



Impact of coal mining on groundwater of Luohe Formation in Binchang mining area

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Abstract Groundwater of Luohe Formation is the main water source for industrial and agricultural and residential use in Binchang mining area, which is one of the key elements to water conservation coal mining. However, few studies are available to document the enrichment characteristics and influence of underground coal mining on groundwater for the Luohe Formation. This study evaluates the changes of groundwater levels and spring flow caused by mining activities to explore the influence mechanism of coal mining on groundwater by comparatively analysing existing mining data and survey data combined with a series of mapping methods. The results show that the aquifer of Luohe Formation are gradually thinning south-eastwards, disappeared at the mining boundary. In the vertical direction, the lithological structure is distinct, due to alternative sedimentation of meandering river facies and braided river facies. According to the yielding property, the aquifer is divided into three sections, namely, strong water-rich section, medium water-rich section, and weak water-rich section, which are located in northwest and central part, southwest, and the rest part of the mining area, respectively. Mining of Tingnan Coal Mine since 2004 has caused a 3.16 to 194.87 meters drop in groundwater level of Luohe Formation. Until 2015, 70.10% of the mining area undergoes a groundwater level drop larger than 10.00 meters. Another influence of underground mining is that the total flow from 34 springs in 8 southern coal mines of the area has decreased by 286.48 L/s with a rate of decrease at 46.95% from 2007 to 2017. The areas that groundwater level falls or spring flow declines are mainly located in the mine gob areas. Results also indicate that the ratio of the height of water conducted fracture zone to the mining height in Binchang mining area is between 16.85 and 27.92. This may increase ground water flow in vertical direction, causing a water level in the aquifer system to drop and ultimately decreasing the flow from the springs. The research results will provide data and theoretical support for the protection of groundwater resources and water conservation coal mining of Luohe Formation in Binchang mining area.

Keywords Aquifer enrichment · Groundwater level · Water conservation coal mining · Luohe Formation · Binchang mining area

1 Introduction

The west of China is abundant in coal resources, with a weak ecological environment. Protecting water resources is particularly important as water is the material basis for supporting regional ecological environment and economic and social development (Wang et al. 2010; Fan et al. 2019). However, in recent years, massive exploitation of coal has brought in serious environment problems to the area, such as ground surface damages caused by mine subsidence (Chang et al. 2018). In addition, mining induced aquifer

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damages have caused a series of water environment problems, including groundwater levels drop, water resources leakage, and surface spring drying up (Fan et al. 2020). These water environment problems have reduced the ecological function and threatened the drinking water safety in the mining area, and has seriously restricted the ecology and economy development of the region (Ebrahimi et al. 2014). Therefore, reducing water environment damages in coal mining and ensuring environmentally sustainable mining are urgent problems that needs solving in weak ecological areas (Fan 2019).

In view of the water environment problems caused by the exploitation of coal resources in the west of China, the concept of water conservation coal mining was proposed in 1992. During the past three decades, a plenty of field investigations, theoretical research, and engineering practices on water conservation mining have been implemented and documented. The water-retaining coal mining technology is aiming at protecting ecosystems (Fan 2017), which researches geological conditions identification (Li et al. 2019a, b), aquifer stability control (Li et al. 2018; Fan et al. 2019), and water and ecological constraints (Cheng et al. 2010; Ma et al. 2019). Based on the theory of water-retaining coal mining, a groundwater monitoring network has been established for large-scale coal production bases in the northwest of China and a geological environment carrying capacity research system has been built (Sun et al. 2019a; Fan et al. 2020). Furthermore, a mathematical model for aquifer water loss has been proposed (Ma et al. 2015, 2018). The water conservation mining has made important contributions to the scientific planning and mining in Shenfu mining area, alleviating the contradiction between coal exploitation and ecosystem, and the coordination of coal resource development and water resources protection.

The Binchang mining area is located in the hilly and gully area of the Loess Plateau in east Gansu Province. It is the core construction area of the Huanglong coal base and belongs to the western drought-deficient mining area. According to statistical data, the total water resources in Binzhou City and Changwu County are 76.87 million m³ and 45.49 million m³ respectively. The per capita water resources are only 210.00 m³ and 249.60 m³ respectively. The aquifers of the Cretaceous Luohe Formation in the area are rich in water and excellent in water quality. They are the main source of water for industrial and agricultural and residential waters in the region. With the exploration and exploitation of coal resources in the area since the 1980 s, a number of fully mechanized mines have been put into production successively. Due to the large aquifer thickness, strong water-richness, and easy to be disturbed by coal mining, the Luohe Formation has become a research focus in the region.

Wu (2019) analyzed the cause of water inrush in the Dafosi coal mine in Binchang mining area. It is believed that the Luohe Formation has become a direct or indirect water-filled aquifer for coal mining due to factors such as mining intensity and stability of the formation. Liu and Ju (2013) identified the water-richness and connectivity of the Luohe Formation aquifer in the Hujiahe Coal Mine, and predicted the height of water-conducting fracture zone through the practical detection and numerical simulation. Liu and Ju (2013) believed that the aquifer water of Luohe Formation is the main source of disasters affecting the safety of mines, and proposed the water prevention and control technology of “appropriate release, enhanced drainage, and active water control”. However, from the perspective of mine water control, large-scale artificial drainage will inevitably lead to changes in groundwater inflow conditions and a decline in groundwater levels, thereby affecting the surface ecological environment and threatening the safety of industrial and agricultural water use in mining areas.

Therefore, researchers have carried out studies on water conservation coal mining from the perspective of coordination between water resources protection and water disaster prevention. Guo and Dong (2019) and Li et al. (2019a, b) conducted detailed exploration of the Luohe Formation in the Gaojiabao Coal Mine and the Hujiahe Coal Mine, analyzed the variation of vertical water-richness, and vertically stratified the Luohe Formation. Guo and Dong (2019) and Li et al. (2019a, b) also established a numerical model of the groundwater seepage field under the condition of fracture zone in lower aquifer of Luohe Formation, and established the water retention mining plan of the area using the seepage law. Shi et al. (2018) performed hydrogeological research on water protective coal mining in the Luohe Formation of Yongzhen-Binchang Mining Area. The results demonstrated the feasibility of implementing water conservation coal mining in the mining area, and proposed technical measures for water conservation coal mining and water resources development and utilization program. Lü et al. (2017) implemented water-retaining coal mining division research on the Cuimu Coal Mine in Yonglong mining area of Huanglong coalfield. The researchers divided the research area into natural water-retaining mining area, controllable water-retaining mining area, and water-retaining limited mining area, and proposed corresponding water-saving coal mining method in each district.

The studies above show that the Cretaceous Luohe Formation is not only the main source of industrial and agricultural water in the mining area, but also the main source of disasters for the mine roof water inrush in the mining area. It is also the main target aquifer in the study of water conservation coal mining. However, most of the

previous research are based on a single mine, and there are few reports on the whole mining area. To enrich the research in this area, the research focuses on the fundamental research of water conservation coal mining in Binchang mining area. Drilling data of the Binchang mining area and survey data of groundwater and spring flow in the eastern part of the mining area are to be analyzed to explore the enrichment characteristics of the Luohe Formation aquifer and the impact of coal mining on groundwater. The research results will provide data and theoretical support for the protection of groundwater resources and water conservation coal mining of Luohe Formation in Binchang mining area.

