Overview of surface water hazards in China coalmines

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Abstract

Among all recorded water disasters in China coalmines, 10% can be attributed to surface water, making it one of the top water hazards. Based on the cases analysis of surface water hazards in China coalmines, this article determined surface water sources and inrush conduits as the major factors which caused water inrush disasters of mine, and classified surface water hazards in China coalmines into 15 types according to those major factors and gave the definitions of each type of surface water hazards. Then, it was proposed that there are different types of surface water hazards in different coal-bearing regions by analyzing the relationship to terrain features, climatic impact and mining conditions. Finally, we discussed the co-play of typical water sources and inrush conduits in the hazards formation, in addition to its characteristics and corresponding preventative technologies. The propositions can be of reference for exchanges with other mining countries and regions on surface water hazards treatment.

Key words: characteristics, China coalmines, classification, surface water hazards, treatment

INTRODUCTION

Among the five major types of disasters in China coalmines, namely gas outburst, water inrush, caving, spontaneous combustion of coal, and coal dust pollution, gas and water are the two main culprits to severe accidents. In recent years, water-related disasters have been more frequent and caused far more economic losses than gas. In response to such water disasters, the water is usually cut off and drained from down the mine up to ground surface, a method which would further contaminate surface environment (Coynel et al. 2007; Li et al. 2014; Mohammad & Stefan 2014; Price & Wright 2016; Yakovlev et al. 2019). Therefore, research on the treatment of coalmine water hazards has received much attention from the government, mining enterprises, and academic experts (Jangwan et al. 2015; Wu 2015; Fan & Ma 2018).

Past water inrush accidents in China coalmines have shown over 30 types of water hazards (Gui & Lin 2016), including, among others surface water, pore water, fissure water, karst water. Surface water, for instance, would cause mine flooding and mass casualties once it breaks into the underground mine, thus rated as one of the major water hazards in China. On Dec. 19, 1977, in
Liaoyuan mining district of Jinlin Province, water from nearby reservoir broke into Meihe No.1 Coalmine through mining-caused subsidence and fissures. The whole mine was flooded, killing 64 people and injuring 93 others. On Aug. 17, 2007, Huayuan Mining Co., operating in Xintai mining district of Shandong Province, had a mine flooded by river water irruption and lost 181 men (Wu et al. 2013), the largest casualties from water disasters in China coalmine of this century.

Surface water poses the same threat in other coal-producing countries (Singh 1986; Bukowski 2011). According to Job (1987), Between 1851 and 1970, the United Kingdom had recorded 208 major water inrush accidents, among which, 176 were caused by goaf water, 9 by surface water, and 23 by others (such as loose bed water, formation water, bore hole leakage, underground dam failure, etc.). Surface water ranked the second, responsible for 4.3% of total such tragedies.

It has been proven that surface water hazard is closely related to climatic impact, terrain features, and mining conditions, to name a few (Guan 2013; Marschalko et al. 2014; Zheng 2014; Chen et al. 2018). Katpatal et al. (2010) conducted a study on the changes in ground ecosystem in Chandrapur of India under the impact of mining activities. The study assessed flooding risks to the mining district and proposed probable countermeasures. Analyzed lots of water inrush cases in many coal-producing countries around the world, Vutukuri & Singh (1995) thought that there need to establish a hydrological database so that the surface water dynamics and its potential threat to the coal mines are known well timely, and proposed that it is necessary to use existing methods and develop new technologies to prevent surface water from inrushing into mines so as to avoid coalmine water disasters. Wang et al. (2006) illustrated technical evaluation of mining safety under surface water based on description of surface water bodies, rainfall patterns, geological and hydrogeological conditions of Micun Coalmine of Xinmi mining district, Henan Province of North China coalfield. In order to examine the connectivity of mining fissures in full-mechanized caving mining of thick coal seam under surface water and its impact on surface water, Wang et al. (2013) using strata data availed by bore hole drilling and working face layout of the Henan Daping mining district of North China coal-bearing region, obtained the depth of ground mining fissures (6.59 m) by way of elastic theory. They also have discussed the coupling relationship between ground fissures and mining fissures, leading to sound evaluation of flooding risks in full-mechanized caving mining of thick coal seam under surface water. In recent years, GPS and GIS techniques have been widely used to evaluate the characteristics of landforms, vegetation, surface erosion and surface water distribution in mining district, and study the ground subsidence and ground fissures caused by coal mining (Muntean et al. 2016; Ortega-Becerril et al. 2016; Zhang et al. 2016). Additionally, previous researches on features of water source and evolution of inrush conduits (Chen et al. 2014; Polak et al. 2016; Mostafa & Dieter 2017), both triggers to surface water hazards, have provided valuable reference to treating such hazards in coalmines.

