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Study on Soil Pollution Control and Land Ecological Restoration Technology

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ABSTRACT

This paper discusses the present situation and development trend of soil pollution control and land ecological restoration technology. Soil pollution mainly comes from industrial emissions, excessive use of pesticides and fertilizers and improper treatment of municipal garbage, which poses a threat to agriculture, human health and ecological balance. Treatment technologies include engineering remediation (such as soil replacement and water washing), physical-chemical remediation (such as solidification-stabilization, leaching, etc.), and biological remediation (using microorganisms, plants and animals). Land ecological restoration emphasizes integrity and sustainability, and adopts various methods such as plant and microbial restoration. In addition, prevention and control strategies and policy suggestions are put forward, including strengthening waste treatment standards, rational use of pesticides and fertilizers, and promoting waste classification. It is also suggested to establish a sound legal system for soil pollution prevention and control and raise public awareness of environmental protection.

KEYWORDS

Soil Pollution Control; Land Ecological Restoration; Physical-Chemical Repair; Bioremediation; Phytoremediation.

1. INTRODUCTION

With the rapid development of industrialization and urbanization, the problem of soil pollution has become increasingly prominent and has become a severe challenge in the field of global environmental protection. As an important part of the earth's ecosystem, the health of soil is directly related to the growth of crops, the quality of groundwater and the stability of the whole ecosystem. However, in recent years, due to the discharge of industrial waste, excessive use of pesticides and fertilizers, and improper treatment of municipal waste, the problem of soil pollution has become more and more serious [1]. This not only affects the productivity of land and the quality of crops, but also may endanger human health and even destroy the ecological balance through the food chain.

The research and application of soil pollution control and land ecological restoration technology is of great significance for protecting land resources, maintaining ecological balance and ensuring human

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health. Although a variety of soil pollution control and ecological restoration technologies have been developed and applied, each technology has its scope of application and limitations, and the actual effect is affected by many factors [2]. Therefore, it is still an important topic in the field of environmental science and technology to continuously explore and innovate soil pollution control and land ecological restoration technology to improve the efficiency and effect of governance.

The purpose of this study is to deeply discuss and analyze the existing soil pollution control methods and land ecological restoration technologies, evaluate their effects and limitations in practical application, and put forward the direction of improvement and innovation. This study provides scientific basis and technical support for soil pollution control and land ecological restoration.

2. PRESENT SITUATION AND HARM ANALYSIS OF SOIL POLLUTION

With the continuous increase of human activities, soil pollution has become an environmental problem that cannot be ignored. Soil pollution mainly comes from industry, agriculture and cities. In the industrial field, heavy metal pollution is particularly prominent. The waste water, waste gas and waste residue produced in the production process of many factories, if discharged without proper treatment, will directly lead to the pollution of the surrounding soil by heavy metals such as lead, cadmium and mercury [3]. In addition, some chemicals, such as polychlorinated biphenyls and petroleum hydrocarbons, will also enter the soil due to leakage or improper treatment. Excessive use of pesticides and fertilizers is another major source of soil pollution in agricultural activities. The accumulation of these chemicals in soil not only affects the growth of crops, but also may enter the human body through the food chain, posing a potential threat to health. In urban life, a lot of domestic garbage and wastewater will also pollute the soil if they are not treated properly. In particular, heavy metals and other harmful substances contained in electronic waste will exist for a long time once they enter the soil and are difficult to remove [4].

The harm of soil pollution is multifaceted, which not only affects agricultural production, but also has a long-term impact on human health and ecological environment [5]. Soil pollution will directly lead to crop yield reduction and quality degradation. In polluted soil, harmful substances will hinder the normal growth of plant roots and affect their absorption of water and nutrients, thus reducing the yield and quality of crops. Contaminants in the soil will enter the human body through the food chain, posing a threat to human health [6]. Long-term intake of contaminated food may lead to serious health problems such as heavy metal poisoning and cancer. Soil pollution will also destroy the ecological environment. Harmful substances in soil will kill or inhibit the growth of soil microorganisms and reduce the biodiversity of soil. At the same time, these harmful substances may also spread to a wider area through groundwater infiltration and surface water runoff, which will have a long-term impact on the entire ecosystem. The present situation and harm of soil pollution should not be underestimated. In order to protect land resources, maintain human health and ecological balance, effective measures must be taken for soil pollution control and ecological restoration.

3. STUDY ON SOIL POLLUTION CONTROL TECHNOLOGY

3.1. Engineering restoration technology

Engineering remediation technologies mainly include soil replacement technology, soil replacement technology, water washing technology, etc. These technologies directly treat contaminated soil by physical means to achieve the purpose of quickly removing or reducing pollutant concentration.

