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Toxicological effects of major environmental pollutants: an overview

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Abstract The last quarter of the twentieth century had witnessed a global surge in awakening against the unabated menace of environmental pollution. Among the various types of environmental pollution, water pollution is an age-old problem but it has gained an alarming dimension lately because of the problems of population increase, sewage disposal, industrial waste, radioactive waste, etc. Present scenario of water pollution calls for immediate attention towards the remediation and detoxification of these hazardous agents in order to have a healthy living environment. The present communication will deal with the toxicological effects of major environmental pollutants, viz. heavy metals, pesticides, and phenols.

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Introduction

Environmental pollution implies any alteration in the surroundings but it is restricted in use especially to mean any deterioration in the physical, chemical, and biological quality of the environment (Moschella et al. 2005). All types of pollution directly or indirectly affect human health. The pollutants fall under the broad category of xenobiotic compounds and are released into the environment by the action of man and occur in concentrations higher than "natural levels" (Richards and Shieh 1986). Pollutants are generally classified as biodegradable and non-biodegradable: Biodegradable pollutants consist of sewage effluents and organic matter that are readily decomposed under normal circumstances. Non-biodegradable substances are those which are not degraded by microorganisms, e.g., heavy metals, plastics, and detergents. Fast urbanization and industrialization have resulted in the tremendous release of xenobiotic compounds into the environment (Tabrez and Ahmad 2011a). Large quantities of highly toxic chemicals emitted by industries are generally used in developing countries for enhanced agricultural productivity (Ansari and Malik 2009a; Alam et al. 2011).

Most of the organic pollutants originate from five major industrial categories: petroleum refining, organic chemical and synthetic industries, steel mining and coal conversion, textile processing, and pulp and paper milling (Nye 2000; Tabrez and Ahmad 2009, 2010; Gupta and Ahmad 2012). However, industries alone are not totally responsible for exposure of the chemicals to environment, consumers too share a part. Utilization of gasoline, aerosol sprays, pesticides, and fertilizers lead to the release of pollutants by the consumers directly into the environment (Richards and Shieh 1986).

Effluent from wastewater treatment plants is another cause of xenobiotic pollution (Aboulhassan et al. 2006). Accidental spillage, illegal dumping, poorly chosen landfalls, and uncontrolled hazardous waste sites are other routes through which the environment is getting contaminated. In fact, inadequate disposal techniques have been cited as the main cause of contamination of biota as well as soil surface and ground matters which could lead to the emergence of disease-producing microorganisms and ultimately result in serious health problems (Malik and Ahmad 1995; Tibbetts 2000).

Among the various types of environmental deteriorations, water pollution assumes the most significant proposition. Several studies suggested that the major toxicants present in surface water are heavy metals, pesticides, and phenolics (Siddiqui and Ahmad 2003; Siddiqui et al. 2011a, b; Tabrez and Ahmad 2009, 2010; 2011a, b; Wasi et al. 2008, 2011a, b). It is a matter of great concern since these pollutants pose a constant threat to the well-being of humans, animals, and plants rather the whole biosphere. Continuous production of scientific data concerning toxicological effects of major environmental pollutants demands for frequent reviewing of the current body of information. As per our knowledge, we are the first to report the toxicological effects of heavy metals, pesticides, and phenols in a single article.

Heavy metals in the environment and their toxicity

Metal pollution is a widespread problem, in fact in industrially developed countries, it is normal to find elevated levels of metal ions in the environment. Various environmental problems due to heavy metal pollution have been reported worldwide (Tyagi et al. 2000; Mena et al. 2009).

In addition, it has been estimated that approximately 37 % of sites in the USA are contaminated with organic pollutants, such as pesticides, which are additionally polluted with metals (Roane et al. 1996). There have been also reports from India of similar water contaminants like metals, pesticides, and phenols (Fatima and Ahmad 2005, 2006; Tabrez and Ahmad 2009, 2010).

