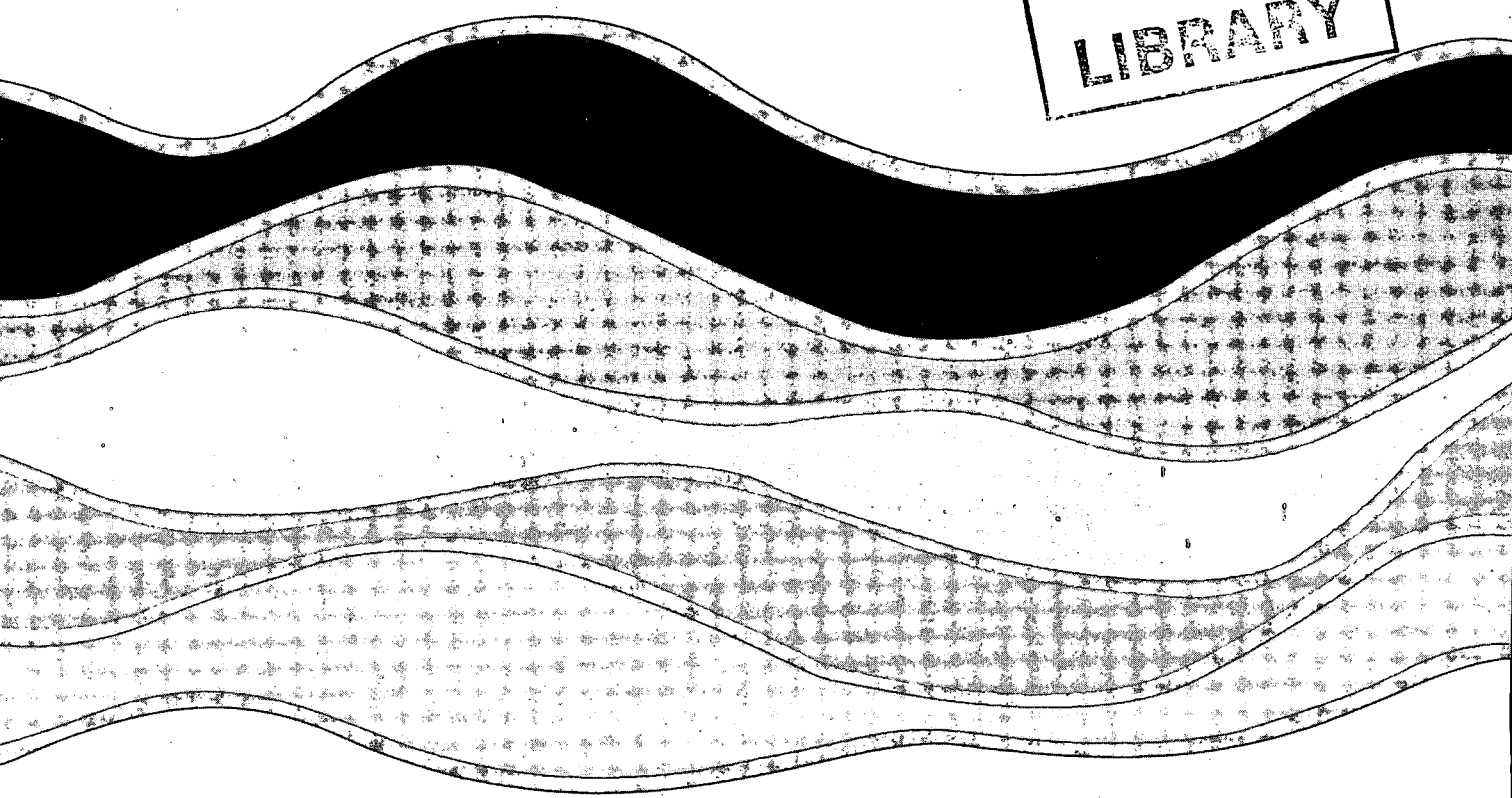
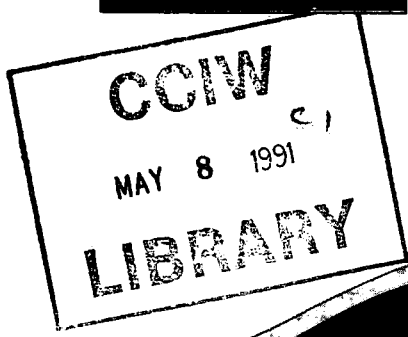
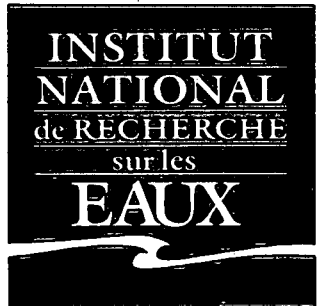
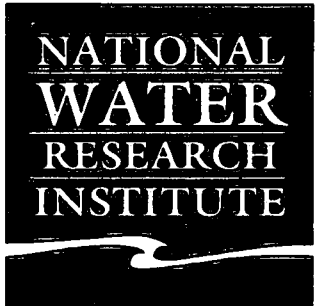
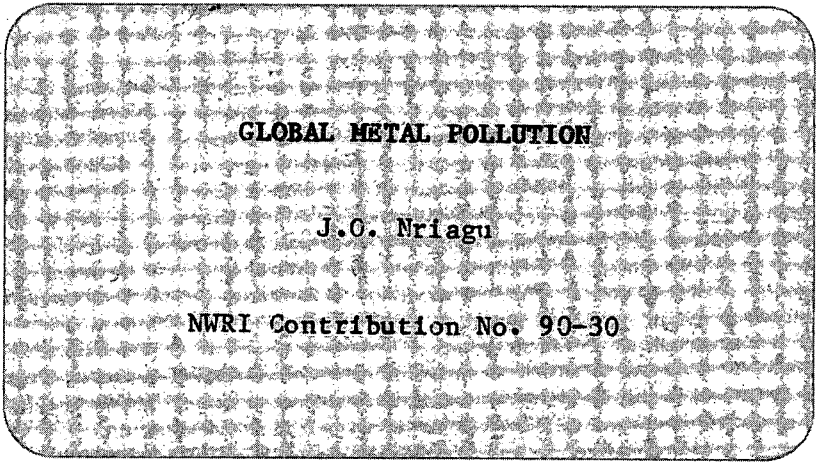


