Soil Pollution and Human Health

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Abstract

The soil is a natural entity acting as a buffer, and provides medium, anchorage, and nutrition to crop plants. Contaminants from agricultural soils entering into the human food chains have become a serious problem. Trace elements may enter into human food web via soil to water, plants, and animals. Soil once contaminated due to heavy metals (HM) or pesticide residues poses serious risks to human health and environmental safety. Anthropogenic sources lead to accumulation of trace metal elements in soil which persists for exceptionally longer period because of non-decay and their longer biological half-lives. Excessive fertilization and pesticide usage pollute ground water through runoff and leaching. Non-judicious application of agrochemicals is a threat to humans besides affecting nontarget plants and other macro and microorganisms in the agroecosystem. Necessary modifications in agricultural practices are needed on the use of fertilizers and pesticides. Highest safety against the use of agrochemicals may be ensured by imparting training, education, and policy considerations. Regulations are needed to abate cultivation on contaminated sites and disposal of harmful effluents on agricultural lands and avoid soil enrichment with potential pollutants. Remedial measures that can accelerate rejuvenation of contaminated sites, alternatives to intensive conventional agricultural practices, and safe strategies for plant protection are the need of the day. Information and data support on soil contaminants, their pathways, and mechanisms affecting human health are sparse. Further research with a multidisciplinary approach may handle the obstacles of the current techniques.

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13.1 Introduction

Soil pollution is the introduction of any material, biological organisms, or energy consequently leading to reduction in the soil quality which may influence day-to-day soil use or pose a threat to living environment and public health (Kumar et al. 2013). Complex structure of soil contains the major components viz. mineral matter, organic matter, water, air, and living organisms. The proportion of these components varies with location and thus soil plays a key role in sustaining the living being. Rapid industrialization has exerted ill effects on the environmental components threatening human health in long term. Occurrence of the heavy metals is natural and a few metals are essential in trace quantities, but their higher concentration is deleterious, indicating the extent of contamination in a particular area. Soil pollution has emerged as a widespread problem during the past few decades because of strenuous use of fertilizers and pesticides in agriculture, urban waste, industrial activities, and atmospheric discharges. The degree of occurrence depends on the extent of agrochemical use and industrialization. Soil pollution interferes in many ways by change in soil structure, reduction in soil fertility, disrupting the balance between soil flora and fauna, and contaminating crops and groundwater posing a serious threat to living organisms.

13.2 Sources of Soil Contaminants

The various soil pollutants include pesticides, heavy metals, petroleum hydrocarbons, dibenzo-*p*-dioxins/dibenzofurans, and polychlorobiphenyl. Heavy metals enter into the soil through anthropogenic sources (fertilizers, pesticides, organic and inorganic materials, wastes, and sludge residues). Contrary to injurious organic compounds, heavy metals do not break down or disappear and persist in the soil for many years (Lionetto et al. 2012). Disposal of industrial effluent and sewage (treated/untreated) to agricultural soil is one of the prime reasons for heavy metal contamination. An appropriate land management retaining quality of soil and precise information about heavy metals are required to equip us for suitable soil management (Chopra et al. 2009).

