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Restoration and Preservation of Degraded Soils for Crop Production

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Abstract: *A broad range of ecological issues may be traced back to agricultural soil management methods that have a significant influence on ecosystems health across the globe. Agriculture has a major influence on the environment via soil quality deterioration or degradation.*

There are several types i.e., salinity, erosion, water logging and soil pollution with organic and inorganic contaminants and contributing factors to soil degradation.

The inclusion of sustainable development goals (SDGs) related to the soil use as zero hunger (SDG 2), decent work and economic growth (SDG 8), climate action (SDG 13), life on land (SDG 15) contributes and important in human wellbeing via producing food crops (SDG 2), increasing economic growth (SDG 8), sequestering atmospheric emissions for climate change mitigation (SDG 13), and betterment of life on earth (SDG 13).

Factors include non-suitable agricultural practices, usage of wide fields without limits to impede water flow, and improper ploughing techniques.

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The key element to limit the soil degradation is reducing pressure on natural resources and their over-exploitation. In this chapter, authors have discussed the soil degradation, causes and their remedies in detail.

Keywords: Soil quality, soil fertility, crop production, organic amendments, food security

8.1. Introduction

Soil is a non-renewable natural resource and maintains life on earth by sustaining roughly 95% of global food production. It also delivers ecosystem services such as biomass generation, filtration of toxins and movement of mass and energy across all the spheres of the earth. The Globe Health Organization estimates that more than 3.7 billion people are undernourished in the world, and the loss of agriculture is a major concern. More than 10 to 40 times as much soil is being lost as is being replaced, putting future human food security and environmental quality at risk (Pimentel 2006).

Unsustainable management practices and climate change are threatening the natural fertility and structure of the soils, particularly in the areas with arid to semi-arid regions, where increasing population and industrialization, rapid land-use changes, associated socio-economic activities and climate change are imposing high pressures on the soils. This is important and imperative to back the efforts to combat soil deterioration in the affected areas. Soil degradation cause decline in its productivity that continues unabated. For example, desertification was deemed a high or very high danger on 411,000 km^2 of European land in 2017, a 14% rise from 2008, mostly in southern Europe (Janjić and Pržulj 2020; Ferreira et al. 2022). Soil salinity, erosion, water logging and organic and inorganic pollution are the key soil deterioration types. Moreover, depletion of organic matter (Pržulj and Tunguz 2022a; Pržulj et al. 2022b) and biodiversity, sealing and compaction are the key soil problems around the globe. The degradation processes e.g., soil salinity and erosion, their effects and remedies are well-documented, whereas others, such as water logging remain poorly addressed, with little data availability (Paustian et al. 2019).

With the increasing population and reducing natural sources, there id food security threats predicted in coming times. That's why United Nation's (UN) has published the 17 sustainable development goals (SDGs) which include which involve all aspects of life. SDGs number 2, 8, 13, and 15 directly addresses the soil resources aspects i.e., zero hunger through sustainable agricultural crops production, economic growth with more profits from agriculture crops and rehabilitation of *degraded soils for crop production, carbon sequestration in soils after their rehabilitation to address climate change, and betterment of life on earth* (Keesstra et al. 2018).

For these purposes, numerous physical, chemical, and biological activities in soils contribute to the formation of soils. It takes millions of years for soil formation or genesis but poor management after soil formation has resulted in overexploitation and deterioration of this precious non-renewable natural resources, putting biological and economic productivity in jeopardy. Recent threats have pushed soils throughout the globe to the point where they can no longer provide ecosystem functions. Therefore, 60–70% of soils in the European Union (EU) have lost considerable potential to serve ecological services for many types of life (Haygarth and Ritz 2009).

Many socioeconomic and biophysical factors have been identified contributing in soil degradation. Excessive use of fertilizers, use of waste or brackish water for irrigation, intensive tillage (Pržulj 2020), etc. contributes to soil degradation and reduction in its fertility. In this chapters, the factors, causes and remedial measures to control soil degradation are briefly described. Along-with some examples for crop production after soil degradation control to emphasize on the use of this precious non-renewable source to use as productive resource for addressing the increasing food security problem.

8.2. Salt-affected soils

Globally, soil salinity and sodicity is one of the most serious threats to farmland's productivity. Salt-affected soils refer to soils with high levels of soluble salts (saline soils) or exchangeable sodium (sodic soils) or both (saline-sodic soils). Arid and semi-arid areas of Asia, Australia, Africa, and South America all have salt-affected soils. Approximately 953 million hectares of land in 120 countries are impacted by salt-affected soils, resulting in a worldwide productivity loss of 7–8%. Australia has the most sodic soils (about 50%), whereas drylands in Asia and the Pacific have around 20% salty soils and irrigated areas have about 40 million hectares of secondary salinized soils (about 50%) (Mandal et al. 2018; Hossain 2019). The entire salt-affected land in India is about 6.73 million hectares, of which 3.77 million hectares are sodic and 2.95 million hectares are saline. Because of inadequate land and water management and unprecedented regional and global climate change, salt-affected lands are growing 1–2% annually. When it comes to management and reclamation, salt-affected soils fall into one of two categories: saline, or saline-sodic soils. Soluble salts or exchangeable sodium (Na^+) on cation exchange sites in soil may generate weak and patchy crop stands, with uneven and stunted development, which reduces the yield. However, salt-affected soils must be reclaimed and cultivated as soon as possible in order for us to fulfil the global food security issues. These soil can be effectively reclaimed and utilized for agricultural purposes by taking steps to reduce the negative effects of salts on plants or to remove soluble or exchangeable Na^+ (Jovović et al. 2017; Jovović et al. 2018; Hossain 2019).

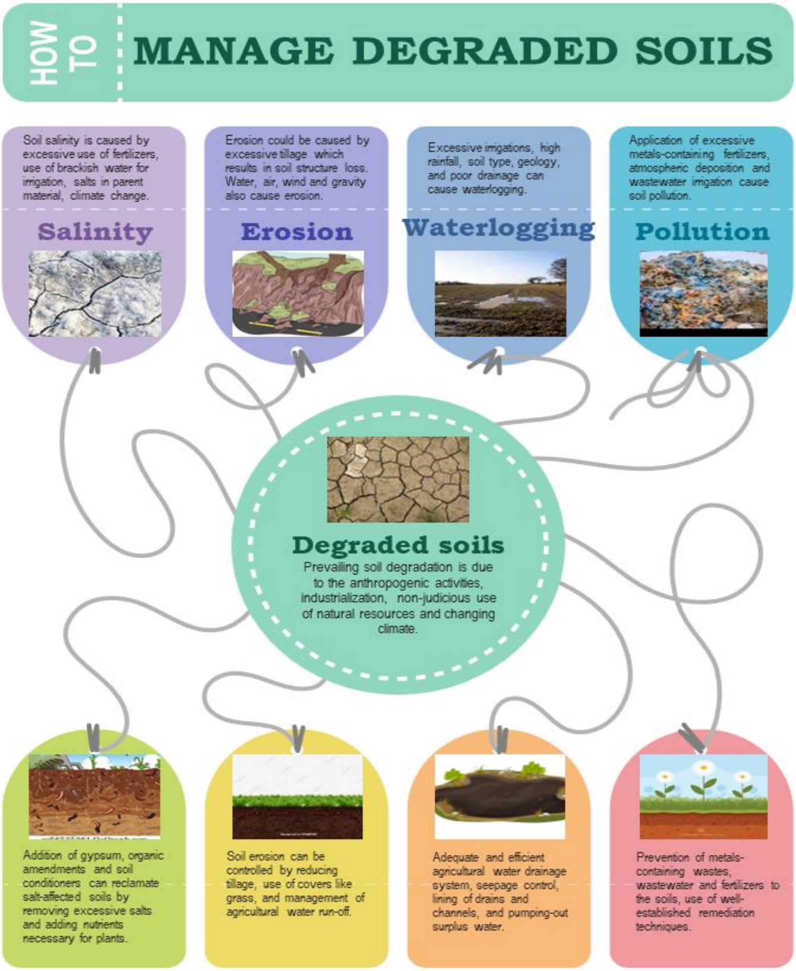
Reclamation of saline soil is simple, if good-quality water is available and there is no obstruction to water passage from the soil (i.e., good internal drainage). Whereas the replacement of Na^+ from the soil profile with divalent ions i.e., Ca^{2+} with excess amount of good-quality water are required for the reclamation of saline-sodic and sodic soils. As one of the major sources of Ca^+, gypsum is commonly acknowledged for replacing exchangeable Na^+ in saline-sodic and sodic soils. It works equally well in calcareous and noncalcareous soils as well. Solubilizing native calcite (calcareous soils only) using acids or acid-forming chemicals is another chemical reclamation strategy that may remove Na^+ from the cation exchange sites. However, it is widely accepted that a sustainable reclamation approach is mostly dictated by the site-specific geographical and soil physical and chemical factors (Sheikh et al. 2022).

A variety of organic amendments, such as farm and poultry manure as well as compost and pressmud are also widely used alone or in-combination with gypsum. They improve soil fertility, plant development and yield in saline and saline-sodic soils by increasing their physical, chemical, and nutritional attributes. The addition of organic amendments to saline soils provide essential nutrients and helps to increase the leaching/washing of salts out of the soil by: (1) improving and maintaining soil porosity and thus improving water movement in soil; and (2) increasing root vigour and growth that in turn improves soil structure and creates water channels to increase water movement in soils. Soil salinity can also be overcome by using salt-tolerant plants and better fertilizer and irrigation techniques, as well as a variety of other methods (Dahlawi et al. 2018).

