Review Paper

Management of Increasing Soil Pollution in the Ecosystem

ABSTRACT

The present paper is a mini review of the increasing soil pollution in the environment and the possible handy options available, to curb its rate. Soil being a non-renewable resource, must be protected from all types of pollutants. The health of all life forms is associated with the health of soil. Any degradation in the quality of soil can significantly produce many undesirable changes in the environment. Adoption of suitable strategies to protect our motherland from contamination is must for all of us to save ourselves and continuation of natural cycles in the ecosystem.

Keywords: Soil; pollution; pollutants; remediation measures.

1. INTRODUCTION

Soil is an important natural resource to sustain life on earth because of its diverse functions that it play in nature. It is the ultimate recipient of any waste that we throw or dispose as waste product in the environment. The different layers of soil involved in physical (sieving), chemical (adsorption-precipitation), and biological filter (decomposition of organic wastes) is necessary to maintain a healthy environment and reduce the pollution [1]. These buffering capacity of soil is limited and must be managed properly to maintain the qualities of a healthy soil. Several human activities like agriculture, industrial setup, etc. pollute the soil with organic and inorganic substances (solid wastes, heavy metals, solvents) [2]. Over the years, there is an increasing worldwide concern of environmental pollution associated with soil because degradation of soil health increases the risk of health of all forms of life [3]. The potential organic (e.g., pesticides) and inorganic (e.g., heavy metals) pollutants released into the environment are toxic and persistent in nature [4]. They enter in the food chain and accumulate within the tissues of animals (biological magnification) [5]. Soil helps in protecting the groundwater by acting as a filter of these toxic compounds. This indicate pollution of soil can lead to water pollution if the process is unchecked. Therefore, we must focus on prevention of our motherland from contamination.

2. SOIL POLLUTION

The introduction of undesirable substances or contaminants in the environment is termed as pollution [6]. Soil pollution is the changes in properties of soil by addition of materials that adversely effects on its functioning and health of organisms living on it [7]. It may occur naturally or can be aggravated by the experiments of man. Soil pollution results in decrease of soil quality, disturbance in the soil's

natural composition leading to erosion of soil, imbalance in the population of soil flora and fauna, contamination of groundwater, decline in productivity of crops, etc.

3. TYPES OF SOIL POLLUTION

3.1 Agricultural Pollution

Various chemical compounds used in agriculture to enhance the crop yield are fertilizers, pesticides, insecticides, fungicides, etc. contaminate the soil [8]. Surface runoff help in spreading of these chemicals. They penetrate deep inside the soil and infect the groundwater system. The organic compounds which resist degradation, bioaccumulate in terrestrial and aquatic ecosystem by transferring from one place to other and have potential to impact on the health of human and environment, are termed as persistent organic pollutants (POPs). Faulty irrigation practices and use of poor quality of water also help in degrading the soil [9].

3.2 Industrial Pollution

Disposal of industrial effluents from chemical industries, mining industries, paper industries, tanneries, steel industries, pharmaceutical industries, food processing industries, cement industries, thermal industries, nuclear power plants, etc. in soil cause such type of soil pollution. These include mainly heavy metals like lead, chromium, cadmium, mercury, etc. [10]. Burning of fossil fuels, smelting and processing of metals in factories dump the wastes in the soil. The heavy metals become toxic when they are present at high concentration. Acid rain caused due to smoke released from the factories, act as acidic pollutants in soil. Sulphur dioxide (SO_2) and nitrogen oxides (NO_x) act as a major sources of acid rain.

3.3 Solid Wastes

Unscientific disposal of any type of waste (city/village waste, sewage, nuclear waste) will contaminate soil. The municipal and domestic waste include garbage, paper, plastics, glass, metals, paints, rubber, leather, textiles, varnishes, etc. Leakage of stored waste from dumping site pollute soil and groundwater [11]. Nuclear waste can cause mutation in the organisms. The problem of hospital wastes and e-wastes generated per day are dangerous urban waste and should be focussed on recycling instead of dumping. Disposal of waste at sanitary landfills are better than open burning. Improper management of night soil can increase the spreading of harmful diseases.

