

Investigation and Evaluation of Groundwater Resources of Juxian

Li Xinyi¹, Li Wanglin^{1,*}, Zhang Xiaojiao¹, Zhu Deling², Yan Huadan²

¹School of Resource and Environment, University of Jinan, Jinan 250002, China.

²Shandong Shuizhiyuan Water Conservancy Planning Design Co. Ltd, Jinan 250002, China.

*Corresponding author, e-mail: cswlwe@sina.com.

Abstract. The investigation and evaluation of groundwater resources refers to the analysis of groundwater quantity, quality, spatial-temporal property and exploitation status. Based on the collected data and field investigation, the groundwater resources in plain and hilly area of Juxian were calculated by replenishment method, discharge method and comprehensive infiltration coefficient method, and the groundwater quality was analyzed and evaluated. The conclusions are as follows: (1) The amount of groundwater resources is 224.940 million m³/a, including 89.585 million m³/a of plain area and 142.523 million m³/a of hilly area respectively. (2) The allowable yield of groundwater is about 162.948 million m³/a, in which the amounts in the plain area and the hilly area are 74.585 million m³/a and 88.363 million m³/a, respectively. (3) The pH value of groundwater ranges from 6.5~7.5 and the degree of mineralization of groundwater was lower than 1 g/L at most. In addition, the total hardness varies from 150 mg/L to 450 mg/L in plain area and 300 mg/L to 550 mg/L in hilly area, respectively. The investigation and evaluation of groundwater resources was of great significance in ensuring the sustainable development of groundwater resources, establishing the scheme of groundwater resources exploitation and utilization.

1. Introduction

In 1968, the United States compiled the first national water resources assessment report, including water supply, water demand and water shortage^[1], and attempted to establish a division of water resources in first time^[2]. Since then, the relevant departments of the United States would complete a national water resource evaluation during 5 to 10 years^[3]. Since 1977, many countries have carried out an investigation and evaluation about the relationship between the quantity and quality of water resources^[4]. In 1983 and 1984, Japan developed the evaluation work of water demand prediction and utilization in twenty-one Century, respectively^[5]. In the middle of nineteenth Century, to grasp and understand groundwater level and water quality accurately, India began to carry out groundwater exploration and evaluation, thus, large number of groundwater monitoring wells were built^[6].

In 1980, China has completed the first water resources investigation and evaluation^[7], and now, there has been nearly 30 years from the first national water resource investigation and evaluation. Due to the progress of society, the water demand on life is increasing, more seriously, the water resources have been also affected adversely in varying degrees by the climate change and human activities. To keep abreast of the water resources situation in our country and improve the evaluation accuracy, it is necessary for us to apply the existing and abundant survey data to re-evaluate the water resources comprehensively^[8].



Juxian is one of the typical water shortage cities in northern China with a per capital water resource of 570m^3 , which is lower than the per capital water resources of Shandong Province. The groundwater resources were evaluated and analyzed in Juxian for further investigate and scientifically evaluate the quantity and quality of water resources.

2. Overview

2.1. Natural geographic survey

Juxian, the southeastern of Shandong Province and the east of Rizhao, covers an area of 1821.1km^2 . It has a sub-humid monsoon climate of warm temperate zone with an average annual rainfall of about 750 mm.

There are 26 rivers in Juxian, including Shuhe River, Weihe River, Xiuzhen River, Maobu River, Yuangong River and Luohe River and so on, which belong to Shuhe River system and Weihe River system, respectively. There are 2 large reservoirs of Juxian, which are called Qingfengling Reservoir, Xiao Shiyang Reservoir. In addition, there also exists 1 medium-sized reservoir and 503 small reservoirs.

2.2. Hydrogeological conditions

Juxian, located in the eastern edge of Yimeng Mountain, the terrain North High South low, surrounded by hills ups and downs, there is an alluvial plain in the middle and both sides of Shuhe River. Juxian territory to hills, plains, accounting for 43.4% and 31.3% of the total area respectively, and 18.6% in mountains areas.

Juxian located on the Yishu fault zone, the two major faults of Jingzhi-Dadian and Anqiu-Juxian run through the county from north to south with extremely complicated geological structures. Most of the mountains affected by the geological structure are north north-east and north north-west. The stratigraphy lithology of Juxian includes metamorphic and igneous rocks, limestone, clastic rocks and Quaternary loose sediments.

The occurrence of groundwater is related to lithology. The metamorphic rocks and igneous rocks are mainly fissure water, the limestone is mainly karst water or karst fissure water, the clastic rocks are mainly composed of fissure water and the distribution of loose sediments is mainly sand pore water.

