SOIL POLLUTION, CAUSES, EFFECTS AND MANAGEMENT STRATEGIES

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Introduction

The present global population of 7.6 billion is expected to reach 9.2 billion by 2050, which owes approximately 32 per cent increase from the current population scenario. As per the reports from FAO, nearly all of this population expansion will occur in developing countries. Urbanization will continue at an accelerated pace, and about 70 percent of the world's population will be urban (compared to 49 percent today). Income levels will be many multiples of what they are now. In order to feed this larger, more urban and richer population, food production must increase by 70 percent. Hence growing population vis a vis, the challenges to maintain the food security to feed them is an alarming issue all through the globe. Food production from the limited land amidst urbanization and industrialization is hence becoming a handicap to sustainable agriculture.

One of the major amenities required for sustainable food production is a healthy soil with favorable physical, chemical and biological indicators. A farming system can be considered sustainable, if it ensures that "today's development is not at the expense of tomorrow's development prospects" (World Commission on Environment and Development, 1987). Soil forms the pivotal component of all farming systems. Hence soil resources have to be managed scientifically and systematically to meet the present and future needs.

But soil quality degradation is also occurring all over the world as a resultant of various anthropogenic factors as well as natural factors. The Status of the World's Soil Resources Report (SWSR) identified, soil pollution as one of the main soil threats affecting global soil productivity as well as to the ecosystems services provided by them.

Soil Pollution, a hidden danger under our feet

Soil pollution is an alarming issue as far as the sustenance of life on the planet earth. Soil pollution refers to the presence in the soil of a chemical or substance out of place and or present at a higher than normal concentration that has adverse effects on any non-targeted organism. As per the FAO report soil pollution is a dangerous phenomenon and should be of concern worldwide. The consequences of soil pollution have the potential to poison the food we eat, the water we drink and the air we breathe. The presence of certain pollutants may also produce nutrient imbalances and soil acidification. Soil pollutants can be those compounds which are naturally present or are being added to the soils by human interventions. Addition of pesticides and herbicides for agriculture, accidental leakage or spilling of chemicals such as gasoline and diesel, manufacturing processes, mining activities, chemical waste dumping and all are some of the man made activities contributing to soil pollution. However, the natural sources of pollution is due to the accumulation of compounds in soil due to imbalances between atmospheric deposition and leaching due to rainfall, or due to the natural production of certain compounds such as per chlorates. Hence we can see a diverse array of factors contributing to soil pollution and consequent degradation. This diversity, and the transformation of organic compounds in soils by biological activity into diverse metabolites, make soil surveys to identify the contaminants both difficult and expensive.

Types of soil pollution

Depending on the mode of entry of the pollutants to the soil, there are two types of soil pollution.

1. Point Source soil pollution
2. Diffuse soil pollution

Point Source soil Pollution

When the source of pollution emerges from a specific event or through a series of events within a particular area, in which the contaminants are released to the soil, and we can easily identify the source of pollution, it is referred as point source pollution. The pollutants dispensed out from the industrial units, over application of agrochemicals, mining and smelting activities, petroleum compound released from the oil and petroleum industries, all account for the point source pollution in soil. Pollutants from these sources can create risk to human health directly, apart from contaminating the soil.

Diffuse Pollution

If the pollution from the soil is spread over a wide area and is accumulated in soil and does not have a single and easily identified source, it is referred as diffuse pollution. Diffuse pollution occurs where emission, transformation and dilution of contaminants in other media have occurred prior to their transfer to soil (FAO and ITPS, 2015). As the diffuse pollution involves the transport of pollutants through air-soil-water systems, analysis of these components are necessary to assess the extent of pollution (Geissen et al., 2015). Some of the examples of diffuse pollution are sources from nuclear power and weapons activities, uncontrolled waste disposal and contaminated effluents released in and near catchments, land application of sewage sludge, the agricultural use of pesticides and fertilizers which also add heavy metals, persistent organic pollutants, excess nutrients and agrochemicals that are transported downstream by surface runoff, flood events and also atmospheric transport and deposition. Diffuse pollution has a significant impact on the environment and human health, although its severity and extent are generally unknown.

Sources of soil pollutants

The various sources of soil pollution either natural or manmade should be understood for evolving suitable management strategies to combat soil pollution.