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## **EXECUTIVE SUMMARY**

This is an invited feature article to be published in the journal, *Environment*. The report provides a review of the sources, distribution and fate of trace elements in various environmental compartments. Present-day emissions of metals into the biosphere by mining and industrial activities exceed the mobilization by natural weathering processes by several orders of magnitude for such metals as lead, copper, mercury, cadmium, chromium and zinc. The conclusion is reached that the contamination of our environment with toxic metals has become a global phenomenon and that the current levels of metal pollution may be harmful to the most sensitive organisms in some ecosystems. The human perturbation of the regional and global trace metal cycles is highlighted and concern is expressed about the growing trace metal pollution in the developing countries.

## RÉSUMÉ

Il s'agit d'un article vedette sollicité, qui sera publié dans la revue *Environment*. L'auteur examine les sources, la répartition et le sort des éléments traces dans divers compartiments de l'environnement. Les émissions actuelles de métaux, comme le plomb, le cuivre, le mercure, le cadmium, le chrome et le zinc, dans la biosphère, entraînées par les exploitations minières et industrielles, excèdent de plusieurs ordres de grandeur la capacité de mobilisation des processus naturels d'altération. On conclut que la contamination de l'environnement par des métaux toxiques est devenue un phénomène mondial et que les valeurs actuelles de pollution par les métaux pourraient nuire aux organismes les plus vulnérables de certains écosystèmes. On souligne le fait que les activités humaines perturbent les cycles régionaux et mondiaux des métaux traces et que la pollution due aux métaux traces prend de plus en plus d'importance dans les pays en développement.

# GLOBAL METAL POLLUTION

By

Jerome O. Nriagu\*

## INTRODUCTION

Since the beginning of this century, the rapid increase in metal production has been closely linked to the marked increase in the gross national product of the developed countries and to the total increase in global population. As economic conditions improved and basic needs were satisfied, modern societies increasingly made sophisticated demands entailing a range of new metallic products with specific physical and chemical properties. Each new process or compound employed by the advanced science and technology generates a different type of metallic waste which must be discharged into the environment. Large quantities of metal-enriched wastes likewise arise from the ever-increasing production of goods and services for human comfort and the huge quantities of fossil fuels which must be burned to generate the energy needed to sustain the industrial and domestic activities.

In a modern affluent society, goods and services are bought not just because of need, but also on the basis of advertisement and fashion or to sustain a particular techno-economic institution that provides employment. Such a stimulus of demand encourages frequent discarding and replacement of goods while the industrial survival is often determined by the unending supply of disposable goods. This consumption feature of industrialized societies predicated upon changing

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fashion and planned obsolescence on the part of the industry has resulted in a drastic shortening of the lifetimes of many products and the generation of enormous amounts of metal-containing wastes. The near total reliance on energy-inefficient systems (anchored by fossil fuels), the wastefulness in the traditional manufacturing technology and the societal demand for short-lived goods and services leads to the suggestion that a high proportion of our resources is consumed to generate toxic metallic wastes. Inevitably, a build-up of toxic metals in the food chains has resulted from the massive quantities of the metals being discharged into the various environmental compartments. This report focuses on the sources, distribution and effects of trace metals in various environmental compartments. It concludes that the contamination of our environment with toxic metals has become a global phenomenon, and that man-induced changes have overwhelmed the natural biogeochemical cycle of trace elements in many ecosystems. The available information suggest that the current levels of pollutant trace metals have become stressful to a large number of the sensitive fauna in the biosphere.

## **HISTORICAL**

Environmental contamination with trace metals began with the discovery of fire. The burning of firewood released small amounts of metals to the air and the metal-enriched wood ash was generally discarded in the surrounding field. With the discovery of mining and metal working techniques in ancient times, the close linkage between metals (and metal pollution) and human culture was forged. By the time of the Roman Empire, large quantities of metals especially lead (aptly called a "Roman metal") were required to sustain the high standard of living (Ref. 1). The mine workings were done on a small scale but the uncontrolled smelting in open fires often resulted in severe local contamination. Both Xenophon and Lucretius observed that the noxious

emissions from the precious metals mines at Laurion (in Greece) and other places were harmful to health. Vitruvius spoke of extensive water pollution in his time while Pliny observed that emissions from mines and smelters were dangerous to all animals and especially to dogs. The interdiction of mining operations near ancient cities and the Roman edict forbidding any mining activities in Italy have been attributed to the concern for environmental quality (1, 2). The well-documented pandemic lead poisoning during the period of the Roman Empire, however, had little to do with environmental pollution but was a consumer disease which stemmed from extensive contamination of food, water and wines with lead (see Ref. 1).

