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Analysis and Evaluation of Hydrogeological Condition in Jingxin Mining Area

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ABSTRACT

This study a systematic analysis on the hydrogeological conditions of Jingxin mining area to prevent water inrush accidents in coal mine shafts. Based on industry norms such as the "Mine Water Prevention Detailed Rules" and the "Procedures for the Layout and Pressure Mining of Coal Pillars and Water Bodies in Buildings, Water Bodies, Railways and Main Shaft and Tunnel Coal Pillars", the key elements such as the aquifers and water bodies affected or damaged by mining in the mining area, the distribution of old void water in the mining area and surrounding areas, the mine water inflow volume, the water inrush volume during mine outbursts, and the difficulty of water prevention and control were analyzed. The mine hydrogeological type was determined. In addition, the height of the water-conducting fracture zone of the coal seam and the water volume in the abandoned area were calculated using relevant formulas. Through analysis and calculation, it was concluded that the aquifers and water bodies affected or damaged by the current mining coal seam in the mining area are the overlying Lower Shizheji Formation and the sandstone fracture aquifers of the Shanxi Formation; most areas of the water-conducting fracture zone of the No. 3 coal seam can reach the surface, and the surface of the working face during mining can form ground cracks, and the mine water inflow volume is affected by atmospheric precipitation and surface water during the rainy season, and they are positively correlated with each other. Although it has an impact on mining, it is generally controllable, and the difficulty of water prevention and control is relatively low. On this basis, targeted water prevention and control suggestions were proposed in accordance with the "Regulations on Mine Geological Work".

KEYWORDS

Mining Area; Hydrogeological; Aquifer; Water Inflow Forecast; Analysis and Evaluation.

1. INTRODUCTION

The mine is located on the southern edge of a basin in the Taihang Mountains, within a tectonically denuded low hilly area characterized by well-developed valleys. The terrain in this region is complex, generally featuring higher elevations in the central-northern part and lower elevations in the southeast. Surface rivers are underdeveloped in the area, typically consisting of dry gullies and channels of varying sizes. These channels only carry significant rainwater during the flood season, which eventually drains into the Huoze River and then converges into the Qin River. A reservoir with a storage capacity of approximately 10,000 m³ is situated in the central-western part of the mining field. During the rainy season, floodwaters from three gullies to the northwest, northeast, and southeast flow into this reservoir.The area of the mining area is approximately 5.13 square kilometers. No. 3 Coal Seam and No. 5 Coal Seam have been approved for mining, and the No. 3 Coal seam is currently being mined. The No. 3 Coal seam of the mine is divided into two mining areas (eastern mining area and western mining area), and the two mining areas alternate in production. The production organization mode adopted is " One Mining Face with Two Development Faces ", and the mining method is longwall fully-mechanized top coal caving mining. The roof management adopts the total caving method. The minable coal seams within the mining field are briefly described as follows:

(1) No. 3 Coal Seam: Located in the middle-lower part of the Shanxi Formation, interbedded with silty mudstone or mudstone partings. The seam structure is simple and is minable across the entire area.

(2) No. 9 Coal Seam: Situated in the middle-lower part of the Taiyuan Formation, with a simple structure, generally free of coal waste and usually lacking partings.

(3) No. 15 Coal Seam: Found beneath the limestone at the top of the Taiyuan Formation, with a thickness ranging from 0.90 to 3.09 m.

Tab. 1 List of Minable Coal Seams

Coal-bearing Strata		P_{1s}	C_{3t}	
Coal Seam Number		3	9	15
Coal Seam Thickness (m) Minimum~Maximum / Average		5.55~6.55 6.03	0.48~3.85 1.61	0.90~3.09 2.14
Coal Seam Spacing(m) Minimum~Maximum / Average		37.17～55.59 45.28		19.75～33.47 25.96
Coal Seam Structure	Parting Number of Layers	0～2	0	0～2
	Category	Simple	Simple	Simple
Roof Lithology		Siltstone, Fine Sandstone, Sandy Mudstone, Mudstone	Siltstone, Sandy Mudstone, Mudstone	Limestone
Floor Lithology		Mudstone	Mudstone, Siltstone	Mudstone
Coal Seam Stability		Stable	Extremely Unstable	Stable
Minability		Mineable Throughout the Entire Area	Locally Mineable	Mineable Throughout the Entire Area

2. HYDROGEOLOGICAL CONDITION ANALYSIS

The mining field belongs to the Yanhe Spring catchment as its regional hydrogeological unit. The catchment covers an area of 2,765 km², of which 1,084.8 km² is exposed soluble rock. The long-term average discharge of the spring is 3.38 m³/s, with maximum and minimum discharges of 6.32 m³/s and 2.36 m³/s, respectively.