2 Overview of the study area

2.1 Geomorphological features

The Binchang mining area is located in the hilly and gully area of the Loess Plateau in east Gansu Province. The altitude is generally 900 to 1200 m. Jinghe River passes through the middle of the study area, and the surface generally inclines from the southern and Northern tableland area to the middle Jinghe River Valley area. According to the characteristics of topography and geomorphology, this area can be divided into valley area, loess plateau area and loess ridge and residual tableland areas. The valley area mainly consists of Jinghe River and its tributaries, Heihe River and Hongya River Valley. Jinghe River Valley is about 210 m lower than the Loess Plateau, with a width of 3.00 km. The terrace is developed, which is the main agricultural area in this area. The loess plateau area is mainly located in the north of Jinghe River and Heihe River, and the landform is mainly Loess Plateau. From the east to the west, there are Xinmin tableland, Arctic Tableland and Changwu tableland. The tableland is open and flat, with an altitude of 1000 to 1200 m. The terrain is high in the East and low in the west, high in the north and low in the south. The highest altitude of the temple is 1260 m. Loess ridge and residual tableland area is mainly located in the south of Jinghe River and Heihe River, and its main geomorphic form is loess residual tableland and loess ridge. There are Shuikou tableland, Yongping tableland and Jujia tableland from the east to the West. The tableland surface is narrow and broken, and most of them are inclined to the valley. The altitude is generally 1000 to 1200 m.

2.2 Current situation of coal mining scale in the study area

Binchang mining area is the core construction area of Huanghong coal production base. It is the main mining area for the energy sources in Shaanxi Province and is the main energy supply in Shaanxi Guanzhong area. The mining area is about 46.00 km long from east to west, 36.50 km wide from north to south, and the area is 978.00 km². The geological exploration of coalfield in Binchang mining area began in the 1980 s. By the end of 2016, the coal reserves in the mining area was 7.562 billion tons. At present, there are 11 coal mines under production and 2 coal mines under development, with 12 large coal mines with a capacity of 1.20 Mt/a or more, and one medium-sized coal mine with a capacity of 0.45 to 1.20 Mt/a. The total production capacity of the mining area is 49.60 Mt/a (Table 1).

2.3 Coal seam characteristics

The formation of Binchang Mining area, according to the occurrence order from the earlier to the later, are the Triassic Zhongtong Tongchuan Formation (T_2t), Triassic Shangtong Hujiacun Formation (T_3h), Jurassic Xiaotong Fuxian Formation (J_1f), Jurassic Zhongtong Yan'an Group (J_2y), Jurassic Zhongtong Zhiluo Group (J_2z), Jurassic Zhongtong Anding Group (J_2a), Cretaceous Xiatong Yijun Formation (K_1y), Cretaceous Xiatong Luohe Formation (K_1l), Cretaceous Xiatong Huachi Formation (K_1h), Neogene (N), and Quaternary (Q). Among them, the Jurassic Yan'an Formation is a coal-bearing stratum with a total of 8 coal layers. The 5 layers with comparative significance and mining value are numbered 1, 2, 3, 4-upper, and 4 from top to bottom, respectively. These 5 layers are contained in three coal-bearing sections: the upper coal-bearing section contains the No. 1, No. 2, and No.3 coal seams, medium coal section contains the No. 4-upper coal seam, and the lower coal section contains the No. 4 coal seam. The No. 4 coal seams are fully recoverable while other coal seams are partially recoverable. The thickness of No. 4 coal seam is 0.15 to 35.04 m, and the average thickness is 10.64 m. The coal seam is thin in the east, west, and south, and thick in the middle north. The average thickness in the eastern region is 9.94 m and the maximum is 15.10 m. The average thickness in the southern region is 8.27 m and the maximum is 19.16 m. The average thickness in the northern region is 13.67 m and the maximum is 35.04 m (Shaanxi 186 coalfield geology Co., Ltd. 2017) (Fig. 1).

Table 1 Production capacity of the 13 mines in Binchang Mining area

Coal mine name	Production capacity (Mt/a)	Status	Coal mine name	Production capacity (Mt/a)	Status
Mengcun Coal Mine	6	Production	Wanjiapo Coal Mine	3.2	Production
Hujiabe Coal Mine	5	Production	Dafosi Coal Mine	3.0	Production
Gaojiabao Coal Mine	5	Production	Huoshizui Coal Mine	3.0	Production
Tingnan Coal Mine	5	Production	Xiagou Coal Mine	3.0	Production
Xiaozhuang Coal Mine	5	Production	Shuiliandong Coal Mine	1.5	Production
Yangjiaping Coal Mine	5	Development	Jiangjiahe Coal Mine	0.9	Production
Yadian Coal Mine	4	Development			

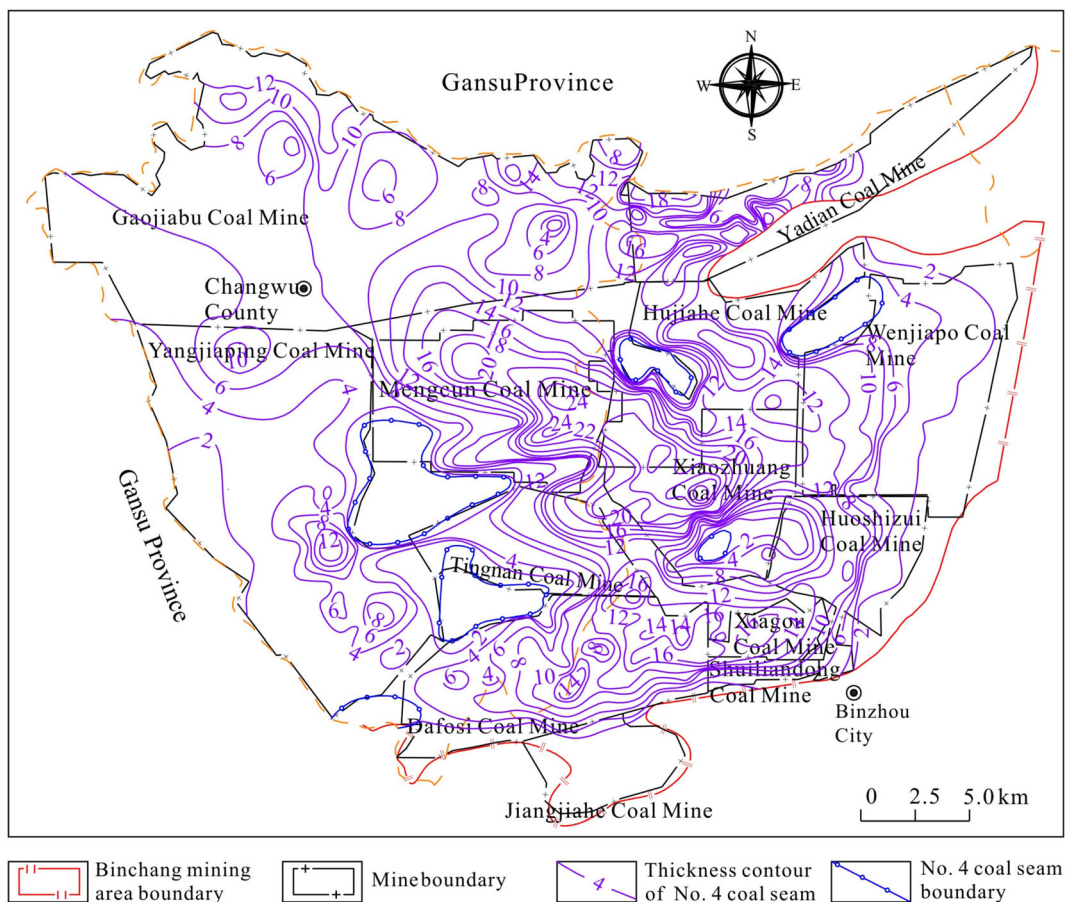


Fig. 1 Thickness contour of No. 4 coal seam in Binchang mining area

2.4 Characteristics of the aquifers

The water bearing or impermeable layers in the Binchang mining area are, from top to bottom, the Quaternary loess pore aquifer, Neogene red soil aquifuge, Cretaceous Huachi Formation pore-fracture aquifer, Cretaceous Luohe Formation and Yijun Formation pore-fracture aquifer, Jurassic Anding Formation aquifuge, Jurassic Zhiluo Formation pore-fracture aquifer, Jurassic Yanan Formation pore-fracture aquifer, and Jurassic Fuxian Formation

aquifuge (Fig. 2). Among these aquifers, the Cretaceous Luohe Formation aquifer are rich in water and excellent in water quality, thus has water supply value and ecological significance.

