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Ecological impacts of water resources utilization in the Tarim River Basin of China

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Abstract Water resources and ecosystem stability are the most conspicuous and sensitive issues in arid areas of China. In this paper, exploitation of water resources and the corresponding environmental problems in the Tarim River during the past five decades are evaluated. An increasing use of water in the source area caused problems with secondary salinization of the soil; whilst an increasing consumption of water in the upper- and middle-reach areas caused droughts in the lower-reach area. Serious water pollution intensifies scarcity of water resources. Groundwater levels have dropped substantially and ecosystems have been seriously damaged. The purposes of our study were to reveal the relationship between exploitation of water resources and ecosystem succession, to put forward the measures for rationally utilizing the water resources and effectively protect the ecosystem integrity in the Tarim River watershed, and to provide the scientific basis for overall harnessing of the Tarim River.

Key words ecology; Tarim River; water consumption; water management; water resources

INTRODUCTION

Water resources and ecosystem stability are the most conspicuous and sensitive issues in the arid areas of China. Located in the arid area of northwestern China, the Tarim River, approx. 1321 km in total length, is the longest inland river in the world. Its watershed is rich in natural resources, but vulnerable in ecological environment, and is well known worldwide for its distinctive regional features and conspicuous issues of water resources and environment. During the past five decades, intensive exploitation of water resources has resulted in changes to the temporal and spatial distribution of water resources and serious environmental problems in the Tarim River Basin. The ecosystems and the ecological process dominated by natural vegetation are seriously impacted because the natural temporal and spatial distribution of water resources is artificially changed.

The increasingly severe problems of declining water resources and ecosystem degradation have received a great deal of attention by all levels of governments. The state has invested 10.7 billion yuan for saving the "Green Corridor" (The lower reach of the Tarim River is called "Green Corridor", since it is between two large deserts. National Highway 218 runs through this Corridor and connects Xinjiang Province to inland China. A proposed new railway line will also be constructed in this region). Many experts and scholars have analysed the change and decreasing water resources in the Tarim River watershed (Chen & Li, 1998; Hamid *et al.*, 2000) and researched the ecological degeneration and the protection measures from different aspects (Chen, 1999; Tang & Zhang, 2001). The Tarim River has become one of the critical regions with the most conspicuous problems of water resources utilization and ecological environment in the arid areas in China. In this paper exploitation and utilization of water resources and the resulting environmental problems during the past five decades were evaluated. The analysis was based on data collected in a multi-year field investigation. The purposes of the study were to put forward the measures for rationally utilizing water resources and effectively protecting the ecosystem integrity in the Tarim River watershed and to provide the scientific basis for overall harnessing of the Tarim River and saving the "green corridor" along its lower reaches.

COMPOSITION AND CHARACTERISTICS OF THE WATER RESOURCES

The Tarim River is composed of three principal tributaries (i.e. Yarkand River, Hotan River and Aksu River) and the mainstream (see Fig. 1). It is mainly fed by glacial/snow melts and rainfall. In the composition of the runoff, the glacial melt, mixed water of rainfall and snow melt, and base flow of the rivers occupy 48.2%, 27.4% and 24.4%, respectively. The interannual change of the annual runoff volume is small, the CV values vary in a range of 0.15–0.25, and the maximum and minimum modular coefficients are 1.36 and 0.79, respectively. The seasonal runoff is poorly distributed, and the runoff volume in the flood season from June to August occupies 60–80% of the annual runoff volume, which reflects that the rivers are mainly fed by the mountainous glacial-snow melts in the arid areas.

