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Research on Coal Mine Environmental Pollution Management and Ecological Restoration Technology

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Abstract: This paper analyses the current situation of environmental pollution in coal mines, its causes, and its impact on the ecological environment, and systematically researches the management of environmental pollution in coal mines and ecological restoration technology. The paper analyses the main categories of coal mine environmental pollution, including water pollution, air pollution, and solid waste pollution, and discusses the causes of these pollution and their destructive effects on the ecological environment. Immediately after that, the article elaborates on the treatment technologies of coal mine environmental pollution, including physical, chemical and biological treatment technologies for water pollution control, blocking, adsorption and covering technologies for air pollution control, and landfill, incineration and resource utilization strategies for solid waste disposal. This paper also discusses coal mine ecological restoration techniques, including species selection and allocation for vegetation restoration, vegetation restoration models, physical, chemical and biological methods for soil improvement, and engineering, vegetation and agricultural measures for soil and water conservation. Through the research of this paper, the researchers aim to provide scientific basis and technical support for the management of coal mine environmental pollution and ecological restoration and to promote the restoration of the ecological environment in mining areas and the sustainable development of the coal industry.

Keywords: Coal mine environmental pollution; Ecological restoration; Governance technology; Water pollution; Air pollution

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1. Introduction

As the main energy source in China, coal has long occupied an important position in economic and social development. However, the environmental pollution problem generated during coal mining has become increasingly serious, which not only destroys the ecological environment of the mining area but also has a serious impact on the quality of life of the surrounding residents. Coal mine environmental pollution mainly includes water pollution, air pollution, soil pollution ecological damage, and so on. These problems have become the bottleneck restricting the sustainable development of China's coal industry. For this reason, it is of great practical significance and strategic significance to research coal mine environmental pollution management and ecological restoration technology.

In recent years, China's government has attached great importance to environmental protection and has introduced a series of policies and regulations, requiring coal mining enterprises to strengthen environmental pollution management and ecological restoration. However, due to the complexity of the causes of coal mine environmental pollution and the difficulty of the treatment technology, coupled with the long cycle and high investment in ecological restoration, coal mine environmental pollution treatment and ecological restoration work face many challenges. In this context, the study of coal mine environmental pollution management and ecological restoration technology is of great significance to promote the green development of the coal industry and realize the good cycle of mining for the ecological environment.

Meanwhile, some research results have been achieved in the field of coal mine environmental pollution management and ecological restoration at home and abroad, but there are still many urgent problems to be solved. For example, it is difficult for the existing treatment technologies to meet the needs of the complex environment in the mining area, the ecological restoration effect evaluation system is not perfect, and the integrated innovation of the treatment and restoration technologies is insufficient. Therefore, it is necessary to conduct an in-depth study on the governance of coal mine environmental pollution and ecological restoration technology, to provide scientific and effective technical support for the environmental protection of China's coal mines.

This paper is based on the current situation of environmental pollution in China's coal mines, combined with domestic and foreign research dynamics, coal mine environmental pollution management and ecological restoration technology for systematic research. By analyzing the causes of environmental pollution in coal mines and exploring the principles and methods of governance and restoration technologies, it aims to provide a theoretical basis and practical guidance for China's coal mine environmental protection and ecological civilization construction.

2. Analysis of the current situation and causes of environmental pollution in coal mines

The mining and utilization of coal resources have brought about environmental problems that cannot be ignored while promoting China's economic development. The following chapters will discuss in detail the current situation and causes of environmental pollution in coal mines and its impact on the ecological environment.

2.1. Current situation of coal mine environmental pollution

At present, China is facing the increasingly prominent problem of environmental pollution in coal mines, which has a wide range of impacts, involving water pollution, atmospheric pollution, soil pollution, ecological damage and other levels. In the coal mine production process, the existence of related construction activities will also lead to the formation of a certain amount of pollution in the construction, living sewage pollutants in the precipitation, the wind, and then in the surface water body, causing surface water pollution. Coal gangue in the case of long-term accumulation, will also cause pollution of surface water sources. The presence of oxidation, chemical reaction, and hydrodynamic leaching situations will also lead to the occurrence of different types of leaching solutions, and heavy metals will also have an impact on human life after entering the water [1]. In addition, atmospheric pollutants such as dust and sulphur dioxide produced by coal mining activities have a significant negative impact on air quality, not only reducing visibility but also posing a serious threat to the health of mining residents. At the same time, the stockpiling of large quantities of coal mine solid waste not only encroaches on valuable land resources but also in the process of long-term stockpiling, the harmful components in these solid wastes may penetrate the soil through leaching, which in turn causes soil pollution and poses a potential risk of contamination to the groundwater environment. Therefore, the comprehensive management of coal mine environmental pollution has become an important issue to be solved in China's environmental protection and ecological civilization construction.