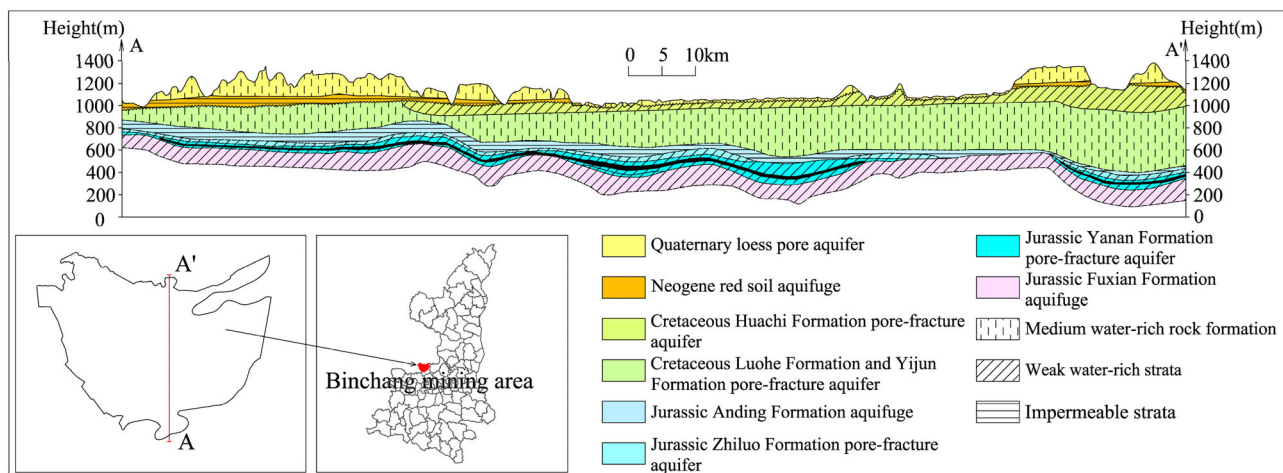


Fig. 2 Hydrogeological profile of Binchang mining area

3 Enrichment feature of Cretaceous Luohe Formation Aquifer

3.1 Aquifer occurrence characteristics of Cretaceous Luohe Formation aquifer

The Cretaceous Luohe Formation in the study area is located in the east valley of the Jing River and its branch ditch, and is located to the north of the Cretaceous Huachi Formation, with a thickness of 0 to 580.84 m, generally 200 to 300 m thick (Shaanxi 186 coalfield geology Co., Ltd. 2017). The lithology is mainly composed of purple-dark purple medium and coarse-grained sandstone, followed by conglomerate and glutenite, and mudstone and sandy mudstone are rare. In the horizontal direction, the bottom interface of the Luohe Formation is an integrated surface, which is in contact with the lower Yijun Formation. The bottom plate is generally a north-west inclined monoclinic structure. The thickness of the Luohe Formation gradually thins from the northwest to southeast and is pinched at the southeastern boundary of the mining area (Fig. 3). In the vertical direction, the Luohe Formation can be divided into upper, middle, and lower sections due to the influence of the alternate sedimentation of the meandering river facies, the braided river facies, and the meandering river facies (Fig. 4). The meandering flood plains and channel sediments are well developed, and the positive cycle is obvious, with a binary structure. The structure of lower section is the nearshore sedimentation, which is mainly caused by lateral accumulation. The upper structure is deposited in the floodplain and is mainly deposited vertically. The central braided section is characterized by a coarse and fine positive rotation from bottom to top. The sediments are mainly gravel grade and sand grade, the overall grain size is relatively coarse, and the water-richness is stronger than

that of the upper and lower meandering river sedimentary sections (Li et al. 2019a, b).

3.2 Water-rich feature of Cretaceous Luohe Formation

The heterogeneity of the horizontal and vertical distribution of the Luohe Formation in Binchang Mining Area determines the difference in water-richness. In the evaluation of water-rich aquifer, the unit water inflow, permeability coefficient, and aquifer thickness can intuitively represent the water-rich intensity and is positively correlated with water-rich intensity (Wu et al. 2015; Sun et al. 2019b). In order to evaluate the water-richness of the mining area, the author collected pumping test data of 35 boreholes in 11 coal mines from Shaanxi 186 Coalfield Geological Co., Ltd. (Table 2), and used the variation coefficient method to determine the weight values of the three indicators—unit water inflow, permeability coefficient, and aquifer thickness (Table 3). And the meanization method was applied to measure the indicators in a dimensionless manner, and obtain the water-rich index of each indicator (Table 4). The variation coefficient method determines the weights as shown in Eq. (1) and (2), and the mean-valued dimensionless treatment is shown in Eq. (3) (Zhang and Zhao 2005).

$$v_k = \frac{\sigma_k}{\bar{x}_k} \quad (k = 1, 2, \dots, m) \quad (1)$$

where v_k is the coefficient of variation for the k th indicator, σ_k is the standard deviation for the k th indicator, \bar{x}_k is the mean of the k th indicator, and m is the number of indicators.

