POTENTIAL IMPACT OF MINING ACTIVITY ON XIN'AN KARST SYSTEM, SHANXI, CHINA

C.S. Wang
The School of Resource and Earth Science, China University of Mining and Technology, Xuzhou, China 221008; E-mail: cougar3wcs@163.com

ABSTRACT

Xin'an Karst system, located in the southeast of Shanxi Province, China, is noted for its availability of Ordovician karst water resources. The karst water is the main water resources for local domestic, industrial, agricultural and mining water use. Since 1980s, local Xin'an Basin Management Agence dedicated to the integral management of Xin'an Karst System. The new round National Water Resources Assessment in 2005 showed that the Xin'an Karst System can reach water balance and pose great potential water use. The continuous drawdowns of karst system are mainly dominated by dry period of weather. The south Qinshui Coalfield belongs to the North China Permo-Carboniferous Coalfield and is mined by Lu'an Mining Group. Lu'an Mining Group is one of the main water users of Xin'an Karst system. This article assessed the status of the Karst system, observed the water use patterns of mining, and investigated the trend of karst water regime by hydrochemical and isotopic method. The result shows that the karst hydrogeologic cycle is obviously accelerated and karst is developed downwardly in mining area by intensive mining water use. Actually, the potential use of karst water is limited.

Keywords: mining activity; Xin'an Karst System; water regime; hydrochemical method;

1. INTRODUCTION

In China, the groundwater sustainable use in mining area is greatly challenged by intensive water use or dewatering. Usually, the results of intensive groundwater development haven't completely loomed out and the overall pumpage can easily be confused as recharge. That is an important reason why the groundwater condition of some Noth-China coal mining areas is continuously worsening.

Early in 1940, Theis (1940) definitely showed that the water that can be used is initially derived from removal of water in storage, but over time is increasingly derived from decreased discharge and/or increased recharge. Bredehoeft (1997, 2002) re-stressed that sustainable ground water development has nothing to do with its virgin recharge; that the size of a sustainable water development depends on the dynamic response of the aquifer system to the water development; and that the groundwater system must reach its new steady state and consume no more storage. M. Sophocleous (1997, 2000) put forwards using transition curve (a curve of aquifer system from groundwater storage depletion to induced recharge) to assess the steady state of groundwater system. Frans (2005) stated that the aquifer system can reach many steady states, but there is only one optimal steady state for specified development horizon.

Xin'an Karst system, located in the southeast of Shanxi Province, China, is noted for its availability of Ordovician karst water resources. The karst water is the main water resources for local domestic, industrial, agricultural and mining water use. Since 1980s, local Xin'an Basin Management Agence dedicated to the integral management of Xin'an Karst System. The new round National Water Resources Assessment in 2005 showed that the Xin'an Karst System is still within its water balance and pose great potential water use.

But the persistent decline of drawdown and spring indicated that the system is consuming storage and reach far form its new equilibrium. The safe yield of the karst system was over-estimated.
This article assessed the status of the Karst system, observed the contribution of intensive mining water use by Lu'an Mining Group to overall basin water use patterns, investigated the trend of karst water regime by hydrochemical and isotopic method, assess the equilibrium state of karst system, and discuss the reasonability of the safe yield assessment.

2. XIN'AN KARST GROUNDWATER BASIN

Xin'an Karst Spring is one of most important karst groundwater system in the semi-arid North China Platform. The Xin'an Karst Spring System is surrounded by surrounding mountains: the Taihang Mountain to the east, the Taiyue Mountain to the west (Fig. 1).

