Journal Home page : www.jeb.co.in ★ E-mail : editor@jeb.co.in

JEB

Journal of Environmental Biology

ISSN: 0254-8704
CODEN: JEBIDP

Characteristic monitoring of groundwater-salt transportation and input-output in inland arid irrigation area

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Publication Info

Paper received:
08 June 2014

Revised received:
29 August 2014

Re-revised received:
04 September 2014

Accepted:
18 September 2014

Abstract

The rules of microscopic water-salt transportation can be revealed and the impact on the macroscopic water and soil resources can be further predicted by selecting a typical study area and carrying out continuous monitoring. In this paper, Jingtaichuan Electrical Lifting Irrigation District in Gansu Province (hereinafter called as JingDian irrigation district (JID)) located at the inland desert region of northwest China was selected as study area. Based on the groundwater-salt transportation data of representative groundwater monitoring wells in different hydrogeological units, the groundwater-salt evolution and transportation tendency in both closed and unclosed hydrogeological units were analyzed and the quantity relative ratio relationship of regional water-salt input-excretion was calculated. The results showed that the salt brought in by artificial irrigation accounts for the highest proportion of about 63.99% and the salt carried off by the discharge of irrigation water accounts for 66.42%, namely, the water-salt evolution and transportation were mainly controlled by artificial irrigation. As the general features of regional water-salt transportation, groundwater salinity and soil salt content variation were mainly decided by the transportation of soil soluble salt which showed an obvious symbiosis gathering regularity, but the differentiation with insoluble salt components was significant in the transportation process. Besides, groundwater salinity of the unclosed hydrogeological unit presented a periodically fluctuating trend, while the groundwater salinity and soil salt content in water and salt accumulation zone of the closed hydrogeological unit showed an increasing tendency, which formed the main occurrence area of soil secondary salinization.

Key words

Arid irrigation area, Groundwater-salt evolution, Groundwater-salt input-excretion, Hydrogeological unit

Introduction

In the arid inland desert region, water is the most active factor that determines the ecological environment and the living conditions of human beings, animals and plants. Developing artificial irrigation oasis by constructing large-scale water diversion and irrigation projects is an important measure to improve the living conditions of local residents and to expand reclamation area in the inland desert region. During the 1970s and 1980s, to meet the requirements of rapid population growth and social development, more than 50 artificial irrigation regions were constructed in the northwest China, with an irrigation area greater than 0.2 million hm^2. In these regions, a large area of arable but long-term deserted land was developed into artificial oasis by the way of water diversion irrigation, thus fundamentally improving the production and living conditions, as well as the micro-climatic and ecological conditions. However, the special natural climate conditions and long-term artificial seasonal irrigation have been constantly changing the process and situation of regional water-salt circulation (Hu *et al.,* 2002). The abundant ex-transportation water further leads to the transportation, recombination and accumulation of groundwater-salt. As a result, water-salt circulation within the irrigation regions has obvious particularity combined result of man-made and natural factors, intersection, limitation and superposition (Wang, 2005; Li *et al.,* 2001; Ortega *et al.,* 2002). Meanwhile, these phenomena can drive the transportation and evolution of water and soil resources in different hydrogeological units of these regions (Troeh and Frederick, 2003). The evolution and transportation of water and salt is unique in inland arid irrigation regions. Under special climate conditions of low rainfall, high evaporation and adequate light and heat, long-term artificial seasonal irrigation is constantly changing the process and situation of regional water-salt circulation (Hao and Kang, 2006; Ji *et al.,* 2009), and some negative effects appear at different levels such as land secondary salinization, deterioration of groundwater quality (Wang, 2005; Li *et al.,* 2001; Yang *et al.,* 2014). In view of this, researchers have carried out a number of studies the water-salt circulation and water and soil environment problems (Hao and Kang, 2006; Sudhakar and Thyagaraj, 2007). Lapidus and Amundson (1952) proposed simulation model of convection-dispersion equation (CDE), which was considered as the prelude to study solute transportation. Subsequently, Scheidegger, 1970 Nielson and Bigga, 1962 improved CDE from the aspect of comparison between theory and experiment, and established a determination model known as CDE which is one-dimensional (Scheidegger, 1970; Nielson and Biggar, 1962; Cai *et al.,* 2003; Wang and Gu, 2002; Feng *et al.,* 2006). In 1982, Willian A.Jury, came up with a random transfer function model, which became one of the most effective models to simulate solute transportation rules of large-scale field without sufficient observation data in such field (Jury *et al*.,1982; Xu *et al.,* 2010; Chen *et al.,* 2001). In addition, Van.Genuchten, professor of U.S National Laboratory of saline, put forward a mobile and immobile water model based on the analysis of convection-dispersion model after taking the impact of immobile water into consideration (Yao *et al.,* 2001; Yang and Xian-xiang, 1999). While, the continuous in-situ monitoring of regional water-slat transportation tendency and the mechanism investigation on the degradation of resulting water and soil resources are insufficient. To curb the local water-salt accumulation of arid lift irrigation regions and the resulting secondary salinization of land, it is necessary to strengthen the study on characteristics and rules of water-salt input and output in these irrigation regions (Jasonsmith *et al.,* 2011). In the present study JID was selected as study area to understand the groundwater-salt evolution and transportation tendency in both closed and unclosed hydrogeological units under the irrigation infiltration-evaporation condition and ascertain the distribution patterns and evolution rules of groundwater and salt content of soil in arid lift irrigation regions. The results could be theoretical and decision-making proofs for prevention of land secondary salinization and improvement of water-soil resource conditions.

