

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 analysis of cases of surface water hazards in China coalmines, this article determined surface water sources and inrush conduits as the major factors that have caused water inrush disasters in mines, and classified surface water hazards in China coalmines into 15 types according to those major factors and gave definitions of each type of surface water hazard. Then, it is 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 discuss how typical water sources and inrush conduits work together in hazard formation, in addition to the characteristics and corresponding preventative technologies. The propositions can be of reference for exchanges with other mining countries and regions on surface water hazard 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 in 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 in the mine up to the ground surface, a method which would further contaminate the surface environment (such as surface water and soil) (Coynel *et al.* 2007; Li *et al.* 2014; Mohamad & Stefan 2014; Price & Wright 2016; Yakovlev *et al.* 2019). Therefore, research into the treatment of coalmine water hazards has received much attention from the government, mining enterprises, and academic experts (Jangwon *et al.* 2013; Wu 2013; 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, and karst water. Surface water, for instance, will cause mine flooding and mass casualties once it breaks into the underground mine, and thus is rated as one of the major water hazards in China. On December 19, 1977, in the

Liaoyuan mining district of Jinlin Province, water from a 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 August 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 a China coalmine 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 other types of water (such as loose bed water, formation water, bore hole leakage, underground dam failure, etc.). Surface water ranked second, and was responsible for 4.3% of all such tragedies.

It has been proven that surface water hazards are 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 the ground ecosystem in Chandrapur, India, under the impact of mining activities. The study assessed flooding risks to the mining district and proposed probable countermeasures. Analyzing numerous water inrush cases in many coal-producing countries around the world, Vutukuri & Singh (1995) thought that there was a need to establish a hydrological database so that the surface water dynamics and the potential threat to coal mines are well known in a timely manner, and proposed that it is necessary to use existing methods and develop new technologies to prevent surface water from inrushing into mines to avoid coalmine water disasters. Wang *et al.* (2006) illustrated the technical evaluation of mining safety under surface water based on a description of the 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 fully-mechanized caving mining of a thick coal seam under surface water and its impact on surface water, Wang *et al.* (2013), using strata data from bore hole drilling and the 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 have also discussed the coupling relationship between ground fissures and mining fissures, leading to a sound evaluation of flooding risks in fully-mechanized caving mining of thick coal seams 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 districts, and to 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 sources 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 for treating such hazards in coalmines.

China has six coal-bearing regions, namely the 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 deluges, rivers, 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 to over 1 billion tons annually by the end of the 1980s. In the last 10 years, annual coal output has been more than 3 billion tons, almost half of the world's total output.

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

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

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

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

SN	Date	Location	Water source/inrush conduits	Strength of water flow	Losses and casualties
1	Jul. 22, 1959	Zhaogezhuang Coalmine, Hebei Kailuan mining district	Deluge-river water/deserted pits	Water flow 9,756 m ³ /h	Production halt
2	Aug. 2, 1960	Benxi Caitun Coalmine, Liaoning Shenyang mining district	Deluge-river water/deserted pits	Total water volume 960,000 m ³	30-day production halt, 13 deaths
3	Dec. 19, 1977	Meihe No. 1 Coalmine, Jilin Liaoyuan mining district	Reservoir water/cavings	Total water (sand) volume 56,520 m ³	9,130 m tunnel under water, 23-day production halt, 64 deaths, 93 injured
4	Aug. 25, 1985	Yangmeishan Coalmine, Hunan Zixing mining district	Deluge-river water/karst breakdowns and fault	Water flow 7,180 m ³ /h	90-day production halt, 1 death
5	Jun. 5, 1986	Shanjiaoshu Coalmine, Guizhou Panjiang mining district	Deluge/shaft	Total water (sand) volume 11,601 m ³	3,363 m tunnel under water, 21-day production halt, 8 deaths, 1 severely injured
6	Mar. 2, 1987	Private pit, Xinzhuang Zi Coalmine, Anhui Huainan mining district	Collapse pond/water-conductive fissures	Total water volume 137,000 m ³	270-day production halt, 12 deaths
7	Aug. 5, 1993	Longshan Coalmine, Shandong Linyi mining district	Deluge/deserted pits	Water volume of several tens of thousands m ³	Mine flood, 58 deaths
8	Jul. 13, 2006	Jinli Coalmine, Inner Mongolia Erdos mining district	Deluge/shaft	Water volume of several tens of thousands m ³	Mine flood, 2 deaths
9	Aug. 17, 2007	Huayuan Mining Co., Shandong Xintai mining district	Deluge-river water/goaf area in deserted pits	Total water (sand) volume 12.6 million m ³	Mine flood, 181 deaths
10	May 23, 2013	Su'er Coalmine, Fujian Subang mining district	river/collapses in riverbed	Total water volume 90,000 m ³	Flooding of two mining pits, central pump house (−110 m) and one power substation