Exotic soil technology can quickly cover polluted soil and reduce the contact between pollutants and plant roots [7]. Suitable for lightly to moderately polluted soil. The operation is relatively simple and the period is short. But it needs a lot of clean soil, which may put some pressure on resources. Can't fundamentally solve the pollution problem, just isolate the polluted soil from the plant roots. The long-term effect needs to be verified, and there may be the risk of secondary pollution. Suitable for farmland and orchards with mild to moderate heavy metal or organic pollution. Suitable for scenes that need to quickly restore land use.

Soil replacement technology solves the pollution problem by completely replacing the polluted soil [8], which is suitable for all types and degrees of soil pollution, especially for treating heavily polluted industrial land, abandoned mines and other scenes, as well as places with high requirements for land use, such as residential and commercial land. However, the cost of this method is high, which requires a lot of resources, and the replaced contaminated soil needs to be properly treated to avoid secondary pollution, and it may also cause damage to the original soil structure and ecological environment. On the other hand, water washing technology can effectively remove soluble pollutants and some heavy metals in soil, so that the treated soil can be recycled and reduce the waste of resources. However, it needs a lot of water resources and may produce wastewater pollution during the treatment process, and the treatment effect of insoluble pollutants is not good, and it may change the physical properties and structure of soil [9]. Therefore, water washing technology is more suitable for soil polluted by soluble pollutants (such as some heavy metals and salts) and areas with abundant water resources and wastewater treatment capacity.

3.2. Physical-chemical repair technology

Physical-chemical remediation technologies mainly include soil solidification-stabilization technology, leaching technology, oxidation-reduction technology, chemical improvement, photocatalytic degradation technology, electrodynamics remediation technology and organic matter improvement [10-11]. These technologies can be used alone or in combination with other technologies to improve the restoration effect.

Soil solidification-stabilization technology is to reduce the mobility and bioavailability of pollutants by adding curing agents or stabilizers. This method is suitable for soil polluted by heavy metals, which can effectively fix heavy metals in soil particles and reduce their impact on the environment. Leaching technology is to dissolve or extract pollutants by injecting solvents or washing liquids into the soil. This method is suitable for the treatment of organic pollutants and some inorganic pollutants, but it may lead to groundwater pollution. Oxidation-reduction technology is to reduce the toxicity or make it easy to remove by changing the chemical state of pollutants. For example, organic pollutants are oxidized to carbon dioxide and water by oxidants, or heavy metals are reduced to insoluble forms by reductants. Chemical improvement is to improve the physical and chemical properties of soil by adding chemicals, thus promoting the removal of pollutants [12]. This includes adjusting soil pH value and increasing soil organic matter content. Photocatalytic degradation technology is to degrade organic pollutants by using active oxygen species generated by photocatalyst under light conditions. This method is environmentally friendly and efficient, but it needs special light source and catalyst. Electrokinetic remediation technology is to promote the migration and removal of pollutants by applying electric field in soil. This method does not require the input of chemical agents and has little impact on the environment. Organic matter improvement is to improve soil structure and fertility by increasing soil organic matter content, thus promoting the degradation and removal of pollutants.

Physical-chemical remediation technology is suitable for different types of soil pollution, including industrial pollution, farmland soil pollution and urban pollution. When selecting remediation technology, factors such as soil characteristics, pollutant types, remediation objectives and economic costs need to be considered. For example, for soil polluted by heavy metals, solidification-stabilization technology is a better choice; For organic pollutants, photocatalytic degradation technology may be more suitable.

Table 1 Advantages and disadvantages of physical-chemical remediation technology and its applicable scenarios

Technical name	advantage	disadvantage
Soil solidification-stabilization technology	Can effectively fix heavy metals and reduce mobility.	It may affect the agricultural utilization value of soil.
Leaching technology	Pollutants can be quickly removed.	May lead to groundwater pollution.
Oxidation-reduction technology	Can reduce the toxicity of pollutants.	It is necessary to precisely control the reaction conditions.
Chemical improvement	Can improve soil properties and promote pollutant removal.	New chemicals may be introduced.
Photocatalytic degradation technology	Environmental protection and high efficiency	Requires specific light sources and catalysts.
Electrodynamic repair technology	Does not need chemical agents, and has little impact on the environment.	The equipment cost is high.
Organic matter improvement	Can improve soil structure and fertility.	The effect is limited by soil conditions.