1. Natural Sources of soil pollution

The parent material from which the soil is derived can be a source of soil pollution, as with the fact that volcanic releases are rich sources of arsenic (As). Also weathering of arsenic containing minerals and ores releases arsenic to the soil (Díez et al., 2009). Arsenic is slightly bioaccessible when coming from natural sources (Juhasz et al., 2007). Soils and rocks are also natural sources of the radioactive gas Radon (Rn). Radon diffusion from deeper layers to the surface is controlled, in part, by soil structure and its porosity (Hafez and Awad, 2016). High natural radioactivity is common in acidic igneous rocks, mainly in feldspar-rich rocks and illite-rich rocks (Blume et al., 2016).

Sometimes natural events such as forest fires and volcanic eruptions can cause natural pollution during which many toxic compounds such as dioxin like compounds (Deardorff, Karch and Holm, 2008) during which polycyclic aromatic hydrocarbons are released into the soil. Heavy metals such as mercury, chromium, copper, nickel and zinc are also released during volcanic activity. However, this natural pollution does not normally cause environmental problems due to the regenerative ability and the adaptation capacity of plants (Kim, Choi and Chang, 2011). The problems arise when the ecosystems are subject to external pressures, which alter their resilience and response ability. Polycyclic aromatic hydrocarbons (PAHs) can also occur naturally in soils originating cosmogenically or from the diagenetic alteration processes of waxes contained in soil organic matter. Biogenic production of PAHs is favoured under reducing conditions (Thiele and Brümmer, 2002). Naturally occurring asbestos (NOA) are fibrous minerals that occur in soils formed from ultramafic rock, especially serpentine and amphibole. The main risk associated with NOA is inhalation exposure of humans related to extraction activities, while its natural presence in soils poses a negligible risk to the environment. However, NOA can be easily dispersed by wind erosion, and their mobilization will depend on the characteristics of the asbestos-containing materials, soil properties, humidity, and local weather conditions (Swartjes and Tromp, 2008). The environmental issues caused by NOA arise when they are released from soils close to urban areas, because asbestos is a carcinogenic substance, posing a high risk to human health from inhalation (Lee et al., 2008).

2. Anthropogenic sources of soil pollutants

The main anthropogenic factors associated with soil pollution are the chemicals produced during industrial activities, domestic and municipal wastes, agrochemicals for plant protection operations, petroleum derived products. Heavy metals from anthropogenic activities are present in industrial sites (Alloway, 2013). Mining is another man made activity adding up to the woes of soil pollution. Mining and metal smelting activities add heavy metals and other toxic elements to the environment, which may persist for long periods (Ogundele et al., 2017). Toxic mining wastes are stocked up in tailings, mainly formed by fine particles that can have different concentrations of heavy metals. These polluted particles can be dispersed by wind and water erosion, sometimes reaching agricultural soils. Kumar and Maiti (2015) reported that toxic concentrations of chromium and nickel were also found in agricultural soils near an abandoned chromite-asbestos mine waste in India and in crops grown in those soils which may pose a high risk to human and livestock. In oil producing areas, spills of crude oil from well sites and from pipelines are a major source of soil pollution. One of the after effects of urbanization is the wide spread development of infrastructure such as housing, roads and railways which have contributed substantially towards environmental degradation resulting in soil sealing. By way of transportation activities, there will be emission of petrol and oil which will contaminate the environment. Soil pollution associated with roads and highways is especially important in urban and peri-urban soils, and can be a major threat when food production occurs in adjacent areas. Foliar deposition and root uptake and transfer to above-ground tissues of bioavailable heavy metals are the main processes observed in roadside soil (Hashim et al., 2017; Kim et al., 2017; Zhang et al., 2015b). Grazing in roadside soils is also quite common, and the ingestion of contaminated soil and plants constitutes potential dietary transfer of pollutants affecting animal and human health (Cruz et al., 2014).

Chemicals released as part of the routine house hold activities through deposition of sewage disposal, paints, cleansing agents, detergents and other miscellaneous articles have the potential for contaminating the soil environment. Vector control programmes particularly with regard to mosquitoes for the eradication of dengue, and malaria releases toxic and hazardous chemicals to the environment (Mansouri et al., 2017). Coupled with the above mentioned activities plastic pollution is an imminent threat for soil health. Plastics can accumulate heavy metals (Mato et al., 2001). They can reach the soil and aquatic systems and negatively affect the aquatic organisms as well as the soil activity. The presence and effects of plastic in aquatic organisms and ecosystems are well documented (Browne et al., 2008; Thompson, 2004).