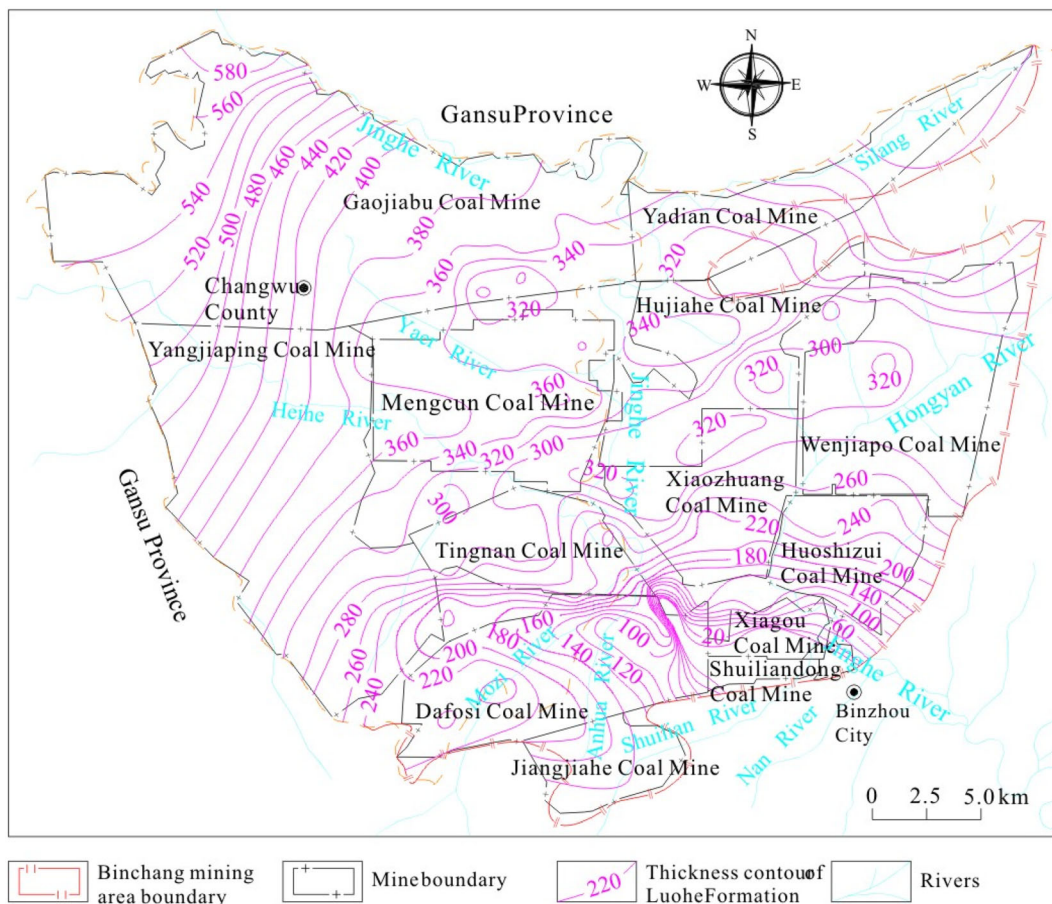


Fig. 3 The thickness contour of Luohe Formation in Binchang mining area

$$w_k = \frac{v_k}{\sum_{k=1}^m v_k} \tag{2}$$

where w_k is the weight coefficient for the k th indicator.

$$A_i = \frac{x_i}{\bar{x}_i} \tag{3}$$

where A_i is the dimensionless value, and \bar{x}_i is the mean of indicator data.

In order to determine the aquifer water-rich zone threshold, the author uses SPSS software to cluster the water-rich index for the 35 holes (Shaanxi 186 coalfield geology Co., Ltd. 2017). SPSS software is a data processing tool developed by IBM Company. Its functions include data management, statistical analysis, chart analysis, etc. it plays an important role in social science and natural science. According to the cluster analysis results, the water-rich index can be divided into four categories (Fig. 5). The hole T9 has the highest water-rich index of 2.8420 and is classified into one group. 5 holes (T2, J138-2, J151, 2-5, and 1-1) with water-rich index ranging from 1.7332 to 2.3751 are identified as the second group. The third group contains 11 holes with water-rich index

between 0.7676 and 1.1656. The fourth group contains the rest 18 holes with water-rich index in the range of 0.1890 to 0.6428. Since general classification method divided water-rich aquifer into three levels: strong water-rich, medium water-rich, and weak water-rich, the author combines the first group (T9) and the second group (T2, J138-2, J151, 2-5, and 1-1) into one group so that the water-rich index is divided into three categories. Therefore, the partition thresholds of different water-rich types are determined to be 0.7 and 1.7. According to the partition threshold of water-rich index, the Binchang mining area is divided into three regions, that is, water-rich index less than 0.7 is a weak water-rich region, 0.7 to 1.7 is a medium water-rich region, and greater than 1.7 is a strong water-rich region.

According to the water-rich index value of each hole, the water-rich zoning map of Binchang mining area can be obtained. Figure 6 shows the Water-rich Partition of Binchang Mining Area. The strong water-rich areas of the Luohe Formation aquifer are mainly distributed in the northwest, and central part of the mining area, namely the northwest of Gaojiabao Coal Mine, the south of Hujiahe Coal Mine, and the northwest of Xiaozhuang Coal Mine.

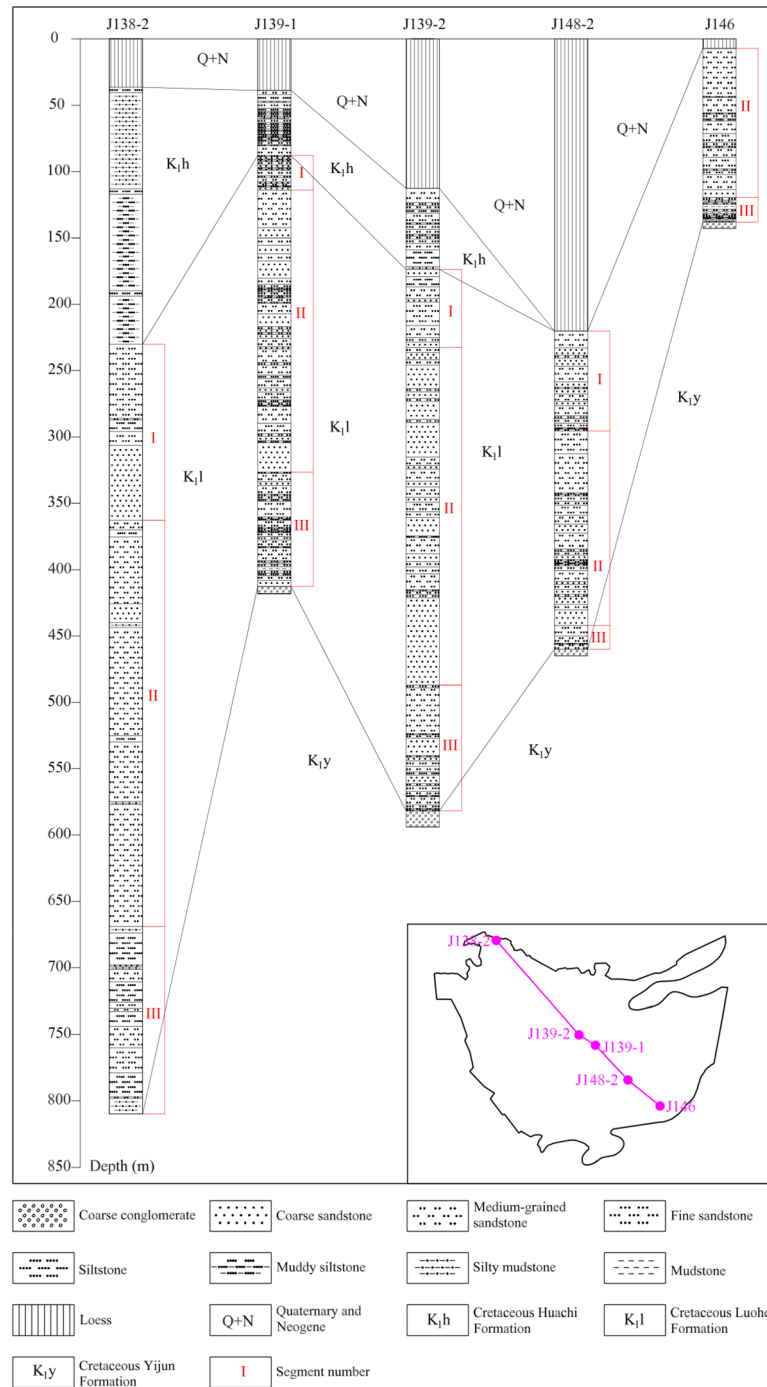


Fig. 4 Columnar contrast profile of Luohe Formation and above in Binchang mining area

The weak water-rich area is mainly distributed in the southern part of the mining area, namely the southern part of the Tingnan Coal Mine, the southern part of the Wenjiapo Coal Mine, the Dafosi Coal Mine, the Xiagou Coal Mine, the Huoshizui Coal Mine, the Shuiliandong Coal Mine, the Gaojiabao Coal Mine, and the Yadian Coal Mine in the northern part of the mining area. The other areas are medium water-rich area.

