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TECHNICAL ARTICLE

Hydrogeological Classification and Water Inrush Accidents in China's Coal Mines

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Abstract In 2012, China's State Administration of Coal Mine Safety conducted a reconnaissance and statistical analysis to better understand and characterize water inrush accidents in China's coal mines. Data collected from 12,985 mines from 26 provinces and municipalities were used to study each mine's hydrogeological classification, water content coefficient, and the level of effort being spent in preventing and controlling these accidents. Analysis of the water inrush accidents in these mines suggests that their likelihood reflects a mine's hydrogeological characteristics, and that they can be controlled by professionals who are specifically trained for mine water prevention and emergency responses. In terms of hydrogeological complexity, there were 78 extremely complex coal mines, 827 complex mines, 4141 moderately complex mines, and 6458 relatively simple mines. Advances in mine water control and management methods and techniques and implementation of safety standards and regulations have significantly reduced the number of people killed per ton of coal produced, but analysis of the 2013 water hazard accidents indicates that continued effort is needed to better understand hydrogeological classification and implement safe procedures in water prospecting and dewatering.

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Keywords Water hazard · Extremely hydrogeologically complex coal mine · Hydrogeologically complex coal mine · Major water inrush accidents · Grave water inrush accidents

Introduction

Table 1 summarizes the coal production and water disaster accidents in China's coal mines, from 2000 to 2013. Over these 14 years, there were 1131 water inrush accidents, which resulted in 4533 deaths. However, although annual coal production increased from 1 to 3.7 billion tons during those years, the number of water inrush accidents and associated fatalities have trended downwards. Water inrush disasters in China are categorized as ordinary (with <3 deaths), major ($3 \leq$ deaths < 10), grave ($10 \leq$ deaths < 30), and extremely grave accidents ($30 \leq$ deaths). There were 94 grave accidents with a total of 1734 deaths and 9 extremely grave accidents with a total of 426 deaths (Table 1). The fatality rate due to water inrush accidents per million tons of coal production fell from 0.35 to 0.02 %. This progress is not only due to advancements in water control and management methods and

Table 1 Water disaster accidents in China's coal mines from 2000 to 2013

Years	Coal production (×100 million tons)	Fatality rate due to water inrush accidents per million tons of coal produced	No. of water inrush accidents	No. of deaths	Accidents with 10 or more victims		Accidents with 30 or more victims	
					No. of accidents	No. of deaths	No. of accidents	No. of deaths
2000	10	0.35	104	351	5	65	–	–
2001	11.1	0.39	109	432	9	168	–	–
2002	14.1	0.36	159	509	9	130	–	–
2003	17.3	0.32	137	551	14	231	1	35
2004	20	0.18	118	357	5	107	1	36
2005	21.5	0.28	109	605	13	357	3	193
2006	23.3	0.18	99	417	5	124	1	56
2007	25.2	0.10	63	255	3	56	–	–
2008	27.2	0.10	59	263	8	135	1	36
2009	26.2	0.06	47	166	4	54	–	–
2010	32.5	0.07	38	224	6	137	2	70
2011	35.2	0.05	44	192	6	85	–	–
2012	36.6	0.03	24	122	5	57	–	–
2013	37	0.02	21	89	2	28	–	–
Total	337.2	0.13	1131	4533	94	1734	9	426

The data in this table comes from China's State Administration of Coal Mine Safety

techniques (Dong 2010; Dong et al. 2012a, b; Qian 2010; Shen et al. 2011; Sun et al. 2012a, b; Wang et al. 2011; Wu and Li 2002; Wu et al. 2011, 2012; Wu 2014), but also to implementation of better safety standards and regulations (State Administration of Coal Mine Safety 2009, 2011, 2013, 2014; State Administration of Work Safety 2009, 2011). The complementary 2009 Provisions on Mine Water Prevention and Control and the 2011 Coal Mine Safety Regulations (Water Control Part) were particularly important.

Hydrogeological Classification

In order to tailor the water control and management methods and techniques to each coal mine, the 2009 Provisions on Mine Water Prevention and Control and 2011 Coal Mine Safety Regulations require that all coal mines be hydrogeologically classified as simple, moderately complex, complex, or extremely complex, as the likelihood of a water inrush event is directly proportional to hydrogeologic complexity. This hydrogeological classification helps define the need and nature of supplemental exploration requirements, and the level of effort required to prevent and control water inrush events (Gong 2012; Wang and Jiang 2011; Wu 2014). Table 2 presents the classification criteria, which is based on the following factors:

- The degree to which aquifers or water bodies are affected or destroyed by mining,
- The distribution of goaf water inside and near the coal mine,
- The amount of water inflow,
- The amount of water inrush,
- The risk posed by water hazards, and
- The difficulty in water prevention and control.

