Environ Earth Sci (2015) 73:2127–2139
DOI 10.1007/s12665-014-3563-4

ORIGINAL ARTICLE

Soil salt and groundwater change in flood irrigation field and uncultivated land: a case study based on 4-year field observations

Xiaoyu Gao · Zailin Huo · Yining Bai · Shaoyuan Feng · Guanhua Huang · Haibin Shi · Zhongyi Qu

Received: 13 January 2014 / Accepted: 21 July 2014 / Published online: 9 August 2014

Abstract Salt transport in soil profile and shallow groundwater changes are significant seasonal response to flood irrigation in arid area. Understanding soil salt and groundwater level change is useful to determine irrigation schedule and agricultural development. In this study, based on observation data at six fixed sites from 2007 to 2010, soil salt and groundwater depths change were investigated in irrigation fields and uncultivated lands of upper, middle and lower reaches in the arid irrigation district of Hetao irrigation district. The results indicated that the fluctuation of soil salinity in each layer in irrigation fields was more frequent, while the soil salinity in uncultivated lands presented a surface accumulation phenomenon. The groundwater level had similar trends in 4 years and the groundwater changed gradually deeper from upstream to downstream. Meanwhile, relationships between soil surface salinity and groundwater depth were various for irrigation field and uncultivated land. Furthermore, the groundwater recharge and evapotranspiration were calculated with water table fluctuation method. In all the crop growth periods, the influence of groundwater recharge on evapotranspiration was significant. For the irrigation fields, the mean contributions of groundwater to evapotranspiration of 4 years in upper, middle and lower reaches were 25.57, 11.96 and 15.23 %, respectively, while the values were 53.92, 21.61 and 36.84 % at the uncultivated land, respectively. The results can contribute to determine the water resources management plan for sustainable development of the irrigation district with shallow groundwater.

Keywords Soil salt · Groundwater levels · Groundwater charge · Irrigation field · Uncultivated land

Introduction

The problem of soil secondary salinization is still outstanding in the district with shallow groundwater in the world. Understanding soil salt and groundwater level change is useful to determine irrigation schedule and agriculture development.

The Hetao irrigation district is a typical, arid area with shallow groundwater and soil salinization with irrigation water supplied from Yellow River. Due to severe water scarcity, various water-saving measures including lining of main, sub-main and distributor canals have been implemented in the irrigation district since 2000 (Wang 2002; Cai et al. 2003; Wang et al. 2005). The application of these water-saving measures leads to a decline of the groundwater table that controls the water logging and salinity. The Hetao district is primarily agricultural; hence the deeper or shallower groundwater of this district may affect water stress on plants. Soil salinization caused by agriculture is a serious environmental problem (Dehaan and Taylor 2002; Verma et al. 1994; Masoud and Koike 2006; Yu et al. 2010; Szabolcs 1989); therefore, understanding of the dynamics of water and salt is of significance for sustainable

X. Gao · Z. Huo (✉) · Y. Bai · G. Huang
Centre for Agricultural Water Research in China, China Agricultural University, No. 17, Qinghua East Road, Haidian, Beijing 100083, People's Republic of China
e-mail: huozl@cau.edu.cn

S. Feng
College of Water Science and Engineering, Yangzhou University, Yangzhou 225009, People's Republic of China

H. Shi · Z. Qu
Inner Mongolia Agricultural University, Hohhot 010018, People's Republic of China

agriculture irrigation. Affected by precipitation, irrigation and evapotranspiration, the fluctuation of groundwater level and soil salt is very complex in Hetao irrigation district with shallow groundwater and salinization problems. Irrigation is essential for crop cultivation in arid region in order to increase the water availability in the soil and to leach a fraction of accumulated salts. Again, autumn irrigation is a particular irrigation mode in the Hetao irrigation district, which can leach accumulated salt and store water for next spring (Feng et al. 2005).

Soil salinity is a limited factor to crop growth, especially in shallow groundwater land. Farifteh et al. (2006) presented a conceptual framework on soil salinity with a method of remote sensing, solute modelling, and geophysics. Wang et al. (2004) used SWAP model to analyze the water flow and salt transport for different water table and irrigation scenarios. The HYDRUS-1D was used in Zeng et al. (2014) in Hetao irrigation district, which found that increases in irrigation amount could accelerate salt leaching. Peng et al. (2012) found that soil salt only leached to deeper layers in a short time after autumn irrigation and it was mainly discharged from fields during early freezing period in Hetao irrigation district. Liu et al. (2013) reported that the dissolved concentrations in the soil profile increased significantly when groundwater was used for infiltration as compared to the use of surface water. By analysis of satellite-based, remote-sensing images, Yu et al. (2010) indicated that groundwater depth was the major controlling factor for the regional soil salinity. Metternicht and Zinck (2003) adopted remote sensing to analyze the spatial distribution and temporal changes of the soil salinity. Xu et al. (2010) referred that the decline of groundwater level caused by water-saving measures favored salinity control through analyzing the temporal and spatial dynamics of the groundwater table. Wang et al. (2000) investigated the water and salt transport features for saline soil through drip irrigation under film and found that the increase in irrigation water would expand the standard district for the normal growth of plants. Jia et al. (2013) analyzed the groundwater balance from 1991 to 2010 in Yichang irrigation sub-district and the results showed that the groundwater level had dropped 0.74 m.

In the shallow groundwater district, the contribution of groundwater to evapotranspiration could not be ignored (Lerner et al. 1990). Some studies showed that for field with groundwater from 0.7 to 1.3 m, the contribution of groundwater to evapotranspiration of maize was 15.69 % (Yang et al. 1999). Wang and Hou (2006) also indicated that the contribution of groundwater accounted for a large proportion of evapotranspiration in shallow groundwater field. In a former study, Ragab and Amer (1986) took two independent procedures of which the first was a computer model based on Darcy's Law to calculate the capillary flux and the second was based on the soil-water balance to estimate evapotranspiration and to determine water table supply through capillary rise to the crop water requirement. It was found that the water table contribution estimated by the two procedures was both in the range of 19–22 cm, which amounted to about 40 % of the total ET over the 75-day growth period with groundwater depth about 0.5 m. Babajimopoulos et al. (2007) found that the specific field conditions about 3.6 mm/day of the water in the root zone originated from the shallow water table amounting to about 18 % of the water, which was transpired by the maize with the water table observed at a mean depth of 0.58 m below soil surface. With lysimeter experiments, Kahlown and Ashraf (2005) found that with the water table at 0.5 m depth, wheat met its entire water requirement from the groundwater and more than 80 % of sunflower's required water was absorbed from groundwater. Similarly, as Wallender et al. (1979) said, the studies conducted to evaluate the contribution of groundwater to evapotranspiration could develop an irrigation schedule that made the water resources used effectively. Therefore, studying the contribution of groundwater to evapotranspiration district is significant for making reasonable irrigation system and reducing the secondary salinization in the area with shallow groundwater.

In order to explore these issues further, this paper intends to (1) clarify the soil salt and groundwater change in irrigation field and uncultivated land with a 4-year field experiment. Furthermore, (2) estimate the contribution of groundwater to evapotranspiration.

Materials and methods

Study area

The Hetao irrigation district with a design area of 11.6×10^3 km^2 is one of the largest irrigation districts in China. The district, surrounded by the Lang Mountain, the Yellow River, and the Ulan Buh Desert, is located in the west of Inner Mongolia, China. The district consists of five irrigation areas, i.e., Ulan Buh, Jiefangzha, Yongji, Yichang and Wulate. The Yellow River at the south of Hetao irrigation district is the main source of water for agricultural irrigation with annual water consumption of about 47.89×10^8 m^3 (Fig. 1).

