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IMWA INSIGHTS

Avoiding Coal–Water Conflicts During the Development of China's Large Coal-Producing Regions

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Abstract Coal and water resources are important and fundamental to the sustainable development of China's national economy and society. However, coal–water conflicts are beginning to restrict coal production. In order to study this serious problem, the threat of mine water disasters, the supply–demand imbalance of water resources in coal mining areas, and the nature of polluted mine water were considered. Our results show that these problems are best resolved by viewing coal and water as coupled resources, using an optimized five fold combination of mine water control, treatment, utilization, groundwater recharge, and environment-friendly treatment. Water that is pumped to the surface to make a mine safer to operate can be used without being treated if it is kept separate from contaminated mine water and can be a resource, as can mine water that has been properly treated.

Keywords Coal producing regions · Countermeasures · Restriction analysis · Water inrush · Water resources

Introduction

China is a country with water resources that are abundant in the south and east and insufficient in the north and west; the spatial distribution of its coal resources is the reverse. China has high water consumption requirements, principally for agriculture, industry, and domestic water. In southern China, most of the water supply is surface water, while the north depends more on groundwater. A large amount of groundwater is pumped during coal mining, for the sake of mine safety, but if effective measures are not taken to protect water resources, this pumping can trigger supply and demand conflicts between coal extraction and water supply, which will restrict development. In this paper, we will examine the current water and coal supply and demand issues in the 14 large coal-producing regions in China (Fig. 1) and propose reasonable measures to protect water resources, while supporting scientific exploitation of the coal resources.

During the 11th 5-year plan period (2006–2010), most coal was extracted from 13 large coal producing regions, Shandong, Jinbei, Jinzhong, Jindong, east Inner Mongolia-Northeast, Yunnan-Guizhou, Henan, Western Shandong, Huaibei-Huainan, Huanglong (Huating), Jizhong, Ningdong, and Shanbei. During the current 12th 5-year plan period, the Xinjiang region will become the 14th large coal-producing region (Fig. 1).

The eastern coal regions (eastern Inner Mongolia-Northeast, Jizhong, Western Shandong, Henan, and Huaibei-Huainan) are mostly located in plain lands, and have a long history of exploitation. Over 83×10^9 metric tons (t) coal of usable reserves have been extracted, and 98×10^9 t will be produced in the future. The water table is high in these regions and karst water and fissure water (water transmitted through fractures) represent major water inrush hazards.

The central coal regions, including Shandong, Jinbei, Jinzhong, Jindong, Huanglong, Shanbei, and Ningdong, are located in arid and semi-arid areas. The high-quality coal resources being developed in these areas make up 55% of China's total resources. More than 110×10^9 t coal of usable reserves were extracted, and 471×10^9 t will be produced. Fissure water and pore water are the major water inrush hazards.

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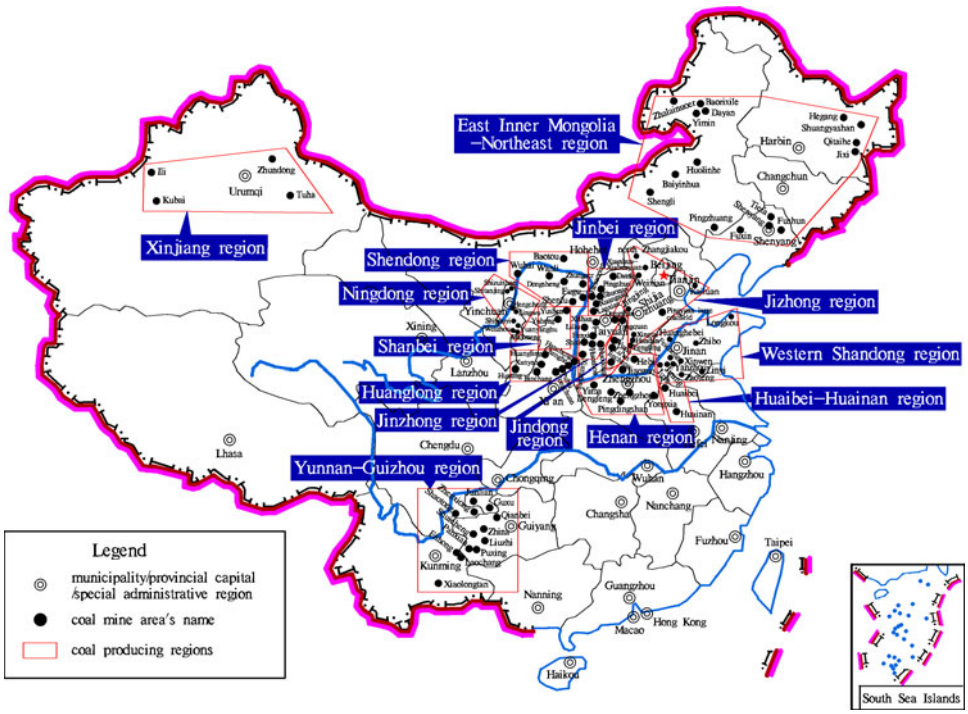

