-MONITORING OF HEAVY METALS**

Bio-monitoring is a tool that can be used to assess the human exposure to various environmental agents that are capable of inducing adverse health effects in exposed...
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It can measure the chemicals and metabolites in human tissues or specimens. It relies on the biomarkers or measurable indicators of change. The human tissues commonly called “matrices”, which are extensively used in bio-monitoring of different heavy metals, include urine, blood, plasma, serum, saliva, amniotic fluids, breast milk, hair, and nails. Biomarkers have been used as surrogate measures of biological impact such as in laboratory- and field-based studies, and for bio-monitoring of the general population (Gupta, 2014).

Depending on the stability of the heavy metals or their compound(s) in the biological system, there are different biomarkers used to estimate their exposure (Table 1). For instance, in a study conducted among 100 workers of a telephone plant in Bengaluru, India, the cadmium exposure of the workers was assessed through urine samples. The level of urinary total N-acetyl-beta-D-glucosaminidase (NAG, which is a lysosomal enzyme) in urine was found to be 5.09 µg/g of creatinine in cadmium-exposed people and 2.77 µg/g of creatinine in control groups (Kalahasthi, et al. 2007). However, the incorporation of biomarkers into the environmental quantitative risk assessment of chemicals for development of regulations has been limited.

<table>
<thead>
<tr>
<th>Heavy metals</th>
<th>Biomarkers of exposure</th>
<th>Biomarkers of effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chromium VI</td>
<td>Urinary chromium, blood chromium</td>
<td>Urinary 8-hydroxydeoxyguanosine (8-OHdG) (Kuo, et al. 2003)</td>
</tr>
<tr>
<td>Lead</td>
<td>Blood lead</td>
<td>Erythrocyte zinc protoporphyrin (BZPP), urinary delta aminolevulinic acid (U-ALA) (a non-proteinogenic amino acid) and pyruvate kinase activity (Feksa, et al. 2012)</td>
</tr>
<tr>
<td>Arsenic</td>
<td>Urinary arsenic</td>
<td>Urinary inorganic arsenic (urinary arsenite, As3+ urinary arsenate, As5), urinary monomethylarsonic acid (MMA) and urinary dimethylarsinic acid (DMA) (Jansen, et al. 2015; Kile, et al. 2009)</td>
</tr>
<tr>
<td>Mercury</td>
<td>Methyl-mercury/mercury in urine, blood and hair (URL 1)</td>
<td></td>
</tr>
</tbody>
</table>

“Biomarker” is defined as a characteristic that is objectively measured and evaluated as an indicator of normal biological processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention (Biomarkers Definitions Working Group 2001).
Table 1: Various heavy metals and their biomarkers commonly used to estimate the levels of these heavy metals in humans

<table>
<thead>
<tr>
<th>Heavy Metal</th>
<th>Biomarkers in Blood and Urine</th>
<th>Biomarkers in Plasma and Serum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cadmium</td>
<td>Cadmium in blood and urine (Adams and Newcomb 2014)</td>
<td>Urinary N-acetyl-beta-D-glucosaminidase (NAG) and its isoenzymes A and B (biomarkers for renal dysfunction) (Kalahasthi, et al. 2007)</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Urinary aluminium</td>
<td>Serum neopterin (specific to bauxite dust) (Pingle, et al. 2015)</td>
</tr>
<tr>
<td>Selenium</td>
<td>Urinary selenium</td>
<td>Urinary trimethylselenonium ion (TMSe), urinary selenosugar 2 (ß-galactopyranoside isomer) (Francesconi and Pannier 2004)</td>
</tr>
<tr>
<td>Iron</td>
<td>Plasma/serum ferritin, serum transferrin (Fonseca-Nunes, Jakszyn and Agudo 2013)</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td>Silver in blood sample</td>
<td>Dopamine levels are potential biomarkers for silver nanoparticles neurotoxicity (Safari, Bidgoli, and Rezayat 2016)</td>
</tr>
</tbody>
</table>