China has six coal-bearing regions, namely Northeast and Northwest Jurassic, North China Permo-Carboniferous, South China late Carboniferous, Yunnan Tibet Mesozoic, and Taiwan Tertiary (Gui et al. 2016a, 2016b), with the first five regions spreading over 500,000 km². Statistics from past years have shown that one in ten water-related accidents in China coalmines were caused by surface water, recorded in varying severity across the over 500,000 km² coal-bearing regions of inland China.

By analyzing the cases of surface water hazards in China coal-bearing regions, we can see that the deluge, river, lakes and other types of surface water could rush into mines through deserted tunnels, karst breakdowns and many other conduits, forming different types of surface water hazards (Evans et al. 2016; Polak et al. 2016; Wang et al. 2016). Each type poses varying levels of threats to mining safety, calling for different preventative treatments. This article classifies surface water hazards on the basis of water recharge conditions (source and conduits) with knowledge of past surface water-related accidents and presents the distribution of each type for future references.
METHODOLOGIES

Case analysis of surface water disasters

Growth of coal output in China is the fastest worldwide. In 1950, national coal output was 42.9 million tons, which rocketed over 1 billion tons annually by end of 1980s. In the last 10 years, annual coal output was more than 3 billion tons, almost half of world total output.

However, as output grew, accidents caused by surface water also increased. Accumulatively from 1959 to 2013, more than 40 surface water accidents broke out across China, some of which are presented in Table 1. The severities of these accidents were horrifying both in economic losses and human casualties.

According to Table 1, some enlightenments are obtained as following:

(1) surface water as threats to coalmines falls into multiple types, including deluge, river, and lake water (sea water is also one type of surface water. But it has never incurred mining accidents in China, thus not under discussion in this article).

Table 1 | Major surface water disasters in China coalmines (1959–2013)

