Influence of water resources in Xinjiang on exploitation of coal resources and measures for their use

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Abstract. Xinjiang is rich in coal resources, but the extremely shortage of water resource in some regions has significant impact on coal exploitation. Water is required in coal exploitation, as well as cleaning, utilization and upgrading of coal, so the shortage of water resource is impacting the fate of coal directly. Xinjiang area is the 14th coal base of our country, a foothold of the strategy of West-Development in China, and a support point of national strategic layout of the Belt and Road Initiative. If the problem of coal and water is solved, the problem of energy safety and nationality will be solved. Based on the comprehensive analysis of coal geological conditions and water resources conditions in Xinjiang, we have studied the spatial distribution relationship between coal resources and water resources in this paper, and find that the whole water resource is short in regions of Xinjiang with rich coal resource. In this paper, some feasible suggestions have been put forward to solve the problem of asymmetric distribution of water and coal resources as the key problem at present, in order to provide reference for departments of resource development and planning.

1. Introduction

Coal is the food for industry, supports the healthy and sustainable development of national economy in our country. The current situation of energy is lacking in oil and gas but rich in coal, which urges us to base on coal, the most economical, stable, reconcilable and safe main energy [1,2]. However, coal exploitation is restrained by geological conditions [3] and water resources [2,4], wherein the problem of geological conditions could be solved through technical progress in engineering, but the shortage of water, in particular in western region, is so serious that the coal reduces to soil if there is no water along with it. Whether the mining water for coal exploitation is sufficient matters the safety of coal mine, as well as miner's life and production environment. Because water is required for dust removal and reduction of impurities in coal during coal exploitation, let alone domestic and environmental water [5]. At present, most coal mining areas in China mainly rely on pumping underground water
resources and comprehensive utilization of mine water, water shortages are common, the contradiction between water supply and demand inevitably becomes an important restriction factor for the exploitation and utilization of coal resources in central and western China [2,6]. Xinjiang is the 14th coal base of our country, its premeasured amount of coal resource is as high as 2190 billion tons [7], and its significant regional differences in water resources make it difficult to get water for coal exploitation. Key laboratory of terrestrial water circulation and surface processes of INSTITUTE OF GEOGRAPHIC SCIENCES AND NATURAL RESOURCES RESEARCH, CAS has predicted in 2012 that mining water consumption will reach $4.90 \times 10^8 \text{m}^3$ [8] in 2020 only in Xinjiang, as we can see there is a big difference between supply and demand. If combined with coal chemical industry, power generation and other water demand in comprehensive utilization of coal, the gap is even an astronomical figure. Some Suggestions on Further Promoting Economic and Social Development of Xinjiang made by the State Council in 2007 proposed to accelerate the development of coal energy bases in Xinjiang, "steadily build large coal bases, enhance the strategic position of coal in Xinjiang, and actively promote the exploration, development, processing and transformation of coal-bed gas and the orderly development of the coal-bed gas industry" [9], which is of great strategic and practical significance for revitalizing the development of the autonomous region, improving the living conditions of the people in the remote areas with minorities, and ensuring prosperity, stability and national security. Therefore, in addition to the in-depth study of the characteristics of coal resources of Xinjiang, more attention should be paid to the matching relationship between coal resources & water resources. Besides, in a sense, water resources in some areas of Xinjiang are more significant than coal resources themselves.

2. Conditions of coal resources in Xinjiang

2.1. Geological conditions

2.1.1. Coal-bearing strata. Many early and middle Jurassic coal accumulation basins are widely distributed in Xinjiang, containing abundant coal resources [10,11]. Coal accumulation occurred from carboniferous to Jurassic in Xinjiang, the characteristics of coal accumulation in early, late carboniferous, early Permian, late Triassic and early-middle Jurassic are consistent with the main coal accumulation period in China, wherein coal accumulating basins in early-middle Jurassic developed extensively, which is main coal accumulation stage in the region. The coal bearing strata at other stages are less distributed in Xinjiang and much have no industrial mining value. The coal bearing strata in early-middle Jurassic developed extensively in Jungar, Barkol-Santanghu, Yili basin, Turpan-Hami Basin, etc., also with these characteristics. The coal bearing strata in Jungar coal bearing area includes Xishanyao Formations ($J_{2x}$) and Badaowan Formations ($J_{1b}$), wherein Badaowan Formations ($J_{1b}$) is fluvio-lacustrine swamp facies coal bearing deposit, carbonaceous mudstone interbedded coal; Xishanyao Formations ($J_{2x}$) is mainly a set of fluvio-lacustrine facies swamp deposit, grayish-black carbonaceous mudstone interbedded coal and siderite thin strata, which is the main coal bearing strata formations in this area. The coal bearing strata in the northern margin of Tarim basin are lower-middle Jurassic Karasu group ($J_{1-2k}$), wherein Tariq Formations ($J_{1t}$), Yen-gisar Formations ($J_{1y}$) and Kezilenur Formations ($J_{2k}$) contain coal, Tariq Formations ($J_{1t}$) are swamp facies deposit, containing A coal formation; Kezilenur Formations ($J_{2k}$) are lacustrine swamp facies deposit, containing C coal formation. The coal bearing strata in the south and southwest margin of Tarim basin are Yarkant group ($J_{1-2y}$), wherein Kangsu Formations ($J_{1k}$) and Yang ye Formations ($J_{2y}$) contain coal, Kangsu Formations ($J_{1k}$) are lacustrine swamp facies deposit, and coal bearing strata formations, the coal strata in Kangsu area is the best; Yang ye Formations ($J_{2y}$) are lacustrine swamp facies, the coal strata is mainly distributed in the Kucherapu and Kalatuzi mining areas. In the Karamilan area in the west of east Kunlun, the coal bearing strata is the same as the southern margin of Tarim basin as the Yarkant group ($J_{1-2y}$), the lower Jurassic Bagunblanca group ($J_{1b}$) in the Karakoram region is the interactive marine and terrestrial deposit, the coal bearing property is bad; the
Zhongtong Longshan Formations (J2l) is neritic facies carbonate clastic rocks deposit, basically containing no coal.