With the development of large furnaces equipped with tall stacks during the 16th century, the sphere of influence of smelters and industrial installations was extended drastically. Trace metal profiles in peats, lake sediments and ice sheets show that by the end of the 17th century the pollutant metals released by industries in Britain and central Europe were reaching most regions of Scandinavia (3). Accelerated accumulation of lead pollution in Greenland ice fields began around the turn of the 18th century (4). A large volume of literature on historical records in soils, peats, ice sheets, sediments and tree rings in most parts of the Northern Hemisphere documents pervasive trace metal pollution of increasing severity from the beginning of Industrial Revolution (3). Between 1850 and 1900, worldwide industrial emissions of Cd, Cu, Pb, Ni and Zn to the atmosphere averaged about 380, 1800, 22000, 240 and 17000 metric tonnes per year, respectively (5). Since the turn of this century, the ever-expanding technological development has resulted in sharp increases in the industrial consumption and release of toxic metals to the environment. Between 1900 and 1980, the mine production of Al, Ni, Cr, Cu and Zn increased by 114-, 35-, 18-, 5-, and 4-fold while the mine outputs of Cu, Pb, Ni and Zn during this time totalled about 250, 160, 17 and 185 million tonnes, respectively (5, 6). Sooner or later, all the "new" metals from the mines will be dissipated in the biosphere. During the first 80 years of this century, the industrial emissions of Cd, Cu, Pb, Ni and Zn to the air increased by 8-, 6-, 9-, 51-, and 8-fold, respectively (5). These figures certainly show that the quantity of toxic metals being discharged into the environment is considerable. Once dispersed in the biosphere, the metals cannot be

degraded or recovered using current technology. Any environmental effects of trace metal pollution therefore tend to be permanent.

## INDUSTRIAL EMISSIONS OF TRACE METALS

Metals are discharged into the air, water and soils from a wide variety of natural and industrial sources. The derivation of any inventory of global emissions is hampered by the sparsity of data on metal contents of raw material and by uncertainty in the global distribution of sources especially in the developing countries. Nevertheless, global inventories that have been published recently, though crude, leave no doubt as to the great impact of industrial activities on the regional and global cycling of the trace metals.

The emissions of trace metals from primary natural sources to the atmosphere are shown in Table 1. Wind-uplifted soil particles account for over 50% of the Mn, Cr and V, and for 30-50% of the Sb, Ni, Mo and Zn. Volcanoes contribute over 60% of the Cd, 40-50% of the Hg and Ni, and 30-40% of the As, Cr and Cu fluxes from natural sources. Biogenic sources (biologically mediated processes in various ecosystems) are the leading contributors of As, Hg and Se while wild forest fires or seasalt sprays generally account for less than 15% of the total natural emission of each element. It is conceivable that some of the metals emitted by natural sources are derived anthropogenically; for instance, some of the metals in windblown dusts may be of industrial origin. Thus, the data in Table 1 probably overstate the actual natural fluxes of metals into the pre-industrial atmosphere.

The three main industrial sources of atmospheric metal pollution are the mining, smelting and refining of metals, the burning of fossil fuels and the production and use of metallic commercial products (Table 2). The burning of fossil fuels to generate energy accounts for over 95% of the pollutant V and 80% of the pollutant Ni, hence the use of these two elements to identify air parcels derived from power plants. Fossil fuels also account for about 60% of the Hg, Se and Sn and are also a

significant contributor of the Sb, As, and Cu emitted anthropogenically. Smelters represent the leading source of As, Cu and Zn while the manufacture of steel is responsible for the largest fractions of pollutant Mn and Cr released to the global atmosphere. In spite of the reduced use of leaded gasoline in many countries, the automobile tailpipe still accounts for about two-thirds of the lead emission. A large fraction of the airborne As is still being derived from the aerial application (commercial use) of arsenical insecticides (Table 2).

A comparison of Tables 1 and 2 leads to the inescapable conclusion that industrial emissions have become dominantly responsible for most of the trace elements in the air. Anthropogenic emissions of Pb, Cd, V and Zn exceed the fluxes from natural sources by 28-, 6-, 3- and 3-fold, respectively. Industrial contributions of As, Cu, Hg, Ni and Sb, amount to 100-200% of emissions from natural sources. In urban areas and around some point sources in particular, the natural inputs may be insignificant in relation to pollution metal burden.

The concentrations of any trace metals in continental waters are controlled by atmospheric precipitation and the weathering processes on soils and bedrocks. Since these pathways and processes are being significantly altered by mankind, the flux and distribution of trace metals in a large fraction of our freshwater resources must have obviously increased. In particular, the atmosphere has become a key medium in the transfer of pollutant trace metals to remote aquatic ecosystems. On a global scale, this pathway annually supplies over 70% of the V and Pb, about 30% of the Hg and 20% of the Cd flux into aquatic ecosystems (Table 3). In many rural and remote regions, the atmosphere actually supplies most of the trace metal budgets of the aquatic ecosystems. For example, well over 50% of all the trace metal getting into the Great Lakes is via the atmosphere (9).

Domestic and industrial wastewaters, sewage discharges (and urban runoff) also contribute large quantities of metal pollution to the aquatic environment (Table 3). These discharges often occur at point sources and can lead to excessive local metal burdens in water. The scientific literature is replete with case histories of lakes, rivers and marine coastal zones in every part of the world that are being polluted



with trace metals. The inventory in Table 3 suggests that the problem has, in fact, become global in scope.

Modern societies generate large quantities of metal-containing wastes of many types which are discarded on land (Table 3). In terms of the source categories used in this report, the disposal of coal and wood ashes and the general wastage (associated with corrosion, decomposition, abandonment, etc) of commercial products (including industrial installations) on land together account for about 55-80% of the metal pollution in soils. The large volumes of wastes associated with animal husbandry, logging, agriculture and food production often affect the trace metal budgets of many soils. Agricultural soils generally receive most of their trace metal pollution from the atmosphere and from fertilizers, pesticides and manure (Table 3). Because of their very high trace metal contents, municipal and industrial sewage sludges are sometimes considered unsafe for disposal on land and clearly represent one of the most important sources of trace metal contamination in local soils. It should be noted that the inventories in Table 3 do not include the site specific disposal of highly contaminated mine tailings and smelter slags on soils.