Fig. 1 China's 14 large coal producing regions

The sulfur content is higher in southwest China's Yunnan-Guizhou region than in the other regions, so the exploitation of that coal should be limited. Twelve billion t of usable reserves have been extracted, and 72 $\times$ 10^9 t will be produced. Karst water and fissure water cause in rush hazards in the Yunnan-Guizhou region.

Northwest China's Xinjiang coal producing region contains 2.19 $\times$ 10^{12} t of predicted resources, more than any other region, and 40% of all of China's predicted resources. The output of Xinjiang coal mines was only 100 $\times$ 10^6 t in 2010, of which 26 $\times$ 10^6 t were exported; production was limited by the extent of industrial development. With the introduction of Xinjiang as a large coal producing region during the 12th 5-year plan period, all kinds of hydrogeological explorations, the production of large and super-large coal mines, and the development of transport channels for coal will radically resolve the existing bottlenecks, assuming that potential water shortage problems can be resolved (Gao 2008; Tan et al. 2008; Wu and Li 2002).

Water Resources and Coal Production

Chinese produced 3.24 billion t of coal in 2010, and expects to produce 3.79 billion t/year by the end of the 12th 5-year plan in 2015. The increase will largely come from western China, but the water resources of this arid and semi-arid area will inevitably restrict coal field development. The effect of coal exploitation on water resources has been widely studied (Adam and Paul 2000; Andreas and Nikola 2011; Karen and Paul 2006; Tan 2008; Wu and Chen 2008; Wu et al. 2002, 2005; Zhang et al. 2009). However, there is little information on how limited water resources affect coal exploitation. We analyzed the key influential factors in China.

The Threat of a Mine Water Disaster

Coal mines in eastern China have a long history of exploitation and most mining takes place underground. Because near-surface coal has been fully exploited, the average depth of mining is now over 650 m. As these lower seams are mined, the water pressure of the underlying limestone aquifer has increased, increasing the risk that high-pressure karst water will burst into the mine through the mine floor. According to incomplete statistics, more than 5 billion t of coal reserves in China's eastern coal fields are threatened by water inrush (Hua et al. 2006).

The central and Xinjiang coal regions have thick coal seams that are located in arid and semi-arid areas, relatively near the surface. Large-scale mechanized coal mining disturbs overburden strata, so overlying fractured sandstone, a porous quaternary aquifer, and surface water may threaten the safety and production of coal mines.

Mine water inrush events in China are generally through the mine roof or floor, rather than through the working face. The water hazard situation in large coal producing regions is summarized in Table 1. As mining depth increases, hydrostatic pressures also increase, so that safe

