J. Hortl. Sci.
Vol. 3 (1): 1-29, 2008

FOCUS

Environmental risks associated with heavy metal contamination in soil, water and plants in urban and periurban agriculture

A. N. Ganeshamurthy, L. R. Varalakshmi and H. P. Sumangala[1]
Division of Soil Science and Agricultural Chemistry
Indian Institute of Horticultural Research
Hessaraghatta Lake Post, Bangalore-560 089, India
E-mail: angmurthy@rediffmail.com

ABSTRACT

The India's population living in cities and urban areas has doubled to 27.8% since Independence. Our cities face enormous challenges of environmental pollution and health related problems. City authorities have often been reluctant to accept urban and periurban agriculture because of perceived health risks. Nevertheless, in most cities the world over, periurban agriculture is practiced on a substantial scale, despite prohibitive laws and regulations. Non-degradable pollutants added to the system through anthropogenic activities like heavy metals in air, soil, water and crops bother us more than others as these tend to bioaccumulate. Throughout history, heavy metal contamination has long plagued mankind - undermining intelligence and causing debasing behaviour. Toxicity of some of the heavy metals even leads to deficiency of essential metals like Zn, Cu, etc. in both human and animals. Climate, nutritional status, genetic predisposition, type of work and exposure level influence the intensity of impact on health. Permissible levels prescribed by different organizations differ because of differences in tolerance levels of people of different origins and differences in threat perception of the people. With our current level of knowledge a permanent and foolproof method to stop entry of heavy metals into the food chain is impossible. However, methods are available to reduce intensity of the effects. Alternative land use with crops not directly consumed by humanbeings and animals offers a better remedy to contain heavy metal entry into food chain. India has a wide ranging set of environmental laws that lay down norms for air, water, soil, wastes, etc. Legislative frame work has been developed in the belief that a policing model is sufficient. It does not go beyond that. Regulatory mechanisms may not be effective in isolated cases but are essential drivers to augment other approaches, by putting a "cap" on the level of degradation that is socially acceptable, as well as creating space for other, cleaner and more acceptable alternatives to be "viable".

Key words: Environmental risk, Heavy metal contamination, Periurban agriculture.

INTRODUCTION

With rapid pace of urbanization, the percentage of India's population living in cities almost doubled to 27.8 % in 2001 from 14% at the time of Independence. This is expected to accelerate even further and, by 2021, over 40 % of all Indians will be living in urban areas. The scale of urbanization in India can be seen in 6 mega cities (>5 million), 29 metro cities (>1 million), 500 cities (>100,000). By 2011, urban India will contribute over 65% to Indian GDP. Indian cities provide a setting for economic growth and, at the same time, face enormous challenges, particularly, environmental pollution and health-related problems. Pollution is defined as "Introduction by man into the environment of substances or energy liable to cause hazards to human and animal health, living resources and ecological systems, damage to structures or amenity or interference with the legitimate use of environment" (Holdgate, 1979). Contamination, on the other hand, refers to anthropogenic accumulation of substances which may or may not inflict harm. Thus, pollution is an extreme case of contamination where toxicity-damage has already occurred. Pollution in cities and other industrial pockets has a profound influence on agricultural lands in urban and periurban areas and consequential effect on the health of human residing in such areas. Several pollutants affect human and animal health. However, non-degradable pollutants like heavy metals bother us much more than others. Throughout history, heavy metal contamination has plagued mankind - undermining

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[1] Division of Ornamental Crops

intelligence and inducing debasing behaviour. Only now we are beginning to understand how heavy metals damage the brain. Toxicity of some of the heavy metals leads to deficiency of essential metals like Zn, Cu, etc. in both human and animals. For example excess molybdenum induces Cu deficiency in animals. This paper reviews the current status of heavy metal pollution in urban and periurban areas.

Urban and Periurban Agriculture (UPA)

UPA refers to the production of a range of food crops, fodder, vegetables, aromatic plants, medicinal plants, flowers, ornamental plants, fruit trees and mushrooms, rearing of fish, poultry, meat and dairy animals grown mainly in intensive production systems with high levels of inputs located in the city or at its close periphery where there is competition for access to land between agricultural and other human activities, the products of which are consumed in the city (Ganeshamurthy, 2007). The acute shortage of water for irrigation gives rise to use of alternative sources in UPA. In urban areas, city waste- water is the main source for irrigating UPA lands. City solid - wastes and sewage sludge are often used as manure in UPA. Effluents and sludge contain concentrations of metals and other organic toxic substances that may impact human health, due to ingestion of food produced in areas receiving sewage sludge and irrigated with waste-water or contaminated surface waters. There are many studies on the possible effects of chemical substances on human through laboratory experiments in animals and information is available on incidence of cancer by prolonged exposure to toxic substances. Experiments in plants and insects (*Drosophila*), demonstrate that toxic substances of chemical origin induce genetic mutations and chromosome aberrations (Maria Luisa de Esparza, 1998). These experiments demonstrate that there does exist a risk, which is not simple to extrapolate to human beings. Theoretically, waste-water of industrial origin should not be used for this purpose, but in many countries, formal and clandestine industries dispose off effluents into municipal sewerage with or without authorization and without any treatment. This exposes the population, perpetually to relatively small quantities of metals, chemical compounds and may produce chronic intoxication with serious consequences. Another health hazard posed by inadequate disposal of waste-water is that sediments are used for soil improvement and these may contain toxic elements which may accumulate.

Environmental impact of chemical residues in waste-water and solid wastes used in UPA and the prediction of their effects on human health is a very complex matter. In addition, it should be recognized that standards of safe levels in developed countries do not apply to areas with different characteristics. Factors that influence nature and intensity of the impact on health are: climate, nutritional status, genetic predisposition, type of work and exposure level. Racial differences in tolerance are anybody’s guess.

Identification/confirmation of adverse effects of UPA is difficult because epidemiological studies last long, populations migrate, and exposure time is unknown. In addition, chronic diseases can have various causes and, in many cases, these are not classified correctly. Unfortunately, there is no statistical information on trends and causes of diseases owing to ingestion of chemical substances from agricultural and livestock products. However, several studies have demonstrated absorption of heavy metals by plants and these can affect the consumer (WHO, 1992). The nature of human health hazards caused by exposure to heavy metals and other toxic chemical compounds varies considerably. It is long known that heavy metal contamination has plagued mankind, undermining intelligence and causing debasing behaviour. In general, it increases birth defects, abortions and some forms of cancer and decreases average weight of children at birth. Only now we are beginning to understand how heavy metals damage the brain. The relationship between the so called life style diseases (cardiovascular disease, diabetes, obesity, fatigue to small physical work, hair loss, etc) in urban populations and consumption of contaminated vegetables and fruits produced in UPA is an area that has not received adequate attention of researchers.

It is essential to address health risks associated with UPA for two main reasons (Flynn 1999): i) To protect consumers from contaminated foods and farm workers from occupational hazards; and ii) To secure support of municipal and national authorities for sustainable urban food production. City authorities have often been reluctant to accept UPA because of perceived health risks. Nevertheless, in most cities the world over, urban agriculture is practiced on a substantial scale despite prohibitive laws and regulations. Rather than general laws that prohibit UPA and which are largely ineffective, policies are needed to actively manage health risks related to UPA.

Health risks associated with UPA

Birley and Lock (1999) extensively reviewed literature on health issues related to UPA. The main health risks associated with urban agriculture can be grouped into following categories:

a. Contamination of crops by uptake of heavy metals from contaminated soil, air or water

b. Occupational health risks to farmers in UPA and workers in the food-production and food-processing industries

c. Contamination of crops and/or drinking water by residues of agrochemicals

d. Contamination of crops with pathogenic organisms (e.g. bacteria, protozoa, viruses or helminthes) due to irrigation water drawn from polluted streams, or, inadequately treated waste-water or organic, solid waste products

e. Human diseases transferred from disease vectors attracted by agricultural activity

f. Transmission of disease from domestic animals to people (zoonosis) during animal husbandry, processing or meat consumption

g. Human diseases associated with unsanitary post-harvest processing, marketing and preparation of locally produced food

Review of available literature indicates that although insight into potential health risks of UPA is growing, detailed information on actual health impact of UPA is scant. This review concentrates only on issues of heavy metal pollution.

Unlike other contaminants, contamination of crops by uptake of heavy metals from contaminated soils, air or water is of special interest because once these heavy metals enter the system, these remain forever without undergoing any change. These are further dangerous as they tend to bioaccumulate. Bioaccumulation refers to an increase in concentration of a metal in a biological organism over time, compared to its concentration in the environment. Metals accumulate in living beings any time they are ingested and stored faster than they are excreted, and, are reported to be exceptionally toxic (Ellen *et al***,** 1990).

Heavy metals

These are generally defined as “a group of toxic metals and metalloids associated with pollution and toxicity, having density of more than 6 Mg m^{-3} and having atomic weight more than that of iron (Alloway, 1990). There are 35 metals that concern us because of occupational or residential exposure; 23 of these are heavy elements or “heavy metals”: antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc. Interestingly, small amounts of these elements are common in our environment and diet and are actually necessary for good health, but large amounts of any of them may cause acute or chronic toxicity (poisoning).

Health hazards associated with heavy metals

By definition, many of the human and plant essential elements fall under the group of heavy metals. All the micronutrient cations Zn, Cu, Fe, Mn and Ni are classed as heavy metals and, depending upon their levels in plant and animals, they exhibit either deficiency or toxicity. In addition Pb, Cd, Cr, Hg, Se and As are the other heavy metals and metalloids which exhibit only toxicity (not deficiency) in human beings, animals and plants. Heavy metals become toxic when they are not metabolized by the body and accumulate in soft tissues. Oliver (1997) compiled data (Table 1) on permissible levels of heavy metals in human diet, along with impact of both deficiency and toxicity on human health. The danger lies in the fact that once heavy metals enter into the soil-plant-animal continuum, their removal is extremely difficult and expensive.

Lead (Pb)

Lead accounts for most of cases of pediatric heavy metal poisoning (Roberts, 1999). It is a very soft metal and was used in pipes, drains, and soldering materials for many years. Millions of homes still contain lead (e.g., in painted surfaces), leading to chronic exposure from weathering, flaking, chalking and dust. Vegetables and fruits grown in areas adjacent to highways and in periurban areas and those receiving Pb containing pesticides accumulate Pb. Target organs are bones, brain, blood, kidneys and thyroid gland. Chronic exposure to Pb may result in birth defects, mental retardation, autism, psychosis, allergies, dyslexia, hyperactivity, weight loss, shaky hands, muscular weakness and paralysis (beginning in the forearms). Children are particularly sensitive to lead (absorbing as much as 50% of the ingested dose).