Application of sewage sludge on agricultural, arable fields for enhancing productivity has been a common practice in developing countries for many years and has adverse long-term effects on soil microorganisms. During the last few decades, the toxicity of heavy metals to plants and microorganisms has drawn the attention of many environmental scientists because of the tendency of uptake of toxic metals and metalloids (Athar and Ahmad 2002; Wasi et al. 2008, 2010, 2011a, b). A number of small- and large-scale industries in India are reported to spill large amount of heavy metals into the sewage in the form of industrial wastes (Malik and Ahmad 1995; Fatima and Ahmad 2005; Tabrez and Ahmad 2009, 2011b, c, d; Tabrez et al. 2011). Tyagi et al. (2000) reported that the concentration of heavy metals in industrial areas in India is much higher than the permissible limit of World Health Organization. They have also reported that these metals in the ground water have caused various diseases in human beings and which have also disturbed the metabolic functions.

Despite this, biological treatment or bioremediation of contaminated sites has largely focused on the removal of organic compounds and attention has been directed towards the treatment of metal-contaminated wastes (Srivastava 2000; Das et al. 2008). Due to their toxic nature, the presence of metals in organic-contaminated sites often complicates and limits the bioremediation process (Uher et al. 2011). Such metals include the highly toxic cations of mercury and lead, but many other metals and metalloids are also of concern, including arsenic, beryllium, boron, cadmium, chromium, copper, nickel, manganese, selenium, silver, tin, and zinc.

Metal pollution arises when human activity either disrupts the normal biogeochemical cycles or concentrates metals (Roane et al. 1996). Examples of such activities include mining and ore refinement, nuclear processing, and industrial manufacture of a variety of products including batteries, metal alloys, electrical components, paints, preservatives, and insecticides (Suzuki et al. 1992; Saxena et al. 2001). Much of the research on metal bioavailability has been done in soil systems because understanding the fate of metals in soil and sediments is crucial to determining metal effects on biota, metal leaching to ground waters, and metal transfer up to the food chain (Roane et al. 1996; Wuana and Okieimen 2010). Soil usually exhibits higher concentrations of metals than water because metals are more likely to accumulate in soil and are composed of minerals.

Elevated metal concentrations in the environment have wide-ranging impacts on animals, plants, and microbial species (Fatima and Ahmad 2006; Tabrez and Ahmad 2009; Siddiqui et al. 2011a, b). For example, human exposure to a variety of metals causes disorders and symptoms like hypophosphatemia, heart diseases, liver damage, cancer, and neurological disorders (Agency for Toxic Substances and Disease Registry 2008; Beyersmann and Hartwig 2008; Jomova and Valko 2011). Exposure to metals is the cause of most morphological and mutational changes observed in plants (Brooks 1983; Manios et al. 2002). These include shortening of roots, leaf scorch, chlorosis, nutrient deficiency, and increased vulnerability to insect attack (Ekosse and Fouche 2005). Likewise, microbial growth is often slowed or inhibited completely in the presence of excessive amounts of metals (Bojić et al. 2002; Uher et al. 2011). Toxic metals exert their toxicity in a number of ways including the displacement of essential metals from their normal binding sites on biological molecules (e.g., cadmium compete with zinc), inhibition of enzymatic functioning, and disruption of nucleic acid structure (Jomova and Valko 2011; Tabrez and Ahmad 2011c).

Some metals are essential components of microbial cells; for example, sodium and potassium regulate gradients across the cell membrane, and copper, iron, and manganese are required for activity of key metalloenzymes in photosynthesis and electron transport (Roane et al. 1996; Uher et al. 2011). However, certain metals can also be extremely toxic to microorganisms and thus affecting microbial growth, morphology, and biochemical activities as a result of specific interactions with cellular components (Beveridge and Doyle 1989; Freedman 1995). Perhaps the most toxic metals are the nonessential metals such as cadmium, lead, and mercury (Roane et al. 1996).