Table 1 The water hazard situation in 13 of China's large coal producing regions

Coal-producing regions	Mining districts	Hydrogeology	Source of water
Shandong	Dongsheng	Simple	–
	Shenfu-Xinmin	Simple	Roof
	Zhungeer	Simple	Roof
Jinbei	Datong	Simple	Floor
	Pingshuo-Shuonan	Simple-medium	Floor
	Hebaopian	Simple	Roof
Jinzhong	Xishan-Gujiao	Simple-complex	Floor
	Huozhou	Simple-medium	Floor
	Lishi-Liulin	Simple	Floor
	Xiangning	Simple	–
	Qinyuan (Huodong)	Simple	–
Jindong	Yangquan	Simple	Floor
	Lu'an	Simple-medium	Floor
	Jincheng	Simple	Floor
Eastern inner Mongolia-Northeast	Shengli	Medium	
	Baiyinhua	Medium	
	Zhalainuoer	Simple	
	Huolinhe	Medium	
	Baorixile	Simple	
	Yimin	Simple	
	Jixi	Medium	
	Hegang	Medium-complex	
Yunnan-Guizhou	Six mines such as Panxian	Simple-medium	
	Guxu-Junlian	Simple-medium	
Henan	Pingdingshan	Simple	Floor
	Dengfeng-Zhengzhou	Simple	Floor
Western Shandong	ZaoTeng	Simple	Roof, floor
	Juye	Simple	–
	Huanghebei	Simple	Roof, floor
Huaibei-Huainan	Huaibei	Medium	Roof, floor
	Huainan	Medium	Roof, floor
Huanglong	Binchang	Simple-complex	–
	Weibei	Medium-complex	Floor
Jizhong	Handan-Xingtai	Complex	Floor
Ningdong	Lingwu-Yuanyanghu	Simple	–
Shanbei	Yushen	Simple	Roof
	Yuheng	Simple	–

zones become dangerous. The increased of depth of mining, especially in central and eastern China, means that more coal mines will face the threat of water inrush from underlying high-pressure karst water.

The Supply–Demand Imbalance of Water Resources in Coal Mining Areas

Eleven of the fourteen large coal producing regions are located in arid and semi-arid areas where water is in short supply, though the situation is not too limiting in Yunnan-Guizhou, Huaibei-Huainan, and eastern Inner Mongolia-Northeast. It is estimated that by the year 2020, the total projected water requirement of the thirteen regions (not including Xinjiang region, which is still being developed) will be 608.14×10^4 m^3/d. The present water supply totals 212.37×10^4 m^3/d, so there is a water shortage of 404.14×10^4 m^3/d. The details are shown in Fig. 2. Water shortages seriously restrict the continuous development of the coal industry in most of these areas.

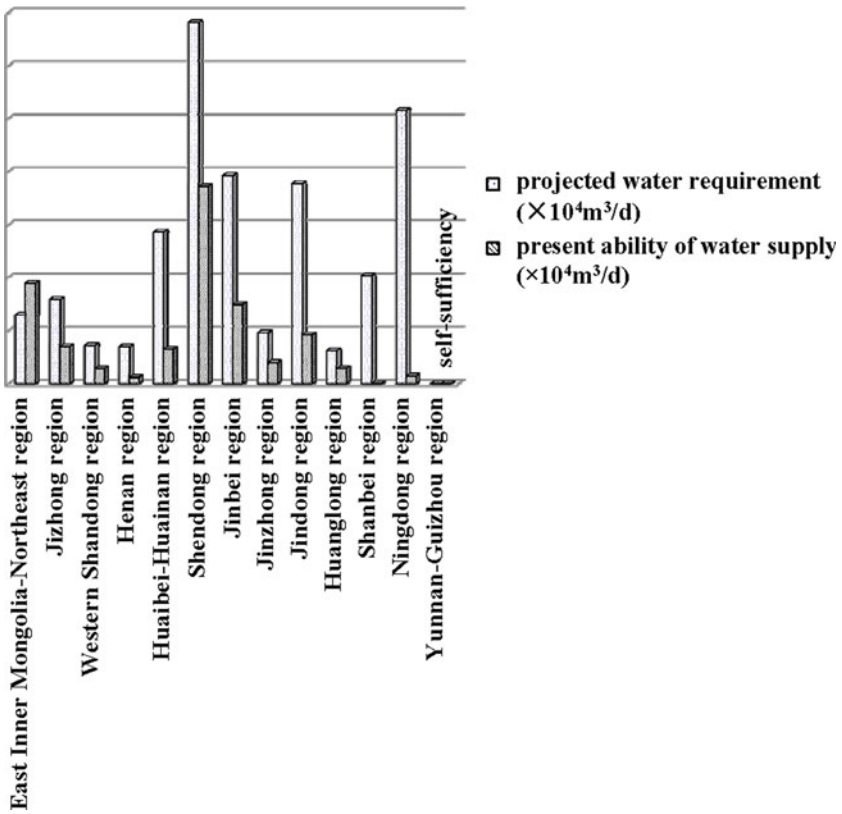

Fig. 2 The projected water requirement (to 2020) and the present water supply in 13 of China's large coal producing regions

Mine Water Pollution

Suspended and dissolved minerals can contaminate water pumped from coal mines. If the mine drainage is polluted and highly corrosive, it is also detrimental to coal mine production. In addition, the electricity required to pump all of this water to the surface significantly increases coal production costs, which restricts production capacity.

