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A brief outlook on soil pollution and its control measures

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Abstract

An enormous ecological threat, soil pollution or soil contamination, has a significant negative influence on human wellbeing, agricultural productivity, and environmental balance. The loss of soil productivity brought on by the presence of soil contaminants is known as soil pollution. As a result of the addition or removal of components and compounds that harm plants, soil quality, and groundwater quality, soil becomes contaminated. The soil may be contaminated or polluted by both human activity and natural processes. Chemicals including pesticides, herbicides, ammonia, petroleum hydrocarbons, lead, nitrate, mercury, naphthalene, and other substances in excess can cause soil pollution. It reduces soil fertility, nitrogen fixation, erodibility, imbalances in the soil's fauna and flora, ecological imbalances, pollutant gas emissions, increased salinity, obstructions in drains, problems with public health, and contamination of sources of drinking water. Physical, chemical, and biological traits, actions, and features that can be quantified to track soil changes are known as soil quality indicators. To concentrate conservation efforts on preserving and enhancing soil quality, assess soil management practises and procedures, compare soil quality to that of other resources, and gather the necessary data to identify trends in the nation's soil health, soil quality indicators are crucial. So, this paper's goals are to examine recent efforts to define soil quality, discuss the variables and processes that affect soil quality, identify the soil and crop management methods that have an impact on these processes, and present a method for assessing soil quality.

Keywords: Pollution, soil, contaminant, environment, management

1. Introduction

The Indian population's primary source of income over time has been agriculture. The private sector experienced constrained expansion between 1940 and 1970, and the Gross Domestic Product (GDP) increased at a rate of 1.4% annually. Industries experienced a spectacular 8.4% growth rate in 1994-1995 and continued to contribute more to GDP after that. However, a surge in the flow of harmful effluents into the environment, including water and land bodies, was also linked to rapid industrial growth. A large area of soil resources and groundwater bodies have been reported to be contaminated by the entry of pollutants, either directly (by the release of discharges on land) or indirectly (by the use of polluted water as watering to crops), harming agricultural output as well as animal and human health through contaminated food (Saha *et al*. 2017) [55]. Since the industrial and green revolutions, there has been a significant growth in the production, extraction, usage, and disposal of chemicals. Daily use of thousands of different chemicals is predicted to increase by 2030, according to projections from around the world, creating an ever-increasing load of environmental pollutants (Rodriguez *et al*. 2020) [81].

The preservation or improvement of soil fertility or health is crucial for sustainable agriculture. The main connection between the strategies of preservation management techniques & the accomplishment of the main objectives of sustainable agriculture is thought to be the quality of the soil (Andrews 2004) [2]. Ecological quality, plant, animal, and human health, as well as the sustainability of agriculture, are all influenced by soil health and quality. Management of soil and taking care of land are of utmost importance to guaranteeing agricultural sustainability, which is necessary to feed the growing population. The International Union of Soil Sciences (IUSS) founded World Soil Day in 2002 to recognize the significance of soil and its essential contributions to the safety and health of humans.

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As we confront escalating global production, climate, as well as sustainability issues, this day serves as a reminder to us all that we owe our existence to the land (Basha 2023) [82].

The soil, which is the top layer of the earth's outermost layer, is constantly changing due to weathering and other biological, chemical, and physical processes. The layers or soil horizons include O (organic or humus), A (topsoil), B (subsoil), and C (parent material), are made up of mineral particles, organic substances, water, and living things. The majority of the soil's minerals are made up of elements like silicon and oxygen, while the main groups of organic compounds are humus, fatty acids, resins, and waxy substances, sugars, organic nitrogen-containing materials, and phosphorus compounds. In the ecosystem of the Earth, soil is essential because it anchors plant roots, gives nutrients, filters precipitation, controls how surplus rainwater is released, and prevents flooding. Additionally, it can store a significant quantity of carbon from organic matter and act as a barrier against pollutants, preserving the quality of the groundwater. In addition to reflecting natural processes, soil serves as a record of both recent and historical human activity (Tripathi *et al*. 2019) [62].

The term "pollution" has become a common occurrence in our ordinary and day-to-day lives. Pollution happens when pollutants from multiple sources pollute our natural surroundings, negatively affecting our regular lifestyles due to the changes that these substances bring. Therefore, these pollutants are the key elements of pollution, which are found as waste material of different forms. This pollution causes an imbalance in the ecology and environment, which is our most important resource. Because it collects and sometimes concentrates contaminants, soil serves as a natural absorber for them. Despite the fact that most pollutants are the result of human activity, some may also come from the environment. While soil pollution is defined as the presence of a chemical as well as any substance that is in the wrong place, present at higher than normal concentration, and/or has detrimental effects on any untargeted organism, soil contamination relates to the existence of a chemical or any substance in soil at an amount that is greater than would be expected naturally but is not directly causing harm (FAO and ITPS 2015) [16].

