Research article

Influences of Agricultural Irrigation on Regional Salinity Balance in Arid Areas of Northwestern China

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Received 15 December 2011 Accepted 2 April 2012 (* : Corresponding Author)

Abstract It is widely recognized that saline transfer and distribution are important considerations in arid areas, where salinization is prevalent, not only for sustainable agricultural production but also for regional environmental conservation. This study discusses the saline balance of the irrigation area in the Tarim River basin of northwestern China. Water quality was investigated at irrigation and drainage channels from 2007 to 2011. The regional water balance was calculated using the water supply and drainage volume data owned by the Xayar Water Management Office and its branches. Comparing the quality of irrigation and drainage water, the concentration of cations (except K^+) in drainage water was found to be 15 times more than that in irrigation water. Based on the estimation of water balance, it was confirmed that only approximately 5% of the irrigation water flowed out as drainage water. The remaining supplied water is used for evapotranspiration, and groundwater recharge was considered. In addition, the output load of K^+, Ca^{2+}, and Mg^{2+} was lower than the input load. However, the output load of Na^+ increased by approximately 20% of the input load. This indicates that continuous irrigation does not necessarily promote saline transfer and that salinity is retained in groundwater or soil in this region. Finally, because of the substantial exhaustion of Na^+, it is necessary to consider the influence of increased levels of Na^+ in downstream drainage areas.

Keywords salinization, saline movement, irrigation and drainage, water balance, water quality

INTRODUCTION

In arid areas where salinization is prevalent, an important question to consider is where the salinity moves. If saline simply moves downstream through drainage, then water containing saline nourishes irrigated areas and natural vegetation in the downstream areas. If saline does not move downstream through drainage, it may accumulate in the groundwater or soil and lead to problems in future groundwater use. Thus, it is widely recognized that saline transfer and distribution are important considerations in arid areas, where salinization is prevalent, not only for sustainable agricultural production but also for regional environmental conservation.

While many studies have described soil salinization and prevention of salinization in the field (Chen, 2010, Barrett-Lennard, 2002), research concerning saline movement and saline balance over wide areas, particularly in arid areas such as the Tarim River basin, is lacking. In the Tarim River basin, soil salinization has occurred in approximately 80% of the irrigated area (Yamamoto et al., 2006). Consequently, it is necessary to examine saline movement and saline balance not only at the field level but also over wide areas in this region.

METHODOLOGY

The study was conducted at the Xayar County in Xinjiang, northwest China (Fig. 1). Xayar County is located in the Ugen River basin. Ugen River is a branch on the upper stream of the Tarim River. The county population is approximately 180,000 and its area is 31.97×10^3 km^2. The main local crop is cotton and other crops such as wheat and corn. The cultivated area is 0.632×10^3 km^2, where cotton plants cover approximately 50% of the total cultivated area. Irrigation relies mainly on surface water from the Ugen River and ground water is used mainly in cotton and fruit fields for drip irrigation. Annual rainfall is 47.3 mm, potential evapotranspiration is 2000.7 mm and the annual mean temperature is 10.7°C (maximum temperature, 41.6°C and minimum temperature, −28.7°C) (Xayar Government HP).