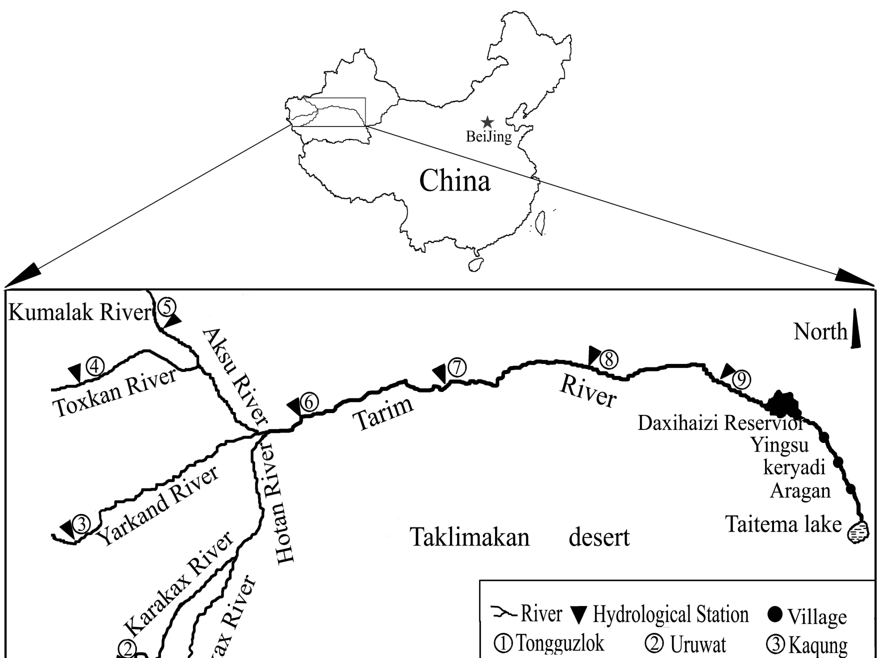

Fig.1 Sketch map of the Tarim River.

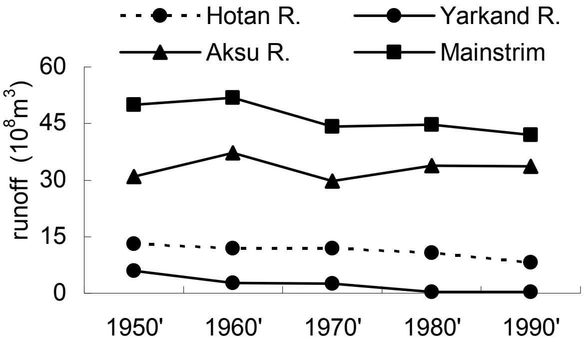

Fig. 2 The change of water volume supplying the Tarim River.

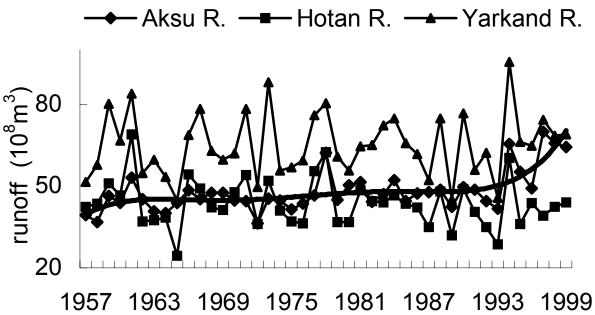

Fig. 3 The changes of annual runoff in the three source tributaries.

Development on tributaries reduces flows

The water volume supplied from the three source tributaries to the Tarim River has been decreasing over time, due to the large-scale development in the source area. Statistical data showed that the water volume had decreased from 51.79×10^8 m^3 in the 1960s to 42.04×10^8 m^3 in the 1990s and then decreased progressively at a rate of 0.25×10^8 m^3 per annum (Fig. 2). The Hotan River flows into the Tarim River only in the flood season from July to September, and the Yarkand River flowed into the Tarim River only in 1994 during the 15-year period from 1986 to 2000. Currently, the Aksu River is the main water source to the mainstream of the Tarim River, accounting for 73.2% of the total; the remaining 23.3% coming from the Hotan River and 3.5% from the Yarkand River.

Analysis of the runoff volume change of the source areas of the Tarim River showed that the total annual inflow volume of the three source tributaries varied in a range of 174×10^8~194×10^8 m^3 on average during the period 1950s–1990s. Moreover, in the 1990s the annual volumes of runoff from the mountainous regions of the source stream areas were obviously increased (Fig. 3), in which the average annual runoff volume of the Aksu River and the Yarkand River increased by 19×10^8 m^3 (or 10.9%), since the 1950s.