In addition to the direct addition of xenobiotic (man-made) chemicals, acidic precipitation, industrial waste, agricultural runoff waters, and radioactive fallout are additional causes that can poison soil. Organic (those containing carbon) or inorganic contaminants are both possible in soil. The most common chemical types of organic pollutants include polynuclear aromatic hydrocarbons, fuel hydrocarbons, polychlorinated biphenyls, chlorinated aromatic compounds, detergents, and pesticides. Phosphates, nitrates, heavy metals including, Cr, Cd and Pb, inorganic acids, and radionuclides (radioactive compounds) are examples of inorganic pollutants. Agricultural runoffs, industrial waste products, acidic precipitates, and radioactive byproducts are a few of the sources of these pollutants lowers the soil's productivity (Mishra *et al*. 2016) [42]. The Status of the World's Soil Resources Report (SWSR 2015) identifies soil pollution as one of the major soil risks harming global soils and the ecological services they supply. In order to meet the projected growth in global population from 7.5 billion in 2017 to 9.8 billion by 2050, agricultural production must rise by almost 70% between 2005 and 2050 (Lal 2015; DESA 2017) [33].

Water pollution from soil contamination may occur if dangerous chemicals seep into the groundwater or if polluted runoff reaches streams, lakes, or oceans. Another typical method that soil naturally contributes to air pollution is by the release of volatile compounds into the atmosphere. Nitrogen can leave the body by denitrification and ammonia volatilization, respectively. The degradation of organic compounds in soil can release SO_2 and other sulfur-based chemicals, which can result in acid rain. Heavy metals and other potentially dangerous compounds are the worst kind of soil contaminants found in sewage. Sewage sludge contains heavy metals that can accumulate when applied often or in large amounts, rendering the treated soil incapable of supporting even plant life (Mishra *et al*. 2016) [42]. The effects of soil contamination on human health, however, have received far less attention up until lately. The science associated is very complicated due to the variety of pollutants that are continually changing as a result of emerging industrial and agrochemical innovations. Identification of the pollutants is a challenging task due to their diversity and the biological activity in soils' transformation of organic molecules into a variety of metabolites. Since soil characteristics affect contaminant mobility, bioavailability, and residence time, they also have an impact on the impacts of soil contamination (FAO and ITPS 2015) [16].

Because soil contamination is a persistent issue, it differs from other types of pollution. By addressing the disease's causes before deciding on a course of therapy, it can be entirely removed and eliminated. Industrial activity, mining, poor waste disposal, and mechanized agriculture all contribute to soil degradation; it affects both developed and developing countries' economies. Soil pollution may have an effect on crop productivity as well as human health. As a result, research understanding the origins, evolution, and prevalence of soil contamination as well as the dangers it poses to human health has become vital. It has become more and more important to find innovative and long-lasting solutions for cleaning up contaminated soil. The multiple problems associated with the remediation of polluted soils have been resolved with the aid of thermal desorption, the application of soil additives, electrokinetic, soil cleaning, remediation, and bioremediation (Paz-Ferreiro *et al*. 2018) [50].

2. Status of Soil Pollution in India

About 329 million hectares of land make up all of India. Statistics on land use are available for over 93% of the total area, or about 306 million hectares. Soil degradation in India is a pervasive problem (Bhattacharyya *et al*., 2015) [5]. Approximately 120.7 million hectares of land are considered to be degrade (NAAS 2012), with water erosion accounting for 70% of this degradation, according to the government's harmonized database. For example, in 2011, by superimposing spatial soil erosion rates and soil loss tolerances for various states, Mandal and Sharda built a database on allowed limits of erosion for 29 Indian states while recording soil erosion risk (Sharda *et al*. 2011) [57].

There is an ever-increasing demand for residential land in towns and villages due to the growing population and high standards of living. Additionally, land is required for the development of commercial, transportation, and recreational infrastructure. All lands occupied by structures, roads, railroads, industrial facilities, or those that are submerged beneath water, such as rivers and canals, are included in the non-agricultural use area. It is quite concerning that more land is being used for purposes other than agriculture due to population expansion. Between 1950 and 2000, the area of land used for non-agricultural purposes increased by 11.73 million hectares. Future strain on agricultural land would be increased by the growing population and changing way of life.

The loss of soil's quality and quantity is referred to as soil degradation. The following are some examples of its effects: (a) erosion by air and water; (b) biological breakdown (loss of humus and plant/animal life); (c) physical degradation (changes in permeability, loss of structure); and (d) chemical degradation (acidification, fertility, falling, variations in salinization, chemical toxicity, and pH). The degradation of soil includes a number of varying spatial and temporal scales problems. This demonstrates that estimates of soil degradation in India are mostly focused on the loss of soil and its productivity as a result of either natural processes or accelerated natural processes due to inadequate soil and water management, such as erosion and ionic movements. There is no arguing that preventing soil erosion and increasing soil productivity through the previously mentioned forces is crucial for maintaining the nation's food security. Soil quality and human health are frequently related (Parr *et al*. 2009) [83]. Since a sizeable portion of the area's food needs are provided by agricultural operations, the soils around cities and industrial areas with large population densities are crucial to maintaining human health. Using a wide network of organizations and institutes, including the Soil and Land Use Survey of India and the ICAR National Bureau of Soil Survey and Land Use Planning, it has been possible to estimate the area affected by soil degradation (such as erosion, flooding, salinity buildup, and acidity). This quantitative assessment of the area affected by industrial, urban, and mining activities is however only possible with understanding of the locations of these activities in addition to in a direct calculation of the amount of pollutants building up in the soil and transferring to food and organisms near to the areas of high activity. The following sections provide information on the pollutants build-up in environmental samples connected to food and agriculture.