2.2. Coalfield structure

Xinjiang is located in the Tethys tectonic domain, the circum-siberian tectonic domain and the Cenozoic composite orogenic region, forming a complex basin-mountain structure, the basin is embedded in or inside of Kunlun orogenic belt, Qilian orogenic belt, Tianshan-Xingmeng orogenic belt, Altay orogenic belt and Altun fracture belt, orogenic belt (or fracture belt) has a regional controlling effect on the development and evolution of basin structure, there are differences in basin types and tectonic deformation characteristics[12]. The overall framework of Xinjiang coalfield structure is composed of "three belts" and "three blocks" (Table 1), that is: the first belt: Altay Caledonian fold belt; the second belt: Tianshan Wallissie fold belt; the third belt: Kunlun Wallissie indo-Chinese fold belt. The first block: Jungar stable block (basin), Turpan-Hami micro block (basin); the second block: Tarim stable block (basin); the third block: Ili-Middle Tianshan micro block. The general rule of tectonic deformation in coal bearing basins is that the deformation intensity of thrust nappe, compact fold, wide and slow fold or fault block decreases successively from the basin margin to the inside. Therefore, both the basin and coal measure have the characteristics of concentric ring deformation with strong basin margin and weak basin interior, which were strengthened and shaped in the Himalayan period.

Table 1. Abridged table of tectonic structure units division in Xinjiang.

| Primary structural unit | Secondary structural unit | Structural properties |
|-------------------------|---------------------------|-----------------------|
| Altay-Irtysh Block      | Altay Caledonian fold belt| Altay-Ertiz fold belt |
|                         | Ertiz Wallissie fold belt |                       |
|                         | Western Jungar Caledonian-Wallissie fold belt |                       |
|                         | Eastern Jungar Caledonian-Wallissie fold belt |                       |
| Kazakhstan-Jungar block | Jungar block              | Stable block          |
|                         | North Tianshan Wallissie fold belt |                       |
|                         | Turpan-Hami micro block   | Tianshan fold belt    |
|                         | Ili-Middle Tianshan micro block |                   |
|                         | Middle Tianshan Caledonian fold belt |                   |
|                         | South Tianshan Wallissie fold belt |                   |
| Tarim block             | Tarim block               | Stable block          |
|                         | East Kunlun North belt (Caledonian fold belt) |     |
|                         | East Kunlun Middle belt   | Kunlun fold belt      |

Western Jungar Caledonian-Wallissie fold belt presents a belt shape extending from north east to south west, a small faulted or depressed basin is developed in the Caledonian-Wallissie fold belt, accepting Jurassic coal-bearing rock measures, formed a coalfield with industrial value, such as Hoboksar-Fuhai coalfield, Tori-Hoxtolgay coalfield, etc.

Eastern Jungar Caledonian-Wallissie fold belt presents a belt shape extending from north west to south east, a depressed basin is developed in the Caledonian-Wallissie fold belt, formed a Jurassic coalfield with industrial value, such as Kamster coalfield, Barkol coalfield, Santanghu coalfield, Naomaohu coalfield, etc.

Jungar block is a central block type compound superimposed basin. Under the conditions of paleostructure, paleogeography, paleoclimate and paleovegetation suitable for coal formation, the coal-bearing construction was formed in the early-middle Jurassic period, its function of coal accumulation is extensive and strong, and is characterized by the repeated occurrence of extremely thick single layer coal strata.

Turpan-Hami micro block is located in the eastern section of the north Tianshan fold belt; coal-bearing construction was accepted in early - middle Jurassic, abundant coal resources exist in the Ewirgol coal district, Tokesen coalfield, Shanshan coalfield, Turpan coalfield, Shaerhu coalfield, Hami coalfield, Dananhu-Wutong wowzi coalfield and Yemaquan coal mine.
Ili-Middle Tianshan micro block was located in the western section of the middle Tianshan fold belt, the main coalfields include Yining coalfield, Nyerke coalfield, Xinyuan-Gongliu coalfield, Zhaosu-Tex coalfield, etc. Tarim basin is a stable landmass with ancient basement of pre-Changchengian Period and Precambrian, the main coalfields are distributed in the periphery of Tarim basin, such as Wensu-baozi east coalfield, Kuqa-Baicheng coalfield, Yangxia coalfield, Lop Nor coalfield and so on in the north margin, Wuqia coalfield, Aktaw coalfield and Shache-Yecheng coalfield in southwest margin and Minfeng-Qiemo coalfield in southeast margin.

### 2.3. Coal seam

#### Table 2. Coal bearing characteristics of Badaowan Formations in Jungar coal bearing area.

| Coalfield | Thickness of coal seam (m) | Number of exploitable layers | Exploitable Thickness (m) | Coalfield | Thickness of coal seam (m) | Number of exploitable layers | Exploitable Thickness (m) |
|-----------|-----------------|-----------------|-----------------|-----------|-----------------|-----------------|-----------------|
| Tori-Hoxtol gay coalfield | 9.0~41.8 | 2~15 | 2.9~30.2 | Southern Jungar coalfield | 2~69.8 | 1~15 | 1.5~66.3 |
| Karamay coalfield | 0.8~30 | 2~6 | 2.7~9.8 | East Jungar coalfield | 0.3~26.7 | 1~8 | 0.8~7.7 |
| Kunes coal district | 14.8 | 3 | 9.3 | Yining coalfield | 18.0~74.0 | 6~10 | 18.4~73.2 |
| Houxia coalfield | 7.7~19.8 | 3~7 | 6.8~19.4 | Nyerke coalfield | 6.5~131.0 | 6~8 | 9.3~98.7 |
| Dabancheng coalfield | 0.5 | | | Shanshan coalfield | 0~10.6 | 1 | 0.7~10.6 |
| Ewirgol coal district | 3.6~81.9 | 12 | 1.0~75.6 | Hami coalfield | 0~33.6 | 2~4 | 0.7~27.8 |
| Tokesen coalfield | 0.8~28.8 | 1~10 | 0.8~29.5 | Kamster coalfield | 7.0~17.4 | 2~9 | 7.7~14.4 |

Note: The data comes from the exploration data of Xinjiang Uygur Autonomous Region Coal Geology Bureau.