Materials and Methods

JID is one of the large-scale cascade lift irrigation districts in arid desert region of northwest China, located in central Gansu province, within the geographic area of 103°20'-104°04'E and 37°26'-38°41'N, with elevation of 1596 ~ 1906 m and it has a total irrigation area of 2746.67 hm^2. Fig. 1 shows the schematic geographic location of JID. JID is a typical inland foreland pluvial plain, having two hydrogeological units from east to west. In JID, one is a closed hydrogeological unit from Baidunzi to Manshuitan basin and the other is an unclosed hydrogeological unit from Haizitan to Yanghuzitan basin. Each of them has its special geological structure (Idowu *et al.,* 2008).

JID has a typical arid inland climate features of low precipitation, drought, high evaporation, sparse vegetation cover and severe wind corrosion. The local meteorological data during 1969-2010 are listed in Table 1. The surface water is scarce short in JID. There are 46 flood-discharge rivers, but almost no groundwater recharge except a short period of surface runoff in the rainy season. Thus the main water source in JID is supplied by irrigation engineering. The runoff of flood-discharge rivers lasts short in rainy season and interaction between surface water and groundwater can be ignored. Therefore, the main groundwater recharge in JID is infiltrated irrigation water, and the groundwater-salt evolution is controlled by transportation of infiltrated irrigation water (Zavala *et al.,* 2009).

The strata in JID have been fully developed, including sedimentary rock, metamorphic rock, magmatic rock and Quaternary unconsolidated sediments. These strata were formed in the geological history when the effects of drought and torridity, evaporation and concentration took place, rich in chloride (such as NaCl, KCl, $MgCl_2$, $CaCl_2$), sulfate ($CaSO_4$, $MgSO_4$) and some other soluble salts. The type of topsoil is mainly the desert sierozem, and the salt content of this sierozem at different depths are listed in Table 2. The physical clay account for 4.9% ~ 26% in the topsoil, the organic matter content of topsoil is about 1.0%, the average bulk density is 1.45g cm^{-3} and the average porosity is 44.49% (Li, 2001).