Physical-chemical remediation technology is an important means of soil pollution control, and each technology has its own unique advantages and disadvantages and applicable scenarios (Table 1). In practical application, we should choose the appropriate repair technology according to the specific situation, or combine various technologies to achieve the best repair effect. At the same time, it is necessary to consider the problem of secondary pollution in the process of remediation to ensure that the impact of remediation activities on the environment is minimized.

3.3. Bioremediation technology

Bioremediation technology mainly relies on the metabolism of organisms to degrade, transform or fix pollutants in soil. These organisms include microorganisms, plants and small animals. Bioremediation technology can be divided into microbial remediation, plant remediation and animal remediation.

Microbial remediation is to degrade or transform organic pollutants and some inorganic pollutants in soil by using the original or additional microorganisms in the soil. Natural attenuation includes biological stimulation and biological reinforcement [13]. Phytoremediation is to use plants and their root microorganisms to absorb, accumulate, degrade or fix pollutants in soil. Phytoremediation technologies include plant extraction, plant stabilization and plant volatilization. Animal remediation is to use small animals (such as earthworms) in the soil to improve the soil structure and promote the degradation and transformation of pollutants.

Microbial remediation has low cost, simple operation, little impact on the environment and no secondary pollution. At the same time, it can be carried out in situ without digging and transporting soil, but its remediation speed is relatively slow, and its effect on some refractory pollutants may be poor, and it is greatly affected by soil conditions such as pH, temperature and humidity. Phytoremediation can improve soil quality and landscape at the same time, and can also be carried out in situ, and can be combined with other remediation technologies to improve remediation efficiency, although it requires a long remediation cycle, which may be unbearable for plants with high concentration of pollutants, and may require regular harvesting and treatment of plant residues.

Animal remediation can improve soil structure, increase aeration and water permeability, and at the same time promote microbial activities and accelerate pollutant degradation. However, its effect is affected by the species and quantity of animals, which may interfere with other organisms in the soil, and it is necessary to manage and maintain animal populations regularly.

Bioremediation technology is suitable for many kinds of soil pollution, including organic pollutants (such as petroleum hydrocarbons and polycyclic aromatic hydrocarbons), heavy metals and radioactive substances. For example, microbial remediation may be a better choice for soil with slight organic pollution; For heavy metal contaminated soil, phytoremediation may be more suitable. Bioremediation technology is an environmentally friendly and low-cost method for soil pollution control. Although there are some limitations, bioremediation technology can provide effective solutions in many cases through reasonable design and management. Future research should focus on improving the efficiency of bioremediation, expanding the scope of application and reducing costs.

4. STUDY ON LAND ECOLOGICAL RESTORATION TECHNOLOGY

4.1. Basic principles of ecological restoration

In order to ensure the effectiveness and sustainability of land ecological restoration, some basic principles must be followed. These principles not only guide the formulation and implementation of the restoration scheme, but also serve as an important basis for evaluating the restoration effect.

Ecological restoration should follow the principle of wholeness, and comprehensively consider the structure and function of the whole ecosystem, including soil, water, vegetation and biodiversity, not just for a single pollution problem or damaged part. At the same time, the principle of sustainability emphasizes that restoration measures should focus on long-term effects, so as to ensure the self-maintenance and sustainable development of the restored ecosystem, which requires the selection of schemes with little environmental impact and sustainable utilization. If possible, priority should be given to using the natural resilience of ecosystems and reducing human intervention. Ecological restoration scheme should be based on scientific research and professional evaluation to ensure the effectiveness and feasibility of restoration measures, and at the same time consider the feasibility and economy in actual operation. The principle of paying equal attention to prevention and restoration emphasizes that while carrying out ecological restoration, we should pay attention to the implementation of preventive measures to avoid new ecological damage. The principle of public participation and education points out that public participation and supervision should be encouraged in ecological restoration work to improve public awareness and sense of responsibility for ecological environmental protection. Finally, the principle of flexibility and adaptability takes into account the complexity and dynamics of the ecosystem, and the ecological restoration scheme should be flexible and adaptive, and the restoration strategies and methods should be adjusted in time according to the actual situation to ensure the maximum restoration effect.

4.2. Phytoremediation technology

Hyper-enriched plants refer to those plant species that can absorb and treat a large amount of heavy metals or other pollutants (Table 2). These plants play an important role in soil pollution remediation projects. Heavy metals such as zinc, cadmium and lead can be effectively extracted from soil and stored in plant tissues by planting super-enriched plants, such as Brassica oleracea and Sedum alfredii. Subsequently, these heavy metal-rich plant parts can be harvested and treated, thus reducing the pollutant content in the soil.