2.1. The main aquifer and the aquifuge

2.1.1. The main aquifer

Based on the characteristics of lithological combinations, the coal seams that can be exploited, and the degree of fissure development in the rock layers, the aquifers within the mining area can be classified into four types.

2.1.1.1. Quaternary Loose Sediment Porous Aquifer

The lithology is dominated by silt-clay with interbeds of fine sand, exhibiting significant variations in thickness and water yield property.

2.1.1.2. Permian Sandstone Fractured Aquifer

This aquifer is of clastic rock-fracture type, primarily recharged by atmospheric precipitation, as well as by groundwater in weathered bedrock areas and vertical percolation between aquifers. The sporadically outcropping Upper Shihezi Formation within the mining area is mainly composed of medium-grained sandstone, with structural fractures serving as the primary storage space. Directly recharged by rainfall, most of the water discharges as "descending springs" after deeper subsurface flow. The Lower Shihezi and Shanxi Formation sandstone fractured aquifers consist of medium- to fine-grained stratified fissure water, with water mainly derived from medium- to fine-grained sandstone layers. The thickness of the Permian clastic fractured aquifer ranges from 35.37 to 150.69 m. According to mine data, the main water-rich interval is located 118.50–126.40 m above the roof of the No. 3 coal seam, with a thickness of 7.90 m. It is inferred that this aquifer is the main source of water seepage into the roof of the No. 3 coal seam.

2.1.1.3. Carboniferous Taiyuan Formation Fracture-Karst Aquifer

Composed of sandstone and multiple limestone layers (K2–K5). The K2 limestone serves as the direct water-filling aquifer for the No. 15 coal seam, with a thickness of about 8.26 m. Its water-rich section is located at 207.60–210.60 m, with a thickness of 3.00 m. Pumping tests indicate weak water yield, with a specific capacity of only 0.0006 L/s·m.

2.1.1.4. Ordovician Limestone Karst Aquifer

Buried at greater depths, karst fracture development increases with depth, and water yield enhances downward. The main water-rich intervals are distributed between 332.00 and 393.20 m, with a cumulative thickness of about 23.45 m. The water level elevation ranges approximately from 483 to 486 m, with overall groundwater flow from northwest to southeast.

2.1.2. The main aquifuge

Based on lithological associations, minable coal seam positions, and fracture development characteristics, the aquifuges in the mining field are classified as follows:

2.1.2.1. Aquifuge Group of the Benxi Formation and the Base of the Taiyuan Formation

From the floor of the No. 15 coal seam to the top of the Ordovician limestone, a suite of fine-clastic rocks approximately 21.35 m thick is developed. These consist largely of low-permeability argillaceous rocks, among which the bauxitic mudstone of the Benxi Formation is particularly notable. It is fine-textured and provides effective water-blocking capacity, serving as the primary aquiclude within the mining field and a key barrier against recharge from the Ordovician limestone aquifer.

2.1.2.2. Inter-formational Aquifuge of the Carboniferous-Permian

Within both limestone and sandstone aquifers, there exists a suite of mudstone and sandy mudstone layers of varying thicknesses. These layers exhibit low permeability and are relatively impermeable, thereby impeding hydraulic connections between different strata and serving an inter-formational water-blocking function. However, in shallow near-surface strata, due to weathering and fracture development, their aquiclude properties have been weakened or compromised to varying degrees.

2.2. Analysis of Regional Groundwater Recharge, Runoff, and Discharge Conditions

This area is dominated by the Middle Ordovician Majiagou Formation, which exhibits relatively high water abundance and contains abundant groundwater, primarily recharged by atmospheric precipitation. Locally, groundwater also receives recharge from river infiltration and vertical leakage from overlying aquifers, with concentrated discharge occurring through the Yanhe Spring in the southwestern direction. Groundwater within the karst cavities of the Middle Ordovician limestone generally flows from northwest to southeast.

The Carboniferous and Permian strata form a typical interbedded aquifer–aquitard system characterized by alternating water-bearing and water-resistant layers. Recharge from atmospheric precipitation and surface water is limited, particularly due to the underdevelopment of deep karst fractures, resulting in minimal vertical percolation of surface water into the deeper aquifers.

