CHINESE GEOGRAPHICAL SCIENCE
Volume 12, Number 1, pp. 50 – 54, 2002
Science Press, Beijing, China

THE IMPACT OF HUMAN ACTIVITIES ON GROUNDWATER RESOURCES IN THE SOUTH EDGE OF TARIM BASIN, XINJIANG

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ABSTRACT: In the modern times, the population growth, development of industrial and agricultural production and the petroleum exploitation, brought about the unceasing expansion of artificial oasis and abrupt increase of water demand. The artificial hydraulic irrigation engineering took the place of the natural river system, the reservoirs took the place of natural lakes, which in turn enhanced the space-time redistribution of surface water based on the natural evolution, and so did groundwater. The groundwater recharge reduced 26. 2% in 46 years from 1950 to 1995 in the southern piedmont flood plain of Tarim Basin due to mean yearly population increase rate of 27. 7‰ and associated with the water use rate increasing from 24. 6% to 58. 4%. At the same time the artificial water system seepage give primary play to groundwater recharge, which is up to 57. 6% whilst that of the natural system reduce to 33. 7%. As a result, groundwater level drop 3 – 5m widespread except some irrigation area and surroundings of plain reservoir. Spring water discharge also reduce about 37. 6% and discharge zone continuously move away to the north with the value of 0. 5 – 1. 2km in the past 40 years.

KEY WORDS: human activities; groundwater resources; recharge; Tarim Basin

CLC number: P641. 8 Document code: A Article ID: 1002-0063(2001)03-0050-05

1 INTRODUCTION

Water shortage has become an increasingly serious problem in China. Especially the arid zone of northwest China, situated in the hinterland of Eurasia, is one of the driest zones in the word. The surface water and groundwater resources only account for 3. 3% and 5. 5% of the national total whilst the area occupies 24. 5% of China total land (SHI *et al*., 1995). Groundwater is more important for drinking, agriculture and eco-system. In the arid zone of northwest China, resulting from the human activities of socio-economic development and engineering construction for water resources exploitation, not only surface water quantity and quality have changed seriously in the several river basins, but also the aquifer has been disturbed intensively (FAN, 1990). The impact of human activities on aquifer and environment is discussed in the context of the south edge of Tarim basin, which is one of the new developing areas in northwest China.

Tarim Basin, the largest inland basin in China with the second world largest desert, i. e., Taklimakan Desert, lies in the hinterland of Eurasia and is surrounded by high mountains. It is very difficult for wet airstream to arrive there so that the condition for water resources formation is extraordinary harsh. Both groundwater and ecosystem are extremely vulnerable to climate change or human activities. Especially, the south edge of Tarim Basin, located in the northern piedmont of the Kunlun Mountains with an area of 358 600km^2 and 17 200km^2 of artificial oasis, belongs to the typical ecological vulnerable zones and groundwater vulnerable zones (MA, 2001), which is an ecotone between oasis and desert, between agriculture and husbandry, between mountains and plain, and between surface water and groundwater as well. The yearly mean precipitation is about 50mm in the oasis plain and and the maximum precipitation occurs at the 2500m height

Received date: 2001-04-15
Foundation Item: Under the auspices of the National Natural Science Foundation of China (No. 49731010).
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Notthern Mts. Because of the high mean air temperature of 12.1℃, with maximum of 25℃ in July, the evepotranspiration is extremely strong, amounts to 2800mm. Therefore, the water resources come mainly from precipitation and glacier melt in the Kunlun Mountains, which represent the renewable water resources for the entire river basin practically since no surface runoff occurs in the piedmont plain. There are about 5016 modern glaciers with 75 400km^2 area and 755.3km^3 volumes, and there are about $3.7 \times 10^9 m^3$ of melt water recharging the river every year. There are 43 rivers originating from northern Kunlun Mts and the total runoff is about $7.26 \times 10^9 m^3$.