Table 4 compares the anthropogenic releases of trace metals with their mobilization during the weathering cycle. The data show the dominating influence of industrial discharges on the trace metal economy of the biosphere, with the possible exception of Mn and V (the geochemistry and industrial discharges of this element are poorly known). For Sb, Cu, Pb and Zn, the industrial discharges exceed the weathering flux by about 3-fold; for Hg it is 10-fold. When the mine outputs of the metals are also taken into account, there can be no doubt that mankind has become the key agent in the global redistribution of trace metals into the biosphere. Most of the industrial discharges occur in the Northern Hemisphere and the perturbations of the trace metal cycles in this region should be profound.

## GLOBAL DISTRIBUTION

The metals released from industrial sources are rapidly dispersed

in the different environmental compartments. The strong influence of anthropogenic inputs on the global and regional cycling of trace elements can be adduced from the causal relationships that have been observed between emission rates and ambient concentrations in many ecosystems. This point is amply demonstrated by the high concentrations of trace metals in the urban environment which can be regarded ecologically as "hot spots" of toxic metals. Average concentrations of trace metals in the urban air generally exceed the levels in rural areas by 5- to 10-fold and the levels in remote locations by up to 100-fold for many elements (Table 5). If the current loading rates were to continue, the contamination of urban air with toxic metals will likely become one of the major public health issues for the future generations. It should also be noted that the concentrations some toxic metals sometimes observed in urban rainfall now exceed the levels considered safe for drinking water; in some developing countries, rainwater is widely consumed by people who live in the urban areas. Furthermore, most of the toxic metals are associated with fine particles (less than one micrometer in size, see Table 5) which are readily absorbed in the bronchial tracts.

An extensive survey of the global distribution of lead in the marine atmosphere (10) found the highest concentrations near the urban/industrial areas off western Europe and eastern North America and the lowest levels in Antarctica. A previous study by Boutron and Patterson (11) had reported a 4-fold increase in the lead concentration between the recent and pretechnological ice layers of the Antarctica. Patterson and Duce (12) found a strong association between the distribution of airborne lead and cadmium over remote North Pacific and suggested that most of the cadmium is also derived from anthropogenic sources. In late spring of each year, the Arctic region is covered by a haze containing elevated levels of trace metals derived from industrial sources in Eurasia (13). The Arctic haze affects nearly 9% of the earth's surface area and is the most extensive air pollution system known. The examples above and many other regional surveys thus point to the fact that few places on earth are free of trace metal pollution.

Freshwater ecosystems are particularly sensitive to external trace metal inputs. The volumes of freshwater ecosystems are often small and the background concentrations of the trace metals in such waters are

notoriously low. Small additions from anthropogenic sources can therefore alter the size of the metal pool in the reservoir and hence the distribution and flow of metals in an aquatic ecosystem. The chemical forms of trace metals in water are often available to the biota and seemingly small concentrations may be strongly bioaccumulated in the food chain. If it is assumed that only 10-30% of the total discharge goes into lakes and rivers, the calculated pollution load would in fact dwarf the expected baseline concentrations of the trace metals in most lakes and rivers (8). Our freshwater resources can be considered to be at greatest risk in terms of toxic metal pollution.

The human influence on the oceanic cycle of trace metals is becoming increasingly manifested. For example, the flux of anthropogenic lead to the ocean is now large enough to change significantly the normal marine cycle of this element. Evidence for the perturbation is unequivocal. The typical profile of lead in the ocean water column is now determined by the intense atmospheric flux and is unlike the profiles of the other trace metals showing less anthropogenic influence. There is a measurable shift in the isotopic composition of lead in surface ocean waters towards the isotopic ratios of industrial lead in a particular source region. The average lead content of the mixed surface layers of the North Atlantic (polluted) is about 26-fold higher than the levels in similar layers of South Pacific (less polluted). The 15-fold difference in the lead content of recent coral shells compared to the growth layers deposited a century ago gives another indication of the magnitude of the oceanic lead pollution (see references cited in No. 14 for detailed discussion). Even the sediments of the deep Atlantic Ocean show a sharp increase in the lead content and a change in the isotopic signature of the most recent deposits which have been attributed to the increased flux of industrial lead (15).

Soils represent the ultimate sink for trace metals in the continental areas. Since metals are generally immobile in soils (except under the influence of acid rain), metal pollution tends to accumulate in the surface layers primarily. The build-up of toxic metals in the biologically most active part of the soil system, that is, the organic top soil, makes the metals readily accessible to some crops and vegetables. The chemistry of trace metals in soils thus plays an important role in the

possible transfer of contaminant metals to our food supply.

The human influence on trace metals in soils is demonstrated dramatically by the highly elevated levels of trace metals which now characterize the soils in urban areas and around major industries (see 16, 17); as to be expected, most of the pollution is delivered via the atmosphere. The median values and typical ranges (in brackets) of values reported for atmospheric fallout of trace metals in the urban areas of North America are 160 (20-980)  $\text{g ha}^{-1}\text{yr}^{-1}$  for Cu, 910 (140-3500) for Pb, 18 (7-36) for Cd and 3200 (80-4800)  $\text{g ha}^{-1}\text{yr}^{-1}$  for Zn (18). The values for urban areas of Europe are 320 (78-500) for Cu, 400 (180-600) for Pb, 310 (33-530) for Ni, 15 (3-28) for Cd and 1000 (220-5850)  $\text{g ha}^{-1}\text{yr}^{-1}$  for Zn (18, 19). At these deposition rates, the levels of most of the trace metals in surface soils should be doubled in 2-10 years depending on the baseline metal contents. Atmospheric fallout of metals in rural areas has also risen sharply; the rates in rural Europe have been estimated to be 150 (14-320)  $\text{g ha}^{-1}\text{yr}^{-1}$  for Cu, 550 (38-3900) for Zn, 220 (63-550) for Pb, 32 (7-100) for Ni and 4 (2-13) for Cd (18). Since only a fraction of the metal pollution is supplied via the atmosphere (Table 3), the human perturbation of the distribution of trace metals in urban soils is obviously substantial.