8.2.1. Genesis, causes, effects, and reclamation

As a general rule, soil is made up of a mixture of saturated sediments. Most of the rocks are pyroclastic, with minor amounts of quartz, volcanic ash, and numerous types of minerals. As a result of weathering and other natural phenomena, the soils are formed. As a result, they include more kaolinitic, smectite, and interstratified expansible clay. In the US, the soil taxonomy orders of mollisols, alfisols, entisols, and vertisols make up the vast majority of the salt-affected soils found in this area (Imbellone et al. 2021).

Anthropogenic sources and practices which adds to the soil salinity problem are use of excessive fertilizers which contain salts. Use of brackish water for irrigation purposes is also a main source of soil salinity as brackish water contain soluble and dissolved salts which occupy the cationic exchange sites of the soil clays. Waste and sewage water also contain different nutrients necessary for plant growth like different forms of nitrogen (N), phosphorus (P) and potassium (K) along with soluble salts. Farmers applied unfit water to their crops without knowing the future consequences on the soil health and productivity due to salts deposition (Hossain 2019) (Fig. 8.1).



HOW TO MANAGE DEGRADED SOILS

Soil salinity is caused by excessive use of fertilizers, use of brackish water for irrigation, salts in parent material, climate change.

Salinity

Erosion could be caused by excessive tillage which results in soil structure loss. Water, air, wind and gravity also cause erosion.

Erosion

Excessive irrigations, high rainfall, soil type, geology, and poor drainage can cause waterlogging.

Waterlogging

Application of excessive metals-containing fertilizers, atmospheric deposition and wastewater irrigation cause soil pollution.

Pollution

Degraded soils

Prevailing soil degradation is due to the anthropogenic activities, industrialization, non-judicious use of natural resources and changing climate.

Addition of gypsum, organic amendments and soil conditioners can reclamate salt-affected soils by removing excessive salts and adding nutrients necessary for plants.

Soil erosion can be controlled by reducing tillage, use of covers like grass, and management of agricultural water run-off.

Adequate and efficient agricultural water drainage system, seepage control, lining of drains and channels, and pumping-out surplus water.

Prevention of metals-containing wastes, wastewater and fertilizers to the soils, use of well-established remediation techniques.

Fig. 8.1. Soil degradation, causes, and remedial technologies

Сл. 8.1. Деградација земљишта, узроци и технологије ремедијације

The diffuse double layer (DDL) hypothesis explains how high levels of Na^+ in soil may dissolve soil aggregates via swelling and dispersion of clays. Infiltration and hydraulic conductivity are negatively impacted by the formation of a hard crust on the surface of the soil due to swell and dispersion. Swelling and dispersion are hampered by high salt concentrations i.e., of SAR > 13 or ESP > 15], although soil flocculation is aided by high electrolyte concentrations ($EC_e > 1.5$ dS m^{-1}). Adsorbed cations are pushed closer to the surface of the soil particles by high salinity of irrigation water or soil solution, which helps maintain excellent porosity in salt-affected soils and improves air and water conductivity. It is thus essential to remove Na^+ and raise the electrolyte content to improve the physical qualities of salty or sodic soils. High levels of electrolytes in soil solution, on the other hand, may cause significant output losses owing to poor seedling emergence and development, as well as insufficient water supply. In salt-affected soil, reduced plant development may lead to a decrease in soil organic C inputs, resulting in poor soil structure (So 2020).

Salt-affected soils are more prone to nutrient deficits and ion toxicities because of the deteriorated physical, chemical, and biological conditions. Overly salty or exchangeable soil may reduce the mass flow of mineral nutrients to roots, either by interfering with ion exchange or by increasing the osmotic pressure of the solution itself. Several factors contribute to salt-affected soils having lower levels of N, P, and K than non-salt-affected soils, including limited input from plant biomass and substantial losses of organic matter, particularly in distributed sodic soils (dispersion of aggregates on wetting of sodic soils can increase accessibility and availability of previously protected organic matter and accelerate its decomposition).

Leaching losses of mineralized nutrients may be increased in sodic soils because organic matter is more easily dissolved. Salinity or sodicity, on the other hand, has an influence on soil microbial populations and the availability of nutrients to plants. Increased losses of N to the atmosphere are another way that high salinity and/or sodicity may impact soil and plant nutritional status (Nisha et al. 2018).

For the reclamation of these and naturally salt-affected soils, gypsum application in the form of powder is the most effective technique. Gypsum contains Ca^+ which is a competitor of Na^+, the dominant monovalent cation present in salt-affected soils. The conjunctive usage of gypsum and salt-tolerant crop varieties might further decrease the soil salinity hazards. In addition, application of different organic amendments rich in carbon and nitrogen are also practiced replenishing the nutrients deficiency in these types of soils. The decomposition of organic amendments produced carbonic acid that solubilize the naturally present calcium carbonate ($CaCO_3$) and results in increase the level of Ca^{2+} in soil solution of calcareous salt impacted soils. The application of farmyard manure (FYM) to calcareous sodic soils irrigated with high RSC water (10–12.5 $mmol_c\ L^{-1}$). FYM addition at the rate of 25 t ha^{-1} lowered the sodic soil pH, exchangeable sodium percentage (ESP), electrical conductivity, but increased infiltration rate. Precipitated $CaCO_3$ dissolution was accelerated by application of municipal solid waste compost (MSWC), which resulted in the removal of Na^+ and Ca^{2+} ions from the soil exchange complex. It was shown that MSWC (10 t ha^{-1}) and gypsum treatment jointly resulted in a greater decrease in soil pH and increase in N and P availability than gypsum application alone.

More microbial biomass carbon, and nutrient availability were found in MSWC-treated saline-sodic soils compared to control plots. Promising findings have resulted in more emphasis on developing MSWC as a viable commercial modification. An experiment has just been launched to see whether 'Reliance Formulate Sulphur' can be used as a sodic soil reclaimant (Meena et al. 2019).

8.2.1.1. Sub-surface drainage

Successful demonstration of sub-surface drainage (SSD) reclamation has been proven in different sites of India i.e., Haryana, Rajasthan, Maharashtra, and Karnataka states. Both governmental and private investments in SSD initiatives have resulted in the re-emergence of almost 70,000 ha of land in various agricultural districts. Slower adoption of SSD technology suggests that more design and drain spacing improvements are needed to boost its acceptance among farmers. SSD installation costs INR 65,000 ha^{-1} for government-funded programs in Haryana’s alluvial soils and INR 1,25,000 ha^{-1} for peninsular India’s vertisols need to be reduced so that even small landowners may invest in individual projects, according to current estimates.

Additionally, the absence of complete reclamative pumping at diverse project locations is hindering the proliferation of SSD technology. Increasing SSD use will need more cost-effective and environmentally benign alternatives (like as solar-powered pumps) rather than further decreases in government subsidies for diesel-powered engines. Sugarcane, wheat, and soybean yields have more than doubled in Maharashtra’s Sangali district, where SSD is in operation on 1000 acres of waterlogged salty land occupied by 1300 farmers.

A similar rise in cropping intensity was seen in the Belgaum District of Karnataka state, where the installation of an SSD (around 925 ha area) resulted in a cropping intensity increase from roughly 60% (pre-SSD) to 78% (post-SSD) (Kumar et al. 2022).

8.2.1.2. Bio-drainage

It is done by planting trees that can withstand salty conditions and have a high evaporation rate in canal channels. Bio-drainage is most effective when tree plantings coincide with the start of irrigation projects since it is a preventative method. Eucalyptus, poplar, and bamboo have all been proven to be effective bio-drainers. Tree roots penetrate deeper soil layers (>2 m) than annuals, allowing them to quickly remove saltish groundwater, lowering the water table by 1–2 m in a course of 3–5 years. Because of its great bio-drainage capacity, eucalyptus trees may remove up to 5000 mm of water from water tables as shallow as 1.5 meters deep. Bio-drainage efficiency, on the other hand, decreases with increasing salinity in both shallow (1 m) and deep (2 m) water tables. Despite this, eucalyptus trees were able to transpire around half of the water they normally would at salinities of up to 12 dS m^{-1}. During the first 64-month rotation of *Eucalyptus tereticornis* strip plants on north-south ridges, the water table was reduced by 0.85 m (Kumar et al. 2022).

8.2.1.3. Irrigation Management

Three-fourths of the world’s water is used for agriculture, while the rest is utilized for industrial and municipal purposes. Climate change impacts (e.g., glacial melt and river drying) are expected to further reduce freshwater availability, especially in arid and semi-arid regions where irrigated lands will have to rely increasingly on poor quality and waste waters. According to India's Center for Pollution Control and Prevention, irrigation water should have Ca^{2+}concentrations of 40–100 ppm and Mg concentrations of 30–50 ppm. However, larger quantities of Na^+ and Chloride (Cl^-) may be tolerated by ornamental plant depending on their sensitivity. Sodium Adsorption Ratio (SAR) is limited to a maximum of 26 and boron is limited to a maximum of 2 parts per million (ppm). In areas where good quality water is not enough to achieve the leaching requirement, blending of good and poor quality water or their cyclic use is also recommended especially for the treatment of sodic soils. Drizzle irrigation has many benefits over more traditional surface ways of watering, including the ability to reduce irrigation flow, weed control, and fertigation. It has also been discovered that drip irrigation works well in locations with only salty or sodic water. There are ways to avoid salt build-up on the topsoil, however, such as switching to subsurface drip irrigation, which pushes salts deeper into the soil. As another option, irrigation water might be administered below a crop’s evapotranspiration need to reduce water use. Fruit and vine crops in semi-arid and sub-humid locations that get enough rainfall to partially cover crop water demands during crucial irrigation stages seem to be especially well adapted to deficit irrigation (Romano-Armada et al. 2020).