The volume of feeding water from the source tributaries into the mainstream catchment of the Tarim River has been continuously reduced. It resulted mainly from the large-scale development of agriculture in the source stream areas. The population and the irrigation area in the source areas increased from 1.56 million and 348 000 ha.

in 1950 to 3.95 million and 1 257 000 ha. in 2000. The water consumption in the irrigated areas of the three source tributaries increased from 51 × 10^8 m^3 in the 1950s to 155 × 10^8 m^3 in 2000, about a 2-fold increase. Meanwhile, the secondary soil salinization in the interior areas of the oases has become more severe, and approx. 38% of cultivated lands in the irrigated areas of the three source tributaries have experienced severe secondary salinization.

Increasing consumption of water caused droughts in the lower-reach area

Water consumption in the upper and middle reaches of the Tarim River increased from 12.59 × 10^8 m^3 and 23.23 × 10^8 m^3 in the 1950s to 13.10 × 10^8 m^3 and 26.69 × 10^8 m^3 in the 1990s, respectively. The water consumption between the upper and middle reaches from the Aral to Qara hydrological stations rose from 72.9% of the total water volume in the 1950s in the Tarim River, to 95% at present (Fig. 4), and the water volume arriving in the lower reaches actually reduced from nearly 13.53 × 10^8 m^3 in the 1950s to 2.67 × 10^8 m^3 in the 1990s, which led to drying up of the watercourse for more than 320 km in the lower reaches of the river. The Lake Taitema and Lop-nor (the terminal lakes of the river) dried up during this period.

From a further analysis of the reduction process of runoff volumes along the different river sections of the Tarim River in the past 50 years, we found that the inflow volumes in the 1990s were reduced by 15.9%, 24.7%, 38.3% and 80.3%, respectively, at the sections of the Aral and Xinqiman in the upper reaches (Fig. 5), the Yingbaza in the middle reaches, and the Qara in the lower reaches of the mainstream of the Tarim River, and the inflow volume was reduced more severely downstream. The reduction amplitude of the inflow volume at the lower reaches was much higher than at the Aral section in the upper reaches of the Tarim River mainstream. These results indicate that the impact of change in the stream water volume along the river itself is much more severe than the change in volume of the feeding water from the three source tributaries. The ecological environment in the Tarim River watershed has been significantly changed by intensive socio-economic activities dominated by exploitation and utilization of water resources. With increasing local agricultural production, industrial utilization benefits, and population, the problems resulting from utilization of water resources in the watershed are becoming increasingly conspicuous. Deterioration of water quality and the environment severely affect the sustainable development of society and economy in the watershed.

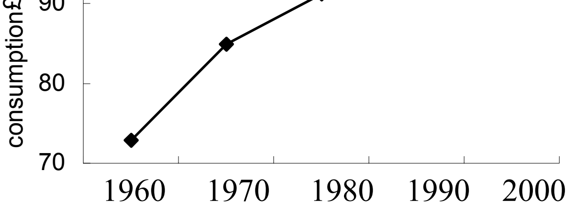

Fig. 4 The water consumption in the lower and middle reaches of the river.

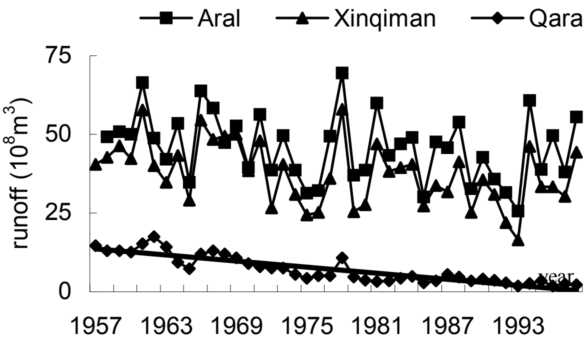

Fig. 5 The annual runoff changes in the main current of the river.

THE ECOLOGICAL IMPACTS OF WATER RESOURCES UTILIZATION

Increasing use of water resources in the source area caused ecological problems such as water pollution. The watercourse dried up in the lower-reach area, and groundwater levels dropped and ecosystems degraded severely.