Indeed, numerous studies have demonstrated that soils in urban areas, whether from parks or domestic gardens, cities or small towns have become so highly contaminated with a wide variety of trace elements that any differences based on local geology have become obfuscated (16, 17). Typical concentrations of many toxic metals in urban and rural soils are now 2- to over 10-fold higher than the levels in uncontaminated soils (17). Moreover, the *available* levels (defined as the fraction extractable using mild reagents) have also increased markedly in urban soils (17). In terms of the elevated levels and the chemical form of trace metals, soils in urban areas have become quite unique and are unlike anything produced by natural weathering processes. Soils downwind of urban and industrialized centers also receive large doses of trace metal pollution. For example, the concentrations of Pb, Cd, As and Sb in surface soils of southern Norway are about 10-fold higher than the levels in the northern part of the country (20). The regional difference has been attributed to the exposure of southern Scandinavia to long-

range transported pollutants from Britain and central Europe. The lead contamination of forests in large areas of the northeastern United States is well documented and is due primarily to the long-range transport of industrial emissions from New England and Midwest states (21).

For arable soils, primary sources of metal pollution also include fertilizers, agricultural chemicals as well as liquid and solid wastes (Table 3). It has been estimated that the average Cd input into agricultural lands in Europe is about  $8 \text{ g ha}^{-1}\text{yr}^{-1}$  from the atmosphere and  $5 \text{ g ha}^{-1}\text{yr}^{-1}$  with the phosphate fertilizer (22). The addition of metal contamination (from fertilizers and the atmosphere) to agricultural soils in Belgium has been estimated to average 16, 20, 260 and  $3800 \text{ g ha}^{-1}\text{yr}^{-1}$  for As, Cd, Pb and Zn, respectively (23). At such loading rates, there is a growing concern that large areas of arable soils in Europe may be close to exceeding their carrying capacity for trace metal pollution. In Japan, on the other hand, the problem has already become reality -- about 9.5% of the paddy soils have been rendered unsuitable for growing rice for human consumption because of excessive metal contamination (24).

## GLOBAL EFFECTS

Environmental metal pollution may result in direct assaults on human health or have indirect effects on human welfare by interfering with the integrity and vitality of the life-support systems. Expectably, the concern for the wanton fouling of the biosphere with toxic metals has centered around the effects on human health, and specifically on acute rather than chronic effects of the toxic metals. Reported case histories of acute poisoning in the general population by metals in the environment are few -- the Itai-itai (cadmium poisoning) and Minamata (mercury poisoning) diseases of Japan being familiar examples. On the other hand, the chronic effects of toxic metals on human and animal populations and on ecosystem health have yet to receive necessary attention.

The exposure dose of a given element to any organism is a function

of element's concentration in the environment and the duration of exposure. Since the some of the trace metals tend to accumulate in the body or an ecosystem, long-term exposure to low concentrations can lead to adverse effects when the toxic dose is reached. In general, however, the long-term effects of exposing human populations to small doses of toxic metals in the environment are likely to be subclinical, ranging from early lesions to nascent clinical diseases with unrecognizable symptoms, and can lead to inordinate depletion of the functional integrity of the cell, tissue or organ. With the possible exception of lead, the current level of sensitivity of clinical tests is inadequate for the diagnosis of such subtle biochemical or so-called "no-effect" distress syndrome (6). Changes in vital signs become manifested only after the intoxication process has advanced to the stage where the homeostatic mechanisms can no longer maintain the body fuction with the accepted normal range. With the wide spectrum of non-specific adverse health effects, there is a divergence of opinion as to the risks of exposure to elevated levels of trace metals in the environment.

Lead is one of the most pervasive and pernicious toxins being released into the environment. Exposure to ambient environmental levels of lead has been associated with a wide range of metabolic disorders and neuropsychological problems especially in children (25). These health effects apparently have no known threshold in terms of measurable lead concentrations in the body fluids or organs and lead-induced biochemical changes have been detected down to picomolar lead concentrations (26). Depending on the criteria used to define excessive exposure, 9-25% of the preschool children in the United States may be at risk of having their health impaired by lead in the environment (25). It has been suggested that about one-third of the world's urban population is being exposed to either marginal or unacceptable air lead concentrations; the number of persons with elevated levels of lead in their blood is estimated to be 130-200 million (6). It is not surprising that chronic lead poisoning has been called one of the major public health issues of our time (27).

The discharge of other metals in the environment also represents a health hazard to many people. It has been estimated that, worldwide, about 250,000-500,000 persons may have renal dysfunction due to Cd

poisoning while 40,000-80,000 persons (mostly in fishing villages) may be suffering from mercury poisoning as a result of eating mercury contaminated seafoods. About 250,000 persons are believed to be suffering from skin cancers due to As poisoning (6). Furthermore, exposure to pollutant trace metals is being increasingly implicated in the aetiology of a large number of ailments including cardiovascular diseases, reproductive failures, dermatitis, allergies as well as cancers. The fact that a large number of people are at risk of being poisoned by persistent exposure to environmental doses of trace metals is a public health issue that will remain with us for a long time.

Human beings are by no means the only organisms at risk. For example, a large number of cats and dogs living in cities are known to suffer lead poisoning. High concentrations of lead have been detected in pigeons living in London, England with the most contaminated birds showing signs of acute lead poisoning (28). About 2-3% (or one million individuals) of the fall and winter population of waterfowls in North America suffer fatal plumbism by ingesting spent lead pellets (29). In central Canada, advisories have been issued against eating moose, deer and bear kidneys and livers because they contain dangerous levels of cadmium (30); it is not known whether the cadmium has impaired the health of the moose in any way. These examples are enough to suggest that few living organisms are safe from the undue trace metal insults over an extended period of time.