Nickel compounds are widely used in modem industries (Bennett 1984). Several industrial processes, like nickel refining, electroplating, production of long-lasting nickel–cadmium batteries, combustion of fossil fuels, and the incineration of nickel-containing solid waste are responsible for the production of nickel containing aerosols in the workplace and in the surrounding environments (Zoroddu et al. 2002). Because of the widespread use of these compounds, workers in these facilities are at risk of occupational exposure. Moreover, the release of nickel into the environment represents a potential for non-occupational exposure (Huang et al. 2001; Ding et al. 2006).

Inhalation is the main route for human exposure to nickel compounds, and epidemiological studies have demonstrated a correlation between the incidence of respiratory (lung and nasal) cancer and worksite exposure to nickel (Langård 1994; Cameron et al. 2011). Tumors have also been induced in several animal models after inhalation, ingestion, or injection of various nickel compounds (Sunderman 1989; Denkhaus and Salnikow 2002; Huang et al. 2002).

Chromates are widely discharged into the environment, and thus, high concentrations of chromium are found in both marine and freshwater sediments and in soil associated with industrial discharges such as steel production, wood preservation, and leather tanning (McLean and Beveridge 2001; Viti et al. 2003). Chromium occurs in oxidation states from +2 to +6 with +3 and +6 being the most important biologically (Sultan and Hasnain 2003; Jomova and Valko 2011). Furthermore, experimental and epidemiological lines of evidence exist for the carcinogenicity of some chromium compounds (De Flora 2000; Beyersmann and Hartwig 2008) and mutagenicity in bacteria (Gasiorowski et al. 1997; Dillon et al. 2000). Owing to its mutagenic and carcinogenic behavior hexavalent Cr is about 100-fold more toxic than trivalent form (Cervantes 1991; Shen and Wang 1993).

Cadmium ranks as a major anthropogenic pollutant especially released from the industrial effluents (Fatima and Ahmad 2005; Raja et al. 2006; Tabrez and Ahmad 2009). Its transfer in the soil–plant system may lead to cadmium accumulation in roots, stems, and leaves (Mench et al. 1989; Liu et al. 2011), especially in the edible parts of crops and most particularly in market garden products (Hooda and Alloway 1995). As a consequence, the crop production may become unfit for animal and human consumption (Lebeau et al. 2002; Ansari and Malik 2009a).

The toxic effects of cadmium on microorganisms are well documented (Stohs and Bagchi 1995; Pagano et al. 2003) and derive from several mechanisms. Disruption of protein function can occur through binding of cadmium to sulfhydryl groups (Cunningham and Lundie 1993; Jomova and Valko 2011). In addition, cadmium competes with several divalent ions such as Ca^{+2}, Zn^{+2}, and Mn^{+2} for metal binding sites in biological systems (Wang et al. 1997; Jomova and Valko 2011). Binding of cadmium to nucleotides leads to single-strand breaks in cellular DNA (Wang et al. 1997; Saplakoglu and Iscan 1998; Sabdono 2010). Cadmium toxicity can result in prolonged lag phase, decreased growth rate, lower cell density, and even death of bacteria and algae at levels below 1 ppm (Les and Walker 1984; Wang et al. 1997).

Lead is the most common metal found at superfund sites (Enger and Smith 1992; Jomova and Valko 2011). There are reports of high lead accumulations in surface soil horizons due to a large capacity for lead immobilization, and its accumulation in relation to the soil organic fraction, soil pH, and redox (Nederlof and Van Riemsdijk 1995; Roane 1999). Despite the apparent immobility of lead, organic soils or sediments do not retain approximately 30 % of the total lead ecosystem input (Johnson et al. 1995; Roane 1999). Consequently, the soil becomes a major source of lead exposure for microbial communities.

Lead is an environmental nephrotoxicant and probable human carcinogen, it is also reported that lead acetate causes chromosomal aberrations in human cells (Waalkes et al. 2004; Jomova and Valko 2011). Lead poisoning of children is common and leads to retardation and semi-permanent brain damage (Järup 2003).