Mercury (Hg)

Mercury is generated naturally in the environment from degassing of earth’s crust from volcanic emissions. It exists in three forms: elemental, organic and inorganic mercury. Mining operations, chloralkali plants and paper industries are significant producers of mercury (Goyer, 1996). Atmospheric mercury is dispersed across the globe by winds and returns to the earth in rainfall, accumulating

Table 1. Limits of deficiency and toxicity of metals in human and their impact on human health

Element	Recommended safe intake	Impact on health due to deficiency	Toxic limits	Impact on health due to toxicity
Arsenic	15-25 μg d^{-1} (adult)	-	3 mg d^{-1} for 2-3 weeks	Cancer of skin and internal organs, hyperkeratosis, hyperpigmentation, black foot, rashes
Cadmium	Maximum tolerable intake 70 μg d^{-1} Children 2-25 μg d^{-1} Adults 15-50 μg d^{-1}	—	220 μg kg^{-1} fresh weight	Renal tubular disfunction, proteinuria, glucosuria, aminoaciduria, itai-itai disease
Chromium	50-200 μg d^{-1}	Cardiovascular disease	—	—
Copper	Children 40μg d^{-1} Infants 80 μg d^{-1} Adults 2 μg d^{-1}	Hypocupremic anaemia neutropenea, leucopenia Hypopigmentation of hair and skin, coronary heart disease, arthritis	Children 150 mg d^{-1} Adults 12 mg d^{-1}	—
Lead	Children 9- 278 μg d^{-1} Adults 20-282 μg d^{-1}	—	≥500 μg d^{-1} Concentration in blood in children 250-500 μg L^{-1}	Encephalopathy(damage to brain), failure in reproduction, metabolic disorder, neurophysical deficit in children, affects the haematologic and renal systems
Selenium	100-200 μg d^{-1}	Kashin Beck disease Keshan disease	9 mg d^{-1}	Persistant adverse clinical signs developed with as high as 50% morbidity
Zinc	Deficient 0.2-0.3 mg d^{-1} Safe intake 15 μg d^{-1} Recommended upper limit 45 μg d^{-1}	Hypogonadism, dwarfism, hepatosplenomegaly, geophagia, anaemia, premature birth, anorexia	150 μg d^{-1}	Interference with reproduction, growth of embryo impaired

in soil, aquatic food chains and fish in lakes (Clarkson, 1990). Mercury compounds were added to paint as a fungicide until 1990. These compounds are now banned; however, surfaces painted with these old supplies still exist. The organic form is readily absorbed by the gastrointestinal tract (90-100%); lesser but still significant amounts of inorganic mercury are absorbed by the gastrointestinal tract (7-15%). Target organs are brain and kidneys (Asami 1981, Roberts 1999). Symptoms of acute exposure are cough, sore throat, shortness of breath, metallic taste in the mouth, abdominal pain, nausea, vomiting and diarrhea, headache, weakness, visual disturbance, tachycardia and hypertension. Chronic exposure to mercury may result in permanent damage to the central nervous system (Ewan *et al*, 1996) and kidneys. Mercury can also cross the placenta from the mother's body to the fetus (levels in the fetus are often double those in the mother) and accumulate, resulting in mental retardation, brain damage, cerebral palsy, blindness, seizures and inability to speak. Symptoms in adults and children include tremors, anxiety, forgetfulness, emotional instability, insomnia, fatigue, weakness, anorexia, cognitive and motor dysfunction and kidney damage. Those who consume more than two fish meals a week have been known to show very high levels of mercury in serum.

Cadmium (Cd)

Cadmium is a by-product of mining and smelting of lead and zinc. It is used in nickel cadmium batteries, PVC plastics and paint pigments. It can be found in soils because insecticides, fungicides, sludge and commercial fertilizers containing cadmium are used in agriculture. Cadmium may be found in reservoirs containing shellfish. Cigarettes also contain cadmium. Lesser-known sources of exposure are dental alloys, electroplating, motor oil and exhaust. Inhalation accounts for 15-50% of absorption through the respiratory system; 2-7% of ingested cadmium is absorbed in the gastrointestinal system. Target organs are liver, placenta, kidneys, lungs, brain and bones (Roberts, 1999). Symptoms of acute cadmium exposure include nausea, vomiting, abdominal pain and breathing difficulty. Chronic exposure to cadmium can result in chronic obstructive lung disease, renal disease, fragile bones, alopecia, anemia, arthritis, learning disorders, migraines, growth impairment, emphysema, osteoporosis, loss of taste and smell, poor appetite and cardiovascular disease.

Chromium (Cr)

Cr (VI) compounds are emitted into the air, water and soil by a number of different industries. In the air, chromium compounds are present mainly as fine dust particles that eventually settle over the land and water and finally enter the plants. Workers who breathe hexavalent chromium compounds at their jobs for many years may be at increased risk of developing lung cancer. Breathing high levels of hexavalent chromium can irritate or damage the nose, throat and lungs. Irritation or damage to the eyes and skin can occur if hexavalent chromium contacts these organs in high concentrations or for a prolonged period of time.

Nickel (Ni)

It enters the human body through inhalation, ingestion of drinking-water and food, and through skin contact. Tobacco smoking is also an important source of nickel exposure. The relative amounts of nickel absorbed by an organism are determined not only by the quantities inhaled, ingested, or administrated, but also by physical and chemical characteristics of the nickel compound. Solubility is an important factor in all routes of absorption, following the general relationships: nickel carbonyl absorption> soluble nickel compounds absorption> insoluble nickel compounds absorption. Nickel carbonyl is the most rapidly and completely absorbed nickel compound in both animals and human. Nickel and nickel compounds have a strong sensitizing potential on the skin, which is manifested by irritation, eczema and allergic contact dermatitis. Oral intake of low doses of nickel may provoke allergic dermatitis in sensitized individuals. Besides the carcinogenic effect on lung and nasal cavities associated with an exposure to nickel, many other respiratory effects have been described. Frequent clinical findings include fever with leukocytosis, electrocardiographic abnormalities suggestive of myocarditis and chest X-ray changes (ATSDR, 1997).

Iron (Fe)

Consuming food containing toxic levels of iron or ingesting dietary iron supplements may acutely poison young children (e.g., as few as five to nine 30-mg iron tablets for a 30-lb child). Ingestion accounts for most of the toxic effects of iron because iron is absorbed rapidly in the gastrointestinal tract. The corrosive nature of iron seems to further increase absorption. Other sources of iron are drinking water, food, iron pipes and cookware. Target organs are liver, the cardiovascular system and kidneys (Roberts, 1999).

Arsenic (As)

Though not a heavy metal, it is the most common cause of acute poisoning in adults. It is released into the environment by smelting process of copper, zinc and lead as well as by manufacture of chemicals and glass. Arsenic gas is a common by product in manufacture of pesticides that contain arsenic. Arsenic may also be found in water supplies worldwide. Other sources are food produced on water containing high ‘As’, paints, rat poisoning, fungicides and wood preservatives. Target organs are blood, kidneys and central nervous, digestive and skin systems (Roberts, 1999). Exposure to ‘As’ occurs mostly in the workplace, near hazardous- waste sites, or, in areas with high natural levels. Symptoms of acute ‘As’ poisoning are sore throat from breathing, red skin at contact point, or severe abdominal pain, vomiting and diarrhea, often within 1h after ingestion. Other symptoms are anorexia, fever, mucosal irritation and arrhythmia. Cardiovascular changes are often subtle in the early stages but can progress to cardiovascular collapse. Chronic or low levels of exposure can lead to progressive peripheral and central nervous changes, such as sensory changes, numbness/tingling and muscle tenderness. A symptom typically described is a burning sensation (“needles and pins”) in hands and feet. Neuropathy (inflammation and wasting of the nerves) is usually gradual and occurs over several years. There may also be excessive darkening of the skin (hyper pigmentation) in areas that are not exposed to sunlight, excessive formation of skin on the palms and soles (hyperkeratosis), or white bands of ‘As’ deposits across the bed of the fingernails (usually 4-6 weeks after exposure). Birth defects, liver injury and malignancy are possible. (‘As’ has also been used in homicides and suicides).

Aluminum (Al)

It is not a heavy metal and the information on entry of Al through foods grown on contaminated soils is not available. Studies on effect of Al on human health are relatively new (two decades) and are inconclusive. A possible connection with development of Alzheimer’s disease is proposed as researchers found, what they considered to be significant amounts of, aluminum in the brain tissue of Alzheimer’s patients. Although aluminum was also found in the brain tissue of people who did not have Alzheimer’s disease, recommendations to avoid sources of aluminum received widespread public attention. As a result, many organizations and individuals reached a level of concern that prompted them to dispose of all their aluminum cookware and storage containers and to become wary of other possible sources of aluminum, such as soda cans, personal care products and even their drinking water (Anon., 1992). However, WHO (1998) concluded that although there were studies that demonstrated a positive relationship between aluminum in drinking water and Alzheimer's disease, WHO had reservations about a causal relationship (because the studies did not account for total aluminum intake from all possible sources). Although there is no conclusive evidence for or against aluminum as a primary cause of Alzheimer's disease, most researchers agree that it is an important factor in the dementia component and most certainly deserves continuing research efforts. Therefore, at this time, reducing exposure to aluminum is a personal decision. Target organs for aluminum are the central nervous system, kidney and digestive system. In the home, we are in constant contact with aluminum in foods and in water; from cookware and soft drink cans; from consuming items with high levels of aluminum (e.g., antacids, buffered aspirin, or treated drinking water; or even by using nasal sprays, toothpaste and antiperspirants) (Anon.,1992). Citric acid (e.g., in orange juice) may increase aluminum levels by its leaching activity. Interestingly, aluminum-based coagulants are used in purification of water. However, beneficial effects of using aluminum in water treatment have been balanced against potential health concerns. Water purification facilities follow a number of approaches to minimize level of Al in "finished" water (WHO, 1998). Symptoms of aluminum toxicity include memory loss, learning difficulty, loss of coordination, disorientation, mental confusion, colic, heartburn, flatulence and headache.

Classical examples of heavy metal toxicity

Epidemiological evidence was found in Toyama, Japan, where the population was affected by ingestion of cadmium contained in rice; the origin of this element lay in a nearby mine that contaminated irrigation water. Typical examples of heavy metal toxicity to human beings include itai-itai disease and minamata disease reported again from Japan, due to excessive dietary intake of Cd and Hg by human (De and Anil Kumar, 2000). Among animals, a typical example is excess Cu induced Mo deficiency in fodder. Animals feeding on such plants suffer from molybdenosis. Hence, heavy metals are classified as dreaded pollutants, which have the potential of affecting human and animal health via soil - solid - soil - solution - plant roots - edible parts - animal continuum. A typical diagram of heavy metal cycle in the environment is shown in Figure 1. Some of the other, most important disasters with heavy metals are given below:

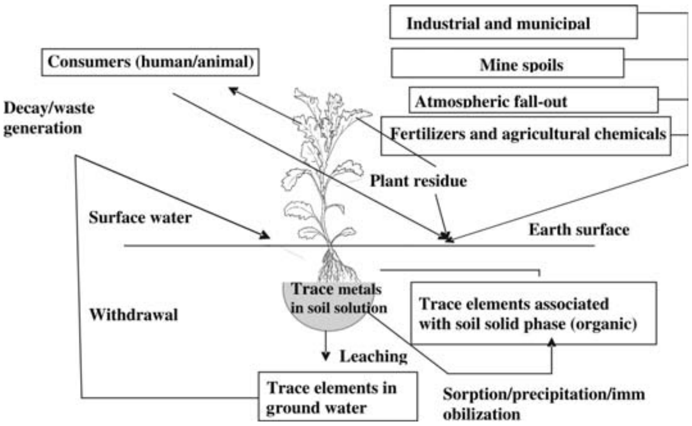

Fig 1. Heavy metal cycle in the environment

- * 1932 Minamata: Sewage containing mercury is released by Chisso's Chemical Works into the Minimata Bay in Japan. Mercury accumulated in sea creatures, leading eventually to mercury poisoning in the population.
- * 1952 Minamata Syndrome: In 1952, the first incidents of mercury poisoning appear in the population of Minimata Bay in Japan, caused by consumption of fish polluted with mercury, bringing over 500 fatalities. Since then, Japan has had the strictest environmental laws in the industrialized world.
- * 1986 Sandoz: Water used to extinguish a major fire carried 30 t fungicide containing mercury into the Upper Rhine. Fish were killed over a stretch of 100 km. The shock drew many FEA projects forward.
- * 1998-2004 Spanish nature reserve contaminated after environmental disaster. Toxic chemicals in water from a burst dam belonging to a mine contaminated the Coto de Donana nature reserve in southern Spain. 5 million mt of mud containing sulphur, lead, copper, zinc and cadmium flew down the Rio Guadimar. Experts estimate that Europe's largest bird sanctuary, as well as Spain's agriculture and fisheries, will suffer permanent damage from the pollution.

Potential sources of heavy metals in UPA

There are two major sources of heavy metals in UPA: Anthropogenic and Geogenic. While geogenic cases are rare in UPA (not discussed in this review), anthropogenic cases are common in cities all over the world.

Table 2. Global emission of trace metals into atmosphere, water and soil (000 metric tones/ year)

Element	Air	Water	Soil
Zinc	132	226	1372
Copper	35	112	954
Manganese	38	262	1670
Molybdenum	3.3	11	88
Cadmium	7.6	9.4	22
Lead	332	138	796
Nickel	56	113	325
Mercury	3.6	4.6	8.3
Arsenic	18.8	41	82
Antimony	3.5	18	26
Selenium	3.8	41	41
Vanadium	86	12	132

Anthropogenic accumulation

Air, water and soils are polluted with heavy metals through several anthropogenic activities like smoke-generating industries, effluent-generating industries, sewage, sludge, municipal solid and liquid wastes, fossil fuel burning, etc. Nriagu (1998) made an estimate of global emission of trace metals into the atmosphere, water and soil (Table 2). He measured it in terms of quantity of water needed to dilute such waters to drinking water standards and stated that toxicity of all the metals being released annually into the environment far exceeded the combined total toxicity of all radioactive and organic wastes. This emphasizes the seriousness of heavy metal pollution compared to other pollutants and needs special attention to prevent or minimize entry of heavy metals into the environment.

