CHINESE GEOGRAPHICAL SCIENCE
Volume 10, Number 1, pp. 52- 60, 2000
Science Press, Beijing, China

CHARACTERISTICS OF WATER TRANSFORMATION AND ITS EFFECTS ON ENVIRONMENT IN THE ARID REGION —A case study in Alar irrigation region of Xinjiang, China

LI Xin, SONG Yu-dong, NIAN Fu-hua
(Xinjiang Institute of Ecology and Geography, the Chinese Academy of Sciences, Urumqi 830011, P. R. China)

ABSTRACT: The characteristics of water balance in arid regions is that the streams are formed in mountain area and continuously evaporates and infiltrates in the process of flowing to plain area, streams finally disappear in the desert or flow into the lakes, which are the low reaches of the rivers. But the distribution and transformation of water in Xinjiang, China have changed under the influences of human activities. The influences of human activities take place in a short time and regionally, especially in arid land where water is the key factor of environment. Water inside of oasis has increased, and water out of oasis or at the lower reaches of the river has decreased. Human activities have caused the environment changes in both positive and negative aspects by changing the circulation and distribution of water. Under the influence of human activities, oases in Xinjiang have expanded, meanwhile some lakes have contracted desertification is serious, natural vegetation has declined and natural environment out of oasis has degenrated.

KEY WORDS: arid region; water transformation; human activity; environment

CLC number: P941. 71 Document code: Article ID: 1002-0063(2000)01-0052-09

1 CHARACTERISTICS OF WATER TRANSFORMATION IN ARID LAND

The regularities of water transformation in stream forming areas and stream disappearing areas are very different. In stream forming areas, water transformation is mainly from precipitation, snow melt and ice melt water to surface water and groundwater, and groundwater to surface water. Groundwater in mountain area is mainly crevice water, aquifer receives water from ice melt, snow melt and rainfall. Because river course in mountain area cuts down deeply, hydrological system is densely covered, which is suitable for groundwater to drain into rivers. Even though some rivers flow through large structural valleys, river water and groundwater transform for times, but the groundwater is generally transformed to surface water in mountain areas. Ground water feed is around 22% of the total runoff in the river.

In the stream loss area, water transformation is mainly that surface water seeps into ground. When the stream flows out of mountain areas, most of river water directly seeps into ground except evaporation. Water transformation in plain areas can be divided into two processes: first process is that the water table in river is 10- 200 m higher than groundwater when surface water flows out of mountain areas and reaches pluvial fan and alluvial fan. Riverbed and the layer below it is combind by pebble, which is good for water to permeate, and heavy seeps into ground. On the other hand, surface streams first seeps into ground in the structural basins in front of mountains, and

Received date: 1999-04-12
Foundation item: Under the auspices of the National Natural Science Foundation of China(49771009).
Biography: LI Xin(1940-), male, a native of Anhui Province, professor. His research interest includes water resources.

flows in the aquifer with large discharge. Then it seeps out to the surface as spring at the edge of alluvial fan and pluvial fan affected by landform and geological conditions. Therefore, the water feed to groundwater in front of mountain in arid area could be estimated according to the discharge and seepage loss of water in rivers or canals. The natural groundwater feed in the piedmont plain is 24.16 km^3 in whole Xinjiang①.

Some small rivers disappear when flow out of mountains because of seepage loss of water. Other rivers could flow into the plain, but seepage loss of water in the alluvial fan and pluvial fan is about 30% – 60% of the total runoff of rivers. For example, annual runoff in the Kaqun Hydrological Station of the Yarkant River (one of the tributaries of the Tarim River in south Xinjiang) is 6.45 km^3. But it is only 3.45 km^3 in Yiganqi Hydrological Station 80 km from Kaqun in the lower reaches, seepage loss is 31% of the annual runoff. Seepage loss in Hotan River (one of the tributaries of the Tarim River) is 11% – 23% in flood season, and is 82% – 85% in dry season. Annual seepage loss is 29% on an average.

When rivers flow to the lower part of pluvial fan with fine soil, water table rises because of the lower elevation and poor permeable soil. Rivers cut down the aquifer, therefore water table in the edge of pluvial fan flows to the river as spring. In the plain area, water of some rivers is mainly come from spring and groundwater in arid land.