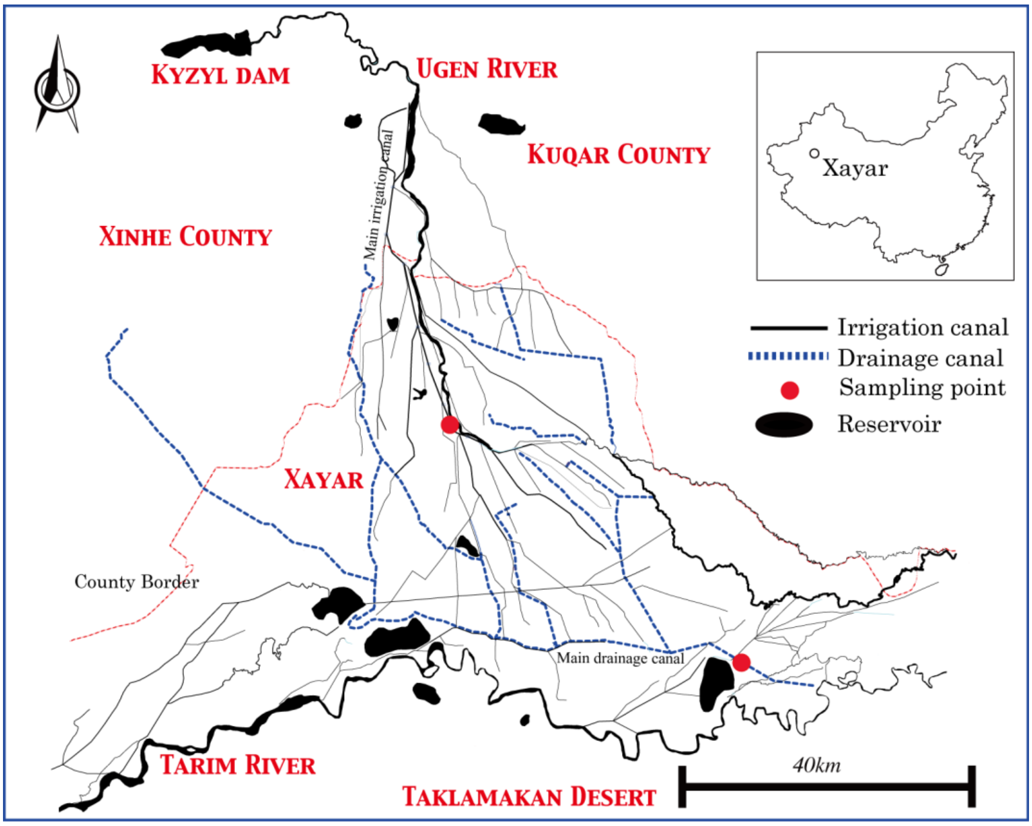

Fig. 1 Outline of Investigation Area

The regional water balance was calculated by using the 2007 - 2009 data of daily water supply and drainage discharge owned by the Xayar Water Management Office. Each discharge was calculated several times a day by flow measurement. Evapotranspiration data was derived from Ge Gao et al. (2007) because it was not available for this site. Water was collected at irrigation and drainage canals several times in 2007-2011 only during which water flowed, and then these samples were analyzed in the laboratory. Electric conductivity (EC) was measured by EC meter (HANNA Instruments) and sodium (Na^+), calcium (Ca^{2+}), potassium (K^+) and magnesium (Mg^{2+}) were analyzed by ion chromatography (SHIMADZU Corp).

RESULTS AND DISCUSSION

Discharge of irrigation and drainage and water balance

To estimate the water balance in Xayar County, the irrigation and drainage discharge data supplied by water management office were used. In addition, the drainage volume flowing through Xayar and Xinhe counties was estimated by multiplying the irrigation distribution rate by the total drainage volume. Irrigation water from Ugen River is distributed to these counties at a constant rate (Xayar, 32.5%; Xinhe, 28.0%; Kuqar, 39.5%) at Longkou headwork located at the upper point of these counties (Abdisalam Jalaldin, 2005) and the drainage discharge was assumed to depend on the irrigation requirement as rainfall runoff has little influence. To estimate evapotranspiration in Xayar County, we multiplied potential evapotranspiration by the constant 0.1. This constant is the ratio of annual actual evapotranspiration to annual potential evapotranspiration during 1971 - 2000 (Ge Gao et al., 2007). Fig. 2 shows the monthly change in irrigation and drainage discharge and Fig. 3 shows the annual water balance in 2007 - 2009.

The largest discharge of irrigation water occurs in March and in summer season because water demand rises during the sowing and growing periods. In addition, irrigation water is required in November for sowing wheat in autumn. The largest discharge of drainage occurs in March and April, decreasing in summer. Drainage discharge is believed to increase when shallow groundwater outflows by thawing of the frozen soil layer. In contrast, drainage discharge is believed to decrease when outflow from shallow groundwater is restricted by soil drying that is a result of increasing evapotranspiration potential in summer.

The water balance in 2007 and 2008 showed the same tendency. However, the supplied water volume decreased in 2009. This reduction is believed to have been caused by decreasing water intake from the river resulting from improved water-conserving irrigation techniques, such techniques being introduced widely to farmers at the beginning of 2007 (T. Yamamoto et al., 2010). Water balance data suggest that approximately 800-1000 mm y^{-1} of supplied water seeps into the ground. Water management office data suggest that water-conserving irrigation techniques have been implemented in 10% - 20% of the total cultivated area. The net water requirement of cotton is 540 mm y^{-1} in this area. If this volume is pumped up from groundwater in the water-conserving irrigation area, we can estimate that 5% - 13% of seepage water was utilized, which is equal to the reduction in water supplied during this period.