<table>
<thead>
<tr>
<th>SN</th>
<th>Date</th>
<th>Loc.</th>
<th>Water source/inrush conduits</th>
<th>Strength of water flow</th>
<th>Losses and casualties</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jul. 22, 1959</td>
<td>Zhaogezhuang Coalmine, Hebei Kailuan mining district</td>
<td>deluge-river water/deserted pits</td>
<td>water flow 9,756 m³/h</td>
<td>production halt</td>
</tr>
<tr>
<td>2</td>
<td>Aug. 2, 1960</td>
<td>Benxi Caitun Coalmine, Liaoning Shenyang mining district</td>
<td>deluge-river water/deserted pits</td>
<td>total water volume 960,000 m³</td>
<td>30-day production halt, 13 deaths</td>
</tr>
<tr>
<td>3</td>
<td>Dec. 19, 1977</td>
<td>Meihe No. 1 Coalmine, Jilin Liaoyuan mining district</td>
<td>reservoir water/cavings</td>
<td>total water (sand) volume 56,520 m³</td>
<td>9,130 m tunnel under water, 23 day production halt, 64 deaths, 93 injured</td>
</tr>
<tr>
<td>4</td>
<td>Aug. 25, 1985</td>
<td>Yangmeishan Coalmine, Hunan Zixing mining district</td>
<td>deluge-river water/karst breakdowns and fault</td>
<td>water flow 7,180 m³/h</td>
<td>90-day production halt, 1 death</td>
</tr>
<tr>
<td>5</td>
<td>Jun. 5, 1986</td>
<td>Shanjiaoshu Coalmine, Guizhou Panjiang mining district</td>
<td>deluge/shaft</td>
<td>total water (sand) volume 11,601 m³</td>
<td>3,636 m tunnel under water, 21 day production halt, 8 deaths, 1 severely injured</td>
</tr>
<tr>
<td>6</td>
<td>Mar. 2, 1987</td>
<td>Private pit, Xinzhuang Zi Coalmine, Anhui Huainan mining district</td>
<td>collapse pond/water-conductive fissures</td>
<td>total water volume 137,000 m³</td>
<td>270-day production halt, 12 deaths</td>
</tr>
<tr>
<td>7</td>
<td>Aug. 5, 1993</td>
<td>Longshan Coalmine, Shandong Linyi mining district</td>
<td>deluge/deserted pits</td>
<td>water volume of several tens of thousands m³</td>
<td>mine flood, 58 deaths</td>
</tr>
<tr>
<td>8</td>
<td>Jul. 13, 2006</td>
<td>Jinli Coalmine, Inner Mongolia Erdos mining district</td>
<td>deluge/shaft</td>
<td>water volume of several tens of thousands m³</td>
<td>mine flood, 2 deaths</td>
</tr>
<tr>
<td>9</td>
<td>Aug. 17, 2007</td>
<td>Huayuan Mining Co., Shandong Xintai mining district</td>
<td>deluge-river water/goaf area in deserted pits</td>
<td>total water (sand) volume 12.6 million m³</td>
<td>mine flood, 181 deaths</td>
</tr>
<tr>
<td>10</td>
<td>May 23, 2013</td>
<td>Su’er Coalmine, Fujian Subang mining district</td>
<td>river/collapses in riverbed</td>
<td>total water volume 90,000 m³</td>
<td>flooding two mining pits, central pump house (~110 m) and one power substation</td>
</tr>
</tbody>
</table>
(2) surface water rushes into coalmines through multiple conduits, such as shaft, deserted pits, cavings, etc..
(3) coalmines are subject to different types of surface water threats.

Classification principles of surface water hazards

The reasonable classification of water hazards is the premise of effective prevention and cure of water disasters. From the practice of coal mining, the two preconditions to the formation of coalmine water hazards are water source and inrush conduits. From Table 1, it can be inferred that major sources of surface water menacing coalmines are, among others, deluge, rivers, and lakes, which correspond to deluge water hazard, river water hazard, lake water hazard, etc. around coalmines. Surface water, coming from different sources, invades into mines through various conduits, such as shaft, deserted pits, mining-caused cavings and water-conductive fissures, karst breakdowns, protogenic rifts, etc., contributing to the complexity of surface water hazards, such as rainfall deluge bursting into mines through shaft, river water bursting into deep mining working face through shallow deserted pit, etc.. Therefore, the classification of surface water hazards in coalmines is based on surface water sources and water inrush conduits.

RESULTS AND DISCUSSION

Types and definitions of surface water hazards

Analysis on the past surface water-related disasters in China coalmines, common types of surface water hazards can be summarized in 15 categories (Table 2), the definitions of which laid out in Table 3.

Reginal differences of surface water hazards

Surface water (such as river, lake, deluge, etc.) are replenished by precipitation, under constraints of weather conditions. In mining district, for surface water to become a coalmine hazard, there are multiple determining factors, such as terrain features and mining conditions. Each coal-bearing region of inland China differs in climate and terrain features, as well as mining history and mining conditions. As a result, each region is subject to assorted surface water hazards (Table 4) with varying characteristics.

