

Mining influence on underground water resources in arid and semiarid regions

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Abstract. Coordinated mining of coal and water resources in arid and semiarid regions has traditionally become a focus issue. The research takes Energy and Chemical Base in Northern Shaanxi as an example, and conducts statistical analysis on coal yield and drainage volume from several large-scale mines in the mining area. Meanwhile, research determines average water volume per ton coal, and calculates four typical years' drainage volume in different mining intensity. Then during mining drainage, with the combination of precipitation observation data in recent two decades and water level data from observation well, the calculation of groundwater table, precipitation infiltration recharge, and evaporation capacity are performed. Moreover, the research analyzes the transforming relationship between surface water, mine water, and groundwater. The result shows that the main reason for reduction of water resources quantity and transforming relationship between surface water, groundwater, and mine water is massive mine drainage, which is caused by large-scale coal mining in the research area.

1. Introduction

Coal is a basic energy and an important raw material in China, the exploitation and utilization of coal resources are the impetus of national economy's rapid development, which laid a solid material foundation for promotion of comprehensive national power and people's livelihood. But coal resources exploitation brings numerous adverse impacts ^[1-3], especially for arid and semiarid regions of a shortage of water resources and vulnerable ecological environment ^[4-6]. Coal mining causes pit dewatering, which led to regional spring dry up, ground subsidence, river cutoff, and ecosystem degradation. If requisite precautions are not taken, intensification imbalance between supply and demand of water resources in the mining area will extend ^[7-10]. Therefore, this research takes Energy and Chemical Base in Northern Shaanxi as research area, which situated in arid and semiarid area in western China, with abundant high quality coal resources, shallow coal seam, simple geological structure and low operating costs. Additionally, the research area built a bulk of large-scale integration



coal mines after 2000. During large-scale coal mining, water resources quantity reduced markedly. Thus, the short-term economic development which merely relies on resources exploitation has been delayed [11-12]. In order to guarantee the coordinated mining of coal and water resources, the research on the basis of statistics analysis on coal yield and drainage volume from several large-scale mines in the mining area. It takes four typical years, with combination of precipitation observation data and water level of observation well, to conduct specific calculations and analysis. Meanwhile, the research discusses the impact of high intensity coal mining on circulation of water resource.

2. General information of coal mining drainage

Energy and Chemical Base in Northern Shaanxi consists of three mining areas: Shenmu-Fugu, Yulin-Shenmu and northern region of Yuyang-Hengshan, with a total area of about 10592km². The main overlying aquifer is Quaternary Salawusu Formation and Jurassic Zhiluo Formation, and the spacing between the coal seam and aquifer is only few meters to more than hundreds of meters. As the underground excavation continued, the failure of overlying strata formed fracture zone that connects the aquifer, which led to drainage of groundwater. Small-size mines usually adopt room-and-pillar mining and roadway pillar mining, with less damage on overlying strata, hence unconfined groundwater table usually does not drop greatly. But large-scale mines tend to adopt long-wall caving mining method, an extensive form which easily causes mine water inflow, decline of groundwater table, and ecological environment deterioration. Therefore, this research carries out investigation and survey on mine water inflow during excavation in large-scale modern coal mines. In accordance with the equation of water volume (per ton coal), the water volume of each mines and average water volume per ton coal of the entire research area were calculated:

$$K_p = Q/P \quad (1)$$

Where K_p is water volume of a mine (or panel) within 1 year ($10^8\text{m}^3/\text{a}\cdot\text{t}$); Q is drainage volume of a mine (or panel) within 1 year ($10^8\text{m}^3/\text{a}$); P is coal yield within 1 year (t). Through statistical analysis on 15 large-scale mines' output and drainage volume in 2014 (Table 1), the average water volume per ton coal is $0.8116 \times 10^8\text{m}^3/\text{a}\cdot\text{t}$.

Table 1. Water volume (per ton coal) of main large-scale mines in the research area.

