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Environmental Engineering Issues Induced by Abandoned Coal Mine Hidden Disasters

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Abstract. The abandoned coal mine hidden disasters have been important factors that influencing safety production and social lives. Based on the analysis of the types of hidden disasters in abandoned coal mines and their impacts on the environment, the exploration techniques and methods of goafs and water hazards, spontaneous combustion or fire area distribution in abandoned mines are discussed systematically, and the monitoring and forecasting technologies for the instability of abandoned goafs and subsidence disasters, mine groundwater level changes and water pollution disasters, spontaneous combustion and gas pollution disasters, mining ecological environment disasters are proposed. Then the environmental engineering problems caused by abandoned coal mines, the comprehensive prevention and control methods, and the technologies of grading utilization of abandoned coal mines are put forward. The conclusions are shown as follows: Firstly, the hidden disasters of abandoned coal mines mainly include such six disasters as the goaf instability and collapse disasters, old goaf water accumulation disasters, mine groundwater level drop and water pollution disasters, spontaneous combustion and gas pollution disasters in the goaf, coal waste dump and backfill areas spontaneous disasters, secondary disasters caused by geological and environmental damage; secondly, the environmental engineering issues induced by abandoned coal mines include three aspects: living environment problems, working environment problems and ecological environment problems; thirdly, the utilization of abandoned coal mines is mainly divided into three aspects: gas drainage and utilization, comprehensive utilization of underground space, and comprehensive utilization of surface.

1. Introduction

The number of coal mines in China has decreased from more than 87,000 in 1995 to 6,302 in 2018. Some of more than 8,000 coal mines have been closed and integrated into production mines, and others have become abandoned coal mines. The hidden disasters of abandoned coal mines have become an important factor influencing the safety production and society of coal mines.

In view of the hidden disasters of abandoned coal mines and the environmental problems caused by them, some experts and scholars have carried out evaluations and treatments on hidden disasters such as goaf instability, water inrush and water pollution, coal waste dump spontaneous combustion, and ecological environment restoration. On the basis of previous studies, this paper systematically researches the types of hidden disasters in China's abandoned coal mines and their impacts on the environment, and systematically studies them from disaster exploration, monitoring and forecasting, comprehensive prevention and utilization technologies.

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2. Types of hidden disasters in abandoned coal mines and their impacts on the environment

The hidden disasters of abandoned coal mines mainly include such six disasters as the goaf instability and collapse disasters, old goaf water accumulation disasters, mine groundwater level drop and water pollution disasters, spontaneous combustion and gas pollution disasters in the goaf, coal waste dump and backfill areas spontaneous disasters, secondary disasters caused by geological and environmental damage. The functional classification of abandoned coal mines is seen in Figure 1.

