New Perspective on Land Pollution Control- -Soil Microbiology Abstract

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Abstract. Soil pollution constitutes an important environmental challenge globally, affecting ecosystems and human health. This paper, exploring in depth the current soil pollution situation and treatment strategies, emphasizes the multifaceted response of biological, physical, and chemical methods. Focusing on the key role of soil microorganisms, studies cover their contributions to organic pollutant degradation, heavy metal remediation, soil structure improvement, and plant growth promotion. The study highlights the critical importance of interdisciplinary collaboration and innovative technologies such as genetic engineering and nanotechnology in soil pollution control. Through a comprehensive analysis of soil microbial functions and their potential for ecological restoration, the complexity of soil pollution treatment is revealed in this paper. The importance of research lies not only in a comprehensive understanding of soil pollution but also in providing useful insights into sustainable environmental management. The study provides a valuable reference for policy makers, scientists and the public to promote a comprehensive understanding of soil pollution and pave the way for effective mitigation strategies.

Keywords: Soil pollution; Innovative Technologies; Environmental impact; Governance Strategies; Sustainability.

1. Introduction

With the rapid development of modern society, industrial emissions, the widespread use of agricultural fertilizers and pesticides, as well as municipal waste treatment and other factors, the soil pollution gradually upgrades, and its self-purification ability is increasingly weakened. As an important natural resource, the health status of soil is directly related to the quality of agricultural products, the cleanliness of water resources, and even the balance of the whole ecosystem. If the soil pollution is not effectively controlled by artificial means, it will cause serious damage to the ecological environment, and then threaten many aspects of human life. In such an urgent situation, to effectively reduce the harm caused by soil pollution to human beings, domestic and foreign scientific research institutions have invested in the research and development of soil pollution control technology.

For soil pollution, scientific research institutions are committed to developing a variety of treatment technologies, including innovation in bioremediation, physical remediation and chemical remediation. The widespread application of these technologies has improved the situation of soil pollution and improved soil quality to some extent. In terms of bioremediation, some outstanding microbiologists have deeply studied the characteristics of soil microorganisms and proposed a series of innovative treatment methods, including the use of specific microorganisms to degrade harmful substances. The research on physical remediation focuses on the improvement of soil structure and the isolation of pollutants and restores the natural state of soil through artificial means. In addition, the continuous development of chemical remediation techniques, such as the application of adsorbent and chemical reduction, provides more options for soil governance. However, to comprehensively solve the problem of soil pollution, it requires not only continuous technological innovation but also interdisciplinary cooperation and deeper research.

The research on soil microorganisms is not only about the innovation of governance technology but also provides a deeper understanding and understanding for the article. Therefore, based on analyzing the source of soil pollution and the current situation of treatment, this paper focuses on the current commonly used treatment technologies, such as bioremediation, physical remediation, chemical remediation and combined remediation technologies, in order to provide a reference for a more comprehensive and effective solution to the problem of soil pollution. At the same time, by focusing on the innovative perspective of soil microorganisms, a series of novel suggestions are proposed for soil pollution control, hoping that it can contribute more to soil health and the sustainable development of human society in future research and practice.

2. Analysis of the Current Situation of Soil Pollution

2.1. Pollution Sources and Type

At present, there are four main types of soil pollution, namely, chemical pollutants, physical pollutants and radioactive pollutants [1].

2.1.1. Chemical pollutants

Chemical pollutants are mainly heavy metals, such as lead, cadmium, mercury, and chromium, which often come from industrial emissions, waste disposal, and agricultural activities [2]. Organic pollutants are also chemical pollutants, including pesticides, herbicides, residual drugs, industrial compounds and so on. These substances may cause harm to soils and ecosystems. Volatile organic compounds (VOCs), such as benzene, toluene, xylene, etc., usually come from industrial processes and combustion activities. Nitrogen compounds include ammonia, nitrates, nitro compounds, etc., which mainly come from chemical fertilizers, livestock and poultry breeding, and wastewater discharge.

