Biological Magnification of Soil Pollutants

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Abstract

The mad rat races among the nations for development have jeopardized the human beings. The increasing population of the world is the major cause of anxiety for scientists as it leads to force human beings to change the natural environment, which is responsible for various types of pollution. These toxic pollutants are incorporated in the environment through soil, air, and water and in turn administered to the organisms at different trophic levels through food chains. Biomagnification is a condition where the chemical concentration of a compound in an organism exceeds the concentration of its food when the organism's diet is the major way of exposure for that compound. The toxic chemicals are exposed at different trophic levels and in turn are magnified through food chains and food webs. Soil is the most active site where the presence of various xenobiotics, chemicals pesticides, and heavy metals alters the natural soil environment as these chemicals are indispensable part of agriculture accounting for the main components of fertilizers. At successive trophic levels, these components are incorporated through producers to consumers and in turn amplified. Thus, soil pollutants play a pivotal role in biological magnification as they are the main source of contaminated products which are amplified in nature to affect adversely human beings. According to modern research, it has been concluded that human activities are mainly responsible for the majority of different types of soil pollutants. In this chapter, we will try to summarize the main sources of soil pollutants and their role in biological magnification along with their adverse role at different trophic levels.

Keywords

Trophic levels · Biomagnifications · Xenobiotics · Pesticides · Slag · Solid waste

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12.1 Introduction to Soil Pollutants

Soil pollution can be defined as build-up in soils of persistent toxic chemicals, compounds, radioactive materials, salts, or disease-causing agents at enough concentration, which may cause a risk to human health, ecosystem, or both (Okrent 1999). Presently polluted soil is a burning challenge of current living organisms on earth. The soil contaminants are mainly caused by human activities including industrial processes, mining, household, business waste, human and animal pharmaceuticals. Apart from these chemicals, soil has also been reported to contain several types of biological contaminants such as parasites (hookworm) and pathogens (tetanus), which cause many well-documented impacts on human health (Brevik and Burgess 2013).

12.2 Sources of Soil Pollution

The increasing population and urbanization posed a serious threat to its environment for unscientific disposal of huge solid and liquid waste to its precious water bodies and agricultural land. Apart from this, in third world countries, modern economies include various types of activities such as industry, agriculture, and transportation, and produce a large amount of waste and pollutants. On considering major types of soil contaminations, the most common kinds of soil wastes can be classified into three groups: agricultural, industrial, and nuclear (Alloway 1995).

12.2.1 Agricultural Wastes and Their Magnification

The main agricultural source of soil pollutants includes a wide range of organic materials, pesticides, and animal wastes.

12.2.1.1 Pesticides

The most common organic materials and pesticides belong to organochlorines, organophosphates, and carbamates. Organochlorine hydrocarbons include DDT and could be separated into dichlorophenyl ethane, cyclodienes, and other related compounds. The concentration of these hydrocarbons increase at successive trophic levels because DDT is metabolized and excreted much more slowly in comparison to other nutrients. Thus, the amount of these compounds tends to be accumulated especially in fat bodies of the organisms involved in food chain (Fig. 12.1).

Organophosphates are insecticides and were found to be toxic for insects. In other animals including birds, amphibians, and mammals, its toxicity was mainly due to phosphorylation of acetylcholinestrase enzyme (AChE). Some organophosphates such as diazinon, fenthion, and methyl parathion have been reported to be lipid soluble and had shown fat storage property and bioaccumulation (Roberts and Aaron 2007). Carbamates (carbaryl, carbofuran, and aldicarb) are the class of insecticide derived from carbamic acid, which is structurally and mechanistically similar to

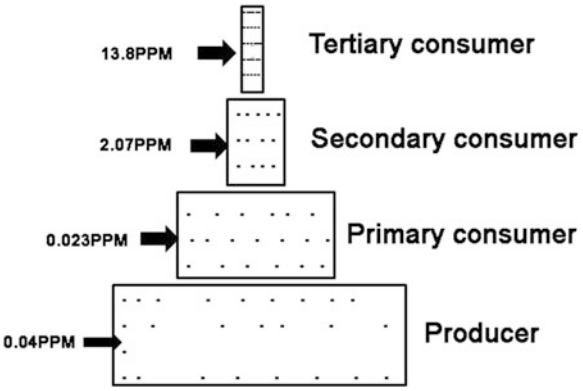

Fig. 12.1 Biomagnification of dichlorodiphenyltrichloroethane (DDT) at different trophic levels from producer to consumer: The magnified amount of DDT has been denoted from producer to consumer in parts per million (ppm) at successive trophic level

organophosphate insecticides. The toxic exposure of these compounds has been reported to occur via dermal, inhalational, and gastrointestinal (GI) route. Further research has proved that carbamate compounds are also magnified in food chains and can create serious hazardous effects to human health (Vengayil et al. 2011).