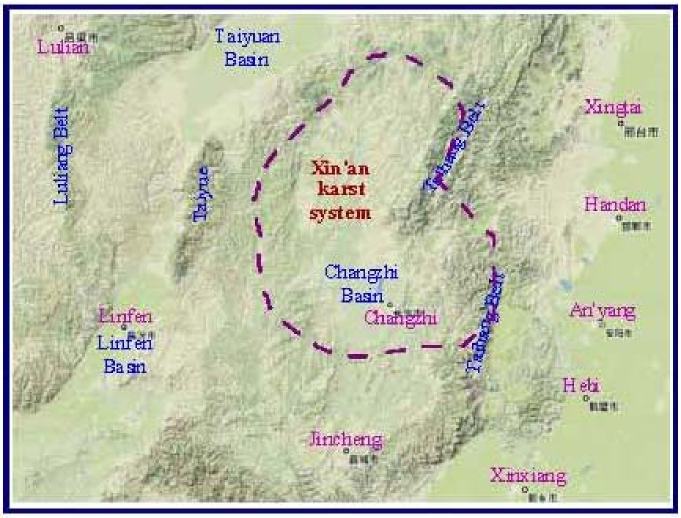

Fig. 1. Location Map of Xin’an Karst groundwater Basin

In geology, the Xin’an Karst system occurs in early Cenozoic Changzhi Basin. The geologic formations of the Changzhi Basin are Cambrian and Ordovician carbonate rocks, Permo-Carboniferous sandy and clay clastic sedimentary rocks, and Quaternary unconsolidated sediments upwardly. The dominated geologic structures of the Changzhi Basin are as shown in Fig. 2.

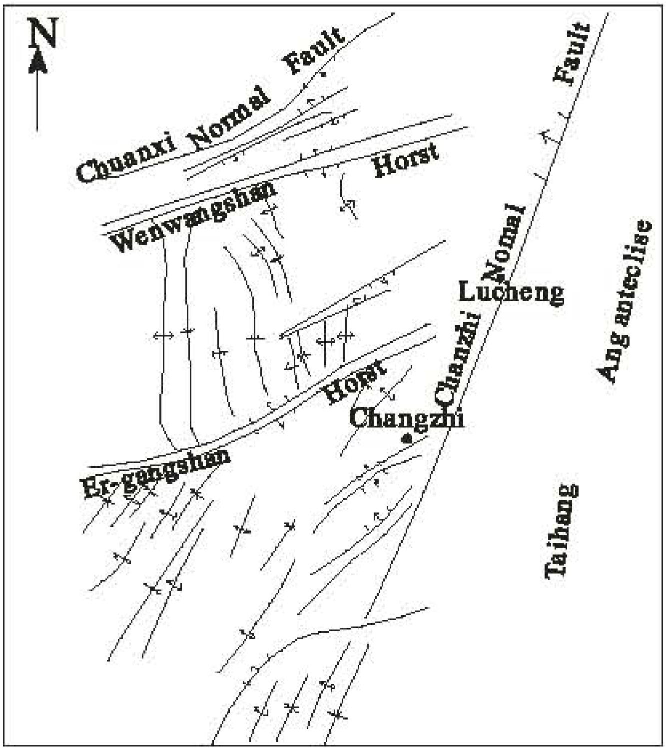

Fig. 2. Structural Map of Changzhi Basin (Xin’an Spring)

In hydrogeology, the aquifers of the basin mainly include: middle Cambrian~ middle Ordovician carbonate karst aquifers, upper Carboniferous clastic rock and interlayer limestone fissure aquifers, Permian clastic fissure aquifers, and Quaternary unconsolidated aquifers.

The upper Carboniferous clastic rock and interlayer limestone fissure aquifers and the Permian clastic fissure aquifers are somewhat isolated and relatively separated from the overlying pore water and underlying karst water system. The upmost unconsolidated aquifers are recharged mainly by precipitation, and discharge into rivers.

The dominated groundwater water system of the basin is Ordovician carbonate karst system, also called “Xin’an Karst Spring System”. Boundaries of the Xin’an Karst Basin are: topographic ridges to the west, aquifuge boundaries of igneous and metamorphic rocks to the south-east, groundwater ridges to the north and south. The Ordovician karst aquifers are recharged by precipitation in the east Ordovician outcrop of Chanzhi Basin, conflux in the middle of the basin, and discharge as series of springs near Xin’an village. The runoff and discharge of the karst water are strictly controlled by the regional geologic structures and erosion basis. The Xin’an Spring area is hydrogeologically divided into western stagnant zone, eastern runoff zone, middle concentrated runoff zone, and spring discharge zone. The coalfield of Lu’an Mining Group (with output of 30 million tons per year) just locates in the middle concentrated runoff zone.

The National Water Resources Assessment (NWRA) in 2005 showed: (1) by adding the statistic withdrawral of karst water to the natural spring flow rate, that the average natural karst water resource is 10.25 m^3/s; (2) by method of spring flow attenuation, that the safe yield of spring system is 8.96 m^3/s; (3) by checking and tradeoff the recharge, that the safe yield is reliable; and (4) owing to less current karst water withdrawral (2.68 m^3/s), Xin’an Karst water System poses great potential for water development.