| Table 2 | Types of surface water hazards in China coalmines |
|---------|-------------------|------------|------------|
| Sources | Deluge | River | Lake |
| Shaft | #1 | #2 |
| Deserted pits | #3 | #4 | #5 |
| Cavings | #6 | #7 | #8 |
| Water-conductive fissures zone | #9 | #10 | #11 |
| Karst breakdowns | #12 | #13 | #14 |
| Protogenic cavity | #15 |

Notes: i. Deluge includes mountain torrents and gully water induced by precipitation.
ii. Lake water includes reservoir and mine subsidence lake, etc..
iii. Deserted pits include deserted shaft, tunnels, and goaf, etc..
iv. Cavings and water-conductive fissures are caused by mining.
v. Protogenic cavity includes mountain gullies, water-conductive faults, etc..
### Table 3 | Definitions of surface water hazards in coalmines

<table>
<thead>
<tr>
<th>Type</th>
<th>Definition</th>
<th>Type</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>Rainfall deluge (incl. mountain torrents, gully water, etc.) that bursts into mines through shaft</td>
<td>#9</td>
<td>Rainfall deluge that bursts into mines through mining-caused roof water-conductive fissures</td>
</tr>
<tr>
<td>#2</td>
<td>River water that bursts into mines through shaft</td>
<td>#10</td>
<td>River water that bursts into mines through mining-caused water-conductive fissures</td>
</tr>
<tr>
<td>#3</td>
<td>Rainfall deluge that bursts into deep mining working face through shallow deserted pit</td>
<td>#11</td>
<td>Lake water that bursts into mines through mining-caused roof water-conductive fissures</td>
</tr>
<tr>
<td>#4</td>
<td>River water that bursts into deep mining working face through shallow deserted pit</td>
<td>#12</td>
<td>Rainfall deluge that bursts into mines through karst breakdowns</td>
</tr>
<tr>
<td>#5</td>
<td>Lake water (incl. reservoir, mine collapse pond, etc.) that bursts into deep mining working face through shallow deserted pit</td>
<td>#13</td>
<td>River water that bursts into mines through karst breakdowns</td>
</tr>
<tr>
<td>#6</td>
<td>Rainfall deluge that bursts into mines through mining-caused roof-caving sinkholes</td>
<td>#14</td>
<td>Lake water that bursts into mines through karst breakdowns</td>
</tr>
<tr>
<td>#7</td>
<td>River water that bursts into mines through mining-caused roof-caving sinkholes</td>
<td>#15</td>
<td>Rainfall deluge that bursts into mines through protogenic cavities, such as gullies and water-conductive faults</td>
</tr>
<tr>
<td>#8</td>
<td>Lake water that bursts into mines through mining-caused roof-caving sinkholes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4 | Characteristics of surface water hazards in China’s coal-bearing regions

<table>
<thead>
<tr>
<th>Region</th>
<th>Province</th>
<th>Climate</th>
<th>Precipitation</th>
<th>Terrain and mining conditions</th>
<th>Major surface water hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast</td>
<td>Heilongjiang, Liaoning, Jilin, east Inner Mongolia, etc.</td>
<td>Humid to sub-humid</td>
<td>60% of 400–600 mm 25% of 600–800 mm</td>
<td>Flat; long mining history; many shallow deserted pits</td>
<td>Deluge or river water invades through shaft or deserted pit, eg. #1, #2</td>
</tr>
<tr>
<td>North China</td>
<td>North Shaanxi, Ningxia, Gansu, Qinghai, southwest Inner Mongolia</td>
<td>Dry</td>
<td>80% of 25–100 mm 20% of 100–400 mm</td>
<td>Ravines and gullies, more mountain torrents; long mining history, many shallow deserted pits</td>
<td>Deluge invades through shaft, deserted pits, and protogenic cavities, eg. #1, #3, #15</td>
</tr>
<tr>
<td>North China</td>
<td>Shandong, Hebei, Shanxi, Henan, Shaanxi, north Anhui, north Jiangsu</td>
<td>Sub-humid to sub-dry</td>
<td>75% of 600–1,000 mm 20% of 200–600 mm</td>
<td>Flat; long mining history, many shallow deserted pits</td>
<td>Deluge or river (lake) water invades through shaft, deserted pits, caving sinkholes, eg. #1, #3</td>
</tr>
<tr>
<td>South China</td>
<td>South Anhui, south Jiangsu, Jiangxi, Hubei, Hunan, Guangdong, Guizhou, Sichuan, Guizhou, east Yunnan, Chongqing</td>
<td>Humid</td>
<td>Over 95% of 1,200–2,000 mm</td>
<td>Karst depression, shallow karst, hidden karst breakdowns, frequent flooding</td>
<td>Deluge or river water invades through caving sinkholes, karst breakdowns, eg. #6, #12</td>
</tr>
<tr>
<td>Yunnan-Tibet</td>
<td>West Yunnan, Tibet</td>
<td>Humid to sub-humid</td>
<td>55% of 300–600 mm 35% of 800–1,000 mm 10% of 1,000–2,000 mm</td>
<td>Large altitude difference; frequent mountain torrent; shallow karst, hidden karst breakdowns</td>
<td>Deluge invades through protogenic cavities, karst breakdowns, eg. #12, #15s</td>
</tr>
</tbody>
</table>
Typical surface water hazards