3.4 Oil Pollution

With growing population, the consumption of fossil fuels has increased tremendously. Crude oil and its hydrocarbon derivatives may pollute soil during its extraction, transportation, storage and use. Spilling and leaking of such oil products are the major threat to soil and water quality, and health of plants and animals [12]. These toxic compounds remain for very long time in soil, affecting the physical and chemical properties of soil. They reduce the concentrations of nutrients in the soil.

Therefore, the common pollutants reaching the soil through different sources can be listed as (Fig. 1):

i) Fertilizers and other salts

ii) Pesticides

iii) Heavy metals

iv) Organic waste materials

v) Radionuclide

vi) Acid rain

4. EFFECTS OF SOIL POLLUTION

Fertilizers can change reaction of soil. Excessive use of acid forming fertilizers (ammonium sulphate) and basic fertilizers (sodium nitrate) may develop soil acidity and alkalinity respectively [13]. Leaching loss of nitrate (NO_3^-) can pollute groundwater. According to the World Health Organization (WHO), 10 mg/L of NO_3^-—N in water is safe for drinking water. Methemoglobinemia (blue baby syndrome) is seen in infants if this limit of NO_3^- is exceeded in water [14]. The adverse effects of nitrate poisoning are seen in animals, particularly in ruminants because the rumen microbes fail to convert nitrite (NO_2^-) to ammonia (NH_3), leading to accumulation of excess NO_2^- [15]. Nutrient enrichment of nitrogen (N) and phosphorus (P) in water bodies cause algal bloom and natural aging of lakes (eutrophication) [16]. The process is extremely costly to recover and takes long time in natural way. The NO_3^- lost to the atmosphere in the form of N_2O gas by denitrification, contributes to greenhouse effect [17].

Pesticides used to target specific pests may also kill beneficial organisms living in the soil (non-target damage, extinction of species, and habitat destruction), and the species which survive give rise to highly resistant generations known as super pests, and lead to outbreak of secondary pests. Several diseases of skin, nervous system, respiratory system, and other body organs are found in human as long term exposure to pesticides, and these may even lead to cancer, Parkinson, Alzheimer, etc. [18]. Some of these chemicals remain in soil for years, e.g., dichlorodiphenyltrichloroethane (DDT), aldrin, triazine herbicides, etc., while other pesticides like organophosphate insecticides (parathion, malathion), phenoxy herbicides [2,4-dichlorophenoxyacetic acid (2,4-D)], carbamate insecticides persist only for few days or months. The potentially toxic elements (Cd, Cr, Hg, etc.) are extremely phytotoxic, accumulate in plant tissues, and cause health hazards in humans and animals consuming these plants or their parts as food [19]. They are also reported to cause nutrient imbalance in soil (soil infertility). Sewage sludge contain many pathogenic bacteria, and form the basis of spreading many types of diseases. Radioactive elements which enter in the food chain can cause abnormalities in animals. Acid rain leads to acidification of soil, hampers in functioning of microbes, decreases enzymatic activities, reduces the vegetation cover, and can even alter the composition of forest species [20].

