Technical progress of soil pollution control and land quality restoration

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Abstract

With the rapid development of industrialization and urbanization, the problem of soil pollution has become increasingly serious, which has become an environmental problem of global concern. Soil pollution not only affects the yield and quality of crops, but also may pose a potential threat to human health through the food chain, and at the same time limit the sustainable use of land and have an adverse impact on social and economic development. Therefore, soil pollution control and land quality restoration are particularly important. In recent years, scholars at home and abroad have done a lot of research on soil pollution control and land quality restoration, and achieved remarkable results. However, with the diversification and complexity of pollution types, the traditional treatment and recovery technology has been difficult to meet the actual needs. Therefore, it is of great significance to discuss the latest progress of soil pollution control and land quality restoration technology for improving the efficiency of governance and restoring the ecological function of land. This paper summarizes the research progress of soil pollution control and land quality restoration technology in recent years, analyzes the advantages and disadvantages of existing technologies, and looks forward to the future development trend. Through the discussion of this paper, I hope to provide useful reference for the research and practice in related fields, and jointly promote the development of soil pollution control and land quality restoration technology.

Keywords

Soil; pollution control; land quality restoration.

1. Introduction

With the rapid development of industrialization and urbanization, the problem of soil pollution has become increasingly serious, which has become an environmental problem of global concern. Soil pollution not only affects the yield and quality of crops, but also may pose a potential threat to human health through the food chain. At the same time, polluted land also limits its sustainable utilization, which has a negative impact on social and economic development. Therefore, soil pollution control and land quality restoration are particularly important [1-2].

In recent years, scholars at home and abroad have done a lot of research on soil pollution control and land quality restoration, and achieved remarkable results [3-4]. However, with the diversification and complexity of pollution types, the traditional treatment and recovery technology has been difficult to meet the actual needs. Therefore, it is of great significance to discuss the latest progress of soil pollution control and land quality restoration technology for improving the efficiency of governance and restoring the ecological function of land.

This paper aims to summarize the research progress of soil pollution control and land quality restoration technology in recent years, analyze the advantages and disadvantages of existing technologies, and look forward to the future development trend. Through the discussion of this paper, I hope to provide useful reference for the research and practice in related fields, and jointly promote the development of soil pollution control and land quality restoration technology.

2. Soil pollution control technology

At present, soil pollution control technologies mainly include physical methods, chemical methods, biological methods and physicochemical methods, as shown in Table 1.

Table 1 Soil pollution control technology

method	advantage	disadvantage
physical method	1. Direct and effective, suitable for all kinds of pollutants. 2. The processing speed is fast and the effect is obvious. 3. Suitable for small-scale high-concentration pollution.	1. There may be secondary pollution. 2. High energy consumption and high cost.
Chemical method	1. Can transform pollutants into harmless or low toxic substances. 2. The treatment effect is stable, and it is suitable for large-scale pollution.	1. New chemicals may be introduced. 2. Professional operation is required, and the safety requirement is high. 3. It may have a certain impact on soil ecology.
Biological method	1. Environmental protection, without introducing new pollution. 2. Low cost and strong sustainability. 3. It can improve the ecological function of soil.	1. The repair cycle is long. 2. It is greatly influenced by environmental conditions.
Physicochemical combination method	1. Combine the advantages of physical and chemical methods. 2. The treatment efficiency is high, and it is suitable for complex pollution. 3. It can handle various types of pollutants.	1. The technology is complex and the operation is difficult. 2. It may involve high equipment and material costs.

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2.1. Physical method

In soil pollution control, physical methods are widely used because of their direct and efficient characteristics. These methods mainly separate, remove or fix pollutants in the soil by physical means, so as to achieve the purpose of purifying the soil.

Precipitation method is to add a proper amount of precipitant to polluted soil, so that pollutants react with precipitant to generate insoluble precipitate, and then separate it from soil. This method is especially effective for treating soil polluted by heavy metals. By adjusting the pH value of soil or using specific precipitants, heavy metal ions can be promoted to form insoluble salts or oxides, thus reducing their mobility and bioavailability in soil [5].

The filtering rule is to filter the polluted soil solution through specific filtering media, such as activated carbon and sand, so as to remove the pollutants in it [6-7]. This method shows good effect in treating organic pollutants, especially for those organic substances that are easily soluble in water. By selecting appropriate filter media and optimizing filter conditions, pollutants can be effectively intercepted and removed.

Adsorption method uses materials with large specific surface area and strong adsorption capacity, such as activated carbon and bentonite, to adsorb and fix pollutants in soil [8]. This method can not only reduce the migration of pollutants, but also reduce their harm to the environment and biology to a certain extent. In recent years, some new adsorption materials, such as nano-materials and graphene, have also been applied to soil pollution control, showing good application prospects.

