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SAFETY ANALYSIS OF WATER RESOURCES AND ECO-ENVIRONMENT IN SHIYANG RIVER BASIN

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ABSTRACT: The research on the present situation of soil and water development and utilization in Shiyang River Basin shows that water resources and eco-environment situation in this area are near the edge of collapse. Since the water crises occurred in the 1970s, problems caused by continuous decrease of water resources have been becoming serious year by year and eco-environment crisis occurred as a consequence. Up to now, 10 380ha of irrigated lands have been abandoned due to sand coverage and water shortage in the basin. Ground water was over exploded in Wuwei and Minqin because of water shortage. Ground water table in many places dropped under 5m (which is the ecology water table level), thus about 3000ha of *Elaeagnus angustifolia* forest come to dead and another 5800ha become feeble, and wind-drift sand near the oasis become alive. According to the current situation, if water utilization scope was not enlarged, a water transfer volume of $600\times10^6m^3/a$ from other areas will be suitable to keep water resources and eco-environment safety in the basin, and also $70\times10^6m^3/a$ will be left as spare water. Under this condition the water resources and eco-environment of the basin can reach the critical safety line of $2.032\times10^9m^3/a$; or if $180\times10^6m^3$ of water can be transferred from other areas, the water resources can reach the safety warning line of $1.732\times10^9m^3/a$.

KEY WORDS: water resources; water resources safety; Shiyang River Basin

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1 INTRODUCTION

Fresh water has been attracted more attention since the 1990s, people may scramble for fresh water instead of petroleum in the 21st century, meanwhile with moving of big enterprises from developed countries to developing countries, more and more rivers in developing countries will be polluted, which will cause water resources crisis. In July 1998, Mr. L R BROWN, director of American World Watch Institute published the article "*China's Water Shortage Could Shake World Food Security*" after his previous article "*Who Will Feed China*". The articles have caused a sensation throughout the world and a new round of China Threaten Theory, meanwhile more attention have been attracted on China's water resources (BROWN and HILWEIL, 1998; KANG and OHMRURA, 1994). Mr. ZHANG Guangdou, an academician of Chinese Academy of Sciences and Chinese Academy of Engineering suggested Chinese Government in 1999 to pay much attention to water resources security. KANG Er-si, professor of Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, through long-term study on the water resources variation forecast, considered that there exists the maximal indeterminacy of the response of water resources to global climate change in Northwest China. LIU Chang-ming, an academician of Chinese Academy of Sciences also raised his opinions on water resources security and reasonable water resources development and utilization in China in the 21th century (LIU, 1995; LIU and HE, 1996). Water resources issues in Northwest China were always the focal point of government and scientists. In recent years, severe water resources crisis occurred in Northwest and North China have made the Huanghe (Yellow) River be cut off, therefore, eco-environment deterioration the in Tarim River, the Shiyang River and the Heihe River basins have attracted much more at-

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tentions from domestic and abroad (SHI and CHEN, 2001). In 2000, Ministry of Water Resources conducted concentrated water transfer program in the Huanghe (Yellow) River, the Tarim River and the Heihe River, and it raveled out the problem of the Huanghe River cut-off. Thus eco-environment deterioration situations in the down stream of the Tarim River and the Heihe River were preliminarily controlled under the drought conditions of that year (ZHANG *et al*., 2001; 2002; 2004). This action shows to the world that China has the ability to deal with its water resources security. Water resources and eco-environment crisis in Shiyang Rivre Basin accounts the first in China, but water resources and eco-environment security situation in Shiyang River Basin are still remain unchanged while same problems in other river basins have been primarily solved. The water distribution plan of Ministry of Water Resources does not include Shiyang River Basin, so people are more concerned about eco-environment problems, ecology disasters and ecology refugees caused by water resources shortage in Shiyang River Basin.