13.2.1 Impact of Agricultural Practices

13.2.1.1 Inorganic Fertilizers

Inorganic fertilizers are the principal source to meet the demand for essential nutrients under intensive cropping systems. In order to ensure food security for ever-increasing population coupled with limited availability of the cultivable land puts a challenge to enhance the productivity per unit area per unit time. An increase in productivity demands a greater quantity of nutrients leading to excessive use of inorganic fertilizers in agricultural fields. Crop nutrition is one of the most important aspects that determine the productivity and quality of the produce. The inherent capacity of the soil to supply the nutrients essential for the crop growth varies with soils and the agricultural practices followed. The plant efficiency in utilizing the nutrients applied to soil also varies and largely depends on the characteristics of crop, soil, fertilizer, and its management practices. The trend of high fertilizer use may continue for the next three decades to achieve the required productivity. Excess fertilizer application causes eutrophication of surface water bodies and leaching of nitrate to ground water. Inorganic fertilizers mainly contain ammonium, nitrate, phosphate, and potassium salts. Leaching of highly mobile nitrate is considered a major pathway for N loss. The nitrate leaching depends upon rate and timing of N application and its synchronization with the demand and uptake by the crop. Besides the soil characteristics, source of N fertilizer, and availability of moisture/irrigation also play a crucial role in determining the quantum of leachable nitrate. Efficient management of N may substantially reduce the leaching potential. Ground water is one of the principal sources utilized for drinking water in India. Various inorganic and organic pollutants deteriorate the quality of ground water, making it unsafe for human consumption. Nitrate (NO_3^-) is one of the major inorganic pollutants dispensed by nitrogenous fertilizers, human and animal refuses, organic manures, and industrial effluents via biochemical activities of microbes. Apart from nitrate (NO_3^-) containing nitrogenous fertilizers, other forms viz. amide (NH_2^-) and ammonium (NH_4^+) are rapidly converted to nitrate in soil. High solubility and poor retention by soil particles lead to contamination of ground water with nitrate. Higher use of nitrogenous fertilizers is the principal cause for occurrence of more nitrates in ground water. Ground water with high nitrate concentration used as drinking water causes several health disorders viz. hypertension, methemoglobinemia, birth malformations, goiter, gastric cancer, etc. Increase in the use of nitrogenous fertilizers and the quantum of organic wastes generated may aggravate and pose an alarming situation in years to come. The maximum permissible limit for NO_3^-N in drinking water is 10 mg l^{-1} (Majumdar and Gupta 2000). Nitrate reaches water environment by way of leaching, drainage, and surface flow of water. Drinking water with high nitrate concentration (>50 mg NO_3^- l^{-1}) causes inflammation, methemoglobinemia in infants (a blood disorder limiting oxygen supply to cells), and carcinogenic effects (Savci 2012). Fertilizers carrying heavy metals viz. arsenic (As), copper (Cu), cadmium (Cd), mercury (Hg), nickel (Ni), lead (Pb), and natural radionuclides deteriorate environment. Fertilizer application should be based on prior soil analysis, at right time, appropriate source and method to minimize the loss of energy, finance, and to environment (Savci 2012). Soils are integral to production of food and fiber in all terrestrial ecosystems. Reducing excessive nitrogen fertilizer use to economic optimal doses improves water quality but involves the risk of lowering the crop production. Improvement in timing and placement enhances the efficiency of the applied fertilizers with co-benefit of water quality particularly with the suboptimal nitrogen use (Paustian et al. 2016).

13.2.1.2 Antibiotic Loaded Manures

Addition of antibiotics in animal feed supplements is common, aimed to enhance growth of food animals. However, excreted urine and feces contain substantial share of added antibiotics due to their incomplete absorption in the animal gut. Results of a greenhouse study revealed that the test crops i.e. cabbage (*Brassica oleracea* L. Capitata group), green onion (*Allium cepa* L.), and corn (*Zea mays* L.) grown on a mixture of pig manure and soil artificially spiked with antibiotics absorbed the antibiotic Chlortetracycline but Tylosin was not absorbed. The low concentrations of antibiotic Chlortetracycline found in plant tissues but it increased with increasing rate of antibiotics added to manure soil mixture. The study indicates the potential risks to human health associated upon consumption of crops grown on a soil altered with antibiotic loaded manures. Higher risks are involved for people allergic to antibiotics with chances of enhanced antimicrobial resistance due to consumption of such vegetables (Kumar et al. 2005).