4 Influence of coal mining on groundwater in Luohe Formation

4.1 Influence of coal mining on the groundwater level of the aquifer in Luohe Formation

The Luohe Formation groundwater is an important source of industrial and agricultural water in this area, which is

Table 2 Pumping test results of the Luohe Formation aquifer in main coal mines of Binchang mining area

Coal mine name	Hole number	Units-inflow q (L/(s m))	Permeability K (m/d)	Aquifer thickness (m)	Coal mine name	Hole number	Units-inflow q (L/(s m))	Permeability K (m/d)	Aquifer thickness (m)
Gaojiabao Coal Mine	1-1	1.13	0.32	329.78	Yadian Coal Mine	S10	0.29	0.10	875.23
	1-3	0.21	0.07	334.24		5-4	0.16	0.03	341.20
	2-1	0.50	0.14	368.13	Tingnan Coal Mine	ZK8-2	0.29	0.14	182.70
	T2	1.49	0.51	390.07		9-1	0.35	0.17	231.82
	J138-2	1.47	0.20	580.68		W5	0.22	0.08	259.96
	J138-3	0.73	0.14	399.32		6-5	0.22	0.17	202.50
	3-3	0.22	0.05	371.98		J136-1	0.12	0.03	319.22
Wenjiapo Coal Mine	H14	0.49	0.20	241.12	Xiagou Coal Mine	J146	0.19	0.19	81.90
	3-5	0.07	0.12	158.70	Hujiahe Coal Mine	T5	0.44	0.26	295.00
	J149-2	0.10	0.14	170.73		T9	0.44	1.35	324.00
	2-4	0.23	0.16	271.10	Huoshizui Coal Mine	J145	0.10	0.10	93.92
	4-3	0.29	0.22	281.18	Mengcun Coal Mine	M2-3	0.45	0.16	301.13
	W1	0.26	0.49	158.70		M6-6	0.36	0.14	290.20
	Xiaozhuang Coal Mine	J148-2	0.16	0.08		249.97	T7	0.28	0.35
Dafosi Coal Mine	2-5	0.31	0.81	249.98	W3	0.33	0.09	265.74	
	D52	0.15	0.26	25.66	Jiangjiahe Coal Mine	JJ1	0.11	0.25	38.20
D30	0.05	0.05	85.93	J151		0.50	0.87	171.40	
D9	0.13	0.02	63.81						

Notes: Data from Shaanxi 186 Coalfield Geological Co Ltd

Table 3 Coefficient of variation and weights of the indicators

Indicator	Coefficient of variation	Weights
Unit-inflow	0.9446	0.35
Permeability	1.1332	0.42
Aquifer Thickness	0.5937	0.23

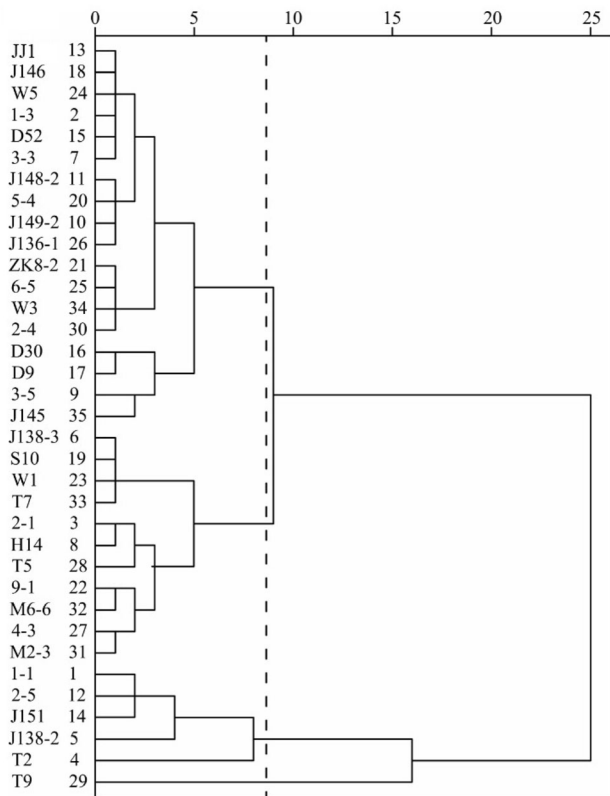
related to the economic development of the area and the drinking water safety of residents. After nearly 20 years of high-intensity development, the Binchang mining area has produced a strong disturbance to the groundwater of the Luohe Formation. As the relatively comprehensive groundwater monitoring network of the mining area has not been fully completed, the collected water level monitoring data is limited. The author takes the Tingnan Coal Mine in the middle of the mining area as an example. The Tingnan Coal Mine started construction in 2003 and was put into operation in 2005. The current production is 5.00 Mt/a. The mine adopts fully mechanized coal mining technology, with fully caving method for roof control. The main mining coal seam is the No. 4 coal seam of Yan'an

Formation, with a thickness of 1.00 to 23.24 m, and average thickness of 9.35 m. Since production, the area of the gob has been formed to be about 3.65 km².

In order to study the influence of the mining of the Tingnan coal mine on the groundwater level of the Luohe Formation, the author collected the hydrological data of 14 monitoring holes of Luohe Formation aquifers from 2004 to 2015 in Tingnan Coal Mine (Shaanxi 186 coalfield geology Co., Ltd. 2017). According to the monitoring data, the SPSS software is used to plot the dynamic change curve of groundwater level in groundwater monitoring hole (Fig. 7). The monitoring data for 12 years shows that the groundwater level decreased by 3.16 to 194.87 m with the average decline of 52.50 m. The water level of the monitoring hole W3 in the northeastern part of the minefield has the largest drop of 194.87 m. Based on the groundwater level drop data of each monitoring hole, using Golden Software Surfer software, the contour map of groundwater level drop in Luohe Formation of Tingnan coal mine can be obtained. Figure 8 shows that the area of the minefield, that the water level decline is less than 10.00 m, is about 10.63 km², and the area is about 13.94 km² where water level drop is 10.00 to 50.00 m. Area of 50.00 to 90.00 m

Table 4 Water-rich index of each borehole

Coal mine name	Borehole number	Water-rich index	Coal mine name	Borehole number	Water-rich index	Coal mine name	Borehole number	Water-rich index
Gaojiabao Coal Mine	1-1	1.7332	Yadian Coal Mine	S10	1.1594	Wenjiapo Coal Mine	H14	0.9378
	1-3	0.5751		5-4	0.4863		3-5	0.3891
	2-1	0.9652	Tingnan Coal Mine	ZK8-2	0.6282		J149-2	0.4511
	T2	2.3751		9-1	0.7676	2-4	0.6800	
	J138-2	2.0242		W5	0.5297	4-3	0.8481	
	Mengcun Coal Mine	J138-3	1.1656	Hujiage Coal Mine	6-5	0.6351	Dafosi Coal Mine	W1
3-3		0.5916	J136-1		0.4361	D52		0.5598
M2-3		0.8814	T5	1.0301	D30	0.2033		
M6-6		0.7699	T9	2.8420	D9	0.1890		
T7		1.1153	Jiangjiahe Coal Mine	JJ1	0.5303	Xiaozhuang Coal Mine	J148-2	0.4768
Xiagou Coal Mine	W3	0.6428	Huoshizui Coal Mine	J151	1.8707		2-5	1.7943
	J146	0.5308		J145	0.3286			

**Fig. 5** Cluster tree of water-rich index system

water level drop is 7.15 km^2 and area that water level drop larger than 90.00 m is 3.83 km^2 . The area where the groundwater level drops more than 10.00 m accounts for 70.1% of the mine area. According to the location of gobs and the drop of groundwater level, the area with a large drop in the groundwater level is mainly distributed in the

gob area in the north and southeast of the minefield, while the water level of unmined area in the west has decreased by a small margin. This indicates that the groundwater level decline of the Luohe Formation caused by coal mining has reached a relatively serious level, which is one of the main reasons for the contradiction between water supply and demand in the area.