Aquatic organisms, especially those at the top of the food chain, such as fish-eating birds and mammals, are much more sensitive to toxic metals in their habitat than the terrestrial biota. Although dose-effect relationships have been documented in local aquatic environments, adverse effects on a regional scale attributable directly to the trace metal pollution have not been demonstrated unequivocally. The field of aquatic toxicology is still grappling with developing proper test protocols for determining any ecological stress due to toxic metal insults. There is, however, some circumstantial evidence to suggest that the "no-effect" thresholds for some metals are fairly close to their current levels in natural waters (31). Apparently, the margin of safety for the most sensitive organisms has either been depleted or is being rapidly eroded.

The persistence and propensity of metals to bioaccumulate can lead to metal concentrations in fish and other seafoods that are above the levels considered safe for human consumption. The most familiar example is the contamination of aquatic habitats with mercury which is bioaccumulated in invertebrates, fish and wildlife to levels above the guidelines to protect human health. It has been estimated that in Sweden, about 10,000 lakes contain northern pike (*Esox lucius*) with Hg concentrations in excess of  $1000 \text{ ug kg}^{-1}$ , and about 42,000 lakes have fish containing over  $500 \text{ ug kg}^{-1}$  of Hg (32). Highly elevated Hg concentrations have also been reported in fish in remote acidic lakes of Ontario, Wisconsin and northeastern United States (33). It would appear that in these regions, most of the mercury is derived anthropogenically.

Acid rain exacerbates the hazards associated with trace metal pollution. Increased acidification can increase the rates of mobilization of metals from soils and sediments, the capacity of suspended sediments to retain metals as well as the speciation and hence the toxicity of the metals. Because of the close linkage between acidification and the behavior of metals, it has been suggested that the adverse biological effects of acid deposition may stem, at least in part, from the increased concentration of bioavailable forms of metals (34). Increased trace metal concentration can also affect soil biological processes such as the rates of litter decomposition, soil respiration and nitrogen mineralization as well as the activity of key soil enzymes (35). Although trace metals may not be the primary causative factor, they may mediate the forest die-off in some acid-sensitive terrains.

From the discussion above, one must view the worldwide contamination of our air, water and soils with some concern. Each environmental compartment has only a limited carrying capacity for toxic metals. At the current rate in which the metals are being discharged by industries, the ability of many ecosystems to cope with the insults is being rapidly depreciated and the margin of environmental safety for an increasing number of organisms is also being destroyed.

## FUTURE TRENDS



Historically, the developed countries have accounted for most of the industrial metal emissions and the toxic metal wastes. Current events, however, point to future sharp increases in the release of trace metals by the developing countries. For example, the much higher rate of population growth in the developing countries compared to the developed countries implies a larger demand potential for services and metallic goods. Most of the population growth is concentrated in urban areas which have traditionally been "hot spots" of metal pollution. Unplanned urban growth typical of developing countries is accompanied by increased traffic, energy consumption, undesirable industrial locations and consequently metal pollution. On a global scale, the most rapid growth in the number of vehicles in use is now in the developing countries of Asia and South America; most of the vehicles still run on leaded gasoline. Indeed, the highest ambient levels of trace metals are now being encountered in the urban areas of the developing countries. Typical concentrations of airborne lead in Hong Kong, Rio de Janeiro, Buenos Aires, and Guatemala City have been reported to be 0.15-24, 0.13-1.7, 0.3-3.9, and 0.24-2.9  $\mu\text{g m}^{-3}$ , respectively (36); these values are much higher than what is generally being reported in the urban areas of Europe and North America.

Economic pressures are likely to stimulate increased metal loadings into the environmental compartments of the developing countries. Inadequate financial resources have encouraged the establishment of "dirty" manufactories and constrained any environmental improvement efforts. The huge foreign debts force these countries to exploit their natural resources for short-term economic benefits with little regard for any long-term environmental consequences. For example, the exploitation of the huge base metal deposits in Peru, Chile, Zaire, Papua, New Guinea and Mexico now release large quantities of Pb, Cu, Cd, As, Ni and Sb into the global environment. Concern for environmental quality remains subservient to job creation and environmental health lags far behind endemial diseases and shortages of food and accommodation in determining government policy. Although a concerted effort is being made to regulate the level of trace metal emissions in the developed countries, few restrictions are being imposed on metal discharges in the developing countries. The lax or ineffectual

environmental controls have encouraged some multinational companies to relocate their industries in the developing countries where they can also employ manufacturing processes that use banned material and liberate hazardous metallic wastes.

Thus, the combination of natural resource endowments, the constraints imposed by population growth and economic development, and the lack of government regulations can only lead to an increase in the rate of discharge of toxic metals by the developing countries. Sociologically, the human populations in these countries are much more predisposed to being poisoned by the toxic metals in their environment. The poor nutritional and health status, the high population density and poor hygienic conditions of the crowded cities and the preponderance of the age group (notably children and pregnant women) considered to be most at risk all enhance the susceptibility to environmental metal poisoning. In the absence of adequate food preservation practices, the people in the developing countries are more likely to consume a higher proportion of foods grown locally in metal contaminated areas. Many endemic health problems can also affect the course and severity of metal poisoning as well as the ability of the medical professionals to diagnose any metal-induced health problems. It would be a fatal mistake to presume that environmental metal pollution is a problem only in the developed countries; the phenomenon will likely become more devastating in the developing countries.

