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GIS BASED ANALYSIS OF DISTRIBUTION OF HEAVY METAL POLLUTANTS IN INDIA: SOURCES, TOXICITY AND THEIR MITIGATION

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ABSTRACT

The major heavy metals of concern for India in terms of their environmental load and health effects are lead, mercury, chromium, cadmium, copper and aluminum. Their source is mostly anthropogenic- industrial activity, vehicles, etc. Natural causes like seepage from rocks, volcanic activity and forest fires can also contribute. Geographical information system (GIS) provides a platform in which attributes data related with heavy metals pollutants can be integrated with spatial data. In this study, ARC GIS-10.3 software is used for data integration and analysis. Minerals like fluoride and arsenic salts are of natural origin, but human activity can also aggravate the situation. The toxic chemicals are discharged by industries into air, water and soil. Once they enter our biological system they disturb the biochemical processes. In the present study, state wise distribution of heavy metals like Chromium (Cr), Lead (Pb), Mercury (Hg), Copper (Cu), Arsenic (As) and Fluoride (F) were identified in India. These chemicals presumably pose the problems of health hazards, so that it is necessary to exercise strict control on those which offer the most serious threats during manufacturing and handling. In general heavy metal toxicity can cause chronic degenerative diseases the symptoms being mental disorders, pain in muscle and joints, gastro intestinal disorders, vision problems, chronic fatigue, and susceptibility to fungal infections. Sometimes the symptoms are vague and difficult to diagnose at early stage. Industrial workers and populations living near the polluting industry are more susceptible and have to be monitored. Malnourished people and pregnant women are vulnerable.

KEY WORDS: Heavy metals, Toxic chemicals, GIS, Degenerative diseases, Health hazards.

INTRODUCTION

The metals, having specific weight more than 5.0 g/cm^3, are defined as heavy metals and categorized into three classes: toxic metals (e.g. Hg, Cr, Pb, Zn, Cu, Ni, Cd, As, Co, Sn, etc.), precious metals (e.g. Pd, Pt, Ag, Au, Ru, etc.) and radionuclides (e.g. U, Th, Ra, Am, etc.) (Nies, 1999, Bishop, 2000 and Ahemad, 2014). Heavy metals are considered serious pollutants not only because of their persistence and non-degradability in the environment but also because most of them have toxic effects on living organisms when they exceed a certain concen-tration (Nriagu and Pacyna, 1988; Enserink *et al.*, 1991). Both atmospheric and other, more direct, me-tal inputs are historically recorded worldwide in the sediments of lakes and rivers which have experienced significant human influence (Nriagu *et al.*, 1979, Dominik *et al.*, 1983 and Ca-rignan *et al.*, 1994). Natural lakes and reservoirs have probably been most impacted by point source discharges since wastewater releases to flowing water are most common all over the world. Most heavy elements or heavy metals con-cern researchers because of environmental or human exposure, however 10 of them (As, Cd, Cr, Cu, Hg, Ni, Pb, Sb, Sn and Zn) are of major interest in bioavailability and toxicology studies because of the potential for increased environ-mental and health risk (McKinney and Rogers, 1992). The toxicity of heavy metal is a great concern for the environmentalists due to very low degradability and high persistence capacity in the environment (Ahemad, 2012). Toxicity of the metals varies according to their concentration or nature of the element. Some of the heavy metals display toxicity even at the concentration (1.0–10 mg/L). The elements Hg and Cd ions show toxicity at the concentration of 0.001–0.1 mg/L. whereas some elements change their nature in the changing environment (Alkorta *et al.*, 2004; Wang and Chen, 2006). Although metals and metal compounds are natural constituents of all ecosystems, moving between atmosphere, hydrosphere, lithosphere, and bios-phere (Bargagli, 2000). It is widely accepted that heavy metal contamination in sediment, soil, and groundwater is one of the largest threats to environmental and human health (Salomons and Förstner, 2012). It has been estimated that the anthropogenic industries and domestic sources enhances the emissions level of lead, cadmium, vanadium, and zinc up to 100 fold. The exceeding level of these heavy metals pose serious health and ecological risks (Gomathy and Sabarinathan, 2010). Currently the levels of some heavy metals in the environments are increasing, and it reaches up to the level of toxicity. The industrialization of fertilizer, pesticide, metallurgy industry, combustion of fossil fuels, directly or indirectly released huge amounts of toxic metals into the environment resulting hazardous impacts on both ecological and human health (Chibuike and Obiora, 2014 and Carlos *et al.*, 2016). However, understanding distribu-tion of pollutants is critical for the environmen-tal management and decision-making (Liu *et al.*, 2006) and spatial distribution of metals in se-diments is among the most essential informa-tion for environmental research (Marvin *et al.*, 2002).