3. Causes of soil pollution

Both natural and man-made factors can contribute to soil pollution (Fig 1). Natural sources of pollutants may include elements of minerals found naturally in soil that, at larger concentrations, can be hazardous to people, animals, or plants. Because of centuries of human activity, undesired materials have been introduced into the natural system, and the majority of these pollutants are to blame for global soil contamination. According to studies, 5 to 6 million hectares of arable land globally are lost permanently every year as a result of soil degradation and other factors (Hamdy *et al*. 2014) [22].

These processes may steer to direct (point sources) and/or indirect (non-point sources) accumulation. Any visible, constrained, discrete channel (such as a discharge pipe) and/or single identified source of pollution that releases pollutants into the environment are considered point sources of pollution. This might include wastewater treatment facilities and factory effluents that are mostly caused by human activity. Nonpoint source pollution, on the other hand, happens when toxins are released across a vast area and cannot be directly linked to a single source. It typically happens as a result of drainage, atmospheric deposition, seepage, rainfall and hydrological alteration. It is challenging to predict its influence and severity on the environment due to its diffuse character (Saha *et al*. 2017) [55].

A. Natural Sources

The pedo-geochemical process and environmental dynamics that resulted in the creation of the soil are related to the soil thickness in a given area. Numerous rocks are natural suppliers of various heavy metals and other elements since they are the parent substance of soil. Their higher concentration can have detrimental effects on the environment and human health. Soil contamination is also a result of natural occurrences like volcanic eruptions, changes in rainfall patterns, air pollution, earthquakes, forest fires and glacier melting. High concentrations of heavy metals have been found in volcanic soils. These concentrations may be related to the ongoing volcanic activity, as in the case of mercury (Hg), or to the weathering of the parent material, as in the case of high concentrations of chromium (Cr), copper (Cu), nickel (Ni), and zinc, which are naturally derived by pedo-geochemical processes (Saha *et al*. 2017) [55].

B. Anthropogenic Sources

i) Industrial Activities

Pollutants are released into the environment either directly or indirectly through industrial activity. Either directly or indirectly, industrial operations release toxins into the environment. Gaseous pollutants and radionuclides that are emitted into the atmosphere can reach the soil directly through atmospheric deposition or rainfall (as acid rain). Inappropriate chemical handling or direct waste release into the soil is two ways that agricultural land might become contaminated. The soil is contaminated by heavy metals and other substances that are regularly employed in industrial processes in a variety of ways. In particular, textiles, chloralkaline, glass, rubber production, metal processing, animal hide processing and leather tanning, medicines, oil and gas drilling, ceramic production pigment production, and cosmetic production are associated with salinization of the soil.

Since ancient times, the mining sector has had a significant negative impact on the environment. Many contaminants have been released into the soil as a result of metal smelting to extract minerals. Large amounts of heavy metals and other harmful substances are released during mining and smelting processes, and they linger in the environment for a very long time. Wind and water have the ability to spread these toxins, occasionally getting to agricultural soils. There is a significant risk to the health of people and livestock due to toxic quantities of chromium and nickel discovered in agricultural soils close to an abandoned chromite-asbestos mining waste and in crops grown in those soils (Kumar *et al*. 2015) [31]. The radioactivity of the phosphate rocks used to make fertilisers results in a byproduct termed phosphogypsum, which retains about 80% of its initial radioactivity thanks to breakdown products including radon (^{226}Ra) and polonium (^{210}Po). The spilling of crude oil and brines, which have high salt levels and may also contain harmful trace elements and naturally existing radioactive compounds, causes significant soil pollution during the extraction of oil and gas.

ii) Agricultural Activities

Fertilizers, pesticides, fertilizers, and animal dung are examples of agricultural practices that contaminate the soil. Cu, Cd, Pb, and Hg, which are trace metals from these sources that can affect plant metabolism and reduce crop productivity, are also regarded as soil contaminants. Environmental problems associated with agriculture and soil productivity are primarily caused by excessive fertilizer and manure application or inadequate use of nutrients like nitrogen and phosphorus (Kanter & David 2018) [29].