Petroleum substances, including petroleum hydrocarbons, and polycyclic aromatic hydrocarbons, are often caused by oil exploitation, transportation and use. Chemical pollutants of inorganic salts include chloride, sulfate and so on. They usually come from the use of industrial wastewater and chemical fertilizers.

2.1.2. Physical contaminant

Among soil contaminants, physical pollutants usually refer to those substances that adversely affect the soil structure and physical properties. The main physical pollutants include solid waste, construction and industrial waste residues.

Solid waste mainly refers to plastics, metal, glass and so on. These wastes may accumulate in the soil, leading to reduced soil permeability, affecting plant root growth, and hindering the activity of microorganisms in the soil.

Construction and industrial waste residues include concrete debris, slag, etc., which may change the soil structure, increase the soil density, and affect the soil aeration and water retention capacity.

Moreover, the loss of soil surface layers due to factors such as human activity, water flow and wind, may lead to decreased soil quality and reduced vegetation. Particulate matter from atmospheric settlement and sediments imported from rivers may contain pollutants and have negative effects on the soil. At the same time, the soil compaction caused by human activities and vehicle driving will affect the soil porosity and ventilation, and hinder the growth of plants.

2.1.3. Radioactive pollutants

Radioactive pollutants refer to substances with radioactive decay properties, which can produce radioactive radiation, causing potential harm to the soil and the environment. The main soil radioactive pollutants include uranium (U), thorium (Th), and other artificial radionuclides.

Uranium is a natural radioactive element, but in some cases, the concentration of uranium in the soil may increase due to human activities such as mining, nuclear fuel production, etc. Thorium is another naturally occurring radioactive element and often exists along with uranium. It may also be introduced into the soil in some industrial processes and fuel production.

In addition to uranium and thorium, some artificial radionuclides such as strontium (Sr-90) and plutonium (Pu-239) are often caused by nuclear accidents or nuclear facility leaks, which may pollute the soil.

2.2. Impact and Consequences

Whether it is chemical pollutants, physical pollutants, or radioactive pollutants, they together constitute a complex network of soil pollution. These pollutants have caused a serious impact on soil, and the consequences not only involve the destruction of soil ecosystem, but also a direct threat to human health. The composition of soil pollutants varies among regions based to industrial structures, agricultural practices and human activities, leading to the environmental impact of diversity. Chemical pollutants pose potential hazards to soil ecosystems and human health. They may cause water to penetrate difficult, limit root growth, and cause damage to vegetation and soil microorganisms. Physical pollutants mainly play a role in destroying the soil structure and permeability, making the water penetration difficult, and then affecting the natural function of the soil. The presence of radioactive pollutants has long-term negative effects on soil and ecosystems, and also poses a potential threat to human health.

3. Measures to Alleviate Soil Pollution

3.1. Physical Control Measures

Physical remediation technology has a relatively mature application in soil pollution control. These technologies are based on physical principles and realize the remediation of contaminated soil through different means, among which thermal desattachment remediation technology is one of that has attracted much attention. Thermal desorption and remediation technology uses heat energy to act on the soil contaminated by heavy metals, and realizes the removal of volatile substances through the heat energy generated by energy combustion [3]. This method can remove organic matter efficiently, especially in the treatment of polychloride biphenyls and polycyclic aromatic hydrocarbons, the highest performance removal rate is about 99.3%. Moreover, it is noteworthy that this technique has done a good job of guaranteeing soil fertility, and minimizing the impact on the soil itself. On the other hand, electric repair technology is mainly used to treat soil contaminated with heavy metals by inserting electrodes.

The technology does well at removing large amounts of heavy metals and some organic matter, however, it requires a lot of energy in practical use, which may be a trade-off. Engine need to fully consider the environmental impact and the sustainable use of energy. In general, physical remediation technology provides a series of effective means for soil pollution control, but it also needs to comprehensively consider the cost, benefit and possible secondary pollution problems in practical application. In the future, with the continuous progress of science and technology, these technologies may welcome more innovations, improve governance effects, and achieve more sustainable soil remediation.