Copper is readily available as Cu (I) or Cu (II) in inorganic salts and organic complexes (Jomova and Valko 2011). About 30–50 % of the oral intake is absorbed mainly from the duodenal mucosa through copper-binding proteins (Satake and Taguchi 2003). Copper is an essential trace element required for several bacterial enzymes, particularly oxidation–reduction enzymes and proteins involved in electron transport, redox reactions, and others (Lim and Cooksey 1993; Sharma and Kuhad 2008). However, at higher concentrations, it is highly toxic to microbial cells exerting an inhibitory effect on the bacterial growth, and has also been incorporated as a key component of agricultural bactericides (Al-Haq et al. 2005; Montesinos and Bardaj 2008). Islam et al. (2007) reported that copper pollution in soils is widespread, and its accumulation in crop products could pose a risk on human health.

Pesticides in the environment and their toxicity

Pesticides are one of the vital components of modern agriculture practices. Some of these chemicals also play an equally important role in the eradication of human and domestic animal pests. Adoption of modern agricultural practices of highly intensive nature to feed the ever increasing population of the world resulted in the widespread pollution of synthetic pesticides in the environment. Thus the presence of these compounds is ubiquitous, often contaminating surface and ground waters as they migrate from their point of application (Thomas et al. 2001). The movement of pesticides from one place to another has been thoroughly studied (Widenfalk et al. 2008; Feo et al. 2010) and is dependent on factors such as soil-type, drainage, physical and chemical properties of the pesticides, and weather (Tiryaki and Temur 2010). In nut shell, the indiscriminate use of these pesticidal agents has posed a great threat to man and his environment in several ways such as harming non-target organisms, causing ecological imbalance, destroying useful plants, entering into food chain and causing toxicity to both man and animals. Moreover, the rivers, streams, and ponds have also become highly polluted with these harmful agents (Phillips and Bode 2004).

The most important pollutants among the environmental toxicants in India are the organochlorine and organophosphorus pesticides because of their massive use for the agricultural purposes (Fatima and Ahmad 2006; Ansari and Malik 2009a, b; Singh et al. 2011). A high proportion of pesticides used in India is applied on crops and only a small quantity is used for soil and seed treatment (Ansari and Malik 2009a). Soil contamination, however, has become a serious problem with the persistence of organochlorine and some organophosphorus pesticides (Rehana et al. 1995; Nawab et al. 2003; Pazou et al. 2006). Lindane (γ HCH) was banned in 1976 but still India, China, Japan, Pakistan, Brazil, some African countries, Canada, and most European countries used lindane. India, China, and Japan were the most polluted countries by lindane, and India was the highest contaminated country in 1990s (Ergüder et al. 2003).

The toxicity of pesticides to aquatic microorganisms has been exhaustively reviewed by De Lorenzo et al. (2001). Microorganisms are important inhabitants of aquatic ecosystems, where they fulfill critical roles in primary productivity, nutrient cycling, and decomposition. Microorganisms of the aquatic environment are exposed directly to the pesticides because of the direct and indirect input of the pesticides (Yadav 2010). Though certain pesticides are known to elicit a variety of chronic and acute toxicity effects in microorganisms, some of them still have the ability to accumulate, detoxify, or metabolize pesticides to some extent (De Lorenzo et al. 2001; Wasi et al. 2008, 2011a, b). It is supposed that detrimental effects of pesticides on microbial species may have subsequent impacts on to higher trophic levels (De Lorenzo et al. 2001). To understand the mechanisms of pesticides action on our environment, a summary of their action on target organisms has been presented in Table 1. Besides these specialized actions, pesticides have been shown to cause various kinds of organ toxicities such as cardiotoxicity, neurotoxicity, and ocular toxicity as a result of short-term or chronic exposure to common pesticides such as DDT, endosulfan, and HCH (Seth et al. 2000). A number of types of cancer have also been attributed to the exposure of pesticides (Muniz et al. 2008; Mena et al. 2009).