No.	Mine	Yield in 2014 (Mt/a)	Mine water inflow (m ³ /h)	water volume (per ton coal)	No.	Yield in 2014 (Mt/a)	Mine water inflow (m ³ /h)	Water volume (per ton coal)	Yield in 2014 (Mt/a)
1	Shigetai	11.97	1218	0.8912	9	Yujialiang	18.00	151	0.0735
2	Halagou	16.16	353	0.1913	10	Sandaogou	10.67	46	0.0378
3	Daliuta	17.84	448	0.2200	11	Yushuwan	8.00	594	0.6504
4	Huojitu	20.67	413	0.1750	12	Jinjie	19.26	3698	1.6821
5	Sunjiacha	4.00	80	0.1752	13	Jinjitan	4.00	139.11	0.3047
6	NingTiaota	20.15	660	0.2869	14	Xiaojihan	5.00	700	1.2264
7	Zhangjiamao	9.99	200	0.1754	15	Yuyang	2.00	1357	5.9437
8	Hongliulin	15.00	240	0.1402	Water volume (per ton coal)			0.8116	

Checking the coal yield in the Shenmu-Fugu-Yulin mining area in the past 20 years, it can be found that the output has been increasing slightly every year before 2000, and the total yield is small. With the establishment of Energy and Chemical Base in Northern Shaanxi after 2000, coal yield is growing in multiples. In this case, the research takes 1994, 2000, 2007 and 2014 as typical years, and calculates four typical years' total mine drainage volume, in combination with coal yield and average water volume of each year (Table 2).

Table 2. Total water volume of the research area.

Year	K_p	P (Mt)	Q ($108m^3/a$)
1994		10	0.081
2000	0.812	16.15	0.131
2007		120	0.974
2014		362	2.938

It can be seen that as coal yield surged after 2000, a mass of groundwater was drained and the drainage volume increased sharply year by year.

3. Coal mining drainage impact on water resources quantity

The impact of coal mining and drainage on water resources is not only reflected in the increase of total drainage volume of the mine, but also the subsequent environmental problems caused by it, which is more obvious in arid and semiarid regions.

3.1. Impact on ground water table

Based on water level data from 26 unconfined groundwater aquifer observation wells in the research area, the contour map of the groundwater level in four typical years was plotted, respectively, see figure 1.

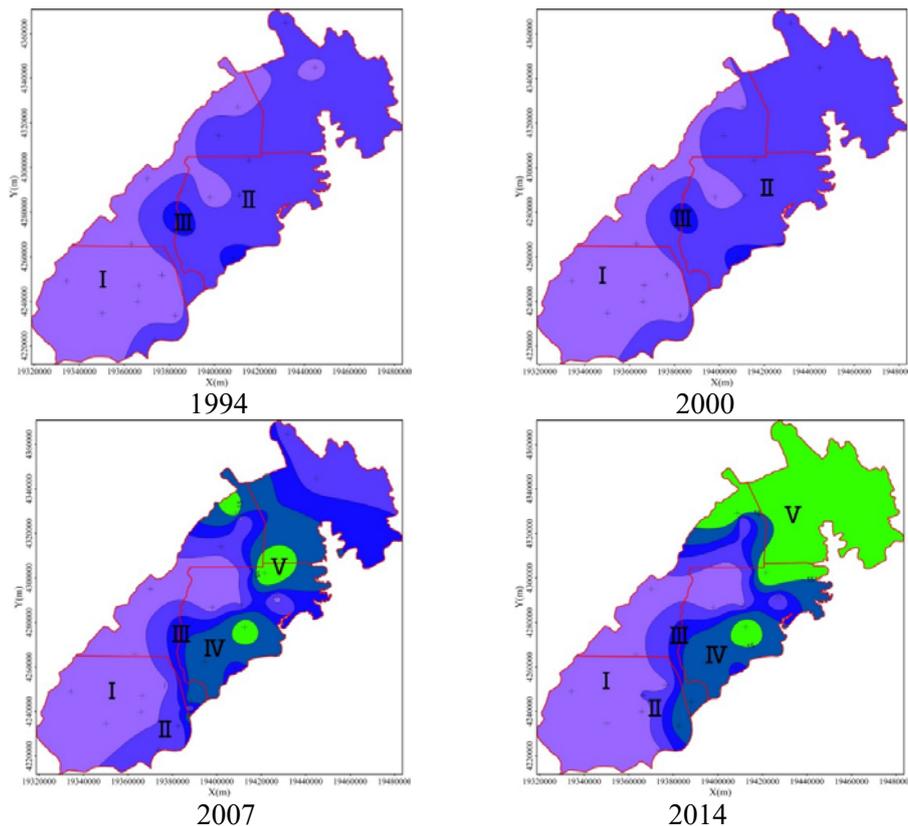


Figure 1. Water table depth of groundwater's contour map in four typical years.