13.2.1.3 Industrial Effluent and Sewage Sludge

Addition of treated sewage sludge (biosolids) to agricultural land facilitates a way for waste management besides providing organic matter, essential nutrients, and considerably improving soil properties. However, it contains organic contaminants (dioxins) and pharmaceuticals in detectable concentrations (Clarke and Smith 2011; Wu et al. 2012). Accumulation of such contaminants in soil may lead their subsequent translocation to the food chain. Contaminants even at low levels may harm human health and environment. The possible human exposure pathways for soil-applied biosolids include entry of contaminants to food chain via consumption of edible plant parts and/or milk, meat, contaminated source (surface and ground water) of drinking water or by airborne inhalation. The utilization of biosolids to agricultural fields is often suggested to get benefit of recycling of nutrients, disposal of waste, sustainability, and economical aspect. However, potential risks involved due to the presence of emerging pollutants (PPCPs—pharmaceuticals and personal care products) and persistent organic pollutants (POPs) which may accumulate in the soil finally transferred to humans via contaminated produce (Clarke and Cummins 2015). Use of fertilizers, pesticides, and wastewater for irrigation has enhanced the heavy metal contamination in agricultural fields during past decades and showing an increasing trend. The assessment of heavy metal sources and their dispersal in agricultural land indicates that the pedogenic factors act as primary inputs of Ni, cobalt (Co), and chromium (Cr) and, anthropogenic sources for Cu, Zn, and Pb while Cd is linked with agricultural and industrial pollution. The heavy metals Cu, Cd, Ni, and zinc (Zn) evinced the high pollution risk because of agricultural practices and use of wastewater. Such results may be utilized for the formulation of remedial strategies in the affected area (Hani and Pazira 2011). Effect of heavy metal pollution (Zn, Cu, Cr, Co, Ni, and Pb) due to sewage and wastewater irrigation was assessed in soils on leafy and non-leafy vegetables, forage grass, and milk from cattle. Results have shown that high levels of Cu, Zn, and Cr were linked with labile fractions and thus were highly mobile and available to plants. The associated risk to human was assessed who were consuming these contaminated foods. Results revealed that the hazard quotient was high for Zn followed by Pb and Cr particularly with leafy vegetables viz. spinach and amaranthus (Chary et al. 2008). Vegetable crops viz. radish (*Raphanus sativus*), cabbage (*Brassica oleracea* var. *capitata*), tomato (*Lycopersicon esculentum*), okra (*Hibiscus esculentus*), brinjal (*Solanum melongena*), chili (*Capsicum annum*), spinach (*Spinacia oleracea* L), coriander (*Coriandrum sativum*), cress (*Lepidium sativum*), and dill (*Peucedanum graveolens*) showed variable patterns for accumulation and translocation of heavy metals. Regular irrigation with mixed industrial effluents results in higher concentration of metals [iron (Fe), manganese (Mn), Cd, Cr, Cu, Zn, Ni, As, and Pb] in soil and later in plants. Cultivation of spinach, radish, tomato, chili and cabbage was found to be unsafe in the areas receiving irrigation with mixed industrial effluent. High content of toxic metals (Cd, Cr, Ni, Pb, and As) found in the edible parts of such crops indicated their high accumulation and translocation potential. Results indicate enhanced risk and toxic impact on human health and ruminants via food chain. Hence, produce of polluted sites should be examined first for safe consumption of the human being or vice-versa discarded for cultivation. Vegetable crops that limit toxic metals in nonedible parts may be opted for cultivation at contaminated sites. Such studies suggest choice and planning of safe cropping system and helps in monitoring of agricultural fields for determination of toxic metals, management, and disposal of industrial effluents (Tiwari et al. 2011).

13.2.1.4 Pesticides

The term pesticide includes a vast range of substances namely herbicides, insecticides, fungicides, nematicides, molluscicides, rodenticides, plant growth regulators, and others (Aktar Md et al. 2009). Pesticide is substance or their mixture used for prevention, destruction, to repel, or mitigate any pest or weed. Pesticides are used as an effective means for control of pests and weeds, protect yield losses, and for economic viability. More than 500 pesticide formulations are repeatedly being used. The major concern related to pesticide use includes their deleterious effects on nontarget organisms. Adverse effects have been identified on human beings, fishes, birds, and on the environment. In fact, $<0.1\%$ of the pesticide used reaches the target pest; the rest enters the environment polluting soil, water, and air harming nontarget organisms. Longer persistence of many pesticides may result its accumulation and progressive increase leading to higher concentrations in the tissues of living organisms (biomagnifications) after entering into the food chain. Pesticides use in agriculture will result in their existence in nonagricultural environments. Pesticides added directly to soil in the form of granules or sprayed on crop foliage reaches soil as wash-off. The residues of pesticides enter the surface or ground water through soil. The ultimate fate of pesticides within soil or their spread to air, water or food stuff varies with chemical properties of both product and soil. Several processes viz. uptake by plants, biological and chemical degradation, sorption, volatilization, leaching, and runoff also plays vital role. Physicochemical and biological properties of the soil environment like pH, proportion of clay particles, organic matter, moisture content, etc. governs the pesticide degradation and transfer of their carry over residues to air and water resources (Arias-Estévez et al. 2008).

