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Original Research Paper

Study on the Feasibility of Karst Water as a Source of Water Supply in Beijing

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ABSTRACT

Under the situation of the increasingly serious water shortage, karstic water in Beijing, which still has the potential to be exploited, will become the ideal source of urban water supply and water for life. With the fantastic geographical location and topographic features, the city of Beijing offers huge storage spaces, abundant source of supply and high resource utilization rate for karst water. The existing modes of the exploitation and utilization of karst water resources over the last several decades have been summarized in this article, so as to explore a variety of methods to predict the yield of karst water, and then put forward a series of protection measures and concrete analysis of the reasons for it on the basis of the current karst water pollution. Thus, making it possible to achieve the modernization management of karst water resources, and utilize, protect water resources in an efficient manner.

INTRODUCTION

Water is the extremely precious living resource which the mankind depends on for a living. In the "twelfth five-year" plan period, Beijing takes advantage of the south-to-north water diversion project, sea water desalination, karst water, north Yellow River etc., to ensure an adequate water supply. As a result, a safe and reliable water supply system was formed (Guo et al. 2011). According to the data reported by water resources bulletin, Beijing suffered severe water shortage in 2012 and the per capita availability of water had fallen to about 191 m^3, only one-eighth of the national availability average, below 1000 m^3 per capita, which is severe water shortage standard (Qin 1978).

In order to avoid a series of environmental and geological problems caused by the excessive exploitation of water resources, there is an urgent need to develop an alternate source in the city of Beijing. Since 2003, Beijing has built five alternate sites of water resources, such as using the Zhang Fang and Beijing-Xishan karst water to supply the water system in Beijing, thus achieving a sustainable and highly efficient supply of water resources. Therefore, conducting researches on the characteristics of karsts underground reservoir and their storage capacity, studying the hydrology characteristics of karst water and exploring reasonable methods to develop karst water resources, are the important ways to solve the contradiction between supply and demand of water resources in Beijing, promote social and economic development, and form a virtuous circle of ecological environment.

ENVIRONMENT OF THE AREA

A general introduction of the water-resources: Located in the north temperate zone, Beijing has the semi-arid subhumid monsoon climate. With the dryness lasting for fifteen years since 1999, the average annual amount of water in Beijing is 2.1 billion m^3, reducing to about a half of the multi-year mean amount (Liang et al. 2008). Through the diversion from abroad, construction of emergency water source, expanded use of recycled water, borrowing from other provinces, etc., Beijing meets the water demand of annual average of 3.6 billion m^3 with the scarce quantity of water.

Between 1999 and 2010, Beijing had an average annual rainfall of 475 mm, 730 million m^3 surface water and 1.72 billion m^3 groundwater resource, thus forming a total of 2.12 billion m^3. But with the increase of population and the improvement of the life quality year by year, the rigidity of city water demand requirement enhances constantly. The per capita water availability in Beijing was only 107 m^3 in 2010 (Yang et al. 2007).

The distribution of karst water: Beijing is rich in karst groundwater resources, with the high water quality and good supply conditions, which has been called the "sons's water". It is enough to show, on the other hand, that karst water is a very rare natural resources in Beijing. The distribution area of karst water in Beijing is approximately 4900 km^2, among which 2900 km^2 distributed in mountainous areas, and 2000 km^2 in the plain areas (Yang et al. 2007). In Beijing, most of the extensional faults such as Babaoshan fault and

Huang Zhuang-Gaoliying fracture, coordinates the layout of the karst aquifer (Ji et al. 1996).

The exploitation of karst water: Since the 1950s, karst fissure karst water in Beijing has been used in fountains primarily. Since the 1980s, Beijing stepped into the phase of trekking water and conducted karst geological prospecting work for the purpose of water supply in Cijiawu, Louzishui, Changgou, Shihuadong, Dengzhuang and Huazhuang. In 1990, China conducted the research work of forecasting, utilization and management of karst water resources. In 1995, Beijing implemented the exploration and evaluation of concealed sources of karst water in Tongzhou Longwang region. Between 1997 and 2010, eyes bedrock in Shijingshan -Yang Zhuang entirely explored the ordovician limestone karstic fissure water. Since 2003, Beijing launched "the construction of emergency water source", and constructed the Beijing Xishan, Zhangfang-Fangshan and Pinggu-Zhongqiao karst water emergency water source (Allry et al. 2004).

The construction of the second largest water plant in Beijing - the third phase of water factory, from 1980 to 2010, has successively constructed about 40 eye wells. Yungang, Liyuan and the seventh chemical plant also have a huge number of civilian bedrock wells, which is the highest mining degree area of karst water. Now, Beijing enjoys a karst water supply capacity of 490000 m^3/d.