At the piedmont plain, when water resources finished the transformation of surface water– groundwater– surface water, it may begin the second transformation if there are structural basins in the lower reaches of rivers. However, water is less and less after the process of transform. Spring water is also getting less and less down to disappearance. Finally little water in rivers flow to the destination of river in the lower land or lake to consume by evaporation or seep into ground. That is the whole process of water circulation of inland rivers.

2 THE RELATIONSHIP BETWEEN WATER TRANSFORM AND ENVIRONMENT

Water is the most important resource in arid areas, it is not only the basis for the formation, development and stability of natural environment, but also the important part of environment factor. Water resources are related to other factors of environment through the transformation of itself, to act each other and affect each other. Environmental situation and environmental quality are decided by water distribution to a certain extent.

There is sufficient surface water in stream forming areas. Forest and grassland would appear if the climate, landform and soil conditions are suitable. Much of river water seeps into ground in the piedmont gobi zone and water table at the lower part of alluvial fan or pluvial fan is near ground surface. Appropriate water condition is good for the growth of desert vegetation, so the sparse vegetation grows in front of mountains in arid areas. Water conditions there is also the guarantee of oasis formation. When rivers flow to plain areas, water seeps to both sides of a river, and river water will overflow to the sides of a river in flood period to seep into ground. Groundwater can supply water to the vegetation through capillary and roots, so vegetation usually grows beside river in arid areas. However, salt in the soil always moves along with the movement of groundwater. The lowland at the lower reaches of a river is often the collection of water and salt, which is possible to be desert of dried salt land if river water is reduced.

The surface water, which just flows out of mountain areas, is channeled into irrigating canal system and field in the piedmont plain, and transforms into groundwater. Part of water in canal system and irrigating field also seeps into ground. Groundwater transforms into surface water in the front edge of plain as the important water resources for lower reaches. It would be oasis if there is enough water, and it would be desert if there is no water at all. The size of oasis depends on the amount of water, and the stability of oasis depends on water feed affected by natural or human activities.

The effect of water on environment can be divid-

① Xinjiang Water Conservancy Bureau, 1996. Collection of Statistical Data of Water Conservancy in Xinjiang. China.

ed into two types: protogenic effect and secondary effect (TANG, 1992). The protogenic effect is the effect of natural change in a region. Because the changes of natural conditions need a long geological period, it can be considered changeless in a short period and no effect on environment. The river course in the middle reaches and lower reaches of inland rivers moves frequently, it could change the hydrological condition at the lower reaches rapidly in a short time, and could cause the changes of natural environment. The oasis beside old river course would become desert because of water loss, the desert beside present rivers would become oasis. Even some destination lakes of rivers moved to another place, the old lakes became salt shells in lowland.

Secondary effect is the environment change caused by human activities. These are mainly the construction of water conservancy projects and exploitation of groundwater. Exploitation and utilization of water resources takes place in a short time and regionally, especially in arid areas where water and irrigation are the key factors of environment.

3 EFFECTS OF HUMAN ACTIVITIES ON WATER BALANCE AND ENVIRONMENT IN ARID AREA

Xinjiang is an arid area in the center of Asia, water resources are not rich enough and the spatial and temporal distribution is not even since the effects of landform and climate. To meet the demand of water to human life and production in time and space, people developed the activity of water conservancy construction to change water distribution in region and time. Water conservancy projects include building reservoirs, channeling water in different basins, building canals to draw water and exploiting groundwater. Agricultural and forest projects include expanding irrigation area, afforestation, irrigating natural forest and grassland, and drain wastewater away. The above human activities have changed evaporation, seepage and runoff in arid areas, changed the distribution of surface water, soil moisture and groundwater. That means the process of water circulation and water balance to be changed.