#### Table 3. Coal-bearing characteristics of Xishanyao Formations in Jungar coal-bearing area.

| Coalfield | Thickness of coal seam (m) | Number of exploitable layers | Exploitable Thickness (m) | Coalfield | Thickness of coal seam (m) | Number of exploitable layers | Exploitable Thickness (m) |
|-----------|-----------------|-----------------|-----------------|-----------|-----------------|-----------------|-----------------|
| Tori-Hoxtol gay coalfield | 15.0~45.1 | 7~13 | 12.8~37.9 | Houxia coalfield | 17.1~55.2 | 5~9 | 15.1~40.7 |
| Qinghe coal mine | 0.7~8.0 | 1~5 | 1.5~6.9 | Dabancheng coalfield | 6.1~37.5 | 5~14 | 8.5~29.3 |
| Kamster coalfield | 7.1~27.8 | 2~5 | 5.5~24.0 | Tokesen coalfield | 10~28.8 | 4 | 4.0~18.9 |
| Southern Jungar coalfield | 11.4~188.6 | 3~47 | 10.9~184.1 | Shanshan coalfield | 3~88.3 | 4~6 | 4~31.8 |
| East Jungar coalfield | 0.4~111.4 | | 1.1~87.3 | Turpan coalfield | 12.6~27.8 | 1~2 | 5.7~20.5 |
| Barkol coalfield | 13.0~154.7 | 12 | 28.0~52.2 | Shaer lake coalfield | 7.2~314.5 | 8~25 | 2.0~314.5 |
| Santanghu coalfield | 1.3~89.9 | 4~26 | 7.8~71.3 | Dananhu~Wutong wowzi coalfield | 36.5~148.7 | 20 | 28.5~133.1 |
| Naomaohu coalfield | 1.1~56.6 | 2 | 17.6 | Nyerke coalfield | 0.3~100.2 | 5 | 22.5~69.9 |
| Yining coalfield | 26.3~55.4 | 3~6 | 19.5~43.1 | Zhaosu ~ Tex coalfield | 2.5~10.4 | 5 | 5.8~10.1 |

Note: The data comes from the exploration data of Xinjiang Uygur Autonomous Region Coal Geology Bureau.
There are 26 Jurassic coalfields (coal district and coal mining spots) in the coal-bearing areas of Xinjiang, and the coal-bearing strata are lower Badaowan Formations (J1b) and middle Xishanyao Formations (J2x)\[12-14\]. Xishanyao Formations and Badaowan Formations are widely developed in Tianshan-Jungar, Tarim, Turpan-hami, Santanghu-Naomaohu, Yanqi, Ili and other large coal bearing basins in Xinjiang, the coal-bearing properties of Urumqi, Shaer lake and Danan lake in Jungar basin are very good (Table 2, 3), containing 5-30 layers of super thick coal seams with total thickness of 174-182m; Yining contains coal of 6-13 layers with thickness of 40-47m. The early-middle Jurassic coal seam was stable then relatively stable.

2.4. Conditions of coal quality
Jurassic coal seams in Xinjiang are widely distributed, with good coal quality and abundant resources, and unique chemical characteristics and technological properties, through making full use of these characteristics, its broad use prospects can be greatly increased [10,12-14].

In the Jurassic coal seam of the whole Xinjiang, the coal seams of low, medium and high rank are distributed, among which low rank bituminous coal is the main one, followed by medium and high rank bituminous coal. Young bituminous coal is a good power fuel; gas coal is an ideal blended coal for coking; High volatile long-flame coal is the main raw material for comprehensive utilization of tar; gas-fat coking coal is used for coal-coking or blended coal for coking [14]. Details are as follows:

Ash yield of raw coal in coal seam of Badaowan Formations is 4.7-27.24%, referring to ultra-low ash coal-medium ash coal; total sulfur is 0.2-0.93%, 0.44% on average, referring to ultra-low sulfur coal-medium sulfur coal, relying on ultra-low sulfur coal-low sulfur coal mainly, phosphorus content of raw coal is 0.00-0.064%, 0.01% on average, referring to ultra-low phosphorus coal, chlorine content of raw coal is 0.00-0.059%, 0.035% on average, referring to ultra-low chlorine coal, arsenic content of raw coal is 0.00-0.02%, 0.0056% on average, referring to grade I coal containing arsenic, Grade I and II coal containing arsenic; the coal of Badaowan Formations is No.41 long-flame coal. See Table 4 for details.

### Table 4. Characteristics of raw coal quality of Badaowan Formations in East Jungar coalfield.

| Project                  | Wucaiwan mine | Dajing mine | Xiheishan mine | Region-wide average content | Grade                  |
|--------------------------|---------------|-------------|----------------|----------------------------|------------------------|
| Ad(%)                    | 5.12-0.63     | 5.2-9.98    | 4.7-27.24      |                            |                        |
| St.d(%)                  | 0.2-0.93      | 0.3-0.41    | 0.2-0.32       | 0.44                       | ultra-low sulfur coal  |
| Pd(%)                    | 0.00-0.064    | 0.00-0.003  | 0.00-0.06      | 0.01                       | ultra-low phosphorus coal |
| Cld(%)                   | 0.03-0.038    | 0.04-0.059  | 0.00-0.034     | 0.035                      | ultra-low chlorine coal|

Note: The data comes from the exploration data of Xinjiang Uygur Autonomous Region Coal Geology Bureau.

Ash yield of raw coal in coal seam of Xishanyao Formations is 4.7-27.74%, 11.48% on average, referring to low ash coal-ultra-low ash coal, relying on ultra-low ash coal mainly; total sulfur is 0.2-0.88%, 0.51% on average, referring to ultra-low sulfur coal-low sulfur coal; phosphorus content is 0.01-0.040%, 0.024% on average, referring to low phosphorus coal; chlorine content is 0.04-0.070%; 0.055% on average, referring to low chlorine coal; arsenic content is 2.0-2.82ug, 2.48ug on average, referring to grade I coal containing arsenic, fluorine content is 22.644.28ug, 34.89ug on average; the coal of Xishanyao Formations is No.31 non-caking coal, No.41 long-flame coal can be founded in local individual points. See Table 4 for details.