However, this article thinks that the NWRA overestimated the karst water resources. After 1980s, due to intensive karst water development, the karst spring flow rate and water level ceaselessly declined, aquifer storage accounted for large part of pumped karst water, and the karst system was far from its steady state. Therefore, the time series of spring flow can’t directly be used to estimate the safe yield and the overestimated recharge can’t be used to testify the safe yield.

3. STATUS OF THE KARST WATER SYSTEM

Karst Spring Flow Rate and its Decline

Based on the time series of spring flow rate from 1956 to 2006, the curve of spring flow is shown in Fig 3. It is showed that: (1) The average spring flow rate is 9.64m^3/s, the maximum 16.03m^3/s in 1964, and minimum 4.72m^3/s in 1999; (2) Before 1980s, the spring flow was stable, average spring flow 11.44 m^3/s; the spring flow indicates an annual and a about 10-years periodic cycle; (3)after 1980s, the spring flow drastically decline, magnitude of spring flow decline 6.46 m^3/s, average spring flow 6.86 m^3/s.

Xin’an Karst Spring is a typical complete drainage spring. By adding the total water use to the spring flow rate, the karst water resource is shown in Fig 3. It is showed that: (1) even after restoring the karst water withdrawral, the karst water resource obviously reduced 3.09 m^3/s from 11.45 m^3/s to 8.36 m^3/s; (2) the karst wate withdrawral can’t tradeoff the decline of spring flow; (3) karst water use contributes more to the decline of spring flow. (4) The karst water system is under the development far from its balance, that the current water balance did not indicate stable status of the system.

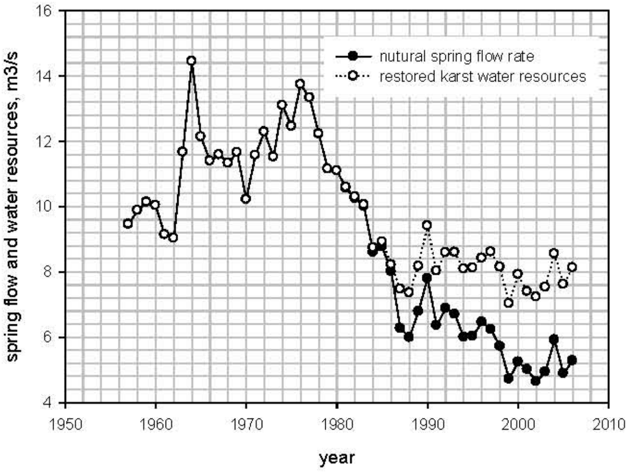

Fig. 3. Curves of Xin’an spring karst flow and restored karst water resource

Precipitation and its Trends

The time series of precipitation (Fig 4) shows that: (1) the precipitation is stable and periodically changed since 1954 to 2006, average precipitation 572.83mm, maximum 853.83mm in 1971 and 932.1mm in 2003; (2) the precipitation shows a downward trend since 1980s, average precipitation before 1980 is 587.8mm and average precipitation after 1980 is 557.2mm; the average precipitation after 1980s is less than the overall average value;(3) The precipitation shows an almost 20~30 years dry/wet hydrologic periods; After 1980, the Xin’an karst area goes into hydrologic dry years.

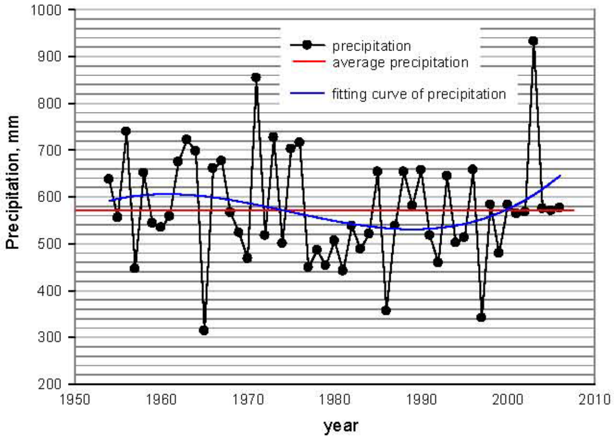

Fig.4. Precipitation of Xin'an Spring Basin

Karst Groundwater Level and its Dynamics

The Xin'an karst water development started from 1980s. From then on, the karst water level dropped down continuously.

In runoff zones, the water levels continuously declined from +670~680m in 1980s to +640~650m in 2000s, magnitude of drawdown is about 30m. In discharge zones, the water level also linearly dropped about 10m. The curves of karst water level in runoff and discharge areas are shown in Fig 5 and Fig 6.