Pollution via agricultural activities

Agriculture forms the basis for the sustenance of human existence on earth. Huge quantities of agrochemicals find its route to soil as a mandatory option to sustain crop productivity. Fertilizers, pesticides, herbicides, growth hormones etc are rich sources of heavy metals such as copper, lead, cadmium and mercury as well as that of persistent organic pollutants having the potential to impair crop metabolism and to impair crop productivity. Irrigation sources are also source of heavy metal contamination in soil especially when water driven from deep sub surface sources. Excess N and heavy metals are not only a source of soil pollution, but also a threat to food security, water quality and human health, when they enter the food chain (FAO and ITPS, 2015).

Livestock production can also be a source of pollution, especially if the waste is not properly managed and disposed of: the urine and faeces may contain parasites and medical substances that can persist and accumulate in the soil (Zhang et al., 2015a). Excessive application of fertilizers and manure or inefficient use of the main nutrients (N and P) in fertilizers are the main contributors to environmental issues linked to agriculture (Kanter, 2018). These two nutrients are a source of diffuse pollution. Excess N can also be lost to the atmosphere through greenhouse gas emissions, and excess P contributes to the eutrophication of neighboring sources of water. Excessive fertilizer usage can lead to soil salinity, heavy metal accumulation, water eutrophication and accumulation of nitrate, which can be a source of environmental pollution but also a threat to human health. The fertilizer industry is also considered to be a source of heavy metals such as Hg, Cd, As, Pb, Cu, Ni and Cu, and natural radionuclides. Proper handling and management of fertilizer is crucial to avoid polluting the soil (Stewart et al., 2005).

Major pollutants in soil

Soil pollutants are broadly categorized as

1. Inorganic pollutants
2. Organic Pollutants

Inorganic pollutants includes metals (cadmium, lead, copper and zinc) and non metals (cyanides, ammonium and sulphur) whereas organic pollutants include chlorinated and non chlorinated compounds (Swartjes, 2011).

Metals and heavy metals which are essentially required for the plants and animals may become toxic if the concentration exceeds a particular level, as they are non degradable and are bio accumulating. Through the bio geo chemical cycling, these compounds will accumulate in the soil and will persist in the food chain. They degrade the quality of atmosphere, water bodies and food crops apart from posing threats to human and animal health.

Over usage of fertilisers will cause the accumulation of nutrient elements which if reaches above the carrying capacity of soil will interact with other nutrient elements hindering their bio availability to plants. In the case of nitrogen and phosphorus, excess accumulation in the soil causes its leaching to the water bodies causing eutrophication and associated ill effects. This in turn will affect the aquatic biodiversity. Along with the direct effect, many heavy metals such as arsenic, cadmium, chromium, mercury, lead and zinc are also found in phosphatic and nitrogenous fertilisers (Brevik, 2013). Because of its effect on the diversity of microbial community, nitrogen pollution will affect the soil organic matter decomposition (Shen et al., 2010).

Persistent organic pollutants (POPs) are chemical substances that persist in the environment, bio accumulate through the food chain, and have adverse effects on human health and the environment (UNEP, 2001). They enter the food chain by accumulating in the body fat of living organisms and becoming more concentrated as they move from one organism to another by the process of bio magnification. Having high mobility, they can easily penetrate water in its gaseous phase during warm weather and volatilize from soils into the atmosphere which will lead to their deposition many miles away from the release point as temperatures cool (Schmidt, 2010).

Persistent Organic Pollutants (POP) such as poly cyclic aromatic hydrocarbons and heavy metals are also released into the soil environment through the application of plant protection chemicals in the soil. Polycyclic aromatic hydrocarbons accumulate in the lipid tissues of plants and animals, but they do not tend to accumulate in plant tissues with high water content.

Effect of soil pollution

The ill effects of soil pollution are mainly reflected in three ways: 1. On food chain through crop uptake 2. On the ecosystem services 3. On the human health

1. Effect of soil pollution on food chain

Soil pollution reduces food security both by reducing crop yields due to toxic levels of contaminants and by causing the produced crops to be unsafe for consumption (FAO and ITPS, 2015). Those contaminants which are highly toxic to plants when they are not translocated to the fruits and shoots, may not enter the food chain. But when the translocation efficiency is high, it can readily enter the food chain and poses serious health hazards.