The main recharged source of groundwater in Juxian is atmospheric precipitation. The runoff direction of groundwater in the area is basically the same as that of surface water. The groundwater runoff drainage volume and river sidestream seepage discharge volume are small, and artificial exploitation is the main way of drainage.

3. Calculation of groundwater resources quantity

The quantity of groundwater resources refers to the dynamic amount of water that has direct replenishment with the local precipitation and surface water, including to recharge, discharge and allowable yield of groundwater. The focus on this assessment is on shallow fresh water, taking the average annual groundwater resources quantity from 1980 to 2015 as the average annual groundwater resources quantity under recent conditions.

3.1. Plain groundwater resources quantity

3.1.1. Recharge of plain area. The plain area groundwater resources quantity has been calculated by the precipitation supply method, which usually defines the total groundwater resources quantity as total recharge without the quantity of well irrigation water return.

The specific Juxian plain region groundwater resources quantity calculation results are shown in Table 1 and the table shows that the annual average quantity of groundwater resources in the plain area is $93.234\text{ million m}^3/\text{a}$, the corresponding annual average recharge modules is $19.7\text{ thousand m}^3/\text{km}^2\cdot\text{a}$.

Table 1. Groundwater recharge in the plain area of Juxian.

Calculating Units	Calculating Area (km ²)	Precipitation Infiltration Replenishment (10 ⁴ m ³ /a)	Piedmont lateral Recharge (10 ⁴ m ³ /a)	Surface Water Recharge (10 ⁴ m ³ /a)	Well Irrigation Recharge (10 ⁴ m ³ /a)	Total Recharge (10 ⁴ m ³ /a)
Qingfeng Ridge	30.5	172.9	15.9	314.1	7.0	509.9
Juxian Station	172.2	2518.3	413.4	752.4	276.0	3959.1
Uncontrolling Area	271	3963.1	287.6	520.8	81.9	4853.4
Sum	473.7	6654.3	716.9	1587.3	364.9	9323.4

3.1.2. Discharge of plain area. The annual average discharge of Juxian is the sum of the phreatic evaporation, river discharge, lateral outflow and the actual groundwater exploitation. According to the analysis and calculation, the annual average total discharge of groundwater in plain area is 84.84 million m³/a. Among them, the actual amount of groundwater exploitation is 47.62 million m³/a and accounts for 56% of the total; the phreatic evaporation is 17.829 million m³/a, which accounts for 21% of the total; the sum of other recharge is 19.391 million m³/a, accounting for 23% of the total.

3.2. Groundwater resources in hilly area

Due to complicated of the terrain, landform, geological structure and formation lithology in hilly regions and difference of hydrogeological condition. When calculating the groundwater resources, type of groundwater are usually divided into general hilly areas and karst mountain areas.

3.2.1. Groundwater resources in general hilly regions. The total discharge in general hilly regions include river basal flow capacity, piedmont lateral outflow, groundwater exploitation and phreatic evaporation, which could represent groundwater resources. The specific calculations of exploitation in general hilly areas in Juxian are shown in Table 2 and the table shows that the annual average total exploitation in general hilly areas is 126.81 million m³/a, this means the annual average quantity of shallow groundwater resources is 126.81 million m³/a.

3.2.2. Groundwater resources in karst mountain area. The precipitation synthetic infiltration coefficient method was used for calculation in karst mountain areas. The formula is as follows:

$$W_{\text{karst}} = P \cdot \alpha_{\text{karst}} \cdot F \quad (1)$$

Where the parameter of P and F respectively means the calculation of the average precipitation and area of the calculating units. The determination of precipitation infiltration coefficient, α_{karst} , is based on the comprehensive analysis of the natural and hydrogeological conditions. The annual average quantity of groundwater resources in karst mountain areas is 15.71 million m³/a after calculation.

The results indicated the total annual average quantity of groundwater resources in Juxian hilly areas is 142.523 million m³/a and the groundwater module is 10.7 thousand m³/km²•a according these calculation results.

3.3. The allowable yield of groundwater

The allowable yield of groundwater refers to the maximum amount of water that can be obtained from aquifers within the foreseeable period through economically reasonable and technically feasible measures without any deterioration of the ecological environment.

The mining coefficient method was used for calculate the allowable yield of groundwater, the formula is as follows:

$$Q_E = \rho \cdot Q_R \quad (2)$$

Where the parameter of ρ and Q_R respectively means the exploitation coefficient and total recharge.