The rate of groundwater level decline is 0.2~0.51 m/a in discharge zone, 0.66～0.99 m/a in south Changzhi runoff zone and 0.50~1.84m/a in north Xiangyuan runoff zone.

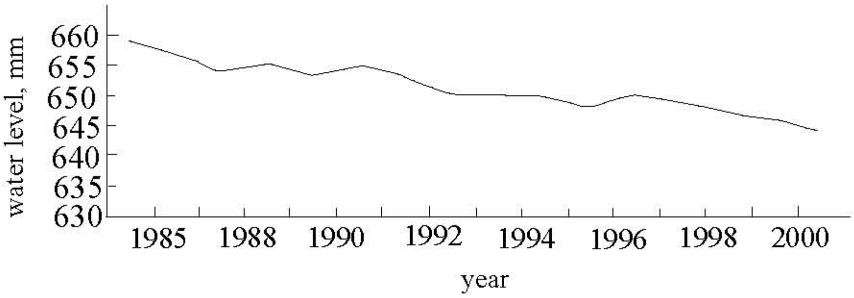

Fig 5. Curve of Karst Water Level in Runoff Zone

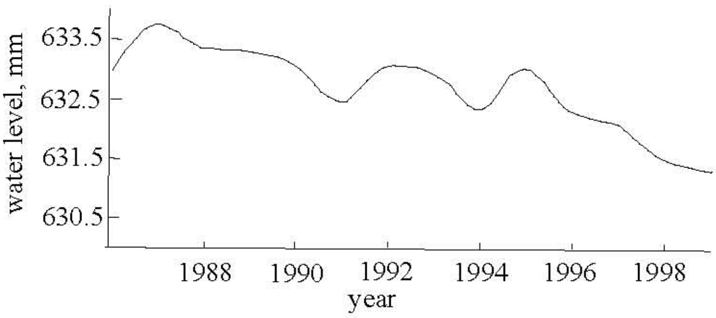

Fig 6. Curve of Karst Water Level in Discharge Zone

The coal mines of Lu'an Group take up most areas of north Xiangyuan runoff zone. The karst water level has declined from the original +670～690m in 1980s to +630～650m. The average rate of drawdown is over 1.2 m/a, maximum of 2.81m/a. According to the *Guideline of Assessing Groundwater Over Exploitation Area (SL286—2003,*China), the area where drawdown rate exceeds 1m/a belongs to groundwater over exploitation area. So, the mining area is locally exploited.

As a result, the gradient of the karst water decreased and water pressure in discharge area declined. At present, the spring flow decreased and many original springs have disappeared. The Karst system is far from its final balance.

Karst Water Development and Mining Water Use

The Fig 7 illustrates the inflation of karst water withdrawal since 1980s. Now, the spring karst water is developed by spring diversion project, spring power lift project and deep well pumping. The spring diversion project directly diverts at Xin'an Spring 0.12 m^3/s (in 2003) spring water to Linxian, Henan Province. The two spring power lift projects pump total 1.19 m^3/s karst water at Xin'an Spring respectively to Changzhi Water Supply Company and Shanxi Concrete Plant. Now, totally there are 129 deep wells distributing in south and north runoff zones. They pumps total 1.37 m^3/s karst water for industry and domestic purpose. The most concentrated karst pumping centers are composed of Houpu, Changcun Coal Mine, Shikejie Coal Mine, etc. In the deep well pupmpage, the karst water use by coal mines takes up 0.6~1.0 m^3/s. So the deep well pumping would shed more than spring diversion project and spring power lift project influence on the whole spring karst system and coal mining water use play an important role in the evolution of karst aquifer system.

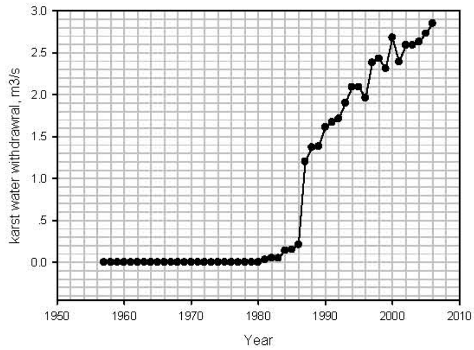

Fig.7. withdrawal of karst water since 1980s from Xin'an karst basin

Dynamics of the Karst System

By stochastic time series analysis and statistical analysis, the relationship between spring flow rate and precipitation is that (1) at first, the longer the span of average precipitation is, the bigger the correlation coefficient between to spring flow rate and average precipitation is; (2) the spring flow rate has closest relationship with 11-year average precipitation (Fig 8), the correlation coefficient is 0.67, and after 1980s the spring flow rate curve obviously deviates the 11-year average precipitation curve; (3) then, the correlation coefficient is getting small; the spring flow rate has negative relationship with 20 year average precipitation.