The Quaternary unconsolidated aquifer mainly develops along slopes, gullies, and other depressions. Near the foothills and bedrock, residual slope-wash aquifers are primarily recharged by atmospheric precipitation and fissure water from the bedrock, discharging through topographic depressions. The region is widely covered by Upper Pleistocene yellow-brown silty clay, which exhibits high permeability but very low water-yielding capacity. Underlying this, the Middle Pleistocene brown-red silty clay has very low permeability, often creating a zone of relatively high water abundance at the interface between the two units. In valleys, band-like deposits of Holocene sand and gravel within the Quaternary act as recharge zones for surface water and precipitation, discharging into underlying strata and topographically low-lying areas.

2.3. Analysis of the Distribution Pattern of Regional Groundwater Strong Runoff Zones

From the hydrogeological perspective of this region, the area is predominantly characterized by Ordovician carbonate aquifers. Karst fractures within the aquifer are relatively well-developed, generally exhibiting high water abundance and favorable water quality, with a hydrochemical type of HCO_3-Ca·Mg. The primary recharge mechanism includes atmospheric precipitation infiltrating exposed limestone areas, supplemented by leakage through fractures into deeper zones, as well as contributions from surface water and groundwater in overlying aquifers. After flowing through the runoff zone, groundwater ultimately discharges into the Yanhe Spring catchment.

3. ANALYSIS OF MINE WATER INFLOW CONDITIONS AND INFLUENCING FACTORS

3.1. Analysis of Water Filling Sources

3.1.1. Atmospheric Precipitation and Surface Water

3.1.1.1. Atmospheric Precipitation

Atmospheric precipitation primarily infiltrates the mine through various types of fractures and pores in loose sediments, serving as an indirect source of recharge during mining operations via interconnected fractures. Additionally, during coal extraction, rainwater can directly enter the mine through these fractures. Surface rivers are undeveloped within the mining field, and the gullies of all sizes remain dry under normal conditions. Therefore, the main surface water sources contributing to mine water inflow are atmospheric precipitation and the short-term floods formed in the gullies. The average annual precipitation in the area is 583.9 mm, with the wet season occurring from July to September, making rainfall a significant source of water replenishment for the mine.

The elevations of the openings of all four mine shafts are higher than the historically recorded highest flood level (700 m), thus preventing floodwater from intruding into the underground workings through the shafts and ensuring that flooding does not impact mining operations.

3.1.1.2. Surface Water

There is a reservoir on the western side of the mining field, with a storage capacity of approximately 10,000 m³ and a base elevation of about +650 m. The burial depth of the No. 3 coal seam near the reservoir is about 45 m. Due to the extreme heavy rainfall events on July 11, July 20, and September 24 during the 2022 rainy season, significant water accumulated in the reservoir after the rainfall. The accumulated water has three main pathways: ① Infiltration into the underground workings, flowing westward along the old roadways of a coal mine (now closed) located to the west of this mine, and entering the mining field of Xigou Coal Industry; ② Partial water from the reservoir flows westward by gravity into the Xiaoxi River downstream of Xiali Village, infiltrating through surface cracks during overland flow into the old roadways of the former Shangli Coal Mine, and subsequently entering Xigou Coal Industry; ③ A protective coal pillar of about 100 m exists between the reservoir and the goaf of this mining field, resulting in minimal impact of the reservoir water infiltration on the current mining field.

Fig. 1 Reservoir Water Accumulation After Heavy Rainfall

Fig. 2 Reservoir Condition After Water Drainage

3.1.2. Groundwater

The No. 3 coal seam to be developed in this mining area is overlain by multiple layered sandstone fractured aquifers. Among them, the Permian Shihezi Formation consists of sandstones with varying grain sizes (medium, coarse, and fine) and serves as an important indirect recharge source for the No. 3 coal seam. It is closely related to surface runoff. The Permian Lower Shanxi Formation sandstone fractured aquifer contains multiple layers of medium- to fine-grained sandstone, with fractures locally developed, making it one of the main direct water-filling sources for the mining of the No. 3 coal seam.

3.1.3. Goaf Water Accumulation

Extensive goafs exist in the No. 3 coal seam within the mining field, containing varying degrees of accumulated water. This water may enter the working face through the surrounding rock or poorly sealed barriers, or seep into roadways and mining faces through fractures in the surrounding rock, constituting a significant water source during coal mining. However, the locations and volumes of the accumulated water are clearly understood. Overall, the accumulated water in the old goafs in this area does not pose a threat to the safe mining of the mine.