The different water table depth of groundwater in the figure is divided. With the utilization of spatial analysis function of ARCGIS, the area of each zone was extracted separately, and the statistical results were shown in table 3.

Table 3. Water table depth of groundwater zone and its area (10^9m^2).

Water table depth	I	II	III	IV	V
Year	0-3m	3-6m	6-9m	9-15m	>15m
1994	4.276	6.058	0.258	0	0
2000	3.88	6.48	0.232	0	0
2007	3.491	2.485	2.025	2.09	0.501
2014	3.513	1.082	0.866	1.701	3.43

According to figure 1, the water level of 1994 was basically in line with 2000. The area (III zone) that has 6-9m water table depth of groundwater is located in the city of Yulin. This indicated that the groundwater table at this stage is mainly influenced by water consumption of industry and agriculture and residential water consumption in rural. Nevertheless, large-scale mining began from 2000, and therewith the water table depth of groundwater in the Shenmu-Fugu and Yulin-Shenmu mining area declined year by year, especially for the Shenmu-Fugu mining area, where the water table depth of groundwater declined more than 10m. It can be seen that mining drainage have a strong impact on groundwater resources quantity.

3.2. Impact on precipitation infiltration recharge

Precipitation infiltration recharge is the most important natural recharge in arid and semiarid regions. Average annual precipitation P_i in the atmospheric precipitation infiltration recharge calculation is the mean value of statistical data that from multiple meteorological station and precipitation station in the area for twenty years. $P_i = 0.395\text{m/a}$. Precipitation infiltration recharge in different zones is calculated with the combination of water table depth of groundwater table zone and infiltration coefficient of each water table depth, and then calculate results are added together. Below is the calculation equation of precipitation infiltration recharge in the research area:

$$Q_p = \sum_i \alpha_i P_i S_i \quad (2)$$

Where Q_p is the average atmospheric precipitation infiltration recharge in years in the research area (m^3); α_i is the atmospheric precipitation infiltration coefficient of each zone; P_i is the average precipitation in years (m/a); S_i is the area of each zone (m^2).

Among which the atmospheric precipitation infiltration coefficient α_i has many influential factor, including groundwater depth, raininess, lithological characters of vadose zone, geographic and geomorphic conditions, and vegetation et cetera. The impact of groundwater depth on α_i is among the most significant and easily quantification factor. Combining with existing research result, precipitation infiltration coefficient in different groundwater depth zone was divided, refer to table 4.

Table 4. Table of precipitation infiltration coefficient in different groundwater depth zone.

Zone	I	II	III	IV	V
	0-3m	3-6m	6-9m	9-15m	>15m
α	0.45	0.35	0.30	0.20	0.12

The area of each zone and precipitation infiltration coefficient was put into equation 2. The results are shown in table 5.

Table 5. Four typical years' precipitation infiltration recharge computation sheet.

Year	Zone Number	S 10 ⁹ m ²	P m/a	α	Q _p 10 ⁸ m ³ /a	Total 10 ⁸ m ³ /a
1	I	4.276		0.45	7.60	
9	II	6.058		0.35	8.38	
9	III	0.258	0.395	0.3	0.31	16.28
4	IV	0		0.2	0.00	
	V	0		0.12	0.00	
2	I	3.88		0.45	6.90	
0	II	6.48		0.35	8.96	
0	III	0.232	0.395	0.3	0.27	16.13
0	IV	0		0.2	0.00	
	V	0		0.12	0.00	
2	I	3.491		0.45	6.21	
0	II	2.485		0.35	3.44	
0	III	2.025	0.395	0.3	2.40	13.93
7	IV	2.09		0.2	1.65	
	V	0.501		0.12	0.24	
2	I	3.513		0.45	6.24	
0	II	1.082		0.35	1.50	
1	III	0.866	0.395	0.3	1.03	11.74
4	IV	1.701		0.2	1.34	
	V	3.43		0.12	1.63	

3.3. Impact on unconfined groundwater evaporation drainage volume

Under the action of capillary force, shallow groundwater deliver water to vadose zone, the water passes through soil and plant, and get into the atmosphere. Above process is unconfined groundwater evaporation. It is an important link in transformation of precipitation, surface water, and groundwater. When water table depth is shallow, unconfined groundwater evaporation is the main drainage pattern of groundwater in arid and semiarid regions. Consequently, the effect of coal mining drainage on unconfined groundwater evaporation is linked to many other aspects. The calculation equation of unconfined groundwater evaporation capacity at this time is:

$$Q_e = E \cdot S \cdot \alpha \cdot t \quad (3)$$

Where Q_e is the total evaporation capacity (m³/a); E is the annul evaporation capacity that observed by evaporating dish (mm); α is the unconfined groundwater evaporation coefficient; S_i is the area of calculation region (m²); t is the unconfined groundwater evaporation transformation coefficient.