8.2.1.4. Agro-forestry models

Plantation of agroforestry species with or without soil additions like gypsum, is beneficial for sodic soils treatment as it improves physical, chemical, and biological properties. Gypsum, for example, has been shown to be a valuable tool in the management of sodic soil, when initial pH and ESP are high, by significantly improving the development of mesquite (*Prosopis juliflora*) trees in comparison to control plants. Litter fall and rhizospheric depositions seem to have lowered soil pH and salt concentration, while increasing soil organic carbon (SOC) and N, P, and K content. Even though intercropping Karnal grass with mesquite lowered biomass output, the soil characteristics improved quicker and more significantly in the mixed system than in the solitary mesquite stand. Acacia, Eucalyptus, and Populus-based agri-silvicultural systems had better rates of microbial biomass carbon, SOC, inorganic N, and N mineralization than rice-berseem rotation in a sodic soil. Soil carbon in tree-crop integrated systems rose by 11–52%. *Acacia nilotica* and *Casuarina equisetifolia* plantings lowered soil pH, EC, ESP, and SOC, and increased SOC and accessible NPK compared to the control soils (pH2: 8.8–10.5, ESP: 85–92). Karnal grass cultivation has also been shown to reduce the pH and ESP of degraded sodic soils owing to in situ biomass breakdown and root-mediated soil quality improvements. In sodic soil, aromatic grasses such as palmarosa (Cymbopogonmartinii) and lemon grass (*C. flexuosus*) provide ameliorative benefits without reducing essential oil yields. The effectiveness of agro-forestry interventions depends on factors such as the manner and distance of planting, irrigation water availability, the amount of sodicity, and the economic worth of a specific species. Gypsum (3 kg) and FYM (8 kg) ameliorated auger holes resulted in better plant development than those planted in trenches in extremely sodic soil (ESP: 94). Similarly, planting mesquite in 90 cm deep auger holes resulted in much greater shoot and root development than planting the trees at a shallow depth (30 cm) in trenches and pits (Yousaf et al. 2021).

8.2.1.5. Organic amendments

Organic additions, such as farm and poultry manure and compost, may give varying quantities of plant nutrients. The MSW-compost improves soil structure and permeability, increasing salt leaching, decreasing surface evaporation, and inhibiting salt accumulation in surface soils, all while releasing carbon dioxide during compost respiration and decomposition. This MSW compost is an excellent tool for reclaiming salt stressed soil. Soil fertility in salt-affected areas may be improved by adding biochar, which is made from organic waste and so includes varied levels of plant nutrients with different release rates. As a result, plants growing in these soils may benefit from biochar's improved soil fertility. Based on feedstocks and pyrolysis circumstances, biochar may be an immediate source for several nutrients, as previously indicated. According to the latest research, biochar may significantly improve the nutritional content of salt-affected soils. Soil and plant quality may be improved by altering application rates of biochar, soil type (organic matter, texture, and mineralogy), and biochar aging in soil (fresh versus residual impact). It was shown that the amount of total nitrogen in a sandy loam (Spodosol) rose significantly when biochar was created from a mixture of feedstocks (2:1:1 bull manure: dairy manure: pine wood). In salt-affected soils, applying biochar may increase overall porosity and water holding capacity, but the results seem to be highly dependent on the feedstock, pyrolysis conditions, and the quantity of biochar applied to the soil. Corn (*Zea mays* L.) plants cultivated in sandy loam soil treated with wood biochar boosted N and P absorption, whereas uptake of these elements reduced in a silt loam soil improved with the same biochar. Biochar that is older contains more oxidized functional groups, more carbon exchange capacity (CEC), and greater anion exchange capacity (AEC) than biochar that is younger, and this might lead to differing soil effects. Biochar-added soil organic C, on the other hand, enhances the stability of organic molecules that would help bind soil aggregates for extended periods of time, compared to readily degradable molecules from other organic additions (Zhang et al. 2018; Gunarathne et al. 2020).

Recent research demonstrate that organic amendments improve salt-affected soil’s physical qualities. When applied to soil, biochar enhances water holding capacity, bulk density, and total porosity, although the impact seems to be dependent on the kind of feedstock, pyrolysis conditions and quantity of biochar used. Additionally, biochar may enhance the structure of salt-affected soils by influencing processes such as aggregation in the soil, as well as enhancing above and below ground plant development, which in turn affects root zone processes and the activity of soil microbes. In deteriorated salt-affected soil, increasing the Ca content by biochar may assist improve physical characteristics by increasing aggregation and making it easier to drain Na from the soil profile (decreasing ESP). Examples of how biochar improves soil aggregates and increases saturated hydraulic conductivity of saline-sodic soil include laboratory incubation and column leaching tests. Biochar adjusted salt-sodic soils have been shown in previous research to significantly enhance the Ca content, as well as the proportion of water stable aggregates, hydraulic conductivity, and water retention, when compared to control soils. In Na-dominant soils, not all forms of biochar will be equally successful in improving physical qualities due to Ca concentration in biochar varies on the feedstock used to make it (Mahmoud et al. 2020).

8.2.1.6. Crop production and salt-tolerant cultivars

In the absence of additional salinity management techniques, farmers might achieve steady yields using high-yielding cultivars that can tolerate salt stress, waterlogging, and similar restrictions. Several salt-tolerant cultivars of rice and wheat have been developed because of extensive genetic improvement programs. Genetic stocks that might be used as parents in future selection and hybridization programs have also been generated. Using rice as an example, high yielding salt tolerant crops (STCs) may boost rice yields by 1.5–2 t ha^{-1} in a salt-sensitive plant that is ineffective at limiting the input of Na^+ via the roots. Fruits and vegetables (mango, bael, ber, guava, and pomegranate) have also yielded potential salt resistant genotypes (chilli, capsicum, okra, and tomato). In low-cost protected structures, a method for using saline groundwater in vegetable crops has been standardized (EC up to 10 dS m^{-1}). Sodic land has been largely restored, and a germplasm bank including medicinal and aromatic plants has been created. Fruits including guava, bael, Indian jujube, and pomegranate have also been successfully grown in salty shallow water table circumstances, where they would typically be regarded inappropriate for even field crops (Asad et al. 2018; Grigore and Cojocariu 2020).

The second strategy encourages soil dedication to crop production systems where saline or sodic waters predominate, and disposal options are restricted. In the long term, utilizing salt-tolerant plant species and drainage water to power production systems might turn an environmental burden into an economic advantage. Discharging drainage water into major irrigation canals, local streams, or rivers would be discouraged in favour of keeping the water in the irrigated districts where it is created. Soil and water conservation, as well as economic and environmental sustainability, might be the key to future agricultural and economic prosperity in locations that have salt damaged soil and water. Saline soils are notoriously low in SOC, N, P, and K due to antagonism between Na^+ and these elements; hence, K and Ca^{2+} deficiencies are common occurrences. Soil physico-chemical characteristics, such as structural stability and bulk density, are negatively impacted by excessive salt concentration (Na^+) although clay dispersion is accelerated, reducing soil permeability as well. Conditions that may lead to surface crusting and hard setting, as well as processes like slaking and swelling, produce structural issues in soils that are high in sodicity. As a result, nitrogen imbalances in sodic and saline soils have an impact on plant development because of these issues with water and air movement, plant-available water holding capacity, root penetration, runoff, erosion, tillage, and sowing (Asad et al. 2018).

8.2.1.7. Sustainable management of reclaimed soils

In Etawah district of Uttar Pradesh, out of total (3,905 hectares) recovered sodic land, approximately one fourth had relapsed displaying the indicators of deterioration. It indicates that areas in proximity of canals; notably those suffering from difficulties of hard sub-soil pan, drainage congestion and shallow water table, are very sensitive to reclamation. Similarly, re-salinization of reclaimed saline soils may be attributed to climate- and human-induced redistribution of salts to the surface soil. In both the situations, inadequate on-farm water management tends to aggravate the level of salt build-up. Available evidence also suggests that indiscriminate irrigation and agro-chemical use have led to many secondary problems such as groundwater depletion and contamination, loss of SOC and nutrients, pest and disease outbreaks and crop residue burning in several parts of rice wheat cropping systems covering nearly 12 M ha area in India. These concerns along with static and/or falling agricultural yields have broad reaching repercussions for the food, environmental and economic security of the nation. Sustainable crop intensification may be achieved using conservation agriculture (CA) methods and the substitution of rice with crops that need less water, such as maize. It has been observed that resource conservation technologies (RCTs) such decreased tillage, residue management and crop substitution resulted to higher system production and profitability. Maize-wheat systems may also benefit from sustainable intensification, which results in significant water and power savings while simultaneously boosting crop and water production (Meena et al. 2019; Kaledhonkar et al. 2019).