To sum up, JID has special geographic location, climatic conditions, soil and rock properties, and hydrological conditions. Therefore, it is a good typical area to investigate water-salt evolution and circulation caused by artificial irrigation in arid desert region of northwest China.

The data from 1994 to 2010 were used to classify and analyze the water level of monitoring wells, groundwater salinity and groundwater inorganic ion content. The groundwater salinity and mineralization ions were analyzed using traditional methods (Zhao *et al.*, 2002; Zhou and Qiang, 2003).

Results and Discussion

According to the monitoring results, it can be seen that two hydrogeological units had different characteristics in water-salt transportation process. From periphery to middle of closed hydrogeological unit (Baidunzi ~ Manshuitan basin), it initially formed the infiltration-runoff zone and the active solute transportation zone with relatively smooth water exchange and then gradually formed water and salt accumulation zone with slow

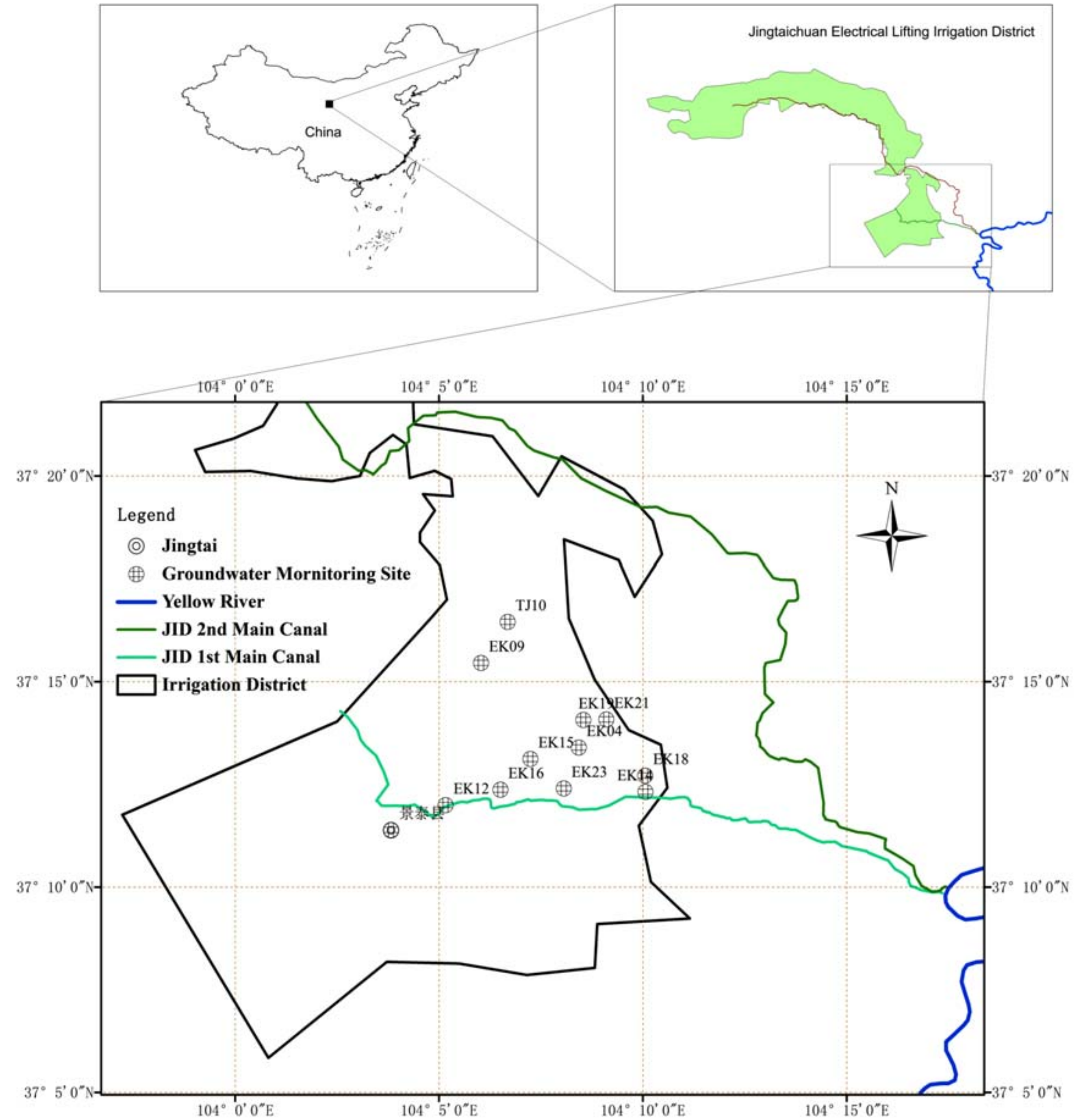

Fig. 1 : Geographic location schematic of JID and 23 wells for monitoring of ground water level

water exchange. For the unclosed hydrogeological unit (Haizitan ~ Yanghuzitan basin), it has also formed the infiltration-runoff zone and the active solute transportation zone, but then transformed to groundwater drainage zone, with the flow directions coinciding with the terrain changes.

Totally 12 monitoring wells were set in the closed hydrogeological unit of JID, of which TJ10, ZK09 and ZK15 were set in the typical infiltration-runoff zone; ZK12, ZK16 and ZK23 in the typical active solute transportation zone; and ZK14, ZK18 and ZK21 in the water and salt accumulation zone at the basin center. While only 7 monitoring wells have complete and continuous monitoring data, which were selected as the representative, i.e., TJ10, ZK15, ZK12, ZK23, ZK14, ZK18 and ZK21.