Agricultural production in Xinjiang was in a little scale before 1949, water in rivers, especially in large inland rivers was not fully controlled and used. Most river systems and surroundings were in natural state. Since 1950, the effect of human activities on natural water resources has got heavier. Especially in some rivers, water resource system of whole basin has been controlled by human activities in the upper reaches, water distribution in time and space has been changed by water conservancy projects. Artificial waters and oasis intercepted much surface water in the upper reaches, which caused the change of evaporation and the change of original balance between surface water, soil moisture and groundwater. Irrigating agriculture has developed in a large scale with the construction of large water conservancy projects. Increases of channeling water from river caused regional redistribution of river system and water resources. And desert environment and oasis environment related to water resources are also changed remarkably.

(1) Part of river course has been replaced by artificial canal system (FAN, 1996). There were few artificial canals when water utilization was in a little scale, channeled water from rivers was very limited, which has a little effection rivers. When a river flow out of mountain areas, it is separated into a few branches in the alluvial fan or pluvial fan. In the alluvial plain, a river flows to the lower reaches on line, it is separated into several branches in the lower delta of a river. Along with the exploitation of water resources in the upper reaches, water was channeled to the irrigation field when flowing out of mountains. Artificial canal system has been formed in the irrigation area. The more the channeled water in upper reaches, the less the runoff flowing to lower reaches. Some rivers became seasonal rivers, and some rivers are dried up. At the beginning, sub-branches of a river are separated from branch stream, then the branches are separated from trunk stream, finally the trunk stream can not flow to the destination, natural water system was replaced by artificial canal system. Annual channeled water from rivers in Xinjiang is

about 46 km^3, which is about 52% of the surface water resources a year. Irrigation area in Xinjiang has expanded from 1.07 million ha in 1950 to 4.06 million ha in 1996, but the lower reaches of most rivers are dried up now.

(2) Some lakes are replaced by reservoirs (FAN, 1996). There were 150 lakes in Xinjiang in the 1950s, the area of lake was 9000 km^2. Most lakes were terminal lakes in the end of a river, only a few lakes were in the middle of river, such as Bosten Lake and Tianchi Lake. The reservoirs built after 1950 has intercepted river water, which can not flow to the end. The lakes in the end of rivers have changed greatly. Some of them are contracted and some are dried up. Tens of lakes in Xinjiang were dried up in last 40 years, and the area of lakes reduced by 4395 km^2. Continuously drying up and contracting of plain lakes are caused by human activities which changed the regional distribution of surface water. Most of flood and winter stream is drawn into reservoirs, that means some lakes move to the upper reaches, the location of lakes has changed owing to human activities.

(3) Water table has changed. Groundwater in plain areas mainly comes from the seepage of surface streams. Human activities changed the regional distribution of surface water and affected the seepage of surface water into ground, which caused the change of water table and quality of groundwater. Increase of channeled water from river to oasis caused more water seeps into ground, so water table has risen up and the quality of groundwater is desalted within oasis. However, surface water out of oasis is reduced, water table has fell down, and mineralization of groundwater is increased. In some cities where groundwater is used as the main water resources for life and irrigation, water table fell down rapidly.

In the oasis, groundwater is not only from river water, but also from canal water, reservoir water and irrigation water. Original water balance and hydrological geology situation has changed with the increase of seepage water. For example, at Alar irrigating area in the upper reaches of the Tarim River, water table was 4– 6 m before the reclamation. It rose up for 0.3– 0.8 m every year in the first three years after the reclamation, when the water table goes to 1.5 – 2.0 m, evaporation and seepage are basically balanced and water table will not rise up (Table 1). Drained groundwater in horizontal direction increased with the increase of irrigation water. In some places soil was salinized and marshy if drainage water condition is poor.

Table 1 The change of water table in No. 12 Construction Corps since reclamation (FAN, 1998)

Year	Water table (m)	Increasing (m)	Increasing per year (m)	Period
1958	4– 6	—	—	
1961	2.1– 3.7	1– 2.5	0.33– 0.8	1958– 1961
1965	2– 3	0.5– 2.0	0.13– 0.5	1961– 1965
1974	1.5– 2	0.3– 1.9	0.03– 0.2	1965– 1974
1982	1– 2	0– 0.5	0– 0.06	1974– 1982
1995	1.7– 2.7	-0.7– -0.3	-0.05– -0.02	1982– 1995

4 THE INFLUENCES OF OASIS CONSTRUCTION ON WATER BALANCE

4.1 Hydrological Situation in Alar Irrigation Region

Alar irrigation region is a new oasis located in the Tarim Basin, and water for irrigation there is from the Aksu River. The head of the Aksu River in high mountains is in the Tianshan Mountain, annual precipitation is up to 600 mm. Annual precipitation at the hydrological stations of the two tributaries of the Aksu River in the mountain foot is 160.1 mm and 118.7 mm, but it is only 54 mm in the plain area (Fig. 1). Evaporation and seepage are heavy and it is impossible to form surface flow in the plain area, so plain area is the steam disappearing area.