Soil

The natural variability of heavy metal content in soils is very high. To ascertain contamination of any soil with heavy metals, one should have a reference level of each metal beyond which soil can be considered as contaminated. Unfortunately, reference levels for different soils are not available, or rather, are not feasible. The normal range of some of the heavy metals in soils reported by two different authors shows a very high degree of variability (Table 3). However, the extent of contamination due to anthropogenic activities can be judged far better by comparison with adjacent, non-polluted soils.

Accumulation in soil

The ultimate destination of pollutants is the soil, where they accumulate. Pollutants so accumulated are disseminated through plants or ground water into the food chain. Soils are highly buffered. Hence, any small and short- term application of sewage sludge and effluents containing heavy metals in low concentrations may not cause serious accumulation of heavy metals in bio-available forms. Therefore, plants grown on such soils may not absorb dangerous levels of heavy metals. However, long-term applications, as it happens in urban and periurban areas, river beds, industrial pockets and other such areas, may lead to accumulation of heavy metals in soil to levels exceeding permissible limits. Levels of heavy metal accumulation in soils of UPA in different cities of India are summarized in Table 4. Variability in the content of heavy metals in these soils is so wide that it is difficult to draw any conclusion from this information, as, their initial levels are not available. The variability is due to several factors like i) amount and period of addition of wastes ii) heterogeneity in the type of material added to the soil, like industrial effluents, sewage effluent, sludge, city garbage iii) type of soil like, light-textured or heavy soil and iv) climate (heavy rainfall or low rainfall, extreme temperatures or moderate temperatures). However, one conclusion that can be drawn from these data is that in many such cases, the levels of heavy metals have not exceeded permissible levels for soils, proposed by PFA (Tables 4 and 5).

Once heavy metals enter the soil system, they may undergo several changes depending upon physical, chemical and biological properties of the soils. Bioavailability of these heavy metals is very important as this is a gateway for entry of heavy metals into the food chain. Current information on the effect of long term application of sewage and industrial effluents, sludge, garbage etc on the available heavy metal status of soils in different UPA areas is presented in Table 6. Again there is wide variability in the bioavailable fractions of heavy metals in these soils attributed mainly to the nature of waste material applied, period of application and soil type. However, one point that emerged from these data is that application of domestic origin sewage water which contains low concentration of

Table 3. Normal range of heavy metals in soil

Author	Pb	Cd	Ni	As	Se	Zn	Cu	Mo
Bowie and Thornton, 1985	10-150	<1-2	2-100	<5-40	<1-2	25-200	2-60	<1-5
Jorgensen, 1979	<10	<0.06	NA	NA	NA	<5	<20	NA

NA = not analysed/not available

Table 4. Heavy metal content (Total) in soils of UPA in different cities in India

Source	Zn	Cu	Fe	Mn	Cd	Pb	Co	Ni	Cr
Bangalore(Varalakshmi, 2005)	71.8	3.52	NA	NA	0.35	35.2	NA	NA	NA
Kolkata (Adhikari *et al*, 1997)	1300	160	212	16	4.0	170	NA	NA	126
Durgapur (Barman and Lal, 1994)	309	41.5	NA	NA	6.11	180	NA	NA	NA
Varanasi (Sharma *et al*, 2007)	87.9	33.5	NA	145.7	2.7	18.3	NA	15.6	79.3
Ludhiana (Azad *et al*,1986)	NA	NA	NA	NA	1.1	NA	24.1	43.9	NA
Coimbatore (Malarkodi *et al*, 2007)	397.4	157.1	NA	NA	8.1	175.5	NA	171.4	114.9
Hyderabad (Jeevanrao and Shantaram, 1993)	2.9	4.3	386	39	0.4	8.1	5.0	1.4	6.0
PFA standard	300-600	135-270	NA	NA	3-6	25-50	NA	75-150	NA

NA = not analysed/not available

Table 5. Permissible level of heavy metals (mg L^{-1}) in water, soil and plants as recommended by various organizations

	Fe	Mn	Cu	Zn	Ni	Cr	Co	Cd	Pb	As
Drinking water										
USPH standards	0.3	0.05	1.0	NA	NA	0.05	NA	0.01	0.05	0.05
WHO standards	1.0	0.50	1.5	NA	NA	0.05	NA	0.01	0.10	0.05
Sewage water										
Pes Cod,1992	NA	0.2	0.2	2.0	2.0	0.1	NA	0.01	0.5	NA
FAO,1979	NA	NA	NA	NA	2.0	1.0	NA	0.05	2.0	NA
The Environmental Protection Rules, 1986, India	3.0	2.0	3.0	5.0	3.0	2.0	NA	2.0	2.0	NA
Soil										
PFA, India	NA	NA	135-270	300-600	75-150	NA	NA	3-6	250-500	NA
Austria	NA	NA	100	300	100	100	50	5	10	NA
Canada	NA	NA	100	400	100	75	25	8	200	NA
Poland	NA	NA	100	300	100	100	50	3	100	NA
Japan	NA	NA	125	250	100	NA	NA	NA	400	NA
Great Britain	NA	NA	100	300	50	50	NA	3	100	NA
Germany	NA	NA	50	300	100	200	NA	2	500	NA
Vegetables and Food										
PFA	NA	NA	30	50	1.5	0.2	NA	1.5	2.5	1.1

NA = not analysed / not available

micronutrients and very low concentration of heavy metals may not lead to accumulation of these metals in soils.

Build - up in soil receiving heavy metals from different sources depends upon the period of its application. Longer the period, greater is the accumulation. However, information on relationship between initial concentration of heavy metals in the source, period of application and rate of build-up in soils receiving different kinds of waste material are very scanty. In one such study, Bansal *et al*. (1992) reported that build-up was more in soils, which received industrial effluent from Ludhiana city for a period of five years as compared to only two years. Whereas, Palaniswami and Sriramulu (1996) reported build-up of Fe in 15 year effluent treated plots as compared to 2 year irrigated plots (Fig 2). Zn content remained unaltered and Cu increased only marginally. One general point that emerged from such studies is that Mn content of soil depleted with increase in

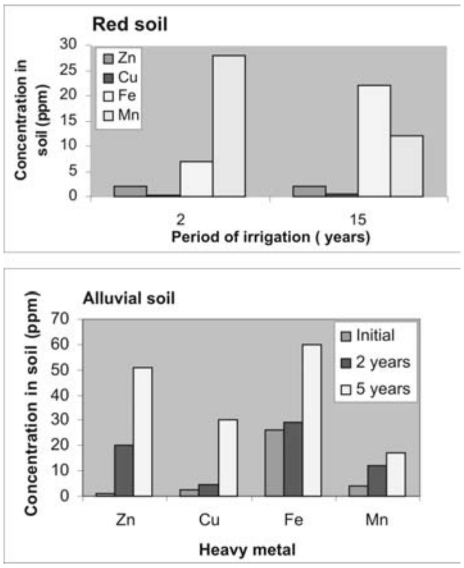

Fig 2. Effect of period of application of effluents on accumulation of heavy metals

Table 6. Bioavailable heavy metal status of soils treated with different sources of wastes

Source	Zn	Cu	Fe	Mn	Cd	Pb	Co	Ni	Cr	As	Hg
Indo-Gangetic plain-Alluvial soils											
IARI (NewDelhi)	5.0	3.3	23.3	12.1	NA	2.2	NA	0.4	NA	NA	NA
(Datta *et al*, 2000)	2.2	1.1	6.7	9.8	NA	1.7	NA	0.2	NA	NA	NA
Domestic sewage											
Tubewell											
Jalanandhar (Delhi)											
(Rattan *et al*, 2002)	14.7	4.20	39.7	18.9	NA	NA	NA	1.27	1.72	2.09	NA
Sewage effluents	2.9	0.99	13.8	14.3	NA	NA	NA	0.56	0.81	1.87	NA
Tubewell											
Keshopur(Delhi)	6.77	5.42	40.30	5.17	0.15	2.34	NA	0.91	NA	NA	NA
(Rattan *et al*, 2002)	1.92	1.79	9.22	5.69	0.14	1.65	NA	0.36	NA	NA	NA
Sewage effluents											
Tubewell											
Ludhiana(Punjab)											
Sewage effluents											
(Arora *et al*, 1985)	4.38	5.5	36	10.9	0.07	1.88	NA	0.37	0.57	1.02	0.51
Malerkotla(Punjab)											
(Arora *et al*, 1985)											
Sewage effluents	5.56	2.5	11	7.9	0.04	1.41	NA	0.32	0.36	0.56	0.38
Samrala(Punjab)											
(Brar *et al*, 2000)											
Non-Sewage effluents	1.67	2.2	17	8.9	0.06	1.24	NA	0.42	0.39	0.77	0.61
Varanasi (U.P.)											
(Singh and Singh 1994)											
Sewage effluents	15.63	30.41	82.79	229.3	3.8	22.48	NA	NA	4.25	NA	NA
Patna (Bihar)											
(Sakal *et al*, 1992)											
Sewage sludge	11.4	14.5	54.9	19.4	0.21	10.2	NA	NA	NA	NA	NA
Ganga delta-Alluvial soils											
Howrah											
(Som *et al*, 1994)											
Sewage effluents	19.4	NA	NA	NA	0.02	0.18	NA	NA	0.60	NA	NA
Kolkata											
(Mitra and Gupta,											
1999) Sewage effluents	281	36	115	24	0.45	104.3	1.8	9.45	12.5	NA	NA
Non-sewage effluents	3.5	2.25	53.5	21.6	0.006	4.25	0.9	4.40	3.15	NA	NA
Deccan Plateau-Red soils											
Bangalore (Varalakshmi											
and Ganeshamurthy,											
2007) Sewage effluents	0.03	0.101	NA	NA	Tr	0.73	NA	0.01	0.10	NA	NA
Hyderabad											
(Rao *et al*, 1994)											
Fresh garbage	6.8	10.9	16.2	16.0	0.14	10.5	0.40	0.46	0.34	NA	NA
Control	1.0	0.9	6.5	9.0	ND	0.04	0.04	0.05	ND	NA	NA
Avaniyapuram											
(TamilNadu)											
(Jayabaskaran and											
Sriramulu, 1996)											
Sewage effluents	10.6	6.9	32.3	37.0	0.20	5.7	0.4	6.9	2.7	NA	NA
Sakkimangalam											
(TamilNadu)											
(Jayabaskaran and											
Sriramulu, 1996)											
Sewage effluents	5.9	5.7	32.3	39.0	0.10	3.7	0.20	4.9	2.9	NA	NA
Ukkadam (Jayabaskaran											
and Sriramulu, 1996)											
Sewage effluents	10.4	9.7	28.5	37.0	0.20	6.30	0.50	14.6	3.8	NA	NA

NA = not analysed/not available, ND = not detected, Tr = traces

Table 7. Profile distribution of heavy metals in soils treated with industrial effluents

Soil depth	Ukkadam Farm, Tamil Nadu (Jeyabaskaran and Sriramulu,1996)				Periurban Patna (Mean of 11 sites)(Sakal *et al*, 1992)					
(cm)	Zn	Cu	Fe	Mn	Zn	Cu	Fe	Mn	Pb	Cd
0-15	15	16	50	70	4.19	5.21	40.98	13.93	3.95	0.075
15-30	11	9	25	40	2.30	1.85	24.36	9.94	2.50	0.047
30-45	5	3	9	15	1.87	1.08	15.76	8.89	2.20	0.043
45-60	2	1	2	3	1.75	0.88	14.17	8.06	1.99	0.038

duration of irrigation. Perhaps this is due to leaching of reduced forms of Mn from such soils.

Texture of soil has profound influence on the pattern of heavy metal accumulation. Light - textured soils accumulated lower levels of heavy metals than heavy soils under similar conditions. However, no direct study on such effects has been conducted anywhere. It has been found that bioavailability of heavy metals in light-textured soils of Sakkimangalam and Avanigapuram were more or less similar in sites that received sewage water for eight years or 50 years (Jayabaskaran and Sriramulu, 1996). But, Ukkadam sewage farm on clay soils contained higher bioavailable heavy metals after 40 years of sewage water irrigation than the silty clay loam soils of Avanigapuram after 50 years of sewage irrigation (Table 6).