It is imperative that sustainable methods for controlling salt-affected soils and enhancing agricultural production be developed. Microorganisms have the capacity to restore damaged soil fertility via numerous mechanisms, nitrogen fixation and mobilization of important nutrients (phosphorus, potassium, and iron), microbial activity restoration is an essential stage in the reclamation of saline soil. The success rate of these processes in the field relies on their antagonistic or synergistic interactions with indigenous bacteria or their inoculation with organic fertilizers. Using high-quality water, judicious use of chemical fertilizers, integrated use of organic amendments, and suitable cultural methods may help maintain salt soil's physical and chemical qualities. For the reclamation of salt-affected soil, many technologies have been developed in recent years, including physical amelioration (deep ploughing, subsoiling, and profile inversion), chemical amelioration (amending soil with various reagents: gypsum, calcium chloride and limestone), and electro-reclamation (treatment with electric current). Salt-tolerant plant species, on the other hand, can only be a cost-effective method of increasing agricultural productivity. Several organic additions have been studied for their involvement in soil remediation and found to increase soil sustainability, such as MSW, manure, and composts. Organic additions enhance salt-affected soils' physical, chemical, and biological qualities over time. NPK, carbon, organic carbon, microbial biomass, and enzymatic activity in salt-affected soils were all boosted by the addition of organic amendments. The MSW compost is an excellent tool for reclaiming salt stressed soil. However, nutrient delivery to ecologically sensitive receptors and the build-up of trace elements in the soil profile, as well as their entrance into the food chain, might pose ecological and health hazards. It is critical to solve these challenges to reduce the negative effects on the environment while also increasing the efficiency with which compost is used in agriculture. Therefore, several nations and states have established regulations to ensure its safe usage, but these standards are still being debated (Singh 2018; Asad et al. 2018).

8.3. Soil erosion

As a worldwide issue, soil erosion has emerged as a serious concern in many nations. Natural and man-made elements (e.g., water, wind, and snow) work together to destroy soil in the form of soil erosion. Environmental and public health concerns are exacerbated by soil erosion. Around 10 million acres of agriculture each year are lost to soil erosion, limiting the amount of cropland that can be used to feed the world's growing population. Depending on the pace at which it occurs, erosion is either a naturally occurring process or one that has been accelerated. First, there is natural soil erosion, which has been occurring for millions of years and is responsible for the development of new soils. Human actions, such as deforestation, overgrazing, and unsuitable agricultural methods, are mostly to blame for accelerating soil erosion. Agricultural output, water quality, and ecosystem health are all negatively impacted by soil erosion. This kind of soil erosion may be caused by a combination of variables such as soil erodibility, climatic erosivity, topography, and ground cover (Borrelli et al. 2021).

Agriculture relies heavily on the quality of the soil. Agriculture's long-term viability has been compromised by soil erosion in the surrounding region. Expanding soil erosion has negative consequences for both the environment and the economy. In addition to the long-term and short-term production losses caused by soil erosion, there are three interacting impacts that contribute to the loss of output on and off-site. When rain splashes contact the soil surface that is already loose due to poor agricultural practices like heavy tillage, the detachment and segregation of soil particles occur. Heavy rains may drive soil particles several centi-meters up in the air as they hit the soil, causing it to become weaker over time. Cropping has been shown to have a significant impact on erosion rates in several experiments. Soil erosion may cause topsoil to be eroded and soil fertility to be reduced, making the area unsuitable for cultivation, and affecting agricultural yields. In addition, the fine elements of the eroded silt, which will eventually reach surface water bodies, will cause difficulties such as excessive sedimentation, which subsequently leads to floods, as well as other issues. If pesticides or fertilizers are present in the eroded debris, water quality will be degraded, and aquatic creatures will be exposed to these toxins (Pennock 2019).

8.3.1. Types and causes of soil erosion

The major forms of water-borne soil erosion are: a) sheet erosion, b) rill erosion, c) gully erosion, d) bank erosion. Sheet erosion occurs as sediment is moved by raindrop splash and runoff. In most cases, it remains undiscovered until the fertile topsoil has been completely eroded away. The eroded dirt is deposited near the slope's base or in low spots. Changes in horizon thickness and poor yields on shoulder slopes and knolls are also indicative of knoll soil conditions.

Rill erosion occurs when concentrated water flows through small streamlets or head cuts and removes soil. Detachment in a rill happens if the sediment in the flow is below the amount the load can convey and if the flow exceeds the soil's resistance to detachment. As separation continues or flow increases, rills will get broader and deeper. Small, well-defined channels form due to concentrated overland flow, which is the primary cause of rill erosion. These waterways operate as sediment sources and transport passageways, resulting to soil loss (Toy et al. 2002; Chen et al. 2018).

Gully erosion the removal of soil or soft rock material by water, generating separate narrow channels, bigger than rills, which normally transport water only during and soon after rainfall. This is a more advanced kind of rill erosion known as "gully erosion." Gully is a separate watercourse cut into a hillside or valley bottom by periodic or ephemeral runoff. As a function of its mass 4 and velocity, the force produced by flowing water creates these channels. In addition to removing valuable farmland from production, gully erosion also puts agricultural equipment operators in danger (Valentin et al. 2005).

Surface water runoff and subsurface drainage systems have exits in the form of both naturally occurring streams and man-made drainage canals. The undercutting, scouring, and slumping of these drainage routes is known as "bank erosion." Scavenging, mass failure, and slumping are the primary causes of bank erosion, and it is critical to identify which one is taking place at any given location to adjust management accordingly. It is common in tiny streams and in the upper stages of bigger streams and rivers, when the physical force of rushing water removes bank debris directly. Slumping and collapse of the bank are examples of mass failure, in which a considerable amount of bank material falls into the river all at once. Mass failure is common in the lower levels of big streams and is often accompanied with scouring of the banks (Fawcett et al. 1994).

8.3.2. Causes

Erodibility of the soil: The wind carries very small particles of dirt into the sky, where they are dispersed across long distances (suspension). Particles of fine-to-medium size are raised into the air and fall back down to the soil surface, harming crops and causing additional dirt to be dislodged (saltation). Dislodged soil particles that are too big to rise off the ground are rolled around the soil surface as they are carried by the wind (surface creep). Abrasive windblown particles break disintegrate surface aggregates, which in turn enhances the soil's erodibility even more.

Surface roughness: Rough soil surfaces provide better wind resistance than smooth ones. Wind events may dry up the ridges left in the soil, which means that more loose and dry earth is available to blow. The roughness of soil surfaces is gradually eroded by abrasion over time. Therefore, the surface is more vulnerable to the wind.

Wind speed and duration: These have a direct bearing on the amount of soil erosion in each area. During times of dryness or heavy evaporation, soil moisture levels drop to the surface, allowing particles to be dispersed by the wind.

Distance that isn't shielded: trees, bushes, crop leftovers, and other windbreaks (such as fences, walls, and fence posts) may help reduce soil abrasion and erosion. Knolls and hilltops tend to be the most vulnerable to the elements.

Greenery as a protective shroud: wind erosion is exacerbated by the absence of persistent vegetation cover in certain areas. In general, crops that generate little residue (such as soybeans and a large number of vegetable crops) are less resistant than those that do. A lot of residues may not be enough to safeguard the soil in extreme instances.

Erosion due to tillage: the soil is re-distributed due to tillage and gravity. Consequently, dirt moves downslope, resulting in significant soil loss on the top slopes and a build-up of material at lower slopes. This kind of erosion is a primary means of transport for eroded soils containing water. Tillage action transfers soil to convergent regions of a field where surface water runoff gathers. Furthermore, water and wind often erode exposed subsoil. While water and wind may cause some erosion, tillage erosion has the greatest potential for "on-site" movement of soil (Valentin et al. 2005).

8.3.3. Effects and remedies for soil erosion

Crops are sandblasted, plants are buried, and seeds are exposed to the elements due to wind erosion. Delays and reseeding are necessitated because of crop damage. Sandblasting leaves plants prone to disease, resulting in lower yields (Pržulj et al. 2020), worse quality, and a lower market price. Fields plagued by wind erosion might suffer from poor crop development and lower yields due to soil drifting, which is a fertility-depleting process. The texture of the soil changes over time as a result of drifting. In sandy soils, the loss of fine sand and silt, clay, and organic particles reduces the soil's ability to retain moisture. There are additional off-site implications from the transport of soil nutrients and surface-applied pollutants. Blowing dust may also be hazardous to one's health and safety, as well as to the health and safety of others around one's (Rashmi et al. 2022). Farm yields are also affected by tillage erosion. Due to weak soil structure and loss of organic matter, crop development on shoulder slopes and knolls is sluggish and stunted and more vulnerable to stress under harsh circumstances. It is possible that changes in the structure and texture of the soil might lead to an increase in soil erodibility, exposing the soil to greater erosion by water and wind (Chuenchum et al. 2019).

Soil conservation is a question of deciding what kind of land use and management is most appropriate. As a whole, soil conservation is a mix of land use and management strategies that supports the productive and sustainable use of soils while minimizing soil erosion and other types of land degradation. Unsustainable subsistence farming techniques, such as slash-and-burn, are common in less developed countries. Deforestation is often followed by large-scale erosion, soil nutrient loss, and even desertification in certain cases. Crop rotation, cover crops, conservation tillage, and planted windbreaks all contribute to better soil conservation. Here are some well-known techniques for halting soil erosion: ploughing on a contour, farming on terraces is known as terracing, design of the keyline and runoff management along the perimeter (Dregne 1987).