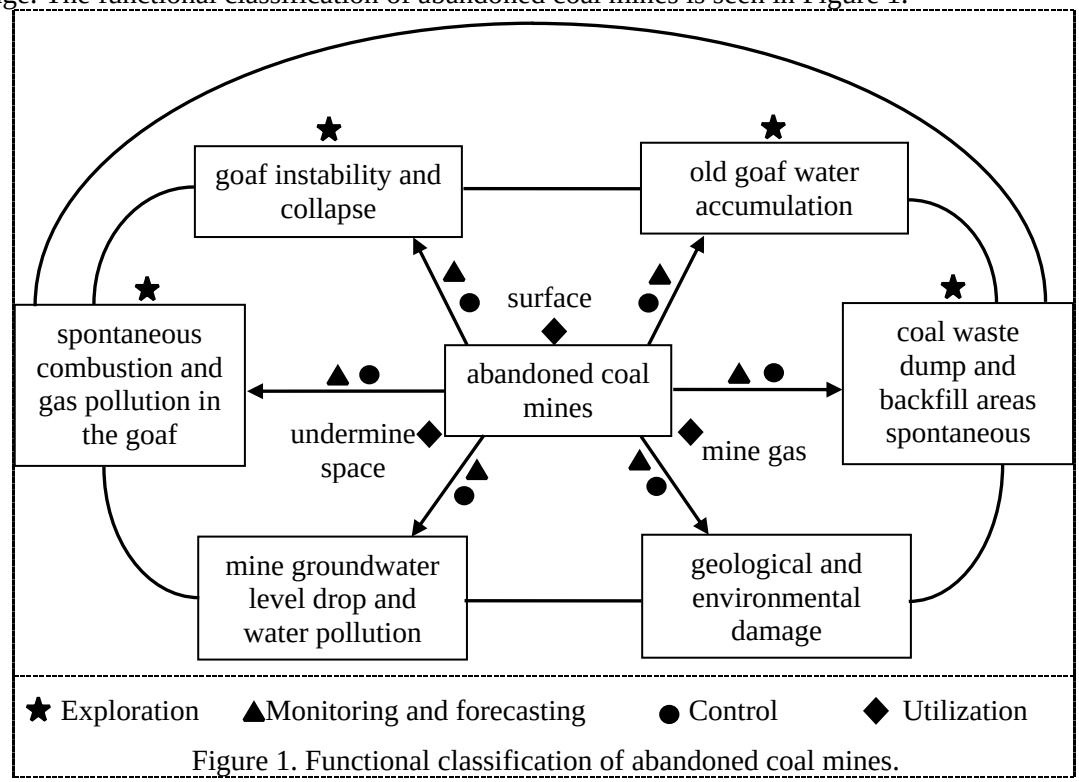

Figure 1. Functional classification of abandoned coal mines.

The goaf instability and collapse disasters are the most direct and significant disasters in abandoned coal mines. In 2005, the first national survey of mine geological environment was completed in China, involving 113,149 mines, and the area of coal mine subsidence accounted for 97.43% of the total collapse area. The research shows that the average subsidence land per 10,000 tons of raw coal is 0.07-0.30hm^2. The goaf instability and collapse disasters and related environmental engineering problems will be the most important problem for abandoned coal mines in China in the next few decades.

The old goaf water accumulation disasters are the most serious disasters in the coal mines in recent years. From 2011 to 2017, there were 75 serious water accidents in coal mines, including 61 old goaf water accumulation accidents, accounting for 81.3%. The old goaf water accumulation disasters in abandoned coal mines have seriously affected the safety production and underground working environment of surrounding coal mines.

The mine groundwater level drop and water pollution disasters have been receiving more and more attention in recent years. After the coal mining, the aquifer is destroyed, and the groundwater level is drop, which makes the industrial and domestic water use difficulties in the mining area. Especially for scattered residential areas near abandoned coal mines, the problem of domestic water is more serious due to the lack of support from production mines. Abandoned coal mines will cause changes in water level and groundwater flow fields, which will cause the water quality of aquifer and surface polluted to a certain extent, and threaten the water safety of surrounding residents.

The spontaneous combustion and gas pollution disasters in the goaf are mainly caused by the failure of goaf overburden damage, cracks to penetrate the surface or adjacent production mines. The pollution of spontaneous combustion, toxic and harmful gases in the goaf will cause the carbides and

sulfides in the atmosphere near the mining area or adjacent production mines to exceed the standard, thus endangering the safety of residents and miners.

The coal waste dump and backfill areas spontaneous disasters are mainly caused by the oxidation of floating coal in the deposits after the underground or open-pit mining. The manifestations are toxic and harmful gases and high temperature disasters. The coal waste dump spontaneous disasters in Datong and Taiyuan, Shanxi Province and the backfill areas spontaneous disasters of the open-pit in Wuhai and Erdos City of Inner Mongolia have caused serious pollution to the surrounding atmospheric environment, and have been highly valued by the local environmental protection department.

The secondary disasters caused by geological and environmental damage are mainly landslides formed by subsidence, debris flow disasters caused by surface vegetation damage, and slippage caused by unloading of open pit mines. In southern China, due to the heavy rain, the geological and environmental damage and secondary disasters caused by abandoned coal mines are more serious.

The hidden disasters of abandoned coal mines and their impacts on the environment can be identified separately by means of exploration, monitoring and forecasting according to their different types of disasters. The hidden disasters can be identified by exploration techniques mainly for goafs and water hazards, spontaneous combustion or fire area distribution; the hidden disasters that can be identified through monitoring and forecasting techniques are the goaf instability and collapse disasters, mine groundwater level and water pollution disasters, spontaneous combustion and gas pollution disasters, mining area ecological environmental disasters, etc.