12.2.1.2 Fertilizers

Fertilizers are used by farmers to maintain the soil deficiencies but excess use of fertilizer had also shown adverse consequences. The mostly used mixed fertilizers contain phosphorus as P_2O_5, potassium as K_2O, and nitrogen as NH_4NO_3. The raw materials used in the preparation of these fertilizers contain several types of heavy metals (As, Pb, and Cd) as well as other inorganic contaminants. Most of these metals had been reported to be nondegradable, causing indestructible poison for crops. The excess use of NPK (Nitrogen, Phosphate, and Potassium) fertilizers reduces the vegetable quality and crops grown for the years (Muhammad et al. 2014). Further researchers had been reported that the content of the carotene and vitamin C in a plant largely depends on the use of fertilizers (Ijdo 1936).

The heavy metals (Hg and Pb) and other inorganic substances used in the fertilizers had been reported to be biologically magnified at different trophic levels. The nondegradable nature of the ingested heavy metals is magnified in the food chains starting from the soil to tertiary consumers. On the other hand, heavy rain and draining water is responsible for leaching of these waste, which ultimately percolates to the water bodies and is taken by aquatic organisms such as fishes which in turn amplified at successive trophic levels through food chains and food webs.

12.2.2 Industrial Waste and Their Magnification

Industrial development of a country represents its growing GDP and plays a pivotal role in its economy. On the one hand, the growth of industries is important to make our life more convenient, easy, and opportunistic while on the other hand the waste releases from these industries had been proved to cause toxicity to our natural environment (water, air, and soil). The effluents discharged by the industrial units on to the land contain many toxic chemicals, which include mainly nonbiodegradable heavy metals, solid waste, and red mud deposition (Fig. 12.2).

12.2.2.1 Heavy Metals

Heavy metal contamination had been reported mainly from the waste water stream of fertilizer, dyes, and the metal processing industries. The waste water streams of these industries are finally discharged in the rivers, which ultimately reach to our land ecosystem through leaching and irrigation management. Heavy metal contamination of the soil from industrial waste mainly includes Cu, Ni, Cd, Zn, Cr, and Pb (Hinojosa et al. 2004). These heavy metals had been reported to change the soil texture mainly in terms of clay content, organic matter, pH, etc. On one hand the contaminated heavy metals are reported to change the soil biochemical and biophysical properties while on other hand they also influence the soil microbial community by changing the enzymatic activities of soil (Belén et al. 2004; Vyas et al. 2017).

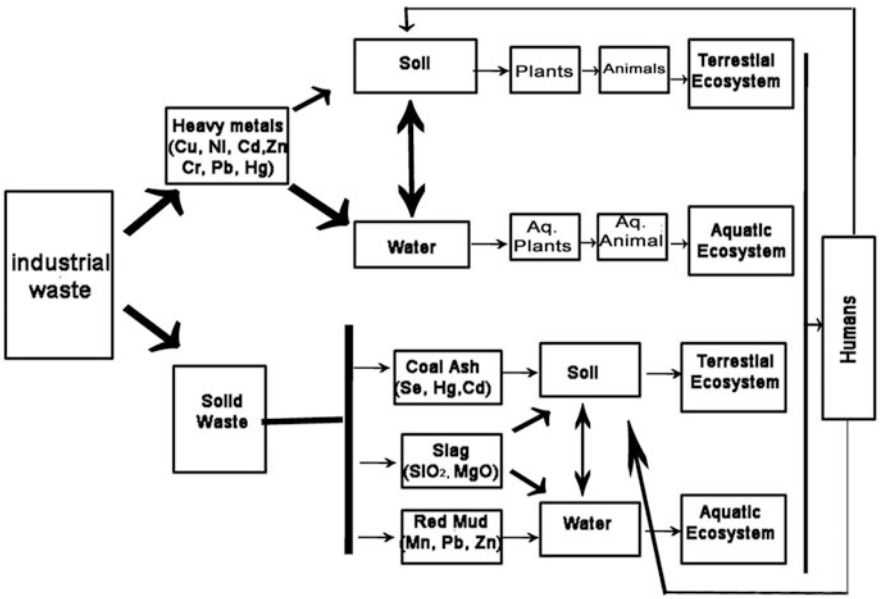

Fig. 12.2 Biomagnification of industrial waste through soil: A schematic diagram representing different types of industrial waste released in the soil and their magnification up to humans