2 HYDROGEOLOGY AND GROUNDWATER RESOURCES

The south edge of Tarim Basin cut across two structural geology units — the southwest depression (Hotan depression) and the southeast depression (Yutian-Roqan depression). In the later Tertiary, with the violently fold uplift of Tianshan geosyncline and Kunlun geosyncline, Tarim basin began to subside down quickly and developed an integrated vast inland basin. At the same time, the basin extensively accepted continental clastic sediments which are the impermeable bed of the Quaternary aquifers. Since the end of Pliocene epoch, with continuing rising up of the surrounding mountains and subsiding of the piedmont depression, the basin accepted deep loose diluvial and alluvial deposits, and some eolian deposits and lacustrine deposits, which formed the good water storing aquifers of 200 – 900 meters thick. Controlled and affected by geological structure and hydrological factors, the hydrogeology and hydrogeochemistry distributed as several regular zones corresponding to the geomorphic and sedimentary from the piedmont to the basin center. The piedmont slope plain is formed into single cobble gravel aquifers, in which the specific capacity is 20 – 500m^3/(d·m), and the coefficient of permeability is 1 – 6m/d. The Quaternary aquifers of front of slope plain is formed by loose diluvial and alluvial cobble gravel, gravel, sand gravel, fine sand and clay, in which the specific capacity amounts to 200 – 1000m^3/(d·m) and the coefficient of permeability is up to 50 – 212m/d. Then with the grain turning to finer, the permeability and capacity become smaller and smaller. The confined aquifers are not widespread and just between the Keriya River and the Niya River extends 70.5 km from south to north and covers approximately 9517 km^2, and there are two layers of impermeable clay in the 150 m depth. The depth of groundwater table varies from 50 – 100 meters in piedmont slope plain to 1 – 3 meters in the fine soil plain, and the water salinity is 1 – 3g/L in the former, and 3 – 10g/L in the later. The groundwater chemistry corresponding become from $Cl - HCO_3 - Ca - Mg$ or $HCO_3 - Cl - Mg - Ca$ to $Cl - SO_4 - Na - Mg$ or $Cl - Na$. The water quality in the ancient channels is better than that in other regions in general.

The total groundwater recharge is $3.681 \times 10^9 m^3$ (MA *et al.*, 2001), which can be classified into two parts: repeated and irrepeated groundwater. The former, $3.447 \times 10^9 m^3$, transformed by surface runoff, is recharged by seepage of natural channel, canal system and field irrigation. The latter is recharged by side ground runoff and rainfall penetration (Table 1).

The majority of groundwater resources is seepage transformation of surface water including runoff and irrigation water in the canal system and field, which is accounting for more than 94% of total groundwater recharge. The precipitation infiltration and side-base flow, only accounts for no more than 6%. The extensive evapotranspiration is the mainly drainage and consume way of groundwater in the fine soil plain while enormously spring groups draining groundwater in the slope plain, at the edge of that a great part of groundwater overflows aquifers and transforms to surface water again, which is the main source of the river runoff and groundwater in the lower reach of river basin in the desert.

Table 1 The groundwater resources of the piedmont plain in the south edge of Tarim Basin ($10^9 m^3$)

River basins	Surface runoff	Channel seepage	Canal seepage	Field seepage	Side-base flow	Rainwater penetration	Groundwater resources
Pishan R.	0.705	0.150	0.255	0.009	0.032	0.009	0.455
Hotan R.	4.391	0.113	1.244	0.041	0.058	0.016	1.472
Qira R.	0.581	0.191	0.191	0.005	0.017	0.009	0.413
Keriya R.	1.007	0.367	0.344	0.012	0.038	0.015	0.776
Niya R.	0.576	0.421	0.084	0.020	0.025	0.015	0.565
Total	7.260	1.242	2.118	0.087	0.170	0.064	3.681

3 HUMAN ACTIVITIES AND WATER RESOURCES EXPLOITATION

The human activities began in 6000 – 7000a B. P. and agriculture characterized by water resources exploitation began in 3000a B. P. in the south edge of Tarim Basin. In the beginning of the Han Dynasty, the population is only 642 000 and human activities distributed at the lower reaches of 100 – 200km north away from modern oasis of convenient for developing water. When the Tang Dynasty conquered the west of China in the 600s, metallurgy and dam technology was imported into Xingjiang. From then on, the water and land resources were developed largely and quickly with the population growth. However, Human activities had played a secondary role on the water system and environment change comparing to climate effect prior to 1949. In 1949, only about $1.8 \times 10^9 m^3$ of surface water was drawn in simple soil channel, the coefficient of which is 0. 2 and the net use water of artificial oasis was just $0.1 \times 10^9 m^3$. The groundwater and the eco-system kept unchanged, and there were still abundant water resources and large area of forest and grassland in the edge of the basin.