### Table 5. Characteristics of raw coal quality of Xishanyao Formations in East Jungar coalfield.

| Project                  | Wucaiwan mine | Dajing mine | Xiheishan mine | Laojunmiao mine | Region-wide average content | Grade                  |
|--------------------------|---------------|-------------|----------------|----------------|----------------------------|------------------------|
| Ad (%)                   | 10.9          | 10.1        | 10.9           | 14.1           | 11.5                       | low ash coal           |
| Cl.d(%)                  | 0.0           | 0.0         | 0.1            | 0.1            | 0.1                        | low chlorine coal      |
| As.d(ug)                 | 2.6           | 2.0         | 2.8            | 2.5            | grade I coal containing arsenic |
| St.d(%)                  | 0.5           | 0.4         | 0.3            | 0.9            | 0.5                        | low sulfur coal        |

Note: The data comes from the exploration data of Xinjiang Uygur Autonomous Region Coal Geology Bureau.
Ash yield of raw coal in coal seam of Shishugou Group is 5.0-26.38%, 14.91% on average, relying on low ash coal mainly; sulfur content is 0.4-12.27%, 3.92% on average, referring to high-sulfur coal; phosphorus content is 0.00-0.056%, 0.022% on average, referring to low sulfur coal; chlorine content is 0.03-0.057%, 0.04% on average, referring to ultra-low chlorine coal; arsenic content is 125ug, referring to grade II-IV coal containing arsenic; the coal of Shishugou Group is No.41 long-flame coal. See Table 5 for details.

2.5. Condition of resource distribution

Xinjiang is rich in coal resources. The total amount of coal resources is about 1.9 trillion tons, wherein a total of 0.23 trillion tons of coal reserves have been discovered, the total resources are estimated at 1.67 trillion tons (Table 6) [14], and the coal resources are concentrated and uneven[10,12]. There are mainly distributed in the coal-bearing basins in Jungar and Tianshan mountains, also distributed in the northern margin of Tarim basin, less or sporadically around other areas. In space, it is mainly distributed in the middle and lower Jurassic period, accounting for more than 99%, few coal seams at other times. With the quickening pace of Western Development and the positioning of the 14th large national base, the state has increased the investment in exploration of Xinjiang. In 2009, the coal pre-inspection results of Xinjiang "358" project in the coalfields of IRA-Ayding lake, Kumutage-Shaer lake, Dananhu-Yemaquan, Santanghu and Naomaohu,etc. submitted the overall report on the investigation of coal resources in east Xinjiang Uygur Autonomous Region, getting the 334 resource volume of 231.792 billion tons. An investigation was carried out in the Xinyuan-Gongliu coalfield and it was determined that no coal was found at a depth of 1000 meters. In 2010, another investigation was carried out in Lop Nor, no coal resource was found. In 2011, exploration was carried out in Santanghu, the Bayanbulak coalfield in Hejing County and the three prefectures of Kashgar, Hotan and Aksu in southern Xinjiang [12]. By the end of 2014, the proved reserves of Xinjiang reached 367.8 billion tons [15], accounting for 24% of that in the whole country, which is second only to Inner Mongolia.

Table 6. Resources in Xinjiang coal mining area [14].

| Mine (coalfield)       | Retained resource reserve (10 thousand tons) | Resource reserve (10,000 tons) | Reserve (10,000 tons) | Mine (coalfield)       | Retained resource reserve (10 thousand tons) | Resources (10,000 tons) | Reserve (10,000 tons) |
|------------------------|---------------------------------------------|--------------------------------|-----------------------|------------------------|---------------------------------------------|-------------------------|-----------------------|
| Tori-Hoxtolgay coalfield | 19681.2                                      | 19681.2                         |                       | Yining coalfield       | 1099588.8                                   | 859423.89               | 1657.2                |
| Southern Jungar coalfield | 32519.88                                    | 31573.55                        | 271.94                | Nyerke coalfield       | 9570.92                                    | 7727.38                 | 739.3                 |
| Dabancheng coalfield   | 4398.8                                       | 2864.21                         | 257.83                | Zhaosu-Tex coalfield   | 681.7                                       | 222.6                   | 99.5                  |
| Houxia coalfield       | 194228.91                                    | 178170.74                       | 6389.28               | Ewirgol coal district  | 51086.71                                    | 5640.92                 | 18030.92              |
| East Jungar coalfield  | 2828                                         | 2828                            |                       | Shanshan coalfield     | 5113.56                                     | 4184.84                 | 504.97                |
| Qinghe coal mine       | 242.03                                       | 193.63                          |                       | Hami coalfield         | 41447.04                                    | 7947.5                  | 13665.75              |
| Barkol coalfield       | 8759                                         | 3742                            |                       | Turpan coalfield       | 317648                                      |                        | 317648                |
| Santanghu coalfield    |                                              |                                 |                       | Shaer lake coalfield   |                                            |                         |                       |
| Naomaohu coalfield     |                                              |                                 |                       |                          |                                            |                         |                       |
| …                      |                                              |                                 |                       |                          |                                            |                         |                       |

2.6. Production scale and layout

In terms of production scale, by the end of 2014, there were 349 production mines in the whole region, with a certified production capacity of 96.73 million tons/year [16]. In 2014, coal output in the whole region reached 143 million tons, 53 million tons more than in 2010, the average annual increase was
13.25 million tons, with average annual growth rate of 12.3 percent, 8 percentage points higher than the national average. In 2014, coal consumption in whole region was 129 million tons, 39 million tons more than in 2010, with an average annual growth rate of 10.3 percent. There are 29 coal mines under construction in the whole region, with a production capacity of 50 million tons per year; Forty-seven projects have received "passes" with a total size of 220 million tons per year. At present, 42 overall plans for mining areas has been formulated or are compiled in the whole region, a total of 368 planned wells (mines) fields, with a planned total capacity of 1.79 billion tons per year, reserving a large number of million tons, ten million tons of large, super large coal mine projects.