STUDY AREA

India is a country of great geographical extent. It sprawls from the snowy ranges of the Himalayas in the north to the shores of Indian Ocean in the south. It belongs to Asia which is the largest continent of the world. It forms a part of south Asia and is separated by the Himalayas from the rest of the continent. It encompasses vast areas of diverse landmasses. In the north are the lofty Himalayas, parts of which are permanently ice-covered. To the south of Himalayas is the Great Indo-Gangetic Plain which is well-known for its fertile soils. India extends from 8^{0} 4' north to 37^{0} 6' north latitude and 68^{0} 7' east to 97^{0} 25' east longitude. Thus, its latitudinal and longitudinal extent is about thirty degrees. Away from the main land of India, the southernmost point of the country in the Andaman and Nicobar Islands, the Pygmalion Point or Indira Point is located at 6^{0} 45' north latitude. Its north-south extent from Indira Col in Kashmir to Kanniyakumari is 3,214 km while its east-west width from the Rann of Kachachh to Arunachal Pradesh is 2,933 km (Fig. 1). The latitudinal extent of India is about one-third the angular distance between the equator and the North Pole and its longitudinal extent is about one-twelfth of circumference of the equator. The longitudinal difference between Saurashtra in the west and Arunachal Pradesh in the east is about 30^{0}. With an area of 32, 87,263 sq. km India is the seventh largest country of the world. India accounts for about 2.4 per cent of the total surface area of the world. Many of the Indian states are larger than several countries of the world. India shares her 15,200 long land frontier with Pakistan, in the west and north-west. Afghanistan in the north-west, China, Nepal and

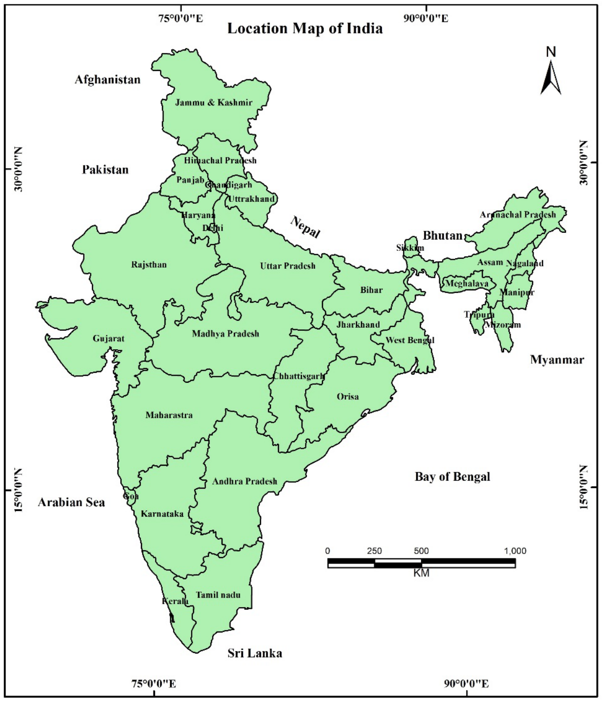

Fig. 1.

Bhutan in the north, and Bangladesh and Myanmar in the east. India's longest border is with Bangladesh while the shortest border is with Afghanistan.

Distribution of Heavy Metals (Cr, Pb, Hg and Cu)

Distribution of heavy metals is a result of heavy metals accumulation and migration under combining influence of edaphic factors and environmental conditions. With rapid industrialization and consumerist life style, anthropogenic sources of environmental pollution have increased. The pollution occurs both at the level of industrial production as well as end use of the products and run-off. Ash dumps from thermal power plants, contain many polluting metals and complexes, which are carried to nearby water bodies and ground water. According to the survey report of CPCB, distribution of heavy metals contaminated sites like Chromium (Cr) is found to be in Ranipet (Tamil Nadu), Kanpur (Uttar Pradesh), Vadodara (Gujarat) and Talcher (Orissa). Lead (Pb) distribution is found to be in Ratlam (Madhya Pradesh), Bandalamottu Mines (Andhra Pradesh), Vadodara (Gujarat) and Korba (Chattisgarh). Mercury (Hg) distribution is found to be in Kodaiknal (Tamil Nadu), Ganjam (Orissa) and Singrauli (Madhya Pradesh). While Copper (Cu) distribution is found to be in Tuticorin (Tamil Nadu), Singbhum Mines (Jharkhand) and Malanjkhand in Madhya Pradesh (Fig. 2).