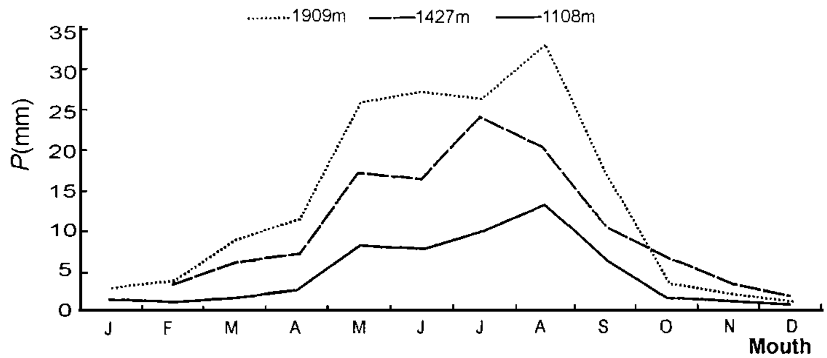

Fig. 1 Monthly precipitation in the Aksu River basin with different elevations

Most of the precipitation in the upper reaches of the Aksu River is snowfall, glacier and snow cover are widespread in mountain areas. Snow melt and glacier melt water is the stable source of the runoff, which is 30% - 60% of the annual runoff of the Aksu River. Yearly change of runoff is little, but monthly change of runoff is great affected by the seasonal change of air temperature and rainfall. Runoff is concentrated in summer and autumn, in flood season, runoff is up to 62% - 68% of the annual runoff.

The formation and distribution of groundwater in Alar area is related closely to the regional geological structure, landform, hydrology and climate characters and the type of Quaternary porous deposit. Spatial condition of regional distribution of groundwater is prepared by geological factor, and feed condition of groundwater formation and distribution is prepared by hydrological and climate factors.

The Tarim River is located in the northwest border of the Tarim Basin, it is at the lowest place of the basin. Regional surface water and groundwater flows to it, so the Tarim River is the confluence of the Tarim Basin. Hydro-geological characteristics in both sides of the Tarim River are obviously different because of the difference of ground flow. Groundwater in the north side of the river comes from the Tianshan Mountain and the seepage water at irrigating field. Groundwater flows to the Tarim River from north-west to southeast with the slope of 0.62% - 0.68 ‰ of flow surface. Water table is generally 2- 3 m with the change of landform. Salt content in groundwater is getting more and more because of evaporation and concentration of groundwater from feed zone piedmont plain area. Mineralization of groundwater is generally 5- 10 g/L, type of hydrochemistry is Cl·SO_4- Na·Mg and Cl·SO_4- Na. According to the investigation, soil in the 1-m-layer deep from ground surface contains 1.3% - 9.8% of salt. Soil is heavy Saline. So there are many salt ponds and salt swamps. In the zone of 300- 500 m wide along the banks of the Tarim River, mineralization of groundwater is decreased because of the seepage of river water. Mineralization is 1- 3 g/L or 3- 10 g/L.

Water table in the south side of the Tarim River is decreased with the distance from the river before land reclamation. It is 1- 3 m along the line zone 1- 2 km from the river, and is 7- 8 m farther from the river. The farther from the river, the heavier the mineralization of groundwater. Groundwater comes from river and consumed by evaporation.

With the expansion of irrigation area after land reclamation, much water seeped into ground from canals and farmland to replenish groundwater. Seasonal variation of water table is based on irrigation periods, so original movement of water table has been changed.