In addition to the above methods, ion exchange method is also an effective physical treatment technology [9]. It uses specific ion exchange resin or natural minerals in soil to exchange ions with pollutants, thus realizing the removal of pollutants. This method has obvious advantages in treating certain types of pollutants, such as contaminated soil containing heavy metals or specific anions.

Although physical methods have achieved certain results in soil pollution control, there are also some limitations. For example, these methods usually need to consume a lot of energy and materials, and the treatment cost is high; At the same time, problems such as secondary pollution or waste residue that may occur during the treatment process also need to be properly solved. Therefore, in practical application, it is necessary to comprehensively consider various factors and choose appropriate physical methods to control soil pollution.

2.2. Chemical method

Chemical methods in soil pollution control mainly change the properties of pollutants through chemical reactions, so as to achieve the purpose of reducing the toxicity and migration of pollutants or transforming them into harmless substances. Specifically, redox reaction is a commonly used method in chemical treatment. For organic pollutants or some heavy metal ions in soil, oxidants (such as potassium permanganate, ozone, etc.) or reductants (such as sulfide and sulfite, etc.) can be added to promote the redox reaction of pollutants, and then they can be transformed into low-toxic or non-toxic substances [10].

Acid-base neutralization reaction is also often used for soil pollution control. For some acidic or alkaline soil pollution caused by industrial production, the pH value of soil can be adjusted by adding appropriate alkaline or acidic substances, thus improving the soil environment and reducing the migration and bioavailability of pollutants [11]. In addition, complexation reaction also plays an important role in the treatment of soil heavy metal pollution. By adding specific complexing agents (such as EDTA, citric acid, etc.), it can form a stable complex with heavy metal ions, reducing its activity and toxicity in soil and reducing the harm to the environment and biology.

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Although chemical methods play an important role in soil pollution control, it is also necessary to pay attention to the selection and dosage of chemical agents to avoid secondary pollution to the soil. At the same time, chemical methods usually need professional operation to ensure the treatment effect and safety.

2.3. Biological method

Biological methods in soil pollution control mainly degrade, transform or fix pollutants by using the biological activity of microorganisms or plants, thus realizing soil purification.

Microbial remediation is an important kind of biological methods [12]. By introducing microorganisms with the ability to degrade specific pollutants, such as bacteria and fungi, they can decompose organic matter or transform heavy metal forms, reducing the toxicity and migration of pollutants (Table 2). This method is especially suitable for treating organic contaminated soil such as petroleum hydrocarbons and polycyclic aromatic hydrocarbons.

Table 2 Application of different microorganisms in treating different types of pollutants

Microbial species	Microbial name	Pollutant Type	Repair Mechanism	application example
germ	Pseudomonas aeruginosa	Petroleum Hydrocarbons	Degradation of Hydrocarbon Compounds	Remediation of oily soil
germ	Bacillus subtilis	Polycyclic Aromatic Hydrocarbons	Biodegradation	Remediation of industrial polluted soil
fungus	Phanerochaete chrysosporium	Lignin, Dyes	Enzymatic Degradation	Wood processing waste treatment
fungus	Aspergillus niger	Heavy Metals	Adsorption and Transformation	Remediation of heavy metal contaminated soil
germ	Rhodococcus sp.	Pesticide Residues	Biodegradation	Agricultural soil remediation
fungus	Trichoderma viride	Organochlorine Pesticides	Biodegradation	Remediation of pesticide contaminated soil
germ	Sphingomonas sp.	Polycyclic Aromatic Hydrocarbons	Biodegradation	Remediation of Contaminated Soil in Petrochemical Plant
fungus	Fusarium solani	Heavy Metals	Bioadsorption	Remediation of heavy metal contaminated soil

Phytoremediation rules use the functions of plants such as absorption, transport, accumulation and degradation to treat polluted soil. For example, some super-enriched plants can efficiently absorb heavy metals in soil and transfer them to the aboveground parts, so as to remove heavy metals in soil by harvesting plants [13]. In addition, some plants can also promote the degradation of organic pollutants in soil through secretions released by roots.

Biological method has the advantages of environmental protection, low cost and sustainability, and is a research hotspot in the field of soil pollution control in recent years. However, the restoration period is relatively long, and the restoration effect is greatly influenced by environmental conditions such as temperature, humidity and soil properties.