In order to better understand the situation and characteristics of water inrush accidents, China's State Administration of Coal Mine Safety hydrogeologically classified the nation's coal mines. As of June 2012, data had been collected in 12,985 coal mines in 26 regional provinces and municipalities, and 11,504 had been classified in terms of their hydrological complexity. The authors participated in this exercise and in statistically analyzing the data. There were 78 extremely complex coal mines, 827 complex mines, 4141 mines of moderate complexity, and 6458 relatively simple mines (Fig. 1). Figure 2 shows the breakdowns in each of the 26 regions.

In addition, the study found that 10,559 independent water prevention and control departments had been established in these mines and that at least 18,748 workers were trained water hazard prevention and control specialists, while at least 42,181 professionals held certificates in water prospecting and dewatering. Approximately 23,828 drill rigs were being used for dewatering.

Table 2 Hydrogeological classification in China's coal mines (State Administration of Coal Mine Safety 2009)

Classification criteria		Hydrogeological classification			
		Simple	Moderate	Complex	Extremely complex
Degree to which the aquifers or water bodies are affected or destroyed by mining	Aquifer's property and recharge conditions	Aquifers (porous, fractured, and karst) affected by mining have poor recharge conditions and limited recharge sources	Aquifers (porous, fractured, and karst) affected by mining have average recharge conditions and certain amount of recharge sources	Aquifers (porous, fractured, and karst) affected by mining have good recharge conditions and recharge sources	Aquifers (porous, fractured, and karst) affected by mining have excellent recharge conditions and recharge source, and poor discharge to surface water
	Water yield (q) (L/s/m) (water inflow per unit drawdown	$q \leq 0.1$	$0.1 < q \leq 1.0$	$1 < q \leq 5.0$	$q > 5.0$
Distribution of goaf water inside and near the mine		No goaf water	Limited goaf water with known position and range of volume	Limited goaf water with unknown position and range of volume	Large volume of goaf water with unknown position and range of volume
Water inflow (m^3/h)	Average (Q_1)	$Q_1 \leq 180$ (in northwest regions, $Q_1 \leq 90$)	$180 < Q_1 \leq 600$ (in northwest regions, $90 < Q_1 \leq 180$)	$600 < Q_1 \leq 2100$ (in northwest regions, $180 < Q_1 \leq 1200$)	$Q_1 > 2100$ (in northwest regions, $Q_1 > 1200$)
	Maximum (Q_2)	$Q_2 \leq 300$ (in northwest regions, $Q_2 \leq 210$)	$300 < Q_2 \leq 1200$ (in northwest regions, $210 < Q_2 \leq 600$)	$1200 < Q_2 \leq 3000$ (in northwest regions, $600 < Q_2 \leq 2100$)	$Q_2 > 3000$ (in northwest regions, $Q_2 > 2100$)
Water inrush (Q_3) (m^3/h)		No	$Q_3 \leq 600$	$600 < Q_3 \leq 1800$	$Q_3 > 1800$
Risk posed by water inrush		No risk	Rare water inrush accidents; limited effect on mining; no threat to mine safety	Occasional water inrush accidents; threat to mining and safety	Frequent water inrush accidents; serious threat to mining and safety
Difficulty in water prevention and control		Simple engineering control	Relatively simple engineering control	Complicated engineering control and difficult to implement	Extremely complicated engineering control and very difficult to implement

(1) The water yield is of representative in the major water bearing stratum of the mine field; (2) the hydrogeological classification is determined by the highest level of q, Q_1, Q_2 and Q_3; (3) when there are multiple coal seams and the hydrogeological conditions vary in the same mine field, the hydrogeological classification should be divided for each minable coal seam; (4) the hydrogeological classification is determined by the highest level among the above indexes