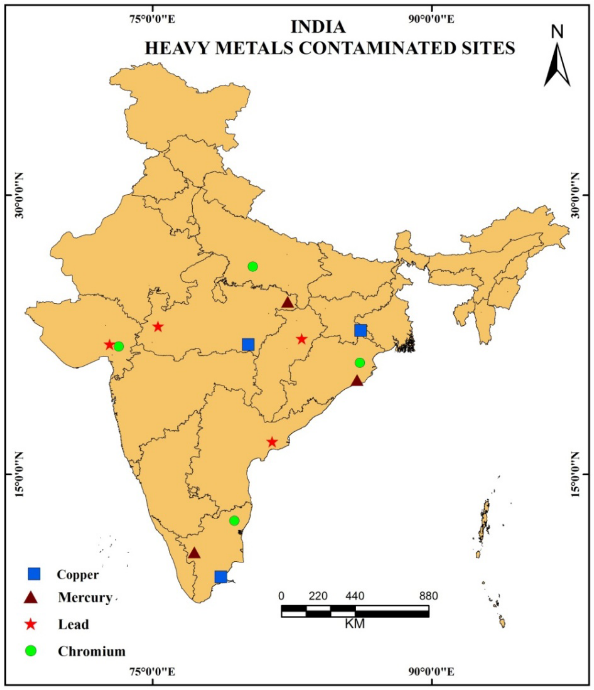

Fig. 2.

Distribution of Arsenic (As)

Exposure to arsenic via drinking water, air, food, and beverage has been reported occurring at many places in the world. In India exposure through drinking water is increasing due to contamination from industrial operation and over withdrawal of groundwater for irrigation. Arsenic contamination in groundwater in the Ganga- Brahmaputra fluvial plains in India and Padma-Meghna fluvial plains in Bangladesh and its consequences to the human health have been reported as one of the world's biggest natural groundwater calamities to the mankind. In India, since the groundwater arsenic contamination was first surfaced from West-Bengal in 1983, a number of other stateshave so far been reported affected by Arsenic contamination in groundwater above the permissible limit. Eight states namely Uttar Pradesh, Bihar, Jharkhand, Chhattisgarh, West Bengal, Gujarat, Assam and Manipur were highly affected due to arsenic contamination in ground water. Eleven states namely Punjab, Haryana, Delhi, Rajasthan, Madhya Pradesh, Maharashtra, Orissa, Andhra Pradesh, Karnataka, Kerala and Tamil Nadu were moderately affected while ten states namely Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh, Nagaland, Mizoram, Tripura,

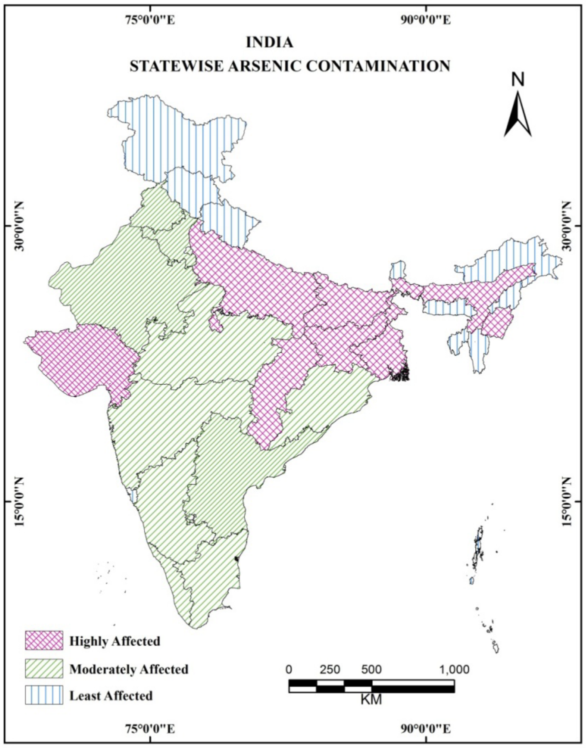

Fig. 3

Meghalaya and Goa were least affected due to arsenic contamination in ground water (Fig. 3).