2.2. Causes of coal mine environmental pollution

The causes of coal mine environmental pollution show complexity and diversity and its main sources can be summarized in the following key aspects. In the process of coal mining, the waste water, waste gas, and solid waste produced constitute the main direct factors of environmental pollution. These wastes contain hazardous components, such as heavy metals, acids and suspended particles, which are released directly into the environment without treatment, causing serious pollution impacts on water bodies, atmosphere, and soil [2]. At the same time, the destruction of surface vegetation and the disturbance of soil structure by mining operations have triggered soil erosion and ecological degradation, which in turn have destroyed the balanced state of the natural ecosystem. Again, the noise pollution and vibration impacts generated by blasting operations and mineral transport in mining activities have adversely affected the surrounding environment and the quality of life of residents. In addition, deficiencies at the management level, such as insufficient environmental protection supervision, low environmental protection awareness, and lack of environmental protection measures, are also key causes of environmental pollution in coal mines that cannot be ignored. These factors interact with each other to exacerbate the severity of coal mine environmental pollution problems, posing a long-term threat to the ecological environment and human health [3]. Therefore, the comprehensive management of coal mine environmental pollution needs to strengthen the management from the source, enhance the awareness of environmental protection, and take scientific and effective pollution prevention and control measures.

2.3. Impact of coal mine environmental pollution on the ecological environment

Coal mine environmental pollution has a far-reaching and complex impact on the destruction of the ecological environment. Pollution of water bodies not only destroys the stability of aquatic ecosystems and affects the survival and reproduction of aquatic organisms, but also poses a serious threat to the safety of human drinking water, resulting in water quality water shortages becoming increasingly prominent. The intensification of atmospheric pollution has reduced air quality and increased the frequency of haze while exacerbating environmental problems such as the global greenhouse effect and acid rain, which adversely affect the climate system and human health [4]. Soil pollution, on the other hand, has led to a sharp decline in the productivity of land, reduced crop yields and quality, and even rendered part of the land incapable of cultivation, thus posing challenges to food security and sustainable agricultural development. In addition, ecological damage has led to a sharp decline in biodiversity, a dislocation of ecological balance, a long-term threat to the ecological environment of the mining area and its surrounding areas, and increased difficulty in ecological recovery. Therefore, the treatment of environmental pollution in coal mines and the implementation of restoration projects for damaged ecosystems are not only the top priority of the current environmental protection work but also an urgent need to realize the sustainable development of the region and safeguard the ecological and environmental rights and interests of the people.

3. Coal mine environmental pollution control technology

For the coal mine environmental pollution in many ways, this paper will introduce a series of environmental pollution control technologies in detail, aiming to provide scientific and effective solutions for the improvement of environmental quality in mining areas.

3.1. Water pollution control technology

Physical methods play a basic and important role in water pollution control, mainly through the physical removal of suspended solids, particles, and some insoluble pollutants in the water. Common physical treatment technologies include sedimentation, flotation, filtration, and centrifugation. The sedimentation method uses gravity to make suspended particles sink to the bottom of the pool, thus achieving solid-liquid separation; the flotation method adds a flotation agent to the water so that the pollutants float to the water surface and can be removed; filtration method utilizes the porous media to intercept the suspended particles in the water; centrifugal method uses the centrifugal force generated by the high-speed rotation to separate solid particles from the water [5]. Physical methods are easy to operate and the treatment effect is intuitive, but it is usually difficult to remove dissolved pollutants in water.

Chemical methods have a wide range of applications in water pollution control, mainly using chemical reactions to convert pollutants in water into harmless or easily treatable substances [6]. Common chemical treatment techniques include coagulation, neutralization, redox, and ion exchange. Coagulation is used to add coagulants to the water to aggregate fine suspended particles into flocs for subsequent settling and filtration; Neutralization is used to adjust the pH of the water to make it neutral; Redox is used to change the chemical properties of pollutants through oxidizing or reducing agents to achieve their degradation or transformation; Ion exchange removes specific ions in the water using ion exchange resins. Chemical methods can effectively deal with a variety of pollutants but may involve the use of chemicals that need attention during handling to control secondary pollution.