Fig. 2 shows variation tendency of groundwater level of 7 monitoring wells in closed hydrogeological unit from 1994 to 2010. It can be seen that long-term irrigation and no-drainage, high irrigation quota, flooding irrigation and channel leakage may result in a significant increase of groundwater recharge in monitoring area. Before irrigation, the groundwater recharge is under basic balance or recharge is less than drainage (mining),

Table 1 : Statistics of meteorological characteristics of JID area

Month	Monthly average Wind Speed (m s^{-1})	Monthly average temperatures (ºC)	Monthly average surface temperature (ºC)	Monthly average relative humidity(%)	Monthly average precipitation (mm)	Monthly average evaporation (mm)
1	2.26	-6.90	-6.98	43.37	0.71	52.45
2	2.72	-3.26	-2.20	40.43	1.22	77.65
3	3.14	3.51	5.81	38.73	3.97	174.28
4	3.38	10.64	14.05	37.10	9.08	273.97
5	3.15	16.05	20.35	40.80	19.81	341.79
6	2.85	20.14	24.91	44.88	24.70	349.71
7	2.71	22.06	26.45	52.59	37.01	338.91
8	2.66	20.52	23.77	57.45	45.48	291.06
9	2.40	15.48	12.94	57.49	27.70	201.37
10	2.46	8.89	7.84	53.33	11.99	157.16
11	2.48	1.03	1.18	48.24	1.64	95.21
12	2.18	-5.20	-5.82	46.22	0.28	53.49
	Average 2.70	Average 8.58	Average 10.19	Average 46.72	Annual total 183.60	Annual total 2407.04

Note: Data comes from Meteorological Bureau of Jingtai County, Gansu Province

Table 2 : Salt content of sierozem in monitoring area

Samples Depth	HCO_3^-	Cl^-	SO_4^{2-}	Na^+	Ca^{2+}	Mg^{2+}	Salt content
(cm)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
0~30	0.06	0.19	0.157	0.123	0.035	0.056	0.61
30~60	0.051	0.16	0.229	0.089	0.043	0.047	0.65
60~90	0.048	0.165	0.253	0.155	0.046	0.064	0.73
90~120	0.056	0.178	0.267	0.187	0.052	0.056	0.682

Note: Data comes from "Investigation and Design Report of Jingdian Second Stage Project of Gansu" (1999).

while after irrigation recharge was more than drainage. As a consequence, the groundwater level has been increasing year by year. Typically, groundwater depth in the water and salt accumulation zone has risen from 20 m in 1994 to about 1.5 m in 2010, with ZK14 rising by 22.6 m; whereas the groundwater depth in the infiltration-runoff zone and the active solute transportation zone has raised by 10.5~ 11m and 8.5~11.5m, respectively.

