Water resources utilization and its influence on the eco-environment in the arid zone of northwest China

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Abstract Over the last 50 years exploitation of water and land resources in the arid northwest regions of China has been expanding to support the sustainable development of industrial and agricultural production. As a result river discharges have been drastically reduced (even dried-up), river courses shortened, and terminal lakes have contracted or dried-up. In the lower reaches of some inland river basins, desertification is rapidly developing at an annual rate of 3.5–6.9%. Economical and effective use of water resources and harmonization of eco-environment benefits with economic benefits are the only fundamental ways to achieve the sustainable development of arid northwest China.

INTRODUCTION

Arid zones in northwest China refer to the inland drylands north of 35°N and west of 106°E, including the whole of the Xinjiang autonomous region, the Hexi Corridor in Gansu Province and the area west of the Helan Mountains in Inner Mongolia; these occupy 24.5% of China's total land area. Owing to the alternating terrain of high mountains and basins, all the rivers form into centripetal stream systems. Some of the small discharge rivers soon disappear in the desert region after flowing out of the mouths of the mountain valleys, while a few larger rivers flow to depressions to form inland lakes.

Generally, inland river basins in the region cross three different physical geographical sub-zones: high-mountain humid-cold or semiarid zone, temperate zone and warm temperate zone. Under the influences of such water resource distribution and climatic conditions, the temperate and warm temperate zones are macroscopically eco-environment fragile belts and thus seriously restrict the exploitation of water and land resources (Niu, 1989). Since the 1940s, great changes have taken place in both the hydrological regime and ecology of these areas due to population growth, socio-economic development and large-scale exploitation of water and land resources.

EXPLOITATION OF WATER RESOURCES AND HYDROLOGICAL EFFECTS

Exploitation of water resources

According to ^{14}C dating, irrigation farming in these regions can be dated back as early as 221 BC. Since the 1940s agricultural production in these areas has been developing rapidly with cultivated land area in the Xinjiang region increasing from 121.0×10^4 ha in 1949 to 310×10^4 ha in 1990. Crop yields have increased 2.6-fold and population increased 2.5-fold. Prior to 1949, there was only one reservoir with a storage capacity of $0.5 \times 10^8 m^3$ in the Xinjiang region. By the 1980s the number of reservoirs had increased to 458, with a total storage capacity of $53.71 \times 10^8 m^3$. By the 1990s the number of reservoirs had further increased to 480, with a total storage capacity of $55.0 \times 10^8 m^3$ (Fan, 1996). By 1993 the number of motor-pumped wells in the Xinjing and Hexi Corridor region had exceeded 4.8×10^4 and the pumped output of ground water reached $20 \times 10^8 m^3 year^{-1}$ and $12 \times 10^8 m^3 year^{-1}$ respectively.

Table 1 shows the present state of water resource use in arid northwest China. In some of the major arid plains, such as the Hexi Corridor region, the Junggar and Tarim basins the utilization ratio of water resources is over 65%, i.e. much higher than the 30% mean utilization ratio of water resources in the world's drylands. In local places such as in the Urumqi River basin and Shiyang River basin the utilization ratios of water resources reach 108.1% and 104.7% respectively, i.e. it exceeds the renewable water volumes of these two basins (Chen & Qu, 1992; Shi, 1995).

Table 1 Water resources and utilization status in arid northwest China (unit: $\times 10^8 m^{-3} year^{-1}$).

Region	Surface runoff	Utilization ratio (%)	Groundwater recharge	Re-use volume of surface water and groundwater	Groundwater utilization ratio (%)	Total volume of water resources	Utilization ratio of total water resources (%)
Hexi Corridor	74.2	63.67	43.12	37.22	38.15	80.10	72.0
Junggar basin	127.0	63.9	68.8	49.8	19.0	146.0	64.5
Tarim basin	407.0	67.0	220.1	196.6	3.9	430.5	65.3
Qaidam basin	45.8	17.1	35.0	31.1	1.8	49.7	17.0
Ertix River	119.0	14.8	20.0	17.7	0.7	121.3	14.6

Variations in river hydrological regime

The Tarim River is the longest inland river in the arid zones of northwest China. It is 2200 km in length, with 183 tributaries. Until the beginning of this century there were 128 perennial rivers but today only three large rivers, the Aksu River, Hotan River and Yarkant River still join the Tarim River; others have dried up or disappeared in respective oases. The Manass River, which has the largest discharge on the north slope of the Tianshan Mountains, has been replaced by an artificial canal network at the mouth of the mountain valley.