THE EXPLOITATION METHODS AND PREDICTION OF ITS YIELD

The means to exploit and use karst water: With the improvement of the understanding of karst water and the technological nature of collecting the groundwater, the way of exploiting karst water also gradually enriches and develops, such as building a variety of irrigation works, using surface river to build hydropower station, etc. We integrate the decades of the ways of karst water exploitation and utilization as follows (Hou 2013).

1. Blocking the exit of the underground river to make the joint reservoir of both the ground and surface water for irrigation and water use, which can bring great economic and social benefit.
2. Leading water in underground rivers and karst springs, expanding spring and cofferdaming is an excellent way for the demand in households and irrigation and production water.
3. Taking karst depression and river valley as water space to construct a soluble depression reservoir and build a joint operation project of the surface and underground water, so as to divert water for irrigation or generate electricity.
4. We can lead underground river by tunnel. Hanoi blocking dam at higher underground river for the water use, such as farmland irrigation, human and animal consumption.
5. Develop surface karst spring water tank. Firstly, build reservoirs in the mouth of karst spring, and then draw the water to the village with a set of pool for storage, finally construct water diversion channels to irrigate farmland. This kind of development mode, to a certain extent, solves the problem of the land concentration for farmland irrigation.

First, exploring the development pattern of water resources and hydrogeological conditions to explore the necessity of technical support, then using karst water resources, and dividing the karst water into areas and setting different units. In this way we can take matchable development methods and means. For the development and utilization of karst water in Beijing, we should carry on the choice of exploration, based on the geographical differences, to adjust the measures to local conditions and achieve the reasonable and efficient use of karst water (Zhang et al. 1995).

Karst water production forecast: Between 1970 and 1990, American scholars put forward the concept of "allowed production" or "safe production" (Liu 2005). The concept of "allowed production" comes from the water supply engineering research, which is used for surface water resources initially. Lee suggested "allowed production" in connection with underground water for the first time in 1915 (Dong 2002) thought "allowed production" means the periodic or continuous exploitation of water resources without causing destructive loss of storage resources (Yang et al. 2008). MeinzCT, Conkling, Banks, Kazmaim are to allow production such as the connotation of the concept of the complement and perfect. MeinzCT, Conkling, Banks, Kazmaim, etc., supplement and perfect the connotation of the concept of "allowed production". Now "allowed production" is generally refers to "under the premise of the economic, legal, no adverse environmental consequences, we can mine from the groundwater system", whose emphasis lies in the economic and legal aspects in the process of groundwater development.

The current forecasting methods of Karst water yield are mainly water balance method, the actual mining survey method, mining experimental method, numerical simulation, the mineable coefficient method, analytical method, multi-year regulating calculation method, the electric simulation method, etc. (Deng et al. 2008, Lu et al. 1973). In field computation, we can comprehensively use geophysical prospecting, drilling, pumping test, groundwater infiltration test, isotopes, underground chemical and other technical means to analyse regional geological and hydrogeological conditions, identify regional boundary conditions, and calculate the hydrogeological parameters. Then plug the calculation of hydrological parameters into three dimensional groundwater mathematical models. Finally, use the numerical model validated through actual data to calculate and evaluate the karst groundwater recoverable resources.

Karst water production equals to precipitation infiltration recharge plus channel infiltration recharge, agricultural irrigation recharge, lateral runoff, under the dam seepage quantity and jacking recharge. The precipitation infiltration recharge is calculated respectively according to the mountains and plains, at the same time according to different lithology sure (Bai 2001). Seepage quantity can be calculated according to the hydrological station of the transit traffic and the river water recharge and excretion between two stations. The calculation of agricultural irrigation regression recharge uses irrigation regression coefficient method, which is obtained through agricultural production by irrigation regression coefficient. Taking Changping district of Beijing as an example, according to the "Changping district water resources census and irrigation districts report for agricultural irrigation", in return to recharge to calculate when selecting irrigation regression coefficient and the quaternary irrigation regression coefficient is 0.35. According to the average agricultural irrigation water consumption from 2000 to 2014 and the agricultural irrigation water quantity for 2014, which is respectively multiplied by well irrigation regression coefficient 0.08, and we can get well irrigation regression. Agricultural irrigation recharge of canal, canal irrigation infiltration recharge and recharge well irrigation regression. Through the actual data and comparison with experimental data, we can determinate whether the model is correct or not. If it meets the demand of precision, we judge whether the hydrogeological conceptual model and mathematical model are accurate or not. If the answer is right, we can think the model is prepared, so we started related calculation.

The key of equilibrium method in the evaluation of karst water resources is the partition and values of parameters. In bare karst area and burial area, for example, the infiltration coefficient value differs greatly, even by an order of magnitude. For karst water in Beijing, we should consider the reservoir leakage recharge, such as the reservoir leakage built in Dove reservoirs and Lujia beach. Due to the extension of the leakage process caused by intersection of water by reservoirs, the infiltration supplement coefficient in reservoir leakage area needs to be properly amplified, but the results differ greatly from that by traditional method.