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Table 1. Worldwide emissions of trace metals from natural sources to the atmosphere  
( $10^6$  kg yr<sup>-1</sup>)\*

Element	Wind-borne Soil Particles	Seasalt Spray	Volcanic Emissions	Wild Forest Fires	Biogenic Emissions	TOTAL EMISSIONS
Antimony	0.78	0.56	0.71	0.22	0.29	2.6
Arsenic	2.6	1.7	3.8	0.19	3.9	12
Cadmium	0.21	0.06	0.82	0.11	0.24	1.4
Chromium	27	0.07	15	0.09	1.1	43
Cobalt	4.1	0.07	0.96	0.31	0.66	6.1
Copper	8.0	3.6	9.4	3.8	3.3	28
Lead	3.9	1.4	3.3	1.9	1.7	12
Manganese	221	0.86	42	23	30	317
Mercury	0.05	0.02	1.0	0.02	1.4	2.5
Molybdenum	1.3	0.22	0.40	0.57	0.54	3.0
Nickel	11	1.3	14	2.3	0.73	29
Selenium	0.18	0.55	0.95	0.26	8.4	10
Vanadium	16	3.1	5.6	1.8	1.2	28
Zinc	19	0.44	9.6	7.6	8.1	45

\* From Reference 7.

Table 2. Worldwide atmospheric emissions of trace metals from anthropogenic sources ( $10^6$  kg yr<sup>-1</sup>)\*

Element	Energy	Mining	Smelting/ Processing	Manufacturing Processes	Commercial Use	Waste Incineration	Transportation	TOTAL
Antimony	1.30	0.10	1.42			0.67		3.5
Arsenic	2.22	0.60	12.3	1.95	2.02	0.31		19
Cadmium	0.79		5.43	0.60		0.75		7.6
Chromium	12.7			17.0		0.84		31
Copper	8.04	0.42	23.2	2.01		1.58		35
Lead	12.7	2.55	46.5	15.7	4.50	2.37	248	332
Manganese	12.1	0.62	2.55	14.7		8.26		38
Mercury	2.26		0.13			1.16		3.6
Nickel	42.0	0.80	3.99	4.47		0.35		52
Selenium	3.85	0.161	2.18			0.11		6.3
Thallium	1.13			4.01				5.1
Tin	3.27		1.06			0.81		5.1
Vanadium	84.0		0.06	0.74		1.15		86
Zinc	16.8	0.46	72.0	33.4	3.25	5.90		132

\* From Nriagu and Pacyna (Reference 8).



Table 3. Worldwide inputs of trace elements into soils and aquatic ecosystems ( $\times 10^6 \text{ kg yr}^{-1}$ ); from Reference 8

	As	Cd	Cr	Cu	Hg	Mn	Mo	Ni	Pb	Sb	Se	V	Zn
<u>AQUATIC ECOSYSTEMS</u>													
Domestic wastewaters	9.2	1.7	46	28	0.30	110	2.2	62	6.8	2.2	3.8	2.3	48
Electric power plants	8.2	0.12	5.7	13	1.8	11	0.65	11	0.72	0.18	18	0.30	18
Base metal mining and smelting	7.4	2.0	12	14	0.10	40	0.51	13	7.0	3.8	12	0.60	29
Manufacturing processes	7.0	2.4	51	34	2.1	21	4.2	7.4	14	9.3	4.3	0.55	85
Atmospheric fallout	5.6	2.2	9.1	11	2.0	12	0.95	10	100	1.1	0.82	26	40
Sewage discharges	4.1	0.69	19	12	0.16	69	2.9	11	9.4	1.5	2.0	3.5	17
<u>Total Input, Water</u>	42	9.1	143	112	6.5	263	11	114	138	18	41	33	237
<u>SOILS*</u>													
Agricultural and animal wastes	5.8	2.2	82	67	0.85	158	34	45	26	4.9	4.6	19	316
Logging and wood wastes	1.7	1.1	10	28	1.1	61	1.6	13	7.4	2.8	1.6	5.5	39
Urban refuse	0.40	4.2	20	26	0.13	24	2.3	6.1	40	0.76	0.33	0.2	60
Municipal sewage sludge and organic wastes	0.25	0.18	6.5	13	0.44	8.1	0.43	15	7.1	0.18	0.11	1.3	39
Solid wastes from metal fabrication	0.11	0.04	1.5	4.3	0.04	2.6	0.08	1.7	7.6	0.08	0.10	0.12	11
Coal ashes	22	7.2	298	214	2.6	1076	44	168	144	12	32	39	298
Fertilizers (including peat)	0.28	0.20	0.32	1.4	0.01	12	0.46	2.2	2.9	0.25	0.27	0.97	2.5
Wastage of manufactured products**	38	1.2	458	592	0.68	300	1.9	19	292	2.4	0.15	1.7	465
Atmospheric fallout	13	5.3	22	25	2.5	27	2.3	24	232	2.5	2.0	60	92
<u>Total Input, Soils</u>	82	22	898	971	8.3	1669	87	294	759	26	41	128	1322

\* Excludes mine tailings and slags at the smelter sites.

\*\* Assumes that metals used for industrial installations and "durable" goods have a definite life span and are being released into the environment at a constant rate.

**Table 4. Industrial versus natural mobilizations of trace metals in the biosphere ( $10^6$  kg yr<sup>-1</sup>)**

Element	Production <sup>(a)</sup> From Mines	Total Industrial <sup>(b)</sup> Discharge	Weathering <sup>(c)</sup> Mobilization
Antimony	55	41	15
Arsenic	45	105	90
Cadmium	19	24	4.5
Chromium	6800 (approx.)	1010	810
Cobalt	36	-	120
Copper	8114	1048	375
Lead	3077	565	180
Manganese	16000 (approx.)	1894	4800
Mercury	6.8	9.2	0.9
Molybdenum	98	95	15
Nickel	778	356	255
Selenium	1.6	76	4.5
Vanadium	34	74	855
Zinc	6040	1427	540

- a: From Reference 6; notice that only a fraction of each metal mined each year is discharged into the environment during the same year.
- b: Calculated as discharges into soils (Table 3) and water (Table 3) minus the emissions to the atmosphere (Table 2).
- c: Calculated using average trace metal concentrations in soils (Reference 16) and suspended sediment flux of  $1.5 \times 10^{16}$  g yr<sup>-1</sup> in rivers; the dissolved trace metal flux is generally much lower than the particulate flux.