Most of the organochlorine pesticides tend to accumulate in animal tissues. They are utmost stable and continue to exist in the environment and as a result can get into the food chain directly or indirectly. Pesticide residues volatilize from the warmer regions (tropical conditions), travel long distances with air and settle in other regions causing widespread contamination. Bioremediation strategy suggests that microorganisms such as several gram-negative bacteria have degrading potential. However, action-bacteria (gram-positive) particularly of Streptomyces genus have potential for biodegradation of inorganic and organic toxic compounds by dealkylation, partial dichlorination, and oxidation of dichlorodiphenyltrichloroethane (DDT), aldrin, and herbicides like atrazine and metolachlor. Streptomyces are befitted for soil inoculation because of their mycelial growth and rapid growth rate, ability of vegetative hyphal mass to differentiate into spores that help in spreading and persistence; longer survival period of spores and resistance against low water availability and nutrient concentrations. Microbial mixed cultures are considered more appropriate for bioremediation of recalcitrant compounds since, usually have elevated growth rates and substrate utilization than individual species. Results suggest that consortia of Streptomyces strains can effectively improve the biodegradation process and degrade xenobiotic from sediments, polluted soils, and wastewaters than the corresponding single strain (Fuentes et al. 2011). Application of herbicides at a wider scale to agricultural fields poses environmental problems. The Jews mallow growth in a saturated soil pretreated many times with cyanobacterial mats indicated the successful biodegradation of a popular herbicide Diuron. The Diuron degrades rapidly at low concentrations in soil (within 30 days) and the effect was more prominent when incubated with cyanobacteria in liquid medium (irrigation water). High concentrations of Diuron (>0.22 mg kg^{-1} soil) may exert toxic effect on cyanobacterial mats. These promising findings suggest that cyanobacterial mats may be used as a remedial technique for water and/or soil pollution caused due to herbicides application (Safi et al. 2014).

With advancement in science and technology, the threats to environment have also increased because of disposal of contaminated wastes and depletion of natural resources. A huge number of chemically synthesized compounds (approximately 6×10^6) are available and about 1000 new chemicals being annually added to this list to restrain such waste materials carrying heavy metals and their unsound disposal creating ecological problems at the global level. Use of traditional methods involves high cost due to excavation and transportation processes. Bioremediation offers an eco-friendly and cost-effective way to replace conventional methods such as incineration which creates a new waste and do not get rid of the problem. The biological processes cause reduction, transform, or eliminate pollutants. The factors viz. type of pollutants, soil pH, moisture holding capacity, soil structure, fertility status, and microbial diversity are important for bioremediation. Bioremediation is the most effective technology to tackle environmental contamination increasing day by day due to anthropogenic activities since use of biological systems for pollution reduction. This novel approach involves multiple disciplines with key focus on microbiology. The technology includes revitalizing native microbial population (bio-stimulation), their artificial introduction (bioaugmentation), gradual buildup (bioaccumulation), as potential metal bio-sorbents (bio-sorption), by use of plants (phytoremediation) and by interaction of soil, microbes, and plant (rhizoremediation). Development of suitable methods and more scientific knowledge are required on natural processes for effective utilization of bioremediation technology to restore the contaminated environments. Interdisciplinary research may address to the present obstacles and issues in near future (Shukla et al. 2010). Assessment of risk and the measures to reduce them are crucial. It appears that there is enormous potential for development of potent, low environmental risk and dependable microbial-derived pesticides. Improved techniques with precise application may reduce pesticide rate. Improved formulations are required to enhance the retention, uptake, and translocation when used on target and reducing off target deposition. Such improvements may curtail transport and also avoid the upsurge of resistance in target organisms. The current environmental concerns related to agrochemical residues from soil, water, and foodstuffs will not disappear. However, to ensure minimal harm, pesticides should have low or no toxicity to the nontarget organisms. Surveys on pesticide sales and market to know pesticide use patterns should be promoted for policy considerations as global strategy (Arias-Estévez et al. 2008). The data on pesticide-associated risk assessment relevant to health and environment are scanty in developing countries which is much needed information for clear understanding of the problem. The strategic interventions to reduce the ill effects should be based on the periodic monitoring studies on high-risk groups. Imparting education and training to field-level workers may ensure safety against pesticides use. Scientific judgment should form prime basis for all pesticides-related exercises rather than the commercial considerations. Pesticides are recognized as an easy, low cost, and rapid solution for control of pests and weeds. Pesticide contamination can be reduced by adoption of nonchemical methods of pest control (including weed control). The prevention of harmful effects on health will lead to sustainable development. Although there is some ambiguity at present leading to lifelong exposure of people, but in spite of all reasons, knowledge-based health education packages are developed to minimize ill effects of pesticides to humans (Aktar Md et al. 2009).