The technique of correlation analysis of big springs flowing trends and local rainfall is an effective method for the analysis of karst water resources in Beijing. Spring is the product of internal and external dynamic geological processes. Tilt of stratified rock structure, fold structure and fracture structure are good geological conditions of the springs. Survey results in 1983 show that among the 1346 points of springs in Beijing, 1293 eyes of which are karst fissure water springs, carbonate fissure karst springs accounting for 22.9% of the total. And among the springs whose flow rate is more than 10 L/s about 74.3% belonging to carbonate fissure karst.

ENVIRONMENTAL PROBLEMS AND PROTECTION MEASURERS

Environmental problems: Karst and karst water in northern China, especially in Beijing, not only in China, but also in the world is of great significance. It is a kind of typical karst fissure water system formed in temperate semi-arid and sub-humid climate conditions and of great development and utilization value. More than 30 years, as a result of climate change and the large-scale development of karst water, coal mining and other activities, the environmental problems of karst water system becoming increasingly serious and posing a great threat to the sustainable development and utilization.

The development of karst water often conceals the risk of a certain geological disaster, and the most common one is the karst collapse. Because many karst strata are directly connected with the quaternary system in Beijing, and the two hydraulic contact closely, so once the karst water exploitation cannot supply promptly (especially for the plains of concealed area), it is easy to cause collapse disaster (Liu et al. 2007).

At the same time, the development of karst water is easy to cause underground karst water pollution. Because the fracture karst aquifer recharge area often ravines crossbar and cannot be used for land use, and often becomes the site of factory or garbage dumps, so it is easy to cause pollution. Some zones near mountain develop secondary fault and structural fissure, and the rock is broken, permeability is strong, but most of these sites do not have strict seepage control measures. In these places, the various harmful components of waste liquid infiltration, directly or indirectly polluting the karst water. For these reasons, great attention should be given to underground water pollution to strengthen protection.

In addition, the reasonable development of karst water is also easy to cause geological disasters of ground deformation problems. Because in Beijing most of the karst regions are located in the piedmont zone, quaternary covers are thinner and the risk of ground deformation is relatively low. But

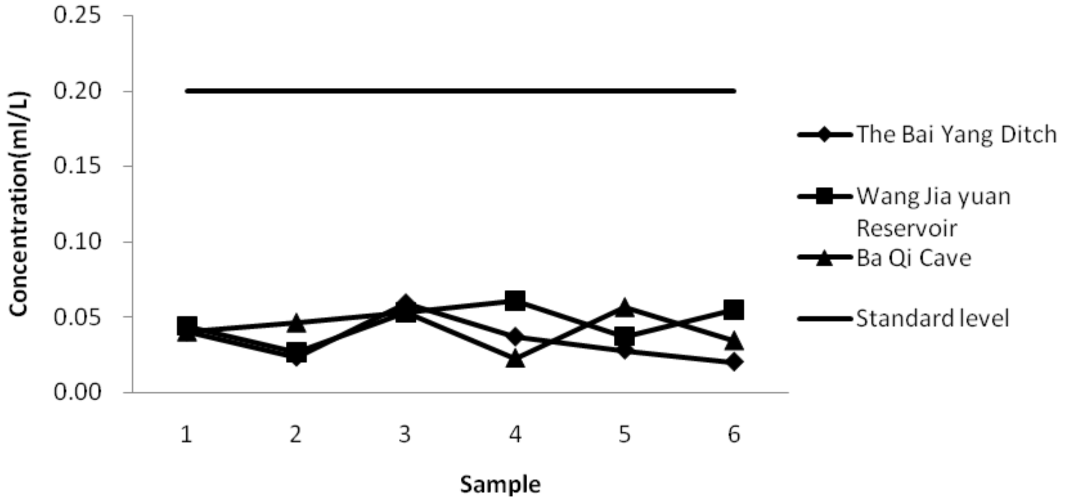

Fig. 1: The content of ammonia nitrogen in water in various places.