- (2) Surface water rushes into coalmines through multiple conduits, such as shafts, 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 a water source and inrush conduits. From Table 1, it can be inferred that major sources of surface water threatening coalmines are, among others, deluges, rivers, and lakes, which correspond to deluge water hazard, river water hazard, lake water hazard, and so on around coalmines. Surface water, coming from different sources, invades mines through various conduits, such as shafts, deserted pits, mining-caused cavings and water-conductive fissures, karst breakdowns, protogenic rifts, and so on, contributing to the complexity of surface water hazards, such as rainfall deluges bursting into mines through shafts, river water bursting into deep mining working faces through shallow deserted pits, and so on. 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

With analysis of 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 are set out in Table 3.

Regional differences in surface water hazards

Surface water (such as rivers, lakes, deluges, etc) are replenished by precipitation, under constraints of weather conditions. In mining districts, 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

Source conduits	Deluge	River	Lake
Shaft	#1	#2	
Deserted pits	#3	#4	#5
Cavings	#6	#7	#8
Water-conductive fissure zone	#9	#10	#11
Karst breakdowns	#12	#13	#14
Protopenic 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 goafs, etc.

iv. Cavings and water-conductive fissures are caused by mining.

v. Protopenic cavity includes mountain gullies, water-conductive faults, etc.

Table 3 | Definitions of surface water hazards in coalmines

Type	Definition	Type	Definition
#1	Rainfall deluge (including mountain torrents, gully water, etc.) that bursts into mines through shafts	#9	Rainfall deluge that bursts into mines through mining-caused roof water-conductive fissures
#2	River water that bursts into mines through shafts	#10	River water that bursts into mines through mining-caused water-conductive fissures
#3	Rainfall deluge that bursts into deep mining working faces through shallow deserted pits	#11	Lake water that bursts into mines through mining-caused roof water-conductive fissures
#4	River water that bursts into deep mining working faces through shallow deserted pits	#12	Rainfall deluge that bursts into mines through karst breakdowns
#5	Lake water (incl. reservoirs, collapsed mine ponds, etc.) that bursts into deep mining working faces through shallow deserted pits	#13	River water that bursts into mines through karst breakdowns
#6	Rainfall deluge that bursts into mines through mining-caused roof-caving sinkholes	#14	Lake water that bursts into mines through karst breakdowns
#7	River water that bursts into mines through mining-caused roof-caving sinkholes	#15	Rainfall deluge that bursts into mines through protogenic cavities, such as gullies and water-conductive faults
#8	Lake water that bursts into mines through mining-caused roof-caving sinkholes		

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

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

Typical surface water hazards

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

Water hazards caused by deluge. Coalmines in mountainous areas usually set up production sites on flat terrain at the foot of the hills (Figure 1). If flood control works are not well designed or constructed, on days of heavy rainfall or downpour, torrents flush down gullies and forcefully burst into mines. Normally, in humid areas (e.g. South China), coalmines surrounded by mountains with gullies developed in a V-shape are susceptible to frequent and severe accidents associated with surface water. On August 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 $7,180 \text{ m}^3/\text{h}$, flooding the whole mine and killing one person.



Figure 1 | Coalmine at mountain foot (red arrows showing water flow through the gullies).

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

The preventative measure against deluge, first and foremost, is to move the production site and constructions away from gullies pointing to valley lows. Second, elevate the collar and main construction on the production site to a location higher than the highest flood levels in local records. Third, around the lower collars and construction onsite, it is imperative to build embankments to stop deluges or canals diverting torrents to the coalmine outskirts. Baijigou coalmine of Ruqigou mining area, Ningxia Province, in the coal-bearing regions in Northwest China, is located in Alpine terrain surrounded by mountains. There was a serious surface water accident in Baijigou coalmine, which caused 17 people to die. 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 the water level to a point where water flow could break water barricades, endangering mining safety (Morrison *et al.* 2019). On July 30, 1998, torrential rain hit Wanzihe Coalmine, Henan Xinmi mining district of the 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 August 16 and 17 around Huayuan Mining Co., Shandong Xintai mining district of North China coal-bearing region, accumulated to 180 mm and caused a mountain flood. The highest flood point passing through the Chaiwen River, east of the coalmine, was as high as $1,840 \text{ m}^3/\text{s}$, which far exceeded the river's discharge capacity ($1,089 \text{ m}^3/\text{s}$). The river embankment failed as a result. River water breached the mine through three conduits (No.#3 is an abandoned shaft, No.#1 and No.#2 are mine collapse pits) (Figures 2 and 3). The tremendous water force washed inland and eroded a $44,000 \text{ m}^2$ area. The mine was scoured by $12,600,000 \text{ m}^3$ of water and $300,000 \text{ m}^3$ of mud and sand, taking 181 lives.