3.2. Chemical Treatment Measures

Compared with physical remediation technology, chemical remediation technology is easier to operate, especially if it can effectively deal with soil pollution of different depths. Therefore, chemical remediation technology has shown significant advantages in the treatment of contaminated soil. However, it is worth noting that soil remediation using chemical remediation technology requires a large amount of money invested, and may cause secondary pollution problems in practice.

Leaching technology is one of the widely used chemical remediation techniques, and its principle is to repair the contaminated soil by adding leaching agents [4]. Different leaching methods have different effects on soil, so when choosing leaching remediation agents, it is necessary to conduct a comprehensive analysis of soil pollution, and select appropriate agents according to the soil test results. It should be noted that because agents contain a lot of water, in addition to the removal of soil pollutants, it may also lead to the decrease of organic matter in the soil, and then have a certain degree of impact on soil fertility.

3.3. Animal Control Measures

Animal remediation techniques are widely used in soil pollution control. The principle is to make full use of the animals in the soil, such as earthworms and nematodes, to absorb, transform and decompose the pollutants, enhance the soil fertility, promote the growth of microorganisms and plants, and realize the remediation of the contaminated soil. Earthworms play an important role in soil improvement, increasing soil fertility, facilitating crop production, and improving soil ecological restoration capacity. Nematodes have large numbers and reproduce rapidly. Through their characteristics, animal restoration technology can absorb and transform the harmful substances in the soil, provide a good environment for microorganisms and plants to grow, and optimize the ecological structure of the soil.

For example, large feeding of earthworms can optimize soil aeration ability and improve soil self-recovery. This method is not only pollution-free, but also can improve soil fertility, accumulate the nutrients in the soil, and provide favorable conditions for plants and microorganisms. Animal remediation techniques play a significant role in treating soils contaminated with heavy metals. However, this technique has some limitations and requires further intensive investigation. It is often more used to treat nutrient-rich water and soil contaminated with pesticides and organic matter.

4. Land Pollution Control Effect of Soil Microorganisms

4.1. Degradation of Organic Pollutants

In soil, microorganisms are biological factories that naturally degrade organic pollutants. In the case of Pseudomonas, a class of bacteria widely found in the soil, known for their excellent metabolic capabilities. Pseudomonas can secrete various enzymes, such as dehydrogenases and oxidases, for the decomposition of complex organic pollutants such as polycyclic aromatic hydrocarbons, petroleum, and pesticides. Through the action of these enzymes, organic pollutants are gradually degraded into relatively simple molecules, and eventually enter the soil recycling system to complete the cleaning process. Another example is the white rot fungi in fungi, which have a strong decomposition capacity of refractory organic matter such as lignin. By secreting enzymes, such as lignin peroxidases, these fungi can break down complex organic structures and decompose lignin into simple organic matter that can be used by other microorganisms, promoting the recycling of organic matter.

The degradation activities of these microorganisms provide the biological basis for the removal of organic pollutants from the soil and protect the health of the soil ecosystems.

4.2. Heavy Metal Repair

In soil, sulfate-reducing bacteria are a class of microorganisms that are active under hypoxic conditions. Its unique metabolic pathway can reduce sulfate to sulfide, which is crucial for heavy metal repair. Because sulfide and heavy metals form insoluble precipitation, effectively reduces its toxicity in the soil. Sulfuric acid-reducing bacteria can reduce the heavy metal ions in the soil, such as cadmium, lead, and chromium, and convert them into insoluble sulfide precipitation, thus reducing the toxicity of heavy metals.

Moreover, the plant-microbial symbiosis system also plays a positive role in heavy metal remediation. Plants such as Acacia secrete organic acids and other substances in the rhizosphere, which cooperate with rhizosphere microorganisms to enhance the stability and not easy migration of heavy metals in soil.

The coordinated activity of these microorganisms provides a unique biological mechanism for heavy metal remediation in soil that contributes to improving soil quality.