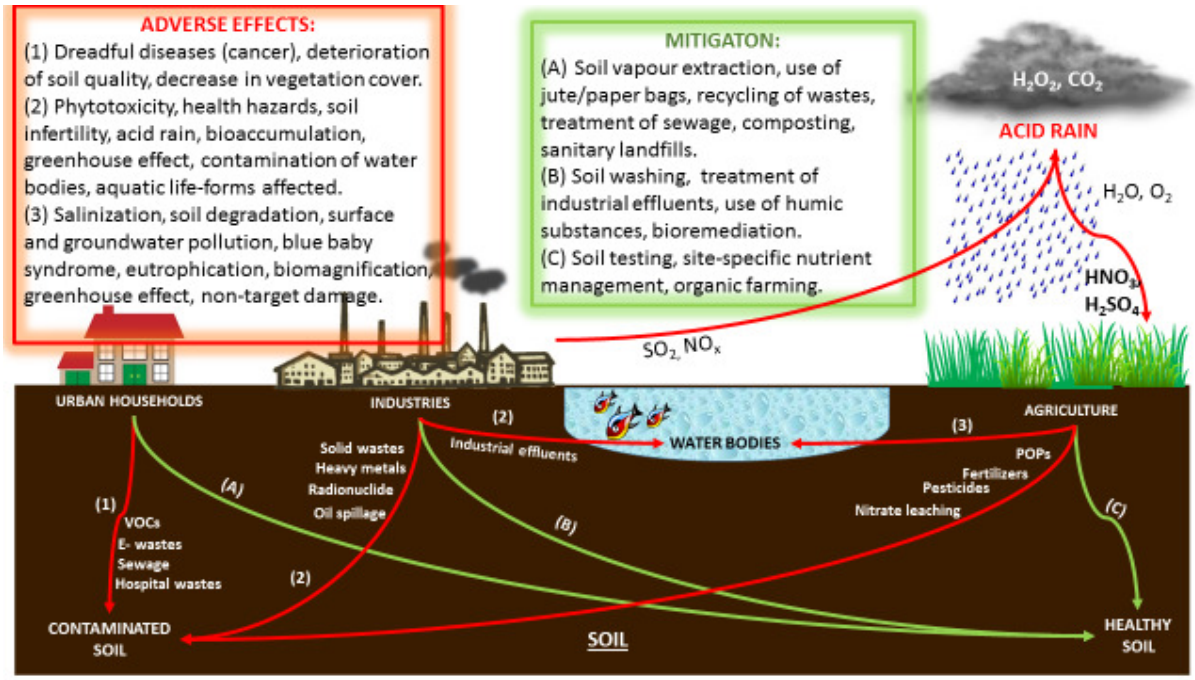

Fig. 1. Schematic representation of the sources and effects of soil pollution, and measures for mitigation. (1), (2), and (3) express the adverse effects of the sources of urban/city, industrial and agricultural wastes respectively, while (A), (B), and (C) are representatives of the mitigation steps to control the soil pollution from the sources: (1), (2), and (3) respectively.

5. REMEDIATION MEASURES

Approaches to be developed to minimise soil pollution as pre and post contamination management strategies are:

- Generation of eco-friendly approaches (organic farming, regenerative agriculture, permaculture, etc.) for farming system, where we focus more on the benefits of crop rotations, crop residues, organic manures, legumes, green manuring, etc. than the use of chemical fertilizers and pesticides [21].

  Long-term experiments of organic and conventional farming in Washington (USA) revealed that the soils of organic farms were less prone to soil erosion than conventional farms because those soils had high organic matter and polysaccharide content, thick depth of topsoil, and lower modulus of rupture [22]. Tuomisto et al. [23] used a meta-analysis for comparing the environmental impacts of organic and conventional farming in Europe, and found that organic systems are better in maintaining soil organic matter content and lowering nutrient losses, *viz.*, N leaching and emissions of nitrous oxide (N_2O) and ammonia (NH_3) per unit of field area. Crowder et al. [24] concluded that organic agriculture act as a natural pest control by promoting evenness among natural enemies. Several researchers [25, 26] highlighted the importance of organic farming on increasing soil fertility and biodiversity in agricultural landscapes. Organically-farmed soils were also reported to show high enzymatic

activities (dehydrogenase, phosphatase, etc.), microbial biomass [27, 25], and potentials of carbon sequestration [28].

- Biopesticides: Formulations made from natural ingredients either derived from animals (nematodes) and plants (*Chrysanthemum* spp., *Azadirachta* spp., etc.) or microorganisms (*Bacillus thuringiensis*, *Trichoderma* spp., etc.), and even include living organisms (natural enemies), their products (phytochemicals, microbial products) and by-products (semiochemicals) for controlling the problem of pests by non-toxic mechanisms, and maintained in an environment friendly manner [29].

Padmavathy and Poyyamoli [30] compared the effects of two pesticides (Monocrotophos and Endosulphon) and one biopesticide (a mixture of fermented extracts of *Caltrops* leaf, *Adhatoda vasica* leaf, *Ipomoea carnea* leaf, *Vitex negundo*, and *Morinda correia*) on selected beneficial non targeted arthropods, and found biological pest control enriches arthropod groups that provide ecological services with benefits for farmers by controlling pest species better from top to down and maintaining soil fertility, while application of the insecticides had negative effects on natural beneficial arthropods, increased the cost in terms of material and labour, and failed to show long term benefits in aphid control. Sethi and Gupta [31] assessed the effect of five pesticides (Cypermethrin, Malathion, Victor, Monocil and Tafgor) and five biopesticides (Folicon, *Paeciliomyces lilacinus*, *Bacillus subtilis*, *Pseudomonas florescens*, and *Beauveria bassiana*) on soil microbial biomass carbon (soil quality indicator) under laboratory conditions. The biomass carbon was found to increase in the soils treated with the biopesticides and the maximum was noted with *Paeciliomyces lilacinus*.