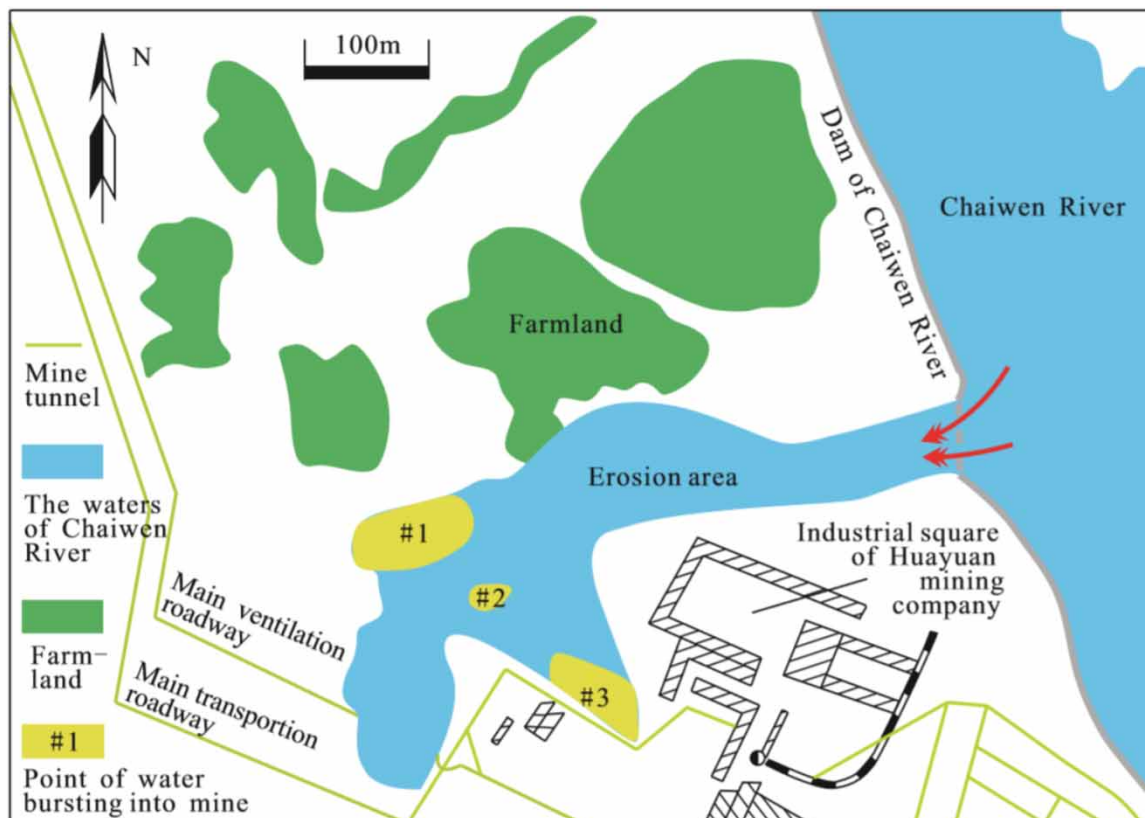


Figure 2 | Water breach point at Huayuan Mining Co.

In order to prevent water accidents caused by river embankment failure, regular desilting at the proper frequency is mandatory to ensure unobstructed river flow. Additionally, flood control works can be reinforced by widening the river bed, building flood-control ditches or levees, or diverting river flows when necessary, so as to keep rivers off mining districts. Hongling coalmine of Shenyang mining area, Liaoning Province, in the coal-bearing regions in Northeast China, is located in the front of the Hun river and Taizi river alluvial plain. Baisha river, the first tributary of the Taizi river, passes through the mine, and 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.



Figure 3 | Erosion area after Chaiwen levee failure (Huayuan Mining Co.).