4.3. Improvement of Soil Structure

Microbes play a positive role in improving the soil structure through their metabolites and secreted adhesions. In the case of bacteria in clay minerals, they are able to secrete polysaccharides that combine with soil particles to form aggregates. The formation of such aggregates enhances soil erosion resistance and water retention, slowing down the rate of water loss. Moreover, some fungi such as filamentous fungi, through their filamentous network structure, promote the agglomeration of soil particles and improve soil permeability, contributing to the penetration of water and nutrients.

In this process, microorganisms increase the stability of the soil by regulating the physical properties of the soil, thus providing a more favorable growth environment for the root system of plants. This is essential for maintaining soil health and promoting plant growth.

4.4. Promotion of Plant Growth

The symbiotic relationship formed between microbes and plants is crucial for plant growth. In the case of the symbiosis of mycorrhizal fungi and plants, this relationship can effectively improve the ability of plants to absorb nutrients. Mycorrhizal fungi expand their range through their filaments to cover a wider area of soil and deliver nutrients to plants. For example, the symbiotic relationship between white poplar trees and mycorrhizal fungi can improve the efficiency of phosphorus uptake, thus promoting plant growth. This relationship extends through the filaments of mycorrhizal fungi, covering wider soil areas, and effectively taking up and delivering nutrients to the plants. The interaction between these microorganisms and plants enables plants to better adapt to the soil environment, and improves their stress resistance and survival competitiveness [5].

4.5. Degradation of Toxic Substances

The degradation of toxic substances is an important part of bioremediation in soil. Deoxidizeflora is a class of microorganisms with the ability to degrade organic pollutants such as polychlorinated biphenyl and dioxins. Through dehalogenation, they reduce the organochlorine substances to the more harmless products. This degradation process is a natural and efficient way to mitigate the ecosystem caused by toxic substances in the soil.

Some fungi, such as white rot fungi, also have the ability to degrade organic pollutants. Through their enzyme system, organic substances are gradually degraded into water and carbon dioxide, completing the cleaning of toxic substances.

5. Recommendations and Discussion

5.1. Feasibility and Implementation

5.1.1. Current status of soil control in China

In order to strengthen soil pollution control, China has formulated policies related to soil pollution control and increased investment in environmental pollution control. In 2019, China's special funds for soil pollution control reached 5 billion yuan.

As of January, 2022, China has adopted multiple measures to improve the soil environment and control soil pollution. In addition to the formulation of policies and regulations and nationwide monitoring and evaluation, the focus on soil remediation engineering, and the use of biological, physical and chemical means, effectively promoted the functional restoration of contaminated land and the improvement of soil quality. In particular, in some areas with more concentrated pollution, such as industrial parks and agricultural areas, China has implemented targeted governance projects to focus more on addressing the challenges of soil pollution. Research and technological innovation play a key role in soil pollution control. China not only encourages scientists and research institutions to conduct relevant research but also actively promotes the continuous improvement of soil pollution control technology. Public participation is also an important strategy in the process of governance. Through publicity and education, the public's awareness of soil environmental problems is improved, the joint participation of the whole society is formed, and the sustainable progress of governance work is promoted. These comprehensive measures show that the Chinese government is highly concerned about soil pollution control, and is committed to ensuring the gradual improvement of soil environmental quality through multi-directional and multi-level efforts.

5.1.2. Feasibility analysis

Soil microorganisms have significant feasibility in soil pollution control. First, microorganisms have the ability of natural restoration, without the need to introduce external elements, in line with the principle of ecological balance. Secondly, microorganisms efficiently degrade various organic and inorganic pollutants through metabolic activities and quickly reduce the impact of pollution on the environment. Microorganisms are highly adaptable and can adapt to different soil and pollutant types, and provide wide applicability for treatment. Moreover, microbial governance costs are relatively low compared to some physical or chemical methods, as microorganisms naturally exist in the soil without large-scale introduction, reducing implementation costs. These characteristics make the use of soil microorganisms become an economical, efficient, and environmentally friendly soil pollution treatment scheme.