8.3.4. Production losses

Agricultural yields and environmental sustainability are negatively impacted by soil erosion. In addition, soil degradation in the agricultural region has threatened the long-term viability of farming. Agricultural production in Asia is one of the world's most important regions. It's critical to understand how to reduce soil erosion in Asian farmland. An estimated 0.43% loss in crop output occurs each year across the EU's 12 million hectares of agricultural land affected by erosion. Around €1.25 billion is the yearly cost of this decrease in agricultural production. The loss in GDP is estimated at roughly €155 million, while the agriculture sector's costs are estimated at about €300 million using the computer general equilibrium model. The agricultural industry in much of Northern and Central Europe is only minimally impacted by soil erosion losses, but Italy is the nation that bears the greatest economic burden (Panagos et al. 2018). Soil erosion management techniques on Asia's agricultural land are the subject of this systematic study, which tries to assess the available literature on the subject (Ahmad et al. 2020).

8.4. Waterlogged soil

The coordination of water absorption by the roots and transpiration by the leaves is necessary for plants to develop normally. When the soil's water-holding capacity is saturated or even super-saturated, it is easy for plants to suffer from waterlogging stress. In waterlogged conditions, the suppression of root respiration and the build-up of toxic chemicals have detrimental effects on both vegetative and reproductive development, resulting in yield reduction or even harvest failure (Pan et al. 2021).

Closing of leaf stomata and chlorophyll degradation, leaf senescence, and yellowing all contribute to a decrease in the photosynthetic rate when plants are swamped by water. Because of the reduced oxygen diffusion rate due to waterlogging, the gas exchange between the soil and the atmosphere is impeded. Root respiration is repressed, root activity is reduced, and energy is depleted. Glycolysis and ethanol fermentation may help plants sustain some energy output under hypoxia induced by waterlogging. Toxic metabolites such as lactic acid, ethanol, and aldehydes, in combination with an increase in reactive oxygen species (ROS), mainly hydrogen peroxide, accumulate when waterlogging and anaerobic respiration continue for a long period of time. The build-up or breakdown of plant hormones may be sped up or slowed down, depending on the case, if gaseous exchange is hindered. Many plants are unable to thrive in wet conditions, but they can respond to the harm caused by this environmental stress via a variety of methods (Zhang et al. 2021).

A combination of floods, submergence and hypoxia are the key factors that restrict agricultural yield. It is hypoxic in the rhizosphere due to flooding that imposes submergence and elevates the ground water table. The anaerobic environment in the rhizosphere inhibits the intake of oxygen, resulting in plant mortality. As a result, flooding, submergence, and waterlogging stress all damage the plant in a similar manner (Pan et al. 2021).

8.4.1. Causes of water logging

Several factors including high rainfall, ineffective irrigation, inadequate drainage in the soil and uneven land surfaces. This suggests that waterlogging stress in plants has a negative impact on grain output. Reactive oxygen species (ROS), free radicals, and leaf senescence are all negatively impacted by waterlogging, which leads in lower grain yield and worse quality of the grain. It is common to see ROS generation and ROS scavenging in a dynamic equilibrium. ROS, such as superoxide anion (O_2O_2), hydrogen peroxide (H_2O_2), hydroxyl radical (OH), and singlet oxygen [O2], rise as a result of waterlogging stress.

Malondialdehyde (MDA) level rises when ROS chemicals accumulate under waterlogged environments. This suggests that waterlogging has a significant influence on membrane lipid peroxidation and integrity, resulting in accelerated cell membrane dissociation and leaf senescence processes, and eventually hindering the plant's growth and development. SOD, POD, and APX (as well as other non-enzymatic components) exist in the leaf tissue of plants in order to control ROS levels and protect cells in waterlogged circumstances; in addition, there are other non-enzymatic components (glutathione, ascorbate, and free proline). Several plants have shown an increase in antioxidant enzyme activity in response to waterlogging. SOD and POD activities increase when plants are subjected to waterlogged environments, as seen in pigeon peas (Tian et al. 2019).

8.4.2. Remedial measures

Waterlogging stress is estimated to harm 13% of the world's cropland. Farmland drainage systems, improved farming practices, selection of waterlogging-resistant cultivars, timely and sensible fertilization, chemical control, and replanting strategies are among the current farmland management measures used to mitigate the effects of waterlogging. It is well accepted that when soil moisture content reaches 80% of field capacity, maize growth and development are adversely harmed. Excessive water in the root zone of terrestrial plants may be hazardous or even lethal, even if upper plants want this.

When a plant is waterlogged, the impacts are complicated and may vary greatly based on its genotype, climatic circumstances, development stage and the time it has been waterlogged for. Oxygen deprivation is caused by excessive waterlogging, and this reduces root respiration, photosynthesis, and CO_2 absorption. To begin with, the waterlogged damage causes the stomata to close; this lowers gas exchange and limits passive water absorption; this will lead to leaf wilting, as well as reduced chlorophyll content, which results in lesser dry matter accumulation; this is the initial effect. Following oxygen deprivation stress, the length of time a plant is submerged in water has been shown to be a critical component in its survival. There is a large decline in production due to a fall in SPAD value, photosynthetic enzymes associated with it, and the PS-II photochemical efficiency. Three different legume crops saw their dry matter build-up decrease over time as the amount of time they were submerged increased. Several studies found that longer periods of waterlogging had a substantial impact on leaf gas exchange characteristics. Another study found that the effects of waterlogging vary depending on the plant's growth stage: the third leaf stage was found to be the most susceptible, followed by the sixth leaf stage and the 10th day after the tassell stage, and the production of crops decreased as the duration of waterlogging increased (Asha et al. 2021; Lee et al. 2022).

8.4.3. Practical examples

Ten winter wheat varieties that were commonly planted in Yugoslavia between 1967 and 2010 have been studied for two years in the field. Plants were subjected to ten days of waterlogging, starting with stem elongation (Zadoks growth stage, GS33). When new cultivars were released, grain output increased by 53 kg ha^{-1} yr^{-1} (0.6% yr^{-1}), but waterlogging tolerance decreased by 35 kg ha^{-1} yr^{-1} (0.51% yr^{-1}) from 1967 to 2010. Higher kernel per spike and 1000-kernel weight, as well as increased harvest index from the 1960s to the 1990s, and increased total biomass from the 1990s to the 2000s, were all factors in the rise in yield. The flag leaf's net photosynthetic rate (NPS) was also greatly boosted as a result of genetic enhancement. Waterlogging reduced the number of kernels per spike, the yield per spike, total biomass, post-anthesis biomass, and milk-ripe leaf area, but it had no effect on spikes per m^2, 1000-kernel weight, harvest index, or any of the other cultivar-specific measurements. Leaf area at milk-ripe and net photosynthetic rate in flag leaf were strongly and positively linked with grain production and singlespike yield. However, only the loss in leaf area was shown to be a significant predictor of their declines. In addition, the flag leaf area was not severely affected by waterlogging. This research implies that flag leaf photosynthesis may be improved to help select wheat cultivars that are waterlogged-resistant and high-yielding. Wheat canopy architecture and photosynthetic responses to waterlogging and their implications for crop output deserve more research (Ding et al. 2020).

The tillering stage was shown to be the most vulnerable to waterlogging in experiment 1. Waterlogging resulted in a 12% decrease in grain output, which was predominantly represented in spike number decreases. Dry matter translocation was inhibited by waterlogging throughout the jointing and booting processes, which resulted in lower grain weight. When fields were submerged for two weeks or four weeks, soil compaction reduced grain yields by 4.8%, whereas flooding worsened this drop by 20.7% and 22.4%, respectively. At the stem elongation stage of growth, there were fewer tillers, which reduced the number of spikes. Root weight was not affected by soil compaction and waterlogging time, but soil compaction decreased above-ground biomass and root weight after the jointing stage. This resulted in poorer maximum photosystem II (PSII) photochemical efficiency (Fv/Fm), apparent electron transport rate (ETR), effective quantum yield of (PSII) and photochemical quenching as a consequence of waterlogging, particularly under compacted circumstances (qP). There was a positive correlation between root weight and total above-ground biomass, but there was a nonlinear relationship between root weight and ultimate grain production. In terms of yield and PSII parameters Fv/Fm and F0, the SPAD value was favourably associated. Root and shoot growth were more negatively affected by waterlogged soils during the tillering stage than at any other point of the plant's development, the research found. Under waterlogging and compaction, SPAD values might serve as a decent proxy for photosynthetic activity (Wu et al. 2018).

8.5. Organic and in-organic pollutants contaminated soils

Agricultural soil is a finite, non-renewable resource that must be managed with care. Heavy metals (and their metabolites), which may impair human health and ecosystems, are routinely released into the soil because of industrial and agricultural activities. Agricultural land may be contaminated by a variety of processes, including mining tailings runoff into local irrigation channels and the atmospheric deposition of pollutants from incinerators and coal-fired power plants (Rodríguez-Eugenio et al. 2018).