The region has a typical arid and semi-arid continental climate and the soil is mainly composed of sandy loam (Table 1). The region is cold with less snow in winter, and high temperature and drought in summer. The experimental sites are located at the average elevation of 1,038.14, 1,037 and 1,013.97 m, respectively, in upstream, midstream and downstream. The average slope of the study area is

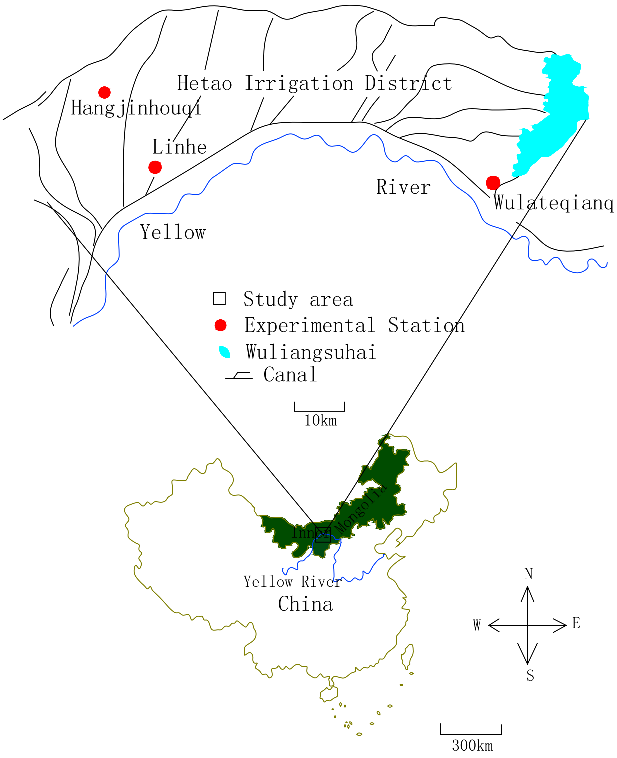


Fig. 1 Location of the study area

1/4,000–1/5,000. Annual potential evaporation of 1,938 mm creates a need for irrigation throughout the crop growth season. In comparison to the high potential evaporation, the average annual precipitation of only 136 mm has little and almost no influence on crop water supply (Li et al. 2012). In this region, the groundwater is shallow with the average depth of 1.46 m in the period of crop growth from May to November. As a result, the soil salinization is very serious and is the main factor hindering agricultural development in the irrigation district.

As with most areas of China, the rainfall occurs mainly in June, July and August, while the crop growth period is from May to October in this region. During the period, the temperature and precipitation are suitable for crop growth (Fig. 2). Wheat, maize and sunflower are the three main crops, which occupy about 70 % of the total planting area in this irrigation district. The main irrigation method is flood irrigation with average amount of 8,000 m^3/ha in crop growth period. The irrigation schedules of different crops are listed in Table 2. It was noticed that there was an autumn irrigation with average amount of 2,600 m^3/ha after the harvest of crops and the irrigation amount almost made up the one fourth of irrigation water. The aims of the autumn irrigation are to leach the accumulated soil salinity within crop growth period and to store up water in soil for the next crop planting.

Water and salt data of soil and groundwater

For investigating the dynamics of hydrology and salt change in soil, three regions, which were called Hanghouqi, Linhe and Qianqi distributed in upper, middle and down streams of the irrigation district, respectively, were selected as detailed study areas. Furthermore, there were two monitoring sites, respectively, located in irrigation field and uncultivated land without vegetation in each area. The uncultivated lands, which were distributed among the irrigation fields, could adjust the salt of near irrigation land. The temporal changes of soil water and salt content and groundwater levels were monitored.

A total of six sites which were monitored for the soil water and salt were located in irrigation field and an uncultivated land in upstream, middle stream and downstream, respectively. At each sampling point, samples were taken from five layers: 0–20, 20–40, 40–60, 60–80 and 80–100 cm depth. The water content was measured by TDR (TRIME-T3, Germany) every 10 days from April to October in 1 year, which was calibrated by soil samples. The soil salinity was measured by earth-fetching with earth boring auger every ten days from April to October in one year. The soil samples were mixed with water according to the proportion of 1:5 to monitor the value of EC. The EC values of three adjoining soil samples were averaged on every layer. The groundwater level was also measured by GSM automatic monitor (ZKGD2000-M, China) at 10 days interval in 1 year and the groundwater salt was measured by water taking at 1 month interval from April to September in 1 year. Totally, 4 years of data from 2007 to 2010 were used in this study. It was found that the average groundwater depth was 1.20, 2.22 and 4.77 m, respectively, in the upstream, midstream and downstream with increasing trend from 2007 to 2010.

Estimation method of groundwater recharge or discharge

Groundwater recharge/discharge is a key component in water and salt budget in irrigation district. Accurate estimation of groundwater recharge/discharge is essential for proper irrigation water management. In previous researches, a great deal of methods had been used to estimate recharge/discharge (Simmers 1988; Simmers et al. 1997; Sharma 1989; Healy and Cook 2002). In this study, groundwater horizontal flow could be ignored because of the shallow groundwater and small hydraulic gradient of groundwater. Due to the limited groundwater-level data, the water table fluctuation (WTF) method was chosen to estimate the groundwater recharge/discharge in the whole period of crop growth (Eq. 1).

$$R = S_y \Delta h \tag{1}$$

Table 1 Soil properties of observation sites in upstream, midstream and downstream of the study area

	Upstream		Midstream		Downstream	
	0–40 (cm)	40–100 (cm)	0–40 (cm)	40–100 (cm)	0–40 (cm)	40–100 (cm)
Bulk density (g/cm^3)	1.52	1.46	1.60	1.53	1.40	1.30
pH	8.94	8.83	7.30	7.27	7.8	7.9
TDS (g/100 g)	0.084	0.092	0.068	0.081	0.066	0.069
Sand (%)	15.8	14.9	6.38	11.29	14.92	14.92
Silt (%)	68.2	72.77	69.68	78.98	75.07	75.07
Clay (%)	16	12.33	23.94	9.73	10.01	10.01

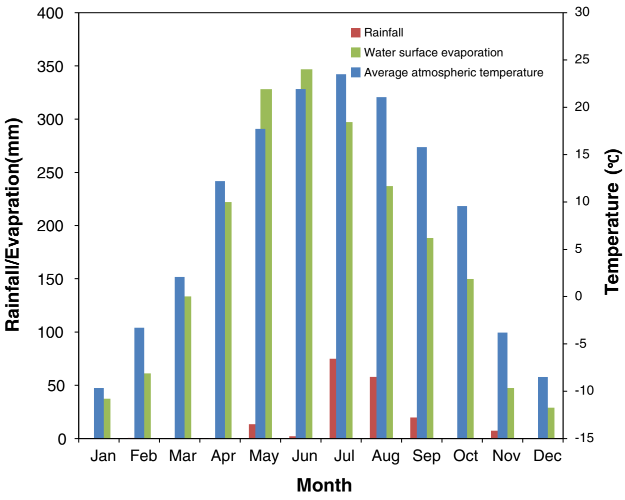


Fig. 2 The meteorological data of Hetao irrigation district

Table 2 Total irrigation amount for different crops within growth stage

Study area	Crop name	Total irrigation amount (m^3/ha.)
Upstream	Maize	3,598.20
	Oil (sunflower)	1,799.10
	Sunflower	2,623.69
	Autumn irrigation	2,848.58
	Spring irrigation	1,349.33
Midstream	Maize	2,998.50
	Sunflower	2,998.50
	Autumn irrigation	2,100
Downstream	Maize	2,893.55
	Oil (sunflower)	974.51
	Sunflower	974.51
	Autumn irrigation	2,250

where R is the groundwater recharge or discharge, S_y is specific yield, Δh is change of water table within a growth period in this study.