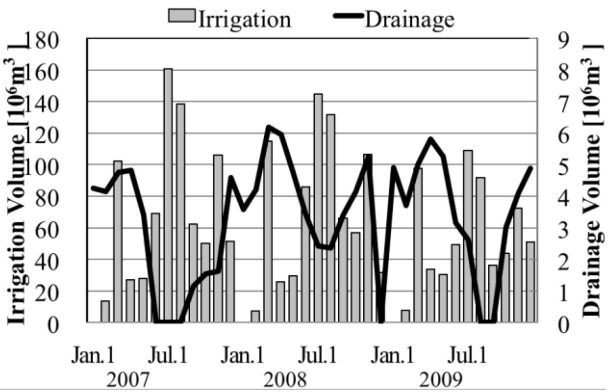

Fig. 2 Irrigation and drainage discharge (2007-2009)

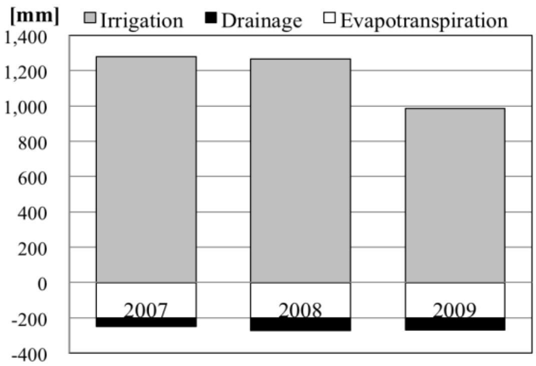

Fig. 3 Water balance (2007-2009)

Water quality of irrigation and drainage water

Table 1 shows water quality of irrigation and drainage water on each sampling day. Changes in EC values were small in irrigation water except for August 2007. Concentration of Na^+ varied considerably, but concentrations of other cations exhibited only small changes. In particular, Na^+ concentrations tended to decrease during summer and increase during winter. EC values of drainage water were stably higher. Changes in cation concentrations in drainage water were lower according to the variation coefficient, but the concentration of each cation measured was higher than that in irrigation water. In addition, the seasonal changes in cation concentrations were not confirmed. When the average quality of irrigation and drainage water was compared, the concentrations of Ca^{2+} and Mg^{2+} in drainage water were found to be 15 times higher than those in irrigation water. Na^{+} concentration in drainage water was also 20 times higher than that in irrigation water. This indicates that the soil in this region is naturally saline or has turned saline because of irrigation with water that became concentrated with salts before running off. In contrast, K^{+} concentration in drainage water was only 4 times higher than that in irrigation water. This is likely because the concentration of K^{+} was lower than that of other cations, and K^{+} in supplied water is absorbed by plants more than other ions because K^{+} requirement for plants is higher.

Sodium adsorption rates (SAR) were measured based on the average concentrations. The SAR of irrigation water was 3.6 and that of drainage water was 19.8. These levels indicate that based on the standards of water quality for agriculture, the risk of soil salinization when irrigation water from the river is used is slight to moderate, but the risk is extremely severe when drainage water is used (Soil Survey Division Staff., 1993, R.S. Ayers & D.W. Westcot, 1994). However, in the lower basin where water shortage occurred, soil salinization might have been promoted because drainage water was used for irrigation.

Table 1 Water quality of irrigation and drainage water

	Irrigation water					Draingae water				
Sampling date	EC ($dS\ m^{-1}$)	Concetration ($mg\ L^{-1}$) Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}	EC ($dS\ m^{-1}$)	Concetration ($mg\ L^{-1}$) Na^{+}	K^{+}	Mg^{2+}	Ca^{2+}
2007/6/6						15.4	1220.1	33.1	349.3	341.0
2007/8/10	0.1	49.3	2.0	ND	6.3	9.2	1271.1	35.0	301.7	264.6
2007/11/25	0.7	117.7	14.6	ND	28.4					
2007/11/26						11.5	1458.5	31.0	354.4	275.0
2008/3/29	0.7	44.8	8.6	28.4	28.0					
2008/3/31						10.0	ND	ND	ND	ND
2008/12/17	0.9	155.3	19.3	11.5	ND	9.5	937.2	80.2	448.2	239.5
2009/6/5						12.4	918.2	124.1	496.6	329.1
2009/8/9	0.6	19.3	7.6	33.8	5.7					
2009/8/10						9.2	1271.1	35.0	301.7	264.6
2010/3/12	0.7	25.0	17.9	33.5	18.8					
2010/3/14						13.7	ND	ND	ND	ND
2010/7/21						12.1	2110.7	22.1	ND	370.5
2010/7/26	0.4	14.5	ND	29.7	3.6					
2010/11/26	0.9	35.2	ND	9.2	55.9					
2010/11/22						11.1	1860.0	18.1	ND	ND
2011/7/27	0.6	171.6	17.3	13.0	16.6					
2011/7/29						18.0	2179.5	76.5	369.7	459.5
Average	0.6	70.3	12.5	22.7	20.4	12.3	1576.1	48.1	386.6	322.4
SD	0.2	61.0	6.5	11.0	17.3	2.6	528.3	37.2	71.9	70.2
Variation Coefficent	0.4	0.9	0.5	0.5	0.8	0.2	0.3	0.8	0.2	0.2