Distribution of Fluoride (F)

The world's fluoride stores in the ground are estimated to 85 million tons. Out of which nearly 12 million tons are located in India. A large population in India is very severely affected by fluorosis. More than 15 states are affected by endemic fluorosis in India. Fluoride is a widespread, non- biodegradable and relatively persistent pollutant, which at low levels of contamination cause serious health problems difficult to cure. Fluoride pollution in India is mainly due to natural sources reported so far. Its concentration in water is much higher than the recommended values by different authorities. Three states namely Rajasthan, Gujarat and Andhra Pradesh were highly affected due to fluoride contamination in ground water. Twelve states namely Uttar Pradesh, Bihar, Assam, West Bengal, Jharkhand, Orissa, Chhattisgarh, Madhya Pradesh, Maharashtra, Karnataka, Tamil Nadu and Kerala were moderately affected while fourteen states namely Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Punjab, Haryana, Sikkim, Delhi, Arunachal Pradesh, Nagaland, Manipur, Mizoram, Tripura, Meghalaya and Goa were least affected due to fluoride contamination in ground water (Fig. 4).

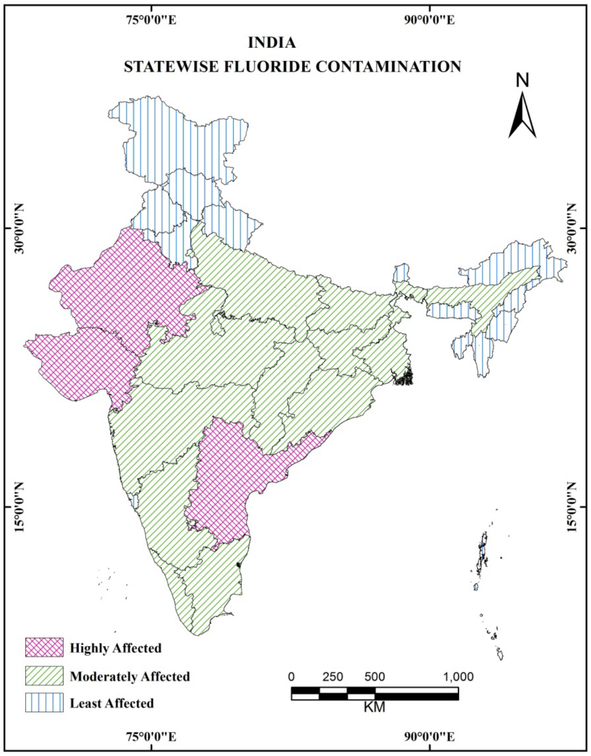

Fig. 4.

Toxicity Due to Heavy Metals

The biotoxic effects of heavy metals refer to the harmful effects of heavy metals to the plants and animals when consumed above the bio recommended limits. Although individual metals exhibit specific signsof their toxicity.

Chromium (Cr)

Chromium compounds used in industrial applications for various purposes has discharged huge amounts of toxic chemicals into water bodies. Chromium enters into the environment both by natural sources and anthropogenic sources. Chromium is known to be a toxic metal that can cause serve damage to plants and animals. Chromium induced oxidative stress involves induction of lipid peroxidation in plants that causes severe damage to cell membranes. High levels of exposurecause liver and kidney damage, skin ulceration and also affects the central nervous system. Oxidative stress induced by chromium initiates the degradation of photosynthetic pigments causing decline in growth. High chromium concentration can disturb the chloroplast ultra-structure there by disturbing the photosynthetic process. Since seed germination is the first

Table 1. Sources of Heavy Metals

Heavy Metal	Sources
Chromium (Cr)	Mining, industrial coolants, chromium salts manufacturing, leather tanning
Lead (Pb)	Lead acid batteries, paints, E-waste, Smelting operations, coal- based thermal power plants, ceramics, bangle industry
Mercury (Hg)	Chlor - alkali plants, thermal power plants, fluorescent lamps, hospital waste (damaged thermometers, barometers, sphygmomanometers), electrical appliances etc.
Copper (Cu)	Mining, electroplating, smelting operations
Arsenic (As)	Geogenic / natural processes, smelting operations, thermal power plants, fuel burning.
Fluoride (F)	Natural geological sources, industrial waste, water additive

Source: CPCB, New Delhi

physiological process affected by Cr, the ability of a seed to germinate in a medium containing Cr would be indicative of its level of tolerance to this metal. Chromium decreases enzyme activity and plant growth; produces membrane damage, chlorosis and root damage.