The ET is the main motive force for the root water uptake and crop growth. The calculation of ET is conducive to obtain the water use efficiency (WUE) and provides the theoretical basis for water-saving. The water balance method is the most basic and straightforward and is used for ET in this study (Eq. 2).

$$\begin{aligned} W_t - W_0 &= P + I + R - ET \\ \Delta W = W_t - W_0 &= H * (\theta_t - \theta_0) \end{aligned} \tag{2}$$

where W_0 and W_t are water storage at the time of initial and t-th, respectively, P is precipitation in the period, I is irrigation, R is groundwater recharge, ET is the evapotranspiration, H is planned moisture layer depth (a value of 0.5), m, and θ_0, θ_t are volumetric water content at time of initial and t-th, respectively.

Results and discussions

Soil salt temporal change and accumulation in soil profile within the crop growth period

Due to the shallow groundwater, arid climate condition and particular irrigation mode (autumn irrigation), which can leach the accumulated salinity and store water for next spring, the dynamic change and accumulation process of soil salt had special features. To investigate salt change along soil deep, soil profile of 0–100 cm was divided into three layers: surface soil (0–20 cm), root zone (20–60 cm) and deep soil (60–100 cm). From Figs. 3 and 4, it was found that the change trends of soil salinity were similar in upstream, midstream and downstream, but the extent of change in the soil salinity was different among surface, root layer and deep layer. At all crop growth periods, the soil salinity changes were dramatic at the soil surface with the shallow groundwater (Fig. 3).

Salt changes during the entire year 2010 were used to clarify soil dynamics (Figs. 3, 4). For example, in the irrigation field upstream, from June 15th to July 1st, the electrical conductivity (EC) of the 0–20 cm layer increased by 1.67 ms/cm, while EC in root layer increased by 0.7 ms/cm. Due to the low rainfall and high evaporation over a

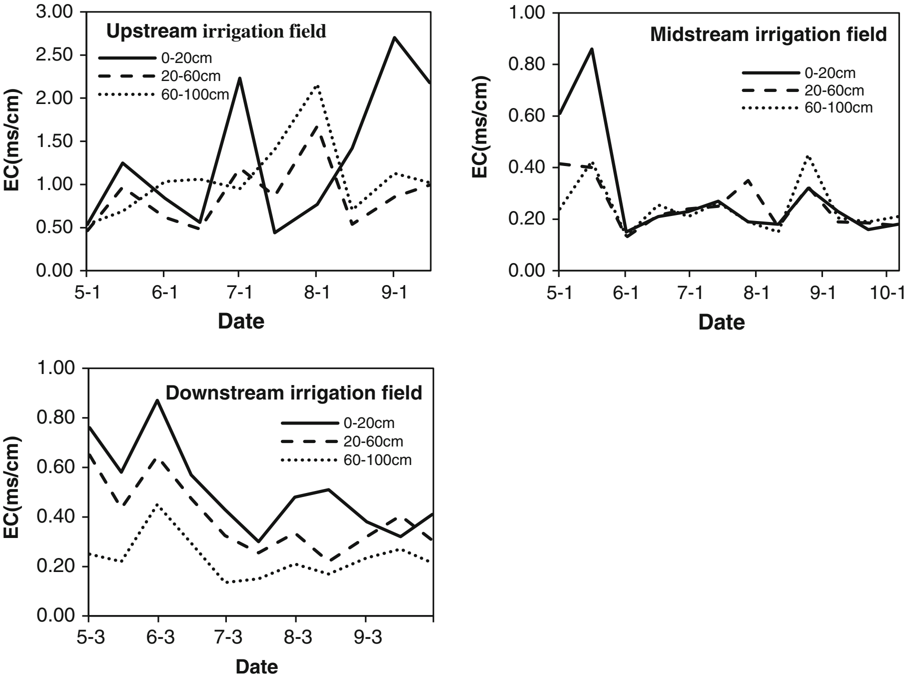


Fig. 3 Temporal change of soil salt within crop growth period in irrigation field (2010)

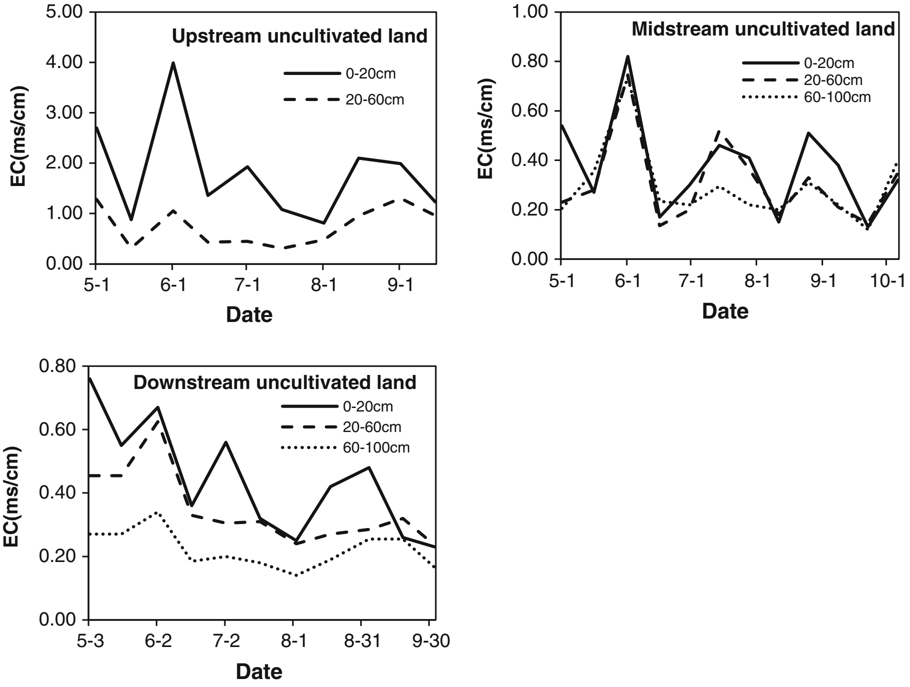


Fig. 4 Temporal change of soil salt in uncultivated land (2010)

longer period, either in the irrigation field or in the uncultivated land, the soil salt distribution trends became increasingly higher to soil surface with upward water movement. On the other hand, at the same condition the water content of 0–20 cm decreased by 1 % and the value in root layer increased by 0.6 %, which may be a factor for soil salt change. Compared with the irrigation field, the fluctuation of soil salt in uncultivated land could be neglected. For example, at upstream, the EC of 0–20 cm increased by 0.57 ms/cm in the uncultivated land from the June 15th to the July 1st, which was lesser than the increased value of 1.1 ms/cm in the irrigation field. In the upstream, the surface soil salt declined in the irrigation field but the salt in the uncultivated land increased from May 15th to June 1st. It indicated that there was salt leaching process as irrigation in the surface layer. The