Excessive use of heavy metals is a global concern due to their potential toxic effects and their bioaccumulation properties, especially in the aquatic ecosystem (Batvari et al. 2015). Some heavy metals from industrial waste such as Cd, Hg, Cr, As, and Pb had been reported to accumulate at different trophic levels without their any role in a biological system (Canli and Atli 2003). On the other hand, metals such as Cu, Na, K, Ca, Mn, Se, Fe, and Zn are reported to be essential in fish metabolism but may also accumulate and reach to the toxic levels that can potentially destroy the ecological environment (Chakraborty 2019).

12.2.2.2 Solid Waste

Solid waste is the major contaminated product of metallurgical, energy, and petrochemical industries. The disposal of solid wastes with violation of hygiene requirements concerning the placement and operation of landfills is the major cause of soil contamination and can become a threat to environmental safety of the population industrial centres (Grebeneva et al. 2014).

Important Industrial Solid Waste and Their Biomagnification

(a) *Coal ash*: Coal ash, also referred to as coal combustion residues are the major contaminants of the thermal power plants. The coal ash includes a number of by-products produced from burning coal, including fly-ash, bottom-ash, boiler slag, etc. According to a report (Gottlieb et al. 2010) coal ash typically contains heavy metals such as arsenic, lead, mercury, cadmium, chromium, and selenium as well as antimony, aluminum, barium, beryllium, boron, cobalt, etc. Most of these toxicants, if eaten, drunk, or inhaled, can cause cancer, and nervous system impacts such as developmental delays, behavioral problem, and cognitive deficits. According to an estimation of the Environmental Protection Agency (EPA), arsenic contamination of land, water, and soil from coal ash had increased the chance of cancer as 1 in 50.

Apart from the arsenic, other nonbiodegradable heavy metals from coal ash like selenium (Se) have also been reported for its bioaccumulation property. Further studies revealed that soil deposition of coal ash in wetlands can contaminate the rivers and agricultural lands which ultimately entered in different types of the food chain and in turn being magnified (Wu et al. 1995).

(b) *Integrated iron and Steel plant slag*: Slag in integrated steel and iron plants is dumped in surrounding areas of the steel plants making hillocks encroaching on the agricultural land. The slag from these steel plants mainly has the oxides of Si, Al, Ca, Mg, Mn, and Fe. Scientists have reported that heaps of steel-slag accumulated during more than 40 years in an agricultural land can change the soil texture by deposition of heavy metals such as Fe, Mg, Ca, and Si (Garcia-Guinea et al. 2010). These contaminants are also responsible for changing the soil pH and microbial strata of soil. Furthermore, most of the oxides of Al, Mg, and Mn deposited from slag industry in their surrounding area can reach to the agricultural lands through leaching and running water during heavy rain, which may become an integrated part of our food chain. Regarding the toxicity and bioaccumulation properties of these oxides, many experiments have been

performed by preparing nanoparticles of these metals; the results showed that oxides of aluminum are accumulated in liver and kidney cells and in turn showed adverse effects to our immune system (Park et al. 2015). Similarly, the manganese oxide (MnO) is reported to be accumulated in the brain, lung, and bone cells of pigeons (Sierra et al. 1998). Thus, from the above discussion, we can draw a conclusion that the deposition of slag from various industries on agricultural lands can create a major problem through incorporation and magnification of its toxic components in the food chain.

(c) *Red mud*: Red mud is a solid waste, generated from nonferrous metal extraction industries like copper and aluminum. Presently, most of the red mud of these industries is disposed in tailing ponds for settling, which more often are reported to find its course into the rivers, especially during monsoon. The red mud toxicity includes various heavy metal contamination like Mn, Pb, and Zn (Liu et al. 2011) and can contaminate the soil and aquatic ecosystem. As previous studies had clearly indicated the bioaccumulation properties of these heavy metals (Canli and Atli 2003), disposal of the red mud is a burning challenge for the ecosystem and had adversely affected the human health.