Lead (Pb)

It may be noted that most of the Pb intake by a typical city dweller is from diet (about 200 to 300 μg per day), air and water adding a further 10-15 μg per day each. Of this total intake, 200 μg of Pb is excreted while 25 μg is stored in the bones each day. Most of the studies looking for a possible link between lead exposure and cancer have focused on workers with high levels of occupational (work-related) exposure to inorganic lead. Lead is extremely toxic and shows toxicity to the nervous system, kidneys and reproductive system. Exposure to lead causes irreversible brain damage and encephalopathic symptoms. People with heavy workplace exposures to lead have been found to have blood lead concentrations many times higher than the average blood lead concentration in the general population. It can enter the body through ingestion and˙inhalation. Its maximum allowable levels may be 5 μg/L (in bottled water) to set elemental impurities limit. It can cause disruption of biosynthesis of Hb, anemia, high B.P., kidney damage, reproductive/fertility problems and brain or nervous system damage.

Mercury (Hg)

Mercury is a very toxic element in its organic form and has been the cause of Minamata disease in Japan. Is approx. 200 people died of poisoning with mercury compounds contained in fish. Mercury was there because of the factory, which was seeing directly into the water. Mercury vapor can cause severe poisoning and even death. It shows toxicity to the physiology of animals and human beings. Its prevalence in environment can lead to bio magnifications in food chain. The impact of seed dressing is enormous since it is applied to a large volume of seed, which is subsequently sowed over millions of acres, thereby causing a widespread of Hg compounds. Furthermore, Hg undergoes translocation in plants and animals and then finds its way into the human food chain. The organic Hg, such as methyl Hg, is more toxic than inorganic Hg due to ease of absorption into human system. The exposure to mercury causes toxicity to the brain, blindness, mental retardation. In the living organism causes severe agitation, tremor, blurred vision, hearing and speech, kidney damage, and in severe poisoning coma, DNA and chromosomal damage, allergic reactions, sperm damage, birth defects and miscarriages. Mercury alsodecreases photosynthetic activity, water uptake and antioxidant enzymes; accumulates phenol and proline.

Copper (Cu)

The Recommended Daily Allowance (RDA) of copper for adults is 0.9 milligrams (mg). The median intake of copper from the typical U.S. diet ranges from 1 to 1.6 mg/day. The safe highest level of intake for an extended period of time (chronic exposure) is 10 mg/day. Copper, as an essential trace element, is required by biological systems for the activation of some enzymes during photosynthesis but at higher concentrations it shows harmful effects on the human body. In humans, the Cu is essentially needed but in high doses, anemia, liver and kidney damage, and stomach and intestinal irritation may occur. High-level exposure of copper dust causes nose, eyes and mouth irritation and may cause nausea and diarrhea. Copper is also toxic to a variety of aquatic organisms even at very low concentrations. Copper is an essential metal for normal plant growth and development, although it is also potentially toxic. Copper is considered as a micronutrient for plants and plays important role in CO_2 assimilation and ATP synthesis. Excess of Cu in soil plays a cytotoxic role, induces stress and causes injury to plants. This leads to plant growth retardation and leaf chlorosis.

Arsenic (As)

The three major biochemical actions of Arsenic are coagulation of proteins, complexation with co-enzymes and uncoupling of phosphorylation. Arsenic enters into the human body through ingestion, inhalation, or skin absorption. After entering into the body it is distributed in a large number of organs including the lungs, liver, kidney and skin. In certain areas the concentration of arsenic may be higher than its normaldose and creates severe health hazards to human beings and animals. The toxicity of arsenic as a result of the contamination of groundwater bodies and surface waters is of great concern. Arsenic groundwater contamination has far-reaching consequences including its ingestion through food chain. Water-soluble inorganic as is readily absorbed from digestive system. Inorganic forms of as are particularly toxic. It causes irritation to lung, stomach and intestine, skin disturbances, and decreased formation of RBCs and WBCs. Arsenic in rice reduces seed germination, decrease in seedling height, and reduces leaf area. Very high concentrations of inorganic as can cause infertility, skin disturbances, decreased resistance to infections, heart disruptions, brain damage. Increased risks of lung and bladder cancer and of arsenic-associated skin lesions have been reported to be associated with ingestion of drinking-water at concentrations 50 μg arsenic/litre. Occupational exposure to arsenic, primarily by inhalation, is causally associated with lung cancer.