Great temporal and spatial changes also have taken place in the interannual water distribution between the upper, middle and lower reaches. As shown in Fig. 1 for the Tarim River basin, although the discharges of the three rivers at the mouth of the mountain valley remain constant, the measured values at the downstream Kala station have reduced by 80.3%. Hydrological variations are also manifest in the annual surface runoff distribution within a basin which is controlled by human and urbanizing activities in particular. For example, the Heihe River basin has been severely affected by intensive water utilization in its middle reaches with the lower reach drying up from May to July. It reforms during the summer flood between August and October and then decreases in discharge or even dries up from November onwards. In addition, acute contradiction exists in water demand and supply in these lower reaches as no runoff occurs just as the water demand reaches its peak.

Hydrological variations and over-exploitation of surface water significantly affect the groundwater table in the middle and lower reaches with irrational oasis irrigation raising the groundwater level and resulting in secondary soil salinization. On the other hand, lowering of the water table is much more widespread. The groundwater table in the downstream basin of the Shiyang River has reduced by 4–17 m and formed a large regional depression cone, with an area of 1.0×10^3 km^2.

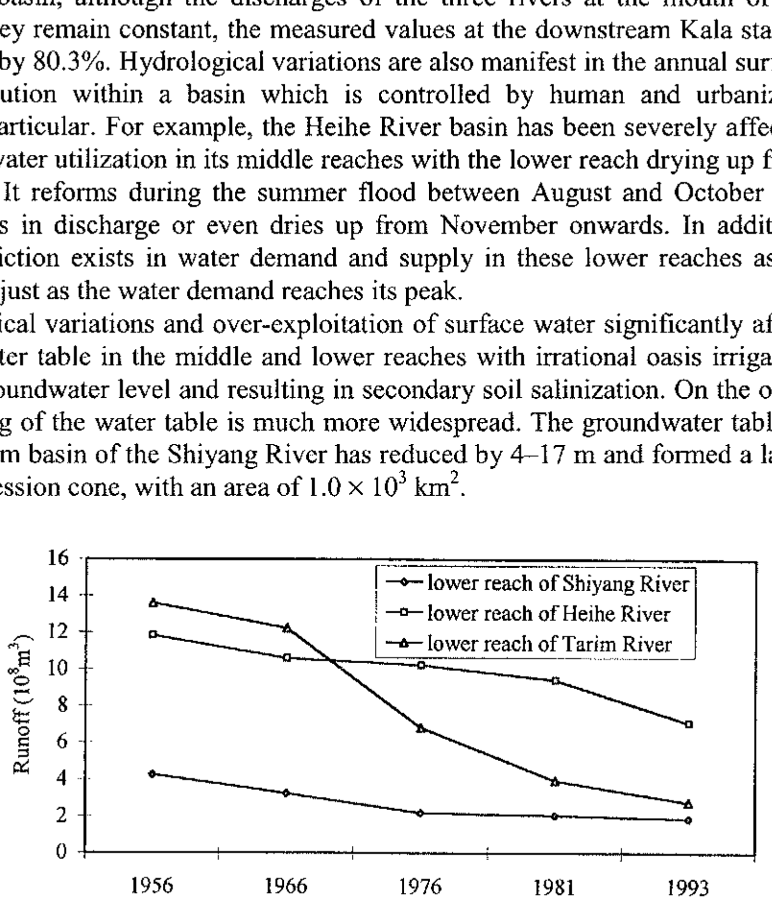

Fig. 1 Multiyear discharge changes in the lower reaches of typical rivers in the arid northwest China.

ECOLOGICAL EFFECTS

Deterioration of water quality

Owing to alteration in the hydrological regimes, the phenomenon of deteriorating water quality in arid northwest China has also occurred, mainly manifesting itself in increasing salinization and man-made pollution of natural water bodies in the middle and lower river reaches. Increased water consumption accelerates the conversion between surface water and groundwater in a basin, with increasing re-use of water resources and decrease in surface water leading to striking salinization of both surface water and groundwater, especially in the lower reaches of rivers (Fig. 2). For instance, the salinity in the lower reaches of the Shiyang River and Urumqi River, on average rose

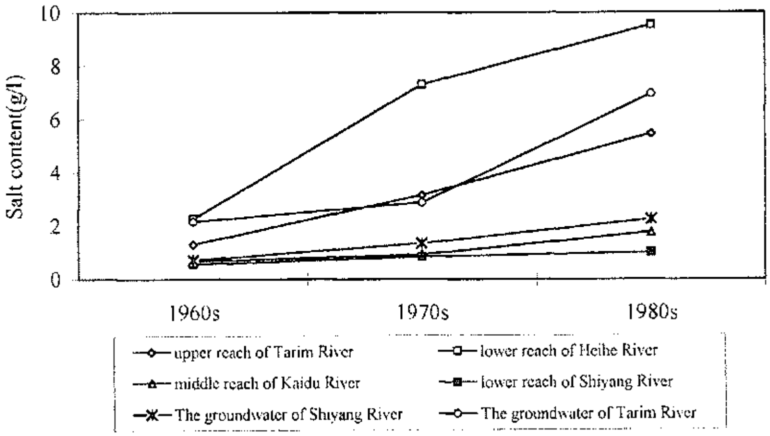

Fig. 2 Variations in natural water salinity in arid northwest China.

by 0.3–1.8 g l^{-1} (Liu & Chang, 1992) and the chemical type of water has changed from HCO_3^{1-}/SO_4^{2-}—Na^+/Ca^{2+} type to dominantly Cl^-/SO_4^{2-}—Na^+ or SO_4^{2-}/Cl^-—Na^+ type.