2.4. Physicochemical combination method

The combination of physical and chemical methods combines the advantages of physical and chemical methods in soil pollution control. Chemical treatment is assisted by physical means, or the effect of physical treatment is enhanced by chemical reaction, so as to achieve more efficient and thorough pollution control. For example, the technology of magnetic nanoparticles is a typical application of physicochemical combination method. In this technology, magnetic nanoparticles are used as adsorbents or catalyst carriers, which have huge specific surface area and excellent magnetic response. Through physical adsorption, these particles can effectively remove heavy metal ions or organic pollutants in soil. At the same time, the chemical modification of the particle surface can also enhance its adsorption selectivity and capacity [14]. After the treatment, magnetic nanoparticles can be easily separated from the soil by external magnetic field by using their magnetic responsiveness, thus avoiding secondary pollution to the soil. This method combines the advantages of physical adsorption and chemical modification, which not only improves the efficiency of pollution control, but also ensures the environmental protection of the treatment process.

Another example of physico-chemical combination method is the combined technology of soil leaching and chemical oxidation. Firstly, pollutants are eluted from the soil by using a specific eluent through soil leaching; Subsequently, strong oxidant, such as potassium permanganate or ozone, is added to the eluent to oxidize and decompose the organic pollutants into low-toxic or non-toxic small molecular substances. This method combines the advantages of physical leaching and chemical oxidation, and can remove organic pollutants in soil more thoroughly. By integrating the advantages of physical and chemical methods, the combination of physical and chemical methods provides an effective solution to the complex and difficult soil pollution problem. With the continuous progress of science and technology, the combination of physico-chemical method is expected to play a greater role in soil pollution control.

3. Land quality restoration technology

3.1. Application of bioremediation in land quality restoration

Bioremediation technology plays an important role in land quality restoration, which mainly uses organisms, such as microorganisms and plants, to degrade and transform pollutants or improve soil environment, thus improving land quality.

Natural attenuation is widely used in land quality restoration. By introducing specific microorganisms, such as bacteria or fungi that can decompose organic pollutants, pollutants in soil can be effectively degraded and the soil environment can be improved. These microorganisms can decompose organic matter and turn it into harmless substances, thus restoring the ecological function of the land. In addition, phytoremediation technology is also an important bioremediation method. By planting plants with the ability to absorb, accumulate and degrade pollutants, such as hyperaccumulator plants, heavy metals or organic substances in soil can be effectively removed (Table 3). These plants can absorb pollutants and turn them into harmless substances, or remove pollutants from the soil by harvesting plants, thus restoring the quality of the land.

Table 3 Main heavy metal hyperaccumulator plants

Plant name	Scientific Name	Heavy metal types
Thlaspi caerulescens	Brassicaceae	Zn, Cd
Sedum alfredii	Crassulaceae	Zn, Cd, Pb
Arabidopsis halleri	Brassicaceae	Zn, Cd
Noccaea caerulescens	Brassicaceae	Zn, Cd, Pb
Solanum nigrum	Solanaceae	Pb, Zn, Cd
Alyssum bertolonii	Brassicaceae	Ni
Alyssum murale	Brassicaceae	Ni
Berkheya coddii	Asteraceae	Ni
Phytolacca americana	Phytolaccaceae	Cd, Pb
Brassica juncea	Brassicaceae	Se, Cd, Pb

Bioremediation technology has the advantages of environmental protection and strong sustainability, and plays an important role in land quality restoration. However, the repair period is relatively long, and the repair effect is affected by environmental conditions such as temperature and humidity. Therefore, in practical application, it is necessary to comprehensively consider various factors and choose appropriate bioremediation technology to restore land quality.

Generally speaking, bioremediation technology provides an effective and environmentally friendly solution for land quality restoration by using natural biological processes. With the continuous development of science and technology, bioremediation technology is expected to play a greater role in land quality restoration.

3.2. Application of physical restoration in land quality restoration

Physical remediation technology plays an important role in land quality restoration, which mainly improves soil structure, removes pollutants or enhances soil fertility through physical means, thus improving land quality.

Deep ploughing and loosening soil are common physical restoration methods. Through deep tillage, soil hardening can be broken, soil aeration and water permeability can be improved, which is beneficial to root growth and microbial activities. Loosening soil can further break soil aggregates and improve soil water retention capacity and nutrient availability. Soil vapor extraction is a physical remediation technology for soil contaminated by volatile organic compounds. It uses a vacuum pump to extract gas from the soil and remove volatile organic compounds from the soil, thus purifying the soil and restoring its use function. For the land polluted by heavy metals, heat treatment technology is also an effective physical remediation method. Through high temperature treatment, heavy metals in soil can be transformed or solidified, reducing their activity and mobility, thus reducing the risk to the environment. In addition, physical restoration also includes soil replacement and other methods, that is, digging out the heavily polluted soil and replacing it with unpolluted soil to quickly restore the use value of the land.

Physical restoration technology has the advantages of simple operation and intuitive effect, and plays an important role in land quality restoration. However, it may also cause some damage to the soil structure and the cost is relatively high. Therefore, in practical application, it is necessary to choose appropriate physical restoration technology to restore land quality in combination with specific conditions.