The physico-chemical interactions in paddy soils are complicated, and the soil properties vary widely. Because of the constant flooding, paddy soils are regarded as excellent nutrient reservoirs for plant development. Fertilizer application, irrigation, and tillage, as well as the mobility of nutrients in the soil, have a major impact on nutrient levels. Because stagnant water limits the mobility rate, these paddy soils often demonstrate less transportation of applied nutrients from the medium than other soils. Anthropogenic activities such as the usage of sewage wastewater, industrial effluent that contains heavy metals, fertilizers, and pesticides, and the leaking of petrochemicals may all damage paddy soils. Microbial activity may oxidize certain natural organic pollutants, however this is not the case for the majority of contaminants. Among the principal contaminants found in paddy soils are heavy metals and organic pollutants (polychlorinated biphenyls, dibenzodioxins, and polychlorinated dibenzofurans) (Ilić et al. 2020; Ilić et al. 2021a; 2021b; 2021c; 2021d; Stojanović Bjelić et al. 2022; Ilić et al. 2022). Toxins produced by human activities may persist in the environment for extended periods of time and travel great distances. Organic pollutants have the potential for bioaccumulation and biomagnification, resulting in dangerously high concentrations that endanger human health and the health of biological ecosystems (Ilić et al. 2021a; Ilic et al. 2022). Hazards to human health, plant and animal health, and soil fertility may be attributed to inorganic pollutants such as the heavy metals Pb, Cr, As, Zn, Cd, Cu, Hg, and Ni (Ahmad et al. 2022; Murtaza et al. 2022; Farooqi et al. 2022). Due to their bioaccumulation properties, these heavy metals are often found in paddy soil and are able to build up over time, resulting in a rise in pollution levels in living systems. Bioavailability, degradation by microbes, adsorption, desorption, leaching, and runoff all have a role in the destiny of these contaminants (Tunguz et al. 2016a; 2016b; 2016c; 2019). Contamination occurs as a consequence of these contaminants being transported and degraded in paddy soils and groundwater. Pollutant sorption or desorption and degradation are influenced by a variety of physical and chemical factors in paddy soil, such as water content; soil organic matter; clay content; pH; and presence or absence of sand. It is the soil ingredients' ionic or neutral behavior, the pesticides' solubility in water, the substance's extreme hardness, and the soil's colloidal character that determine the translocation of natural pesticides in rice paddies (Akram et al. 2018; Khan et al. 2021).

8.5.1. Causes

Environmental pollution with heavy metals is on the rise because of the tremendous growth in global industrialization. Toxic compounds get up in the environment as a bye-product of the long-term use of massive quantities of fertilizers and pesticides, as well as rapid industrialisation and disorderly urbanization.

The main sources of emissions caused by human activities include:

- Emissions from mobile sources related to vehicle transport and fuels, called linear emission.
- Processes of energy combustion of fuels, and industrial technological processes, discharging substances into the air through an emitter (stack) in an organized manner, called point emission sources.
- Emissions related to house heating in the municipal and household sector, called surface emission.

Heavy metal poisoning from eating contaminated plants is a major health concern. Vegetables planted near industrial enterprises and busy highways, as well as crops exposed to municipal and agricultural effluent, have higher concentrations of some elements. As a result, the bioavailability and interaction of these elements with other dietary items and other metals may be considerably affected (Huang et al. 2019).

Heavy metal pollution is caused by a variety of sources, including the metallurgical, paint, and tanning industries; the burning of coal and liquid fuel; the use of grease in motor vehicles; and the smelting of metals (mostly zinc). It is motor vehicle exhaust fumes that constitute the primary cause of lead pollution in the environment. For many years, lead tetraethyl, which was produced during mechanical engine running, was used to add lead to gasoline. There is no longer a supply of universal gas in Poland, and instead, unleaded gasoline is available on the market (Zeng et al. 2019).

Several recent investigations have indicated that urban soils near traffic routes contain a significant amount of street dust. The release of heavy metals from vehicle wear components including tires, brakes, and catalysts is also linked to vehicle exhaust emissions.

A major source of road pollution may be the re-suspension of metal-rich road dust from vehicle traffic, particularly on routes with larger traffic volumes and a higher percentage of heavier vehicles. Vegetables grown in former industrial zones have a high risk of heavy metal pollution, which is a serious issue. Heavy metals may also be found in municipal and industrial sewage. It is standard practice across the globe, and in certain urban areas, wastewater is treated biologically and utilized for farm irrigation. There have been a slew of studies in recent years detailing the dangers of irrigating soils with wastewater that contains heavy metals. Heavy metals have been absorbed by plants, particularly vegetables, as a result of wastewater irrigation, according to their research. Effluent veggies have been shown to have greater levels of heavy metals than groundwater vegetables, according to Pakistani studies (Zwolak et al. 2019; Farooqi et al. 2022).

8.5.2. Remedial measures

8.5.2.1. In-situ remediation techniques

In-situ remediation eliminates the need to remove contaminated soil and transport it to a treatment facility off-site, which minimizes the impact on the environment, reduces worker and public exposure to contaminants, and lowers the overall cost of treatment. However, the right field circumstances, such as temperature, soil permeability, pollution depth, and the possibility of chemical leaching, must be managed with caution.

8.5.2.1.1. Surface capping

The goal of this procedure is to produce a safe and protected surface by covering the polluted area with a water-proof material. Due to the lack of trace element contaminants, this containment approach isn't a true soil cleanup. As a result, the risk of skin contact or ingesting contaminated soil is significantly reduced. As a barrier to water penetration, the surface capping inhibits the discharge of soil and surface water contaminants. Overall, surface capping is an efficient, rapid and dependable method for reducing soil contamination. Soil ecosystem enhancement may be an important consideration at this point, but it's a low priority in terms of resource consumption and expense (Khan et al. 2021).

8.5.2.1.2. Encapsulation

Encapsulation, often known as "cut-off wall," "barrier wall," or "linear shape," is an alternative to capping surfaces. A well-developed barrier system with subsurface enclosures, low-permeability caps, and barrier floors is used to contain dangerous materials in unique situations. Separation and encapsulation of pollutants reduces external pollution dispersion and bio-exposure to contaminants, mostly on-site. The synthetic clay layers or textile sheets often used as these caps prevent pollutants from leaking into the ground and limit penetration of surface water. Pollutants can't migrate horizontally over impermeable barriers buried under the earth (through diffusion or surface interflow). Encapsulation's biggest challenge is to build deep, impermeable vertical barriers at pollution sites. Injection walls may be designed using a variety of approaches, including thin walls, slurry walls, and sheet pile walls. Encapsulation, like surface capping, is limited to pollution in small, severe, and shallow locations. To remediate sites with asbestos, radionuclides, heavy petroleum, and hydrocarbon contamination where there are no other cost-effective options, this approach is often utilized. Barrier constructions are placed under the groundwater to prevent contamination using this method, which is best suited for areas with high groundwater levels. "Subsurface capping" is more expensive than "surface capping" depending on how far the pollutants reach and the geology of the location (Akpoveta 2020).

8.5.2.1.3. Electrokinetic extraction

Electrical adsorption is used to remove toxins from contaminated soil. Using the "electric force per unit charge," the implanted electrodes employ low-density direct current to move ions from the soil solution to one of two electrodes: a negatively charged electrode for cations, and a positively charged electrode for anions. Ion exchange resin complexation, electroplating, or (co-)precipitation are the next steps in removing the metal contaminants. In order to remove soil contaminants, electrokinetic extraction was investigated in the late 1980s. Typically used to separate fine-grained soils with low conductivity from saturated and unsaturated soils. It is important to note that the success of electrochemical remediation varies depending on a variety of factors, including the pollutant concentrations and kinds in the soil as well as soil type, organic content, and pH. Based on the typical average velocity of metal ions migration in soil, electrokinetic remediation may take several days to several years. Electro-osmosis, electromigration, electrophoresis, and diffusion are the primary mechanisms for the movement of metal ions in a direct current electrical field (movement under gradient concentration). As a result of factors such as the kind of metal ion that is present in the solution as well as its mobility, the speed at which this ion travels is affected. It is possible that precipitation, adsorption, and degradation will all have an impact on the mobility of the particle. It is predicted from the Helmholtz–Smoluchowski equation that the speed of metal ion migration in an electric field is This equation represents the electroosmotic velocity of a soil solution at a given point in time: Ve=Zedydxve. The particle zeta potential (z) is equal to the dielectric constant (e). Only in research is electrokinetic remediation employed. Full-scale implementation is rare, although it is useful for a wide range of experimental projects and demonstrations. Using electrokinetic remediation, a contaminated Pb location's Pb level was decreased from 4500 mg kg^{-1} to less than 300 mg kg^{-1} over the course of 30 weeks in a US experimental investigation. For the last 22 weeks, electrokinetic remediation has failed to remove significant amounts of Cd and Cr from the contaminated soil, which may have led to the formation of metal sulphides and NaCl (Fdez-Sanromán et al. 2021).

8.5.2.1.4. Soil flushing

This technique is the remediation of pollutants in-situ by pushing an “extraction fluid” into the soil. The extracting solvent is then collected, recycled, treated, and finally discarded. The approach is effective for highly permeable, coarsely textured, and homogeneous soils. The extraction fluid must be formulated with a particular formula for successfully eliminating trace metals from the soil. Ethylene-diamine-tetraacetic acid (EDTA) is the most effective agent, which is indicated by different chelating and acidic solutions. Consequently, the extraction findings indicate that all non-residual components of metallic materials were mobilized by EDTA, while citric and tartaric acid did not successfully mobilize residual trace elements and organic matter fractions. Compared to water, and surfactants, EDTA was more efficient and reported for scrubbing out 25–75% of metals like Zn, Cu, and Pb industrial loam-sand-columns. However, the biodegradable chitosan agent was much excellent capable of extracting Ni and Cu than EDTA from acidic clay loamy soil. Soil flushing is an easy process; still, it may be costly and difficult to locate subsurface drains or solution collection wells. Trace elements extraction performance is usually poor for soils with high buffering ability, high CEC, and high OM and clay content. This method is further influence by the soil layer arrangement and heterogeneity. The cost of soil flushing treatment was estimated at \$20–104 m^{-3} soil, which increases as the water table deepens and soil permeability decreases. More generally, the method was used to fix organic contaminants through flushing solutions across polluted areas. USEPA (2016) gives several in-situ soil flushing initiatives in North America; the main aim of these soil treatment assignments was to remediate organic pollutants and heavy metals (Pb, Hg, and Cr) at all three sites (United Chrome Products, OR; Lipari Landfill NJ; and Sprague Road Groundwater Plume, TX) (Sun et al. 2018).