Fluoride (F)

The daily intake of F from food and drinking water is usually less than 1 ppm. Fluoride in diet or drinking water above 1.5 ppm causes fluorosis. Fluoride is a widespread, non- biodegradable and relatively persistent pollutant, which at low levels of contamination causes serious health problem. Its concentration in waters is much higher than the recommended values by different authorities.The maximum tolerance level in human body is 1.5 ppm (WHO standard). On the other hand in India levels above 1 ppm are considered unsafe. Fluoride concentrations beyond the standards cause dental and skeletal fluorosis. Chronic ingestion of fluoride-rich fodder and water in endemic areas leads to development of fluorosis in animals. Fluoride toxicity can be acute due to exposure to a single massive dose, as happens with industrial workers (industrial fluorosis) or chronic (endemic fluorosis) due to continuous ingestion of water and food containing high amounts of fluoride. Endemic fluorosis is a serious problem in many parts of India. In endemic areas, large percentage of people suffer from gastrointestinal complaints, diarrhea etc.

Mitigation of Heavy Metal Pollution

Biotoxic effects of heavy metals, when unduly exposed to them could be potentially life threatening hence, cannot be neglected. While these metals are in many ways indispensable, good precaution and adequate occupational hygiene should be taken in handling them. Although heavy metal poisoning could be clinically diagnosed and medically treated, the best option is to prevent heavy metal pollution and the subsequent human poisoning. To mitigate the negative impacts of heavy metals on the health of humans, animals and the environment, a variety of remediation processes exists. These remediation processes are broadly classified into chemical and biological, although the latter is advocated in recent years. Biological remediation processes (microbial remediation and phytoremediation) are indicated to be very effective in the treatment of heavy metal pollutants in wastewater. Microbial remediation is the restoration of the environment and its quality using microorganisms, such as bacteria, fungi, protozoan and algae while phytoremediation is the use of plants to degrade or accumulate toxic metals, thereby leading to a reduction in the bioavailability of the contaminant in the soil or water. In areas where water has high load of arsenic and fluoride, alternative sources- (canal water, rain water harvesting) would have to be provided not only for drinking water but also for farming. Technologies for de-fluoridation of drinking water have been developed. Besides this the responsibility of Management is to ensure that the right technologies are adopted and monitor the end result. Regulations are in place to regulate the release of toxic metals in the environment to ensure safety and health of the workers as well as the public in general. Recycling of wastes containing toxic metals needs to be givengreater emphasis not only from environmental and health considerations butalso as a resource conservation measure. Monitoring of air, water and soil in the vicinity of the toxic metal processingunits needs to be carried out more rigorously for the specific metal. Dumping sites and process wastes lying in locations close to the processing units need to be remediated on priority. Supply of surface water from ponds, rivers etc. for drinking purposes through pipe network system after suitable purification by conventional method of treatment viz. coagulation, flocculation, rapid sand filtration and disinfections, as an alternate option, have been put into practice in some places by the State Government.

CONCLUSION

It is evident from the present study, which was aimed at discussing the distribution, sources, toxicity and mitigation processes for heavy metals pollution in India. Two main sources of heavy metals in study area are natural and human, with the natural factors being soil erosion, urban run offs and aerosols particulate while the human factors include metal finishing and electroplating processes, mining extraction operations, textile industries and agriculture fertilizers. Untreated or inadequately treated heavy metal poses a variety of health and environment impacts to humans, animals and plants. In aquatic ecosystems, heavy metals greatly depress the number of living organisms. Also, heavy metals have negative effect on the growth of aquatic organisms and can cause serious problems in biological cycle. Bioaccumulation of heavy metals in food chains and their toxicity to biological systems due to increased concentration over time have led to tremendous pressure for their separation and purification. There are various remediation technologies that have been used for the removal of heavy metals these are Ion exchange, Membrane filtration, Bioremediation, Heterogeneous photocatalysts, Adsorption, Precipitation and coagulation. In areas where water has high load of arsenic and fluoride, alternative sources- (canal water, rain water harvesting) would have to be provided not only for drinking water but also for farming. Technologies for de-fluoridation of drinking water have been developed. Besides this the responsibility of Management is to ensure that the right technologies are adopted and monitor the end result. In India, a large number of industries in unorganized sector contribute to a great deal of heavy metal pollution and there is no Treatment, Storage and Disposal Facilities is available. So there is need of industries should have their own treatment plants and discharge waste in to sewers after treatment.

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