In terms of industrial layout, coal power and coal chemical industry will be developed on the scale of 12.4 billion tons of proven reserves in Ili coalfield; coal power (west-east transportation) and coal chemical industry will be developed on the scale of 61.5 billion tons of proven reserves in East Jungar coalfield; coal transportation (supply for southern Xinjiang); coal power (west-east transportation) and coal chemical industry will be developed on the scale of 44.8 billion tons of proven reserves in Turpan-Hami coalfield. By the end of 2015, there were 73 entrepreneurs with coal chemical industry scale or above in Xinjiang, among which 66 were traditional coal chemical industry and 7 were modern coal chemical industry, forming a modern coal chemical industry chain with characteristics of coal-based natural gas, coal-based olefin, coal-based oil, coal-based dimethyl ether, coal-based glycol and coal utilization according to quality. Coal-based natural gas of 1.375 billion cubic meters per year, coal-based ethylene glycol of 50,000 tons per year and coal-based dimethyl ether of 600,000 tons per year has been built. By the end of 2014, the installed capacity of coal power in Xinjiang had reached 54.64 million kw; In terms of lines, 17911 km of 220kv line, 166Km of ±800 uhv dcline and 3940 km of 750v line has completed in Xinjiang, wherein the 750Kv power transmission and transformation project line from Ili to Kuqa of Tianshan west looped network has been partially completed in northern and southern Xinjiang. In terms of consumption and output scale, 80 million tons of coal was consumed by the power industry; In terms of output scale, coal shipped out in Xinjiang exceeded 20 million tons for the first time in 2011, 30 million tons in 2013; In 2014, the coal market outside the region was weak, and transfer volume in Xinjiang dropped to 23.4 million tons, mainly transferred to Gansu Jiayuguan, Jinchang Jiuquan and other western regions of Lanzhou. However, compared with the current production capacity of 360 million tons, there was a serious surplus of coal capacity.

3. Conditions of water resources in Xinjiang

3.1. Surface water resources

According to the calculation of Xinjiang hydrological station [17], there are 570 rivers of different sizes in Xinjiang, with 76.5 billion m$^3$ of surface runoff and 2.79 billion m$^3$ of mountain spring flow. The annual runoff in China is 79.3 billion m$^3$, and the average annual inflow runoff from abroad is about 9.087 billion m$^3$, so the runoff of Xinjiang rivers is about 88.4 billion m$^3$ (Table 7). Among them, small rivers are in the majority, with small amount of water and short process. There are 487 rivers with annual runoff of less than 100 million m$^3$, accounting for 85% of the total number of rivers, and 8.25 billion m$^3$ of runoff, accounting for 9.4% of the total runoff in Xinjiang; There were 18 rivers with annual runoff of more than 1 billion m$^3$, accounting for 3% of the total, and the runoff of 53.4 billion m$^3$, accounting for 60.4% of the total runoff in Xinjiang. The main sources of runoff in Xinjiang rely on glacier melt water, seasonal snow cover and rainfall mainly [8]. Glacial melt-water, especially in the Kunlun Mountains, has the largest proportion of river and glacial melt-water supply. Lanzhou institute of glacial permafrost, Chinese Academy of Sciences, estimated that the total area of glaciers in Xinjiang is 24,479.3 m$^2$, accounting for 42% of the total area of glaciers in China; glacier reserves are 2,583.57 billion m$^3$, accounting for 50 percent of the country's total glacier reserves; glacier melt water is 17.86 billion m$^3$, accounting for 32% of the total glacier melt water in China. Among them, the melting amount of Tianshan glacier was the largest, which was 9.59 billion m$^3$. 

7
accounting for 53.70% of the total melting amount [8]. The dynamic part of glacier water resources is glacier melting, accounting for 0.64% of the total glacier reserves in Xinjiang every year, the total runoff of the river, accounting for about 20% of the total runoff, is one of the important sources of runoff in Xinjiang.

### Table 7. Annual runoff of rivers which reach over 1 billion m$^3$ in Xinjiang [17].

| Water reticulation system | River Name | Name of hydrographic station | Area of water catchment (km$^2$) | Annual runoff (100 million m$^3$) |
|---------------------------|------------|------------------------------|----------------------------------|----------------------------------|
| Ili River                 | Tekes River| Kapuchi sea station          | 27402                            | 78.4                             |
|                           | Kashi River| Tuohai station               | 8656                             | 38.3                             |
|                           | Kunes River| Zeketai station              | 4123                             | 20.2                             |
|                           | Burqin River| Qiafu station                | 1307                             |                                  |
|                           | Karakirtshy River| Qunkule station          | 8422                             | 42.0                             |
|                           |           |                              |                                  | 17.9                             |
| Eerqisi River             | Kurirtys River| Kuwei station                | 2494                             | 14.9                             |
|                           |           | Fuyun station                | 1965                             |                                  |
|                           |           | Kelatashi station            | 6111                             | 21.4                             |
| Manasi River              | Manasi River| Hongshanzu station           | 5156                             | 12.6                             |
| Ulungur River             | Ulungur River| Santai station               | 18375                            | 9.8                              |
| Aksu River                | Queenmalick river| Xiehela station          | 12816                            | 46.1                             |
| Hotan River               | Taushgan Darya| Shariqelankane station       | 19166                            | 25.7                             |
|                           | Yurungkash River| Tonggusilock station       | 14575                            | 22.4                             |
|                           | Karakash River| Ulurwati station            | 19983                            | 21.8                             |
|                           |           | Kaqun station                | 50248                            | 64.6                             |
| Yerqiang river station    |           |                              |                                  |                                  |
| Kaxgar River              | Kezi River| Karabelli station            | 13700                            | 20.5                             |
|                           | Gaizi River| Klerk station                | 9753                             | 9.5                              |
| Weigan River              | Muzhati River| Pochengzi station           | 2845                             | 14.6                             |
| Kaidu River               | Kaidu River| Dashankou station            | 19022                            | 32.9                             |
| Tarimi River              | Tarim River| Alear station                |                                  | 47.9                             |