8.5.2.1.5. Chemical immobilization

Precipitation or sorbed fractions of pollutants may be immobilized by chemical agents that are used in situ solidification/stabilization, also known as in-situ solidification/stabilization. Soil pollution cannot be eliminated or removed using this method. In this method, the trace metals in the soil particles are considerably decreased in solubility, mobility, and concentration, restricting their migration to plants, water, and microbes. Soil treatment using the solidification process is both in-situ and ex-situ. The contaminated soil is mixed with an auger spin mix and a binding agent during in-situ solidification, commonly cement, asphalt, or clay. The subsurface may be injected with binder slurries and waste is mixed using an injection head and big blender if the soil contains significant contaminants. The water-resistant nature of the solid block allows the trapped pollutants to be released (Bandara et al. 2020).

It's possible that stored contaminants will re-emerge over time if the solid block is destabilized by uncontrolled mechanical disturbance and natural weathering. As a result, the stabilized location may become constrained in the future. There is no solidification of the soil in stabilization (also known as "in-situ fixing"), but the contaminants are immobilized. Instead of only using binding agents, contaminated soil is being treated with chemical/precipitation reagents that stabilize trace elements and reduce mobilization. Alkaline compounds, phosphates, carbonates, clay and iron-containing minerals, and organic matter are among the stabilizing chemicals and precipitation reagents. Soil additives, such as surface precipitation, precipitation, co-precipitation, surface adsorption, and complexation, lower trace elements leaching and bioavailability, resulting in fewer physiochemical processes. Chemical agents, on the other hand, may be employed to immobilize a variety of different elements in different ways. Stabilization of metals in contaminated soils may be aided using low-cost carbonate and phosphate products. Plants below the danger level limit the mobilization of metal contaminants, therefore the decontaminated soil might be utilized for harvesting. The stabilizing impact of chemicals must be evaluated and tracked on a regular basis since pollutants are not eradicated. To achieve satisfactory soil treatment results, it is essential that stabilizing ingredients be mixed with contaminated soils. As a result, the United States Environmental Protection Agency (EPA) has not used the approach in the clean-up of superfund sites (Zhai et al. 2018).

8.5.2.1.6. Phytoremediation

To eliminate metal (phytovolatilization and phytoextraction) from contaminated soils or to keep them in an inoffensive form, phytoremediation is used (phytostabilization and phyto-immobilization). This is a fast-acting, environmentally-friendly, cost-effective, and widely acknowledged technology. When compared to physical or chemical clean-up, phytoremediation is a more successful method of stabilizing damaged soil. Phytoremediation of contaminated soils is subjected to a thorough examination by experts. Phytoextraction, in which plants take trace elements from the soil and deposit them in leaves and shoots, and phytostabilization, where plant roots absorb the trace elements from the soil, are the two most common ways of phytoremediation. Polluted soil may be cleaned using effective phytoextraction at lower prices than other facilities or at the expense of inactivity, as long as it meets environmental legislation's requirements (Latif et al. 2020; Hussain et al. 2021a; Gavrilescu 2022).

For soil mitigation reasons, the employment of hazardous element hyper-accumulator methods has been avoided due to lack of research and innovation. The hyper-accumulators are very sensitive to trace elements and are limited to their immediate surroundings. The bioavailability of toxic components in soil decreases linearly and occasionally logarithmically with each cropping, resulting in a decrease in phytoextraction. Low plant biomass output may be caused by nutrient depletion or insect infestation over time. One might conclude that phytoextraction is a waste of time and resources (Hussain et al. 2021b; Hameed et al. 2021).

Even under ideal circumstances, it takes an average of 15 years to reduce 1 mg Cd kg^{-1} of contaminated soil using a hyper-accumulator. This prolonged period of time spent on clean-up is not acceptable. Chelating agent stimulation and genetic alteration of plants are only two options that have been proposed as ways to boost phytoextraction and speed up phytoextraction. Because they aren't biodegradable, metals chelates like EDTA and DTPA are able to reach deep soils and groundwater via leaching. The generation process for genetically altered hyper-accumulators is very labour intensive and time consuming. The existing phytoextraction method needs a considerable upgrade to be viable in the real world. A technique that is more feasible is phytoextraction, which aims to reduce the bioavailability of water-soluble and exchangeable element pools by remediating the decrease in total soil element concentration. In this case, the bioavailable pool's long-term sustainment kinetics must be determined. Currently, this remedial procedure is in the early stages of application (Gavrilescu 2022).

Chelate, metal, and soil interactions in the rhizosphere need to be better understood in order to better understand plant absorption, transport, and accumulation of hazardous elements. To determine the efficiency of phytoremediation, a wide range of new variables must be considered, including: soil properties and contaminants; plants; climate; and geography. Phytoremediation technologies have been used in more than 100 field programs for the treatment of soil hazardous elements (Awa et al. 2020).

8.5.2.1.7. Bioremediation

This approach uses microorganisms instead of plants to fully clean the soil. Biosorption, extracellular chemical precipitation, volatilization, and valence transformation are all methods for successfully removing (detoxifying) components. Soil flushing and bioremediation of heavy metal polluted soils are utilized in tandem to increase metals' mobility and phytoextraction. Recent research suggests that the use of a microbial consortium may improve trace element phytoextraction. With the inclusion of bacteria, for example, Alcaligeneseutrophus has been proven to have generated siderophores that might build compounds with metals. Similarly, the presence of the iron-reducing bacteria Desulfuromonaspalmitatis may significantly enhance As removal in calcareous soil. Very few rhizosphere bacteria help plants tolerate toxic elements and promote their growth in contaminated soils.

Using microbial enhanced volatilization, methyl mercury is converted to Hg(II) by bacteria, which then reduces it to Hg(II) (0). Bioremediation of metals using genetically modified microbes has been investigated. Soil remediation using confirmed metals remedial microorganisms, including algae, yeast, and fungus, has the potential to be very beneficial. Nanoparticles (e.g., nano-iron, nano-silicate, and nano-usnic acid) generated by particular plants, bacteria, algae, and fungus may be utilized to remove contaminants from wastewater and soil under regulated circumstances (Lee et al. 2020).

8.5.2.2. Ex-situ remediation techniques

These methods include the removal of contaminated soils and transporting them to a remediation facility where they are treated before being disposed of at a site that has been pre-approved for their disposal. Although ex-situ remediation is more expensive than traditional in-situ remediation, it is possible to manage and improve remediation to achieve better results in a shorter period.

8.5.2.2.1. Landfilling

The simplest method of soil remediation is landfilling, which involves removing the contaminated soil from its original location and transporting it to a landfill. Due to probable groundwater contamination, the landfill's leachate and control system's storage and the dual clay layer lines must be in place. Reduce infiltration of runoff by covering the surface exhaust pipe's top end with a cap to prevent it from getting filled up. Design, construction, and use of a secure landfill in accordance with applicable laws and regulations. When it comes to decontaminating polluted sites, landfilling is a very successful method. This method was the most common in the United States before to 1984. The cost of landfilling varies from \$300 to \$500 per ton in the United States, depending on the distance from the contaminated site to the protected landfill. In order to save money on trash disposal, landfills should only accept soils that have been dug from areas with significant contamination (Kaliaskarova et al. 2019).

8.5.2.2.2. Soil washing

Soil washing is a mix of physical and chemical methods for the removal of metals from the soil. In order to recover raw materials such as plastic leftovers, wood, and stones, this process smashes and filters the soil removed from the polluted site. Soil magnetic compounds may be removed with the use of magnets. Mechanical agitation is used to separate the coarse and gravel particles bigger than 0.05 mm in diameter from the fine soil (silt and clay) fraction of less than 0.05 mm in diameter after the soil particles smaller than 5 mm in diameter have been mixed with a washing solution.

Typically, the coarse component is less dirty, and it returns to its former location after washing it with water. Using a washing solution, the fine dirt grains suspended in the solution are removed, rinsed, and returned to their original place. Recycle, filter, or transport hazardous waste and wash water solutions to a hazardous waste remediation facility. Solidification or stabilization of the waste disposal sludge is also done before landfilling. Soil washing, which affects ionic strength, soil acidity, complexation, or redox potential, is necessary for metal mobilization. It is important that the washing solution improves the solubility and mobility of harmful element contaminants, while also being biodegradable and non-toxic.