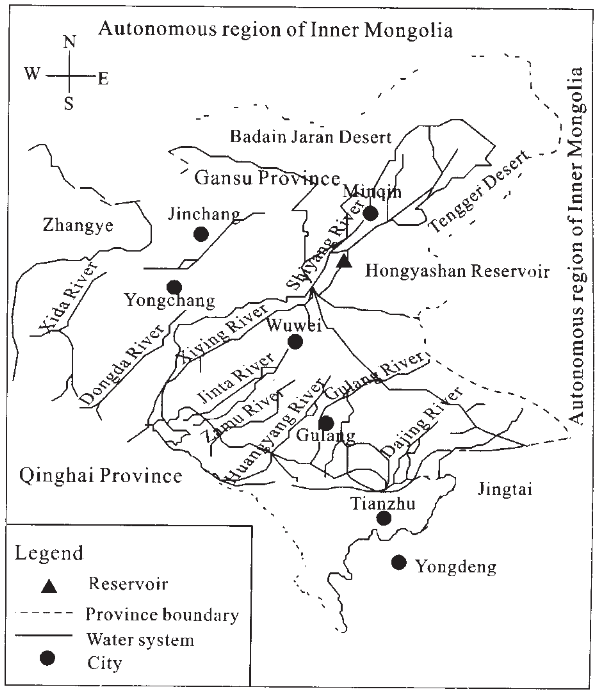

Fig.1 Sketch map of the Shiyang River Basin

2 STUDY AREA

The Shiyang River Basin is located in the east part of Hexi Corridor in Gansu Province, China; and the river originates from Lenglongling of Qilian Mountain and finally disappeares in Tengger Desert (GUO *et al*., 2000). The basin mainly includes 3 basins, namely Wuwei Basin, Minqin Basin and Jinchang Basin (FU *et al*., 1999; KHEM *et al*., 2001; LIU *et al*., 2001; ZHU *et al*., 2001). According to detailed topography materials, the basin faces Qilian Mountain in the south, Dahuang Mountain in the west, Longshou Mountain in the north and Helan Mountain in the tast. The Shiyang River originates from ice glacier and finally reaches the desert, and the whole basin almost consists of humid, semi-humid, semi-arid and arid regions (FU, 2001; GUO *et al*., 1999; SHI, 1999).

The river basin area taken for water resources research is normally 41 600km^2 in the Shiyang River Basin, where there are 8 rivers, namely the Dajin River, the Gulang River, the Huangyang River, the Zamu River, the Jinta River, the Xiying River, the Dongda River, and the Xida River (Fig. 1). Each of the rivers has its isolated outlet, hydrology stations were set up at each outlet, and the 8 outlets can control over 95% of water out of the basin (SHI, 1999). The Shiyang River Basin belongs to Wuwei City, Zhangye Prefecture, Jinchang City of Gansu Province and Alxa League of Inner Mongolia in administration. Though some water was transferred from the Datong River, the main water sources of Jinchang Basin is come from the Dongda River and the Xida River, and both of them join together at Jinchang basin. The Gulang River, the Huangyang River, the Zamu River, the Jinta River, the Xiying River join together at Wuwei, then go through Minqin Basin and finally disappear in the downstream of Minqin.

3 WATER RESOURCES VOLUME AND ITS CHANGE TREND

Like other inland rivers in Hexi Corridor, the Shiyang River also originated from Qilian Mountain. After coming out from the mountain, the river respectively goes through alluvial fan, southern basin and finally goes to Minqin lake area in Minqin County. Because the beaded and closed basin structure, water resources in this area has a same source and is repeatedly transformed and used, which ensures the use rate of water resources reaching the highest in the world, over 170% in the Shiyang River Basin.

3.1 Water Resources Volume at Outlet of Mountain

According to calculation based on hydrology materials for 49 years (1952–2001), the long-term average runoff at the outlet of the mountain for 8 rivers in the Shiyang River Basin is 1.293×10^9m^3/a. The water use volume for industry and agriculture within the control area of hydrology stations is $32.47\times10^6 m^3/a$, and there are also $48.1\times10^6 m^3/a$ of water in all streams out of the control of hydrology stations and $58.3\times10^6 m^3/a$ of water originated from water producing area in front of the mountain, thus the total water resources volume at the outlet of the mountain for the Shiyang River Basin is $1.432\times10^9 m^3/a$, out of which the long term average runoff from Jinchuanxia hydrology station in the Xida River and Shagousi hydrology station in the Dongda River is respectively $133.2\times10^6 m^3/a$ and $297.6\times10^6 m^3/a$.

After the calculation based on the observed data at the same time from the two hydrology stations, the long term average runoff at the outlet of the mountain received by Jinchang Basin is $430.8\times10^6 m^3/a$ (1961–2001), and that received by Wuwei Basin from the Gulang River, the Huangyang River, the Zamu River, the Jinta River and the Xiying River is respectively $322.7\times10^6 m^3/a$, $134.3\times10^6 m^3/a$, $225.9\times10^6 m^3/a$, $134.9\times10^6 m^3/a$ and $63.1\times10^6 m^3/a$, thus the long term average water resources volume at the outlet of the mountain will be $880.9\times10^6 m^3/a$ (Table 1).