There is substantial scientific evidence suggesting an increase in the concentration of heavy metals and veterinary antibiotic residues in soils treated with livestock manure, which may contribute to the growth of resistant antimicrobial bacteria. Heavy metals in cattle faces are primarily derived from diet (Nicholson *et al*. 1999) [45]. Livestock manure and sewage sludge are recognized as significant sources of Zn, Cu, Pb, Ni, and Cr accumulation after atmospheric deposition (Nicholson *et al*. 1999 and Wang *et al*. 2016) [45, 67]. Pesticides have been deliberately introduced into the environment on a wider scale since the Second World War, when the insecticidal qualities of DDT were discovered (Popp *et al*. 2013) [51]. Other agricultural pollution sources include arsenic pollution from concentrated animal feeding operations (CAFOs), plastic wastes from plastic mulching, and irrigation with contaminated groundwater.

iii) Domestic and Municipal Waste

As the world's population grows, waste production is more. According to World Bank research (2012) [12], the global production of solid waste from municipalities was predicted to be 1.3 billion tonnes per year. Future projections, however, provide a challenge because by 2025, waste production is predicted to increase to 2.2 billion tonnes (Hoornweg *et al*. 2012) [24]. In 2015, the population of 192 countries produced 6,300 million tonnes of plastics, of which 9% was recycled, 12% was burned, and the remaining 79% was dumped in landfills or spilled into the environment (Hoornweg *et al*. 2012; Europe, Plastic, 2016) [24, 15].

The production, consumption, and disposal of more than 80% of the plastics detected in marine habitats have all taken place on land. Microplastic contamination is reportedly 4 to 23 times more on land than it is in the oceans. The two most popular methods of waste management are incineration and municipal waste disposal in landfills (Horton *et al*. 2017; De Souza *et al*. 2018) [25, 13] The two most popular waste management methods are municipal trash disposal in landfills and incineration. Many pollutants, such as heavy metals, hydrocarbons, polyaromatic, pharmaceutical compounds, household goods, and their derivatives, accumulate in the soil in both cases, either directly from landfill leachates that may pollute soil and groundwater or indirectly from incinerator ash fallout (Mirsal *et al*. 2008; Ghosh *et al*. 2014) [84, 19].

iv) War and Industrial Accident

Until the twentieth century, most battles were of a small scale and had minimal influence on the soil. Modern warfare, on the other hand, employs non-biodegradable weapons of destruction as well as toxins that can persist in the affected soil for generations after the fight has ended (FAO 2015) [16]. The First and Second World Wars left a considerable legacy of pollution (land mines, ammunition and chemical remnants, radioactive and biological hazardous agents) not just on battlefields but also in locations such as shooting ranges, barracks, and armament storage. The disposal of ammunitions, as well as the lack of care in their manufacture due to the urgency of the circumstances at the time of their production, has resulted in soil contamination for lengthy periods of time. Mustard gas stored during WWII has contaminated some places for up to 50 years (Watson *et al*. 1992) [69].

v) Urbanization

The exponential growth of the world's population is accompanied by rising urbanization and migration, which puts an excessive strain on the development of infrastructure including houses, roads, and railroads. One of the primary causes of soil pollution in and around urban areas is related to transportation-related activities. This is due to emissions from atmospheric deposition and gasoline spills as well as the activities themselves and the changes they cause in general (Mirsal *et al*. 2008) [84]. Splashes caused by driving during rainy events and runoff may transport heavy metals obtained from the corrosion of metal vehicle parts, tyres, and pavement abrasion (Zhang *et al*. 2015; Venuti *et al*. 2016) [78, 66], as well as other pollutants such as PAHs, rubber, and plastic-derived chemicals (Wawer *et al*. 2015; Kumar *et al*. 2016) [31, 70]. Leaded petrol contamination of soils is a significant historical source of soil pollution associated with transportation. Nearly 10 million tonnes of lead were discharged into the environment by the motor vehicle fleet (Mielke *et al*. 1998) [41]. The resulting soil contamination was particularly concentrated around highways and is prevalent in central metropolitan areas.

Plastics, which are widely utilized in everyday things, lack biodegradability, resulting in pollution; a significant fraction reaches oceans via wind and rivers, causing blockage, disease transmission, and water contamination, underlining the importance of assessing threats to human health and ecosystems (Lithner *et al*. 2011; Rillig *et al*. 2012) [64, 53].

4. Effect of soil pollution

Large areas of soil resources and groundwater bodies have been reported to be contaminated by the entry of pollutants, either directly (through the release of effluents on land) or indirectly (through the use of polluted water as irrigation to crops), affecting crop production as well as human and animal health through food contamination (Saha *et al*. 2017) [55]. A wide range of detrimental effects caused by soil contamination affect plants, animals, and the ecosystem as a whole (Table 1). Children are more vulnerable to disease, so contaminated soil is more dangerous to them. Some important effects of soil pollutions are given below-

i) Effects on humans

The effects of soil pollution on human health are significant. Solid, liquid, and gaseous contaminants can all be found in soil. As a result, these contaminants may enter the body of a human through a number of different routes, such as by direct skin contact or inhalation of contaminated soil dust.