Heavy metals are immobile in soil. As a result, these accumulate mainly in surface soils which are, unfortunately, the zone of prime root activity in crops. Profile analysis of soils collected from sewage and effluent irrigated areas showed no build-up of heavy metals below 45 cm depth (Table 7).

A majority of the cities and towns in India is located on the banks of rivers, rivulets and streams. The number of cities on the banks of Ganga alone is 27. River beds in all these cities and towns are put under cultivation of vegetables and fodders. Unfortunately, these river bed soils are among the most polluted soils because of their frequent inundation with heavy - metal rich water during monsoon. The most worrying feature of such sites is that a large proportion of accumulated heavy metals remains in highly mobile and leachable form, which is directly available for absorption by plants. Dry river beds of Kharaai river in the industrial city of Jemshedpur had 8400 ppm Fe, 10 ppm Ni, 7 ppm Pb, 200 ppm Cu, 90 ppm Cr and 5 ppm Co, all above permissible levels (Sinha *et al*, 2002). Analysis of dry river bed soils of periurban Kanpur, where the Ganga flows through the heart of the city, showed (Fig. 3) that a major part of accumulated heavy metals was in the leachable form (Farooq *et al*, 1999). Leafy and succulent vegetables of short duration mainly are grown on such soils, as they find immediate market in the adjacent urban areas. This is a matter of serious concern as these crops are heavy accumulators (Varalakshmi and Ganeshamurthy, 2007) favoured by high availability of heavy metals in soils and short duration crops.

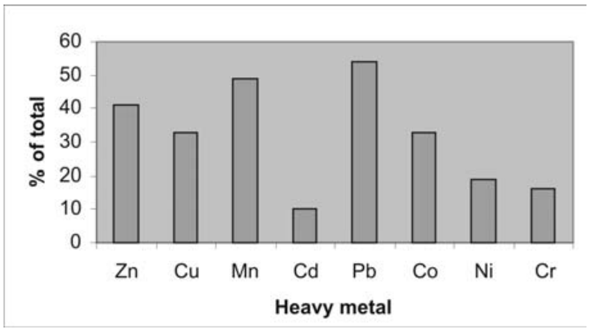

Fig 3. Proportion of various heavy metals in river bed soils present in soluble form

Protected cultivation of vegetables in periurban areas is on the increase. Cultivation in polyhouses is generally done on artificial beds created within by dumping organic manures of varying types. The source of such organic manures may vary but, being in the vicinity of cities, organic manures are likely to get mixed with sewage sludge and other city solid wastes. Data on extent of heavy metals in the bed material and in crops grown in such polyhouses are not available. This is a point which calls for attention of researchers.

Water

Source of heavy metals in water

Urban and industrial waste-water acts both as source and carrier of heavy metals in the UPA. Rapid industrialization and urbanization have been generating huge amounts of effluents and other urban liquid wastes in India and the situation is likely to worsen further. A population of 6 million in Bangalore city alone is generating about 800 million liters of waste-water a day. The total waste-water generated in urban India is of the order of 200

Mm^3d^{-1}. These waste-water contain a wide spectrum of inorganic and organic material and heavy metals (Chonkar *et al*, 2000a, 2000b; Ganeshamurthy, 2007). The major contributors of heavy metals in these wastes include leather tanneries (Cr), distilleries, paper mills, refineries, textile industries, thermal plants, smelters (Zn, Fe), automobiles (Pb, Cd), paints (Pb, Cr), metalliferrous mines, electroplating industries (Zn, Sn, Ni, Cr), ceramic industry (Pb, Cd), lignite-based power plants, aluminum industry, electronics industry (Pb, Hg, Cd, Cr), metallurgical industry, etc.

India produces about 80 million pieces of hides and 133 million pieces of skins annually. These are handled by about 3000 tanneries and 680 leather finishing industries located in various cities for producing semi-finished and finished leather goods. A kg of skin or hide needs about 40 L of water for the process. In the case of finished leather it is about 50 L kg^{-1}. Both vegetable and chrome tanning is used in India. While vegetable tanning is relatively safer, effluent from chrome tanning contains dangerous levels of chromium and other heavy metals (Table 8). Effluents from tanneries are mainly discharged into nearby rivers, streams or other water bodies. Jajmau tannery near Kanpur, in Uttar Pradesh, discharges about 9000 m^3 of effluent per day directly into the river Ganga. It contains high concentrations of chromium (Chandalia and Rajagopal, 1992). Tanneries are concentrated on the banks of Palar, Periyar and Cauvery rivers in Tamil Nadu. Untreated effluents from these tanneries are discharged into neighboring fields, irrigation tanks which finally reach Palar, Periyar and Cauvery rivers.

There are, at present, about 515 units engaged in manufacture of paper, paperboards and newsprint in India. Present production of paper and paperboard is six million tonnes and is expected to go up to eight million tonnes by 2010 (Business Line, 2005). At present, about 60.8 % of the total production is based on non-wood raw material and 39.2 % is based on wood. A ton of paper produces approximately 6000 gallons of effluent. At this rate, effluent discharged by paper mills is approximately 36000 million gallons. A sample data on heavy metal content in paper mill waste-water and sediments from Russia (Labunska *et al*, 2001) is presented in Table 9. Although Patel *et al* (2004) reported lower concentration of heavy metals in paper mill effluents (Table 8) from Gujarat authenticated data on heavy metal content of paper mill effluents from India are not

Table 8. Heavy metal concentration in waste-waters from different sources (ppm)

Type of waste-water	Zn	Cu	Fe	Mn	Cd	Pb	Co	Ni	Cr	Reference
Tannery effluent,Vegetable	2.56	Tr	Tr	0.67	NA	0.23	NA	NA	NA	Karunyal *et al*.,1972;
tanning,Chrome tanning	NA	NA	NA	NA	NA	NA	NA	NA	97-5125	Sakthivel and Sampath 1990
Distillery effluent	4.61	3.65	34.8	12.7	0.48	NA	0.08	NA	0.64	Patil, 1994
Paper mill efluent	0.48	0.34	7.50	0.27	0.01	0.17	0.04	0.11	0.67	Patel *et al*,2004
Textile industry	NA	Tr	Tr	Tr	NA	NA	NA	NA	Tr	Mohmed and Ashan, 1985
Refinery effluent	0.33	0.23	3.77	0.55	NA	0.86	NA	0.23	NA	Singh *et al*,1991
Zinc smelting effluent	10.6	0.05	0.68	NA	NA	0.05	NA	NA	NA	Totawat 1991
Electro plating industry	NA	NA	NA	NA	NA	NA	NA	3.0	2.5	Tiwana *et al,* 1987
Sugar Industry-Spent wash	1.17	0.78	61.3	4.0	0.06	0.68	NA	0.70	NA	Zalawadia *et al*,1997
Fertilizer Industry	0.25	0.12	6.34	0.29	0.03	0.17	0.15	0.55	1.10	Patel *et al*,2004

Tr = Traces, NA = not analysed/not available

Table 9. Heavy metal analysis results in Cepruss Pulp and Paper Mill, Kaliningrad area, Russia, 2001

Sample	Waste-water	Waste-water	Waste-water	Sediments	Sediments
number	BT01010	BT01011	BT01008	BT01009	BT01012
Concentration	µg/l	µg/l	µg/l	µg/kg dry weight	µg/kg dry weight
Cadmium	<10	<10	<10	1	2
Chromium	<20	<20	<20	19	17
Cobalt	<20	<20	<20	10	7
Copper	<20	<20	<20	356	108
Lead	59	<30	<30	143	30
Manganese	298	325	476	541	154
Mercury	<1	<1	<1	0.928	0.1
Nickel	<20	<20	<20	12	13
Zinc	14	16	23	557	212

available. However, concentration of heavy metals like Cu, Pb, Zn, Ni, Co, and Cd in coconut water, root and leaf irrigated with effluents from paper mills, was higher than limits suggested by World Health Organization (Sharif Fazeli, 1991) giving an indication that effluents contained heavy metals above permissible levels.

Textile industries also generate huge quantities of waste-water containing heavy metals. These industries, including both mechanized and hand processing units, are distributed throughout the country in small and medium towns, but, mechanized units are mainly located in Ahmedabad, Mumbai, Surat, Coimbatore and Chennai. For example, Buckingham and Carnatic textile mills in Tamil Nadu produce about 20,000m^3 d^{-1} of waste-water while 760 hand processing units in Pali town in Rajasthan produce about 18000 m^3 d^{-1} (Gupta *et al*, 1992). Untreated effluents from textile units in Pali, Jodhpur and Badmer are discharged into seasonal rivers Bundi, Jojri and Luni, respectively. Pali has been identified as one of the most polluted cities in India. Data on heavy metal content of these waste-waters are not available. Mohmed and Ashanullah (1985) reported that the effluent from Modi Textile Industry in U.P. was below detectable limits (Table 8). However, various chemicals and dyes used in textile industries contain both heavy metals and harmful chemical which ultimately reach irrigation water and soil.

Distilleries are another major source of waste-water containing heavy metals. India produces 2.7 billion liters of alcohol annually from 285 distilleries, mostly concentrated in the three sugarcane producing states of Maharashtra, Uttar Pradesh and Karnataka (AIDA 1995, Joshi *et al*, 1996). The proportion of alcohol to spent wash (waste-water) is 1:15. At this rate, spent wash produced in India is estimated at 4050 M m^3(40.5 billion liters). An example of heavy metal content of the distillery waste-water is given in Table 8.

Effluents from refineries, smelting industries, paint industries, plating industries and many such sources contain heavy metals to varying degrees (Table 8). Data on heavy metal content of such small but potential sources of heavy metals are scanty. In the fertilizer industry sector, total chrome content in the effluent of NH$_3$-urea unit was assessed at 43 t y^{-1}, in addition to 256 t of chrome sludge and 19.5 t of As sludge. However, due care is taken by these units before discharging wastes into the environment (Swaminathan, 1993).

Accumulation of heavy metals in water

City sewage effluents are generally a mixture of industrial and domestic waste-waters. They are potential sources of heavy metals in UPA. Typical concentrations of heavy metals in city sewage effluents and tube wells are presented (Table 10). Lower concentration of heavy metals

Table 10. Heavy metal content in sewage effluents and wells from different cities in India

Source	Zn	Cu	Fe	Mn	Cd	Pb	Co	Ni	Cr	Reference
Agra										
sewage	560	450	4770	660	NA	750	NA	190	NA	
tubewell	Tr	50	1790	90	NA	190	NA	Tr	NA	Singh *et al*, 1991
Howrah sewage	61.6	NA	NA	NA	22.0	35.6	NA	NA	7.2	Adhikari, 1993
Jalandhar										
sewage	1990	400	16400	350	NA	NA	NA	190	2720	Brar *et al*, 2000
sewage+leather	2510	420	24200	440	NA	NA	NA	350	14030	
ground water	70	10	130	4	NA	NA	NA	50	6	
Kolkata										
sewage	356	85.2	449	68.3	4.9	7.0	10.5	11.3	20.3	Mitra and Gupta, 1999
tubewell	17.6	3.6	80.6	22.5	<1	<2	<2	2.6	2.0	
Ludhiana										
sewage	710	6412	307	307	2.3	53.1	357	132	NA	Arora *et al*, 1985
control	260	70	140	140	0.55	9.3	75	1.5	NA	
Ahmedabad										
sewage	6.0	0.13	3.77	0.18	0.01	0.13	0.02	0.09	0.13	Patel *et al*, 2004
Bangalore sewage	179	17	1305	Tr	0.2	13	Tr	18	7	Lokeshwari, and Chandrappa,2006
Coimbatore sewage	4.13	1.87	38.73	11.90	2.77	35.42	Tr	8.76	8.42	Doraisami *et al*, 2003
Varanasi sewage	0.23	0.04	NA	0.15	0.01	0.08	NA	0.03	0.04	Rajendra prasad *et al*, 1985
Udaipur sewage	39.1	11.1	48.0	81.8	33	943	NA	410	NA	Malla and Totawat, 2006

NA = not analysed/not available

Table 11. Seasonal variability in heavy metal content in city sewage water

Source	Zn	Cu	Fe	Mn	Cd	Pb	Co	Ni	Cr	Reference
Bangalore										
Monsoon	NA	NA	NA	NA	0.001	Tr	NA	0.101	0.272	Varalakshmi and Ganeshamurthy, 2007
Winter	NA	NA	NA	NA	0.004	0.030	NA	0.016	0.114	
Summer	NA	NA	NA	NA	0.04	0.136	NA	0.045	0.096	
Kolkata										
Monsoon	321	70.9	656	45.2	1.3	2.9	6.0	57.8	11.7	
Winter	356	85.2	449	68.3	4.9	7.0	10.5	113	20.3	
Coimbatore										
Monsoon	2.5	2.68	30.1	16.2	2.15	23.65	NA	6.35	1.46	Duraisamy *et al*, 2000
Winter	9.75	1.97	56.0	11.6	4.25	55.25	NA	17.12	7.08	
Summer	4.83	1.50	33.8	8.58	3.25	45.70	NA	9.66	9.80	

NA = not analysed/not available

in ground water indicated that metals accumulated mostly in the surface soils and only a small proportion leached down and reached the ground water (Jayabaskaran and Sriramulu, 1996; Sakal *et al*, 1992). The concentrations of metals varied with source of their origin and with season. Varalakshmi and Ganeshamurthy (2007) reported lower concentrations of Cd and Pb during monsoon in Bangalore city sewage and attributed it to dilution effect. Higher concentration of Cr and Ni in monsoon season is attributed to run - off and erosion caused by rainfall and the consequent entry of contaminated soil and silt from nearby plating industries which otherwise do not reach the main drains during summer (Table 11). In some cases, there is no significant relationship between concentrations of heavy metals in different seasons i.e., winter, summer or monsoon, as heavy metals in waste-water have a continuous anthropogenic source from industries. However, higher concentration of metals in a particular season, besides seasonal factors, may be due to intensity of an industrial activity in a particular season. It may also be due to the fact that samples were gathered from drains in industrial premises, a direct anthropogenic discharge resulting from industrial activity.