3.1.4. Ordovician Limestone Water

The karst water level of the Ordovician limestone in this mining field is approximately +483 m to +486 m, while the floor elevation of the No. 3 coal seam ranges from +570 m to +640 m, with a difference of about 100 m between the two. Therefore, the No. 3 coal seam is not subject to confined water pressure during mining.

3.2. Analysis of Water Inrush Channels

3.2.1. Natural Channels

3.2.1.1. Geological Structures

Various types of fractures formed during diagenesis and tectonic activity serve as the main channels for mine water inflow. Weathering fractures are distributed in shallow areas, decreasing in density with depth and showing uneven distribution. Diagenetic fractures are controlled by lithology and generally have low water content. However, as they connect different aquifers, the significant hydraulic head difference makes them key channels for interlayer water exchange. Once connected to other water sources, they pose a high risk.

The overall structural framework of the mining field is a broad, gentle monocline, with strata dipping at 3°–7°, striking approximately east-west, and dipping northward. Accompanying this is a set of wide, gentle fold structures: from west to east, these are the S1 syncline and the S2 anticline. No faults or collapse columns have been identified within the mining field. (See Figure 3 for structural distribution.) Due to water-convergence effects, aquifers near the axis of the syncline in the central-western part may yield relatively high water inflow in the western mining panels (3216, 3218, 3220). The eastern mining panels (3127, 3129, etc.) are located on the eastern limb of the anticline and are less affected by aquifers.

The structural types in the mining field are simple[1]. The fold structures are characterized as follows:

S1 Syncline: Developed in the western part of the mining field. Its axis trends N8°E, traversing the field longitudinally, and plunges to the southwest. It extends for several kilometers, with basically symmetrical limbs and dips ranging from 6°to 8°.

S2 Anticline: Developed in the central-eastern part of the mining field, east of the S1 syncline. Its axis trends N12°E, traversing the field longitudinally, and plunges to the northeast. It extends nearly several kilometers, with generally symmetrical limbs and dips of 7°to 8°.

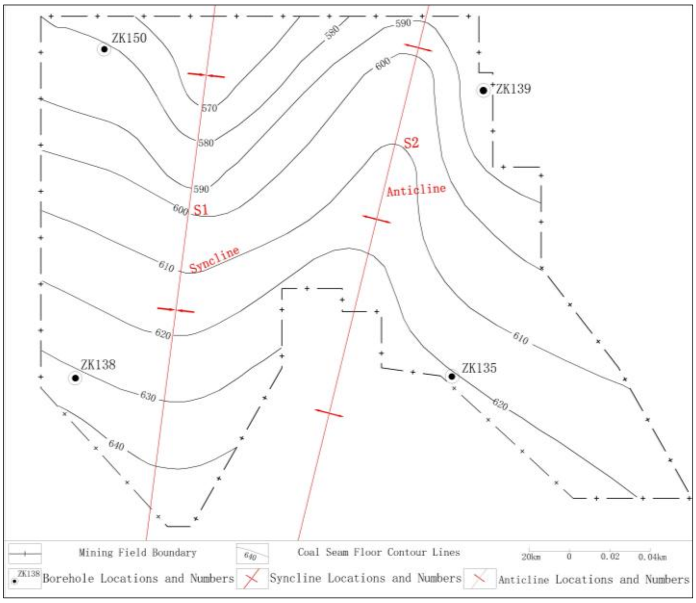

Fig. 3 Structural Outline Map of the Study Area

3.2.1.2. Unfavorable Geological Features

No unfavorable geological features such as paleo-channel scour zones or hydrogeological "windows" have been identified within the mining field.

3.2.2. Artificial Channels

3.2.2.1. Shafts and Boreholes

Existing and abandoned shafts have no impact on mining operations. After completion, all boreholes in the mining field have been properly grouted and sealed according to regulatory requirements, with no defective boreholes. Therefore, they pose no risk to mining.

3.2.2.2. Water-Conducting Fracture Zone

The thickness of the No. 3 coal seam ranges from 5.55 m to 6.55 m, with moderately hard overlying strata. The mining method is fully mechanized top coal caving. The formula (Formula 1)[3] from the

Coal Mine Water Prevention and Control Manual was selected for calculation, with results shown in Table 2.

$$H_{li}=\frac{100M}{0.26M+6.88}\pm 11.49 \quad (1)$$

In the formula: Hli is the maximum height of the water-conducting fracture zone (m); M is the mining thickness of the coal seam (m).