Health risks result from eating food produced by crops and plants grown on contaminated soil. This could explain both minor and deadly illnesses. People who live on polluted soil are more likely to suffer from migraines, lethargy, nausea, skin ailments, and even miscarriages. Long-term exposure to polluted soil alters the genetic make-up of the body, perhaps leading to congenital disorders and chronic health problems. More than 200 diseases, from cancer to diarrhoea, are linked to eating contaminated food, and 24% of people worldwide have helminth infections, which lead to nutritional imbalance and chronic anaemia (WHO 2017a). Heavy metals, gasoline, solvents, and agricultural chemicals can all cause cancer after prolonged exposure. Leukaemia risk has been associated with prolonged benzene exposure. Mercury is linked to an increase in kidney damage. Cadmium can damage DNA and membranes, disrupt the endocrine system, impair the kidney, liver, and bones when it is ingested through food during pregnancy (Brzóska and Moniuszko-Jakoniuk 2005; Souza Arroyo *et al*. 2012). According to Guerra *et al*. (2012) [7, 59, 20] and Jaishankar *et al*. (2014) [27], Pb toxicity affects a number of organs, causing biochemical imbalances in the liver, kidneys, spleen, and lungs as well as neurotoxicity, especially in infants and young children. Nickel harms the kidneys, liver, and stomach in addition to having negative neurological effects (Brevik 2013) [6]. While the adverse effects of copper are rare, long-term exposure can harm a newborn's liver and kidneys (Brevik 2013) [6]. Zinc is connected to anaemia and tissue illnesses. There is a link between cyclodienes and liver damage. Organophosphates can set off a series of events that result in neuromuscular obstruction. Chlorinated solvents cause liver and kidney damage, as well as central nervous system depression.

ii) Effects on plant growth

In order to increase productivity and lower crop losses, modern agricultural techniques heavily rely on fertilizers and pesticides, which accelerate soil contamination. When pollutants reach high levels in the soil, they not only cause soil deterioration, but they can also reduce agricultural output. The soil contamination has an impact on the ecological system's balance Plants are generally unable to adjust to changes in soil chemistry in a short period of time. Through nitrification and other N-transformation processes, excess N in soil has been recognized as the primary source of soil acidity and salinization. According to Guo *et al*. (2010) [21], soils gradually get more acidic over millions to hundreds of thousands of years in the natural environment, although agricultural practices, especially overuse of N fertilizer, which reduces soil pH by an average of 0.26 pH units across different land uses, greatly speed up this process (Lucas *et al*. 2011; Tian *et al*. 2015; Zhao *et al*. 2014a) [37, 60, 80]. Arsenic, cadmium, lead, and mercury are just a few of the excessive heavy metals that can harm plant metabolism and lower agricultural yield, putting additional stress on arable land. Genetic and physiological variations in plants, metal concentrations in the soil, and exposure duration all have an impact on the uptake and transport of metal into aboveground tissues (Tzsér, Magura, and Simon 2017) [61]. According to Baldantoni *et al*. (2016), cadmium can build up in a variety of edible tissues. This can affect the growth of roots, stems, and leaves as well as net photosynthesis, water use efficiency, and nutrient absorption (Rizwan *et al*. 2017) [54]. Large areas of land are become unhealthy by the soil contamination. Because of the decreased soil fertility caused by contamination, it is unsuited for farming and the survival of local vegetation.

iii) Effects on soil

Large areas of soil resources and groundwater bodies have been reported to be contaminated by the entry of pollutants, either directly (through the release of effluents on land) or indirectly (through the use of polluted water as irrigation to crops), affecting the cultivation of crops as well as human and animal health via food contamination (Saha *et al*. 2017) [55]. The chemicals present in the soil as a result of pollution are harmful and can reduce soil fertility, lowering soil production. Nitrates (NO_3^-), which are highly soluble and rapidly leach into groundwater as a result of their accumulation, will accumulate in agricultural soils if the nitrogen content is higher than the amount needed by the plants (Tian *et al*. 2015) [60]. When soil nutrients are more readily available, microbial biomass and activity also rise, but microbial biodiversity changes, leading to imbalances in the nutrient cycle (Lu and Tian 2017) [36]. Agriculture on contaminated soil yields fruits and vegetables with low nutritional value. These may be dangerous and cause major health problems in those who consume them. When soil pollution alters soil structure, it is possible that many beneficial soil organisms (e.g., earthworms) would die. Other than further diminishing the soil's ability to support life, this occurrence may have an impact on larger predators (e.g., birds) and compel them to relocate in search of food.

iv) Effect on food chain

Metals reached the food chain when sewage sludge was added to soil due to their hazard to human health (Chaney 1980) [9]. Contaminants that enter the food chain put human health, water resources, rural livelihoods, and food security in peril. Through a process called as bioaccumulation, plants grown in polluted soil may develop large quantities of soil contaminants. As a result, many important animal species might go extinct. Additionally, these contaminants have the capacity to ascend the food chain and infect people (Tripathi *et al*. 2019) [62].

5. Control of soil pollution

The main objective of soil management is to restore or improve soil qualities in order to produce favourable circumstances for crop development. Soil fertility is essential for feeding the world's rising population in the face of changing climate and land problems. This necessitates that the chemical and physical conditions of the soil remain conducive for plant growth. Maintaining soil fertility, on the other hand, is an important concern. A reduced land area is predicted to offer soil-based commodities and services to the world population during the next few decades. The severity of this disparity is amplified by the fact that soil is a non-renewable natural resource that cannot be replenished in a single human generation (Dalal-Clayton *et al*. 2001) [12].