Large-scale water conservancy construction and water resources exploitation began in 1949 when the P. R. China was founded. The population increased quickly from 662 000 in 1949 to 1. 51 million in 1995, yearly mean increase 27. 7‰. The cultivated area also enlarged rapidly accordingly, in 1960 it arrived 218. 700 ha of maximum, which was almost 2 times of that in 1949. Especially from 1980, mass agricultural water engineering construction and reforming led to irrigating area increase quickly, up to 259 000ha in 1995. Fifty-eight reservoirs of $0.35 \times 10^9 m^3$ volume and 25 000km channel of 0. 4 – 0. 49 using coefficient have been built in the south edge of Tarim basin from the Hotan River to the Niyer River. $5.137 \times 10^9 m^3$ water were exploit for irrigation and drinking, which was 68. 4% of total water resources (Table 2). A big reservoir named Wuluwaty of $0.34 \times 10^9 m^3$ volume now is building in the upper reaches of the Hotan River, and another 80 000ha of irrigating land will be developed. Like many other arid area of China, the majority water was exploited for irrigation (TANG, 1992), which accounts for 92. 3% while that used for industry production and drinking only occupy 7. 7% in the south edge of Tarim Basin. However the groundwater is exploited finitely. There are four groundwater resource sites had been set up for drinking and irrigation, and 108 wells were drilled and $0.037 \times 10^9 m^3$ groundwater pumped, which is less than 1. 3% of the groundwater recharge. Therefore there is potential to certain extent for strengthen groundwater exploitation (MA, 2000).

Table 2 The water resources utilization status in the south of Tarim Basin

River system	Total water resources ($10^9 m^3$)	Water use ($10^9 m^3$)	Water use rate(%)	Irrigation area (10^3ha)				Irrigation water ($10^9 m^3$)	Drinking water ($10^9 m^3$)
				Crop	Gardening	Forest	Grass land		
Pishan R.	0. 745	0. 697	93. 6	23. 2	2. 80	9. 5	8. 0	0. 259	0. 037
Hotan R.	4. 465	2. 994	67. 8	71. 9	16. 25	52. 6	10. 2	1. 045	0. 059
Qira R.	0. 607	0. 486	80. 1	20. 0	1. 20	4. 5	–	0. 147	0. 016
Keriya R.	1. 060	0. 787	74. 2	21. 0	2. 40	9. 8	0. 7	0. 259	0. 024
Niya R.	0. 616	0. 173	28. 1	2. 6	0. 35	1. 6	0. 8	0. 056	0. 003
Total	7. 493	5. 137	68. 4	138. 7	23. 00	78. 0	19. 7	1. 766	0. 139

4 IMPACT OF HUMAN ACTIVITIES ON GROUNDWATER

Groundwater has been changing extensively affected by climate change and Human activities. It was indicates that from late Pleistocene the climate of Tarim Basin tended to a severe aridity and the groundwater depended mainly on the runoff which was composed of melt glacier and snow and rainfall from the Kunlun Mountains. The change of temperature in geologic period led to the altering of runoff flow to Tarim Basin and then caused the change of groundwater recharge. In human history period, climate still played a leading role in the evolution of groundwater. Continuous arid climate resulted in the redution of runoff and change of channels which influenced recharge and distribution of groundwater. As the development of civilization of human society, the impacts of transformation and destruction of human activities on water system played a more and more significant role environmentally. In the modern times, the population growth and improvement of socio-economic condition brought about the expansion of artificial oasis rapidly, which need to consume a large amount of water. Resulted from that, the artificial irrigation canal took the place of natural channel, the artificial reservoirs took the place of natural lakes, which enhanced the space-time redistribution of surface water with the natural evolution, and so did groundwater. Such hydrological influence of human activities can be summarized as Fig. 1. The groundwater recharge reduced 26.2% in 46 years from 1950 to 1995 in the south of Tarim Basin based on the water use rate increasing from 24.6% to 58.4% (Table 3). The table also shows that groundwater was mainly recharged by natural channel seepage, which accounted for 65.4%. But now the artificial canal system seepage gives aprimary play to groundwater recharge, which is up to 57.6%, while the former reduce to 33.7%.