Multiple synthetic materials have been examined to prepare successful washing solutions; these include poly glutamic acid, acetic acid, dithionite, oxalic acid, citric, hydrochloric acid and hydrochloric acid EDDS, DTPA EDTA, ferric chloride and bicarbonate carbonate, formic acid, calcium chloride, ammonium acetate and subcritical water, etc. pH, soil properties, and OM all had an effect on how much metal was removed from a washing solution based on its ability to bind to metallic ions. In general, EDTA and hydrochloric acid displayed the best washing efficiency in a wide range of metals and soils. Some European nations, such as Sweden, began using mobile soil washing machines in the 1980s to cut dirt transport expenses and employ equipment on-site for polluted soils that had not yet been affected. Since 1995, soil washing projects ranging from 0.2 to 10 tons per hour have been developed in Europe, Canada, Australia, the United States, and Korea. In terms of cost and time, soil cleansing is an excellent option (Befkadu and Chen 2018).

8.5.2.2.3. Solidification

An extruder uses a binding agent and an element-polluted soil that has been removed from the site and transported to the remediation facility, where it is screened to remove soil particles bigger than 5 cm in diameter (coarse-grained). As the binding agent spreads throughout the soil, it forms a solid, water-proof shell around the contaminants it is intended to contain. "micro-encapsulation" is a common term for this process. Ex-situ stabilization refers to the use of a stabilizing agent rather than a binding substance to immobilize pollutants chemically. There are polyethylene, polyolefin, molten bitumen, molten asphalt, and portland cement binding agents. Sulfate-free lime and phosphate may be used to stabilize soil rather than harden it. It's also possible to encapsulate filthy soil straight inside polyethylene to create waste disposal blocks that may be disposed of in a non-hazardous landfills. Over 200 soil treatment programs in the United States employ this method, which costs between $120 and $220 m^3 of soil to treat. The cost is high, but the results are immediate. In addition to increasing the amount of waste, the process of solidification also increases the volume of the original soil that has to be treated, which is a major drawback (Liu et al. 2021).

8.5.2.2.4. Vitrification

It is possible to turn dirty soil into glass-like solids by heating it to high temperatures. Design and testing of the technology have been going on since 1980. A high-temperature zone (> 1500 °C) is created when intense electricity is supplied to contaminated soil. Volcanic lava from the high-temperature zone is subsequently turned into a glass-like material as it cools. All organic chemicals are burnt before the metals are enclosed in the glass matrix. It is a solid, stable, chemically non-reactive, and leach-resistant type of vitrification. vitrification can be divided into three broad categories, each of which relies on a different energy source to achieve a high temperature: plasma vitrification (which uses an electric current generated by gas plasma to achieve this temperature), electrical vitrification (which uses graphite electrodes in the contaminated area and applies high voltage electricity to heat the contaminated area), and thermal vitrification (contaminated soil is heated in a rotary retort by some external heat source like natural gas, microwave radiations). Because of the damage done to the soil by vitrification, it cannot be used for agricultural purpose anymore. Ex-situ procedures and in-situ techniques may both be used for vitrification, although in-situ techniques are more often used. Ex-situ vitrification is straightforward to handle, but ambient air pollution and other waste gases might be dangerous, especially if the contaminants contain radioactive or dispersive qualities. High organic matter and moisture content make the process of vitiation ineffective. In addition, combustible organic substances contaminated soils are exempt from this rule. When agricultural waste is kept for lengthy periods of time, the vitrification content of the glassy soil degrades with time. Vitrification is a tried-and-true industrial process. "The best-proven technology available" to deal with soil contamination, according to the USEPA, was the method. Until date, the United States has had four pilot and full-scale vitrification programs. "330–425$/ton" of treated soil was predicted to be the cost for US vitrification, using an ex-situ procedure at the bottom end of the soil (Shu et al. 2020).

8.5.2.2.5. Selection of the best remediation strategies

Bioavailability is linked to the biogeochemical changes of heavy metal(loid)s within soil. Plant-based remediation and microbial bioremediation are then reviewed as cost-effective and environmentally friendly alternatives to standard physical or chemical clean-up methods. The usage of these approaches is assessed based on the location of the contaminated site, the features of the pollution, the goal of the remediation, the cost spent, the execution, the time consumption, and the acceptance of the remediation process.

Following a careful review, the optimal approach will be selected from those above aspects. At various stages and project locations, it is acceptable to utilize two or more soil remediation technologies for integrated usage. To lessen soil metal contamination, a chemical stabilization approach may be employed in a contaminated area.

Phytoremediation will next be used to gradually restore the soil's key functions, which are critical to the ecosystem's well-being. Following are some of the most important phases in the well-executed remediation project: 1-pre-screening of technology and scope of treatability studies, 2-location remediation analysis, 3-study of a strategic review, 4-selection of best and efficient remedial procedures, 5-structure, specification and implementation of remedial practice, 6-evaluation of remedial performance. The beginning step of the assignment should consider the preliminary testing of potential soil treatment technologies by examining technological literature and consulting experts.

An analysis of treatment studies is then conducted when detailed geographical and pollutant information have been determined. Treatability studies include three stages: 1-screening test, 2-selection test, and 3-pilot/miniature-scale treatability testing. Soil treatment approaches that use limited-size screening are evaluated to see whether they are effective in real-world settings. The effectiveness and speed of a system in achieving the specified goals stated during the first stages indicate feasibility or appropriateness. The performance objectives and remedial criteria are changed if any of the procedures are rejected. Consideration and evaluation of alternative restorative approaches are also undertaken here. Following this, selection tests evaluate the technology's performance and estimate the full-scale implementation costs for technologies that pass the earlier checks and screening tests.

Full-scale or pilot equipment selection tests are carried out to determine the best parameters for equipment and operation and the viability of clean-up. Treatability tests, often carried out by technology providers and remediation contractors, assess the viability of remediation approaches before they are fully implemented. Detailed information on the cost, performance, and design of a remediation procedure may be gathered via treatability testing. If the information needed to determine treatability can be found in existing literature and databases, there is no need to conduct further tests (Khan et al. 2021).

8.5.2.2.6. Practical examples

Soil cadmium (Cd) pollution in China has become a severe problem because of its high toxicity to humans via food chains. Cd contamination in rice and wheat fields was remedied using hydrated lime (L), hydroxyapatite (H), and organic fertilizer (F) alone or in combination, as shown in this pot experiment. The amendments had a significant impact on grain production, Cd content, soil pH, $CaCl_2$ extractable Cd, and Cd speciation in the crops, according to the findings of the study. Hydrated lime and hydroxyapatite considerably immobilized soil Cd, and hydroxyapatite, organic fertilizer greatly boosted grain yields in both cropping seasons.

Soil carbonates-bound Cd fractions rose from 16.7% to 36.2% and from 16.8% to 28.3% with hydrated lime; in the DY and YX soils, hydroxyapatite increased Fe/Mn oxides Cd fractions from 19.3% to 33.4% and from 31.4% to 42.1%; organic fertilizer slightly increased soil exchangeable and organic matter-bound Cd fractions. In addition, alkaline and organic elements in combination amendments can both reduce grain Cd and boost grain yield. Combined amendments such as hydrated lime + organic fertilizer, hydrated lime + hydroxyapatite + organic fertilizer are advised in practice because of the effects of amendments on grain yield and Cd concentration, the cost, and the anticipated advantages.

Changes in soil Cd availability and crop root absorption, rather than internal plant translocation, are primarily responsible for how amendments impact Cd immobilization mechanisms (Guo et al. 2018).

8.6. Conclusions

It has been shown that human activity has had considerable effects on agricultural soils contamination and pollution levels. With the increasing food security and increasing demands for food lead the way to decontaminate and reclamate the salt-affected and contaminated soils to meet the food security demands. Soil pollution and degradation can be eliminated by chemical, biological, physical, electrical, and thermal means considering the specific site's wide variety of factors, including the contaminants type, remediation objectives, restoration effectiveness, cost-efficiency, time, and public appropriateness, influence the application of soil treatment approaches. In conclusions, it is recommended that the use of recommended measure for reclamation and de-contamination of soils is need of the time to meet the arising food security problems.

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Обнова деградираних земљишта за биљну производњу

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Сажетак

Широк спектар еколошких питања је у вези са управљањем пољопривредним земљиштем, јер оно има значајан утицај на екосистеме широм свијета. Пољопривреда угрожава животну средину као чест узрочник погоршања квалитета или деградације земљишта.

Постоји више типова деградације земљишта: салинитет, ерозија, плављење и загађење земљишта органским и неорганским загађујућим материјама.

Укључивање циљева одрживог развоја (*Sustainable Development Goals*, SDG) повезано је са коришћењем земљишта за нулту глад (SDG 2), достојанствен рад и економски раст (SDG 8), климатске акције (SDG 13) и живот на земљи (SDG 15). Коришћење земљишта такође је значајно као допринос људском благостању кроз производњу прехрамбених усјева (SDG 2), повећање економског раста (SDG 8), задржавање атмосферских емисија за ублажавање климатских промјена (SDG 13) и побољшање живота на земљи (SDG 13).

Најчешћи фактори деградације земљишта су неприлагођене пољопривредне праксе, коришћење широких поља без ограничења, а уз ометање протока воде, и неправилне технике орања. Кључни елеменат за ограничавање деградације земљишта је смањење притиска на природне ресурсе и спречавање њихове прекомјерне експлоатације. У овом поглављу аутори су детаљно разрадили проблем деградације земљишта, проучавајући узроке те појаве и начине њиховог отклањања.

Кључне ријечи: Квалитет земљишта, плодност земљишта, производња усјева, органске измјене, сигурност хране