2. Effect of pollution on eco system services

Due to soil pollution, the inherent ability of soil to store water and nutrients is adversely affected and the soil microbial diversity and enrichment will also be affected. This causes imbalance in nutrient cycle and hence will adversely affect the uptake of water and nutrients by crop plants. Moreover over use of fertilizers may result in soil acidification and hence can inhibit nitrification and other microbial activities in soil. Intense acidification can also cause the mobilisation of toxic elements. Depending on the leaching movement of fertilisers to ground water as well as to the nearby water bodies, there will be loss of biodiversity and disfiguring of the food web. Negative impact of pesticides and plant protection chemicals on soil biota is well established. Along with the application of animal manures, lot of pathogen such as Salmonella, Campylobacter and Escherichia Coli may gain entry to the soil.

3. Effect of soil pollution on human health

The various soil pollutants describe in the previous section have got numerous ill effects on human health. Depending on the type of pollutant, the extent of hazard to human health varies. These contaminants enter into our body via inhalation, direct skin contact and through the food web. In the case of children sometimes soil eating/ geophagia is a common act and will pave the way for the direct entry of toxic contaminants into their body.

Heavy metals such as arsenic and lead are carcinogenic. Developmental abnormalities in children are associated with the exposure to lead. In addition to this, neurological disorders, damage to central nervous system, mis carriage, pre term/still birth are also associated with heavy metal contamination and human exposure.

Management of soil pollution

Soil pollution owing to the potential risk posing to the sustenance of life on the planet earth need to be effectively contained and managed so as to prevent further deterioration of the environment. On the basis of the mode of removal of the contaminants / pollutants remediation techniques can be divided into in situ remediation and ex situ remediation technique. The remediation techniques may be based on physical, chemical and biological treatments and they offer potential solutions to soil pollution (Scullion, 2006).

Bioremediation-A potential solution for the management of soil pollution

Bioremediation is a technique that relies on the microbial growth and activity for rendering the pollutants/contaminants ineffective to the environment. Since it is a microbial dependent activity, its effectiveness is highly relying on the applied environmental parameters that influence the microbial growth and degradation rate. According to Alexander, 1999 several conditions must be satisfied for bioremediation by microbial activity to take place in the soil. These include the following: 1) presence of organism in the soil containing pesticide 2) an organism must have the necessary enzymes to bring about the biodegradation 3) the pesticide must be accessible to the organism having the requisite enzymes 4) if the initial enzyme bringing about degradation is extracellular, the bonds acted upon by that enzyme must be exposed for the catalyst to function; 5) should the enzymes catalyzing the initial degradation be intracellular, that molecule must penetrate the surface of the cell to the internal sites where the enzyme acts; and 6) because the population or biomass of bacteria or fungi acting on many synthetic compounds is initially small, conditions in the soil must be conducive to allow proliferation of the potentially active microorganisms.

Addition of organic matter to the soil decreases the mobility of heavy metals and pollutants due to the presence of lignin and polyphenols which effectively polymerizes the heavy metals and contaminants. Biochar can also be used as a remediating agent for soil contamination.

Agronomic methods to manage soil pollution

Sustainable soil management options should form the essential component of all the management strategies for combating soil pollution. This encompasses the balanced application of fertilisers considering the soil fertility status as well as to the nutritional requirement of individual crops. Soil testing should be conducted regularly to avoid nutritional imbalances and to optimize the application of chemical fertilisers. Such practices can minimize the cost of cultivation, along with decreasing the environmental stress by way of pollution. Soil acidification is a consequence of over usage of chemical fertilisers, and hence application of ameliorants should essentially form the component of best management practices for crop production. Nutrient recommendations should consider the following parameters:

1. Native fertility status of the soil/soil reserve
2. Available nutrients in the added manures/compost/crop residues
3. Nutrient content in the fertilizers
4. Crop requirement of the nutrients
5. Quality of the produce

Possibility of nutrient addition through green manure/green leaf manure as well as through the incorporation of crop biomass should always be prioritized. Enrichment of soil organic matter content should be done so as to increase the exchange capacity of the soil and to act as a buffering agent towards major fluctuation in soil pH.