Biological methods have the advantages of environmental friendliness and low treatment cost in water pollution treatment, mainly using the natural degradation ability of microorganisms or plants to remove organic pollutants and some inorganic pollutants in water. Common biological treatment technologies include activated sludge method, biofilm method, artificial wetland, and phytoremediation [7]. The activated sludge method and biofilm method cultivate microorganisms through enrichment so that they decompose organic substances in water; artificial wetlands and phytoremediation make use of plant roots and microorganisms to adsorb, degrade, and transform pollutants in water. Biological methods are suitable for treating water bodies with high organic loads, but their treatment effects are affected by water temperature, dissolved oxygen, and other factors, and the treatment cycle is relatively long.

3.2. Air pollution control technology

The blocking method is a direct and effective air pollution control technology, which is mainly through physical means to prevent pollutants from being emitted into the atmosphere. This technology is usually applied to coal mining, transport, and storage to reduce the leakage of dust and harmful gases [8]. Specific measures include efficient filtration of mine vents, the use of sealed hoods or closed conveyor systems to control the spread of dust, and the covering of raw material stockpiles to prevent windblown dust. The containment method is simple and effective, but long-term containment may lead to the accumulation of pollutants, so regular inspection and maintenance of containment facilities is required.

The adsorption method uses adsorbents to capture and immobilize pollutants in the atmosphere and is a widely used air pollution control technology for industrial emission control and indoor air purification. Common adsorbents include activated carbon, zeolite, and activated alumina, which have a highly developed pore structure and a large specific surface area and are capable of effectively adsorbing organic compounds, acid gases, and heavy metal vapours in gases. The adsorption method is characterized by high treatment efficiency and a wide range of applications, but the adsorbent has a limited service life and needs to be replaced or regenerated periodically, which may increase operating costs.

The covering method is a simple and effective method of air pollution control, mainly through covering materials to inhibit dust or reduce the emission of harmful gases. In coal mining operations, the cover method is commonly used to control dust pollution in open pits, stockpiles, and haul roads. Covering materials can be sand, plastic film, asphalt, or chemical covering agents. These materials can effectively cover the surface of the pollution source and prevent dust from flying or harmful gases from escaping [8]. The advantage of the mulching method is that it is low cost and easy to operate, but the durability and environmental adaptability of the mulching materials are the key factors determining its effectiveness. In addition, the covering method may not apply to all types of pollutants, so appropriate covering materials and techniques need to be selected according to the specific situation in practical applications.

3.3. Solid waste treatment and resourcefulness technology

The landfill method is a traditional solid waste treatment method, which is mainly used to reduce environmental pollution and land occupation by filling solid waste into the ground. This method applies to all types of solid waste, especially those that are not easily degradable and harmless. The design and operation of landfills need to follow strict environmental protection standards to prevent leachate contamination of groundwater and soil. Landfilling is simple and relatively inexpensive, but in the long term it takes up a large amount of land resources and the potential risk of contamination requires well-established containment and monitoring systems. In addition, landfilling is not an efficient use of resources, so priority should be given to reduction and resourcing in the choice of solid waste treatment methods.

The incineration method reduces the volume of solid waste by burning it at a high temperature, and at the same time, it can recover some of the heat energy. This method is suitable for solid wastes with high organic content and high calorific value, such as municipal domestic waste and certain industrial wastes. During the incineration process, the harmful substances in the waste are decomposed, which can effectively reduce environmental pollution. However, incineration may produce secondary pollutants such as dioxins, heavy metal vapours, and acidic gases, and therefore needs to be equipped with an efficient flue gas cleaning system [9]. The advantages of incineration are high treatment efficiency and significant reduction, but the construction and operation costs are high and public acceptance is required.

Resource utilization refers to the reprocessing of solid waste as raw material or energy through physical, chemical, or biological methods to achieve recycling and maximize the value of waste. This approach is in line with the concept of sustainable development and can reduce the reliance on primary resources and the burden on the environment. Technologies for resource utilization include recycling, remanufacturing, composting, and energy conversion of waste. For example, construction waste is processed into recycled aggregates, organic waste is converted into bio-fertilizer, or waste plastics and paper are recycled and reused. Resource utilization not only reduces waste emissions, but also creates economic benefits, but it requires classification and pre-treatment of waste, and the selection and application of technology needs to be determined according to the characteristics of waste and market demand.

4. Research on coal mine ecological restoration technology

After solving the problem of environmental pollution in coal mines, ecological restoration becomes the key link to restoring the ecological environment in mining areas. The following chapters will focus on coal mine ecological restoration technology, including vegetation restoration, soil improvement, and soil and water conservation technology, aiming to provide technical support for the restoration and reconstruction of mining ecosystems.