4.2 Influence of coal mining on springs

The springs in the Binchang mining area are mainly divided into three categories, namely, the Quaternary spring group generated by the infiltration of loess dykes, and the Cretaceous Huanhe Formation and Luohe Formation springs produced by the infiltration of the bedrock gully geomorphology. As a weak aquifer, the loess layer accumulates in the loess layer after receiving atmospheric precipitation. When the loess layer is cut, it is concentrated in the top surface of the bedrock to form a spring. The vertical lithology of the Huayu Formation in the Cretaceous is unevenly distributed, mostly in the fine sandstone and mudstone interbeds. The sandstone section is rich in water and the mudstone section is the aquifuge. At the cutting of the Wei River and its branch ditch, the groundwater of the Huanhe Formation is discharged along the top of the mudstone containing aquifer to form a spring. The Luohe Formation is the main water-rich aquifer in the area, which has a bearing property and is mostly excreted in the form of rising springs in the valley cutting area (Fig. 9).

The Binchang mining area belongs to the loess gully landform where the local villagers live along the ditch. The spring water in the valley is the main source of water for

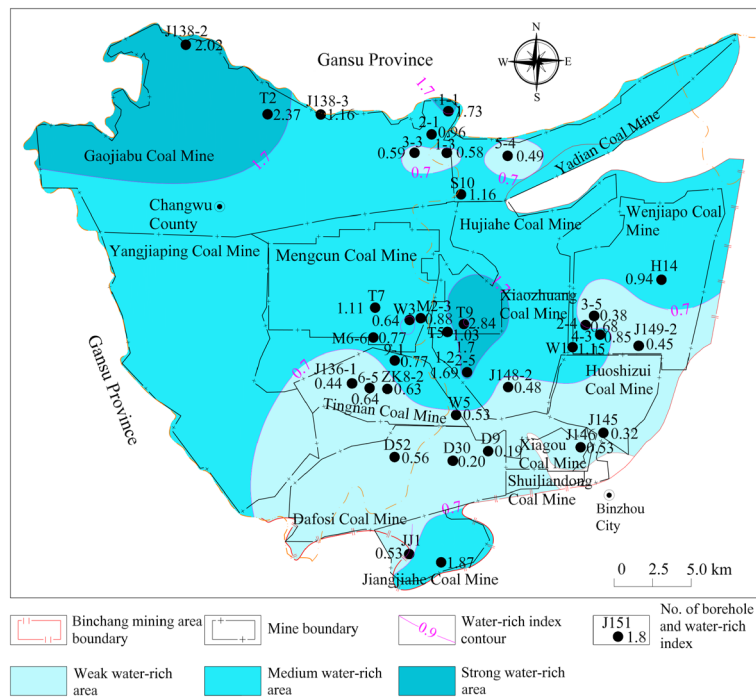


Fig. 6 Water-rich zoning map of Binchang mining area

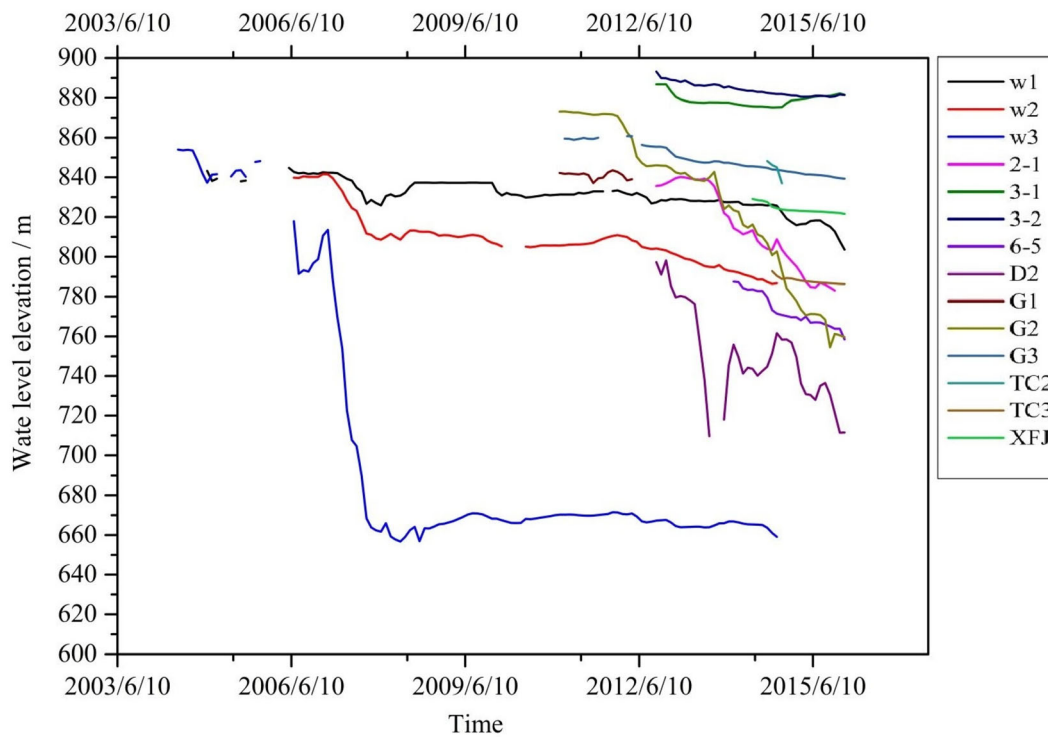


Fig. 7 Dynamic change curves of groundwater level in groundwater monitoring hole of Luohe Formation in Tingnan Coal Mine

the local rural residents and livestock, and also supports the ecological landform of the valley area. According to the “Report of groundwater dynamics thematic research in Binchang mining area” implemented by Shaanxi 186

coalfield geology Co., Ltd. in 2017. 34 springs in 8 mine fields in the southeast of the mining area had a total spring flow of 610.21 L/s before 2007. Among them, there are 23 Quaternary springs, the spring flow is between 0.36 and

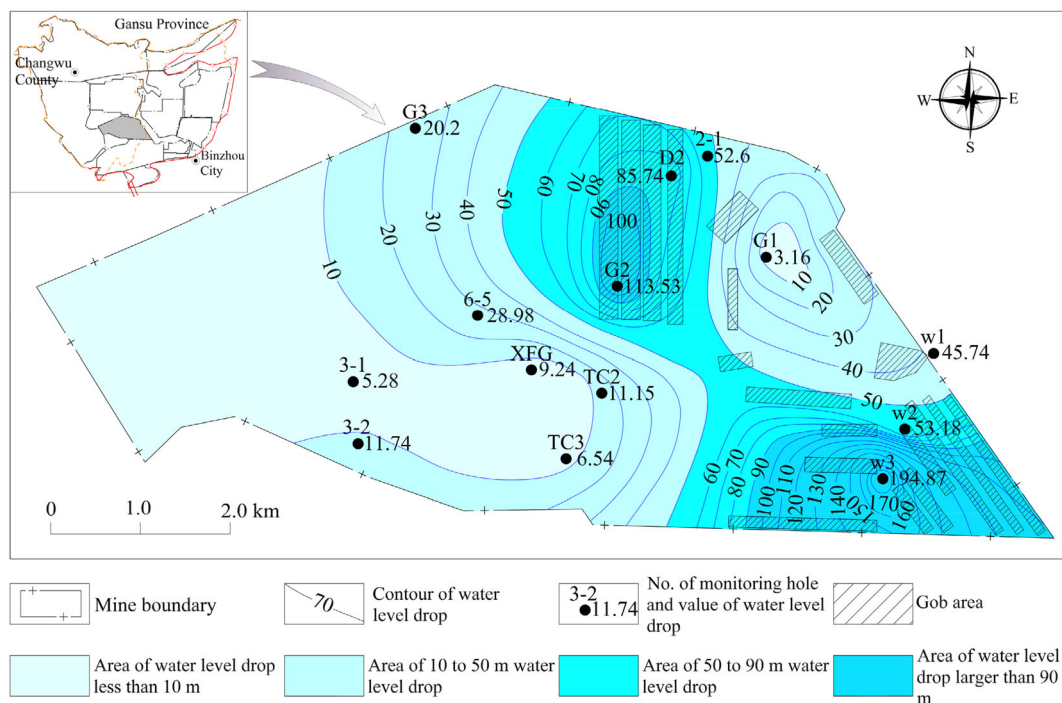


Fig. 8 The contour map of groundwater level drop in Luohe Formation of Tingnan Coal Mine