- Analysis of soil samples (soil testing)
  - i) Assessment of soil quality and development of soil health report.
  - ii) Evaluation of levels of heavy metals and other contaminants present in soil.
  - iii) Fertilizer recommendations and site-specific nutrient management.
- Physico-chemical measures
  - i) Soil vapour extraction (SVE): This is used for treatment of volatile organic compounds (VOCs), where vacuum is applied to soil and activated charcoal is used for filtration or adsorption [32].
  - ii) Soil washing: The toxic compounds are removed by dissolution in water or water-based solution. This is used for organic as well as inorganic pollutants (metals, radioactive substances, etc.) [33].

SVE is suitable to remediate soils (sandy and organic soils) contaminated separately with toluene and xylene, and organic matter contents below 4% and 14% could be used for xylene and toluene extraction [34]. Zhang et al. [35] conducted a pilot experiment on SVE and related combination techniques in China, and concluded that solo SVE treatment has partial effect in removal of semi-volatile organic compounds (SVOCs), but combination technology of chemical oxidation with SVE attains a better remediation effect of 89% removal and costs 216RMB/m3. Im et al. [36] used different washing solutions (1 M HCl, 0.5 M H_3PO_4, and 2%

Na dithionite in 0.01 M HCl) to remediate arsenic (As)-contaminated soils of Korea, and performed the sequential extraction to extract the residual As concentrations in those soils. They found all the solutions were able to lower the residual as well as readily labile As concentrations in soils.

- Recycling and recovery of useful materials from the wastes.

  Medical wastes can be reused after sterilization [37]. Hung et al. [38] used gamma radiation for sterilization of municipal waste of Hanoi city (Vietnam), and reused the waste as a carrier material of inoculants (*Rhizobium* spp and *Pseudomonas* spp). Achilias et al. [39] used dissolution/reprecipitation and catalytic pyrolysis techniques to recycle plastic wastes made from low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polypropylene (PP), and found the first method resulted in high recovery of polymer with the drawback of consuming huge amounts of organic solvents (xylene and toluene); while oil and gaseous fractions recovered from the pyrolysis were mainly of aliphatic nature containing a series of hydrocarbons (alkanes and alkenes), showing a great potential to reuse them for the manufacture of new plastics.
- Promotion of jute/paper bags and exclusion of plastic bags (especially those below 20 microns thickness) for packaging.
- Proper treatment of industrial effluents and sewage before releasing them to soil.

  The action of a wastewater treatment plant has been categorised into four stages: a) pretreatment (removal of large debris such as paper and plastic or any other foreign material, and additional grit such as sand, silt, and stones); primary treatment (reduction of any settleable solids, floating organic compounds such as oils, grease, and fats, and grit within the wastewater by means of settling and sedimentation processes); c) secondary treatment (decomposition of remaining suspended solids and reduction of microbial load); d) tertiary treatment (removal of contaminants, *viz*., nitrates, phosphates, and soluble organic matter, and pathogenic microbes such as faecal coliforms, streptococci, S*almonella* sp., and enteric viruses which could not be removed in the previous treatment stages) [40].
- Composting is an economically and environmentally suitable method for recycling biodegradable wastes in developing countries having limited resources [41]. Nutrient rich manures produced with the help of macrofauna (earthworm) and microflora (bacteria, fungi, and actinomycetes) will help in restoring the soil conditions.
- Sanitary landfilling is a good option for disposing municipal solid waste (MSW). Solid wastes are disposed in thin layers, compacted, and covered with liners made of suitable earth material (clay) or plastic foam as protective measures against pollution of surface or groundwater, dust, wind-blown litter, stink, fire exposure, bird menace, pests or rodents, greenhouse gas emissions, slope instability, and erosion [42]. The leachate is sent for treatment and the methane produced in the decomposition, can be used in electricity generation.
- Humic substances (HS) are ubiquitous in natural environment, having high stability, can be used for remediation of soils contaminated with heavy metals, as they bind with metal ions

and change their speciation forms in soils [43]. Borggaard et al. [44] compared the efficiency of soluble HS, ethylenediaminetetraacetic acid (EDTA), and nitrilotriacetic acid (NTA) in extraction of cadmium (Cd), copper (Cu), nickel (Ni), and lead (Pb) from a strongly polluted calcareous urban soil. They focused on the replacement of synthetic chemicals by cheap naturally occurring compounds as cleaning agents, as HS were found to extract up to 45%, 54%, 17%, and 4% of total Cd, Cu, Ni, and Pb respectively.