**MITIGATION MEASURES TO MANAGE CONTAMINATION OF HEAVY METALS**

The accumulation of various heavy metals has both health and ecological implications. Therefore, there arises a need to mitigate the contamination and exposure of these heavy metals. Various conventional technological methods have been used from a long time to reduce the levels of these metals in water, soil, or air. The various mitigation measures, which can be used to prevent or reduce heavy contamination, are detailed in Box 1.
Box 1: Mitigation measures for contamination of heavy metals

**Adsorption**

*Matrix:* Contaminated water and wastewater  
*Target Metals:* Chromium (VI), Lead, Arsenic, Mercury, Selenium  
*Material used for technique:*

- Saw Dust
- Rice Hull modified with ethylenediamine
- Maize cob and husk
- Marine alga
- Nanoadsorbents like nano crystalline titanium oxide
- Charcoal
- Iron oxide coated sand

A substance is transferred from liquid phase to surface of a solid, and binds by physical and/or chemical interactions (Rodriquez, et al. 2005; Barakat 2011, WHO 2011; Anjum, et al. 2016; Lakherwal 2014).

**Reverse osmosis**

*Matrix:* Water  
*Target metals:* All heavy metals (Algureiri and Abdulmajeed 2016; Balakar, Bugel, and Gajdosova 2009)

Water is passed through a series of semi-permeable filters.
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**Photocatalytic reduction**

The acceleration of a photoreaction in presence of a catalyst (Barakat, et al. 2011).

**Matrix:** Wastewater and water (Wahyuni and Aprilita 2019)

**Target Metals:** chromium (VI) (Zheng, et al. 2015), mercury (II) (Wang, Pehkonen, and Ray 2004), lead (II) (Sreekantan, Lai, and Zaki 2014); selenium (Hoai VI 2005)

**Material used for technique:** Titanium dioxide doped with neodymium

![Neodymium](image1.png)  ![Titanium dioxide](image2.png)

**Resin- based water treatment technology**

This technique uses ion exchange resin that acts as a medium for ion exchange. They provide large surface area on and inside them and are porous. The trapping of ions occur with accompanying release of other ions.

**Matrix:** Water

**Target Metals:** Cadmium, lead, copper, silver, mercury (Azimi, et al. 2017)

**Material used for techniques:**

Resins like Duolite GT-73, Amberlite IRC-748
**Chemical Clarification**

Matrix: Water  
Target Metals: Selenium (Azimi et al., 2017)  
Material used for technique:
- Lime
- Ferric sulphate
- Aluminium Sulphate

The removal of small amounts of fine particulate solids from liquids by chemicals. This involves coagulation, flocculation and separation.

**Phytoremediation**

Matrix: Soil, water-logged soil  
**Target Metals:** Cadmium, chromium, arsenic, lead, selenium, copper, zinc, barium, nickel (Lone, et al. 2008)  
Material used for technique:
- Sunflowers
- Sunflower and mustard farming
- Chinese brake fern
- Southern cattail/cumbungi

Utilization of plants to remediate toxic chemicals found in contaminated soil, groundwater, sediment, wastewater and surface water [Rodriguez 2005]

**Phytodegradation**  
(use of plants to destroy organic pollutants)

**Phytovolatilization**  
(Conversion of metals/metalloids to less toxic and volatile forms)

**Phytostabilization**  
(degradation of organic pollutants by plant root exudates)

**Phytostimulation**

**Other practices**

Matrix: Water, soil  
**Target Metals:** Mercury, Chromium  
Materials/methods used:
- Crop rotation
- Planting non-food crops like cotton, flax etc
- Biochar
- Vermicompost
Policy Implications

In India, heavy metals and other hazardous chemicals are being used or discarded as waste in various industries like thermal power plants, mining and refineries, cosmetic industries, in poorly managed household and municipal waste, and in landfill sites. Some of the regulatory practices and policies, which can be adopted to prevent contamination of heavy metals, are listed in Table 2.