Surface water bodies like rivers, rivulets, streams and lakes are the first to receive heavy metals generated by various industries and waste producing sources. They act as transporters disseminating pollutants into the environment. Both treated and untreated effluents from industries and city municipal wastes are directly discharged into rivers and other water bodies. Data available on heavy metal concentration of some rivers and water bodies are presented in Table 12. Variability in concentration of heavy metals in different rivers, and within a river, at different locations was directly related to the amount of heavy metal containing wastes added at different locations. However, most of these river waters contained heavy metals well above permissible levels both for drinking and irrigation purposes (Table 5).

Drinking - water bodies and other aquifers near agricultural lands receiving irrigation from polluted waters of rivers and streams get contaminated. Surface water contains higher concentrations than ground water. Analysis of water samples within a radius of 1 km from the carpet industry in Gopalgunj and Bhadoni in Uttar Pradesh varied from 0.11 to 0.84 ppm Cr (Singh *et al*, 2001). Similarly, well waters adjoining streams around zinc smelters in Dabari (discharge rate = 4000 $m^3 d^{-1}$) contained 0.0-0.72 ppm Zn, 0.0-0.93 ppm Cd, 0.1-0.6 ppm Fe (Totawat, 1993). Coimbatore city having more than 30,000 small, medium and large industries does not have a facility for treatment of industrial, municipal, hospital and domestic waters. The open - type drainage lets these waters into lakes, wetlands and the river Noyyal. Analysis of water from different lakes (Table 12) in Coimbatore city showed heavy metal concentrations above permissible levels for drinking and irrigation. Although water here is not for drinking, livestock, poultry, fish and other aquatic species do depend on these waters, and wetlands around these water bodies accelerate bioaccumulation of heavy metals in crops. Similarly, water of Hussain sagar lake and ground water in nearby areas in Hyderabad (400 units of industries including paints, drugs, chemicals, etc. on its bank) also contain, a high degree of metal contamination.

Electronic waste (E-waste) as a source of heavy metals

E-waste comprises of waste electronic goods which are no longer fit for their originally intended use. These range from household appliances such as, cellular phone, personal stereo and consumer electronics to computer, refrigerator, air conditioner, etc. E-Waste contains several different substances and chemicals, many of which are toxic and likely to create adverse impact on the environment and

Table 12. Heavy metal concentration in some rivers and water bodies in India

River/sampling site	Zn	Cu	Fe	Mn	Cd	Pb	Co	Ni	Cr	Reference
Rivers										
Brahmani	180	40	1170	40	NA	NA	NA	NA	290	Panda *et al*, 1991
Ganga										Sinha *et al*, 2002
Rishikesh	72	3.5	40	35	ND	0.92	1.5	1.5	5.2	
Haridwar	61	7.8	150	54.9	ND	0.98	2.9	3.5	7.5	
Sultanpur	69.5	9.8	175	89.7	ND	1.30	2.5	5.8	10.5	
Bhopa	68.3	11.5	189	135.9	0.15	1.20	1.9	5.3	12.2	
Parichhatgarh	270	30.2	414	198	0.6	4.5	9.5	9.0	27.5	
Garhmukteshwar	311	49.5	721	211	0.75	6.5	12.5	10.2	32.5	
Anupshahr	135	8.5	209	98.5	0.12	2.7	6.5	3.0	11.5	
Ramgarh	140	9.5	195	109	0.17	2.5	5.7	3.2	15.9	
Kharkal Jamshedpur	16	3.0	64	24	NA	16	NA	NA	NA	Som *et al*, 1994
Other water bodies										
Lake Gopalgunj	NA	NA	NA	NA	NA	NA	NA	NA	0.11-0.84	Singh *et al*, 2001
Lake Bhopal	0.03	0.012	0.413	0.156	0.087	0.041	0.087	0.07	0.011	Srivastava *et al*, 2003
Lake (Coimbatore)	493	177	8080	1257	10	375	NA	6.94	387	Mohanraj *et al*, 2000
Selvachintamani	95	44	520	255	1	26	NA	23	52	
Singanallur	34	18	1425	55.2	0.5	10.5		6.4	29.8	
Ukkadam	53	30.3	1736	71	0.5	4.5	NA	8.6	43	
Perur	99.5	24.5	640	346.2	2	25.5		24.9	48.5	
Valankulam	101	44.1	3285	63.6	0.5	4.5	NA	11.8	42.4	
Ammankulam	52.5	26	3405	82.9	0	15.5	NA	11.5	37.4	
Selvampatti Kumaraswamy	69	28.2	1165	54.5	0	14.5	NA	6.1	61.9	

NA = not analysed/not available

health, if not handled properly. However, classification of E-waste as a hazard or otherwise depends upon the extent of presence of hazardous constituents in it. Chemicals such as beryllium, found in computer motherboards, and cadmium in chip resistors and semiconductors, are poisonous and can lead to cancer. Chromium in floppy disks, lead in batteries and computer monitors, and, mercury in alkaline batteries and fluorescent lamps also pose severe health risks. The end effects of electronic junk (generated from obsolete computers and discarded electronic components) are disastrous to our environment and populace. Second-hand computers from the West are dumped in India, most of it done illegally, by gray - market operators.

Home to more than 1,200 foreign and domestic technology firms, Bangalore figures prominently in the danger list of cities faced with e-waste hazards. As many as 1,000 tons of plastics, 300 tons of lead, 0.23 tons of mercury, 43 tons of nickel and 350 tons of copper are annually generated in Bangalore through e-wastes. More than 300 small industrial units operate in metal extraction from waste and dumped computers. The waste generated from metal extraction is mostly let into sewage or storm-water drains. Most of the industries, especially the Information Technology companies, are only vaguely aware of the problems caused by E-waste

Heavy metal content in crops

Plants absorb nutrients from soil through several mechanisms like mass flow from soil solution along with water, through exchange of ions on root surface with those adsorbed on the soil exchange complex etc. Generally while absorbing, plants do not differentiate between nutrient and non-nutrient elements. Because of this, crop plants grown on polluted soils become major sinks and become a gate-way for entry of heavy metals into the food chain. The magnitude of absorption is largely decided by their concentration in soil, physico-chemical condition in soil and ability of plant roots to absorb.

In UPA, the general trend in selection of crops is in the following order: vegetables, fodder, cereals and millets, ornamental crops and fruits, of which, vegetables and fodders occupy a major area. Among vegetables, short-duration leafy and succulent vegetables, root vegetables occupy the first place followed by fruit vegetables. However, food crops are least accumulators and vegetables and fodders are the highest accumulators of heavy metals. Another paradox is that a major part of nutrient absorption by crop plants is in the first half of their life cycle. Hence, leafy vegetables that are harvested in the first half of their life cycle pose a potential danger with respect to heavy metal circulation in the food chain (Ganeshamurthy, 2007).

There is a wide variability in heavy metal content in vegetable and other crops grown on polluted soils in urban and periurban areas. The content of heavy metals in vegetables depends mainly upon concentration in soil and water, type of vegetable, season, soil type, etc. Permissible levels of heavy metals in different vegetables prescribed by different agencies are given in Table 5. There are significant differences in permissible levels prescribed by various organizations. Reasons for such differences are not clear. However, this may be due to differences in tolerance levels of people of different origin, differences in threat perception of people, racial differences in tolerance levels, etc.

Levels of heavy metals generally found in common vegetables grown on different sources of waste-waters are presented in Table 13. The content of metals varied with source of sewage water. City sewage and dry river bed soils helped in absorption of higher concentration of metals than did domestic sewage. However, vegetables grown using any of these waters accumulated heavy metals above the permissible levels prescribed by PFA. Factual data on heavy metal content of vegetables grown on domestic sewage water are not available. The domestic source data presented in Table 13 is not really of domestic campus waste-water in Indian Agricultural Research Institute, New Delhi, as it might contain the waste-water generated from some labouratories of IARI. Hence content of heavy metals here was higher than expected. However, true domestic sewage water may not result in higher heavy metal content in vegetables. Therefore, waste-water generated in small towns, if industrial activities are not high, may be used for cultivation of vegetables and other crops.

Among the crops grown, vegetables and fodders accumulated more heavy metals than cereals, pulses and fruits (Table 14). Among vegetables, leafy and root vegetables accumulated higher concentrations of metals than fruit vegetables. Further data suggest that no crops grown for direct consumption by human are safe. There is a need to generate data on crops other than those eaten by human like flowers, bio-fuel plants, mulberry, timbers, etc. This would enable us to develop an entirely different land-use strategy for contaminated areas that is economically viable and socially acceptable so that entry of heavy metals into the food chain may be contained (Ganeshamurthy, 2007).

Table 13. Heavy metal content in vegetables grown on soil irrigated with various sources of waste-water

Vegetable	Kolkata sewage (Mitra and Gupta, 1954)				Bangalore sewage (Varalakshmi Ganeshamurthy, 2007)				Dry river bed and (Farroq *et al*, 1999)					Domestic sewage (Datta *et al*, 2000)		
	Cd	Pb	Ni	Cr	Cd	Pb	Ni	Cr	Cd	Pb	Ni	Cr	Cd	Pb	Ni	Cr
Cauliflower	tr	70.0		tr	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Brinjal	-	-	-	-	0.76	1.20	2.40	13.52	-	-	-	-	-	15.1	9.26	-
Chilli					0.96	0.52	2.36	22.60	-	-	-	-	-	10.7	8.90	-
Palak	tr	68.8	-	9.4	2.20	4.12	6.92	28.32	5.2	34.5	13.2	13.0	-	-	-	-
Radish	1.2	12.5	-	1.2	1.20	3.40	3.64	10.40	1.7	3.7	10.1	11.7	-	2.5	7.8	-
Bottlegourd	Tr	0.4	NA	Tr	0.44	2.08	4.36	9.64	8.2	107.8	1.1	2.9	-	19.2	8.7	-
PFA standard: Cd = 1.5, Pb = 2.5, Ni = 1.5, Cr = 0.1																

NA = not analysed/not available; tr=traces

Table 14. Heavy metal content in different vegetable, fodder, cereal and fruit crops grown on sewage water irrigated areas of periurban Bangalore

Metal	Vegetable			Fodder	Cereal		`Pulse	Fruit
	Leafy	Root	Fruit	Napier	Rice	Ragi	Redgram	Citrus
Fe	62	1828.0	1288.0	1115	116	189	480	280
Mn	38	284.0	15.0	33	35	29	150	25
Cu	318	190.0	19.0	20	8	10	128	1
Zn	35.0	48.0	27.0	10	26	58	28	2
Pb	29	28.0	10.9	32	ND	0.5	54	98
Cd	2.40	1.72	1.8	ND	ND	16	ND	ND
Cr	17.12	108.0	5.0	2	ND	ND	ND	ND
Ni	5.16	12.0	56.0	15	ND	18	16	22