3. Exploration techniques and methods for hidden disasters in abandoned coal mines

3.1. Goaf and water hazard exploration techniques and methods

The distribution exploration of unidentified goafs and accumulated water in abandoned coal mines is mostly adopt comprehensive exploration method of geophysical exploration and the drilling verification. Generally speaking, considering that abandoned coal mines have been closed, geophysical exploration uses ground geophysical methods; if there are adjacent production mines, ground geophysical and undermine geophysical methods can be adopted.

The most mature methods in ground geophysical methods are the ground penetrating radar method, the multi-electrodes resistivity method, the transient electromagnetic method(TEM), the seismic method, the controllable source audio magnetotelluric method(CSAMT) and the audio magnetotellurics method(AMT), etc. Through a large number of practical research, in general, the very shallow goafs with depth less than 50m are fit for the ground penetrating radar method and the multi-electrodes resistivity method; the shallow goafs with depth between 50m and 150m are fit for 2D seismic method, the transient electromagnetic method or the multi-electrodes resistivity method; the medium-depth goafs with depth between 150m and 400m are fit for 2D or 3D seismic method, the transient electromagnetic method, the controllable source audio magnetotelluric method and the audio magnetotellurics method; the deep goafs with depth more than 400m are fit for 3D seismic method, the controllable source audio magnetotelluric method and the audio magnetotellurics method or the transient electromagnetic method. In order to improve the detection accuracy, the seismic method is combined with the electromagnetic method, the similar geophysical methods are complemented, and two or more comprehensive geophysical methods are used. Here is an example as in Figure 2. The depth of a coal mine goaf of coal seam 3 is 150m-200m. One CSAMT line passes through two known goafs. It is explained that there is one inferred goaf at 1230-1680, and it was verified by drilling. The explanation is reliable.

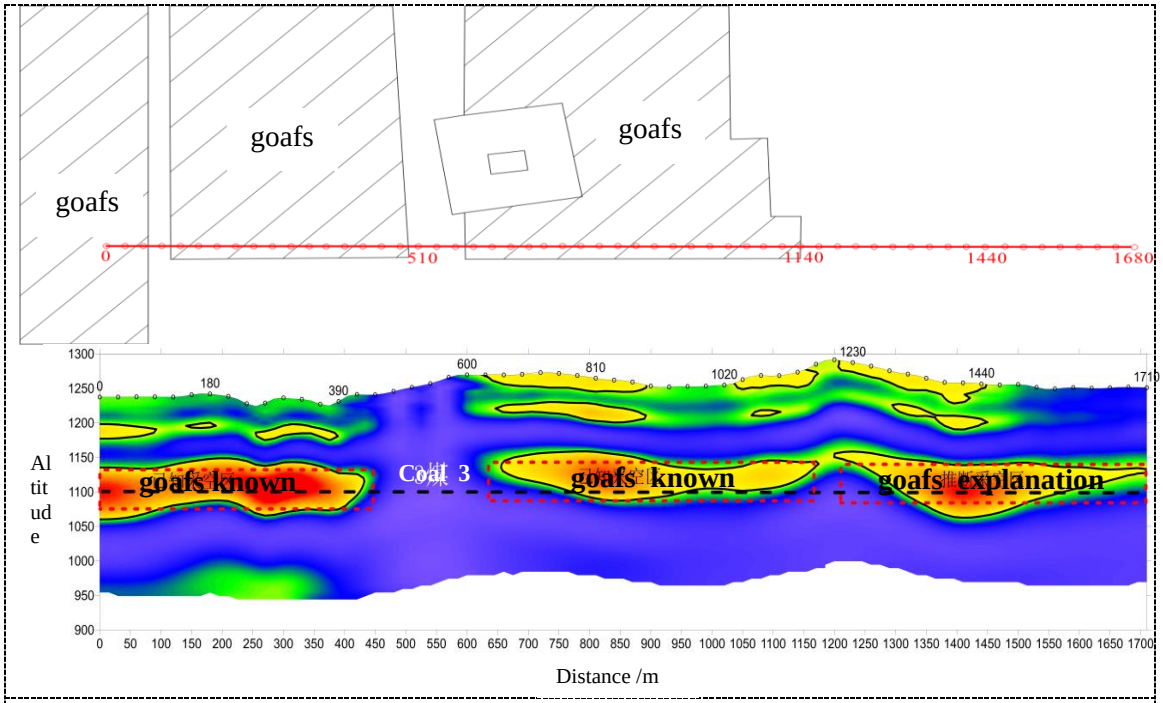

Figure 2. An example of goaf exploration with CSAMT.