Tab. 2 Calculation Results of the Water-Conducting Fracture Zone for the No. 3 Coal Seam

Borehole Number	ZK135	ZK138	ZK139	ZK150
mining thickness M(m)	5.55	6.55	6.17	6.12
Vertical Distance Between Roof and Surface(m)	71.97	77.74	86.24	124.8
Height of Water-Conducting Fracture Zone(m)	78.17	87.80	84.21	83.73

The four boreholes, ZK135, ZK138, ZK139, and ZK150, are distributed at the four corners of the mining field, providing relatively high control coverage. Based on calculations, the development height of the water-conducting fracture zone in the No. 3 coal seam ranges from 78.17 to 87.80 m. In the vicinity of ZK135 and ZK138, the fracture zone can connect the surface and the aquifers above the coal seam, while near ZK139 and ZK150, it can connect to the aquifers overlying the coal seam. Therefore, due to the influence of the water-conducting fracture zone, strong hydraulic connectivity is likely to occur between the No. 3 coal seam and the overlying aquifers.

4. DISTRIBUTION OF WATER IN OLD WORKINGS IN AND AROUND THE MINING FIELD

4.1. Water Accumulation in Goafs within the Mining Field

A total of 34 goaf areas in the No. 3 coal seam were analyzed, covering a cumulative water-accumulation area of 236,655 m². The water volume was calculated using Formula 2, resulting in a total accumulated water volume of 118,420.50 m³.

$$W = KMS/\cos\partial \quad (2)$$

In the formula: W is the water accumulation volume in the goaf (m³); M is the average mining height of the coal seam (m); S is the water accumulation area (m²); α is the dip angle of the coal seam (°); K is the water-filling coefficient.

4.2. Water Accumulation in Goafs of Adjacent Mines

To the northwest, north, and east of the mining field lies a coal mine formed by the merger of two mines, which extracts the No. 3 and No. 15 coal seams. A protective boundary coal pillar has been established at the junction of the No. 3 coal seam between this mine and the adjacent mine, and there has been no history of cross-boundary or cross-seam mining. Currently, the water accumulated in the goafs of this adjacent mine essentially does not impact mining operations in the present mine.

To the west, a mine has been closed. Before closure, it extracted the No. 3 coal seam, and some roadways and goafs remain distributed near its western boundary, with water accumulation in the northern goafs and roadways. The No. 3 coal seam in the northwestern part of the present mine has already been extracted, and the water in the goafs of this adjacent mine has minimal impact on current mining activities.

In summary, water accumulation in the goafs of surrounding mines does not affect mining operations in the present mine.

5. ANALYSIS OF MINE WATER INFLOW CONDITIONS

5.1. Analysis of Underground Water Inflow

From the perspective of water inflow composition, the main sources of water inflow are as follows: ① Water Inflow Point No. 7 in the West Third Level Return Airway, which originates from water seepage through the sealed wall of the 3106 goaf (mined between 2000 and 2002). The goaf distribution near this water inflow point is relatively dense. After coal extraction, roof collapse partially interconnected the nearby goafs, allowing atmospheric precipitation infiltrating into the mine to concentrate and discharge at this location. ② The 1# West First Level Main Roadway, where the water source is roof water, primarily recharged by atmospheric precipitation infiltration. ③ Water inflow in the 4# Material Roadway, also sourced from roof water, mainly supplied by atmospheric precipitation infiltration. The mine water inflow volume is calculated using Formula (3), with the results presented in Table 3.

$$Q_{\text{total water inflow}}=Q_{\text{western mining area}}+Q_{\text{west first-level main roadway}}+Q_{\text{eastern mining area}} \quad (3)$$

Tab. 3 Mine Water Inflow Table

Time	$Q_{\text{eastern mining area}}$(m³/h)	$Q_{\text{western mining area}}$(m³/h)	$Q_{\text{west first-level main roadway}}$(m³/h)	$Q_{\text{total water inflow}}$(m³/h)
1	18.0	7.8	2.5	28.3
2	17.7	7.3	2.4	27.4
3	18.1	7.8	2.5	28.4
4	19.8	7.3	2.4	29.5
5	20.4	7.7	2.5	30.6
6	15.7	5.0	2.3	23.0
7	74.8	91.8	80.3	246.9
8	56.8	101.3	40.3	198.4
9	58.0	101.3	40.2	199.5
10	93.2	95.4	12.5	201.1
11	42.5	88.3	10.3	141.1
12	37.0	28.3	10.3	75.6

Analysis indicates a significant increase in underground water inflow, primarily due to the impact of heavy rainfall during the 2022 wet season. The No. 3 coal seam in the mining field is shallowly buried, making atmospheric precipitation a highly influential factor on shaft water discharge. Moreover, a strong positive correlation exists between precipitation and shaft water discharge.