ND = Not detected

Table 15. Seasonal average heavy metal content of vegetables collected from periurban Bangalore

Vegetable	Summer				Rainy season			
	Cd	Pb	Cr	Ni	Cd	Pb	Cr	Ni
Amaranth	12.52	9.04	7.96	5.40	1.12	11.60	20.68	11.32
Palak	9.56	11.04	9.52	6.20	0.76	8.28	22.52	13.20
Coriander	12.80	4.24	10.10	5.68	1.00	11.68	25.72	14.36
Fenugreek	9.68	7.89	6.98	5.12	0.68	7.32	19.13	12.15
Carrot	10.60	5.04	5.28	7.28	0.76	4.69	18.36	10.24
Radish	11.40	4.92	10.56	3.08	1.00	8.80	17.64	9.92
Tomato	4.52	2.72	2.52	2.72	0.36	3.52	12.20	7.16
Beans	6.16	3.40	11.80	5.20	0.52	6.96	16.20	13.08
PFA standard	1.5	2.5	1.5	0.2	NA	NA	NA	NA

NA = not analysed/not available

Analysis of vegetables grown in different seasons showed that Pb, Ni and Cr content was higher in the rainy season (Table 15). This was due to a higher concentration of these metals in the sewage water of Bangalore during the rainy season (Table 15). Several species of gourd and melon are grown on dry river - beds along the length and breadth of the country during the dry season. The frequency and quantum of irrigation in these crops on sandy river beds is very high. If the river water near the cities is contaminated with heavy metals, as in the case of the Ganga river beds (Table 12), these crops accumulate very high concentrations of heavy metals, and, special attention should be paid to monitor heavy metal content in vegetables and fruits coming to the market from such sources.

Just as crop species differ in their capacity to absorb heavy metals, cultivars within a given crop also differ in their ability to absorb heavy metals. This difference can be exploited to identify cultivars having low absorption capacity. However, work done in this field is very limited. Varalakshmi and Ganeshamurthy (2007) found that the local cultivar of amaranth accumulated lower level of Cd (Table 16) than did cv. Arka Arunima. Similarly, cv. Arka Nishanth of radish accumulated lower level of Cd than cultivar Pusa chatki. There is a need to intensify work to find out donor plants with lower heavy metal absorption capacity which can then be used for breeding.

Remediation

With our current level of knowledge a permanent and foolproof method to stop entry of heavy metals into the food chain is impossible. However, methods are available to reduce intensity of the effects. Heavy metal pollution can be tackled at two stages: I. Treating the pollutants before their entry into the environment. II. Treating the pollutants after their entry into the environment. However, primary and secondary treatment of waste material before disposal/discharge drastically reduces the content of heavy metals in waste. Raw sewage emanating from Howrah was analysed before and after primary and secondary treatments (Som *et al*, 1994) and has been found that secondary treatment considerably reduced the toxic hazards (Fig 4).

Table 16. Cultivar differences in Cd absorption Capacity in some vegetables

Cultivar	Cadmium concentration (ppm)
Amaranth	
Arka Arunima	0.74
Arka Suguna	0.36
Local	0.29
Radish	
Pusa Chatki	1.19
Japanese white long	0.93
Arka Nishanth	0.90

Options are limited for containing heavy metals after their entry into the environment. Pockets of highly contaminated sites like large dumpings in a small area or accidental spillage sites, childrens' playgrounds, etc. can be cleaned up through physical excavation of soil, washing with a suitable method to remove heavy metals and by

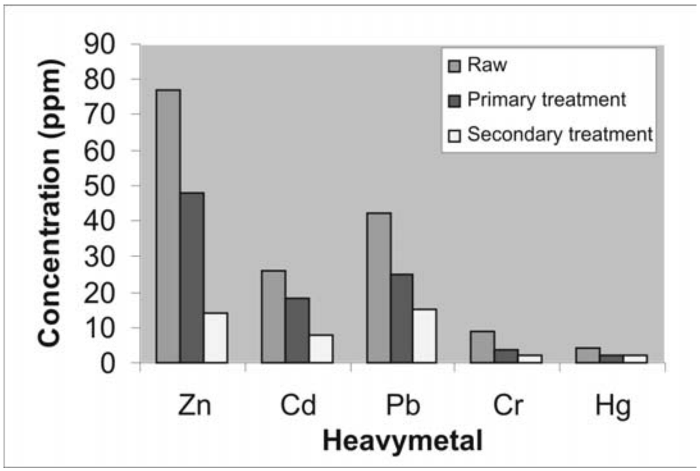

Fig 4. Reduction in concentration of heavy metals after primary and secondary treatment

replacement or disposal after making these areas fit for re - use (USEPA, 1991). Use of such technologies for cleaning polluted urban and periurban agricultural soils is impossible as the volume of soil or water involved is too big and prohibitively expensive. *In situ* technologies would be suitable for remediation to improve soil health, contain heavy metal levels to satisfy compliance requirements and / render heavy metals unavailable for plant uptake. Thus, plants grown on such soils (after treatment) would be fit for human / animal consumption, socially acceptable and economically feasible. Certain amendments that alter soil pH or chelate heavy metals or precipitate/transform heavy metals into insoluble/unavailable/non-toxic form may be effective in preventing heavy metal entry into the food chain. Application of lime, organic amendments like use of FYM, vermicompost and heavy doses of phosphatic fertilizers and oxides of Mn and Fe would reduce transfer of heavy metals from the soil into plant. This lowers the concentration of heavy metals in the food and reduces phytotoxic effect on plants (Hyun *et al*, 1998 ; Impens *et al*, 1991; Singh *et al*, 1989). Such work is rarely found in the Indian context (Rattan *et al*, 2002). In a field study liming proved effective in decreasing the concentration of Cd from 10.9 to 5.0, Cu from 11.7 to 4.6, Ni from 20 to 0.8 and Zn from 408 to 2.8 mg kg^{-1} in soils that has received a one-time heavy application of sewage sludge 16 years earlier (Brallier *et al*, 1996). Liming reduced the uptake of Cd, Ni and Zn in plants grown on such treated soils and was also useful in improving crop yield. Effectiveness of liming depends upon initial soil pH, soil type and crop species. Heavy metals react with phosphorus from applied phosphatic fertilizers, forming insoluble phosphates. For example, added P precipitates Cd as $Cd_3(PO_4)_2$ (Lindsay, 1979). Using this concept, phosphate rock has been used to immobilize Pb on several Pb contaminated soils (Ma and Rao, 1999). However, the quantity of phosphate rock required is abnormally high and, more so, as the pH of the soil increases. As an alternative, they suggested field application of a mixture of water soluble P with phosphate rock to reduce the requirement. Mench *et al* (1994) showed that application of hydrous manganese oxides was more effective than lime, basic slag and hydrous iron oxides in reducing the transfer of Cd and Pb from contaminated soil to soil-solution and further restricted their entry into food chain via plant uptake. In a greenhouse experiment, Singh *et al* (1989) showed that addition of lime and FYM together significantly reduced DTPA extractable Cd in a Fatehpur loamy sand alkaline soil (Table 17). This resulted in reducing the toxic effect of Cd and improved the yield of wheat. Two points emerge from these studies: i) As seen from the work of Singh *et al* (1989), there is limit beyond which application of lime or FYM or a combination is not effective in containing Cd level to a safe limit. ii) Since heavy metals remain in the system in an inactive form, it is a temporary relief and, sooner or later, the immobilized heavy metals become available for plant uptake. In the absence of data on long-term effects of such amendments, it is difficult to suggest such remedies for containing heavy metals in soils.

Alteration in the ratio of different cations in soil may help reduce uptake of heavy metals by plants. For example, Lepp (1981) suggested that maintenance of Zn : Cd ratio of 100:1 in Cd containing wastes helped in exclusion of Cd from the food chain. Garai (2000) further showed that application of Zn to boro rice drastically reduced Cd uptake by rice. However, care should be taken to see that while altering the ratio to reduce the uptake of one heavy metal, it should not lead to accumulation of the other.

Utilization of less water to produce unit biomass would reduce heavy metal input into the soil-water system from heavy metals contaminated waste-waters and their subsequent uptake by crop plants. Hence, increasing water use efficiency of crops will reduce heavy metal content in crops. Garai (2000) showed that judicious, intermittent pounding rather than continuous flooding injected less ‘As’ in soil because less water was used for raising the crop on ‘As’ contaminated soils in West Bengal.

Bioremediation

In recent times, interest has stirred up for finding a biological solution to the problem of heavy metal pollution. Certain organisms and plants have the ability to absorb heavy metals in exceptionally large proportions compared to others. Utilization of such organisms/plants to remove accumulated heavy metals from soil, water and other growth

Table 17. Effect of lime and FYM on DTPA extractable Cd on alkaline soil

Applied Cd	Soil amendment				
mg kg^{-1}	Control	$CaCO_3$	FYM	$CaCO_3$+FYM	Mean
0	0.2	0.2	0.4	0.3	0.3
12.5	8.1	3.5	6.4	5.5	5.9
25	13.9	9.3	13.8	12.6	12.4
50	25.3	18.0	31.6	21.6	24.1
100	61.7	43.3	60.6	47.1	53.2
Mean	21.9	14.9	22.6	17.4	

CD(P = 0.05)Cd = 2.6, Amendment= 2.3, Cd X Amendment = 5.2

media is termed bioremediation. This phytotechnology using plants for clean-up of contaminated site, soil or water is known as phytoremediation. Some aquatic plants absorb heavy metals from contaminated waste-waters and marshy lands (Chigago *et al*, 1982; Selvapathi and Sreedhar, 1991; Wolverton and McDonald, 1978). Panda (1996) showed accumulation of 5320 and 7850 mg Ni kg^{-1} in water hyacinth and water lettuce, respectively. The corresponding values for Zn were 14420 and 18040 mg kg^{-1}(Fig 5). Zinc is preferentially absorbed by both the plants, with water hyacinth being more effective.

Vajpayee *et al* (1995) showed that Cr rich tannery effluents can be treated with mixed cultures of some aquatics to reduce the load of Cr in the effluent before discharge. Some examples of aquatics that are super absorbers of Cr are *Bacopa monnieri, Hydrilla verticillata, Nymphaea albahave and Spirodela polirrhiza.* Monocultures were able to remove Cr to an extent of 50 % from Cr rich effluent. Mixed cultures of *Hydrilla verticillata* and *Spirodela polirrhiza* removed 40.2, 43.0 and 45.0% from 75, 50 and 25% diluted tannery effluents in a period of 14 days (Vajpayee *et al*,1995). If we calculate the removal of Cr in absolute terms, the mixed cultures removed more Cr than monocultures.

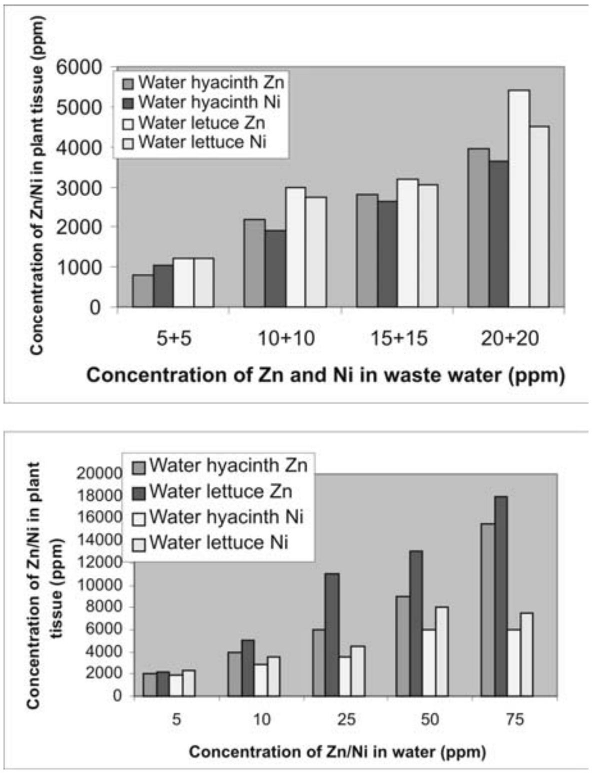

Fig 5. Removal of Zn and Ni from solution culture by water hyacinth and water lettuce

Phytoremediation of contaminated soils

Reclamation through removal of heavy metals from contaminated soils using accumulator plants is the goal of phytoremediation. As already stated, phytoremediation depends upon the ability of certain plants to absorb heavy metals in larger proportions than other plants, such that their cultivation on contaminated soils should remove heavy metals (Baker *et al*, 1994, Brown *et al*, 1994, 1995a, 1995b; Blaylock *et al*, 1997; Carey, 1996; Chaney *et al*, 1997; Cunningham and Ow, 1996; Cunningham *et al*, 1996; Dushenkov *et al*, 1995; Moffat, 1995; Nanda Kumar *et al*, 1995; Raskin *et al*, 1994; Rouhi, 1997; Salt *et al*, 1995). Phytoremediation requires that the target metal must be (1) available to the plant root, (2) absorbed by the roots, and (3) translocated from the root to the shoot. The metal is removed from the site by harvesting the plant material. After harvesting, the biomass is processed to either recover the metal or further concentrate the metal to facilitate disposal.