Water quality is salinized

The Tarim River was a freshwater river before the 1960s and the river water salinity was below 1.0 g L^{-1}. As upstream agriculture expanded and more and more farmland used water discharged into the river, the salinity in the river increased continuously. Statistics shows that the yearly average salinity in the upstream of the main current is 1.85 g L^{-1}, 1.37 g L^{-1} in the middle reaches, and 1.34 g L^{-1} downstream. This pattern of changes in salinity along the river differs from other river systems in arid areas where the salinity generally increases as water flows downstream.

Water quality is closely related to water volume and water origin. When water volume is high with run-off in the summer season, the water quality is better; in the dry season, when more irrigation-used water is drained into the Tarim River, the water quality is reduced. At present water quality monitoring at the Alar Station shows that only 34.9% of the Tarim's water is considered as a freshwater (<1.0 g L^{-1}), 44.2% as lightly-saline water (1–3 g L^{-1}), 16.9% as semi-saline water (3–5 g L^{-1}) and 4.0% as salt water (>5 g L^{-1}) in the upstream of the Tarim River (Ma *et al.*, 1999). The situation has intensified the scarcity of water resources.

At present, the Tarim River is not only the source of water diversion in the irrigated areas, but also the receiving channel of the agricultural drainage. The statistical data about the main sewage outlets show that Tarim River takes in the drained wastewater of about 6.3×10^8 m^3 and the soluble solid wastes of 8.3×10^8 t from the irrigated areas on annual average (Table 1). The pollutants are mainly chloride. The main pollution sources in the upper reaches are the Xinsha trunk escape canal, the Tabei intercept and escape canal, the Awat trunk escape canal and the Tanan trunk escape canal, among which the pollution of the drained wastewater from the Xinsha trunk escape canal to the stream water of the Tarim River is most severe.

Table 1 Statistics of the polluted water volume in the main current of the Tarim River.

No	drainage outlets	Drainage volume (10^8m^3)	Chloride (10^4t/year)	Sulphite (10^4t/year)	Fluorde (10^4t/year)	Hardness (10^4t/year)	Soluble solid (10^4t/year)
1	Shisigongli Qu	0.4605	10.9	6.40		7.92	31.10
2	Xinsha trunk	1.7	102.9	57.30		72.59	265.20
3	Awat trunk	1.924	87.0	45.40	0.0214	57.14	230.90
4	Tabei drainage	0.299	12.6	4.50	0.00352	10.29	31.10
5	Duolangqu trunk	0.1	2.9	1.30	0.0016	3.33	9.60
6	Tabei intercept	0.824	45.8	17.00		36.92	182.10
7	Tanan trunk	0.96	50.6	26.2			85.30
Total		6.2675	312.7	158.10	0.02652	188.18	835.30

Table 2 Water volume ($\times 10^6 m^3$) flow through at four observational stations in the lower reaches of the Tarim River.

Period	Qara Station			Tikanlik	Aragan	Lop village
	Tarim	Kongquehe	Total			
1951–1960	1353	0	1,353	900–800	Water	500–400
1961–1970	1138	0	1,138	288	Intermittent	23
1971–1980	669	100	769	47	Flow stopped	Drought
1981–1990	392	201	593	36	Dry riverbed	Drought
1991–2000	284	226	551	6	Drought	Drought

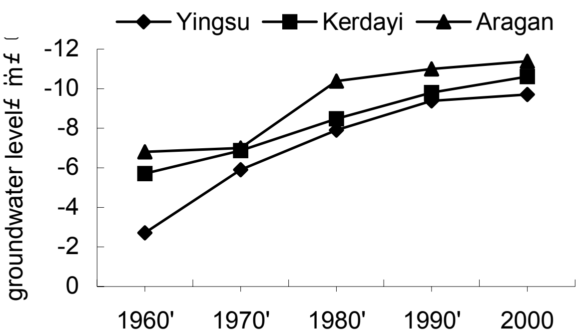

Fig. 6 The change of groundwater level in the lower reaches of the river.