Table 4 shows different surface water hazards in each coal-bearing region in China. This article covers the main types of menacing surface water to mining safety.

Water hazards caused by deluge. Coalmines in mountainous area usually set up production sites on flat terrain down the hills (Figure 1). If flood control works are not well designed or constructed, in days of heavy rainfall or downpour, torrents flush down along gullies and forcefully burst into mines. Normally, in humid areas (eg. South China), for a coalmine surrounded by mountains with gullies developed in V-shape, it is susceptible to frequent and sever accidents associated with surface water. On Aug. 25, 1985, rainfall of 155.7 mm around Yangmeishan Coalmine, Hunan Zixing mining district in South China coal-bearing region, triggered heavy mountain torrents. The collapse area of the coalmine sat at the valley base, with a level difference of 347 m. Mountain torrents rushed to the lowlands and into the mine through mining collapse pits. Maximum water flow was 7,180 m$^3$/h, flooding the whole mine and killing one people.

Shanjiaoshu Coalmine, Guizhou Panjiang mining district in South China coal-bearing region, had high-rise mountain to one side, at a maximum level difference of 500 m. Production site was at the lower end of where two V-shaped gullies converged. The gullies were 800 m and 700 m long, respectively, with up-down stream level difference of 180 m and 150 m each. On June 5, 1986, torrential rainstorm hit the area. Mountain torrents maximized at 48,960 m$^3$/h, washing mud and sand into the mine, killing 8 people.

Preventative measures against deluge, first and foremost is to move production site and constructions away from gullies pointing to valley lows. Second, elevate the collar and main construction on production site to higher than the highest flood levels in local records. Third, around lower collars and construction onsite, it is imperative to build embankment to stop deluge or canals to divert torrents to coalmine outskirt. Baijigou coalmine of Ruqigou mining area, Ningxia Province, coal-bearing regions in Northwest China, is located in the alpine terrain surrounded by mountains. There was a serious accident of surface water in Baijigou coalmine, which caused 17 people died. For this reason, the mine built four flood control dams with a total length of 205 m and a dam height of 5 m (1.5 m higher than the local maximum flood level), effectively curbing the surface water hazards.
**Water hazards caused by river embankment failure.** If a river runs through a mining district, rainfall, especially torrential rain, will push up water level to a point where water flow could break water barricades, engendering mining safety (Morrison et al. 2019). On Jul. 30, 1998, torrential rain hit Wanzihe Coalmine, Henan Xinmi mining district of North China coal-bearing region. Rainfall between 11:00 and 15:30 rose to 64.5 mm. River water broke the 400 m long Wanzihe levee and poured into the mine through 2# ventilation shaft, leaving 20 people dead (Wang & Li 2002). In 2007, two days of continuous heavy rainfall on Aug. 16 and 17 around Huayuan Mining Co., Shandong Xintai mining district of North China coal-bearing region, accumulated to 180 mm and caused mountain flood. The highest flood point passing through the Chaiwen River, east to the coalmine, was as high as 1,840 m$^3$/s, which far exceeded the river’s discharge capacity (1,089 m$^3$/s). The river embankment failed as a result. River water breached into the mine through three conduits (No.#3 is an abandoned shaft, No.#1 and No.#2 all are mine collapse pit) (Figures 2 and 3). The tremendous water force washed inland and erode 44,000 m$^2$ area. The mine was scoured by 12,600,000 m$^3$ of water and 300,000 m$^3$ of mud and sand, taking 181 lives.