Continuing urbanization, desertification exacerbated by climate change, and shortsighted farming practices have led to negative impacts on the ecological environment, harming the soil. In response to this rising hazard, sustainable soil management measures are required. Sustainable practices strive to maintain and enhance soil productivity, avoid and correct soil degradation, and protect the environment. A number of solutions have been suggested to reduce pollution rates. Some of the steps to prevent soil pollution are as follows:

- Prohibition of plastic bags with a thickness of less than 20 microns.
- Recycling of plastic wastes.
- Preventing deforestation and encouraging forestation.
- Encouraging plantation programs.
- Organizing public awareness campaigns.
- Reducing the use of chemical fertilizer and pesticides.
- Suitable and safe disposal of including nuclear wastes.
- Judicious application of organic and inorganic fertilizers.
- Promoting agroforestry, mixed farming and crop rotation.

6. Remediation of soil pollution

Over the past few years, a number of in-situ and *ex-situ* remediation methods have been developed to repair, remediate, excavate, or clean the polluted soils. These remediation approaches will be discussed below.

In-situ remediation techniques

In-situ remediation avoids soil disruptions, worker and public exposure to contaminants, and greatly lowers treatment costs by forgoing excavation and relocation of contaminated soil to off-site treatment facilities. However, it is important to proceed with caution when dealing with acceptable field conditions, such as soil permeability, pollution depth, and potential chemical leaching (Ok *et al*. 2020; Palansooriya *et al*. 2020; Xu *et al*. 2021; Zhang *et al*. 2021) [48, 49, 75, 79].

i) Surface capping

By covering the polluted region with a water-proof substance, the approach aims to create a safe and protected surface. Because it does not get the toxins out of the soil, this containment method is not real soil remediation. However, this approach significantly reduces the possibility of skin contact or ingestion of contaminated dirt. The surface capping prevents soil and surface water impurities from leaking out and serves as a barrier to surface water penetration. In general, surface capping is a reliable, quick, and effective way to lessen the likelihood of soil pollution.

ii) Encapsulation

Encapsulation, often known as "cutoff wall", "barrier wall", or "linear form", is an alternative to surface capping. It is designed to contain hazardous materials under unusual circumstances using a sophisticated barrier system that consists of underground enclosures, low-permeability caps, and barrier floors. These caps, which are often synthetic clay layers or textile sheets, prevent contaminants from leaking into groundwater and limit surface water infiltration. Underground impermeable barriers prevent contaminants from moving horizontally to adjacent areas (through diffusion or surface interflow) (Meuser 2013; Xu *et al*. 2021; Zhang *et al*. 2021) [40, 75, 79]. High groundwater levels are a good fit for this technique since barrier structures are buried there to stop pollution (Kempton 1998) [30].

iii) Electrokinetic extraction

Its purpose is to remove toxins from polluted soil via electrical adsorption. The inserted electrodes employ low-density direct current to separate the ions from the soil solution in this approach. The metal contaminants are subsequently removed by electroplating, ion exchange resin complexation, or (co-) precipitation (Wang *et al*. 2021b; Xu *et al*. 2021) [68, 75].

iv) Soil flushing

This method involves introducing a "extraction fluid" into the soil to remove pollutants in-situ. The extracting solvent is then gathered, recycled, treated, and then disposed of. The approach is effective for uniformly coarse-grained, highly permeable soils (Liu *et al*. 2018) [35].

v) Phytoremediation

In order to remove TEs from contaminated soils (phytovolatilization and phytoextraction) or to keep them inactive (phytostabilization and phyto-immobilization) (Mahmood *et al*. 2015; Amin *et al*. 2018; Hou *et al*. 2020; Palansooriya *et al*. 2020; Antoniadis *et al*. 2021) [38, 26, 49, 3], plants are grown there. This approach is well known, quick to implement, cost-efficient, and ecologically beneficial. Phytoremediation successfully improves the physical, chemical, and biological stability of polluted soil when compared to physical and chemical treatments (Sarwar *et al*. 2017). The two main types of phytoremediation are phytoextraction and phytostabilization (Antoniadis *et al*. 2021; Hou *et al*. 2020; Zhang *et al*. 2021) [3, 79, 26]. Phytoextraction includes plants eliminating toxic elements from the soil and collecting them in leaves and shoots, while phytostabilization involves plant roots absorbing toxic elements in the soil. Effective phytoextraction is defined as the removal of pollutants from soils at a cost that is lower than that of other facilities or the costs of inaction while still meeting environmental regulations (Antoniadis *et al*. 2017b) [85]. Globally, more than 100 field plans by applying phytoremediation techniques to remove soil toxic substances have been reported (USEPA 2016) [64].

vi) Bioremediation

In this method, soil is properly cleaned by microbes rather than by plants (FRTR 2012) [17]. They can effectively remove (detoxify) pollutants using biosorption, extracellular chemical precipitation, volatilization, as well as valence transformation (Garbisu and Alkorta 2003) [18]. To encourage toxic elements mobilization and improve their phytoextraction, bioremediation of polluted soils is combined with additional tactics including soil flushing (Jeyasundar *et al*. 2021) [28]. The presence of the iron-reducing bacterium *Desulfuromonas palmitatis* can significantly increase the removal of as in calcareous soil (Vaxevanidou *et al*. 2008) [65]. Through microbial enhanced volatilization, which involves methyl mercury being converted to Hg (II) by bacteria and reduced to Hg (II) (0), mercury can be eliminated using this method (Wang *et al*. 2020; Xing *et al*. 2020) [86, 74]. The term "nano-bioremediation" refers to a novel concept. Under strictly regulated circumstances, this technique extracts pollutants from wastewater and soil by using nanoparticles (such as nano-iron, nano-silicate, and nano-usnic acid) produced by particular plants, bacteria, algae, and fungi (Yadav *et al*. 2017b) [76].