Aquifer in Alar area generally consists of thin sand, extreme fine sand and powder sand. There is no obvious impermeable stratum. Water quality of shallow groundwater in the sides near the river is good, but deep groundwater is mineralized. However, the irrigating field near Aksu Water Balance station (AWBS) is at the upper reaches of groundwater flow, groundwater is saline on the whole because it is hardly affected by river water. But the salt water in the upper layer is difficult to seep into lower layer because of the existence of the relative impermeable layer to water. Quality of deep groundwater with pressure is good.

4.2 Irrigation in Oasis and the Change of Groundwater Quality

There is much salt in the soil at Alar area, salt content of soil in the layer 1 m below ground surface is up to 20– 80g/kg. In the beginning of land reclamation, water table was 3– 7 m, irrigation water brought salt seeped into ground, salt content of soil near ground surface had decreased. However, along with the rise of water table, groundwater moved to the ground surface to evaporate and to bring salt to ground surface. Surface soil there was saline. Drainage ditch system has been built in the irrigation field to drop water table and to prevent soil salinization. Mineralization of groundwater has reduced but most of the drained water flows into river or lakes, it joins river water as the irrigation water for farmland in the lower reaches. So the river water quality has changed too.

The Aksu River basin is an important area in the southern Xinjiang. The quantity and quality of water from the Aksu River to the Tarim River has changed greatly affected by land reclamation. Annual runoff from the Aksu River to the Tarim River is 3.38 km^3, and 39.9% of it is drained water from farmland and from groundwater with high mineralization, which is 1.35 km^3 a year. The mineralization of drained water from the old irrigation area (was reclaimed over 50 years) is 1– 3 g/L, and it is 3– 15 g/L drained from new irrigation area. For instance, Shajingzi area in Aksu region was reclaimed in the 1950s, annual channeled water from the Aksu River is 420 million m^3, and drained water to the Tarim River pass Aiximan Lake is 100– 200 million m^3. Mineralization of drained water is 5.7– 8.7 g/L, and the highest one is 11.45 g/L. Salt from farmland to the Tarim River within drained water is 1.05– 1.40 million ton per year.

5 INFLUENCES OF HUMAN ACTIVITIES ON WATER BALANCE AND ENVIRONMENT

5.1 Redistribution of Water

The runoff in the Tarim River was in a natural state in historical period to irrigate forest and grassland along the river course, and seeped into ground in flood season. Part of the runoff flows to depression to form lakes or marshland. With the development of agriculture, river water was channeled into farmland for irrigation. Agriculture and irrigation have developed very rapidly since 1950, large area of waste land has been reclaimed at the plain area. So that much of river water has been channeled into farmland, distribution of water has changed. Annual runoff in whole Tarim River basin is 19.66 km^3, 80% of it (15.81 km^3) was directly channeled into oasis for irrigation. In the Yarkant River, 92% of the runoff is used for agriculture, and 64.5% of the runoff is used for agriculture in Aksu River.

Annual precipitation is 45– 50 mm in Alar area. Water demand for natural vegetation in plain areas was mainly supplied by groundwater, which is from river water. Water table was 3– 7 m before the reclamation. After the reclamation, quantity of irrigation water has doubled and redoubled, and water table has risen to 1– 3 m.

The irrigation scale in Alar area has gradually expanded after 1950. In the beginning of the 1950s, irrigation water was directly channeled from river to Alar area. With the construction of channel system and irrigation canal system later, much of river water was channeled into farmland. Quantity of surface water has increased in oasis but has decreased out of oasis. Average quantity of irrigation water is 12 688 m^3/ha in Alar area, which means that 1268.9 mm of surface water is added to farmland, which is equal to annual precipitation in semi-humid zone. Runoff in the river, especially in the lower reaches of the river, is gradually decreased. For example, annual runoff in Alar Hydrological Observation Station in the upper reaches of the Tarim River has decreased for 20% in last 40 years, and in Kala Observation Station in the lower reaches of the Tarim River, it has decreased for 80%.