5.1.3. Implementation plan

In terms of soil pollution control, bioremediation is an important method, which can introduce the degradation ability of microorganisms, such as biological phytoremediation technology, to promote plants and soil microorganisms to accelerate the degradation of pollutants. At the same time, through the microflora guidance, the natural microbial community in the soil can be optimized, the degradation ability of specific pollutants can be improved, and the soil environmental conditions such as temperature and humidity and pH value can help to promote the reproduction and activity of beneficial microorganisms. The introduction of cultivated microbial agents is another implementation to enhance the number and vitality of beneficial microorganisms in the soil, thus improving the self-purification capacity of the soil. In terms of monitoring and evaluation, the establishment of a soil microbial monitoring network can monitor the structure and activity of microbial communities in real time, provide data support for scientific decision-making, and ensure the good performance of microorganisms in the degradation of pollutants. These comprehensive measures show that the Chinese government is highly concerned about soil pollution control, and is committed to ensuring the gradual improvement of soil environmental quality through multi-directional and multi-level efforts.

5.2. Technological Innovation and Research Direction

5.2.1. Technological innovation achievements

Technological innovations in soil microbes in governance cover multiple areas. First, genetically engineered microbial technology enhances the microbial degradation ability through genetic modification, making it more adaptable to the complex environment, so as to improve the governance effect. Secondly, the application of nanotechnology in microbial repair can improve the degradation efficiency, expand the contact area between microorganisms and pollutants, and significantly improve the efficiency and speed of repair. By deeply understanding the genetic information and functions of soil microorganisms, metagenomics research has revealed the underlying mechanisms of microorganisms in pollutant degradation, providing theoretical support for the precise regulation of microbial communities. Finally, the intelligent monitoring and feedback technology are combined to realize the real-time monitoring of microbial activity and community structure, and adjust the governance strategy through the feedback mechanism to achieve more accurate and real-time soil pollution control. Together, these technological innovations provide more powerful and efficient tools and methods for soil microorganisms in governance.

5.2.2. Future direction can be explored

Research on soil microbes in governance will focus on multiple key directions. First, the intensive study of the relationship between diversity and function aims to understand the diversity of soil microbial communities and to explore the functions of different microorganisms in degrading different contaminants. This will help to build more complex and efficient microbial assemblages, providing more flexible and accurate tools for governance. Secondly, the study of microbe-plant governance aims to strengthen the synergy between microbes and plants and promote the joint participation in the degradation of soil pollutants through technologies such as biological phytoremediation, to improve the comprehensiveness and sustainability of governance [6]. Further, the study of the interaction between microbial remediation and the soil ecosystem will deeply explore the impact of microbial remediation on soil ecosystem, including soil biodiversity, soil enzyme activity and other aspects, to ensure that the governance process has a positive impact on the overall health of soil. Finally, the application of novel nanotechnology in microbial remediation aims to improve the efficiency and stability of microbial remediation and slow the migration and diffusion of pollutants. These research directions will provide more in-depth and comprehensive theoretical support for soil microbial governance and promote the continuous progress of governance technology.

6. Conclusion

This paper discusses the current situation analysis of soil pollution, including pollution sources and types, influence and consequences, and the existing treatment situation. In the outline of Chapter 2, various techniques for soil pollution control, such as bioremediation, physical remediation, and chemical remediation, are presented. These mature technologies show that the problem of soil pollution is a serious ecological pollution problem, and human society also attaches great importance to it and carries out related governance work from multiple angles.

In this paper, the role of microbial technology in soil pollution control is because microbial technology is more in line with the current green ecology, and reduces the adverse effects of other remediation technologies, such as high energy consumption of physical remediation technology, and secondary pollution caused by chemical remediation technology. At present, microbial technology is also applied, which is highly feasible and can be matched with other remediation technologies to better control soil pollution through joint remediation technology.

Finally, this paper focuses on technological innovation and research directions in soil microbial governance, including genetic engineering microbial technologies, nanotechnology applications, metagenomics research, and intelligent monitoring and feedback technologies. These innovations provide more powerful and efficient tools and methods that are expected to drive continuous progress in soil pollution control technologies.

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