Water hazards caused by caving. Mining activities cause roof strata to deform and stratify into three layers; from the bottom up these are the caving zone, water-conductive fissures zone, and bending zone (Gui *et al.* 2018). At the same time, the 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 a 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 mines. If the mining working face is very close to the overhead collapse pits, it is very likely that the caving zone and water-conductive fissures zone will join and act as conduits for the pits or fissures. In case of heavy rain or if there is sufficient water in collapse ponds, a 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 7 m wide and 3 m deep (Figure 4). On days of no rain, the ditch had a negligible amount of water. On July 24, 1970, a heavy rain filled up the ditch. Turbulent water flow swirled and pushed the ditch deeper. The #11 coal seam in the mine was only as thick as 1.8 m. The direct roof strata were composed of arenaceous shale (as 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 out in *Protocols for coal pillar retainment in major roadways and compressed coal mining under buildings, water bodies, and railways* (SBCI 2000), the maximum height of the caving zone should have been 6.5 m, a requirement higher than the actual thickness of the 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. A maximum water flow of 18,000 m³/h flooded the whole mine and killed 2 colliers.

There are two approaches to treating surface water hazards caused by roof caving. First, is to retain adequate water (sand)-repellent coal pillars to properly distance the mining site from overlying water bodies. Second, is to realign the surface water if the coal pillars cannot be retained as required. For example, drain smaller water bodies, divert river flows, or grout the river (lake) bed. Zhouyuanshan

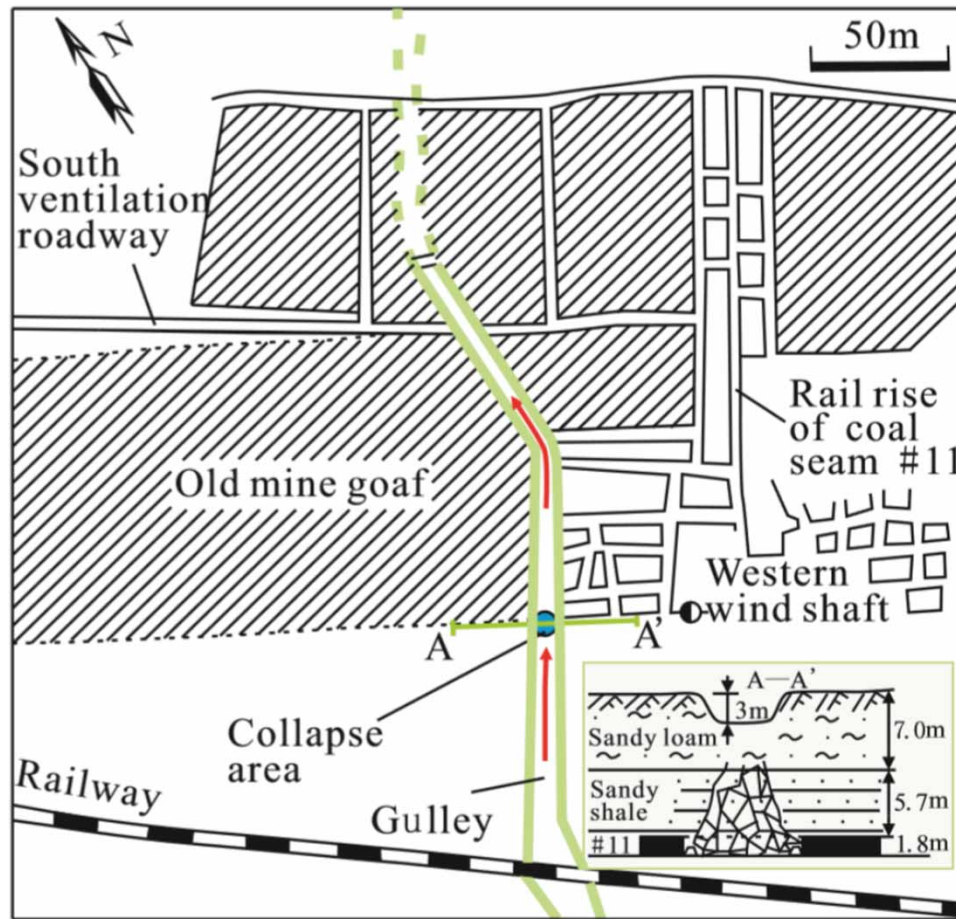


Figure 4 | The accident caused by surface water in #11 seam in Zhangzhuang Coalmine.

coalmine of Sandu mining area, Hunan Province, coal-bearing regions in South China, is located in a 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 with concrete, which reduced 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 a karst cave may break down under self-weight and the negative pressure caused by draining. As the breakdowns grow to reach the ground surface or surface water, they are convenient conduits guiding deluges 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 the 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 June 1984, heavy rain hit the mining district from the evening of the 25th to 7 am on the 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 9 am on the 26th, water flow in the -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 six 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 of tunnel and incapacitated considerable amounts of electric apparatus, halting production for 18 days.