**In order to prevent water accidents caused by river embankment failure, regular desilting at proper frequency is mandatory to ensure unobstructed river flow. Additionally, reinforcing flood control works by widening river bed, building flood-control ditches or levee, or diverting river flows when necessary, so as to keep river off mining district.** Hongling coalmine of Shenyang mining area, Liaoning Province, coal-bearing regions in Northeast China, is located in the front of Hun river and Taizi river alluvial plain. Baisha river, the first tributary of the Taizi river, passes through the mine, which has caused more than 10 surface water accidents in Hongling coalmine since 1927. Therefore, The dam elevation of Baisha river was raised by 3 m, and the width of the river was widened from 115 m to 240 m, which greatly improved the flood control capacity of Baisha River and avoided the occurrence of surface water hazards in Hongling coalmine.
Water hazards caused by caving. Mining activities cause roof strata deform and stratify into three layers, from bottom up are caving zone, water-conductive fissures zone, and bending zone (Gui et al. 2018). At the same time, ground surface subsides. The mining-caused collapse pits adversely affect underground mining in two aspects. For one, the pits draw and hold water, known as collapse ponds, which can be source of water. For the other, fissures developed around the pits (i.e. the collapse fissures) are the conduits through which rainfall or water from collapse ponds invades into mines. If mining working face is very close to the overhead collapse pits, it is very likely that caving zone and water-conductive fissures zone join and conduit the pits or fissures. In case of heavy rain or if there is sufficient water in collapse ponds, water burst would be unstoppable. At Zhangzhuang Coalmine, Shandong Xinwen mining district of North China coal-bearing region, shallow mining created many collapse pits, accompanied by one ditch of 7 m wide and 3 m deep (Figure 4). On days of no rain, the ditch had negligible amount of water. On Jul. 24, 1970, a heavy rain filled up the ditch. Turbulent water flow swirled and pushed the ditch further deeper. The #11 coal seam in the mine was only as thick as 1.8 m. Direct roof strata were composed of arenaceous shale (thick as 5.7 m), covered by a loose bed, which was 7 m thick of sand loam and clay (A-A’ cross section in Figure 4). According to calculations set forth in Protocols for coal pillar retainment in major roadways and compressed coal mining under buildings, water bodies, and railways (SBCI 2000), maximum height of caving zone should have been 6.5 m, a requirement higher than the actual thickness of direct roof strata (5.7 m). Consequently, mining in the #11 seam triggered roof caving and the overlying loose bed collapsed. The ditch water was unleashed forcefully into the mine almost instantly. Maximum water flow of 18,000 m$^3$/h flooded the whole mine and killed 2 colliers.

There are two approaches to treating surface water hazards caused by roof caving. First, to retain adequate water (sand)-repellent coal pillars to properly distance mining site from overlying water bodies. Second, to realign surface water if the coal pillars cannot be retained as required. For example, drain smaller water bodies, divert river flows, or grout river (lake) bed. Zhouyuanshan coalmine of
Sandu mining area, Hunan Province, coal-bearing regions in South China, is located in hilly-plain area. Shuimulong river runs through the mine field from east to west. Water hazards often occur when the river water is injected into the mine through high-angle water-conducting faults and interstitial voids in inclined strata, and shut-off often occurs in Shuimulong river (i.e. all of the river water is injected into the mine). Therefore, the 740 m long leaky riverbed of the river is grouted by concrete which reduces the amount of water leakage from 12,264,000 m³ before treatment to 48,200 m³ after treatment, and ensures the safe mining of the coal mine.