3.2 Changes of High and Low Water Resources

The water resources change procedures at the outlet of the mountain are special in the Shiyang River Basin. According to composition procedures at the outlet of the mountain (1961–2001), water resources volume is slowly decreased in general, but the change is various in different decades: in the most sufficient years of the 1960s, the outlet water resources volume was $1468.2\times10^6 m^3/a$; in the ordinary year of the 1970s, $1342\times10^6 m^3/a$; in the slightly sufficient year of the 1980s, $1442.9\times10^6 m^3/a$; and in the extremely drought year of 1990s, $1253.7\times10^6 m^3/a$. Since the 1990s all the years are in drought condition except 1993, a year with sufficient water. In addition to water resources reduction, water demand increase caused by enlargement of irrigated land is also main reasons for eco-environment deterioration and desertification in Minqin County (Fig.2 and Fig.3).

Currently in the middle reaches of the Shiyang River Basin, wasteland near oasis were over-cultivated, as a result, transition zones between oasis and desert disappeared, consequently cultivated lands lost their ecological prevention belt and were easy eroded by sand and wind. Situation in Huqu, the east part of Minqin County is not only the death of *Populus euphratica* and some bushes, but also a situation of people moving backward while sand moving forward, therefore water resources and eco-environment crisis broke out all around. So water resources and eco-environment are not in a security situation in the basin. The entire situation showed that oasis area is over-burdened and water resources are over-burdened.

Table 1 Water resources volume for each river within Shiyang River Basin ($\times10^6 m^3/a$)

	Jinchuanxia	Shagousi	Jiutiaoling	Nanying Reservoir	Zamusi	Huangyang Reservoir	Gulang	Dajing Reservoir	Total runoff
Observed runoff	131.20	287.40	321.00	133.10	223.20	125.00	59.70	12.50	1293.10
Water use amount	2.00	10.18	1.71	1.22	2.77	9.82	3.36	1.41	32.47
Restored volume	133.20	297.60	322.70	134.30	225.90	134.90	63.10	13.90	1325.60