Fig. 9 The Luohe Formation strata and springs in the valley

83.33 L/s, and the total flow is 538.44 L/s. There are 3 springs in the Huanhe Formation, the flow rate of the spring is ranging from 1.32 to 5.46 L/s, and the total flow is 7.86 L/s. There are 8 Luohe Group springs, the spring flow is between 1.39 and 27.21 L/s, and the total flow is 63.91 L/s. After 10 years of mining, the survey conducted in September 2017 shows that, 34 spring flows were all declined to different degrees. The total flow of springs exposed in different formations was decreased by 286.48 L/s, and the decline rate of total flow was 46.95%. Among them, the decline of Quaternary spring flow is 234.82 L/s, the decline of Huanhe group spring flow is

4.74 L/s, and the drop of Luohe group spring flow is 46.92 L/s (Figs. 10, 11). According to the location of the gob and the contour map of the spring flow decline, it can be concluded that the area with a large amount of flow decline is mainly located in the gob of each mine (Table 5).

5 Influence mechanism of coal mining on groundwater

The impact of coal mining on groundwater depends on the water conductor and the source of water. In coal mining, three fault zones are formed in the overburden strata, namely the caving zone, the fracture zone, and the curved subsidence zone (Li 2019; Li et al. 2020). The water-conducting fracture zone is the main water-conducting channel that affects the upper aquifer of the coal seam and determines the influence range on groundwater. Once the water-conducting fracture zone breaks through to the upper strong water-rich aquifer, it will cause rapid downward leakage of groundwater in the upper aquifer.

5.1 Height of water-conducting fracture zone

The water-conducting fracture zone formed by coal seam mining is a key factor causing the groundwater level to drop and water resources to leak. The thickness of main mining seam of Binchang mining area, No. 4 coal seam, is large thickness, with an average of 10.64 m. Due to the

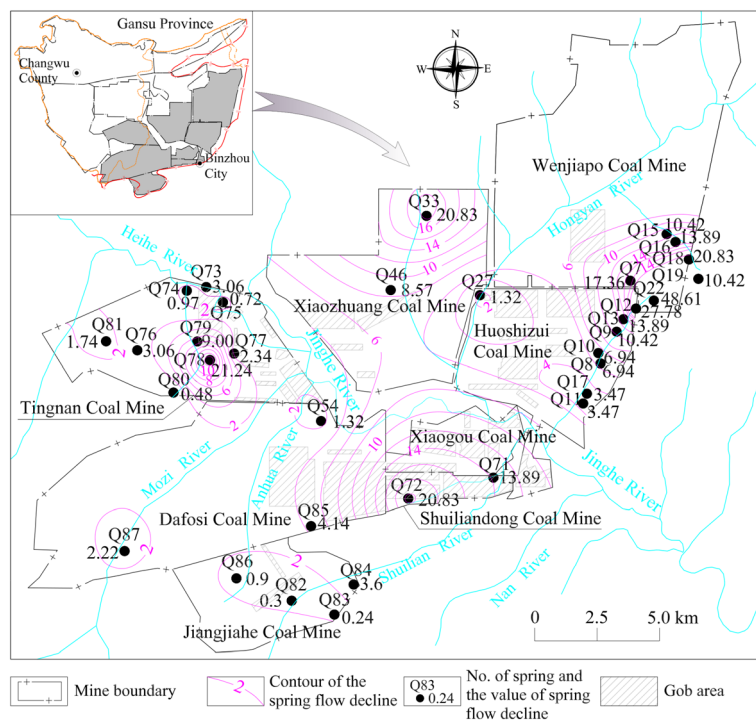


Fig. 10 The contour map of the spring flow decline from 2007 to 2017

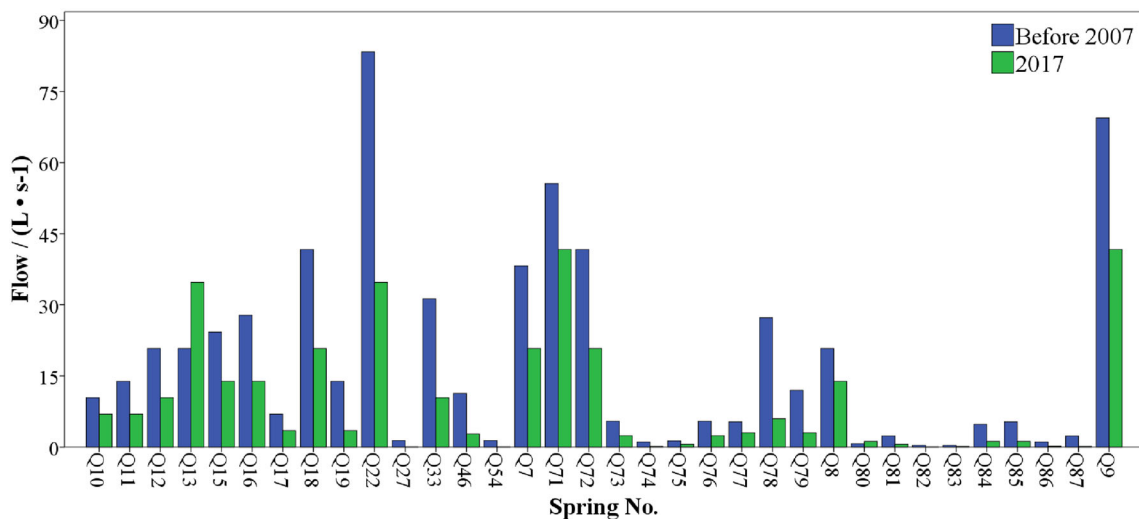


Fig. 11 Comparison of spring flow before 2007 and 2017

Table 5 Spring discharge summary

Exposed strata	No. of location	Total flow (L/s)		Flow decline (L/s)	Flow decline Rate (%)
		Before 2007	2017		
Q	23	538.44	303.62	234.82	43.61
K _{1h}	3	7.86	3.12	4.74	60.31
K _{1l}	8	63.91	16.99	46.92	73.42

large thickness, the formula to calculate the height of water flowing fractured zone recommended by current mining standard is not suitable for Binchang mining area. Therefore, the mining companies have conducted a large number of practical explorations to obtain the actual height of water-conducting fracture zone as shown Table 6 (Li 2019). It is found that the ratio of the height of the fractured zone to the mining height ranges from 16.85 to 27.92 m and all fractured zones are conducted to the aquifer of the Cretaceous Luohe Formation.