4.1. Vegetation restoration technology

Species selection and configuration is the core link of vegetation restoration technology, which is directly related to the success of mining ecosystem restoration. When selecting plant species, the priority in the process of soil environment restoration in mining areas is the adaptability of plants to the soil environment in mining areas, which includes selecting plant species with strong resistance to barrenness, salinity, drought, and flooding. In addition, the fast-growing ability and life cycle of plants are also important considerations, and priority should be given to selecting species that grow rapidly and can achieve surface coverage in a relatively short period. In addition, plant interactions, such as root competition, mutually beneficial symbiotic relationships between organisms, and the ability of plants to improve the soil need to be considered [10]. In terms of configuration, diversified plant communities should be used to construct a multilevel vegetation structure combining trees, shrubs and grasses to enhance the stability and self-sustainability of the ecosystem. Reasonable species selection and configuration can not only promote the rapid recovery of vegetation but also improve biodiversity and ecological function, laying the foundation for the long-term ecological balance of the mining area.

The vegetation restoration model refers to a set of systematic vegetation restoration programs formulated according to the specific environment and restoration objectives of the mining area. This includes vegetation configuration strategies for the initial, medium, and long-term stages of restoration. In the initial stage of restoration, pioneer species that are hardy and fast-growing are usually selected to achieve rapid coverage of the bare ground surface and reduce soil erosion. In the mid-term stage, more species are gradually introduced to increase the diversity and complexity of the vegetation and improve the ecosystem’s resistance to disturbance. The long-term goal is to form a stable plant community to achieve sustainable ecological functions. The vegetation restoration model should also take into account the natural conditions of the mining area such as climate, soil, water, and so on, as well as the impact of human activities, and take corresponding technical measures, such as soil improvement, water retention, seed treatment and so on. The scientific and reasonable vegetation restoration model can effectively promote the restoration of the ecological environment in the mining area and achieve the unity of ecological, economic, and social benefits.

4.2. Soil improvement technology

Soil improvement technology is a key measure to improve the comprehensive performance of soil, enhance the level of soil fertility, and optimize the soil ecological environment. The following is a detailed description of physical improvement, chemical improvement, and biological improvement technology.

Physical amelioration is mainly to improve the physical properties of the soil and enhance the aeration, water permeability, and water retention of the soil, to create a favourable soil environment for crop growth. The methods of physical improvement include deep tilling and ploughing, soil replacement, soil fertilization, and improvement of soil structure. Deep tilling can break the soil plough layer, increase soil porosity, and improve soil aeration and water permeability; soil exchange is to replace barren soil with fertile soil, thus improving soil texture; soil fertilization is to improve soil structure by applying organic fertilizers, green manure, and returning straw to the field to increase the content of organic matter in the soil; and improving soil structure is to adjust soil particle composition, reduce soil capacity, and improve soil structure by applying soil improvers such as zeolite, vermiculite, and so on. Improving soil structure is through the application of soil conditioners, such as zeolite, vermiculite, and so on, to adjust the composition of soil particles, reduce the soil bulk density, and improve soil porosity.

Chemical amendment is to improve soil pH, salinity, and nutrients by adjusting the chemical properties of the soil, to provide a suitable soil environment for crop growth. Chemical amendment methods include acid-base neutralization, salt amelioration, and application of chemical fertilizers. Acid-base neutralization is for acidic or alkaline soil, through the application of lime, gypsum, and other substances, to adjust the soil pH value, so that it reaches the range suitable for crop growth; salt improvement is for saline land, through the drainage of salt, salt washing, the application of ameliorants and other measures, to reduce the salt content of the soil; the application of chemical fertilizers is based on the soil nutrient status and crop demand, the reasonable application of nitrogen, phosphorus, potassium, and other fertilizers, to replenish the soil nutrients and improve soil fertility.

Bio-improvement is the use of biotechnological means to improve the activity of soil microorganisms, promote the decomposition of soil organic matter and nutrient cycling, and improve the soil ecological environment. Biological improvement methods include microbial inoculation, application of bio-fertilizer, and planting green manure. Microbial inoculation is to add beneficial microorganisms to the soil, such as rhizobacteria, phosphorus solubilizing bacteria, and so on, to increase the number and activity of soil microorganisms and promote the transformation of soil nutrients; the application of bio-fertilizers is to make fertilizers by fermenting organic materials with microorganisms and applying them to the soil to increase the organic matter content of the soil and improve the structure of the soil; the planting of green manure is to increase the organic matter of soil and improve the soil fertility by planting plants in legume and gramineous families and turning them into the soil. Through biological improvement, it helps to build a healthy and stable soil ecosystem, providing a good soil environment for crop growth.