Urban activities in the inland river basins of the arid northwest China have severely aggravated the pollution of water bodies. In the lower reaches of the Tarim River, Urumqi River, Heihe River and Shule River, BOD, COD and NH_4–N contents are now too high to be suitable for human and livestock drinking (Table 2). The most severe pollution of groundwater occurs in the areas around the cities due to intensive human activities. For example, in Zhangye city in the Heihe River basin, Wuwei city in the Shiyang River basin and Urumqi city in the Urumqi River basin the sulphate, ammonium-nitrogen and nitrate contents and hardness of the groundwater are all in excess of the state's domestic water standard.

Table 2 Determination results of water pollution indexes (mg l^{-1}).

Dissolved oxygen	COD	BOD	NH_4-N	Volatile phenol	Cr^{6+}	Zn	Petroleum	Fluoride	Permanganate
Zhangye section of Heihe River									
7.88	16.44	1.67	0.54	0.004	0.002	0.005	-	0.34	2.65
Wuwei section of Shiyang River									
7.97	17.73	2.07	0.48	0.010	0.002	0.033	0.225	-	2.39
Jiuquan section of Shiyou River									
8.30	1279.7	2.35	11.11	4.94	0.420	0.49	37.4	-	33.20
Qiala station of Tarim River									
8.09	3.67	-	0.25	-	-	-	-	1.61	-
Urabo section of Urumqi River									
9.1	14.05	12.79	1.86	0.017	0.038	0.038	-	0.198	0.039

Vegetation degradation

Over the past half-century vegetation in northwest China has degraded seriously, mainly manifested by a reduction in the stock of timber, a decrease in area of *populus*

Table 3 Status of land desertification in several regions in northwest China (unit: × 10^4 ha).

Region	Desertified land area	% of total land area	% of oases area	% of severe desertified land	Potential desertification area	% of total land area
Xinjiang	304.71	1.82	43.14	24.99	154.96	0.92
Hexi Corridor	252.22	9.15	19.60	31.82	168.94	6.13
Alxa Plateau	118.00	6.10	-	61.28	60.22	3.10

euphtatica and shrub forests and a drop in the livestock-supporting capacity of grassland. Destruction of mountain forests has resulted in serious soil erosion which has reached 86.3 × 10^4ha in the Shiyang River basin with the sand transport rate reaching 93 × 10^4 m^3 $year^{-1}$. The situation is the same in the Manas basin in Xinjiang where sand transport rate has increased from117 × 10^4 t $year^{-1}$ in the 1950s to 192.6 × 10^4 t $year^{-1}$ in the 1970s (Fan, 1996).

Land desertification

Land desertification is developing rapidly due to the erodible sandy deposits at the surface, frequent wind erosion, and over-exploitation of water and land resources. As shown in Table 3, desertified land accounts for about 19%–43% of the total area. The data for desertified land shown in Table 3 identifies only the oases areas as being desertified since 121 BC. The severely desertified land has now reached 25–61.28% of the total desertified area. Besides the desertified land in northwest China, there are about 384.12 × 104 ha identified as a potential desertification area (Table 3). There are three factors mainly responsible for the rapid development of modern desertification in arid northwest China. The first factor is the wind erosion due to lack of protection, the second factor is the destruction of vegetation due to mis-use of water resources and soil salinization and the third factor is sand dune encroachment of the oases. Of particular importance are the latter two factors with for example, 83% of the total desertified land area in the Tarim basin being attributed to the latter two factors (Zhu, 1992).

CONCLUSIONS

Over-exploitation and severe waste of water resources have long been a problem in arid northwest China due to lack of rational planning and effective water-saving measures and these have caused a series of ill-effects on both the hydrological regime and ecological environment. River discharge in the lower reaches is decreasing, terminal lakes are contracting and water quality is getting worse. Many small rivers disappear soon after flowing from mountain valleys, river courses are shortening, the groundwater table is falling and many lakes are drying up. All these directly cause degradation of vegetation and lead to soil salinization and desertification. Rapid development of desertification results in the decrease of productive land and directly threatens the stability of fragile man-made oases.

Rational planning and effective use of water resources with adherence to "resource-saving" development are the only sustainable and basic ways for economic development and eco-environmental protection in these arid northwest regions of China. In this respect there are many possibilities such as adoption of advanced irrigation techniques and development of water-saving agriculture, etc.

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