3.3. Application of chemical remediation in land quality restoration

Chemical remediation technology in land quality restoration mainly improves soil properties, reduces the toxicity of pollutants or fixes pollutants by adding chemicals, thus restoring the ecological function and agricultural utilization value of land. In the aspect of acid or alkaline soil improvement, chemical remediation technology adjusts the pH value of soil by adding lime, gypsum or other regulators to make it close to neutral, thus improving the soil environment and benefiting plant growth. For the land polluted by heavy metals, passivators, such as phosphate and silicate, can be used for chemical remediation to react with heavy metal ions to generate insoluble compounds, which can reduce the mobility and bioavailability of heavy metals and reduce the toxicity to plants (Table 4).

Table 4 Classification of passivators for heavy metal pollution in soil

Passivator Classification	Representative Substances	Mechanism of Action
Silicon-containing substances	Silicon fertilizer, silicate, diatomaceous earth, zeolite	Form insoluble silicates with heavy metals
Calcium-containing substances	Lime, gypsum	Form insoluble carbonates or sulfates with heavy metals
Phosphorus-containing substances	Phosphate rock powder, phosphate	Form insoluble phosphates with heavy metals
Metal oxides	Iron oxide, aluminum oxide	Adsorb heavy metals and form coprecipitates
Clay minerals	Kaolin, montmorillonite	Adsorb heavy metals and exchange ions
Organic substances	Organic fertilizer, biochar	Adsorb heavy metals and form complexes
Agricultural waste	Straw, livestock and poultry manure	Adsorb heavy metals and increase soil organic matter

Chemical oxidation or reduction technology is also an effective remediation method for organic contaminated soil. By injecting strong oxidants (such as potassium permanganate, persulfate, etc.) or reducing agents into the soil, organic pollutants are oxidized or reduced to low-toxic or non-toxic substances, thus purifying the soil. Chemical remediation technology has the advantages of stable treatment effect and wide application range, but it also needs careful operation to avoid introducing new chemicals to cause secondary pollution to soil and environment.

4. Development trend of soil pollution control and land quality restoration technology

With the increasingly prominent global environmental problems, soil pollution control and land quality restoration technology have attracted more and more attention. The development trend of these technologies is moving towards a more efficient, environmentally friendly and sustainable direction.

In the future, soil pollution control will pay more attention to comprehensive management and combine physical, chemical and biological methods to form complementary advantages. For example, the combination of physical and chemical methods can make use of the advantages of both physical and chemical methods to improve the efficiency and thoroughness of pollution control. In addition, with the rapid development of nanotechnology and biotechnology, new materials and technologies will be more widely used in soil pollution control. Accurate control is an important direction of soil pollution control in the future. By introducing advanced technologies such as big data and artificial intelligence, accurate identification of pollution sources and accurate assessment of pollution levels can be achieved. This will help to formulate more targeted governance programs and improve governance effects. At the same time, the introduction of intelligent technology can also realize the automation and intelligent monitoring of the governance process, and improve the efficiency and quality of governance.

In the process of soil pollution control and land quality restoration, eco-friendliness and sustainable development will become important considerations. Future technology will pay more attention to reducing secondary pollution, protecting ecological environment and restoring soil ecological function. For example, bioremediation technology will be more widely used because it is not only environmentally friendly but also sustainable. The government will play a more important role in soil pollution control and land quality restoration. By formulating stricter environmental protection policies and standards, enterprises and the public will be guided to participate in soil protection and governance. At the same time, the improvement of public awareness of environmental protection will also promote the popularization and application of soil pollution control and land quality restoration technology.

5. Conclusion

The advantages and disadvantages of different technologies, such as physics, chemistry, biology and physicochemical combination, and their application prospects are comprehensively analyzed. Although the physical method has fast treatment speed and is suitable for high-concentration and small-scale pollution, it may produce secondary pollution and the cost is high. Although chemical methods can stabilize the treatment effect and are suitable for large-scale pollution, they may introduce new chemicals and affect soil ecology. Biological methods show the advantages of environmental protection and sustainability, but the restoration period is long and is greatly limited by environmental conditions. The combination of physical and chemical methods combines the advantages of physical and chemical methods, which improves the efficiency and thoroughness of pollution control, but also increases the difficulty of operation and technical complexity, and may involve higher equipment and material costs. The development of soil pollution control and land quality restoration technology needs to comprehensively consider various factors and choose appropriate technologies for pollution control. With the progress of science and technology and the improvement of social awareness of environmental protection, it is expected that more innovative technologies and methods will be developed and applied in the future to achieve more effective, safer and more environmentally friendly soil pollution control and land quality restoration.

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