Saline movement and balance

The saline load balance in Xayar district area located in the Ugen River basin was calculated from the difference between input load and output load. Each load is calculated by multiplying the average concentration of irrigation and drainage water by monthly irrigation and drainage discharge. The average concentration was calculated from the values of Table 1. In our examination, it was assumed that input derives only from supplied water for irrigation and output was the outflow through the drainage canal.

Figure 4 shows the monthly change in saline balance. Input loads increased compared with output loads in summer and vice versa in winter. Even when drainage discharge was low, the output load was high because the concentration of drainage water was higher than that of supplied water. The change in saline balance was divided into outflow and retention types (Table 2). Na^+ was outflow type and other cations were retention type. As determined by three year averages, the output loads of K^+, Ca^{2+}, and Mg^{2+} decreased compared with the input loads; however, the output load of Na^+ increased by approximately 20% of the input load. Because the soil adsorptive property of Na^+ is lower than that of Ca^{2+} or Mg^{2+}; plants require less Na^+ compared with K^+; Na^+ poorly retained in this region was assumed to run off. In addition, each load balance tended to decrease. This characteristic of decrease is because the cations retained in this region gradually flow out to drainage canals and that supplied water decreases. In addition, Ca^{2+} and Mg^{2+} loads indicate that continuous irrigation does not necessarily promote saline transfer and that salinity is retained in groundwater or soil in this region. Moreover, it is necessary to consider how Na^+ outflow to downstream areas affects the lower basin and Tarim River at long term.

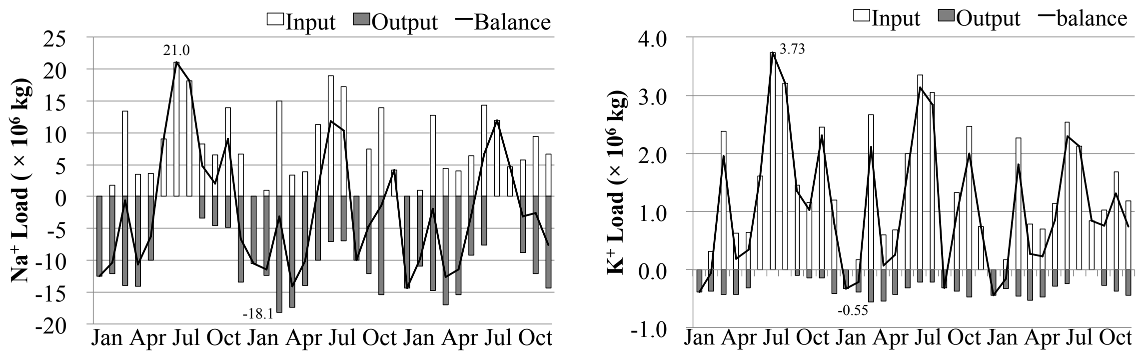

Fig. 4 Monthly change in saline load

Table 2 Saline load balance in 2007-2009

	Na^+			K^+			Mg^{2+}			Ca^{2+}		
	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance	Input	Output	Balance
2007	106	89	17	19	3	16	34	22	12	31	18	13
2008	96	134	-38	17	4	13	31	33	-2	28	27	1
2009	82	125	-43	14	4	11	26	31	-4	24	25	-2
Average	95	116	-21	17	4	13	31	28	2	27	24	4

(Balance = Input - Output, Unit; x10^6 kg)

CONCLUSION

We analyzed discharge water and the quality of irrigation and drainage water and discussed water and saline balance in the Tarim River basin in Xayar County. We found that the saline concentration of drainage water was considerably higher than that of irrigation water. Water balance data showed that approximately 80% of supplied water was seeped into groundwater or soil. In addition, Na^+ runoff from this area was greater than that of other cations and the exhaustion of other cations was smaller than that of Na^+ because Na^+ was not efficiently consumed or retained. Considering the high exhaustion rates of Na^+, it is necessary to consider the influence on downstream areas when developing irrigation strategies in future.

ACKNOWLEDGEMENTS

Xayar County Government, Xayar Water Management Agency and Xinjiang Uyghur Autonomous Region Water Resource Management Bureau supported this research. This study is a part of the academic research (No.21405031) supported by Grant-in-Aid for Scientific Research (B) from Japan Society for the Promotion of Science (JSPS).

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