Plants absorb heavy metals by the same mechanisms as they absorb nutrient elements. Characteristically, plants exhibit a remarkable capacity to absorb what they need and exclude what they don't need. But most vascular plants absorb toxic and heavy metals through their roots to some extent, though to varying degrees ranging from negligible to substantial. Sometimes, absorption occurs because of chemical similarities between nutrient and toxic metals. Some plants utilize exclusion mechanisms, where there is a reduced uptake by the roots or restricted transport of the metal from root to shoot. But, hyperaccumulator plants absorb and concentrate metals in both roots and shoots (Baker, 1981). Some plant species endemic to metalliferrous soils accumulate metals in % concentrations in the leaf dry matter (Brooks *et al*, 1977). The term 'hyperaccumulator' was introduced by Brooks *et al* (1977) for plants growing on serpentine sites that are capable of concentrating Ni to more than 1000 ìg g^{-1} (0.1 %) in their leaves on a dry matter basis. A concentration of 1000 ìg g^{-1} has also been used to delineate exceptional uptake of Cu, Co, and Pb. The delineation level is raised to 10,000 ìg g^{-1} (1.0 %) for Zn and Mn because of greater background concentrations of these metals in soil. Chaney *et al*, (1995) proposed that a viable phytoremediation technology would require breeding for improved cultivars of hyperaccumulators and development of improved agronomic practices. For species like *Thlaspi*, for which yield is too low to support phytoremediation, bioengineering may be necessary to develop high biomass hyper-accumulating plants. They concluded that hyperaccumulator plants could be developed to remedy soils contaminated with heavy metals, and that in the near future, commercial phytoremediation will compete with engineering approaches for remediation of contaminated soils. Entry *et al* (1996) proposed that the concentration of radionuclides in the ash of incinerated hyperaccumulators would be a more desirable outcome than mechanical methods currently employed.

The concept of using hyperaccumulator plants to decontaminate industrially zinc contaminated soil was first tested at a farm managed by Rothamsted Experiment Station in England (McGrath *et al*, 1993). Ten plant species were tested over four seasons. These were: *Thlaspi careulescens*, *Thlaspi achroleucum*, *Cadominopsis halleri*, *Reynoutria sachalinense*, *Cochlearia pyrenaica*, *Alyssum lesbiacum*, *Alyssum murale*, *Raphanus sativus* (radish), and *Brassica napus* (spring rape). Highest Zn uptake was obtained with *Thlaspi careulescens*, which had the potential to remove equivalent of over 40 kg Zn ha^{-1} yr^{-1}. Baker *et al* (1991) conducted a pot study with soils from long-term field plots, using metal-tolerant (including hyperaccumulators) and normal plants. They concluded that phytoremediation using certain species could offer a low cost, low technology alternative to current clean-up technologies. Ernst (1988) harvested plants from natural stands on several contaminated sites and came to a different conclusion. He measured relative abundance in and metal uptake by various plant species and concluded that phytoremediation was not a viable remediation technology. Although hyperaccumulator plants were present on contaminated sites, these were not harvested because of their low growth and rosette characteristics.

Hyperaccumulation is often associated with plants with relatively slow growth rate. Some plant species have lower shoot concentrations of metals but greater biomass production. For example, the natural growth pattern of *Thlaspi* is problematic for mechanical harvesting. But *Silene*, which accumulates metals less than *Thlaspi*, grows more rapidly and vigorously. *Silene* is also more capable of colonizing a contaminated site because of its seed and rhizome production. These factors would favour establishment and harvesting of *Silene* over *Thlaspi* (Baker *et al*, 1994). Fundamental to the environmental and economic success of phytoremediation is existence of plant genotypes that hyperaccumulate metals. To maximize metal concentration in the biomass, it will be necessary to use a combination of improved soil management inputs (e.g., optimized soil pH and mineral nutrition, minimal concentrations of interfering elements, introduction of agents that increase concentration and diffusion of metals in the soil), improved genotypes with optimized metal uptake, translocation and tolerance, and improved biomass yield (e.g., > 20 t ha^{-1}). Individualized (customized) practices may need to be developed for specific sites.

Distribution of hyperaccumulator plants

Hyperaccumulator plants are geographically distributed, are found throughout the plant kingdom and approximately 400 taxa (Table 18) include representatives of many families, ranging in growth habit from annual herbs to perennial shrubs and trees. Hyperaccumulator plants have been identified on all the continents, both in temperate and tropical environments. Natural occurrence of hyperaccumulators for Ni is recorded in New Caledonia, Cuba, Southeast Asia, Brazil, southern Europe and Asia Minor; for Zn and Pb in northwest Europe; and Cu and Co in south-central Africa. Some families and genera are particularly well documented for Ni accumlation [Brassicaceae (*Alyssum* and *Thlaspi*), Euphorbiaceae (*Phyllanthus and Leucocroton*) and Asterceae (*Seeio and Pentacalia*)], For Zn Brassicaceae (*Thlaspi*), and for Cu and Co (Lamiaceae, Scrophulariaceae) (Baker *et al*, 1991; Baker and Brooks, 1989). There are not many Cr hyperaccumulators in nature, but there are numerous Ni hyperaccumulators (Table 18). Few Cr hyperaccumulators have been identified, partly, because in nature, Cr exists predominantly in the +3 oxidation state and is very insoluble, much less available for plant uptake.

Multi-metal accumulators

The ability of a plant to hyperaccumulate any one metal may confer some ability to that plant to accumulate other metals (Reeves and Baker, 1984; Baker *et al*, 1994). Some metals may interact competitively for accumulation (e.g., Zn and Ni in calamine and serpentine soils). The number of Ni hyperaccumulator taxa are over 300 in 35

Table18. Number of metal hyper accumulator plants

Metal	Concentration (% in leaf dry matter)	No. of taxa	No. of families
Cd	>0.01	1	1
Co	>0.1	26	12
Cu	>0.1	24	11
Pb	>0.1	5	3
Ni	>0.1	>300	35
Mn	>1.0	8	5
Zn	>1.0	18	5

Source: Baker and Brooks, 1989; Hossner *et al.*, 1998

Table 19. Time required (years) for cleaning Cd and Pb contaminated soils using toria (*Brassica* sp)

Level of Cd/Pb in soil	Concentration of Cd in toria	Dry matter yield (t ha^{-1})	No of crops to be grown to reduce soil Cd to below permissible limit	Time required to reduce soil Cd to below permissible limit	Concentration of Pb in toria	Dry matter yield (t ha^{-1})	No of crops to be grown to reduce soil Pb to below permissible limit	Time required to reduce soil Pb to below permissible limit
50	44.7	2.36	853	284	103	2.44	-	
100	82.2	2.41	959	320	119	2.40	-	
200	122.4	2.03	1570	523	120	2.40	-	
500	357.9	1.18	2344	781	122	2.06	151	50
1000	407.2	0.80	6109	2036	137	1.89	414	138

Safe level in soil for Cd = 5ppm and Pb = 200 ppm

families. These commonly have 3-4% Ni in leaf dry matter but this may range as high as 25%. *Alyssum betolonii*, which is endemic to serpentine soils, is known for its high concentration of Ni (> 10,000 mg kg^{-1} in leaf). The fact that serpentine (ultramafic) soils also contain other elements such as Cr has led to the assumption that preferential accumulation of Ni in many species of *Alyssum* is due to a selective uptake mechanism. Gabbrielli *et al*, (1991) showed, in controlled experiments, that excised roots of *Alyssum bertolonii* seedlings did not show selectivity for uptake of any specific metal. Plant roots tend to accumulate Ni, Co and Zn without discrimination and with the same saturation trend, demonstrating absence of competitive action between these three elements. Clones of *Salix viminalis* were also found to have high concentrations of heavy metals (Cd, Cu and Zn) in their shoots. Baker *et al* (1994) suggested common mechanisms of absorption and transport of several metals by *Thlaspi* species. They observed high uptake by roots for all the metals studied. Zn, Cd, Co, Mn and Ni were readily transported to the shoot, whereas, aluminum (Al), Cr, Cu, iron (Fe) and Pb were predominantly immobilized in the root. Reeves and Baker (1984) showed that hyperaccumulator plants growing naturally in calcareous soils were able to tolerate serpentine soil and absorb elements other than Ni. It was observed that when a population of *Thlaspi goesingense* ‘Halacsy’, taken from a calcareous soil, was grown on a serpentine soil, extremely high concentrations of Ni, Zn, Co, and Mn accumulated in its above-ground dry matter. Absorbed metal concentrations were similar to those observed in *Thlaspi* growing naturally in serpentine soils.

Indian mustard has been identified as one of the super accumulators and is extensively tested for phytoremediation (Ebbs and Kochian,1997; Su Dc Wong, 2004). A large number of brassica species are grown in India. These species are of short duration and put forth a large biomass in a short period. Screening of brassica species for phytoremedial properties showed that Toria (*Brassica sp*) is better than Indian mustard (Sumangala *et al*, 2007). Using toria as an example we hypothetically calculated the time required for cleaning up a soil contaminated with Cd and Pb (Table 19). The time required to reduce the Cd level in the soil to safe level as recommended by PFA (5ppm Cd kg^{-1} soil) varied from 284 years for soil having initial Cd level of 50 mg kg^{-1} soil to 2036 years in soil having initial Cd level of 1000 mg kg^{-1} soil. Similarly, it requires 50 years to clean up a soil contaminated with Pb to a level of 500 mg kg^{-1} soil to 138 years in soil having Pb concentration of 1000 mg kg^{-1} soil.

Thus, a very long period is required to clean up contaminated soils with this technology. Further, the time required may still be more than estimated because uptake of metals by a plant may not remain constant as the elemental concentration keeps getting reduced. In the present calculation, moreover, only surface soil was taken into account. If subsurface soil were also to be considered, the time taken would increase further. Pierzysnski *et al* (2000) reported that a period of 100 years was required to remove 202.5 kg Ni from surface soil alone. If subsurface is also considered, the time needed would be 2-3 folds higher. Moreover, handling of such a large biomass and its safe disposal, economic and social considerations will all come in the way of implementing these recommendations. Hence, with the present level of knowledge and plant type available, phytoremediation is not a practical way of reducing heavy metal levels in contaminated soils. Biotechnological interventions are required to tailor plants for phytoremediation to make it a viable technology.

Remediation through meat animals

Use of biomass produced on contaminated soils to feed meat animals is reported to be a moderately effective screen against entry of heavy metals into the food chain. In a study (Johnson *et al*, 1981), beef animals fed on a diet containing 11.5% (dry matter basis) of moderately high Cd sewage sludge was fed to six Hertford steers for 106 days to simulate a high sludge intake from sludge-amended soils. The sludge metal content (ppm, dry basis) was: Cd, 98; Hg, 18; Pb, 466; Cu, 1,733, and Zn, 1,733. Addition of sludge increased metal content of the feedlot diet to 30 to 100 times that of the control. Retention of heavy metals in the total animal from sludge ingestion averaged 0.09%, 0.06% and 0.3% for Cd, Hg and Pb; no retention was noted from Cu and Zn. These low fractional retentions increased tissue Cd, Hg and Pb concentrations of liver and kidney by five to 20-fold. Estimates of levels that would enter the human diet from average beef tissue consumption, if all feedlot steers were fed with sludge, are presented for Cd, Hg and Pb (Table 20).