- Government policies focussing on plantation, social, agroforestry, and watershed programmes.
- Awareness in public about adoption of conservation agriculture, crop rotation, conservation tillage, livestock production, etc. practices.
- Application of participatory rural appraisal (PRA) techniques for discussion with the local people about the problems of the area and suggesting them the proper solutions with the use of existing local knowledge so as to promote the dwindling indigenous technical knowledge (ITK) practices.
- Improved scheduling of irrigation, i.e., supply of water as per demand, minimizing leaching, and use of good quality water in agricultural fields.

  Sigua et al. [45] applied three irrigation scheduling methods (ISM) based on Irrigator Pro (IPRO), normalized difference vegetative index (NDVI), and soil water potentials (SWP) in maize, and reported IPRO better in reducing soil water pore nitrate and phosphate concentrations and reducing nutrient losses. Li et al. [46] found that scheduling sprinkler irrigation in winter wheat season resulted in negligible nitrate leaching below the root zone (0 –100 cm); accumulation of the applied water and fertilizer N was mainly in the 0–60 cm soil layer.
- Adverse effect of N can be minimized by application of optimum dose of N in split doses in time and use of slow release fertilizers (sulphur coated urea, neem coated urea, etc.) [47].
- Proper collection of solid waste and use of appropriate techniques for disposal.
- Use of on and off-farms residues and organic manures in the fields.
- Bioremediation and/or biotransformation:
  - i) Phytoremediation: Use of plant species (hyperaccumulators) for remediation of soil contaminants. Plants belonging to the family of Asteraceae, Brassicaceae, Caryophyllaceae, etc. are reported for such type of actions [48].
  - ii) Micro-remediation: Use of microbes (*Trichoderma* spp., *Pseudomonas* spp., etc.) for remediation of soil contaminants.
  - iii) Vermi-remediation: Use of earthworms (*Eisenia fetida*, *Eudrilus eugeniae*, etc.) for remediation of soil contaminants.

  These are soft bioengineering techniques which can be used not only for cleaning the polluted lands but also for stabilizing the eroded lands and check the problem of soil erosion [49]. Water hyacinth (*Eichhornia crassipes*) is an efficient and economic adsorbent in removal of heavy metals like iron (Fe), zinc (Zn), copper (Cu), chromium (Cr), cadmium (Cd), manganese (Mn), mercury (Hg), and arsenic (As) from aqueous solutions or wastewater,

thus, it also act as a bioindicator of heavy metals in water bodies [50]. Placek et al. [51] found that the application of sewage sludge collected from the food industry to soil increased humic acid content and the sorption capacity of the soil, which reduced the leaching of metals and enhanced accumulation of the metals in trees species. After the phytoextraction, the plant biomass can be utilised for energy production, and the bio-ore can further be processed for the recovery of valuable metals. Arfarita et al. [52] showed the potential of *Trichoderma viride* strain FRP3 in biodegradation of glyphosate (herbicide) by growing it in a culture media containing glyphosate as the only P source. Rorat et al. [52] reported the role of adult earthworms (*Eisenia andrei*) in remediation of polycyclic aromatic hydrocarbons (PAHs) and heavy metals concentration during the composting of sewage sludge. The contaminants were found to get accumulated in the bodies of earthworm specimens.

6. CONCLUSION

More studies and researches should be carried out in pollution remediation of soil resources. Region-specific, eco-friendly, and cost effective technologies should be identified. Biological measures has gained worldwide attraction due to its environment friendly nature but selection of appropriate species (plants and micro- and macro-organisms) is the new challenge associated with it. Soil and crop management practices should be dealt more scientifically with judicious use of the toxic inorganic chemicals so that their continuous flow in soil-plant-animal system is reduced.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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