13.3 Soil Contamination and Human Health

The soil is a porous medium containing organic matter, mineral matter, living organisms, water, and gas. The occurrence of heavy metals in soils is obvious though its extent may indicate the pollution load in a particular area. The accurate information about heavy metals is necessary for proper soil management because of their potential toxicity to the crop plants and human health. Usually heavy metals having density >4.5 g cm^{-3} (Cu, Cd, Zn, Pb, Hg, Ni, Cr, etc.) are stable and thus they accumulate in soils and cannot be destroyed being nonthermodegradable or nonbiodegradable. Of several pathways for contamination of agricultural soils, the industrial discharges and sewage (treated/untreated) emerge as a prime source of heavy metal contamination. There is a need to find out potential microbial strains which can degrade heavy metals. Biotechnological approaches such as genetically engineered microorganisms with enhanced degradation efficiency may address the problem. Disposal of any type of effluents to agricultural lands should be stopped (Chopra et al. 2009). Analyses of eight metals of upper layer soils in rice fields revealed that Pb exhibited strong spatial dependency while other metals (Cu, Zn, Cd, Cr, Hg, As, and Co) showed moderate spatial dependency. The degrees of enrichment in rice soils varied with heavy metals since the anthropogenic activity had different influence on them. The results suggest that the anthropic factor controls Zn, Cu, and Cr, natural factors control Cd, Co, and As, while natural and anthropic both factors control Hg and Pb. The spatial map indicated that alterations are required in the present agricultural practices since >85% area under study evinced Zn, Cu, and Cr enrichment while some area shown high Hg (Wu et al. 2010). Heavy metals in low concentrations are found in phosphate rocks (as minor constituents), animal manures, and sewage sludge. The repeated fertilizer and/or large applications of manures may result in accumulation of heavy metals in soil. Among these, Cd may potentially harmful to human health. Other heavy metals are of less concern than Cd since they are not readily absorbed by the plants and relatively lesser harmful to human health. Few countries have imposed their regulations on concentrations of heavy metals in phosphate fertilizers, sewage biosolids and set the tolerance limit for addition of heavy metals to plough layer (upper 20–30 cm) soil. In fact, the rate of phosphorous application controls the input of Cd to soil (Mortvedt 1996).

13.3.1 Assessment of Contamination

Heavy metal contamination poses serious problems at the global level because of their abundant sources, accumulative nature, nonbiodegradable properties, and toxicity. A study assessed the soil HM contamination at a prominent site and measured the contents of Ni, Cr, Zn, Cd, As, Cu, Hg, and Pb in soil and crop samples (1822 pairs). The health risks evaluation as per the model of U.S. Environmental Protection Agency stated that single pollution index was found at unpolluted level while mean Nemerow composite pollution index at cautious level. The mean crop pollution index (CPI) exceeded the national standard value for Ni only. The standard exceeding rates of Cu, Cd, and Hg in soil and Ni, Cr, and As in crops were significantly greater than their corresponding values in crops and soil, respectively. The bio accumulation factor (BAF) indicated the translocation of heavy metals in the soil-crop system. The mean CPIs are noted in the order Ni > Cr > Zn > Cd > As > Cu > Hg > Pb and the BAF in the order of Cd > Zn > As > Cu > Ni > Hg > Cr > Pb. The crops exhibited variable capacities to absorb HMs and cadmium is most readily absorbed by crops than other HMs. The hazard quotient for HMs was at a safe level for various age groups indicating low potential noncarcinogenic risk to residents of the study area due to HMs. However, ingestion was found as the leading pathway to cause carcinogen risk to human health (Hu et al. 2017). Soils act as a (temporary) sink and source of several chemical pollutants and their accumulation in soils enhances the threat for direct (inhalation, ingestion of soil, and dermal contact) or indirect (drinking water or dietary intake) human exposure. Risks assessment to human health should essentially incorporate bioavailability adjustments beyond the routes of exposure at polluted areas. Variable concepts, uncertain methodologies, lack of data, and accurate methodology restrict proper soil risk evaluations and its validation including bioavailability measurements. Development of inexpensive and rapid tools needed to ascertain threshold concentrations of pollutants in soils and their potential risks because of human exposure. This would be useful to utilize the bioavailability data for assessment of risk and decision-making (Rodrigues and Römkens Paul 2018).