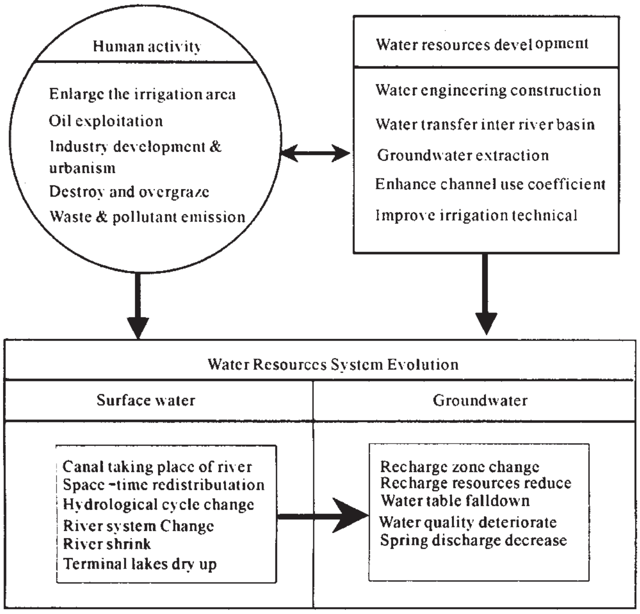

Fig. 1 Impact of human activity on water resources system

Because of water resources utilization and reduction of groundwater recharge, groundwater level drop 3 – 5m widespread except some irrigation area and surroundings of plain reservoir. Spring water also reduced about 37.6% and discharge zone continuously move away to the north with the value of 0.5 – 1.2km in the past 40 years though exploitation and utilization of groundwater was very limit, which was about 1.3% of groundwater resources. At the same time, groundwater pollution begins to rise up quickly. Especially, in some towns and irrigation areas a lot of organic nutrition such as NO_3-N, NH_4-N, DOC and SRP are brought to aquifers where groundwater is recharged by surface water.

Besides, groundwater evolution has led to serious plant degradation and desertification in the south edge of Tarim Basin. The natural Populus forest reduced from 120.0×10^3ha at the beginning of the 1950s to 18.0×10^3ha in the end of the 1980s. The *Tamarix* forest also reduced from 37.0×10^3ha to 10.0×10^3ha. Land desertification area amounts to 16.7×10^3ha, of which the cultivated land accounts for 35% in the Hotan oasis. In some irrigation areas, salinization is also very serious due to backward irrigating techniques. The total salinizated area is up to 35.2×10^3ha, which accounts for 15.8% of the cultivated land.

5 CONCLUSION AND DISSCUSION

Groundwater system has been changed extensively in the south edge of Tarim Basin as the development of civilization of human society, especially in the modern times. Although direct groundwater exploitation is very limited, the surface water use unduly led to the reduction of groundwater recharge and fall of water table. Anyway there is potential to a certain degree for groundwater exploitation. The quantitative aspect of resources availability for sustainable use is a basic concern for the evolution of groundwater water management. The water quality is also critical importance and is closely linked with the water quantity. The management of water resources should be strengthened in accordance with the water law. The solution of the environmental problems of groundwater is a systematic project related to the exploitation, utilization, management and protection of water resources, which should be undertaken in a unified way within a river basin. The surface water and groundwater can be used conjunctively

Table 3 The water resources exploitation and groundwater evolution in the south edge of Tarim Basin

Period	Water use (10^9m^3)	Water use rate (%)	Coefficient of canal use	Channel seepage (10^9m^3)	Canal seepage (10^9m^3)	Field seepage (10^9m^3)	Irrepeated recharge (10^9m^3)	Groundwater resources (10^9m^3)
1950s	1.800	24.6	0.2	3.263	1.440	0.051	0.234	4.988
1960s – 1970s	3.284	44.8	0.23 – 0.3	1.824	2.299	0.157	0.234	4.514
1980s	3.721	50.7	0.35 – 0.41	1.414	2.235	0.302	0.234	4.185
1990s	4.239	58.4	0.4 – 0.49	1.242	2.118	0.087	0.234	3.681

through rational regulation and control so as to get an optimized arrangement of their utilization. The administrative, economic, legal and technical measures should be taken: strengthening the management of water resources, exercising planned exploitation and strictly restricting the overdraft of groundwater. According to MA Jin-zhu *et al.* (2001), the maximum safe yield of groundwater is about $2.05 \times 10^9 m^3$ if the surface water use keeps the scale as present. There will be increase of $2.013 \times 10^9 m^3$ of water, will be resolved if rational steps are taken, the problems of water shortage will be resolved in the region.

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