Ex-situ remediation techniques

In this method, the soil from the polluted region is excavated, transferred to a remediation unit, and the waste from the treated soil is treated at designated locations. For soil extraction, storage, disposal, and site refilling, *ex-situ* treatment is more expensive than in-situ remediation, but remediation can be controlled and refined to produce better results faster.

i) Landfilling

The simplest type of soil remediation is landfilling, which is removing hazardous soil from its original location and bringing it to an appropriate landfill for disposal. To prevent leaks and groundwater pollution, the dual clay layer lines, leachate storage, and control system are essential parts of the landfill. By keeping the surface exhaust from filling, the top cap lowers runoff infiltration. Governmental guidelines for the creation, maintenance, and application of a secure landfill are present. An efficient method of clearing up polluted areas is landfilling (FRTR 2012) [17].

ii) Soil washing

In order to remove pollutants, a physical and chemical technique known as "soil washing" is used. Chemically treated soil solutions are used to wash the soil. Crushed and sifted earth from the pollution site is used to gather raw materials such stones, wood, and plastic waste. Magnets are used to remove magnetic elements from the soil. Before screening the soil particles smaller than 5 mm in diameter, the coarse and gravel particles bigger than 0.05 mm in diameter were separated from the fine soil (silt and clay) fraction smaller than 0.05 mm in diameter using mechanical agitation. The coarse part is usually cleaner and, after being washed with water, returns to its former place. Fine soil particles suspended in a washing solution are removed by settling down, being washed with water, and then being placed back where they were before. The mixture of hazardous waste and wash water is recycled, filtered, or delivered to a facility for remediating hazardous waste. Phosphoric acid, tartaric acid, nitric acid, sulfuric acid, polyglutamic acid, acetic acid, dithionite, oxalic acid, citric acid, hydrochloric acid, DTPA, EDTA, formic acid, calcium chloride, ammonium chloride, sodium hydroxide, and other synthetic materials have all been investigated to prepare successful washing solutions (Yang *et al*. 2018). The soil washing process is both short durational and cost-effective technique.

iii) Solidification

A binding agent and the element-polluted soil are combined in an extruder after the soil has been taken from the site, transported to the remediation plant, and screened to eliminate coarse-grained soil particles larger than 5 cm in diameter. The binders penetrate the soil and surround the impurities in a solid, water-repellent coating. The binding agents for pollutant encapsulation are polyethylene, pozzolan cement, molten bitumen, emulsified asphalt, and Portland cement (FRTR 2012) [17].

iv) Vitrification

Ex-situ vitrification is a thermal treatment procedure that uses heat to convert contaminated soil into glass-like particles. The technology has been designed and tested since 1980. In operation, intense power is transmitted to polluted soil to create a high-temperature area (> 1500 C). The high-temperature soil is subsequently turned into volcanic magma, which cools to produce a glass-like substance (Meuser 2013) [40]. Vitrification is a tried-and-true industrial method. The technique was deemed "the best-proven technology available" by the USEPA for treating pollutants in soil (FRTR 2012) [17].