Table 2: Regulatory measures to prevent contamination of heavy metals

<table>
<thead>
<tr>
<th>Measure</th>
<th>Objective</th>
<th>Potential and Existing Ways</th>
</tr>
</thead>
<tbody>
<tr>
<td>Developing India-specific health-based standards and limits linking environment and health (Mascarenhas, A. 2019)</td>
<td>To set limits of heavy metals at a level preventing any health complication</td>
<td>The Drugs and Cosmetics Rules (1945) prohibits cosmetics containing mercury compounds. Prohibiting use of lead and arsenic in coloured cosmetics. Bureau of Indian Standards (BIS) has specified limits for heavy metals such as lead (20 ppm) and arsenic (2 ppm) in cosmetics (Ministry of Health and Family Welfare 2014). The maximum permissible limits for lead and cadmium in milk are 20 and 10 ppm, respectively (Chandrakar, et al. 2018). Develop India-specific standards for agricultural soil, irrigation water and agricultural produce (Islam, Ahmed, and Habibullah-Al-Mamun 2014). Dutch standards and WHO standards are available for soil and rice but no such standards exist for India. Reassess the drinking water standards considering the synergistic effects of trace metals and anions (Wasana, et al. 2017).</td>
</tr>
<tr>
<td>Regulations for proper disposal</td>
<td>Proper disposal of industry effluents containing high amounts of heavy metals</td>
<td>Industries can have their own treatment plants to treat contamination at source</td>
</tr>
</tbody>
</table>
Central Pollution Control Board (CPCB) has specified limits for effluents discharged in inland surface water. The limits have been set at 0.2 mg/l for arsenic, 0.01 mg/l for mercury, 0.1 mg/l for lead, 2.0 mg/l for cadmium, 0.1 mg/l for chromium (VI) and 0.05 mg/l for selenium for inland surface water. Most of the limits of heavy metals for discharge in land for irrigation are not specified (CPCB guidelines, URL 2).

<table>
<thead>
<tr>
<th>Prohibition</th>
<th>Prohibiting hazardous heavy metals</th>
<th>Lead and aluminium in cosmetics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Encouraging use of alternatives</td>
<td>If prohibition not possible, alternatives will help</td>
<td>Lead joint pipes should be replaced as they release unintended lead concentration in drinking water</td>
</tr>
<tr>
<td>Regular monitoring in different environmental compartments and population</td>
<td>To keep a check on the compliance and adherence to guidelines and standards, track trends and for timely interventions</td>
<td>Improving working conditions and gears to reduce exposure risk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Periodic monitoring of health for early detection of workers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Periodic assessment of air, water, soil and health of residents in vicinity of industries where heavy metals are disposed off</td>
</tr>
<tr>
<td>Raising awareness</td>
<td>To reduce prevalence of health conditions and associated morbidity and mortality</td>
<td>Awareness about the sources and health impacts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ways to prevent exposure at individual level</td>
</tr>
<tr>
<td>Building capacity of individuals as an objective in National Environment Policy, 2006 (Ministry of Environment and Forest 2006)</td>
<td>To emphasise on building capacity of local communities, public agencies, and academic and research community</td>
<td>Build capacities to conduct analyses of environmental contaminants through skill training and network of laboratories for building scientific evidence</td>
</tr>
</tbody>
</table>
**CONCLUSIONS**

Rapid industrialization and increasing anthropogenic activities in a developing country like India have caused severe environmental challenges and resultanty we are faced with the fatal and near-fatal results of heavy metal contamination. The limited scientific evidence proves an escalated concern over the health burdens and effects due to these metals; therefore, the current situation demands identification of environmental health risks in contaminated areas in India. Therefore, development and adoption of mitigation measures along with actionable policies are urgently needed.
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