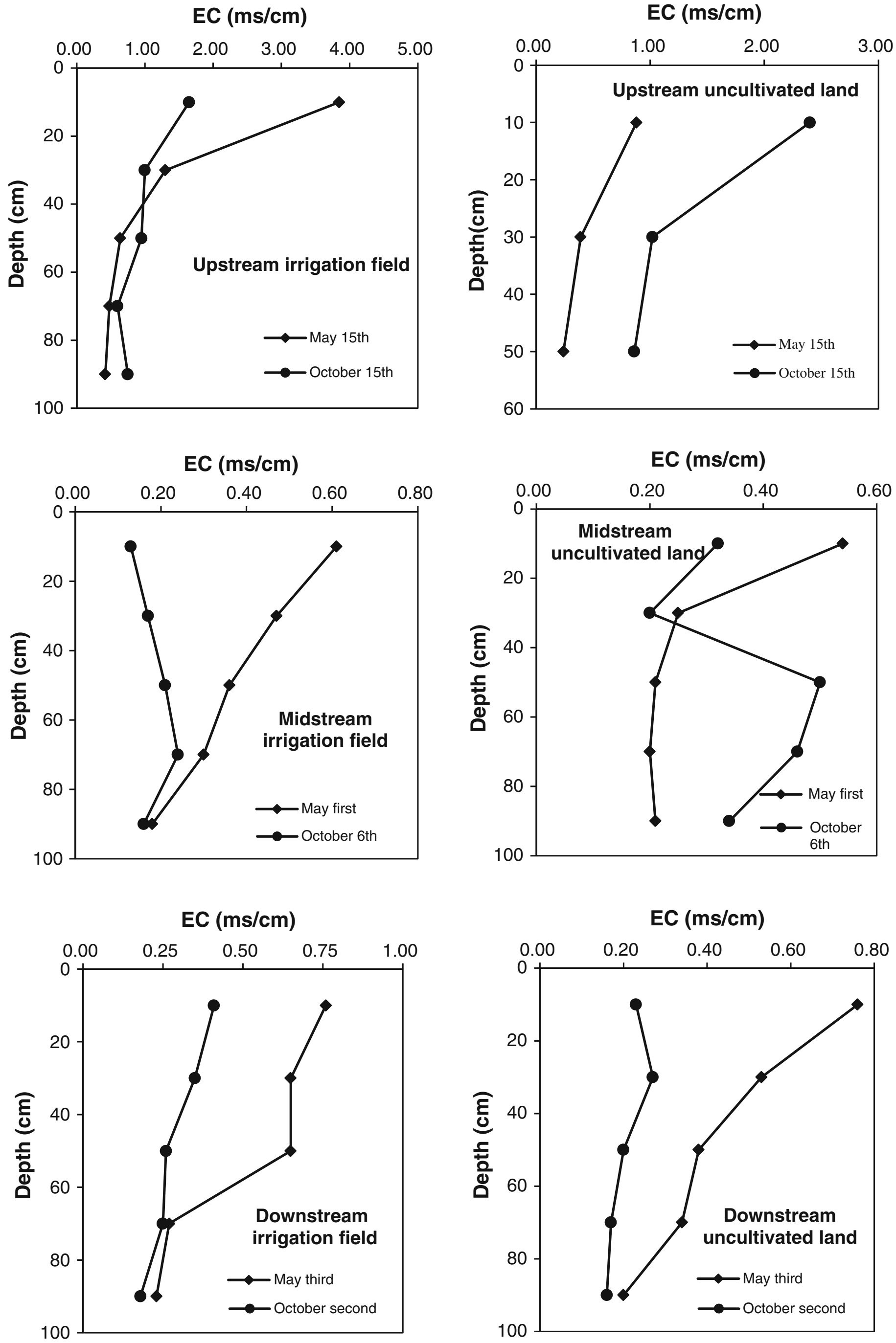
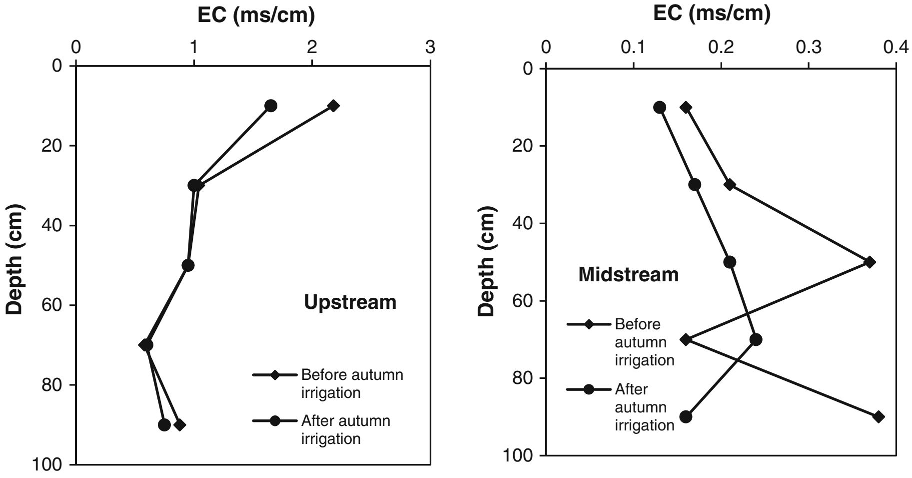


Fig. 5 Salt changes in soil profile of irrigation field and uncultivated land (2010)

same situation happened in the midstream from May 16th to June 1st. All the soil salinity above 1 m had some decrease from August 25th to September 22nd for both irrigation field and uncultivated land in the midstream. This can be attributed to the heavy rainfall of 45 mm from August 25th to September 22nd. It was also indicated by the soil-water content of 0–20 cm that the increased values were 4, 4.1 % in the irrigation filled and uncultivated land, respectively. Meanwhile, in the upstream the surface salinity had an obvious accumulation process through a growth period with the surface EC increasing from 0.54 to 2.18 ms/cm from May 1st to September 15th, while there were contrary salinity accumulation processes in the midstream and downstream. On the one hand, the total of precipitation and irrigation was 340.37 mm in upstream while the total values were 387.25 mm and 391.06 mm in middle stream and downstream, respectively; on the other hand, the average groundwater depth was 1.46 m in upstream while the values were 2.45 and 5.11 m in middle stream and downstream, respectively.

Fig. 6 The salt leaching before and after autumn irrigation (2010)



At the crop growth period, the soil salts at different layers varied. The salt transportation process in the upstream was analyzed as typical. The main crop was sunflower in the irrigation field of upstream and the soil salt in the surface was high on May 15th because of the last autumn irrigation and spring accumulation of salt in the surface soil. With an irrigation process before the July 15th, the soil salt above 40 cm was decreasing and the salt between 40 and 100 cm was increasing. The rest of the time of the growth period had twice leach and accumulation process. However, the salt was accumulated in the surface soil all the way in the uncultivated land without irrigation (Fig. 5).

Overall, the soil salinity in soil profile changed frequently, especially in the irrigation field. However, the distribution trends were as higher as to surface. From the upstream, midstream and down stream's comparison graphs, it was found that their trends were very familiar. At harvest season of crop, the salt distribution was higher on the soil surface and lower on the below at a whole.

Salt change in soil profile after autumn irrigation

The autumn irrigation is important to leach the salinity accumulated in the root zone soil within crop growth period. The salt distributions in soil profile before and after autumn irrigation in upstream and midstream in 2010 were investigated to clarify the effect of autumn irrigation on soil salt accumulation. Both upstream and midstream, the phenomenon of salt leaching was obvious for autumn irrigation (Fig. 6). The salt decreased in the 0–60 cm soil layer and increased in the 60–80 cm soil layer simultaneously. As a result of autumn irrigation, the EC of the 0–10 cm layer decreased from 2.18 to 1.65 ms/cm in upstream. Meanwhile, the EC of the 80–100 cm layer increased from 0.75 to 1.88 ms/cm through the autumn irrigation. Generally, the autumn irrigation leached the salt in the soil between 0–60 cm into the soil between 60 and 80 cm.