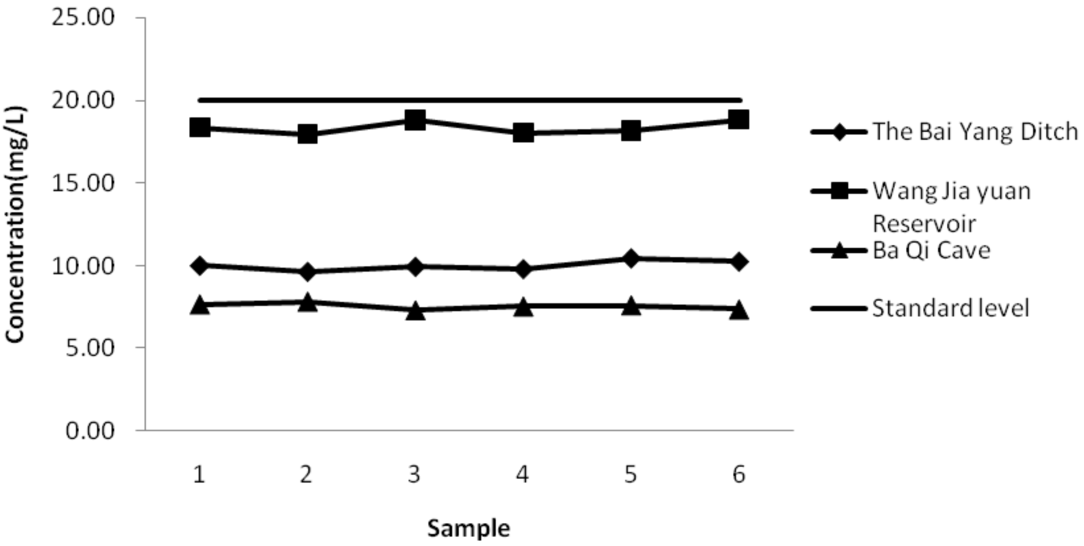

Fig. 2: The content of CODcr in water in various places

we also should nip in the bud so as to realize the reasonable development and utilization of karst water.

The survey of water quality in the field: Field sampling in Bai Yang Ditch underground springs, Wang jiayuan reservoir hydrological station and Ba Qi cave was carried out, and tested for the quality of the water samples. Firstly, we measured deionized water pH, which is around 7.02. Many water samples were alkaline in nature, conforming to the groundwater and surface water III class water standard (based on human body health value, water quality mainly is suitable for the centralized drinking water and industrial and agricultural water). Also, the hardness measured by complexometry is under standard of drinking water hardness 450 mg/L.

The content of ammonia nitrogen in water can reflect the influence of human activities on the environment, because people oriented wastewater contains large amounts of nitrogen organic or inorganic matter (such as protein, urea, etc.).

Ammonia nitrogen content, measured by Nessler's reagent spectrophotometry, was lower than 0.2 mg/L (Fig. 1). Thus all belong to the groundwater quality standard III class; the water quality is good, basically not affected by human activities. This can also further show that, not only the water quality of karst water is better, but also because of the long-term existence in underground, it is not easily affected by human activities, so as to be one of the best choice for drinking water sources.

CODcr reflects the degree of water pollution by reducing agents. The index is one of the comprehensive indexes of relative contents of organic matter pollution, in the situation where the water is polluted by organic compounds. The CODcr content is measured by potassium dichromate method to draw the chart as shown in Fig. 2. The groundwater quality standard for COD index regulation: III class water cap of 20 mg/L. For the research sites it can be seen that, CODcr is above III class water, conforming to the drinking water standard for the water source, and CODcr may vary a little along the river, and there are no outstanding pollution sources around the water. In Wang Jiayuan reservoir, the organic matter content is higher than in other places, which shows that karst water in long term exposure to the surface and water do not flow, can increase the content of organic matter in water.

The protection methods of karst water: For the lack of karst water monitoring mechanism in Beijing, if the pollution of 250 million m^3/a of water production occurs, the consequence is unimaginable. In June 2008, according to the results of investigation on groundwater pollution survey conducted in Fangshan, Louzishui-Xinjie karst water well, there has been V and IV water particles, and the hardness violation. At the same time, there is poor recharge condition, long cycle path, and slow update rate, combined with the existing cases of karst collapse in the plains of concealed area of karst groundwater. It is the time for us to take the effective measures to protect it

Considering the development of karst groundwater resources in Beijing, therefore, we should take the piedmont areas as the main exploration areas, and take shallow buried alongside the river and alongside fracture zone of karst development formation as the main exploration objects. In wet years, covering shall be conducted to improve the underground water. At the same time, we should make special plans for the development of karst water in Beijing. The construction of dynamic monitoring network shall be carried out simultaneously with the exploration engineering, and shall regularly publish monitoring report in order to provide the basis for government decision-making departments.

CONCLUSION

Under the situation of the increasingly serious water shortage, rational development and utilization of karst water resources and making an alternate source of urban water and domestic water use, is an important approach to alleviate the contradiction between supply and demand of water resources in Beijing. While the exploration and development project are carried out, the karst water monitoring network system is also important. We should implement efficient karst water protection to prevent the ground deformation, karst collapse in karst groundwater pollution and other environmental problems. So we can comprehensively design the development plans of karst water in Beijing to develop new city back-up water sources, alleviate water shortages and promote the steady development of the resource conservation and environmental friendly society.

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