Not only has the surface water increased and water table rose within oasis, but also appears marshland. The stream of the Tarim River has run dry for years in the lower reaches, water table there has fallen from 3–6 m to 6–10 m. Lakes at the lower reaches of the river have dried one by one, and reservoirs are built in the plain area at the upper reaches. That means artificial lakes have appeared. Water area of reservoirs in Alar irrigation area is up to 233.6 km^2; storage capacity of water is 0.322 km^3. The redistribution of water is mainly: quantity of water has increased within oasis, but it has decreased out of oasis, water consumption has increased in the upper reaches of the Tarim River, but runoff in the lower reaches has reduced.

5.2 Expansion of Irrigated Oasis and Improvement of Oasis Eco-environment

Alar irrigation area is located in the alluvial plain of the Aksu River and the Yarkant River to the north of Taklimakan Desert. The upper area of the Tarim River was desert with bush and primeval diversiform-lived poplar before reclamation. From 1952 to 1956, 1437 ha of wasted land were reclaimed to be farmland. A canal in the north bank of the Tarim River was built in 1958 to channel river water for irrigation. Up to 1960, 44 000 ha of farmland had built in Alar area, and 156.5 km of trunk canal had built up. Three reservoirs — Shangyou Reservoir, Shengli Reservoir and Duolang Reservoir were built in the irrigation area during the period of 1960–1972. And a sluice gate across the Aksu River was built in 1972, which is a good condition to expand farmland. Up to 1993, cultivation area in Alar irrigation area amounted to 57 000 ha; area of forest was 21 300 ha, 13 100 ha of which was artificial forest. Cultivation area has expanded rapidly since 1990, in 1996, irrigation area in Alar is 66 000 ha (Fig. 2). After the construction for 40 years, Alar irrigation area has become the largest new oasis with stable agricultural eco-environment in the Tarim Basin.

The original climate, hydrological condition and environment have changed after the formation of oasis. Because of human activities, surface water and groundwater are rich in oasis, conditions of ground surface in oasis are very different from desert, so that special oasis microclimate has formed. Firstly, water surface area has expanded, evapotranspiration from crops has increased. Relative air humidity near ground surface has increased; the highest temperature

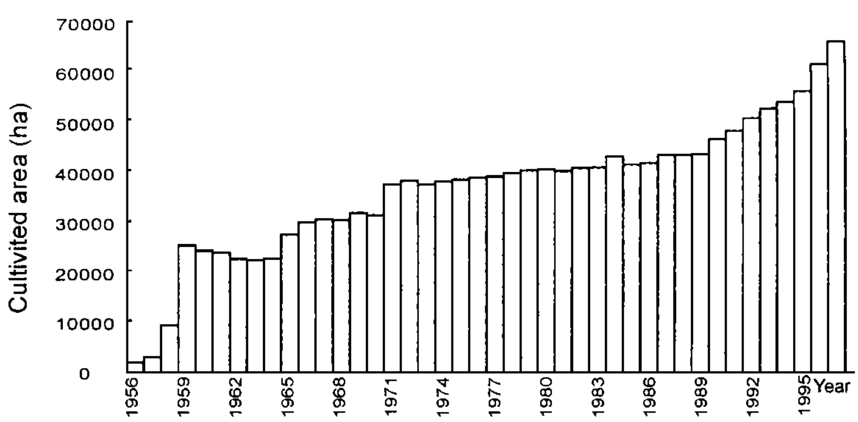

Fig. 2 Variation of farmland area for year in Alar irrigation area

of ground surface has decreased. Original water and heat conditions has changed, new water balance and heat balance formed in oasis. Secondly, the reflection ratio of ground surface in oasis is lower than that in desert, ground absorbs more solar radiation (ZHOU, 1996), changes of air temperature near ground surface in oasis is not so great as in desert. Thirdly, dense vegetation in oasis, especially the shelter-forest of farmland can resist wind and prevent earth from erosion by wind (LI, 1996), and to reduce the dust storm.

5.3 Environment Change in and out of Oasis

Artificial oasis has expanded because much river water has been channeled into oasis, environment in inside of oasis has improved. However, there is seriously lack of water out of oasis, vegetation cover is sparser. Surface soil is very dry and porous, so that dust is liable to float in the sky in windy days. According to the observation in AWBS, there were 39.5 days with float dust year on an average before 1980, but there were 75.9 days from 1981 to 1993. (LI, 1996).