During irrigation in autumn, a large dose of irrigation after crop harvest in the study area leaches the salinity accumulated in the growth period to the lower layers of the soil. However, autumn irrigation can cause groundwater level to rise. With the strong evaporation in spring, the salinity dissolved in the groundwater will migrate upward. The process of salt leaching and accumulation created the specific irrigation and cultivation pattern. As shown in Fig. 7, the salinity distribution in the soil profile of 2007, 2008, 2009 and 2010 demonstrated a phenomenon of surface salt accumulation in spring through strong evaporation. Like the uncultivated land in 2010, the EC of the soil layer of 30 cm in upstream, midstream and downstream were 1.82, 0.21, and 0.43 ms/cm respectively, and were 2.01, 0.25 and 0.53 ms/cm for surface soil, respectively.

Soil salinization seriously affected the plant growth, especially in the shallow groundwater district like Hetao irrigation district, and many factors can influence the soil salt distribution. Therefore, temporal and spatial variations of soil salt attributes should be known to avoid their impacts on plant growth. Guler et al. (2013) evaluated and compared the data of soil salt from 1996 to 2008 and found that soil EC above threshold level (4 ds/m) decreased considerably from 1996 to 2008, which was attributed to that irrigation and complementary drainage removed excess salts away from the soils.

Groundwater depth change

For all four observation years, the groundwater depth showed similar inter-annual patterns (Fig. 8). In spring, the maximum groundwater depth appeared about March 1st normally. For example, the maximum of groundwater depth in irrigation field of upstream were 1.85 m on

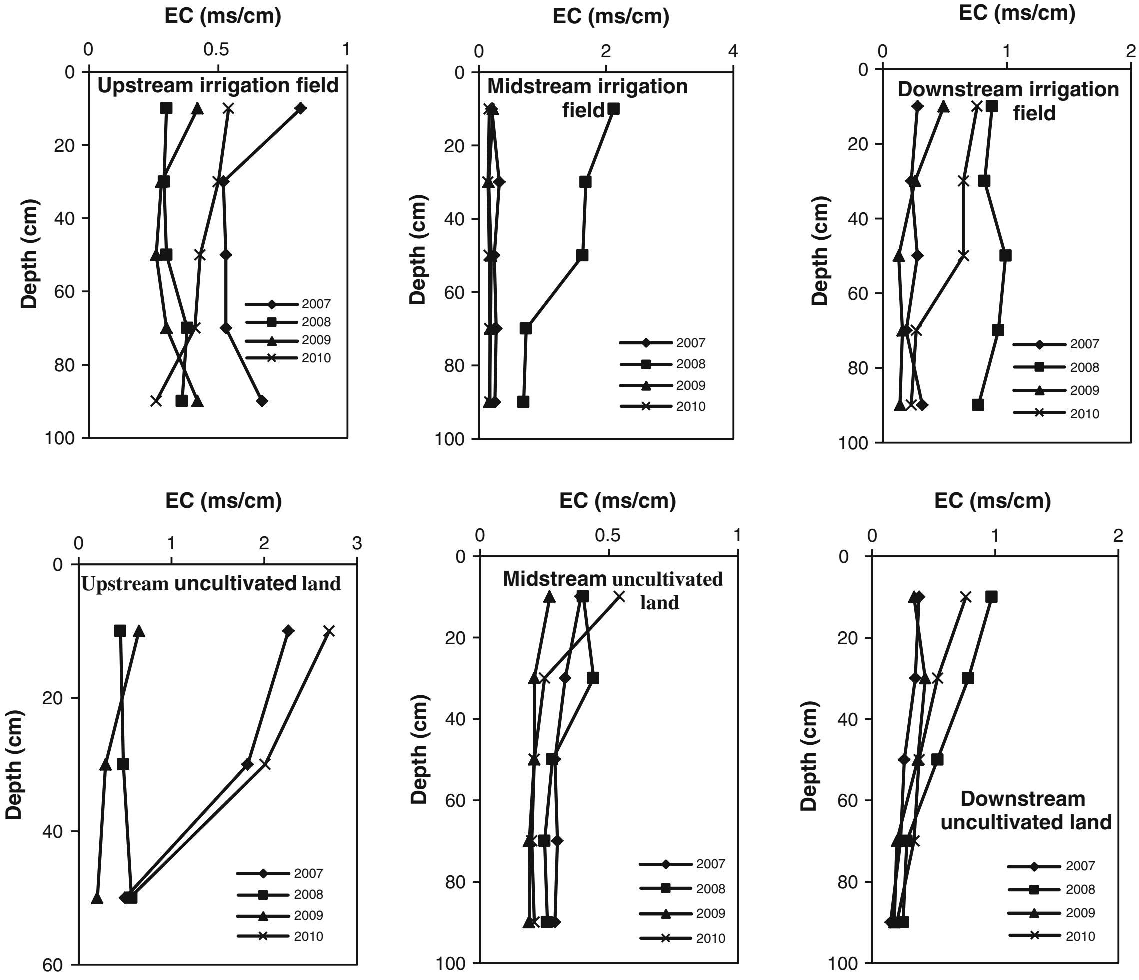


Fig. 7 The salinity distribution profile in spring every year

February 21st in 2008, 1.66 m on March 1st in 2009 and 2.23 m on March 1st in 2010, respectively. On March 11th of 3 years, the groundwater depth also had some decrease due to the temperature rising and soil melting. As shown in the Fig. 8, the autumn irrigation happened after October every year. Considering the upstream, the groundwater depth decreased by 0.94, 1.75, 1.72 and 0.40 m from October 1st to November 11th in 2007, 2008, 2009 and 2010, respectively. From the upstream to the downstream, the groundwater depth had an increasing trend that the average depths were 1.17, 2.23 and 4.73 m in upstream, midstream and downstream, respectively. The observed values indicated that shallow water tables were universal in the Hetao irrigation district, which led to the soil salinization. In the recent years, the problem got some relief due to the water-saving measures such as the channel lining, upgrading the respective hydraulic regulation, control structures, deficit irrigation and so on, which were referred by Xu et al. (2011). From the Table 3, the groundwater depth data in upstream, midstream and downstream indicated that the groundwater was more and more deep from 2007 to 2010. The largest increasing value was 0.95 m appeared in uncultivated land of downstream, while the minimum increasing value was 0.25 m appeared in irrigation field of midstream. The increase of groundwater depth may be caused by canal lining.

Due to the shallow depth, the groundwater in the study area was affected by rainfall, irrigation and so on. Therefore, the annual groundwater depth fluctuated frequently at the crop growth period from May to October (Fig. 9). After the autumn irrigation about in October, the groundwater depth had a decrease from upstream to downstream. For the irrigated fields after autumn irrigation of 2010, groundwater level rose by 1.82, 2.02 and 1.00 m in upstream, middle stream and downstream, respectively. At the growth period from May to October, generally the minimum of groundwater depth appeared in May. The autumn irrigation in October would make the groundwater table an obvious increase, while the groundwater depths remained unchanged with slight decrease from November to