Table 6. Four typical years' precipitation infiltration recharge computation sheet.

Year	Water table depth m	t	E mm/a	α	S 10 ⁹ m ²	Q _E 10 ⁸ m ³ /a	Total 10 ⁸ m ³ /a
1	0-1	0.2			0.167	0.36	
9	1-2	0.14	2500	0.43	2.104	3.17	5.25
9	2-3	0.08			2.005	1.72	
4	0-1	0.2			0.19	0.41	
2	1-2	0.14	2500	0.43	2.114	3.18	4.95
0	2-3	0.08			1.576	1.36	
2	0-1	0.2			0.116	0.25	
0	1-2	0.14	2500	0.43	2.064	3.11	4.48
0	2-3	0.08			1.311	1.13	
7							

2	0-1	0.2			0.095	0.20	
0	1-2	0.14	2500	0.43	1.405	2.11	4.04
1	2-3	0.08			2.013	1.73	
4							

Unconfined groundwater evaporation transformation coefficient is the specific value of unconfined groundwater evaporation capacity and the amount of the water surface evaporation. The amount of unconfined groundwater evaporation is related to weather, water table depth, soil moisture content, water transportation capacity of capillary, lithological characters, and crop cultivation and other factors. Particularly, when water table depth is less than 2.0m, unconfined groundwater evaporation is stronger as the water table depth is shallower. When water table depth is greater than the unconfined groundwater evaporation reduced rapidly, and the maximum depth of evaporation is 3m. The result is given in table 6.

4. Mining drainage impact analysis on circulation of water resource

Natural climatic conditions and natural shortage of water resources are the root causes of water resources and the ecological crisis in arid and semiarid areas. Nevertheless, the excessive exploitation and utilization of water resource accelerate the deterioration of the ecological environment in arid and semiarid areas. During mining stage, the over-exploitation of water resources in Northern Shaanxi Energy and Chemical Base led to a series of environmental geology problems. Through the above calculation of water resources in the research area, it can be seen that the main reason for mining-induced reduction of water resources is massive drainage of coal mines. The drainage changes hydrogeological conditions of the research area, and the transformation relationship between surface water, groundwater, and mine water. The main performance is the following aspects.

4.1. Transforming relationship between surface water and groundwater

By the view of regional water equilibrium, the surface drainage system was mainly dominated by the river system of Kuye River, Tuwei River and its tributaries that formed seasonal flow system. The groundwater system is mainly thick unconsolidated aquifer from quaternary system. With the combination of flow data offered by upstream and downstream hydrometric station of Tuwei River and Kuye River (refers to figure 2), the annual average flow of downstream of Gaojiachuan and Wenjiachuan is significantly greater than the upstream ones. It noted that under field conditions the groundwater recharge surface water is generally the dominate pattern.

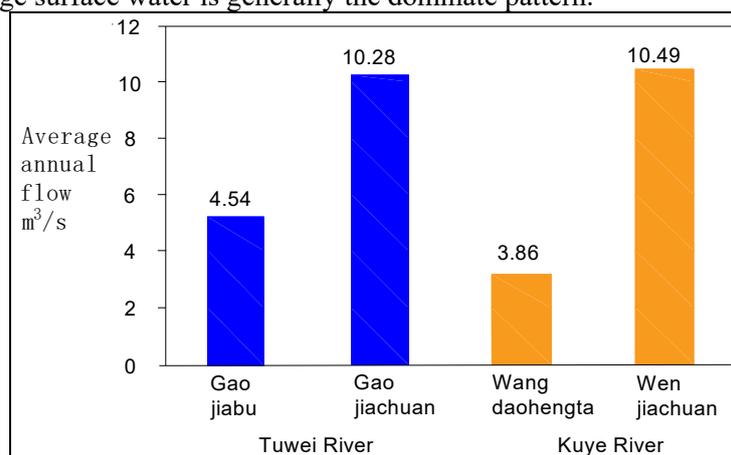


Figure 2. Average flow comparison chart of upstream and downstream.