Table 2 Enrichment ability of different plant species to specific heavy metals

application area	Hyperaccumulator plant species	major function
Remediation of heavy metal pollution in soil	Arabis alpina, Pteris vittata, Pilea cadierei, Brassica napus, Viola baoshanensis, Thlaspi caerulescens, etc.	Absorb and accumulate heavy metals in soil, such as nickel, arsenic, cadmium, lead, zinc, copper and mercury.
	Solanum nigrum	Absorbs cadmium efficiently, and can be used for the remediation of cadmium contaminated soil.
	Sedum alfredii	Super accumulation of zinc and cadmium, which can be used for remediation of zinc and cadmium contaminated soil
	Thlaspi arvense	Super accumulation of zinc and cadmium, widely used as model plants for studying heavy metal enrichment mechanisms
	Amaranthus cruentus, Celosia argentea, Solanum nigrum, Phytolacca acinosa, and Sedum plumbizincicola	Absorb and accumulate cadmium in soil, suitable for cadmium pollution remediation in soils with different pH values
	Chenopodium ambrosioides, Brassica rapa, Arabidopsis halleri, Bidens pilosa, Abutilon theophrasti, etc.	Excessive accumulation of lead, which can be used for remediation of lead contaminated soil
	Sedum alfredii	Super accumulation of zinc and cadmium, which can be used for remediation of zinc and cadmium contaminated soil

The combined phytoremediation technology combines the advantages of phytoremediation and microbial remediation. In this method, specific plants are used to absorb and stabilize pollutants in the soil, and microorganisms (such as bacteria or fungi) are inoculated into the soil to enhance the degradation or transformation process of pollutants. This combined action not only improves the removal efficiency of pollutants, but also promotes the restoration of soil biodiversity and the improvement of soil structure. Through the synergistic effect of plants and microorganisms, the damaged land ecosystem can be repaired more comprehensively.

4.3. Natural attenuation

Screening of specific microorganisms is a key step in natural attenuation. This involves separating microbial strains that can degrade pollutants efficiently from contaminated soil. The screening process is usually based on the ability of microorganisms to degrade specific pollutants. Once the efficient strains are screened out, the following culture process is very important to ensure that these microorganisms can multiply in large quantities and maintain their degradation activity in the remediation project.

Microorganisms degrade pollutants through various mechanisms. Some microorganisms can secrete specific enzymes that can decompose pollutant molecules, such as hydrocarbons, polycyclic aromatic hydrocarbons or other toxic compounds. In addition, microorganisms can also transform toxic substances into harmless or low-toxic substances through biotransformation. These degradation mechanisms are the core of natural attenuation, making microorganisms an indispensable tool for land ecological restoration.

4.4. Animal and mycorrhizal repair technology

Lower animals such as earthworms play an important role in soil ecological restoration. They can effectively improve soil structure and increase soil aeration and water retention through activities such as feeding, digestion and excretion. At the same time, the activities of these animals can also promote the reproduction and activities of soil microorganisms, thus accelerating the decomposition of organic matter and the release of nutrients. In addition, their activities also help to mix the soil, so that pollutants are more evenly distributed in the soil, which is convenient for microorganisms and other degradators.

There is a close symbiotic relationship between mycorrhizal fungi and plants. These fungi can form mycorrhiza with plant roots, and promote plant growth by increasing the ability of plants to absorb water and nutrients. In land ecological restoration, this symbiotic relationship can significantly improve the restoration efficiency. Mycorrhizal fungi can not only enhance the tolerance of plants to pollutants, but also decompose or transform pollutants in soil through enzymes and other compounds secreted by them. Therefore, the introduction of suitable mycorrhizal fungi into the remediation project can greatly improve the effect of soil remediation.

4.5. Combined repair technology

Physical-chemical-biological combined remediation method is the frontier technology in the field of land ecological remediation at present. This method integrates the advantages of physical, chemical and bioremediation, and realizes the comprehensive treatment of polluted soil through the organic combination of various technologies. Physical methods are mainly used to change the physical properties of soil, such as reducing the exposure and migration of pollutants by deep ploughing and soil replacement. Chemical methods use chemical reagents to react with pollutants to reduce their toxicity or convert them into harmless substances. Biological methods use the biological activity of microorganisms, plants or animals to degrade or fix pollutants.

The physical-chemical-biological combined remediation method has shown good results in land ecological restoration, and can effectively solve the problems that can not be overcome by a single technology. The comprehensive application of different technologies can not only improve the remediation efficiency, but also promote the long-term stability and sustainable development of soil ecosystem. However, the implementation of joint restoration technology needs detailed pre-evaluation and careful post-management to ensure the safety and effectiveness of restoration activities.