Fig. 8 Groundwater level change in irrigation field and uncultivated land

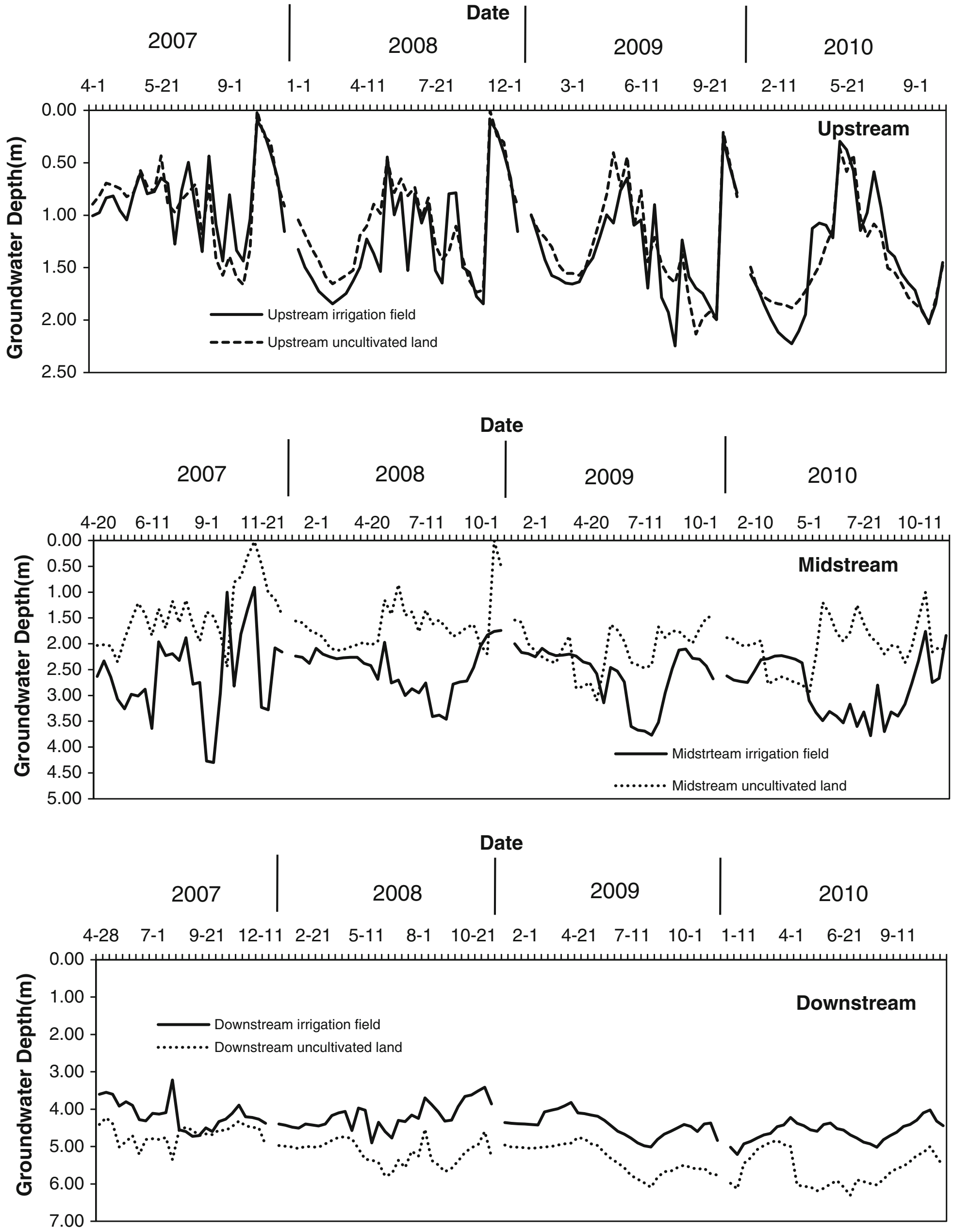


Table 3 The groundwater depth variation within 1 year (m)

	2007	2008	2009	2010
Upstream				
Irrigation field	0.86	1.25	1.35	1.45
Uncultivated land	0.87	1.10	1.25	1.47
Midstream				
Irrigation field	2.60	2.50	2.60	2.85
Uncultivated land	1.43	1.67	2.10	2.05
Downstream				
Irrigation field	4.15	4.20	4.43	4.60
Uncultivated land	4.67	5.16	5.33	5.62

February. From February to April, the groundwater depth decreased by soil ablation.

Due to the special irrigation way and the temperature conditions, the groundwater in the region would achieve to the maximum twice a year. One was in the early November after the autumn irrigation and the other was in mid-May after the soil freezing. A minimum appeared in early March. At the period, the groundwater fluctuated with the irrigation, precipitation and evaporation. As described in Yu et al. (2010), the groundwater dynamics of Jiefangzha belonged to infiltration-evaporation type.

Fig. 9 Temporal change of groundwater depth (2010)

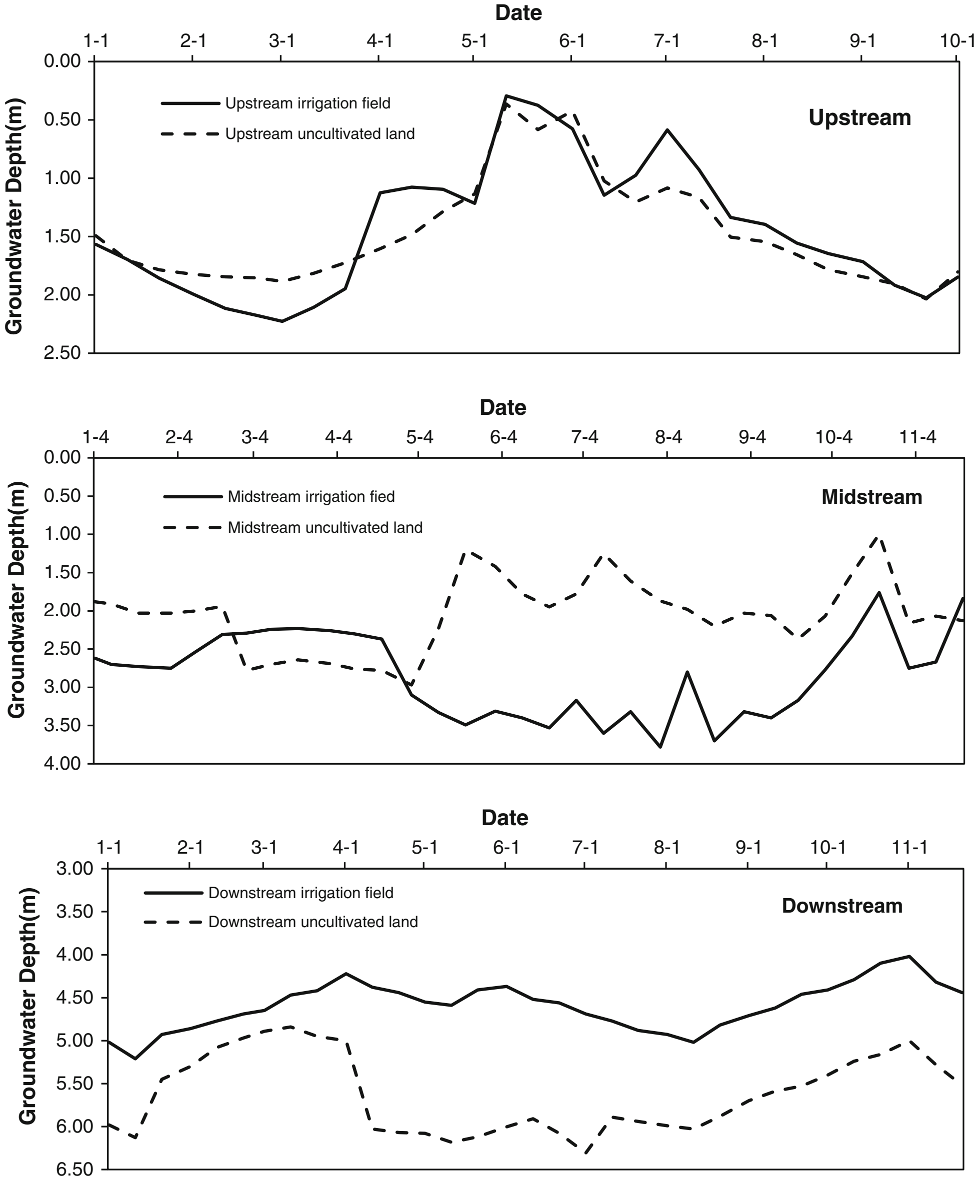


Table 4 Groundwater recharge to soil water in irrigation field and uncultivated land