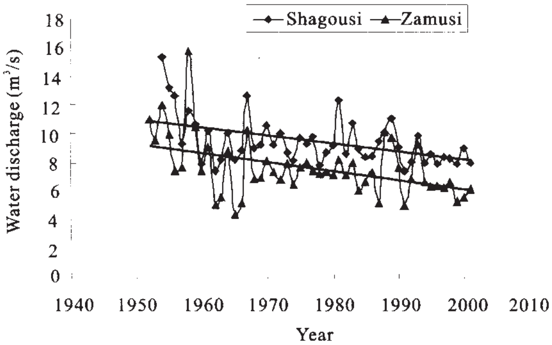

Fig.2 Water discharge in Shagousi and Zamusi

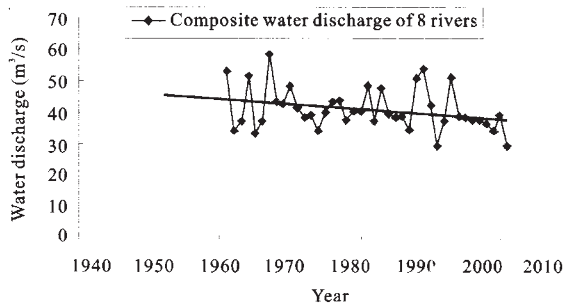

Fig.3 Composite water discharge of 8 rivers in Shiyang River

4 WATER RESOURCES BEARING CAPACITY

Long term average surface water volume in Shiyang River Basin is $1432\times10^6 m^3/a$, and net shallow ground water volume is $530\times10^6 m^3/a$. Total population in the basin was 2.4×10^6 in 2000, with per capita water volume of 816m^3/a, which is far below the "lacking line" of 1000–1700m^3/a accepted in the world, and there are 634 000 big domestic animals and 3 413 000 small domestic animals in the basin. From the view of average per capita water volume, water resources in the Shiyang River Basin are under the security warning line. Within the oasis in Hexi Corridor, multiple crop and intercropping index reaches to 70%, the higher multiple crop indexes with higher water demand. Water resources development and utilization in Wuwei and Jinchang has far over the maximum limit. So the surface water resources in the basin are over-burdened. In the recent 10 years, ground water development and utilization index in the basin remains at 12, every year 670×10^{6}m^3 of ground water was over-explored, thus ground water is also over-burdened. Even if we take the reuse of water resources into consideration, the current water resources are still not in security situation. Especially in Minqin Basin, water inflow reduced from 350×10^{6}m^3 20 years ago to less than 100×10^{6}m^3 in recent years. If plus 120×10^{6}m^3/a of transferred water from the Huanghe River, total surface water volume in the basin is still only 200×10^{6}m^3/a, the water resources and eco-environment situation are nearing the edge of collapse.

4.1 Water Resources Development and Utilization Scope

Over exploration of water resources in Shiyang River Basin is mainly concentrated in Wuwei and Jinchang cities, but water resources development and utilization in upper stream is very small. Like other inland rivers, the water resources development and utilization in the Shiyang River Basin is continuously increased since the foundation of P.R.China in 1949, but it had a relatively slow increase speed before the year 1984, and increased faster after 1984. The increase speed slowed down after 1995 because of the influence of water resources shortage, but still in a trend of increase. It shows that it is difficult to rapidly cut down the water resources demand if water resources development and utilization reach to a certain standard. We can see from Table 2, in the extremely drought year of 1991, water resources development and utilization is still at the level of 2424.6×10^{6}m^3/a, with a use rate of 261%. Water resources development and utilization include considerable ground water, but the ground water ordinarily means shallow water, within 50m underground, which is almost the reappearance of surface water. The depth of water wells for domestic use has reached to 300m, and this kind of water is not the recycle of river water but un-restorable ancient sealed water.

We can see from Fig. 4, natural water resources volume does not match water resources development and utilization volume in the Shiyang River Basin, and water utilization volume is about 2 times of inflow from the mountain. Reuse of water resources ensures water resources utilization volume in the basin remained at a relatively stable level of over 2400×10^{6}m^3/a (exclude rural domestic water, which are not on the record of water resources statistics, and water from self-served water wells in some companies and organizations, 200×10^6 m^3/a in total) and also increased water use efficiency, but it directly brought about sharp dropping of ground water and eco-environment crisis (Table 2–Table 4).

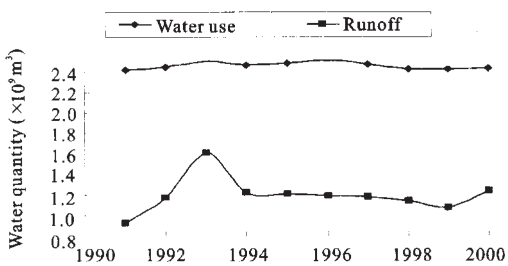

Fig.4 Water use quantity and runoff

Table 2 Water utilization and water inflow in recent 10 years in Shiyang River Basin (×10^{6}m^3)

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Water use	2424.6	2456.9	2512.3	2473.0	2492.0	2515.0	2480.8	2436.2	2430.7	2447.4
Runoff	928.1	1173.7	1612.1	1219.4	1211.1	1190.6	1182.6	1146.8	1073.6	1234.7

Table 3 Water utilization in different sections in 2000 in Shiyang River Basin (×10^{6}m^3)

Water use	Gulang	Wuwei	Minqin	Yongchang	Jinchuan	Alxa	Total
Agriculture	127.72	1047.48	653.27	410.78	36.03	–	2275.28
Industry	0.90	16.68	–	87.99	–	–	105.57
Urban domestic use	2.65	35.42	–	13.87	–	5.61	57.55
Others	–	0.72	–	–	–	8.29	9.01
Total	131.27	1100.3	653.27	512.64	36.03	13.90	2447.41

Table 4 Water supply volume of water resources engineering projects in 2000 ($\times 10^6 m^3$)

Projects	Gulang	Wuwei	Minqin	Yongchang	Jinchuan	Alxa	Total
Water storage	79.27	467.53	64.73	391.91	–	–	1003.44
Water transfer	–	196.78	–	33.40	–	–	230.18
Electrical well	52.00	435.99	588.54	87.33	36.03	–	1199.89
Others	–	–	–	–	–	13.90	13.90
Total	131.27	1100.30	653.27	512.64	36.03	13.90	2447.41