According to the analysis and calculation, the allowable yield of groundwater is about 162.948 million m³/a, of which the amounts in the plain area and the hilly area are 74.585 million m³/a and

88.363 million m³/a respectively and accounts for 69.1% of the total recharge; the module of annual average allowable yield is 8.96 thousand m³/km²•a.

Table 2. Groundwater resources in general hilly areas of Juxian.

Calculating Units	Calculating Area (km ²)	River Basal Flow Capacity (10 ⁴ m ³ /a)	Piedmont Lateral Outflow (10 ⁴ m ³ /a)	Net Consumption of Exploitation (10 ⁴ m ³ /a)	Phreatic Evaporation (10 ⁴ m ³ /a)	Discharge (10 ⁴ m ³ /a)
Weihe River	234	1090.9		301.1	6.1	1398.1
Qingfeng Ridge	88.2	550.4	15.9	79.3	247.5	893.1
Shiyang	124.4	507.9		34.0	270.2	812.1
Juxian Station	452.8	2919.5	413.4	179.0	743.6	4255.5
Uncontrolling Area	445.2	3704.6	287.6	387.8	942.2	5322.2
Sum	1344.6	8773.3	716.9	981.2	2209.6	12681

4. Groundwater quality evaluation

The chemical composition of the groundwater are the product of the interaction between the groundwater and the environment and the long-term activities of human beings. In this paper, the comprehensive evaluation method are adopted and the groundwater quality survey and quality monitoring data as the basis of investigation.

4.1. Groundwater chemistry characteristics and quality

The chemical type of groundwater are determined by the Shukalev classification. There are two kinds of chemical type of groundwater, in which the bicarbonate concentration area of HCO₃⁻-Ca²⁺ is about 901.4 km².

The groundwater mineralization of the plain area of county was less than 1 g/L at most. The groundwater mineralization of the hilly area is mostly less than 1 g/L, and the hilly area is 1306.0 km². The groundwater with salinity greater than 1 g/L is mainly distributed among the Shangjiadianzi area with a total area of 40.4 km².

The total hardness of Juxian plain were greater than 150 mg/L. In mountain area, groundwater with total hardness greater than 300 mg/l is mainly distributed among the area of Niudian village, and the total area is about 43.7 km². Groundwater with total hardness ranging from 300mg/L to 450mg/L is mainly distributed in the vicinity of Dazhuangpo, Dongguan and Sangyuan Towns, with an area of 376.2 km². Groundwater with a total hardness of 450 mg/L ~550 mg/L is mainly distributed near Changling Town and Dacxizhuang, accounting for 833.5km². Groundwater with a total hardness of 450 mg/L to 550 mg/L is mainly distributed near Changling and Dasichuang, covering an area of 833.5 km². The area of total hardness greater than 550 mg/L is 93.7 km², which is distributed in the area among Shangdianzi.

The pH value of groundwater ranges from 6.5~7.5 both in plain and hilly area in Juxian.

4.2. Groundwater pollution analysis

Groundwater pollution is the result of human factors of contaminants into the groundwater, causing water quality declined, so that the quality of groundwater to IV, V, resulting in reduced value of groundwater used or loss of normal function phenomenon.

The plain area of the county is 473.7 km², the area of groundwater category III accounts for 78.45% of the assessed area of the area, the category IV accounts for 31.55%. Water pollution projects are mainly total hardness, nitrite nitrogen. The total area of hilly area are 1347.4 km², the area of groundwater category III accounts for 34.2% of the evaluated area of this area, and IV and V account for 38.5% and 27.3% respectively. Water pollution project is mainly nitrite nitrogen and the total hardness.

5. Conclusion

The amount of groundwater resources and the physical properties in Juxian are calculated and analyzed. It was analyzed and summarized that including the physical properties, hydrochemical characteristics, water quality and water environment quality of groundwater in Juxian.

The following conclusions are drawn through this study:

(1) The amount of groundwater resources is 224.94 million m³/a, including 89.585 million m³/a in plain area and 142.523 million m³/a in hilly area respectively. Besides, double calculation of deductions is 7.168 million m³/a.

(2) The allowable yield of groundwater is about 162.948 million m³/a, of which the amounts in the plain area and the hilly area are respectively 74.585 million m³/a and 88.363 million m³/a.

(3) The degree of mineralization of groundwater in the plain area was lower than 1 g/L at most and the total hardness varies from 150 mg/L to 450 mg/L. The degree of mineralization in the hilly area is mostly less than 1 g/L. The degree of mineralization greater than 1 g/L is mainly distributed among the Shangjiadianzi area and the total hardness varies from 300 mg/L to 550 mg/L in hilly area. The pH value of groundwater ranges from 6.5~7.5.

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