5.2. Analysis of underground water inflow situation

The normal underground water inflow is 108.5 m³/h, and the maximum water inflow is 246.9 m³/h. Based on underground water inflow data in recent years, the normal inflow shows an increasing trend year by year, with the most significant variation occurring in 2022. Among the factors contributing to the increase in underground water inflow, atmospheric precipitation has a notable impact.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

6.1.1. Aquifers Disturbed or Affected by Mining Activities

The currently mined No. 3 coal seam is primarily influenced by the overlying Lower Shihezi Formation and Shanxi Formation sandstone fractured aquifers. The water-conducting fracture zone of the No. 3 seam extends to the surface in most areas, leading to surface cracking during panel extraction. Mine water inflow shows a positive correlation with atmospheric precipitation and seasonal surface water, which may affect mining operations to some extent but does not pose a threat to mine safety.

6.1.2. Distribution of Water in Old Workings Within and Around the Mining Field

There are 34 goaf areas in the No. 3 coal seam, covering a water-accumulation area of 236,655 m^2 and containing approximately 118,420.50 m^3 of water. Although adjacent mines to the north and west contain goaf water, their locations and volumes are well understood, and due to their lower hydraulic position relative to the current mining field, they do not significantly impact safety.

6.1.3. Mine Water Inflow

Main sources include: ① Inflow Point No. 7 in the West Third-Level Return Airway, originating from water seepage through the sealed wall of the 3106 goaf (mined 2000-2002); ② the 1# West First-Level Main Roadway, supplied by roof water recharged through precipitation infiltration; ③ water inflow in the 4# Material Roadway, also derived from roof water via precipitation infiltration. The notable increase in water inflow is primarily attributable to heavy rainfall during the 2022 wet season, given the shallow burial depth of the No. 3 seam.

6.1.4. Water Inrush Volume

No significant water inrush events have been recorded, and such incidents are rare during mining.

6.1.5. Degree of Influence from Water Hazards

Water sources include goaf water, atmospheric precipitation, and fissure water from the roof sandstone and caved zones. Roof fractures connect to overlying aquifers. Apart from the reservoir, no other significant surface water bodies exist in the mining field. Atmospheric precipitation, goaf water, and roof fissure water are the key focuses for water-hazard prevention. Although the No. 3 seam is affected by water hazards due to its poor water abundance and limited recharge, it does not endanger safe mining.

6.1.6. Difficulty of Water Prevention and Control Work

The hydrogeological conditions underground are relatively simple, and water inrush incidents are rare. Water prevention and control measures are therefore comparatively straightforward and do not require extensive engineering.

6.2. Recommendations for Water Prevention and Control

Focus should be placed on goaf water, atmospheric precipitation, and surface water.

6.2.1. Surface Measures

(1) Collect data on seasonal precipitation and peak flood levels; improve mine surveying and data management systems; exchange maps regularly with neighboring mines; and monitor mining conditions in adjacent areas to support goaf-water prevention.

(2) Before the rainy season, backfill surface cracks, fissures, and subsidence pits to prevent infiltration of precipitation and surface water. In high-rainfall areas, consider seasonal adjustment of mining schedules.

(3) Conduct joint drainage tests before the rainy season to assess underground drainage capacity. Increase the number of pumps and drainage pipelines during heavy rainfall to ensure safe operation.

(4) When advancing or extracting near well-sealed boreholes, conduct prospecting drilling in advance and adopt a “probe while advancing” approach.[6]

(5) Upgrade drainage systems to improve reliability of water-control measures[8].

(6) Invest in technology and adopt advanced water-proofing methods to enhance equipment performance.[9]

6.2.2. Underground Measures

(1) Before driving or extracting the No. 3 coal seam, implement the “16-character principle” for probing and draining water from adjacent workings and goafs.[10]

(2) If signs of water inrush appear during mining, stop operations immediately, sound an alarm, evacuate all personnel at risk, and report promptly to the dispatch office.

(3) Inspect and maintain drainage equipment before and during the flood season to ensure preparedness.

(4) Maintain systematic monitoring and record data on water inflow, precipitation, and mining geology. Analyze any anomalies and take necessary technical measures. Re-inspect and service drainage facilities twice annually during the flood season.[13]

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