13.3.2 Pollution Safe Crop/Cultivar

Soils contaminations with heavy metals are important pathway for the entry of these toxic pollutants to the human food chain. Information on crops' responses to these contaminations either by single or multiple metals is scarce. Evaluation of asparagus bean (*Vigna unguiculata* subsp. *sesquipedalis* L.) for accumulation of Cd (low level: 0.8 mg kg^{-1} and high level: 11.8 mg kg^{-1}) by cultivars and their exposure to multiple metals (Cd: 1.2, Pb: 486 and Zn: 1114 mg kg^{-1}) exhibited highly significant variations among the test cultivars regarding Cd accumulation by asparagus bean (stems, leaves, fruits, and roots). The harvested fruits (pods) of low and high Cd exposure (41.7% test cultivars) contained lower Cd concentrations (<0.05 mg kg^{-1}) found safe for consumption. Cultivars having black seed coats proved significantly superior since they showed low Cd concentrations (fruit) compared with red/spotted seed coats. Cadmium accumulations are governed by the genetic factors and asparagus bean is a low accumulator to Cd pollutant. Significant positive correlation noticed between Cd and Pb concentrations in fruits when kept under high-level Cd stress conditions. The study suggests that the Cd accumulation in fruits might be due to the presence of other heavy metals in the soil. Adoption of pollution safe cultivars (PSC) is a practicable strategy for asparagus bean. Further studies are required on various genetic aspects and a new breeding approach to understand the mechanism and develop PSC to minimize the threats of human exposure to heavy metals (Zhu et al. 2007). Agricultural production is continued on large acreage of polluted land in some countries to fulfill the growing demand for food. Growing of pollution safe cultivars (PSCs) which accumulate low level of specific pollutants in their edible parts may restrict the influx of pollutants. Such PSCs offer safe produce for consumption when grown in polluted soil. The feasibility of this concept was attempted in a pot experiment on 43 rice cultivars (23 hybrids and 20 normal cultivars) exposed to a low (1.75–1.85 mg kg^{-1}) and high (75.69–77.55 mg kg^{-1}) cadmium (Cd) level. Thirty test cultivars observed Cd-PSCs at low level of Cd exposure. Results emphasized that the Cd concentrations in grains found highly correlated ($p < 0.01$) among two experiments. Findings suggests that Cd accumulation in rice grains depends on genotype indicating future possibilities of screening PSCs with a definite level of soil contamination. However, at high-level exposure, none of the test cultivars fall under Cd-PSCs. Variations in yield responses of the cultivars at high soil Cd illustrate that reduction in yield is not an indicator of toxicity of the grains. Therefore, it is imperative to initiate breeding programs and screening for PSCs to effectively address the threat of human exposure to soil pollutants (Yu et al. 2006).

13.3.3 Green Technologies

Heavy metal contamination in soils is often irreversible and may suppress/sometime kill parts of the microbial community and lead to more tolerant microbial population. The extent of N-fixing cyanobacterial population and existence of heterocysts are affected in the soils having high chromium levels. The number of Cr (VI) tolerant heterotrophic bacteria significantly increased in the polluted soil than unpolluted one. Further research may help to delineate the chromium-contaminated environments by utilizing the tolerance of heterotrophic bacteria to Cr (VI) and occurrence of heterocysts in cyanobacteria and/or for supervising bioremediation process (Viti and Giovannetti 2001). Heavy metals pose long-term risks being highly reactive and toxic even at low concentrations. Their biotic effects vary as per specific metal and for adapted organisms. Some plants (metallophytes) have evolved mechanisms to contend with heavy metal stress. Hence, metallophytes may be used for cleaning of the metal-contaminated sites and to limit the spread of heavy metals outside the contaminated area. Proper exploitation of the green technologies will require vegetation surveys for possible discovery of hyper accumulating and metal-tolerant plants in more numbers from under studied habitats (Gall et al. 2015).

Phytoremediation is a promising technology that includes phytoextraction and phytostabilization to remediate polluted soils. The capacity of a soil to discharge its functions is termed as soil quality. The reversal process of any heavy metal-polluted soil includes removal of HM from soil with restoration of soil quality. Soil microbial properties are becoming popular as biological indicators of soil quality due to high sensitivity, rapid response, and facts that combine many environmental factors. Restoration of soil quality is judged during phytoremediation of HM via microbial monitoring, although soil microbial properties are highly dependent on circumstances and tough to interpret. Interpretation may be improved by classifying them into groups of higher ecological relevance viz. ecosystem health attributes, ecosystem services, and soil functions (Gómez-Sagasti et al. 2012).

Phytoremediation includes a number of technologies by which plants degrade, remove, reduce, or immobilize environmental toxic pollutants of anthropogenic origin to restore the contaminated sites to a reusable condition. Phytoremediation utilizes plants to hasten the degradation of organic contaminants with rhizosphere microorganisms, or to take out dangerous heavy metals from water or soils. Phytoremediation is eco-friendly technology and relatively inexpensive than alternate remediation strategies. Majority plants in nature are colonized by arbuscular mycorrhiza fungi and the bacteria helping mycorrhization may be exploited to improve it. To take advantage of microbes as bioprotectants against heavy metals and pathogens, their ecological complexity particularly in the mycorrhizosphere needs careful attention. Integration of such information on soil and root microbe activities and their distribution dynamics is required with physicochemical and spatial properties of soil. Such tasks may be accomplished by associative efforts of physicists, soil chemists, and biologists (Shirmohammadi et al. 2014).