In the undermine geophysical exploration method, the mine transient electromagnetic method, the mine direct current method, the mine seismic methods are usually used for the detection of the unidentified goaf and the accumulated water area of the adjacent abandoned coal mine. Through a large number of practices, in general, mine transient electromagnetic method and mine direct current method are sensitive to low-resistance anomalies and have high resolution. They are often used for detecting unidentified water-bearing structures; The rayleigh waves and reflected seam seismic exploration are often used to detect the distribution of lanes head advanced or side coal pillar. In order to improve the detection accuracy, the seismic method and the electromagnetic method are often used in combination.

Drilling verification mainly includes drilling goaf exposed (observation of liquid loss or lost drilling), drilling TV observation, 3D laser scanning observation of goaf, etc. Multiple drilling holes can also perform interwell seismic detection.

3.2. Exploration techniques and methods for spontaneous combustion or fire area distribution

The exploration techniques and methods of coal waste dump and backfill areas spontaneous mainly use isotope radon measurement method, gas detection method, infrared temperature measurement method, borehole temperature measurement method and remote sensing method. In the actual detection process, in order to improve the exploration accuracy, it is often necessary to combine two or more methods. In addition to the above mentioned exploration methods, magnetic exploration and resistivity methods are also used in the exploration of spontaneous combustion and gas pollution disasters in abandoned coal mine goafs.

After a lot of practice, in general, the isotope radon measurement method can not only accurately identify the fire source center position, the fire area range and the development of the fire source, but also has the advantages of fast detection and data processing, low cost, etc., and is widely used; The gas detection method can directly measure the concentration of toxic and harmful gases, and can also provide reference for spontaneous combustion or fire detection; The infrared temperature measurement method is simple, rapid and accurate, and is mainly suitable for shallow goaf, waste dump and backfill areas, etc.; the borehole temperature measurement method is a direct temperature measurement method, but requires a large number of drilling holes, high detection cost, construction

difficulty, and is susceptible to coal thermal conductivity; The magnetic exploration method, resistivity measurement method and remote sensing method are mainly applied to the area where the coal field spontaneous combustion is fired and the fire source temperature is high, but difficult to detect the spontaneous combustion of the deep goaf.

4. Techniques and methods for monitoring and forecasting of hidden disasters in abandoned coal mines

The monitoring and forecasting of hidden disasters in abandoned coal mines mainly include four categories: monitoring and forecasting of goaf instability and collapse disasters, mine groundwater level and water pollution disasters, spontaneous combustion and gas pollution disasters, and ecological environment disasters. See Figure 1.

4.1. Techniques and methods for monitoring and forecasting of the goaf instability and collapse disasters

The monitoring and forecasting of the goaf instability and collapse disasters mainly include the overburden strata damage and surface subsidence. The main monitoring and forecasting techniques and methods include the multi-point displacement monitoring within the rock stratum, microseismic monitoring, surface displacement monitoring, etc., through monitoring changes in displacement or microseismic events, and transmitting monitoring data to servers and mobile Internet terminals in real time to achieve goafs forecasting of instability and surface subsidence.

4.2. Techniques and methods for monitoring and forecasting of mine groundwater level and water pollution disasters

The monitoring and forecasting of the mine groundwater level and water pollution disasters mainly include groundwater level, water pressure, water quantity, water temperature and water quality change. The main monitoring and forecasting techniques and methods include monitoring of changes in groundwater level rebound, monitoring of changes in water flow fields in various aquifers, monitoring of water quality changes in various aquifers. The monitoring data is transmitted to the server and mobile Internet terminals in real time to achieve forecasting of mine groundwater level, water pressure, water volume, water temperature and water pollution disasters.

4.3. Techniques and methods for monitoring and forecasting of spontaneous combustion and gas pollution disasters

The monitoring and forecasting of spontaneous combustion and gas pollution disasters mainly include the temperature, gas concentration and composition change. The main monitoring and forecasting techniques and methods are the abandoned coal mine drilling holes temperature and gas monitoring, surface fissure temperature and gas monitoring, coal waste dump and backfill temperature and gas monitoring, etc., through monitoring drilling holes and surface temperature anomalies, gas concentrations and composition changes, and transmitting monitoring data to servers and mobile Internet terminals in real time to achieve forecasting of spontaneous combustion and gas pollution disasters.