5. PREVENTION AND CONTROL STRATEGY

5.1. Prevention and control of pollution sources

Industrial waste is one of the important pollution sources, and its improper treatment and discharge will pose a serious threat to the environment and human health. Therefore, it is a key measure to formulate strict industrial waste treatment and discharge standards to prevent and control environmental pollution. According to the nature and harm degree of waste, it is classified and treated harmlessly and in a reduced amount by physical, chemical or biological methods. Formulate strict discharge standards for waste water, waste gas and solid waste, and limit the maximum allowable discharge concentration and total amount of harmful substances. Encourage the recycling of industrial waste, such as the recycling of waste residue and waste liquid, so as to reduce the generation of final waste. Implement the industrial waste treatment and discharge permit system to ensure that all discharge behaviors are under supervision. Regularly monitor the treatment facilities and discharge ports of industrial wastes to ensure that they meet the discharge standards. Industrial enterprises that violate the treatment and emission standards shall be punished according to law, including fines, suspension of production for rectification or even revocation of business licenses.

Excessive use of pesticides and fertilizers is one of the important causes of soil and water pollution. Rational use and management of pesticides and fertilizers is very important for protecting the ecological environment and food safety. According to the soil nutrient status and crop demand, soil testing and formula fertilization are implemented to reduce the excessive use of chemical fertilizers. Popularize biological pesticides and biological control technologies, and reduce the use of chemical pesticides. Implement crop rotation and fallow system to improve soil natural fertility and reduce dependence on chemical fertilizers. Implement the registration management system of pesticides and fertilizers to ensure the safety and effectiveness of products circulating in the market. Provide guidance and technical training on the use of pesticides and fertilizers to raise farmers' awareness of rational use. Regularly monitor pesticide and fertilizer residues in agricultural products to ensure food safety.

The treatment of urban garbage is an important part of urban management. The classification and treatment of garbage is not only related to urban environmental sanitation, but also affects the effective utilization of resources and the sustainable development of the environment. The source classification of household garbage shall be carried out, and it shall be divided into recyclables, harmful waste, kitchen waste and other wastes. Establish a classified collection system to ensure that all kinds of garbage are collected and treated correctly. Recyclable materials and kitchen waste are used as resources, such as recycling, biological fermentation and fertilizer production. Harmful waste will be treated harmlessly, such as safe landfill and chemical treatment. Reduce the garbage that cannot be recycled, such as incineration for power generation and sanitary landfill. Formulate laws and policies on garbage classification and disposal, and clarify the responsibilities and obligations of all parties. Strengthen the publicity and education of garbage sorting, and improve the public's awareness and participation in environmental protection. Strengthen the supervision and law enforcement of garbage sorting and disposal to ensure that all measures are implemented.

5.2. Suggestions on policies and regulations

Establish and improve the system of laws and regulations for the prevention and control of soil pollution, and clarify the responsible subjects, prevention measures and legal responsibilities for the prevention and control of soil pollution. Formulate specific soil quality standards and pollution control standards to provide legal basis for soil pollution prevention and control. Strengthen the supervision of soil pollution and implement strict monitoring and evaluation system of soil environment. Strengthen the construction of law enforcement team, improve the efficiency and fairness of law enforcement, severely investigate and punish illegal acts according to law, and form an effective legal deterrent. Through education and publicity activities, improve public awareness of soil pollution and environmental awareness. Encourage the public to participate in soil protection actions, such as soil pollution reporting, community greening, etc., and form a good atmosphere for the whole society to participate in soil pollution prevention and control.

6. CONCLUSION

Ecological restoration should follow the principles of integrity, sustainability, scientific research, equal emphasis on prevention and restoration, public participation and education, and flexibility and adaptability to ensure the effectiveness and sustainability of restoration work. The combined physical-chemical-biological remediation method integrates the advantages of different technologies, which can control polluted soil more comprehensively and promote the long-term stability and sustainable development of the ecosystem. It is important to formulate strict industrial waste treatment and discharge standards, rationally use and manage pesticides and fertilizers, and implement garbage classification and treatment. At the same time, establish and improve the laws and regulations system of soil pollution prevention and control to strengthen supervision. It is suggested to establish and improve the legal system of soil pollution prevention and control, clarify the responsible subject, prevention measures and legal responsibilities, and improve the public's understanding of soil pollution and environmental awareness through education and publicity activities.

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