To study the influence of mining drainage on surface water, the statistical of monthly average flow of upstream and downstream hydrometric station of Tuwei River and Kuye River in four typical years was carried out. As straight line graphs presented in figure 3 and figure 4.

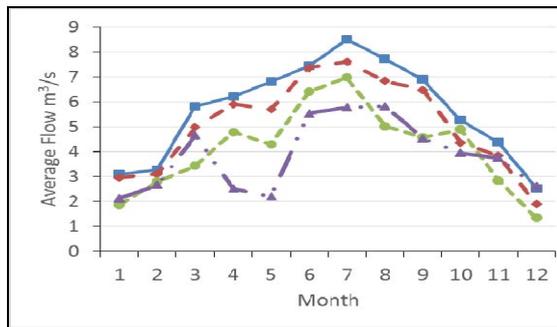


Figure 3. Kuye River's average flow chart of monthly flow in typical years.

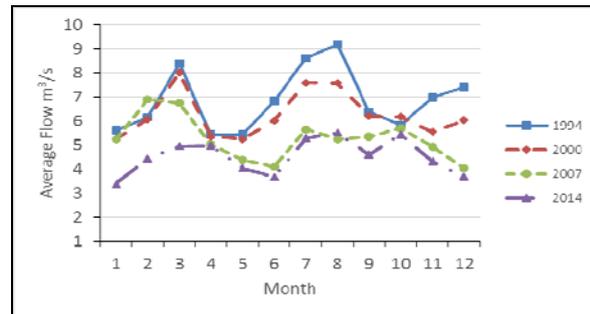


Figure 4. Tuwei River's average flow chart of monthly flow in typical years.

It can be seen that the flow rate of the surface water system decrease with the rapid development of the coal industry. Mining operation causes roof water drainage, which leads to a big decline in groundwater table, thereby the transformation volume from groundwater to surface water decreased, ultimately induces the decrease of flow of the surface water system. It is conceivable that as the excavation continued, when groundwater table declined to a certain threshold value, the transformation relationship between groundwater and surface water will change, in which surface water mainly recharging groundwater. On that occasion, more ecological problems will emerge.

4.2. Transforming relationship between mine water and groundwater

During mining operation, with the drainage of aquifer water from roof, mine inflow water becomes another primary drainage pattern. After the inflow water enters into excavation system, it can be divided to three types that enter into regional water circulation system. Most of inrush water accesses into center water sump directly, the water is taupe or black as it contains coal and rock powder, and dust, meanwhile in related to underground mining and oils that from hydraulic prop and other equipment, the organic, oil and coliform bacteria in mine water will be overtly exceeding the emission standard. It is essential to pump the mine water into ground mine sewage treatment station through the underground drainage system. After treatment processes of "coagulation + precipitation + filtration + ultrafiltration + nanofiltration", the mine water was emission to surface drainage pattern and then participate in water circulation. Additionally, another inflow water flows into goafs and becomes acid goaf water. Small part of inrush water is recycling in underground mining. Although inflow water is eventually participate in regional water circulation, and seems have little impact on water resources quantity, but various emission of waste water and goaf water acidification become a new source of pollution in underground water resource in the mining area. Scarce water resources are at risk of water quality deteriorating, which result in a more severe shortage of exploitable water resources quantity. There will be more limitation on utilization of production and domestic water in the mining region.

5. Conclusion

With the continuous improvement of mechanized mining technology, many thousands of tons of large-scale mines (in the yield of thousands of tons) have been put into production. Mining induced sharply increasing of coal mine water drainage and decreasing of groundwater table, and moreover with each passing year, the substantial growth of drainage volume because of overlying aquifer was connected by a vertical fracture.

Through the analysis on water level data of 26 observation wells in the research area, four representative periods were selected, and the contour map of water table depth was plotted. The research confirms the zones of different water table depth and the area of these zones. Additionally, precipitation infiltration recharge capacity, and evaporation capacity in the research area were calculated. It is established that the change in water resources quantity is mainly influenced by coal mining drainage.

The transforming relationship between surface water, groundwater, and mine water is discussed. The research draw a conclusion that the key factor of hydrogeological condition change in the research area and the transforming relationship between surface water, mine water, and groundwater is massive mine water drainage.

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