Groundwater level drops substantially and ecosystems has damaged severely

Due to the drying up of the watercourses, the groundwater level dropped drastically, from a depth of 3–5 m in the period of the 1950s and 1960s to 10–12 m in 2000 over much of the region (Fig. 6). Duration of the stream-flow cut-off became longer and the groundwater level lower towards the lower reaches (Table 2). Natural vegetation relying on groundwater for normal functioning has severely degenerated: 68% of the natural vegetation has been lost, 47% *Populus euphratica* died. Studies showed that, in the middle and lower reaches of the Tarim River, the area of *Populus euphratica* was at 46.0×10^4 hm^2 and the wood volume was at $383.9 \times 10^4 m^3$ before 1958. However, the area and wood volume of *Populus euphratica* decreased to 17.5×10^4 hm^2 and

239.7×10^4 m^3 in 1978. After 1978 the area and wood volume was restored to some extent due to improved management, the area of *Populus euphratica* increased to 24.0 $\times 10^4$ hm^2 and 29×10^4 hm^2 in 1984 and 1990, respectively. But the area and wood volume of *Populus euphratica* has still not reached the 1958 level. Meanwhile, grassland area decreased by 13.0×10^4 hm^2 due to the drying up of the watercourse in the lower reaches of the Tarim River. Biodiversity has been severely reduced, and desert has expanded rapidly. Of the local lands 150–200 km^2 turns into desert every year. During the 24 years from 1959 to 1983, the desert area increased from 66.23% to 81.23%, especially in the lower reach of the Tarim River. Stormy weather increases over time. For example, in the Yuli County (located in the lower reach of the Tarim River) the days of sandstorms were 108 days in the 1970s, which was about two times of that in the 1960s. At present, the number of days of sandstorms are 130 days and the days of dust are 180 days. Because of the degradation of the environment, the "green corridor" between the Kuluke Desert and the Taklamakan Desert, the second largest mobile desert in the world, has been shrinking continuously. The no. 218 national highway going through the "green corridor" has been suffering from sand encroachment. Ecosystems in the lower reaches of the Tarim River basin have suffered severe damage. The occurrence of disastrous suspended dust and sand-dust storms has increased markedly, the living environment of humans has increasingly deteriorated, and the area at the lower reaches of the Tarim River has become the most severe ecological disaster region in western China.

MEASURES FOR UTILIZING THE WATER RESOURCES

Water is the essential factor for sustainable development of ecosystems and the economy in the Tarim River basin. To restore the ecosystems in the Tarim River drainage area, the severe ecological and environmental problems must be overcome. This requires coordination of development for both ecosystem and the economy; taking "the whole, the coordination, the circulation, the regeneration" as the starting point; implementing integrated water resources management in the basin; using market and government administration to establish a reasonable water resource division plan and adjustment mechanism for the water market; realizing the integrity of water process and the sustainable use of water resources in the basin; applying safety control of water resources for the sustainable development of the local ecosystems and the economy.

(1) The unified management of water resources should be implemented in the Tarim River watershed, and the barriers between the multiple socio-economic units should be broken in the formation and utilization of water resources. A relatively steady water distribution plan needs to be worked out based on the multi-year average discharge and the water requirements for the ecological and economic development in the Tarim River watershed.
(2) The permission system of water diversion and the supervision system of water quality should be strictly implemented so as to balance the water resources and increase the water quality in utilization. The market regulation mechanism should be established and introduced for controlling the water consumption for the

economic construction so as to increase the economic efficiency of the spatial distribution of water resources by compensated utilization.

(3) To guarantee the integration of the system, researchers and administrators should rebuild or decommission the plain reservoirs with severe water loss and poor benefit, and complete the water channeling and water supply systems in irrigated areas of the three source tributaries. Meanwhile, it is suggested to promote water saving and gain an annual volume of feeding water of 46.5×10^8 m^3 from the three source tributaries into the mainstream of the Tarim River.

(4) To scientifically plan the drainage systems, construct and complete the farmland drainage systems in the irrigated areas of the source tributaries and the mainstream of the Tarim River, to strictly restrict the volumes of wastewater and high-mineralization water from the irrigated areas into the Tarim River. The 138 intakes at the upper and middle reaches of the mainstream of the Tarim River should be stopped in a planned way. All the intakes without permission and the temporary intakes must be eliminated. It is suggested to build permanent sluice gates for reducing water loss and to change the uncontrolled water diversion into the planned water consumption.

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