Soil in Alar irrigation area was mainly saline before the reclamation, salt content in the soil 1-m deep from ground surface was 20– 80 g/kg. After irrigation and drainage groundwater away for years, most of the farmland reduced saline soil. Water table has risen after irrigation and salt content of groundwater is less, mineralization of water is getting lower. For instance, salt content in the soil 1-m deep from ground surface at No. 12 Construction Corps irrigation area in the south side of the Tarim River was 36.2– 76.1 g/kg before 1958 when the land was reclaimed, and had reduced to 1.26– 5.1 g/kg up to 1992. Water table had raised from 5m under ground surface to 1.7 m – 2.7 m and mineralization of groundwater had reduced from 11.39– – 35.89 g/L to 1.368– 6.199 g/L (FAN, 1998).

With the construction of irrigation canal system and drain canal system, salt content of soil and mineralization of groundwater have reduced. The drained saline water from irrigation area flowed into rivers, which made the rapid increasing of mineralization of water in the Tarim River. Mineralization of river water at Alar Hydrological Observation Station is over 1 g/L in the 1990's (Table 2). According to the investigation, 707 million m^3 of saline water flows from Alar irrigation area to the Tarim River per year, which contains 3.7 million tons of salt in the drained saline water (FAN, 1998).

Table 2 Monthly change of mineralization of river water in Alar Hydrological Observation Station (g/L) (FAN, 1996)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1976												0.895
1977	0.751	0.540	2.560	4.862	5.462	0.440	0.640	0.530	1.440			
1984										1.972	4.130	0.054
1985	0.976	0.848	1.216	4.016	5.152	5.964	1.276	0.664	1.520	5.028	1.760	1.266
1986	0.932	1.340	3.412	4.823	4.694	6.036	0.463	0.469	3.804	1.824	2.924	1.580
1987	0.976	0.863	3.208	4.560	6.640	4.480						
1991	1.210	1.730	2.240	5.760	4.570	1.850	3.400	1.120	5.990	1.980	5.640	2.870

Water quality of the reservoirs in the Tarim River basin was affected by the mineral water of the Tarim River. Mineralization of water in most reservoirs along the Tarim River is over 1 g/L, and it is higher in the lower reaches than that the upper reaches.

REFERENCES

FAN Zi-li, 1996. *Influences of Land Use to Ecology and Environment and the Countermeasures in Xinjiang* [M]. Beijing: Meteorological Publishing House, 82– 129. (in Chinese)

FAN Zi-li, 1998. *Water Resources, Environment and Sustainble Development of Tarim River Watershed*[M]. Beijing: Science Press, 79 – 84. (in Chinese)

FAN Zi-li, JI Fang, WANG Rang-hui, 1998. *Study on the Evolution of eco-environment and Sustainable Development in Tarim River Watershed*[M]. Beijing: Environment Science Press of China, 188– 190. (in Chinese)

LI Xin, 1996. Characteristics of desert climate in the northern part of Tarim Basin[J]. *Arid Land Geography*, 19(1). 53– 57. (in Chinese)

LIU Chang-ming, REN Hong-zun, 1988. *Water Transference — Experiment and Calculated Analysis*[M]. Beijing: Scien ce Press, 1– 15. (in Chinese)

MARTINEZ-Mena M. *et al.*, 1998. Factors influencing surface runoff generation in a Mediterranean semi-arid environment: Chicamo Watershed, SE Spain[J]. *Hydrological Processes*, 12(5): 741– 754.

SHARMA E., S. C. Rai. 1998. Comparative assessment of runoff characteristics under different land use pattern within a Himalayan watershed[J]. *Hydrological Processes*, 12(13– 14), Land use/cover special issue: 2235– 2248. TANG Qi-cheng, 1992. *Hydrology and Utilization of Water Resources in the Arid Land of China*[M]. Beijing: Science Press, 178– 179. (in Chinese)

ZHOU Hong-fei, LI Yan, 1996. The characteristics of soil moisture budget in oasis farmland[J]. *Arid Land Geography*, 19(3): 66– 71. (in Chinese)