4.4. Techniques and methods for monitoring and forecasting of ecological environment disasters

The ecological environment disasters monitoring and forecasting mainly include surface displacement, soil quality, water quality, atmospheric environment, vegetation distribution and animal migration. In addition to the above mentioned monitoring techniques and methods, they also include the horizontal displacement monitoring caused by secondary disasters (landslides, mudslides, etc.), monitoring of soil quality in mining areas, monitoring of water quality in rivers and lakes in mining areas, monitoring of PM2.5 and PM10 concentrations, and monitoring of vegetation distribution and animal migration, through monitoring the changes in surface displacement, soil quality, water quality, atmospheric environment, vegetation distribution and animal migration, and transmitting monitoring

data to servers and mobile Internet terminals in real time to achieve forecasting of ecological and environmental disasters.

5. Environmental engineering issues induced by abandoned coal mines and their comprehensive prevention and utilization technologies

5.1. Environmental engineering issues induced by abandoned coal mines

The environmental engineering issues induced by abandoned coal mines include living environment problems, working environment problems and ecological environment problems.

5.1.1. Living environment

The impact of abandoned coal mines on the living environment is more prominent in two aspects. The first one is the damage to residential buildings (structures) caused by subsidence or subsidence of the ground, and the other is the difficulties in domestic water and irrigation water caused by the decline in surface water levels. The living environment of 245 mineral resource-based urban residents in China is more or less affected, not to mention the towns and villages where coal mines are located.

In addition, the mine earthquake induced by the sudden instability of the abandoned coal mines, especially the large-area room method goafs, and the uncertainty of the location and time of the collapse in the future tends to cause greater psychological panic to the residents. Many residents in the mining area have moved out of the mining area.

5.1.2. Working environment

The impact of abandoned coal mines on the working environment of adjacent production mines is more prominent in two aspects. The first one is the serious damage caused by goaf water, and the other is the pollution caused by spontaneous combustion, toxic and harmful gases in the goaf, which will make carbides and sulfides exceeded the standard, pollute the working environment, result in a sharp increase in the amount of air used and an increase in production costs.

In addition, the environmental problems caused by the instability of coal mine goaf are mainly derived from the disaster caused by the undermine impact. Roof disasters and impacts of wind and wave disasters not only pose a hazard to operators and equipment (supports, shearers, transfer machines, conveyors), but also cause deterioration of the working environment and affect undermine safety production.

5.1.3. Ecological environment

The impact of abandoned coal mines on the ecological environment mainly includes the following four aspects: Firstly, the ground surface subsidence or cracks cause the surface water level drop, the soil is difficult to retain water, causing soil sandification, crop planting and surface vegetation growth difficulties; secondly, the water level rebound and groundwater flow field changes caused by abandoned coal mines, the contaminated coal-bearing strata aquifer water rebounds to shallow surface, mining areas, rivers and lakes and other waters causing water pollution; thirdly, the coal waste dump, backfill, shallow goaf spontaneous combustion, toxic and harmful gas pollution will cause atmospheric carbides and sulfides in the vicinity of the mining area to exceed the standard, and high temperature disasters will also cause damage to the surface vegetation; Fourthly, the secondary disasters (landslides, mudslides, etc.) caused by the above reasons will make vegetation destruction and animal migration, and these conditions will cause further deterioration of the ecological environment.

5.2. Comprehensive prevention and control technologies for abandoned mines

5.2.1. Goaf disaster comprehensive control technologies

A large number of practices have shown that for the goafs where the important buildings on the surface are to be built and there is a risk of instability, it is necessary to carry out grouting and filling measurement first; and the reinforcement measures and anti-deformation design should be adopted. For the areas with large density of surface vegetation distribution in goaf surface, timely backfilling and reclamation should be carried out. For the shallow roof and pillar method goafs with no important construction with mining rate below 40%, the open-pit stripping measurement is priority to be adopted. For large-area goafs with large risk of mine earthquakes, local fill or blasting should be carried out on site.