### Table 8. Water resources in all administrative regions of Xinjiang [18].

| Region                             | Total amount of water resources | Surface water resources | Underground Water Resources | The coincident amount between surface water and groundwater | Total amount of water consumption |
|------------------------------------|---------------------------------|-------------------------|----------------------------|----------------------------------------------------------|----------------------------------|
| Tuscaloosa area                    | 64                              | 59                      | 32                         | 27                                                       | 43                               |
| Altay                              | 113                             | 109                     | 46                         | 41                                                       | 33                               |
| Bortala prefecture                 | 27                              | 24                      | 16                         | 13                                                       | 16                               |
| Bayingolin prefecture              | 142                             | 135                     | 76                         | 69                                                       | 55                               |
| Aksu region                        | 79                              | 72                      | 69                         | 62                                                       | 108                              |
| Kyzyl prefecture                   | 69                              | 68                      | 44                         | 42                                                       | 12                               |
| Kashi Prefecture                   | 79                              | 73                      | 80                         | 74                                                       | 119                              |
| Urumqi city                        | 13                              | 13                      | 6                          | 5                                                        | 11                               |
| Karamay city                       | 1                               | 0                       | 1                          | 0                                                        | 6                                |
| Shihzei city                       | 0                               | 0                       | 1                          | 1                                                        | 6                                |
| Turpan city                        | 10                              | 9                       | 5                          | 4                                                        | 13                               |
| Hami region                        | 15                              | 13                      | 10                         | 8                                                        | 11                               |
| Changji Hui autonomous prefecture  | 40                              | 36                      | 24                         | 20                                                       | 45                               |
| Ili prefecture                     | 161                             | 158                     | 75                         | 72                                                       | 53                               |
| Hotan region                       | 118                             | 112                     | 62                         | 55                                                       | 46                               |

Note: the unit is 100 million cubic meters

### 3.2. Underground water resources

In 2015, the total amount of underground water resources in Xinjiang was 57.949 billion m$^3$ (table 8)[18], wherein the amount of underground water was 37.092 billion m$^3$ in hilly area, 37.255 billion m$^3$ in plain area, 37.013 billion m$^3$ in plain area, the repeated amount of underground water in hilly
area and plain area was 16.156 billion m³, and the recoverable amount of underground water was 23.586 billion m³. The total recharge modulus of Xinjiang plain area is 67,000 m³/a•km², and the recoverable modulus is 4.28 m³/a•km². The amount of surface water and underground water in Xinjiang comes from natural precipitation. In 2014, for example, precipitation in mountainous areas reached 209 billion m³, accounting for more than 80% of the total precipitation in Xinjiang that year, the mountainous area was the runoff formation area, and the bedrock fissure water supplies the river; the plain area was the area of runoff loss, and the surface water was transformed into underground water through various infiltration ways after coming out of the mountain pass, its conversion amount accounted for 75% of the total underground water supply in the plain area, natural underground water supplies accounted for only 17%.

3.3. Underground water resources of coal district

| Region         | Mine                  | Aquifer                  | Permeability coefficient K (m/d) | Unit water inflow q (L/s·m) | Mine water inflow Q m³/h | Potential for exploitation |
|----------------|-----------------------|--------------------------|---------------------------------|-----------------------------|--------------------------|----------------------------|
| Urumqi coalfield East Jungar coalfield          | Jiangou coal mine      | Jurassic Xishanyao Formations aquifer | 0.0001~0.009                 | 0.0089~0.001              | 150                      | Smaller                   |
|                | Kalassay West Minefield |                          | 0.007                          | 0.005 ~ 0.0051             | 269                      | Medium                    |
| Southern Jungar coalfield          | Kuanggou coal mine     | Jurassic Xishanyao Formations aquifer | 0.132~0.296                  | 0.235 ~ 0.247            | 350                      | Medium                    |
| Yining North coalfield          | Sulesayi Minefield     | Jurassic Xishanyao Formations aquifer | 0.036                         | 0.013                      | 492.23                   | Medium                    |
| Turpan-Hami basin          | No. 3 mine in Dananhu west area | Jurassic Xishanyao Formations aquifer | 4.44~6.77                    | 1.18                      | 1368                     | Bigger                    |
|                            | No. 1 mine in Dananhu east area | Neogene Grape Valley Formations aquifer | 2.8~17.8                     | 4.2                       | 1146                     | Bigger                    |
|                            | Strip mine in Shanshan county | Jurassic Xishanyao Formations aquifer | 0.004~0.038                  | 0.0013 ~ 0.0028         | 40                       | Small                     |
|                            | Mine in Aydingkol Lake No. 1 area | Lower Jurassic Sangonghe Formations aquifer | 0.034~0.036                  | 0.029~0.037              | 37                       | Smaller                   |