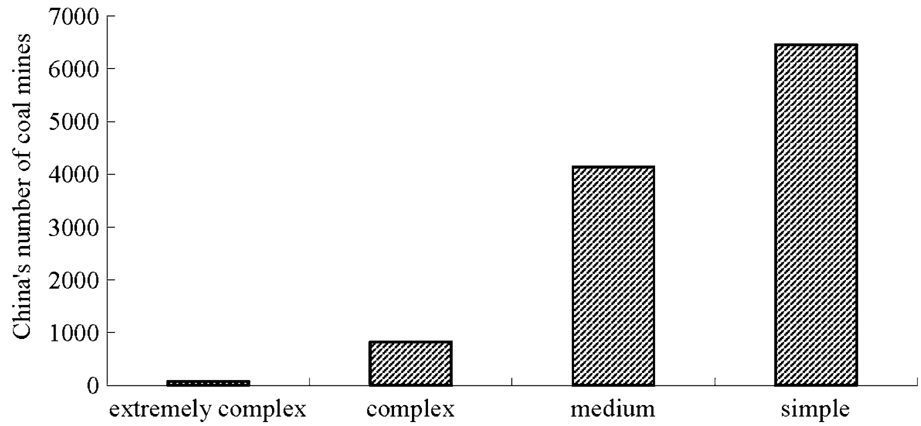

Fig. 1 China's number of coal mines versus their hydrogeological classification

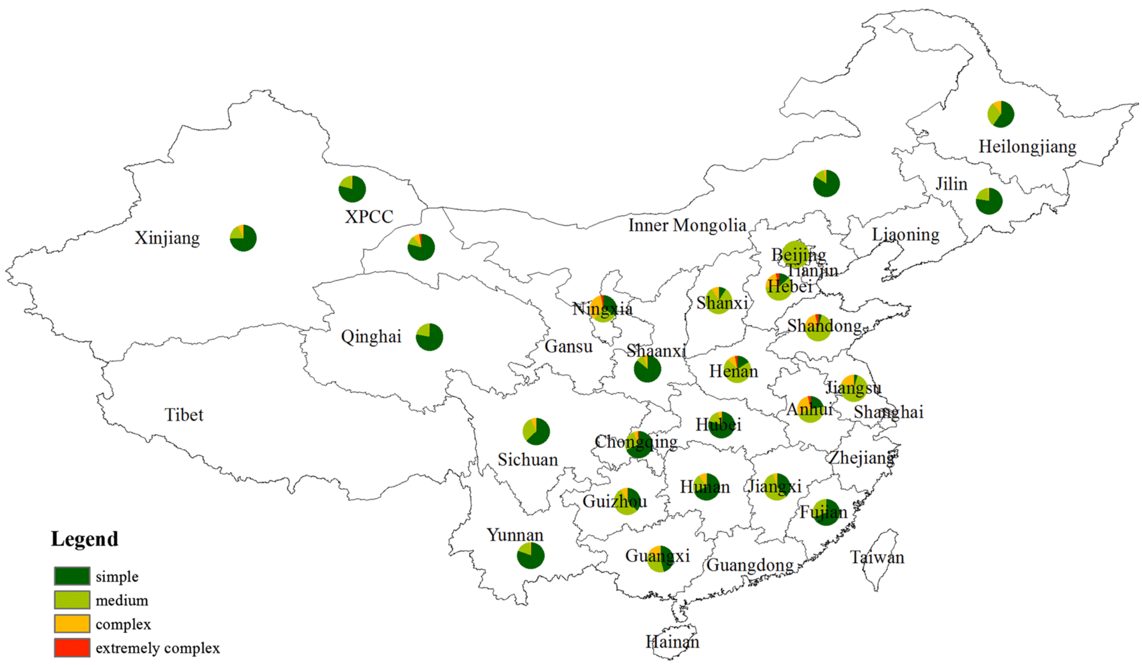

Fig. 2 Distribution of hydrogeological classifications in coal mines of China (*Note* XPCC means Xinjiang Production and Construction Corps.)

Analysis of Hydrogeological Classification

Based on this investigation, Beijing, Jiangsu province, Hubei province, and the Xinjiang autonomous region had hydrogeologically classified all of their coal mines. Eight provinces (Anhui, Fujian, Shandong, Henan, Hunan, Yunnan, Shanxi, and Gansu) had hydrogeologically classified over 95 % of theirs, while Hebei province, the Ningxia autonomous region, and Qinghai province had classified less than 50 % of theirs (Supplemental Fig. 1). There were various reasons for mines not having a reported hydrogeological classification, including having undergone corporate mergers/reorganization, no longer being in production, or not yet having been classified.

Supplemental Table 1 provides the regional distribution of coal mines with complex and extremely complex hydrogeology, where severe and very serious water hazard accidents often occur. Most (74.3 %) of these mines are located in Shanxi, Heilongjiang, Anhui, Shandong, Henan, Hunan, Chongqing, Sichuan, and Guizhou. Preventing and controlling water inrushes are extremely important in these areas.