13.3.4 Indicators of Soil Health

The sustenance of production depends on many factors that are interrelated and influence soil productivity. The soil health indicates the continued capacity of any soil to sustain productivity, maintain/improve the quality of environment within an ecosystem boundary, which supports human health and living. Increasing pressure on soils will require regular assessment and monitoring of soil health. Soil enzyme activities are one of the promising indicators of soil health among proposed biological indicators but require careful judgment and interpretation of the data. Soil enzyme activities are responsive to changes that occur in soil because of crop management practices (crop rotation, tillage, fertilization, residue management, etc.). Determinations of soil enzyme activities are comparatively easy, rapid, and low cost than physicochemical methods. Dependency on single measure (soil enzyme activities) may constitute certain limitations and thus an accurate diagnosis of soil health requires concomitance with physicochemical and other biological measures (Alkorta et al. 2003). Organisms that impart quantitative details about environmental quality are termed as biomonitors. Limitations in use of plants as biomonitors of soil pollution have been advocated by earlier workers. However, plant biomonitors are better indicators of soil quality and have key advantages than soil analyses particularly for large-scale exploration. Total metal concentration can be best measured by direct soil analyses. However, estimation of soil quality by plant biomonitors facilitates direct quantification of a biological effect to assess the influence of pollutants on ecosystem and humans. This approach manifests clearly the consequence on living organisms due to metal and not inferring only the values for total metal concentration in soil (Madejón et al. 2006). Plant biomonitors have certain experiential constraints over soil analyses. None of the single plant species can respond to a vast range of contaminants. The metal bioavailability and their uptake vary across the plant species and varieties therefore restricting the range to specific plant. Metal concentrations in leaves are resultant of time, plant developmental stage, and environmental factors; plant roots may ignore metal hotspots (Mertens et al. 2005). These constraints may be addressed by selection of most suitable plant species (more than one) as biomonitors that are important in the food cycle of an ecosystem (Madejón et al. 2006).

Earthworms improve soil fertility, decompose organic matter, and recycle nutrients. Earthworms can suitably be used as indicator organisms for biological impact assessment of the soil pollutants and soil ecotoxicological research.

Management and measurement of earthworms are easier to assess the biochemical responses, accumulation of pollutants, and its excretion, and facilitates the study on life span (growth and reproduction). Generally, low levels of contaminations turn out more rapidly in cells/tissues of an organism than higher levels such as ecological effects. Therefore, any change (cellular, physiological, and biochemical) in an organism due to pollutant exposure may be used as biomarkers to provide an early warning. Earthworm biomarkers use to monitor soil pollution and effect of contaminants on soil organisms is a recent approach. Identification and characterization of most suitable earthworm species is necessary on priority basis. Development of biomarkers of exposure should be able to address a wide range of soil contaminants since studies conducted so far largely are concerned with heavy metals only. Studies are scanty on earthworm biomarkers under real field conditions with use of native populations for assessment of soil pollution (Lionetto et al. 2012). A long-term screening revealed that microbial biomass, soil enzyme activity, and algal populations reduced in medium-to-high polluted soils with total petroleum hydrocarbon (TPH). The lower TPH pollution enhanced the algal populations but the microbial biomass and enzymes were found unaffected. Inhibitory effect on above parameters was more pronounced in high polluted soil than medium polluted soils. Medium-to-high polluted soils exhibited removal of sensitive algae species indicating a shift in composition. Results suggest such alterations in the soil algal composition may be utilized to find out environmental hazards at polluted sites and for making recommendations on soil quality. The soil algal tests hold extraordinary importance because of confined knowledge on toxicity to microorganisms due to exposure of pollutants' terrestrial environments (Megharaj et al. 2000).

13.4 Research Challenges and Policy Considerations

Assessment of soil quality (SQ) is a tough issue, since soils greatly vary in properties and functions. Development of methods to monitor and assess SQ is needed to ensure sustainable land use without any harm to human health. The holistic approach should adopt indicators of various types (physical, chemical, and biological) for judgment of SQ. Mostly single indicators are used and urban SQ not being properly assessed. Further efforts are needed to develop methodologies by incorporating exposure pathways or human health indicators for assessment of soil quality. Such methodologies should consider soil quality in terms of productivity, sustainability, ecosystem, and human health (Zornoza et al. 2015). Stockholm Convention to oversee identified POPs along with PPCPs on the basis of associated risk factors viz. persistence, bioaccumulation, and toxicity. Continuous addition of the emerging contaminants (PPCPs) is of great concern since it compensates their transformation/removal from the environment. More studies are needed on exposure pathways of contaminants and their long-term influence on human health with focus on PPCPs. Significant knowledge gap exists on long-term risk assessment because of exposure to PPCPs upon human consumption of water, food crops, and meat. Accurate risk assessment to human/environment by these contaminants will depend on execution of proper modeling approaches. Policy considerations are needed to mitigate the ill effects on environment by the use of readily degradable pharmaceuticals (greener pharmacology) and increase in the efficiency of biological treatments (wastewater treatment plants) (Clarke and Cummins 2015).