Due to the different times of coal formation, the types of aquifers accompanying coal seams are significantly different [2]. The Cenozoic tertiary coal seam was dominated by pore water, followed by fissure water and karst water; The Mesozoic Jurassic coal seam was dominated by fracture water, followed by karst water and pore water; The Paleozoic carboniferous-Permian coal seam was dominated by karst water, followed by fracture water and pore water. According to the assemblage relationship between coal seam and aquifer in Xinjiang, the aquifer groups related to coalfield mining are divided into quaternary pore aquifer and Jurassic fractured aquifer. Quaternary pore aquifers are mainly composed of coarse sand, medium sand and gravel of diluvial, alluvial and aeolian deposits with different thickness. Unit water inflow is 0.035-9.5l/s.m, water-abundance is weak to strong, salinity < 1 g L⁻¹, and water quality is HCO₃⁻ + SO₄²⁻·Ca⁺ +Mg type. The fractured aquifer of Jurassic system is composed of brick red clastic rocks, wherein sandstone and conglomerate form the aquifer, while mudstone and argillaceous siltstone form the water-resisting layer. Water-abundance of upper Jurassic was medium with unit water inflow of 0.26-0.378l/s.m, salinity < 1 g L⁻¹, and water quality of SO₄²⁻ + Cl⁻ - Na⁺ +Ca type. Water-abundance of middle Jurassic was weak with unit water inflow of 0.001-0.0044l/s.m, salinity <1-2 g L⁻¹, and water quality of SO₄²⁻+Cl⁻-Na⁺+Ca type. Water-abundance of lower Jurassic was weak with unit water inflow of 0.06-0.08l/s.m, salinity >1 g L⁻¹, and water quality of Cl⁺+SO₄²⁻+HCO₃⁻-Na⁺+Ca⁺+Mg type, the lower part is the main coal-bearing rock formation with unit water inflow of 0.0094l/s.m. Hydrogeological reference is made by means of pumping test [19].
through observing the water level recovery process in the observation hole, field pumping test and hydrogeological data were obtained, the evaluation results of major coalfields in Xinjiang are shown in Table 9. It can be seen that most of the mines in Xinjiang are water-deficient and water-abundance of aquifers is weak under bad recharge conditions, so there is no potential for exploitation and utilization, however, because of the special hydrogeological conditions, water-abundance of aquifers in this area is strong and has great potential for exploitation. Some mine aquifers have a certain potential for exploitation under the condition of sufficient recharge.

3.4. Water resources supply

Water is the source of life, but the whole water resource in China is deficient and unevenly distributed. In order to achieve the full and reasonable utilization of water resource, China is vigorously implementing the strictest water resource management system, establishing three red lines of water resource development and utilization control, water use efficiency control and water functional area pollution limit. In 2013, the General Office of the State Council issued the measures for assessing the implementation of the strictest water resources management system, and identified three red line control index for water resources management in various provinces and regions. The control index of Xinjiang is 51.6 billion cubic meters and 52.67 billion cubic meters respectively in 2020 and 2030 [20]. By the end of 2015, the total water resources in Xinjiang were 93.04 billion cubic meters (Table 8), and the total amount of water resources changed little from 2000 to 2015 (Figure 1), then compared with water resources in 2015 (Table 10), the existing water resources in Xinjiang are sufficient. However, as the coal development strategy moves westward and the western development strategy continues to advance, both industrial and residential water use will increase significantly, and the red line of 51.6 billion cubic meters is expected to be overreached by 2020. In order to keep water consumption within the red line, water saving and water diversion will be the solution (Table 10). In terms of water saving, considering the existing water use model for agriculture and animal husbandry in Xinjiang, it is the most effective way to increase the area of high-efficiency water saving and reduce the area of farmland returned to forest. According to statistics, about 4.7 billion cubic meters of water can be saved by saving water, and about 8.3 billion cubic meters of agricultural water can be withdrawn by returning farmland to forests. In terms of water diversion, given the imbalance of water resources in Xinjiang, and water resources are mostly distributed in mountainous areas, it is possible to transfer water within the region, according to relevant planning, annual outflow water volume of Eerqisi River is 9.5 billion cubic meters, accounting for 80%, and the water diversion capacity is 2.5 billion to 3 billion cubic meters; Through the Ili river diversion project, about 2.6 billion cubic meters of water can be diverted. It can be seen that through the implementation of the above-mentioned schemes, the red line of water consumption in Xinjiang can be ensured. Therefore, Xinjiang has sufficient potential for water supply as a whole.

![Figure 1. Change of total water resources during 2000-2015.](image1)

![Figure 2. The distribution of water resources and water consumption in Xinjiang (Note: data from Xinjiang Statistical Yearbook 2016).](image2)
Table 10. Water consumption in Xinjiang in 2015.

| Region                  | Agriculture sector | Industry sector | Service sector | Lives of residents | Ecological environment |
|-------------------------|--------------------|-----------------|----------------|-------------------|------------------------|
| Urumqi city             | 6.3                | 1.5             | 0.3            | 1.5               | 1.0                    |
| Karamay city            | 3.6                | 0.2             | 0.1            | 0.2               | 1.2                    |
| Shihezi city            | 4.5                | 0.2             | 0.0            | 0.2               | 0.3                    |
| Altay area              | 31.9               | 0.3             | 0.1            | 0.3               | 0.1                    |
| Bortala prefecture      | 15.4               | 0.2             | 0.1            | 0.2               | 0.2                    |
| Bayingolin prefecture   | 51.8               | 0.6             | 0.5            | 0.6               | 0.6                    |
| Aksu region             | 105.8              | 0.7             | 0.7            | 0.7               | 0.0                    |
| Kyzyl prefecture        | 11.7               | 0.3             | 0.1            | 0.3               | 0.1                    |
| Kashgaria Prefecture    | 116.3              | 1.5             | 0.2            | 1.5               | 0.4                    |
| Turpan city             | 12.5               | 0.3             | 0.0            | 0.3               | 0.2                    |
| Hami region             | 9.2                | 0.5             | 0.1            | 0.5               | 0.2                    |
| Changji Hui autonomous prefecture | 41.6 | 0.8 | 0.2 | 0.8 | 0.5 |
| Ili Prefecture          | 49.3               | 1.5             | 0.2            | 1.5               | 0.5                    |
| Tuscaloosa area         | 41.8               | 0.7             | 0.0            | 0.7               | 0.1                    |
| Hotan region            | 44.8               | 0.7             | 0.2            | 0.7               | 0.5                    |

Note: data from Xinjiang Statistical Yearbook 2016

4. Research on matching relationship

4.1. Reverse distribution of water resources and coal resources

As can be seen from the above-mentioned situation of water resources in section 2.1, 2.2 and 2.4, Xinjiang has sufficient potential for water supply as a whole. However, by comparing the distribution of surface water resources in section 2.1, coal resources data of coal mining areas in Xinjiang in section 1.3, and the proved reserves and development positioning of major coal mines in section 1.4, it can be known:

(1) Regional differences in water resources distribution are significant

The distribution of water resources in Xinjiang is different in time and space (Table 10). Water resources are mainly distributed in Ili, Altay and Hotan, accounting for 15%, 17% and 14% of the total amount. Water resources are relatively scarce in Hami and Changji regions. Average surface water resources for many years in Changji prefecture is 3.882 billion m³, only 1.065 billion m³ in Hami. Average underground water resources for many years in Changji prefecture is 2.21 billion m³, only 0.859 billion m³ in Hami. In terms of the development of surface water resources, the utilization rate of Ili in 2011 was 4.5%, with great potential; 65.38% in Changji, exceeding 60% of the warning line; 72.79% in Hami, apparently higher than the warning line. In terms of groundwater, the utilization rates of Ili, Changji and Hami were 4.6%, 73.2% and 86.2% respectively, wherein the potential of groundwater exploitation in Ili area is great, but the groundwater in Changji and Hami area is in the stage of overexploitation.

(2) The overall distribution of coal resources and water resources is unbalanced

Coal resources in Xinjiang are mainly distributed in Ili, Southern Jungar, and Eastern Jungar and Turpan-Hami basin regions, with significant spatial differences. But the point is that there is an inverse distribution between the differences in water distribution and coal distribution (Figure 1 and 2), that is, the Southern Jungar region with more coal resources is relatively short of water resources, other coal mines such as Changji and Hami also have serious water shortages, only Ili area has relatively balanced and abundant water resources and coal resources. Even so, on a whole, water resources in the major coal mines of Xinjiang are extremely scarce (Table 9 and 10). If measures such as water saving, water weight replacement and water diversion are not taken reasonably and efficiently, the development of coal power and chemical industry will be greatly limited in the future.

(3) Solution of water shortage in different mining areas is different
The characteristics of water resources in Xinjiang are as follows: the distribution of underground water resources and surface water resources is not uniform (Table 9). Although Hami and other coal mining areas are located in a region where surface water is relatively scarce, water-abundance in coal-bearing rock series is relatively high, the underground water recharge sources are mainly precipitation and snowmelt in mountain areas, the water quality is good, the available potential is huge, the comprehensive supply can reach 1.35 billion cubic meters. For example, in the Turpan-Hami basin, the No. 3 mine in Dananhu west area and No. 1 mine in Dananhu east area have great water resource potential, and the water inflow of single mine of the former can reach 1368 m³/h. The use of underground water and the improvement of water-use efficiency should be taken as the main solution. Similarly, the East Jungar region, which is short of water but rich in coal, could be considered to transfer water from Eerqisi River due to its proximity to Ulungur River. However, in Changji prefecture, the solution of water consumption scheme should not only rely on the excavation of underground water, but also consider the transfer of water from the outside. If combined with the positioning of coal mining mode in Xinjiang coal mines, for example, most of the coal mines in Xinjiang are integrated production of coal and electricity, equipped with corresponding pithead power plants, and most of them are located in desert areas, with long water transfer radius and other factors, water for production and domestic use is transported long distance by pipelines, therefore, the cost of water consumption in the mine is very high, and the average cost is 6-9 Yuan/ton, bringing huge burden to the production of mine. Therefore, the only way is to improve the utilization efficiency of existing water resources, especially underground water resources, focusing on water resources in coal-bearing strata.

5. Conclusions and exploitation suggestions
The whole coal resources and water resources in Xinjiang are relatively rich and concentrated, but imbalance and difference of regional distribution of coal resources and water resources exists, in addition, the ecological environment is very fragile, bringing great difficulties to coal mining. So, the exploitation planning positioning of coal resources must consider the factors of water resources, the key is to make good use of the available water resources - underground water (water in coal-bearing rock series), exploitation suggestions are as follows:

(1) Optimize the layout and plan the efficient ratio of coal and water resources
Water shortage has become the most critical problem restricting sustainable development in Xinjiang. According to the distribution rules of coal resources and water resources in Xinjiang, the relationship between coal resources and water resources is planned as a whole, so as to prove the solution of water shortage in water-deficient coal areas as a whole and realize the maximum economic and efficient utilization. For example, a large proportion of some coal chemical projects could be performed in Ili area, horse coal and electricity co-production projects could be performed in Changji, North Jungar and part of the Hami area, mining areas along the line with better transportation conditions, such as part of Hami coal mine, should rely on coal output mainly.

(2) Scientific mining gives priority to the development of coal mining under water-containing conditions.
In the practice of coal mining under water-containing conditions in northwest China, the key problem is the exploration of hydrogeological conditions and the relationship between the structure of water-conserving coal mining and the coal seam, and the plans and measures of coal mining under water-containing are developed to realize the protection of water resources. For example, the "underground reservoir concept" proposed by academician Gu Dazhao can be adopted, that is, the safety coal pillars are connected with the artificial dam body to form the reservoir body by using the pore of rock body in the goaf formed by coal mining, at the same time, mine water storage facilities and water intake facilities are constructed, and the natural purification effect of goaf rock mass on mine water is fully utilized to construct underground reservoir project of coal mine.

(3) Multiple measures should be taken simultaneously to solve the problem of water shortage
The shortage of water resources in Xinjiang is the shortage of regional difference, but not the shortage of water resources as a whole, which can be solved by means of tapping new resources and economizing on expense, allocation and water right replacement. Through water weight replacement and water diversion project construction and other measures, increase the amount of available water. For example, in Eastern Jungar and Turpan-Hami basin regions energy bases, by strengthening the construction of water conservancy projects, implement the projects of "diversion of the Eerqisi River water to Karamay City" and "diversion of the Eerqisi River water to Urumchi ", water diversion scale can reach 1.2 billion cubic meters; In Hami and Changji, agricultural water can be effectively reduced by building efficient farmland and converting low-end farmland; In the water-rich coal-bearing rock series in Eastern Jungar and Turpan-Hami basin regions, the mine with low salinity of aquifer can be exploited directly, for the mine with high salinity water, the underground water needs to be treated, and salinity can be reduced by hydrochemistry.

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