Water hazards caused by karst breakdowns. During mining in karst topography, draining lowers water level in karst aquifers (Gui et al. 2017a, 2017b; Jiang et al. 2018). The roof of karst cave may break down under self-weight and the negative pressure caused by draining. As the breakdowns grow to reach ground surface or surface water, they would be convenient conduits guiding deluge and other surface water into the mines. At Enkou Coalmine, Hunan Lianshao mining district of South China, the seam bottom of #2 mine was thick limestone of Permian Maokou formation (thickness over 600 m) with a karstification rate of 4%. On average, there were 9,000 karst breakdowns every square kilometer, with spread-out karst pillars. In Jun. 1984, heavy rain hit the mining district from 25th evening to 7 am on 26th. Water in the close-by Mushan River gushed into the mine at a speed of 8,000 m³/h (Figure 5(a) and 5(b)). At 9am on 26th, water flow in –66 m main roadway soared from 500 m³/h before the burst to 3,500 m³/h. Water level showed no sign of retreating when 6 pumps were operating at full capacity (each at 540 m³/h). The mine was eventually inundated due to insufficient draining (Gui & Lin 2016). Water brought under 4,000 m tunnel and incapacitated many electric apparatus, halting production for 18 days.
The key to treat water hazards caused by draining-induced karst breakdowns in coalmines is based on proven knowledge of the location and size of breakdowns, including karst sinkholes, pits, and pillars. Then grout and seal the breakdowns to cut off their hydraulic connections with surface water. For the karst collapse water disaster caused by coal mine drainage, the first thing is to find out the location and scale of karst collapse (including karst collapse pits, karst collapse caves and karst collapse columns), and then fill the karst collapse pits through grouting works, cut the hydraulic relationship between karst collapse and surface water, or divert surface water and rainwater beyond the well field. Hongyan coalmine of Nantong mining area, Chongqing Province, coal-bearing regions in South China, is located in Karst area. Water accumulation in karst depression and rainstorm pour into the coal mine through karst cave so as to threaten to the safety of production of the mine seriously. According to the investigation, there are three corrosion depressions in the mine field, the total area is 0.399 km², the catchment area is 2.704 km², and the maximum catchment volume of a rainstorm is 380,000 m³. And there are 17 karst caves in these three eroded depressions.

Figure 5 | Hydrogeological map of the flooded section of −66 m main roadway in #2 mine, Enkou Coalmine. (a) Planimetric map, (b) Cross section of A—A'.
Therefore, the construction of 2,676 m drainage tunnel and 600 m open channel in underground mine will connect the these karst caves in the karst depression in series, and lead the water in the karst depression to the Conglin river outside the coalmine, thus completely avoiding the threat of surface water and rainwater to the safety of Hongyan coalmine production.

**CONCLUSIONS AND PERSPECTIVES**

Conclusions and perspectives based on the above analysis are as follows:

1. Surface water as hazards to mining safety can be attributed to the confluence of multiple factors. There are 15 commonly seen types of surface water hazards classified based on water source and inrush conduits. The classification offers reference to devise preventative and treatment plan.
2. The five coal-bearing regions on China mainland are in different climatic regions. Each coal-bearing region shows distinct terrain features, geological and hydrogeological conditions, as well as mining records. The differences in these aspects give rise to the discrepancies in types and characteristics of surface water hazards.
3. In terms of source of water, the most destructive are deluge and river water that breaks embankment during strong rainfall period. In terms of conduits, the biggest menace to mining safety comes from mining-caused roof caving and draining-caused karst breakdown which are the main conduits through which deluge or surface water gushes into mines.

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