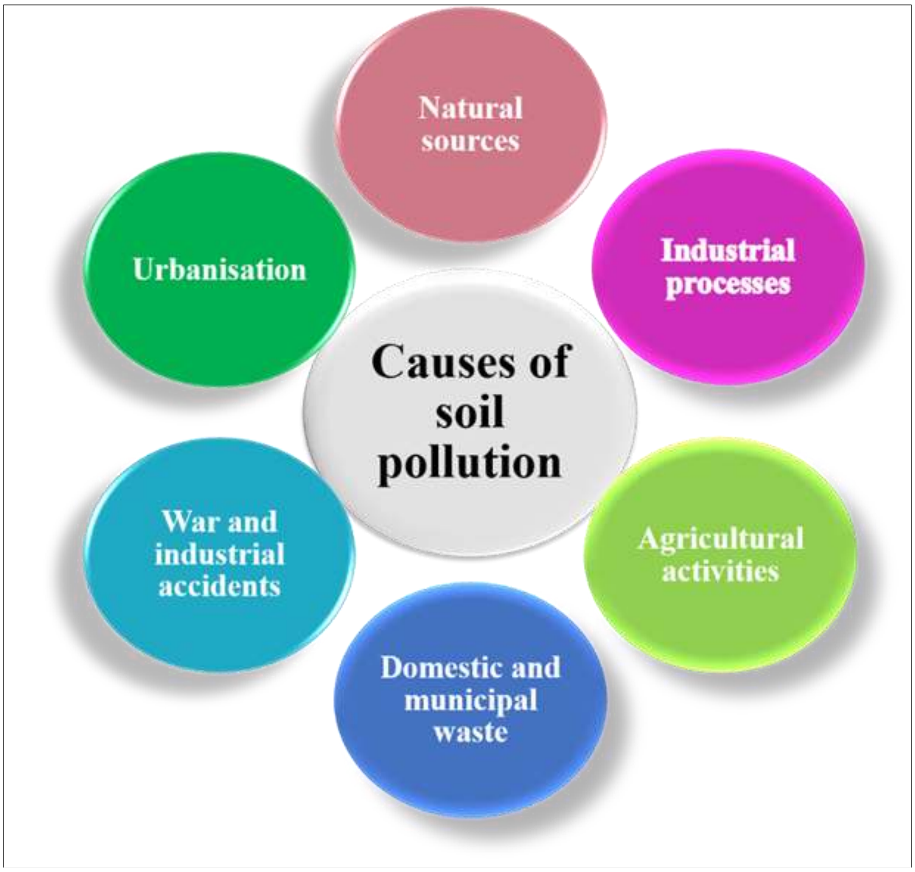

Fig 1: Schematic representation of causes of soil pollution

Table 1: Effect of soil pollutants on human health

Sl. No.	Name of pollutant	Area of study	Health effect	Reference
1.	Pb	Poland	Negative psychological effects (disrupts Ca homeostasis and mimics Ca), reduces IQ and focus a reduction in hand-eye coordination Encephalopathy, Deterioration of bones (Pb has an exceptionally long half-life in bones and interferes with key metabolic processes like calcitonin and vitamin D), kidney disease and hypertension Teratogenic	Charkiewicz *et al.*, 2020 [10]
2.	Hg	India	Hazardous Hg vapour is more quickly absorbed by the lungs and diffuses into the blood. harm to the gastrointestinal system and central nervous system (CNS) Paresthesia (a numbing and tingling feeling in the lips and mouth) decreased IQ as a result of interference with brain development Heart and liver damage Damage to the kidneys, • Teratogenic (MeHg crosses the placenta and blood-brain barrier).	Burger *et al.*, 2013 [87]
3.	Cd	Japan	Renal and liver damage (excreted extremely weakly).Pneumonitis and pulmonary edoema are potential side effects of inhaling Cd vapours. Low bone density, or osteoporosis (Itai Itai illness). Through renal impairment and excessive Ca excretion, Cd impairs Ca-metabolism. Diets deficient in iron and zinc greatly exacerbate the harmful effects of cadmium on human health. cancer-causing (when inhaled)	Nordberg (1974) [46].
4.	As	India	Mees' line (white bands running transversely across the nails) Arsenicosis (As poisoning brought on by ingesting inorganic As), cardiovascular illness, GI tract, skin, liver, and heart damage Organic less hazardous to health and quickly removed from the body Carcinogenic increased chance of stillbirth and miscarriage	Mazumder *et al.*, 2011 [39]
5.	F	India	Fluorosis of the teeth (seen as white, opaque spots on the tooth surface) Fluorosis of the bones Early signs include joint discomfort and stiffness. Osteosclerosis, calcification of tendons and ligaments, and bone abnormalities are linked to crippling skeletal fluorosis. inflammation of the skin, eyes, and respiratory system	Singh *et al.*, 2020 [58]
6.	Be	China	Acute chemical pneumonitis (inflammatory reaction of the entire respiratory tract involving pharynx, alveoli, etc.). Skin problems (most common) occur mainly due to exposure to soluble Be compounds. Impaired lung function Heart diseases Carcinogenic.	Wu *et al.*, 2022 [73]
7.	Cu	China	GI disturbances, Haemolysis , Hepatotoxic effects, Nephrotoxic effects	Wu *et al.*, 2012 [72]

7. Conclusion

Numerous human activities and experiments that contaminate the soil are the main causes of soil contamination. Industrial wastes such toxic gases and chemicals like pesticides, fertilisers, and insecticides used in agriculture are the most frequent sources of soil pollution. Despite the fact that soil is a non-renewable natural resource, humans have increasingly used it as a pollutant sink since their inception. Ignorance about soil management is one of the factors leading to the accumulation of pollutants in soil. It has been associated to negative impacts on soil microorganisms. Soil degradation caused by various types of contaminants is becoming increasingly important. Contaminated soil reclamation is expensive, time-consuming, and energy-intensive. Perhaps a promising low-cost solution is phytoremediation. Supporting natural decomposition processes (also known as natural attenuation) may be a cheap way to lessen the hazards of polluted soils. The potential toxicity of many soil contaminants to humans is less well understood due to a lack of research studies. So, investigations concerning the potential toxicity of single pollutants on human health resulted in the formation of international guidelines, such as the Stockholm Convention on Persistent Organic Pollutants, WHO's International Programme on Chemical Safety, and so on. Despite widespread concern over soil contamination, India lacks a standard soil legislation mechanism to fight the problem.

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