12.2.3 Nuclear Energy and Soil Pollution

Exploitation of nuclear energy through fusion or fission of atoms can provide us an alternate way of large-scale carbon-free electricity source to fulfill the excessive demand for electricity. Presently, the urbanization and industrialization throughout the Globe has created a burning challenge for continuous supply of electricity. Regarding this, nuclear reactors or power plants have been designed, which can generate electricity through controlled nuclear reactions. On the one hand, these nuclear reactors have provided a better alternate opportunity for electrical energy while on the other hand the accidental release of radioactive pollutants from these reactors may adversely affect the ecosystem. Contamination of the soil with radioactive pollutants is an important origin of hazard for the environment and health safety as well as for economy.

The release of radionuclides mainly occurs at the time of processing of radioactive waste during segregation, transportation, treatments, characterization, and disposal. According to an estimation, soil contamination mainly occurs by fission product solidification, whereas leaching from the final disposal may result in the contamination of the soil with ^{90}Sr, ^{137}Cs, and actinides (Aleksakhin 2009). Furthermore, some corrosion products (^{55}Fe, ^{59}Ni, ^{63}Ni, ^{54}Nb, ^{60}Co, ^{39}Ar, etc.) of these nuclear reactors may also significantly cause soil pollution. Apart from the nuclear reactors, regular nuclear weapon tests are the major cause of soil pollution through radioactive elements. The main concern is especially focused on to release of plutonium (Pu) isotopes due to its high biological toxicity and long half-lives of its isotopes (Mary et al. 2003; Gabrieli et al. 2011). Further studies have revealed that released radioisotopes of ^{137}Cs, ^{241}Am, ^{90}Sr, and ^{131}I are the major concern for its hazardous impact on the natural environment and human health issues (Prăvălie

2014). The mentioned isotopes had been reported in most of the nuclear sites worldwide, especially in western US soil (Turner et al. 2003; Cizdziel et al. 2008). In search of major radioactive pollutants of the ecosystem, scientists have found that the accidents held in Chernobyl (Ukrane-1986) and Fukushima (Japan-2011) were responsible for causing global contamination of the environment including air, water, soil, and living organism. In this event, a huge amount of radioactive elements, especially ^{131}I, ^{137}Cs, and ^{90}Sr and the sum activity of ^{239}Pu and ^{240}Pu were found to be dispersed in the environment (Steinhauser et al. 2014). These radioactive elements can also be a major challenge for an aquatic ecosystem, which may reach from the contaminated soil to ground water or by flowing of these soils into rivers during heavy rain. Regarding this, scientists have reported that the Fukushima nuclear disaster delivered a massive amount of radioactivity into the sea and radioactive isotopes soon made their way into the marine food chain.

These radioactive elements which have been found to contaminate our land ecosystem have also been reported to accumulate in our body, which may enter through different food chains starting from soil. As radioactive materials are likely to be long-lived, mobile, and biologically active, once incorporated in our body they are responsible for causing several adverse consequences related to our health. In search of biomagnifications of radioactive elements, it has been found that ^{131}I can be easily taken by fish through their thyroid tissue while ^{137}Cs being mobile and long lived has been reported to be accumulated in organisms up to marine food chains and ultimately to human where we consume these marine creatures as food. Furthermore, ^{137}Cs can be taken up by cells throughout the body and distributed in soft tissue, especially in muscle tissue, increasing cancer risk.

12.3 Conclusions

From this chapter, we can say that the increasing global population is a burning challenge for our ecosystem as the development of society demands to change the natural environment. The changing environment is the major cause of soil pollution that ultimately affects our life adversely. The soil pollutants adversely affect their texture and, in turn, fertility of the soil while on the other hand the components of contaminants (heavy metals, pesticides, radionuclide) can integrate into our food chain and, in turn, biologically magnified. The hazardous effect of these pollutants is the major concern for developing as well as developed countries. Finally, we may say that human activities and the unhygienic disposal of waste are the major area of concern to limit the toxic effect of different pollutants. To overcome these problems, the different summits had been organized by developing and developed countries from time to time and many resolutions and treaties had been signed by their representatives. The major problem is the unawareness and illiteracy of the people about their ecosystem so that the burning challenge is to wake up the people about the hazardous effect of these pollutants. The government of the countries should equip the proper waste management and should ensure its implementation to the agricultural and industrial waste to minimize the toxic effect of different pollutants.

Thus, waste management of pollutants can minimize the soil contaminants on the one hand, while on the other hand the recycling of these pollutants will be helpful for the economy.

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