Analysis of Hydrogeological Characteristics

Characteristics of Mine Water Inflow

According to the investigation, more than 0.2 billion m^3 of water was discharged annually from coal mines in the following 13 provinces/regions: Hebei, Shanxi, Inner Mongolia, Heilongjiang, Jiangxi, Shandong, Henan, Hunan, Chongqing, Sichuan, Guizhou, Yunnan, and Shaanxi. The discharges from these areas accounted for approximately 83.2 % of China's annual mine water discharge, which totaled 7.17 billion m^3.

There were 61 mines dealing with average inflows that exceeded 1000 m^3/h. There were 18 such mines in Henan, 11 in Hebei, 7 in Shandong, 6 in Inner Mongolia, 5 in Heilongjiang, 3 in Shaanxi, 2 in Shanxi, Guangxi, and Chongqing, and 1 in: Liaoning, Jiangsu, Anhui, Jiangxi, and Sichuan. The highest inflow of water into a single underground mine was at the Shendongjinjie mine in Shaanxi province, which had an average inflow of 4900 m^3/h and a maximum inflow of 5499 m^3/h. The second was the Yanmazhuang mine in Henan province, with an average inflow of 4500 m^3/h and a maximum inflow of 5400 m^3/h. Among the open pits, the maximum discharge was at the Yuanbaoshan mine in Inner Mongolia, in which the average inflow was 11,250 m^3/h and the maximum inflow was 12,500 m^3/h.

Data from the reported mines indicates that the ratio of the total maximum inflow to the total average inflow was 1.9. In 9 South China provinces and regions (Guangxi, Hubei, Jiangxi, Chongqing, Guizhou, Hunan, Sichuan, Fujian, and Yunnan), the total maximum inflow was at least twice the total average inflow (Supplemental Fig. 2), indicating that seasonal precipitation affects their discharges greatly. Coal mines in Guangxi province, where the average inflow was 9440 m^3/h and the maximum inflow was 28,540 m^3/h, had the highest ratio, 3.02. The ratio was 20.2 in Chongqing's Sanhuier mine, where the average inflow was 657 m^3/h and the maximum inflow was 13,250 m^3/h, and 6.2 in Guangxi Integrated Coal Company's Eastern Deflecting Mine, where the average inflow was 1860 m^3/h and the maximum inflow was 11,500 m^3/h.

A higher ratio of maximum inflow to average inflow suggests a closer hydraulic connection between precipitation, surface water, and groundwater, and that a large amount of water flows into the mine during the wet season. It is normal for underground mine inflow to increase dramatically during the rainy season in south China, so the coal mines there should have enough backup drainage capacity to be able to respond to a flooding emergency to prevent inundation. When very large storms are expected, it may be best to stop mining and withdraw the miners. The mine should restart production only when the threat of imminent danger has passed.

Characteristics of Water Content Coefficient

The water content coefficient is defined as the amount of mine water discharged per metric ton of coal produced in the same period. The average water content coefficient of China's coal mines is 2.04 m^3/t. The average water content coefficient exceeds 5 m^3/t in Guangxi, Hubei, Chongqing, Jiangxi, Hunan, Fujian, and Sichuan provinces (Supplemental Fig. 3).

Human Resource Distribution and Equipment Management in Coal Mines

Departments Established to Prevent or Control Water Inrush Accidents

According to this investigation, 10,559 mine water control departments had been established by mines to prevent or control water inrush accidents. Every mine in Beijing and Hebei, Fujian, Shandong, and Jiangsu provinces had established one, but less than 70 % of the mines in Guangxi and Shaanxi provinces had done so.

Professionals Specifically Trained for Preventing or Controlling Water Inrush Accidents

The total number of professionals working in preventing and controlling water inrush accidents in China was 18,748. On average, each mine had between 1 and 2 professionals. There were more professionals in the mines in Beijing, Hebei, Shanxi, and Shandong provinces, while in Liaoning, Hubei, and Guangxi provinces, the average number of professionals assigned to water hazard control in each mine was <1.

Technicians Certified for Water Prospecting and Dewatering

The total number of technicians certified for water prospecting and dewatering was 42,181. On average, each mine had 3.67 certified workers. Coal mines in Beijing, Hebei, Shandong, and Henan provinces had more than 10 certified workers, while Fujian, Jiangxi, Hubei, Hunan, Sichuan, Yunnan, Gansu, Qinghai, Xinjiang, and XPCC averaged <2.

Drilling Rigs Specifically Serving the Purpose of Dewatering

The total number of drilling rigs used for dewatering in China was 23,828. On average, each mine had more than two such machines. Coal mines in Beijing, Hebei, Shanxi, and Jiangsu provinces averaged more than four drilling rigs, whereas mines in Guangxi and Gansu province averaged no more than one.