Countermeasures

Viewing coal and water as coupled resources during mine development can be a solution to these problems. It is assumed that as little groundwater as possible will be discharged during the mining process. The water that is pumped to the surface will be recycled, so that the fragile eco-environment around coal mine areas will be protected. Making full use of groundwater and mine water, and avoiding adverse effects on the eco-environment, are key components of attaining sustainable development of the coal and water resources. An optimized five-fold combination of mine water control, treatment, utilization, groundwater recharge, and environment friendly treatment are proposed.

Mine water control means that fractures or fissures that may induce water inrush events are grouted, and that water pressures are decreased, which reduces the risk of inrush events and enhances the stability of coal seam roof and floor strata. Mine water treatment and utilization means that the mine water is treated, either underground or on the surface, or partially treated underground and then polished on the surface, to meet the needs of potential users or for groundwater recharge. After treatment, if the water is reinjected underground, the quality of water used to recharge an aquifer should be better than the background water quality in the objective aquifer. Environment-friendly treatment means that mine water, after treatment, is reused during underground production, used to irrigate disturbed land during revegetation, or used to recharge the aquifer, as discussed above. Recharging the aquifer protects the area's groundwater resources and ensures no contamination downstream, thus protecting the ecological environment from pollution. It also enhances ecologically and economically sustainable development.

Separate Handling of Contaminated and Uncontaminated Mine Water

Mine drainage consists of inflow from various sources, including groundwater that is pumped to the surface to allow mining to take place safely and water that seeps into

the mine and has to be pumped out. Water that is uncontaminated, if kept separate from water that entered the mine workings, can be beneficially used without treatment. Sumps can be set up underground to keep good water from water that has to be treated after it is pumped to the surface. The unpolluted water can be pumped to the surface for direct use, which can greatly reduce water treatment costs.

Reducing Water Pressure in Potentially Dangerous Strata

Pore water in the Quaternary roof rock and Ordovician karst water in the mine floor are the main threats to the safe mining of China's coal seams. In order to ensure the safety of miners' lives and property, the groundwater should be pumped to reduce water pressure from these aquifers. Exploiting shallow karst water in shallowly buried limestone zones can reduce recharge to the stratum at the depth of the coal seam being exploited and thereby reduce the risk of an inrush event. Meanwhile, the water can be used because it is pure. This also reduces the amount of water that enters the mine and thereby reduces water treatment costs.

Making Mine Water a Resource

In eastern China, coal mines have ample water resources and only 22% of the mine water is utilized. About 1.4×10^9 t of water are discharged every year from northern state-owned coal mines and less than 20% of it is utilized. The mine water is treated to meet local and national standards and enhances economic development by being used to meet urban needs. Maximizing the utilization ratio of mine water resources not only improves the market competitiveness of coal enterprises, but also accelerates the sustainable development of regional economy.

Conclusions

By the end of the 12th 5-year plan in 2015, 14 large coal producing regions will be built. The main development areas will be the central and western regions where coal resources are rich. However, the spatial distribution of China's coal resources is the reverse of its water resources. Deficient water resources restrict the sustainable development of coal industry.

In order to study this serious problem, the threat of mine water disasters, the supply–demand imbalance of water resources in coal mining areas, and the nature of polluted mine water were considered. These problems are best resolved by viewing coal and water as coupled resources, using an optimized five fold combination of mine water control, treatment, utilization, groundwater recharge, and environment-friendly treatment. Water that is pumped to the surface to make a mine safer to operate can be used without being treated if it is kept separate from contaminated mine water, and it can be a resource, as can mine water that has been properly treated.

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