	Upstream				Midstream				Downstream			
	Irrigation field		Uncultivated land		Irrigation field		Uncultivated land		Irrigation field		Uncultivated land	
	Δ*h* (m)	*R* (mm)	Δ*h* (m)	*R* (mm)	Δ*h* (m)	*R* (mm)	Δ*h* (m)	*R* (mm)	Δ*h* (m)	*R* (mm)	Δ*h* (m)	*R* (mm)
2007	0.64	96	0.7	105	1.42	213	0.05	7.5	1.16	174	0.48	72
2008	0.76	114	0.97	148.5	0.2	30	0.83	124.5	0.35	52.5	0.61	91.5
2009	0.65	97.5	0.87	130.5	0.17	25.5	0.15	22.5	0.55	82.5	0.88	132
2010	1.34	201	1.48	222	0.09	13.5	0.64	96	0.07	10.5	0.55	82.95

S_y is 0.15

Contribution of groundwater to evapotranspiration

To investigate the groundwater recharge/discharge in shallow groundwater district, the WTF method, which is based on the assumption that groundwater level rises or decline in unconfined aquifers are caused by irrigation recharge or evapotranspiration, was used in the crop growth period according to the limited information. The

Table 5 Evapotranspiration in irrigation field and uncultivated land

	P (mm)	I (mm)	ΔW (mm)	R (mm)	ET (mm)	R/ET (%)
2007						
Upstream						
Irrigation field	121.7	262.37	54.3	96	425.77	22.55
Uncultivated land	121.7	0	6.75	105	219.95	47.74
Midstream						
Irrigation field	142.3	299.85	−0.45	213	655.6	32.49
Uncultivated land	142.3	0	44.95	7.5	104.85	7.15
Downstream						
Irrigation field	114.4	289.36	0.5	174	577.26	30.14
Uncultivated land	114.4	0	−18.25	72	204.65	35.18
2008						
Upstream						
Irrigation field	134.6	262.37	−31.2	114	542.17	21.03
Uncultivated land	134.6	0	−47.6	145.5	232.5	62.58
Midstream						
Irrigation field	111.2	299.85	−7.585	30	448.635	6.69
Uncultivated land	111.2	0	−38.5	124.5	274.2	45.41
Downstream						
Irrigation field	196	289.36	−11	52.5	548.86	9.57
Uncultivated land	196	0	−3.45	91.5	290.95	31.45
2009						
Upstream						
Irrigation field	53.8	262.37	−8.5	97.5	422.17	23.10
Uncultivated land	53.8	0	−9.45	130.5	193.75	67.36
Midstream						
Irrigation field	112.3	299.85	−0.4	25.5	438.05	5.82
Uncultivated land	112.3	0	−8.1	22.5	142.9	15.75
Downstream						
Irrigation field	77	289.36	7.2	82.5	441.66	18.68
Uncultivated land	77	0	−0.9	132	209.9	62.89
2010						
Upstream						
Irrigation field	78	262.37	−23.5	−201	564.87	35.58
Uncultivated land	78	0	−22.15	−222	584.52	37.98
Midstream						
Irrigation field	87.4	299.85	−72.6	−13.5	473.35	2.85
Uncultivated land	87.4	0	−46.9	−96	530.15	18.11
Downstream						
Irrigation field	101.7	289.36	−14.8	−10.5	416.36	2.52
Uncultivated land	101.7	0	5.85	−82.95	468.16	17.72

water table data of 4 years were used in these calculations. The computing results revealed that the groundwater level declined much in the uncultivated land (Table 2). As stated in Yu et al. (2010), the irrigation infiltration was the main inflow to the groundwater. In the other words, the groundwater decline in the uncultivated land was more than that in the irrigation field because there was not irrigation percolation to groundwater in the uncultivated land (Table 4). For example, the mean evaporation of groundwater for 4 years in the irrigation field were 127.13, 70.5 and 79.88 mm in upstream, midstream and downstream, respectively, while the values were 151.15, 62.63 and 94.61 mm, respectively in uncultivated land at the crop growth period. Changes in water levels occurred over different time scales. Seasonal fluctuations in groundwater levels were common due to the seasonality of evapotranspiration (ET), precipitation and irrigation.

Evapotranspiration is the main dynamic for crop growth and the contributors to evapotranspiration are plentiful, such as precipitation, irrigation and so on. Contribution of groundwater to evapotranspiration is very important, especially in shallow groundwater district. The ET has a great deal of influence factors in the shallow groundwater, such as soil matrix potential, crop root distribution, soil texture and so on. Luo and Sophocleous (2010) reported that crop-water use of shallow groundwater depends on many factors, including hydraulic conductivity, evaporative demand, crop root growth and so on. Soppe and Ayars (2003) found that the irrigation method and management also affected shallow groundwater use. Whether there are some relations between the groundwater level and ET is not very clear. It was found that the values of the R/ET fluctuated from 2.52 to 67.36 % in this study area (Table 5). From the result, the groundwater contribution to evapotranspiration in the uncultivated land was greater than the irrigation field. For example, in upstream the values of R/ET in the uncultivated land were 47.74, 62.58, 67.36 and 37.98 % in 2007, 2008, 2009 and 2010, respectively, with the values were 22.55, 21.03, 23.10 and 35.58 % in the irrigation field. In the irrigation field, the maximum could achieve to 35.58 %. Therefore, the groundwater recharge is an important role in the crop growth period.

Like former studies, Luo and Sophocleous (2010) also found that the ratio of groundwater contribution to crop-water use reached as high as 75 % in the case of DTW (depths to water table) = 1.0 m and no irrigation, and as low as 3 % in the case of DTW = 3.0 m and three irrigation applications with experiments conducted in Yucheng, China, where belongs to sub-humid warm temperate continental monsoon climate zone. Torres and Hanks (1989) found that the contribution the water table to evapotranspiration was 90, 41 and 7 % for 50, 100 and 150 cm water table depth, respectively for the silt clay loam with lysimeter experiments of constant water table depths in the greenhouse, while computed values were 89, 45 and 6 %, respectively. In addition, many methods were used to estimate the groundwater recharge. The estimation methods of groundwater recharge were improved gradually. Sophocleous (1991) combined the soil water balance and water-level fluctuation methods to estimate natural groundwater recharge and found that gave better and more reliable results than either of the two well-established approaches used singly. Masoud et al. (2013) studied an approach calculating rainfall-runoff relationships to estimate groundwater recharge in arid regions suffering from lack of data.

Conclusions

Based on 4-year field observation data, it was shown in this study that the temporal and spatial changes of soil salt show significant relationship with the shallow groundwater level. The surface soil salt fluctuated frequently and widely. The Hetao irrigation district is a typical area with seasonal dynamic of water and salt. In the region, uncultivated land was an important role in the crop growth period because that it can store the salinity discharged from irrigation field. On the whole, the soil profile had surface accumulation phenomenon in the uncultivated land because of the strong evaporation. Migration rule of water and salt in saline soil is also not perfect, so the further study of water and salt transport between irrigation field and uncultivated land is still needed.

In this district, the groundwater was so shallow that the water table changed obviously due to the effect of irrigation and precipitation. The groundwater depth would reduce sharply after autumn irrigation and soil thawing and change smoothly at growth period. With the implementation of water-saving measures, the groundwater decreased year by year. The groundwater in this district was shallower in upstream and deeper in downstream.