4.3. Soil and water conservation technology

Soil and water conservation technology refers to a series of technical measures taken to prevent soil erosion and protect and rationally use soil and water resources. These measures mainly include engineering measures, vegetation measures, and agricultural measures.

Engineering measures refer to engineering techniques that reduce soil erosion by constructing various types of soil and water conservation engineering structures that directly intercept and fix the soil. These measures include terrace construction, dam and weir works, slope protection works, ditch improvement, and so on. Terrace construction is to transform sloping arable land into horizontal terraces to slow down the slope, increase soil moisture, and reduce soil erosion; the dam and weir project is to build sand dams and valley mills in ditches to intercept sediment, raise the erosion datum, and reduce the scouring of downstream rivers; slope protection project is to fix the soil on the slopes to prevent landslides and erosion through the construction of stone terraces, concrete grids, and geosynthetics, and so on; gully remediation is to clean, strengthen, and improve the erosion ditches; and ditch remediation is to improve the erosion ditches by removing silt, reinforcing, and constructing drainage channels to reduce ditch erosion and protect the land on both sides of the ditch.

Vegetation measures are technical means of improving the ecological environment by planting various types of plants and using plant roots to fix the soil and increase its resistance to erosion. These measures include returning ploughland to forest and grassland, closing mountains to forests, planting trees, and improving grasslands. Returning farmland to forest and grassland is to return suitable sloping cultivated land to forest or grassland, and reduce the disturbance of soil by agricultural activities; closing mountains for forestation is to implement closed management of mountainous areas, prohibit logging and grazing, and allow natural vegetation to recover and grow; afforestation is to plant trees in bare land, sandy land and other sections to form protective forest belts to prevent wind and water erosion; grassland improvement is to take replanting, fertilizer application, and other measures to degraded grassland to improve the coverage and productivity of grassland and reduce soil erosion.

Agricultural measures refer to technical measures taken in soil erosion areas to improve agricultural production methods, make rational use of land resources and reduce the impact of agricultural activities on soil erosion. These measures include contour ploughing, crop rotation and fallow, rational fertilizer application, and land cover. Contour ploughing is to carry out ploughing along the contour line on sloping arable land to reduce soil erosion; crop rotation and fallow farming are to improve soil structure, increase soil fertility, and reduce soil erosion through crop rotation and fallow farming system; reasonable fertilizer application is to apply chemical fertilizers and organic fertilizers scientifically according to soil fertility and crop demand to improve soil erosion resistance; the land covering is to protect the soil surface layer and reduce the direct impact of rainwater on the soil using straw returning to the field and ground film covering; the land covering is to protect the soil surface layer and reduce the direct impact of rainwater on the soil, reducing the risk of soil erosion. Through these agricultural measures, soil and water resources can be effectively protected while safeguarding agricultural production.

5. Conclusion

This paper provides an in-depth study of coal mine environmental pollution management and ecological restoration technology, analyses the status quo of coal mine environmental pollution, its causes and impact on the ecological environment, and discusses water pollution management, air pollution management, solid waste treatment and resourcing, as well as ecological restoration technology. Overall, China's coal mine environmental pollution management and ecological restoration work has achieved certain results, but there are still many challenges. To achieve a good cycle of ecological environment in the mining area and the sustainable development of the coal industry, the government need to continue to make efforts in the following aspects. Firstly, to strengthen technological innovation and improve the level of governance and restoration technology.

Secondly, to improve policies and regulations, and to increase supervision. Thirdly, to enhance the awareness of environmental protection of the public, and to guide enterprises to fulfil their social responsibility.

The research results of this paper can provide a theoretical basis and technical support for China's coal mine environmental pollution management and ecological restoration work, and provide a reference for the development of related policies. However, given the complexity and long-term nature of coal mine environmental pollution management and ecological restoration tasks, it is still necessary to continue to explore and optimize the management technology and strengthen the multidisciplinary cross-research, to contribute to the realization of the green development of China's coal mines and the construction of ecological civilization. In conclusion, this study aims to provide useful references and insights for researchers and engineers in related fields, to contribute to the promotion of China's coal mine environmental pollution management and ecological restoration.

Disclosure statement

The author declares no conflict of interest.

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