4.2 Soil and Water Resources Balance Analysis

Total irrigated land in the 2000 in Shiyang River Basin was 232 750ha, with total water utilization of $2447.41\times 10^6 m^3/a$, and per unit area water utilization of 9779 $m^3/(ha,a)$. Agriculture irrigation situation in different counties are: $127.72\times 10^6 m^3/a$ of total irrigation water in Gulang, with per unit area water utilization of $4871 m^3/ha$; $1047.48\times 10^6 m^3/a$ of total irrigation water in Wuwei, with per unit area water utilization of 10 661m^3/ha; $653.27\times 10^6 m^3/a$ of total irrigation water in Minqin, with per unit area water utilization of $11433 m^3/ha$; $410.78\times 10^6 m^3/a$ of total irrigation water in Yongchang, with per unit area water utilization of $9816 m^3/ha$; $36.03\times 10^6 m^3/a$ of total irrigation water in Jinchuan, with per unit area water utilization of $3908 m^3/ha$ (only 6400ha of land were actually irrigated with per unit area water utilization of $5630 m^3/ha$). We can see from above mentioned information that Gulang and Jinchuan have the lowest per unit area water utilization volume compared with other regions. Gulang is located near the Qilian Mountain, with a cooler climate, so it has a lower irrigation water demand than other areas; Jinchuan is located near the edge of the desert, it should have a similar irrigation water demand with Minqin County, but due to the severe water resources shortage conditions, per unit area water utilization is near the lowest limitation, similar with the standards in Israel. If we see from above information in general, Wuwei has a large water utilization volume, similar with Minqin near the desert, but multiple crop index in Wuwei is more than 70%, if we take this into consideration, the per unit area water utilization for single crop is only $6270 m^3/ha$ (Table 5).

4.3 Water Resources Security Analysis

The Shiyang River Basin has a large population, vast land and is in shortage of water resources. Water resources security issues are mainly focused on shortage of water resources and eco-environment deterioration in the downstream. Some researchers think that eco-environment in middle reaches of the basin is also becoming worse, but actually it is not true. Although eco-environment in some areas of middle reaches has been destroyed, the main reason is not shortage of water resources but the enlargement of land by local people. In general, oasis planted by people in the middle and upper reaches of the basin have expended a lot, so we can not reach a final conclusion that eco-environment in oasis is becoming worsen. Eco-environment deterioration and decline in the downstream are really caused by over exploration of water resources in the middle reaches.

4.4 Critical Line and Warning Line for Secure Water Resources Development and Utilization

Water resources and eco-environment system in the Shiyang River Basin are not in security situation. There are two ways to solve the problems: one is to reduce cultivated land, conduct reasonable water allocation between agriculture, industry and eco-environment, to adjust products structures. If we reduce irrigation water by means of using water saving technology, it is not practicable because there is no water saving spaces in the Shiyang River Basin under current technology conditions; another way is to transfer water from other areas.

To solve water resources security problem, the only way is to transfer water from other areas. According to investigations, total water demand of different section

Table 5 Water utilization volume in different irrigation areas of Shiyang River Basin in 2000

		Gulang	Wuwei	Minqin	Yongchang	Jinchuan	Total
Irrigation area ($\times 10^3$ha)	Farmland	23.88	92.71	57.14	38.45	7.22	219.40
	Forestry	1.24	5.61	–	1.20	1.10	9.15
	Orchard	1.10	–	–	1.22	0.90	3.22
	Grassland	–	–	–	0.98	–	0.98
	Total	26.22	98.32	57.14	41.85	9.22	232.75
Total water utilization ($\times 10^6 m^3/a$)		127.72	1048.20	653.27	410.78	36.03	2276.00
Per unit area water use ($m^3/(ha\cdot a)$)		4871.00	10661.00	11433.00	9816.00	3908.00	9779.00

in current stage in the Shiyang River Basin is about $2950\times10^6 m^3/a$, and water supplied by water resources engineering projects is remained at a relatively stable level of 2400×10^6–$2500\times10^6 m^3/a$ in recent 10 years. If plus rural domestic water use and self-served water wells of some companies, the total demand will reach $2650\times10^6 m^3/a$, water shortage gap is $270\times10^6 m^3/a$; if take consideration of $260\times10^6 m^3/a$ of over exploded ground water, the total water shortage gap in the whole basin will be $530\times10^6 m^3/a$. It will be proper to transfer $600\times10^6 m^3/a$ of water from other areas under the condition of keeping current water utilization scope, thus we can primarily solve water resources and eco-environment problems, and still have $70\times10^6 m^3/a$ elastic spaces. So water resources and eco-environment security critical line is: to keep water utilization at 1800×10^6–$1900\times10^6 m^3/a$, or to transfer $600\times10^6 m^3/a$ of water to the basin, and to make the surface water resources reach $2032\times10^6 m^3/a$, as a result, there are some elastic space leaved for agriculture irrigation, and eco-environment in the down stream can be rehabilitated step by step.