Exploring the potential of industrial by products which may be dumped at the factory premises causing severe environmental pollution as alternative to soil ameliorants. This include materials such as phosphogypsum, a byproduct of phosphatic fertiliser industry. Research works have shown that, it could ameliorate soil acidity in laterite soils as well as in soils where sub soil acidity is of concern. These findings open up the potential use of phosphogypsum as alternative to liming materials.

Plant protection activities should give prior consideration towards maintaining the ecological balance, enrich the population of natural enemies, enhancing the microbial diversity with regard to beneficial microbes, and Plant Growth Promoting Rhizobacteria. Use of chemical pesticides and fungicides should be resorted only at the most appropriate stage, rather the indiscriminate application of plant protection chemicals should be kept at bay. Adoption of environmental friendly techniques for pest and disease management should be done.

Cropping pattern can be shifted according to the preferential uptake of heavy metals. For example leafy vegetables have the greater potential to accumulate heavy metals that other fruit crops or grain crops. Within the cultivars itself, there will be variation in the rate and mode of uptake of heavy metals. Hence suitable crop rotation plan should be selected to tailor the soil conditions prevailing in the locality.

Phytoextraction of metals

Phytoextraction involves accumulation of heavy metals in the roots and shoots of higher plants which are later harvested and incinerated. These plants should have rapid growth rate, capacity to produce huge biomass, extensive root system and should have the ability to tolerate high amounts of heavy metals.

Phyto extraction can be done by the use of hyper accumulator plants with very high metal accumulating ability such as water hyacinth (Eichornia crassipes) and Brassica spp. Chinese ladder plant (Pteris vitata), a plant belonging to the species of ferns can accumulate large quantities of arsenic from contaminated fields. Spiny amaranths (Amaranthus spinosus) seen in the homesteads has the capacity to accumulate lead from the contaminated area. The ability to accumulate heavy metals can also be induced through the use of chelates which are having metal mobilizing capacity. Hyper accumulator plants have the capacity to exclude the metals through the compartmentalization of these metal ions in the vacuoles or in the cell wall and thus may not have access to cellular sites where vital functions such as respiration or cell division takes place. For a plant to be designated as hyper accumulator, the ratio of shoot to root concentration of the metal ion should be higher than one. The following table shows some of the common plant species present in our locality which are hyper accumulators of certain metals.

Common name	Scientific name	Heavy metal extracted by the plant
Sun hemp	Crotalaria juncea	nickel, chromium
Fat duck weed	Lemna gibba	arsenic
Bermuda grass	Cynodon dactylon	nickel and chromium
Brahmi	Baccoppa Monnieri	cadmium, chromium, lead and mercury
Spiny Amaranth/ Mullan Cheera	Amaranthus spinosus	cadmium, lead, chromium
Water hyacinth	Eichornia crassipes	chromium
Hydrangia	Hydrangia vulgare	aluminium
Sunflower	Helianthus annus	copper

Micro remediation of heavy metal pollution in soil

Certain microbes are able to produce metal complexing molecule such as siderophores as a mechanism for the amelioration of heavy metal toxicity in plants. Siderophores are low molecular weight, high affinity iron chelators that transport iron in the soil solution to the bacterial cells. Pseudomonas fluorescens produce fluorescent siderophores which sequester the iron compounds present in the soil. Heavy metals also under certain conditions stimulate the production of siderophores and consequently affect their bio availability in soil. Microrememdiation can also occur indirectly through the bio precipitation by the sulphate reducing bacteria viz., Desulphovibrio desulphuricans which can convert the soluble sulphates to the insoluble sulphides of cadmium and zinc. Microbes can also reduce the soluble mercuric ions (Hg2+) to the volatile Hg (0) or metallic mercury.

Through the methods of genetic engineering metal binding proteins from higher organisms can be introduced into the microbes which can sequester the contaminated metal ion in soil solution. Addition of organic amendments such as bio char produced by the process of pyrolysis of carbonaceous materials can stimulate the growth and activity of microbes and thereby accelerate the remediation process.

Conclusion

Soil pollution is invariably a malady affecting crop production, soil bio diversity and in the long run acting as a major challenge to human existence in this planet. As a means of survival, pollution in any form should be prevented at the first level itself, or should be managed suitably without allowing the large scale degradation of environment. Food crops and cultivars should as far as possible be grown in areas not under the threat of contaminations. Soil biodiversity should be considered while adopting any developmental activities above ground. As food security forms the key component of our sustainable existence in the planet, preserving the sanctity of soil, 'the soul of infinite life' should be our moto.

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