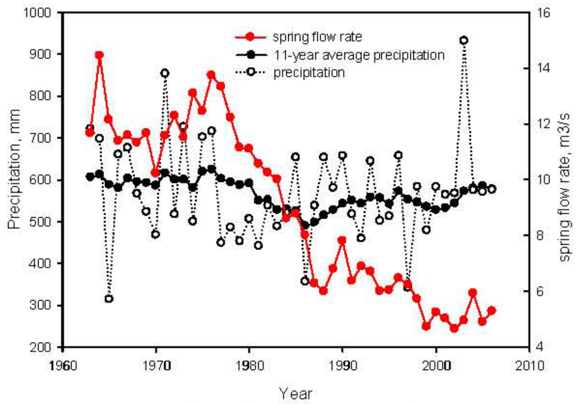

Fig.8. Relationship between Spring flow Rate and 11 year average precipitation

Because Xin'an karst aquifer is a complete drainage spring, finally recharged by precipitation and discharged by spring and water withdrawral, the spring flow rate model is set up as equation (1):

$$Q_t = a_0 + \sum_{i=1}^{M} b_i \cdot P_{t-i} + c \cdot Q_w \qquad (1)$$

where

Q_t is the spring karst flow rate at t year, unit of m^3/s;

a_0 is a constant, varies with M;

b_i is the lag coefficient of precipitation, varies with M;

P_{t-i} is the precipitation with lag time of i years;

M is the maximum lag time, adopting 11 years;

c is a coefficient,

Q_w is the total amount of exploited karst water;

The curves of monitored and fitted spring flow rate are shown is Fig9. The result of fitting justified that the assumption of 11 years of lagging is reasonable and the dynamics of spring flow is controlled by precipitation and water withdrawral. .

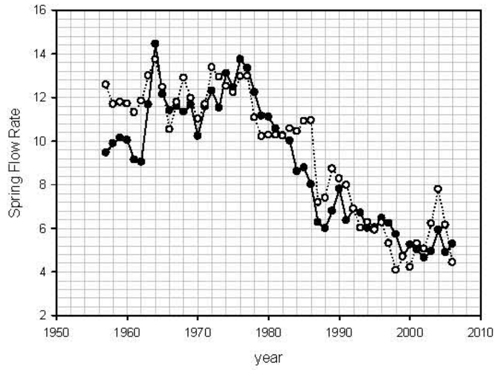

Fig.9. Relationship Between Spring flow Rate and 11-year average precipitation

The correlation between karst water resource and average precipitation is that (1) as prolonging the span of the average precipitation, the correlation coefficient between spring water resource and average precipitation increases; (2) the karst water resource has maximum correlation coefficient with 21-year average precipitation (Fig 10), the correlation coefficient is 0.85; (3) the karst spring system can store and adjust 21 year precipitation.

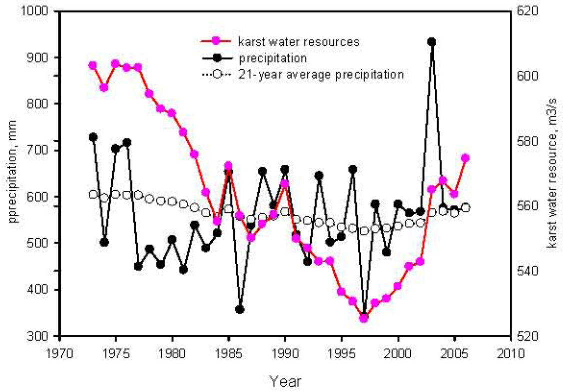

Fig.10. Relationship Between Karst Water Resource and 21-year average precipitation

As the 21-year average precipitation increasing, the karst water resource exponentially grows as equation (2).

$$y = y_0 + a_0 \cdot e^{b \cdot x} \tag{2}$$

The fitted curve of karst spring water resource versus precipitation is shown as Fig 11. From Fig 11 it is concluded that (1) as the 21-year precipitation is known, the curve can be used to estimate karst water resource; (2) average precipitation after 1980s is 557.2mm, the karst water resource is 8.4m^3/s, maximum 9.6 m^3/s, minimum 7.2 m^3/s; (3) the water resource (10.25 m^3/s) and safe yield (8.96 m^3/s) by NWRA are overestimated.