If we do not consider transferring water from other areas, water utilization amount of less than $2300\times10^6 m^3/a$ will be the security warning line for water resources and eco-environment in the basin. In drought years, if less than $260\times10^6 m^3$ of ground water are over explored, then the ground water table can be restored to a reasonable level of 2–3m during water sufficient years. Through this way it will not cause soil salinization and secondary salinization. If we do not reduce irrigated land area, and transfer another $180\times10^6 m^3/a$ of water from other areas, to ensure water inflow to Minqin County reaching $320\times10^6 m^3/a$, water resources and eco-environment can also remain at security warning level.

5 CONCLUSIONS AND DISCUSSION

Water resources crisis in the Shiyang River Basin has gone on since the end of the 1970s, and increasingly become worsen. Water resources shortage situation of the basin ranks first in China and very few in the world. Because over exploration of water and land resources in the upper stream, some springs, with sufficient water before the 1970s, gradually come to drought; inflow to Minqin County reduced year by year; water quality become worsen; a vast land in Minqin County were covered by sand or become saline land. Meanwhile, because shortage of water resources, ground water in Wuwei and Minqin was over exploded, thus ground water level dropped lower than 5m. It caused 3000ha of *Elaeagnus angustifolia* forest come to death and another 5800ha of *Elaeagnus angustifolia* forest and *Populus euphratica* forest become feeble (FENG and CHENG, 1998; FENG *et al*., 1999; FENG *et al*., 2000).

During recent 20 years, the ground water level in the Shiyang River Basin was ordinarily dropped 5–10m. The funnel area in Wuwei is about $34km^2$, and in the center of the funnel ground water level is under 75m; funnel area in Yongchang County is $37km^2$, and ground water level in the center of the funnel is under 62m; in the downstream of Minqin Basin, the situation is even worse, and water wells for rural domestic use have a depth of 300m. By the year 1995, 6670ha of cultivated land were abandoned due to over-exploitation of ground water, and 3710ha of cultivated land were abandoned due to water shortage and windy sand, of which 3150ha were in Minqin County. It causes ecological refugees and ecological migrations (FENG *et al*., 1999).

At the same time, oasis in middle reaches of the basin gradually moved to the upper reaches because shortage of water resources, as a result water resources reserve forests in mountainous area were destroyed, grassland shrink back, soil and water were severely eroded. According to investigation, people lived in mountainous area increased from 90 000 in 1950 to 260 000 in early 1990. About 3000ha of natural forest were destroyed in varying degrees, of which 800ha were severely destroyed. Bushes and grasslands were also destroyed, total destroyed area reached 53 400ha in recent 20 years. At the upper reaches of the Xiying River, the Zamu River, the Jinta River and the Huangyang River 12 900ha of land were brought under cultivation, 670ha of land in Huangcheng and about 3330ha of land in Caoyuanzhong were also brought under cultivation. These activities have severe influence on ecological balance in the middle and down stream. Moreover ground water environment is also become worsen, mineral index in ground water over-exploration area has increased to 3–10g/L in recent years, in Huqu, down stream of Minqin County, mineral index even reach to 18g/L, water quality problem is extending from south to north and caused extremely difficulties for living (FENG *et al*., 2000; CHRIS *et al*., 2001; LAN *et al*., 2000).

As a summary, water resources and eco-environment in the Shiyang River Basin are not in secure situation. One reason is that global warming caused less precipitation; another is population increase, over development and unreasonable utilization of soil and water resources, all these lead to water resources and eco-environment crisis. Some adjustable space should be leaved in water resources management plan in the future; otherwise small natural water resources fluctuation will cause severe water resources and eco-environment crisis, and will be no tranquility in the basin area (WANG and CHENG, 1999; 2000).

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