These data indicate that if all feedlot cattle in the United States ingested 1 kg of sludge containing 98 ppm Cd every day for 100 days, the average daily Cd intake per capita would increase by approximately 2.4 micrograms. Present intake estimates, as reviewed by Underwood (1977), vary from 26 mg/day from a 1969 United States survey, or 67mg /day from a 1971 Canadian survey, to 50 to 15mg / day from a WHO report on world Cd intake. Some segments of the population, such as vegetarians, probably consume considerably greater amounts (Braude and Jelinek, 1977). Pb was the only metal (of the five assayed) showing accumulations in both bone and brain tissue. The tissue with the greatest concentration of Pb in the control animals was bone, with 5.0 ppm, which agrees with the general values in literature (Underwood, 1977). In the sludge-fed cattle, Pb concentrations were highest in kidney tissue, averaging 10.8 ppm. Nevertheless, total retention or increased body content was still found overwhelmingly (>90%) in the skeleton. Entry into the human diet would occur largely through liver and kidney consumption and, on an "all beef fed sludge" basis, would be expected to increase dietary Pb by approximately 1.5mg/person/day. Underwood (1977) has reported that long-term intake of 100mg/day would be necessary before the first clinical sign would be expected to appear in human. Longer and (or) multiple exposure of the United States cow herd could result in greater body burdens than found in these experiments, and it might be argued that concentrations of even 2mg of Cd may be of concern. However, data generally indicate that cattle are a moderately effective screen against entry of Cd, Hg and Pb into the human diet. Since beef is not the major meat in Asian countries, there is need to generate such information for common meat sources like sheep, goat, rabbit, poultry, etc.

Table 20. Accumulation of ingested sludge Cd, Hg and Pb in body tissue (milligrams per steer)

Tissue	Content above control Cd (ppm)	Hg (ppm)	Pb (ppm)
Liver	5.5	0.31	4.74
Kidney	2.3	0.34	1.73
Bone	0.0	0.00	124.0
Spleen	0.09	0.01	0.75
Lung	0.35	0.03	0.11
Brain	0.0	0.00	0.03
Lean separable	1.23	0.47	0.00
Total	9.36	1.16	131.5
% retained in tissue	0.09	0.06	0.30

Alternative land use

With the current level of knowledge, use of UPA land to grow crops that supply food/fodder/vegetables or any other edible crop using any of the remediation methods available today cannot assure prevention of heavy metal entry into the food chain. As the rate of urbanization keeps increasing day after day, so does generation of waste material and pollution becomes aggravated. Hence, we must look at other alternatives of using UPA lands. Several non-food crops can fit well into the UPA and generate remunerative income to farmers and, possibly, reduce entry of heavy metals and other toxic chemicals into the food chain. There is a huge demand for loose flowers like chrysanthemum, marigold, aster, crossandra, jasmine etc in the cities of India. All these flowers can be grown extremely well using city sewage waters and sludges as manures. Sumangala *et al* (2007) evaluated some annual flowers for their performance in heavy metal contaminated soils and found that these plants performed well, even at soil concentrations exceeding 500 ppm of Cd and Pb, in terms of flower quality and yield. Results on marigold crop are presented in Table 21. In periurban Bangalore, mulberry is grown by several farmers, the leaves of which fed to the silkworm. This has not had any adverse effect on growth of silkworms or quality of silk produced. This is a viable alternative to many Indian UPA areas as the climate in most of the cities is suitable for sericulture. Cultivation of crops like maize, sugarcane, tapioca and others exclusively for alcohol production using effluents and sewage sludge can be promoted as an economically viable alternative to

Table 21. Performance of marigold in heavy metal treated soils

Concentration of heavy metal (ppm)	Cadmium (Cd)			Lead (Pb)		
	No. of flowers	Flower diameter (mm)	Yield/plant (g)	No. of flowers	Flower diameter (mm)	Yield/plant (g)
0	5.10	8.25	23.2	4.60	8.89	24.8
50	4.88	7.13	24.3	4.31	7.75	22.7
100	5.15	7.81	24.3	4.85	7.31	24.3
250	4.32	9.38	25.8	4.77	8.93	22.9
500	4.10	7.81	23.9	4.42	8.25	24.3
1000	5.03	7.50	23.5	4.83	9.75	21.8

increase biodiesel production. Other biodiesel plants like jatropha, cimaruba and pongamia also perform well on such soils. However, there is a need to evaluate the performance of such crops in polluted soils. Many timber species like sheesham, rosewood, teak, Arjuna, neem, etc. can also be grown in periurban polluted soils. These can also serve as multipurpose crops like a green belt to the city, prevention of dust, creating congenial atmosphere for many animals and birds, a study spot for school children and a recreation centre for the urban lot. A detailed scientific investigation is required to evaluate crops that are suitable for UPA lands, economically viable, environmentally safe and socially acceptable.

Environmental policies

India has a wide ranging set of environmental laws that lay down norms for air, water, soil, wastes, etc. A dramatic shift in perception and approach to environment from the traditional ways of dealing with problems under various types of nuisance and municipal laws has occurred in the past two decades. People are realizing that the environment is under severe pressure, especially in the current economic development phase. The society has become an important driver and is proactive, despite having little access to information. The mass media is helping citizens to access information. The courts have also interpreted environmental protection as part of fundamental rights besides being very progressive in and cutting through embroiled political process. Besides legislation of several new laws, environmental activism has been high with increasing general awareness. Interpreting Article 21 of the Indian Constitution on “Right to life” to include “Right to a clean and healthy environment”, the Supreme Court has enunciated and activated several other fundamental principles of environmental management, including “Polluter pays” and the “Precautionary principles” in its various judgments.

Soon after the Stockholm Convention of 1972, India embarked upon passing various acts of parliament dealing with environment. Beginning with the Water Act in 1974, and the Air Act in 1981, the subsequent Bhopal gas disaster led to adoption of a broad-based Environment Protection Act (EPA) of 1986 that gave the government powers not only to prosecute offenders but also to frame laws and notify standards, as and when required, for environmental conservation and preservation. Some attempts at enunciating policy were also made. For example, in 1992, Government of India issued the “National policy on pollution abatement” that read more like a wish-list rather than a practicable, actionable document. Alongside, under the provisions of EPA, several new legislations (dealing with various aspects of environment, both urban and rural ,including coastal regions, forests, industry, urban areas waste, noise) have been notified over the years. Several new source standards have been made as minimum National Standards, applicable throughout the country without exception. Prevention of Food adulteration (PFA,1954) is under revision and a revised version will be available in 2008. Efforts are on to ratify multilateral environmental treaties to bring national legislation in line with international laws.

Effectiveness of regulations: The legislative framework is developed on the belief that a policing model is sufficient. However, it does not automatically go beyond that. Despite stringent laws, it is commonly felt and accepted that environmental degradation is on the increase, contamination of soil, water and air is rising. Contamination of food and ground water with heavy metals and other chemicals is alarming. In a nutshell, citizens feel that despite legislative efforts, environment of the country is in sorry state owing to “lack of implementation” of the laws. Our environmental interventions are limited mainly to technical standards and compliance requirements. This approach does not help environmental improvement**.**

It needs to be backed up by governance, house-keeping, and education and involvement of the citizens. There is enormous need for capacity-building in this area.

Involvement of citizenry: Environmental decision-making should involve citizenry at every step. However, little effort is made on sharing information, emphasizing transparency and access. The "Right to information" act is a step forward in this direction. Through this, environmental information may be more accessible, but it is still to be tested out enough. Even now, it is extremely difficult for anyone to obtain information on extent and type of pollution from a neighborhood industrial unit. This demonstrates lack of recognition on the part of policy makers on impact of pollution on health of people and also their role in protecting the environment. In developed societies, where strong regulatory approach has been successful, there is a simultaneous information access and availability, which in itself has a salutary effect on keeping pollution in check. Hence, in the absence of continuous data generation, monitoring and no voices of citizens being heard by the state, the issue of environmental compliance has become an arbitrary business between the regulator and the regulated leading to corruption and increased judicial and citizens activism to protect themselves from the breakdown. On the ground environmental degradation is the order of the day.

New paradigm: In the light of rapid economic development, the state is trying almost literally to do away with the regulatory framework and replace it solely with a system of voluntary action and other instruments like economic and market-based incentives. The draft national policy of August 2004 on environment, which reads more like an environmental economic document, using cost-benefit as the *raison d' etre* rather than what has been the trend until now, of environmental protection as an objective in itself, is a reflection of the government's intention. Key legislations which came up for review, like the Coastal Regulation Zone act (CRZ) and Environmental Impact Assessment (EIA) notifications, restrict the land on which industrial activities are banned, severely controlled, or at least need to go through elaborate environmental justification and procedures for clearance. In 2003, the Central Pollution Control Board drew up a new charter of social responsibility in an attempt to woo industries to take up environmental measures more "voluntarily" since regulation was impossible. These reviews are being watched by the environmental community with horror. Such moves are a reflection of the State's intention about the industry, environmental protection and its own role in this interaction. In short, this is being read as a dismantling of the existing regulatory framework. Regulatory mechanisms may not be effective in isolated cases but are essential drivers to augment other approaches, both by putting a "cap" on the level of degradation that is socially acceptable, as well as creating space for other, cleaner and more acceptable alternatives to be "viable". They need to be augmented with other instruments and approaches, not discarded. This would imply integrating environmental policies in other sectoral and developmental policies, as well as moving towards more grass root level inputs and guidance into decision making. For example, if vegetables consumed have a high level of heavy metal concentration or pesticide residue, the remedy lies in prevention of contamination of water and soil at source by treating water before it is let into rivers, streams and drains; changing land-use in periurban areas or influencing pesticide spray practices in agriculture, improving food marketing, making hygienic retailing outlets as well as raising consumer awareness, and not in stand-alone environmental policies. Also, if local Panchayats have a say in such practices, the farmer can be more effectively addressed. The following case study of a problem of recent origin, briefly stated, argues the case:

Import of second hand computers: Computerization is a part of the 'new economy' and is lauded as a key to development in the region. The current computer density of <5 per 1000 is likely to rise over >20 per 1000 under the new IT policy of 2008. All measures to make this happen, including import of second-hand computers, are being explored and allowed in legislation and policies. As already mentioned earlier, end-of-life computers and electronic products, a major component of e-wastes, are becoming a worrying source of heavy metals and other harmful toxic substances. Looking at the danger from E-wastes, Europe and other developed countries have taken several policy measures calling for a change in material and 'producer responsibility' for recycling and final disposal. Utilizing this opportunity, India is becoming a dumping ground for second-hand computers, favoured by governmental policies. Regulations in the developed countries are becoming more demanding. Added to it, an extremely high obsolescence rate of computers (due to new technology and softwares), falling prices and new features, old computers are sold at the price of junk and grabbed by India, whereas China has banned imports.

In any legislation to follow, the effort should be to include both a regulatory framework and other objectives. There is also a need to lay special emphasis on inclusion of the existing recycling sector as another factor. Such legislation must go beyond mere standards. It must encompass management practices, take back targets which are progressively increasing, efficient collection system and norms and to involve the existing informal recycling sector. Such a law may have to be augmented with financial advantage and disadvantages and information transparency mandate for it to be workable. Alongside, it must recognize that the role of the municipality is a key in an efficient collection system, such as has been seen in several countries. No doubt this process will take more time to evolve than a purely standard-driven system, and it also needs more negotiations. But as past experience demonstrates, it would have a higher likelihood of success (Agarwal, 2006; The Hindu, 2008). The key will be to balance 'standards' with other options.

Looking ahead

Increase in population and maintaining a cleaner environment cannot go together. Pollution is bound to increase with increase in population. This is a reality and we must learn to live with it. Like Survival of the Fittest, it is human intelligence which has to show ways to survive such adverse situations. With the present level of knowledge, a foolproof method to contain heavy metal pollution is not available. But the search for remedial measures should not stop. Alternate land use is a promising area of research to contain entry of heavy metals into the food chain. Work in this direction needs to be intensified. The level and intensity of educating people about problems of heavy metals is not enough. There is need for capacity-building in this field at various levels. The policing model legislative framework is not sufficient. Regulatory mechanisms may not be effective in isolated cases, but are essential drivers to augment other approaches, by putting a "cap" on the level of degradation that is socially acceptable, as well as creating space for other, cleaner and more acceptable alternatives to be "viable".

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