The phenoxyacetate herbicides which include 2,4-dichlorophenoxyacetic acid (2, 4-D), 2,4,5-trichlorophenoxyacetic acid (2,4,5-T), and 4-chloro-2-methylphenoxycetic acid have been used extensively for the control of weeds since their introduction in the mid 1940s. Among them, 2,4-D is being used most extensively as hormone herbicides, resulting in the pollution of soil and natural water (Radjendirane et al. 1991; Chinalia et al. 2007; Hamid et al. 2011). Once their accumulation touches enormity, these compounds become very hazardous to life.

Lindane, γ-isomer of BHC (benzene hexachloride), due to its widespread use, is a common pollutant worldwide (Lal et al. 2010). It has been used since 1940s for the control of disease vectors and agricultural pests (Rogers 1996). Because of its carcinogenity, chronic toxicity to many aquatic organisms, and tendency to biomagnify, BHC has been placed among the priority pollutants and it was banned in 1976 (Watts 1998). However, the use of BHC in developing and even in some technologically advanced countries still continues and it is still manufactured to export (Watts 1998; Ergüder et al. 2003).

After the ban or restriction on various chlorinated hydrocarbon insecticides, carbamates gained prominence in many developed countries. They are widely used throughout the world (Wang and Lemley 2003). Carbamates are potent inhibitors of cholinesterase and hence they are highly toxic to humans (Kamanavalli and Ninnekar 2000; Plimmer 2003; Chaudhaery et al. 2010).

Phenolic compounds in the environment and their toxicity

Phenolic compounds produced from coal gasification, chemical and petrochemical industries, pulp industries, and oil refineries are among the most ubiquitous pollutants in industrial effluents (Borja et al. 1996; Tabrez and Ahmad 2010; 2011b, c; Gupta and Ahmad 2012). Phenol is a hazardous substance and a widely distributed environmental pollutant. It has been in use for disinfection for

Table 1 Summary of pesticide mechanisms of action on target organisms

Pesticide class	General toxic effect	Specific site of action
Organophosphate	Nervous system inhibition	Acetyl cholinesterase
Organochlorines	Nervous system inhibition	GABA receptor
Herbicides	Photosynthesis inhibition	Hill reaction of electron transport
	Photosynthesis inhibition (light reaction)	Reducing side of photosystem I
	Biosynthesis	Carotene
	Inhibition	Accumulation
	Biosynthesis inhibition	Fatty acid synthesis
	Biosynthesis inhibition	Microtubule formation
Broad-spectrum biocides	Multiple inhibiting actions	Phosphorylation, protein synthesis lipid biosynthesis
	Respirators' system inhibition	Mitochondrial ATPase

Adopted from De Lorenzo et al. (2001)

many years (Kirk and Othmer 1978; Leonard et al. 1999; Agency for Toxic Substances and Disease Registry 2008).

The toxic action of phenol is always associated with the loss of the integrity of the cytoplasmic membrane that results in disruption of energy transduction, disturbance of membrane barrier, and related functions and subsequent cell death (Yap et al. 1999). In general, several mechanisms for decreasing membrane fluidity due to various environmental stress factors have been proposed in bacterial system such as *Pseudomonas putida* (Yap et al. 1999; Heipieper et al. 2003), *Escherichia coli* (Mrozik et al. 2004), and *Vibrio* species (Heipieper et al. 2003; Mrozik et al. 2004). These include an increased degree of saturation of fatty acids, conversion of *cis*-unsaturated fatty acid to the *trans*-isomer, and alteration of the polar head groups of phospholipids.

Conclusion

Although the effluent treatment facilities are legally binding to be installed by all industries, a significant amount of toxicants are present in the wastewater samples, which is quite clear from the available reports, especially from developing countries. In the light of present scenario, we recommend strict regulation for wastewater management so that human beings could be protected from the toxicological effects of these xenobiotics.

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