Due to the shallow groundwater depth, the groundwater recharge in this region cannot be ignored for the crop growth. The WTF method was applied to calculate the groundwater recharge. The result showed that the groundwater recharge was less and less from the upstream to the downstream due to the more and more deep groundwater. In the irrigation field, the maximum of R/ET could achieve to 35.58 %, which represented groundwater recharge accounted for 35.58 % for crop water consumption.

In shallow groundwater areas, grasping accurately the dynamic of water level and soil salt and the contribution of groundwater to evapotranspiration had some significance in guiding practice for making reasonable irrigation system, improving crop water use efficiency and alleviating soil salinization.

Acknowledgments This study was supported by the National Natural Science Foundation of China (51321001, 51322902) and the Ministry of Water resources of China (201401007-2). The contributions of the editor and anonymous reviewers whose comments and suggestions significantly improved this article are also appreciated.

References

Babajimopoulos C, Panoras A, Georgoussis H, Arampatzis G, Hatzigiannakis E, Papamichail D (2007) Contribution to irrigation from shallow water table under field conditions. Agric Water Manag 92:205–210

Cai LG, Mao Z, Fang SX, Liu HS (2003) The Yellow River basin and case study areas. In: Pereira LS, Cai LG, Musy A, Minhas PS (eds) Water saving in the yellow river basin: issues and decision support tools in irrigation. China Agricultural Press, Beijing, pp 13–34

Dehaan RL, Taylor GR (2002) Field-derived spectra of salinized soils and vegetation as indicators of irrigation-induced soil salinization. Remote Sens Environ 80:406–417

Farifteh J, Farshad A, George RJ (2006) Assessing salt-affected soils using remote sensing, solute modelling, and geophysics. Geoderma 130:191–206

Feng ZZ, Wang XK, Feng ZW (2005) Soil N and salinity leaching after the autumn irrigation and its impact on groundwater in Hetao Irrigation District, China. Agric Water Manag 71:131–143

Guler M, Aralan H, Cemek B, Ersahin S (2013) Long-term changes in spatial variation of soil electrical conductivity and exchangeable sodium percentage in irrigated mesic Ustifluvents. Agric Water Manag 135:1–8

Healy RW, Cook PG (2002) Using groundwater levels to estimate recharge. Hydrogeol J 10:91–109

Jia SH, Yue WF, Wang JS, Gao HY, Chen AP (2013) Groundwater balance in the Yichang irrigation sub-district in inner Mongolia in the past 20 years. J Beijing Norm Univ (Nat Sci) 49:243–245

Kahlown MA, Ashraf M (2005) Effect of shallow groundwater table on crop water requirements and crop yields. Agric Water Manag 76:24–35

Lerner DN, Issar AS, Simmers I (1990) Groundwater recharge. IAH, vol 8. Heise Ed., Hannover

Li RP, Shi HB, Flerchinger GN, Akae T, Wang CH (2012) Simulation of freezing and thawing soils in Inner Mongolia Hetao Irrigation District, China. Geoderma 173:28–33

Liu XH, Simunek J, Li L, He JQ (2013) Identification of sulfate sources in groundwater using isotope analysis and modeling of flood irrigation with waters of different quality in the Jinghuiqu district of China. Environ Earth Sci 69:1589–1600

Luo Y, Sophocleous M (2010) Seasonal groundwater contribution to crop-water use assessed with lysimeter observations and model simulations. J Hydrol 389:325–335

Masoud AA, Koike K (2006) Arid land salinization detected by remotely-sensed landcover changes: a case study in the Siwa region, NW Egypt. J Arid Environ 66:151–167

Masoud M, Schumann S, Mogheeth SA (2013) Estimation of groundwater recharge in arid, data scarce regions; an approach as applied in the EI Hawashyia basin and Ghazala sub-basin (Gulf of Suez, Egypt). Environ Earth Sci 69:103–117

Metternicht GI, Zinck JA (2003) Remote sensing of soil salinity: potentials and constraints. Remote Sens Environ 85:1–20

Peng ZY, Huang YS, Wu JW, Abuduheni (2012) Salt movement of seasonal freezing-thawing soil under autumn irrigation condition. Trans Chin Soc Agric Eng 28:77–81

Ragab RA, Amer F (1986) Estimating water table contribution to the water supply of maize. Agric Water Manag 11:221–230

Sharma ML (ed) (1989) Groundwater recharge. A.A. Balkema, Rotterdam

Simmers I (ed) (1988) Estimation of natural groundwater recharge, vol 222. Springer, Berlin

Simmers I, Hendrickx GP, Kruseman GP, Rushton KR (1997) Recharge of phreatic aquifers in (semi-) arid areas (iah International Contribution to Hydrogeology 19). Taylor & Francis, London

Sophocleous MA (1991) Combining the soil water balance and water-level fluctuation methods to estimate natural groundwater recharge: practical aspects. J Hydrol 124:229–241

Soppe RWO, Ayars JE (2003) Characterizing groundwater use by safflower using weighing lysimeters. Agric Water Manag 60:59–71

Szabolcs I (1989) Salt-affected soils. CRC Press, Inc., USA

Torres JS, Hanks RJ (1989) Modeling water table contribution to crop evapotranspiration. Irrig Sci 10:265–279

Verma KS, Saxena RK, Barthwal AK, Deshmukh SN (1994) Remote sensing technique for mapping salt affected soils. Int J Remote Sens 15:1901–1914

Wallender WW, Grimes DW, Henderson DW, Stromberg LK (1979) Estimating the contribution of a perched water table to the seasonal evapotranspiration of cotton. Agron J 71:1056–1060

Wang YD (2002) Analysis on changes of groundwater table before and after water saving reconstruction in Hetao Irrigation District. Water-Sav Irrig 1:15–17

Wang XH, Hou HB (2006) Influence of shallow groundwater on the growth law of crops. J Irrig Drain 25:13–17

Wang QJ, Wang WY, Lu DQ, Wang ZR, Zhang JF (2000) Water and salt transport features for salt-effected soil through drip irrigation under film. Trans Chin Soc Agric Eng 16:54–57

Wang XG, Hollanders PHJ, Wang SL, Fang SX (2004) Effect of field groundwater table control on water and salinity balance and crop yield in the Qingtongxia Irrigation District. Irrig Drain 53:263–275

Wang XQ, Gao QZ, Lu Q (2005) Effective use of water resources, and salinity and waterlogging control in the Hetao Irrigation Area of Inner Mongolia. J Arid Land Resour Environ 19:118–123

Xu X, Huang GH, Qu ZY, Pereira LS (2010) Assessing the groundwater dynamics and impacts of water saving in the Hetao Irrigation District, Yellow River basin. Agric Water Manag 98:301–313

Xu X, Huang GH, Qu ZY, Pereira LS (2011) Using MODFLOW and GIS to assess changes in Groundwater Dynamics in Response to Water Saving Measures in Irrigation District of the Upper Yellow River Basin. Water Resour Manage 25:2035–2059

Yang JF, Li BQ, Li YS, Ma R (1999) Preliminary studies on groundwater effects on SPAC system in shallow groundwater field. J Hydraulic 7:27–32

Yang T, Xu CY, Shao QX, Chen X, Lu GH, Hao ZC (2010) Temporal and spatial patterns of low-flow changes in the Yellow River in the last half century. Stoch Env Res Risk Assess 24:297–309

Yu RH, Liu TX, Xu YP, Zhu C, Zhang Q, Qu ZY, Liu XM, Li CY (2010) Analysis of salinization dynamics by remote sensing in Hetao Irrigation District of North China. Agric Water Manag 97:1952–1960

Zeng WZ, Xu C, Wu JW, Huang JS (2014) Soil salt leaching under different irrigation regimes: HYDRUS-1D modeling and analysis. J Arid Land 6:44–58