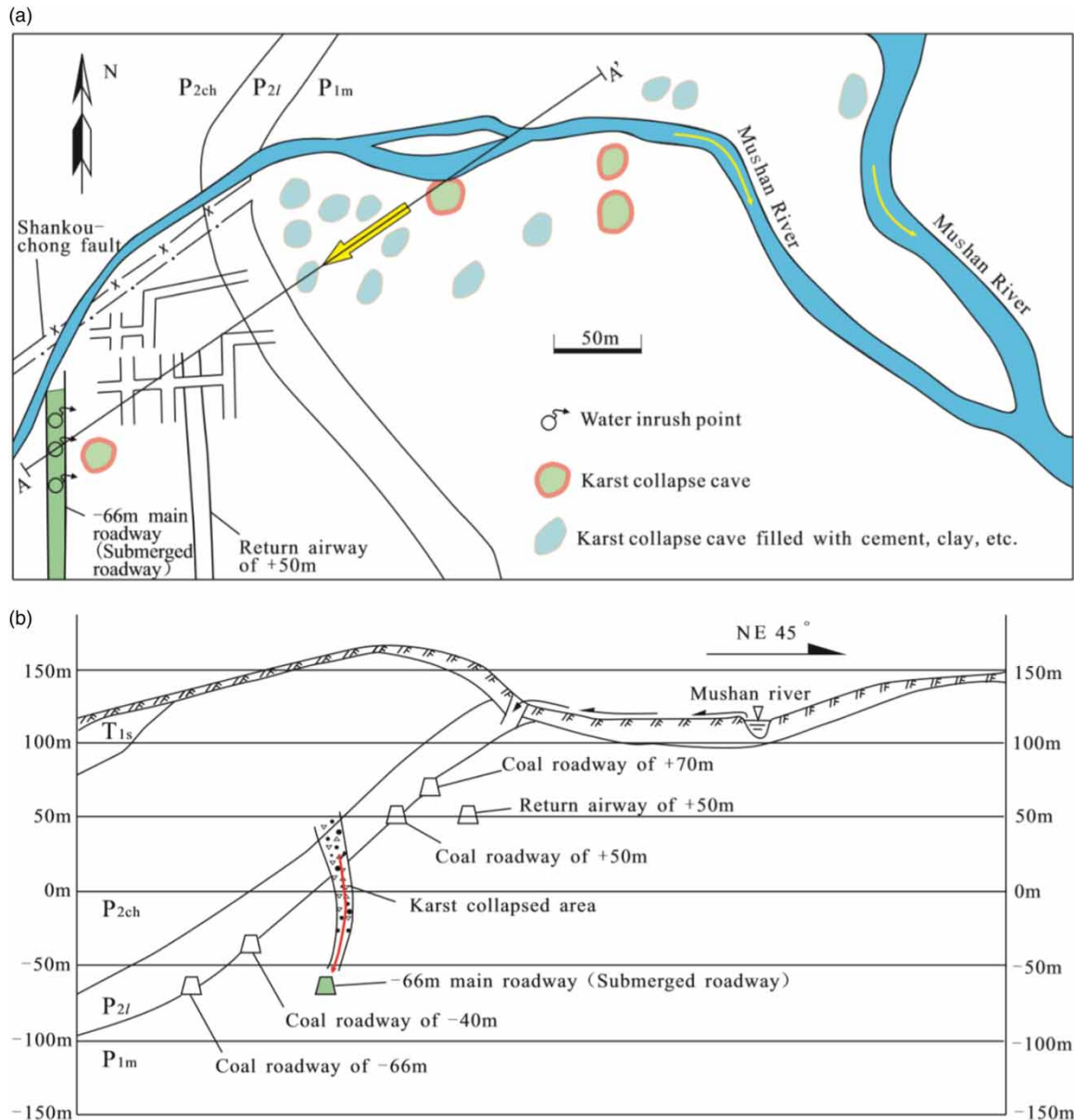


Figure 5 | Hydrogeological map of the flooded section of -66 m main roadway in #2 mine, Enkou Coalmine. (a) Planimetric map, (b) cross section of A—A'.

The key to treating 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 collapses (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 a karst area. Water accumulation in karst depressions and rainstorms pours into the coal mine through karst caves so as to seriously threaten the safety of production of the mine. 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.

Therefore, the construction of 2,676 m drainage tunnel and 600 m of open channel in the underground mine will connect 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 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 plans.
- (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 deluges and river waters that break embankments during strong rainfall periods. 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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