The reducing spring flow rate, unceasing water level drawdown, persistent dry years, and inflating water development indicates that the current pumping is consuming certain amount of storage and that the dynamics and new steady state of the karst aquifer is still under way.

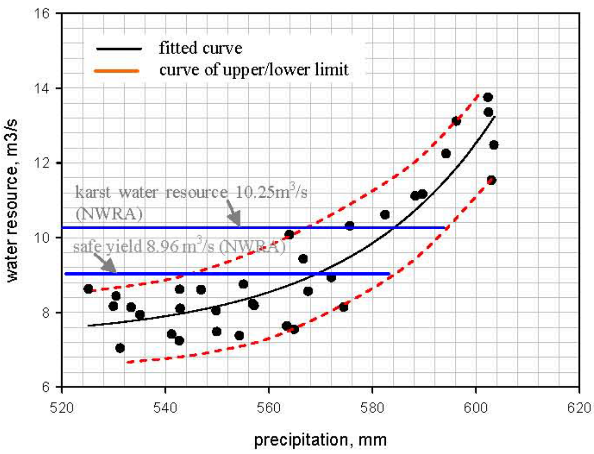

Fig.11. Fitted Curves of Karst Water Resource and
21-year average precipitation

4. EVOLUTIONARY TRENDS OF KARST WATER REGIME

Hydrochemical Evolution

The karst water regime in all hydrogeologic zones is definitely different. In western stagnant zone, total dissolved solids (TDS) is 518~872mg/l, type of water quality belongs to SO_4-Ca·Mg and SO_4·HCO_3-Ca·Mg, and the concentrate of SO_4 is up to 90mg/l. In the south Changzhi runoff zone, total dissolved solids is 373~482mg/l, type of water quality belongs to HCO_3·SO_4-Ca·Mg, and the concentrate of SO_4 is 50~70mg/l. In north Xiangyuan runoff zone, total dissolved solids is usually less than 400mg/l, type of water quality belongs to HCO_3 -Ca·Mg and HCO_3·SO_4-Ca·Mg, and the concentrate of SO_4 is 20~70mg/l. In the discharge zone, total dissolved solids is also less than 400mg/l, type of water quality belongs to HCO_3 -Ca·Mg and HCO_3·SO_4-Ca·Mg.

Under the intensive karst water development, the hydrochemical evolution of the karst water regime behave as : owing to the karst water pumping by Wangzhuang Mine, Zhangcun Mine, Changcun Mine, Wuyang Mine, and Tunliu Mine, the TDS and concentration of SO_4 in west stagnant zone decreased, the water level dropped and the stagnant zone further moved west.

Isotropic Feature

By isotropic method, it is concluded that (1) the values of the used stable and radioactive isotrope are: d18O (‰) -9.0 ~ -13.34, d18D (‰) is 66.7~79.79, and T(TU) is 2~24, and the d34S (‰) is 11.9~22.8;(2) the average age of karst water is 80 years, .(2) the storage of the karst system is 3.15×1010 m^3,which is the amount of water that can adjusted in 21 years;(3) the dissolution rate the 2.28 mm/ka. (4) The system is evolving quickly and the stable state haven't achieved.

5. CONCLUSION

(1) the Xin'an spring flow rate is correlated with 11-year average precipitation; the Xin'an karst water resource is correlated with 21-year average precipitation; the karst aquifer can store and adjust 21 year precipitation;. the Xin'an karst water resource is exponentially grow with the increase of 21-year precipitation,
(2) The reducing spring flow rate, unceasing water level drawdown, persistent dry years, and inflating water development indicates that the current pumping is consuming certain amount of storage and that the dynamics and new steady state of the karst aquifer is still under way.
(3) the hydrochemical and isotropic method testified the karst systm was a quick and cessless evolutionary processs;
(4) the water resource of Xin'an Karst spring was over-estimated by NWRA. In dry year, the infiltration is more complicated, the recharge coefficient is far less than that in wet years. Certain amount of storage pumped be simply viewed as water resource.

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