The importance of soil biodiversity is progressively admitted for offering advantages to human health due to suppression of soil organisms that induce diseases and facilitates clean water, air, and food. Environmental change and faulty land-management practices affect belowground communities globally, resulting in reduced benefits due to decrease in soil biodiversity. Current findings are indicative of the fact that sustainable management can partially restore and maintain soil biodiversity. Better management practices encourage soil biodiversity and ecological complexity and act with potential to improve human health through underused resource. Management options are available to conserve and enhance soil biodiversity for plant, animal, and humans. However, development and promotion of viable practices are urgently required. A new approach should consider usefulness of soil biota in land use and management to provide multiple benefits. Further, enhanced soil food web complexity amends resistance and flexibility to cope up the disruptions and shield the effects of extreme events. The appropriate practices and strategies that enhance soil biodiversity should be included in the land, water, and air use policies at regional and global levels for sustenance of human health. Initiatives have been started on global soil biodiversity to provide relevant information to policy makers and are preparing to publish the first Global Soil Biodiversity Atlas in collaboration with the European Union Joint Research Centre. The Global Soil Biodiversity Initiative is working to consider soil biodiversity at transnational platform on biodiversity and ecosystem services. Soil biodiversity provides a broad ecological foundation, linked to all forms of life and is certainly an underutilized resource. This is high time to save soils and soil biodiversity with effective management, sharing information among scientific community and policy makers, and framing new policies based on current knowledge. Development of implementation mechanism is crucial to get an easy update on related policies and best management practices. This will improve understanding of soil biodiversity management to boost human health (Wall et al. 2015). Public policies should prevent pollution by the factory farms. Strict provisions are required to reimburse the cleanup costs when any such industry pollutes area. Therefore, the products' prices must reflect their influence on the human health, environment, or the social and economic stability of rural communities (Horrigan et al. 2002). Conventional practices are posing threat to the agroecosystem health and the sustainability of the agricultural production system. Management practices opted should be able to address the root causes. Sustainability of the production system in future will depend on the site-specific technologies. Biodiversity of the below and above ground is of greater importance; proper exploitation of the benefits will largely depend on the future strategic research and perception of rhizospheric interactions under diverse conditions (Singh and Singh 2019).

13.5 Conclusion

Soil pollution has emerged as a widespread problem because of strenuous use of fertilizers and pesticides in agriculture, disposal of urban waste, and industrial activities. Contaminants like heavy metals or pesticide residues pose serious risks to human health and environmental safety. Soil pollution interferes in soil structure, reduces fertility, disrupts the balance between soil flora and fauna, contaminate crops and groundwater thus posing serious threat to living organisms. Heavy metals enter into soil through anthropogenic sources, do not break down, and persist exceptionally long in the soil. Disposal of industrial effluent and sewage to agricultural soil is the prime reason for heavy metal contamination. Precise information about heavy metals equip us for suitable soil management. Inorganic and organic pollutants deteriorate the quality of ground water making it unsafe for human consumption. Higher occurrence of nitrates in drinking water causes several health disorders. Fertilizers use efficiency may be enhanced by adoption of proper timing and placement with co-benefit of improvement in water quality. Produce of polluted sites should be examined first for safe consumption of the human being or vice-versa discarded for cultivation. Crops that limit toxic metals in nonedible parts may be opted for cultivation at contaminated sites. The data on pesticide-associated risk assessment relevant to health and environment are scanty in developing countries. The strategic interventions to reduce the ill effects should include periodic monitoring, education, and training to ensure safety. Phytoremediation is eco-friendly and relatively inexpensive technology though the successful use of microbes as bioprotectants will require more information on their activities and distribution dynamics with spatial properties of soil. Regulations are needed to abate cultivation on contaminated sites and disposal of harmful effluents on agricultural lands. Alternative safe agricultural practices and strategies are the need of the day. Information on soil contaminants, their pathways, and mechanisms is required with multidisciplinary research approach to tackle the current problems.

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