5.2 Analysis of groundwater leakage mechanism

Coal mining will cause mechanical disturbance of rock structure in the upper part of the coal seam. The water-conducting fracture zone caused by mining will continue to develop upwards in a certain period of time as the mining area expands, and it can cause large-scale groundwater leakage. The key is whether the water-conducting fracture zone can be connected to the Luohe Formation aquifer with strong water-rich and abundant water. When the water-conducting zone is connected to the aquifer of the Fuluhe Formation, the groundwater enters the gob along the water-conducting channel, which will form a groundwater landing funnel centered on the gob, thus causing the groundwater flow field to change from natural source to manual intervention. In the water-conducting fracture zone, the vertical flow component of groundwater is significantly increased, the groundwater circulation speed is accelerated,

and the groundwater level is greatly reduced, which will cause the groundwater flow field in the entire mining area to change. As shown in Fig. 12, the groundwater level of the Luohe Formation decreased, causing the surface spring water flow exposed by the valley to decrease or even dry up. When the water level of the Luohe Formation aquifer drops to a certain value, the Quaternary aquifer will experience water level drop or even drain, due to the increase of recharge intensity caused by hydraulic connection between the upper part of Quaternary and the Luohe Formation aquifer. The spring flow also decline and even dry up.

6 Discussion

6.1 Strengthen the exploration and research work of the Water-rich of Luohe Formation aquifer

In Binchang mining area, the thickness of the aquifer of Luohe Formation changes greatly in the plane, and there is a great difference in the vertical lithology combination characteristics, which leads to the great heterogeneity of its water-rich. In the vertical direction, the Luohe Formation can be divided into upper, middle, and lower sections, with poor water-rich in the lower sections and good water-rich in the middle and upper section, which is of significance for water supply. In the process of coal mining, due to the uneven water-rich, it is impossible to accurately predict the

Table 6 Measured height of water-conducting fracture zone in five coal mines in Binchang mining area

Coal mine name	Working face number	Width of working face (m)	Mining depth (m)	Mining method	Mining height (m)	Height of water-conducting fracture zone (m)	Ratio of the height of the fractured zone to the mining height (m)	Conducted to the aquifer of the Cretaceous Luohe Formation
Gaojiabao Coal Mine	41101	120	983.8	Fully mechanized	4.36	88.03	20.19	Yes
Hejiahe Coal Mine	101	175	608.40	Fully mechanized	10.10	225.43	22.32	Yes
Huoshizui Coal Mine	8712	200	628.16	Fully mechanized	10.00	220.00	22.00	Yes
Tingnan Coal Mine	204	200	575.00	Fully mechanized	6.00	135.23	22.54	Yes
	304	204	529.50	Fully mechanized	9.10	254.04	27.92	Yes
Dafosi Coal Mine	40106	180.00	391.50	Fully mechanized	9.10	245.52	26.98	Yes
	40108	180.00	391.50	Fully mechanized	11.22	189.05	16.85	Yes

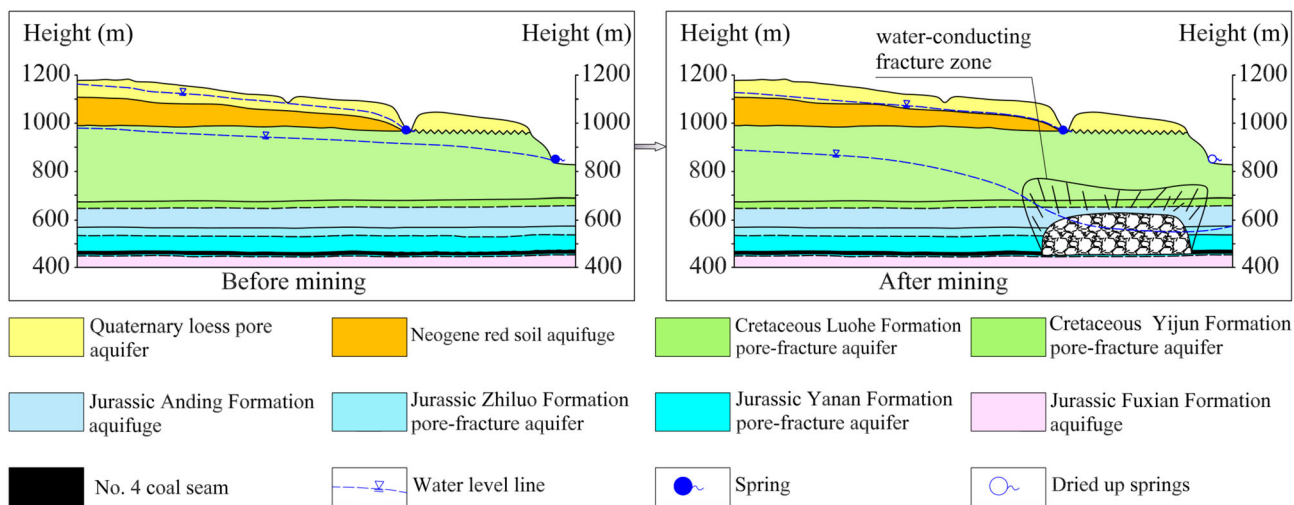


Fig. 12 The influence of coal mining on groundwater level in Bingchang Coal Mine

mine water inflow in the process of coal mining, and it also brings some difficulties for the protection of groundwater resources in Luohe Formation. Therefore, it is necessary to strengthen the exploration and research on the water-rich of the Luohe Formation aquifer. For the area with large stratum thickness of Luohe Formation, the pumping test should be carried out in layers in full combination with the characteristics of sedimentary environment, so as to accurately obtain the hydrogeological parameters of different layers of the aquifer of Luohe Formation, accurately evaluate the characteristics of water-rich, and provide data support for the safe mining of coal mines and the protection of groundwater resources.

6.2 Study on technology and method of coal mining with water conservation

Luohe Formation is the main source of industrial and agricultural water in the Binchang mining area. The development of coal resources in the mining area has an impact on the groundwater and surface spring water of Luohe Formation. In the past 10 years, a number of large mines have been put into operation, and the groundwater level of local Luohe Formation has dropped to 194.87 m. According to the previous exploration results of height of water-conducting fracture zone in this area, most of water-conducting fracture zone extend to the middle and lower sections of the Luohe Formation, and some extend to the upper sections of the Luohe Formation. Therefore, in order to protect the aquifer structure of the middle and upper part of Luohe Formation with regional water supply significance, we should combine the characteristics of uneven vertical water-rich of the aquifer of Luohe Formation, study the technology of limited height mining, control the height of water diversion fracture zone.

7 Conclusions

This study analysed a large number of survey data and investigation data to explore the occurrence characteristics of groundwater in Binchang mining area. It is found that in the horizontal direction, the occurrence characteristics of Luohe Formation aquifer are not uniform, and in the vertical distribution, the formation lithology combination characteristics of Luohe Formation have obvious segmentation.

From 2004 to 2015, the groundwater level of the Luohe Formation in the Tingnan Coal Mine decreased by 3.16 to 194.87 m, with an average decline of 52.50 m. From 2007 to 2017. The total flow of 34 springs exposed in 8 mine fields in the southern part of the mining area dropped by 286.48 L/s, and the decrease rate was 46.95%. The large drop of groundwater level and the decline of spring flow are all distributed in the gob area.

The high-intensity mining of coal resources has a great impact on the industrial and agricultural water use and the drinking water safety of the residents. The ratio of water-conducting fracture zone height to coal seam thickness in Binchang mining area is 18.65–27.92. The water-conducting fracture zone is connected to the Luohe Formation aquifer, which is the main cause of the water level decline, groundwater resource leakage and surface spring flow decline in the Luohe Formation.

In order to protect the groundwater resources of Luohe Formation, it is necessary to strengthen the research of high limit mining technology.

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