In order to prevent the water-bearing goaf from causing damage to adjacent production mines, when there is a large amount of stagnant water in the goaf and a stable recharge source, the anti-separation coal (rock) column should be preferred; When there is less water or no stable supply source, the method of advanced dewatering (release) should be preferred; For unfilled goafs with potential supply sources, isolation measures such as cutting off the replenishment water source or constructing a waterproof gate wall should be taken.

5.2.2. Comprehensive control technologies for spontaneous combustion and gas pollution disasters

For the spontaneous combustion and gas pollution disasters in the coal waste dump and backfill area, China Coal Research Institute technical team has refined a set of technical systems of ‘exploration, digging, cutting, blocking, filling, grouting, sprinkling, covering and pressing’, that is, the fire can be extinguished by spraying, grouting, excavating the fire source and controlling the combustion to use the new fire prevention materials and loose rock mass drilling equipment independently researched and developed. After the fire extinguishing, the slope will be shaped and blocked. Comprehensive control measures for dredging and drainage and covering soil greening.

For the goafs spontaneous combustion and the pollution of toxic and harmful gases disasters, they are often controled by surface crack sealing, undermine closed wall sealing, pressure equalizing ventilation, grouting and rubber injection.

5.2.3. Comprehensive control technologies for ecological environmental disasters

The ecological restoration of abandoned coal mines should make full use of remote sensing, wireless transmission, artificial intelligence technology, real-time monitoring of changes in soil, water quality, agriculture, forestry, pasture and other ecological environments, take measures of artificial restoration, natural remediation and self-repair restoration, then carry out engineering reclamation, ecological reclamation, biological reclamation and combined reclamation according to local conditions. So that, the land reclamation and farmland transformation can be combined, and comprehensive reclamation of agriculture, animal husbandry and fishery can be combined with enterprise ecology. The economic benefits and ecological benefits are unified.

5.3. Comprehensive grading utilization technologies of abandoned coal mines

5.3.1. Abandoned coal mine gas utilization technologies

Gas drainage and utilization of abandoned coal mines can not only relieve the shortage of resources, but also decrease the waste gas emission thus cause air pollution to some extent in China.

5.3.2. Comprehensive classification utilization of undermine space in abandoned coal mines

The underground space also be comprehensive classification utilized according to the category, location, maintainability of the abandoned coal mines. Three utilization levels are divided as follows: underground space such as experiment laboratories, sightseeing, entertainment, garages; underground storage or energy sites; garbage back-fill stations.

5.3.3. Comprehensive classification utilization of surface in coal mining sinkhole region

After the reclamation and ecological restoration, the coal mining sinkhole region left after the abandoned coal mining can be used as construction land for shantytown reconstruction and industrial area, photovoltaic or wind power generation depending on the location, climate characteristics and expected subsidence. The construction of ecological parks and the development of mining industry tourism can be used as construction land for important structures such as roads, railways, oil and gas pipelines.

Figure 3. Construction of photovoltaic demonstration base in Datong coal mining sinkhole region.

6. Conclusions

The hidden disasters of abandoned coal mines mainly include such six disasters as the goaf instability and collapse disasters, old goaf water accumulation disasters, mine groundwater level drop and water pollution disasters, spontaneous combustion and gas pollution disasters in the goaf, coal waste dump and backfill areas spontaneous disasters, secondary disasters caused by geological and environmental damage.

The hidden disasters of abandoned coal mines and their impacts on the environment can be identified separately by means of exploration, monitoring and forecasting according to their different types of disasters. The hidden disasters can be identified by exploration techniques mainly for goafs and water hazards, spontaneous combustion or fire area distribution; the hidden disasters that can be identified through monitoring and forecasting techniques are the goaf instability and collapse disasters, mine groundwater level and water pollution. Disasters, spontaneous combustion and gas pollution disasters, mining area ecological environmental disasters, etc.

The environmental engineering issues induced by abandoned coal mines include three aspects: living environment problems, working environment problems and ecological environment problems. Some specific comprehensive prevention and control technical methods are proposed for the classification of goaf disasters, spontaneous combustion and gas pollution disasters, ecological environmental disasters in hidden disasters.

The utilization measures of abandoned coal mines are proposed from three aspects: gas utilization of abandoned coal mines, comprehensive grading utilization of undermine space, and comprehensive classification utilization of coal mining sinkhole region.

Acknowledgments

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