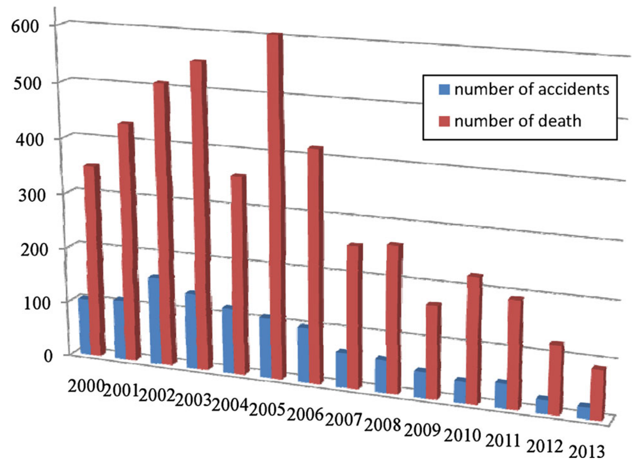

Fig. 3 Water disasters in coal mines of China from 2000 to 2013

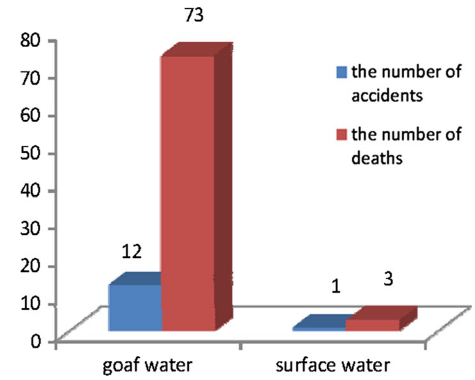

Fig. 4 Water sources for major and grave water disaster accidents in 2013

Analysis of Water Disasters in 2013

Twenty-one water inrush accidents occurred in 2013, resulting in 89 deaths (Fig. 3), compared to 24 such accidents and 122 deaths in 2012. Water disasters accounted for 3.5 % of the total coal mine accidents in 2013 and for 8.3 % of the deaths. Of the 21 water inrush accidents, 11 were major, in which a total of 48 people were killed, and two were grave, with a total death of 28; there were no extremely grave events. In comparison, in 2012, 8 of the 24 water disaster accidents that occurred were major, in which 50 people were killed, and five were grave, with 57 deaths. In comparison with 2012, while grave water inrush accidents decreased, major ones increased, so preventing major water accidents, not just the grave ones, has to be a key focus. Moreover, the data show that major water inrushes often occurred in town-owned mines or at a tunneling face, and that goaf water was the main water source.

Additional effort is essential to detect any symptoms indicative of water hazards. Of the 11 major water inrush accidents in 2013, 10 were caused by goaf water and 1 was caused by surface water, while the water source for both grave water events was goaf water (Fig. 4).

Coal Mines: Hydrogeological Classifications and Ownership

Table 3 presents the major and grave water inrush accidents and the hydrogeological conditions under which these accidents occurred. Of the 11 major water inrush accidents, four occurred in coal mines with simple hydrogeology, five occurred in mines with moderate complexity, and two occurred in mines with complex hydrogeology. The coal mines with simple hydrogeological classifications are all owned by towns. The coal mines with moderate hydrogeological classifications are either owned by towns or the state. The complex mines are all state-owned. The two grave water hazard accidents occurred in coal mines with either moderately complex or complex hydrogeological classifications.

Table 3 Major and grave water disaster accidents of China's coal mines in 2013

Types of water accidents	Hydrogeological classification	No. of coal mines	No. of deaths
Major	Simple	4	14
	Moderate	5	26
	Complex	2	8
Grave	Moderate	1	10
	Complex	1	18

Main Reasons for Water Inrush Accidents

The main reasons for the 13 major and grave water inrush accidents were a poor understanding of the mine's hydrogeological complexity and inadequate implementation of prospecting and dewatering. When obvious evidence indicated the potential for a water inrush, no immediate measures were taken to stop mining and withdraw the miners.

Conclusions

Of the 12,985 coal mines from 26 provinces and municipalities analyzed, 78 had extremely complex hydrogeology, 827 were complex, 4141 were moderately complex, and 6458 were relatively simple. The coal mines' characteristics were affected by their mine water inflow, water content coefficient, and hydrogeological complexity, as well as efforts made to prevent and control water inrush accidents, including establishment of special departments staffed with professionals and certified workers for water prospecting and dewatering, and equipped with drilling machines for dewatering. Detailed analysis of 2013's major and grave water inrush accidents indicated the necessity of continuing to better understand the hydrogeology of the mines and to implement better safety-oriented water prospecting and dewatering procedures.

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