**Table 5. Average particle size (mass median diameter, MMD) and concentrations (median and ranges) of trace metals in the atmosphere at different locations(a)**

Element	Mass Median Diameter (μm)	Average Concentration in ng/m <sup>3</sup> (ranges in brackets)		
		Urban	Rural	Remote
Antimony	0.9	7.7 (15-0.4)	0.48 (0.90-0.05)	0.03 (0.06-0.0005)
Arsenic	1.3	20 (35-5.0)	3.2 (6.0-0.3)	0.29 (0.5-0.07)
Cadmium	1.1	5.2 (10-0.3)	0.26 (0.50-0.02)	0.05 (0.10-0.002)
Chromium	0.96	60 (115-5.0)	14 (25-2.0)	2.3 (4.5-0.04)
Cobalt	2.8	39 (70-8.0)	5.1 (10-0.2)	0.15 (0.30-0.006)
Copper	1.3	155 (300-10)	7.9 (15-0.8)	1.2 (2.4-0.06)
Lead	0.56	715 (1400-30)	16 (30-1.0)	2.5 (5.0-0.01)
Manganese	2.1	92 (180-5.0)	6.2 (12-0.50)	1.5 (3.0-0.05)
Mercury	0.78	4.0 (7.5-0.5)(c)	1.6 (3.0-0.02)	0.38 (0.75-0.004)(c)
Nickel	0.73	52 (100-5.0)	4.3 (8.0-0.6)	0.8 (1.5-0.08)
Selenium	0.92	13 (35-0.4)(c)	2.6 (5.0-0.08)	0.45 (0.9-0.007)(c)
Vanadium	1.6	36 (70-2.0)	1.8 (3.5-0.2)	0.50 (1.0-0.004)
Zinc	1.2	432 (850-15)	26 (50-3.0)	6.2 (12-0.4)

a: Compiled from the literature (see Reference 38 for examples).

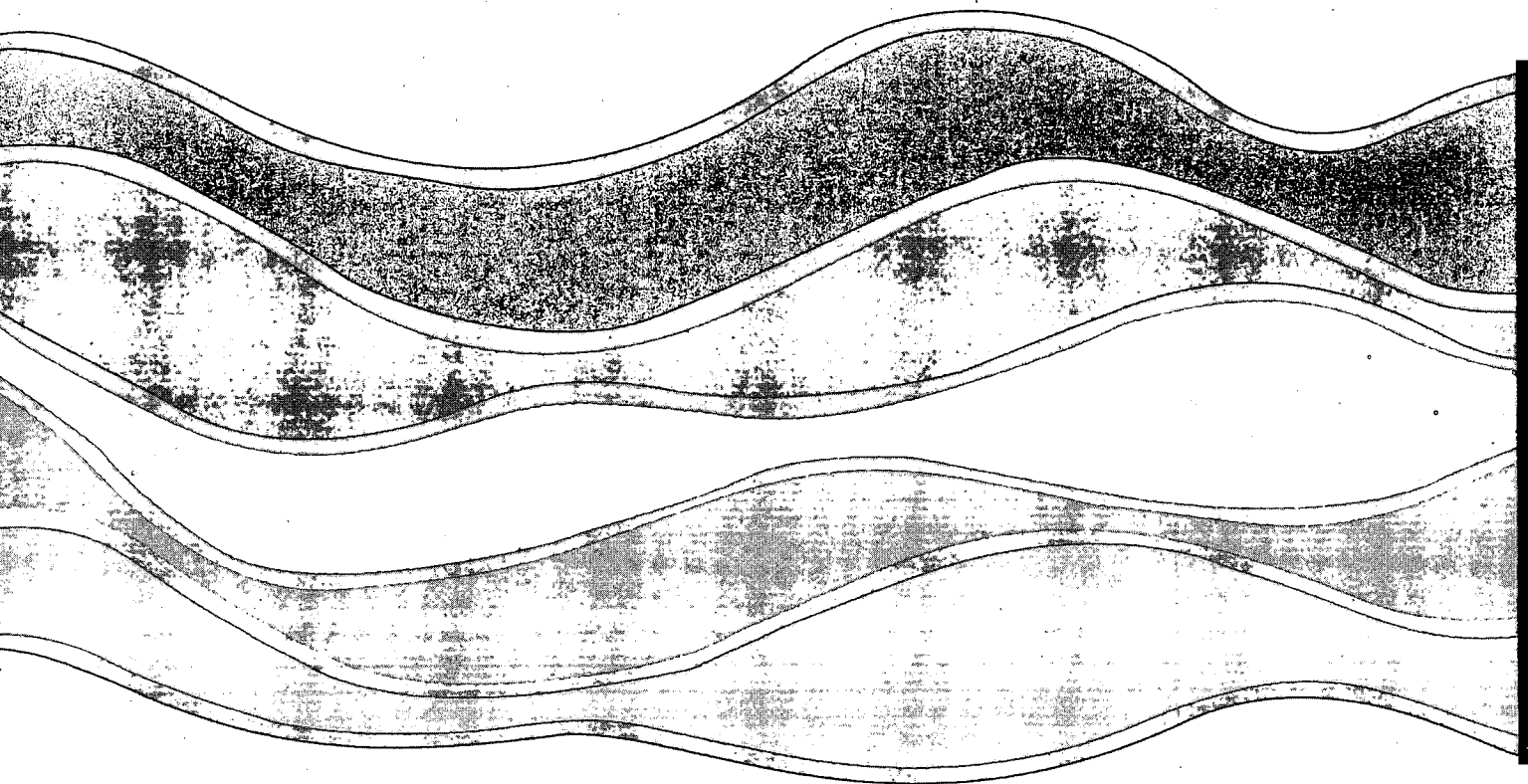
b: From Davidson and Wu (Reference 37).

c: Includes particulate and gaseous phases.

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