Fig. 3 shows the annual tendency of groundwater salinity in the closed hydrogeological unit. The monitoring data showed that the salt content of groundwater in the basin varied with transportation of irrigation return water. In the infiltration-runoff zone, the soluble salts of arable soil were dissolved and transported by irrigation infiltration water, presenting continuous desalination tendency; while in the initial years, the groundwater salinity slightly increased, and then began to decrease and gradually stabilized. In the active solute transportation zone, the groundwater salinity presented a fluctuating and increasing tendency along with desalination of surface soil, and deep soil is controlled by groundwater salt content. In water and salt accumulation zone, salt accumulates with the evaporation of shallow groundwater, which causes continuous rising of groundwater salinity and expansion of salinization area (Xu *et al.,* 2010; Xu *et al.,* 2011). The field monitoring indicates that salinization area increased from 25.83 to 30.88 km^2 during the monitoring period, with an increasing ratio of 19.45% (Xu *et al.,* 2008).

There were total 11 monitoring wells in the unclosed hydrogeological unit (Haizitan~Yanghuzitang basin) of JID, of which ZK33, ZK37 and TK12 were located in the irrigation-infiltration zone; ZK32, ZK27 and ZK34 in the solute transportation zone; and TJ13, TJ16, and TJ22 in the groundwater drainage zone. 7 monitoring wells were selected as representative as previous, i.e., ZK33, TK12, ZK27, ZK34, TJ13, TJ16 and TJ22.

Fig. 4 shows the interannual tendency of groundwater level of seven representative monitoring wells in the basin, and Fig. 5 is the tendency chart of groundwater salinity of these monitoring wells. It was noted that the groundwater depth ranged from 70 m to 40 m in the basin, which was mainly controlled by the basement structure and river formation. In these locations, the accumulative increasing range of underground water level was 1.2 ~ 4.6 m over the years, and the underground water level in a year varied in the range of 0.5 ~ 2.6 m with the change of irrigation water infiltration. As for groundwater salinity, it ranges between

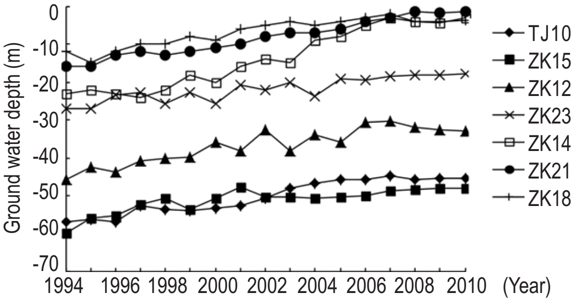

Fig. 2 : Variation of groundwater level in the closed hydro-geological unit

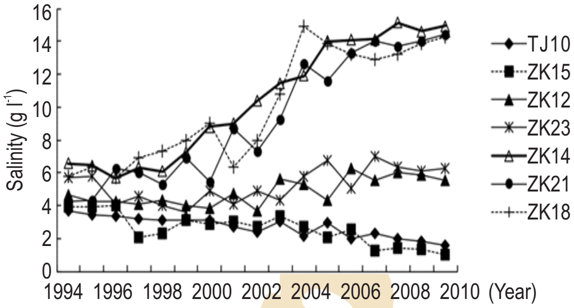

Fig. 3 : Variation of groundwater salinity in closed hydro-geological unit

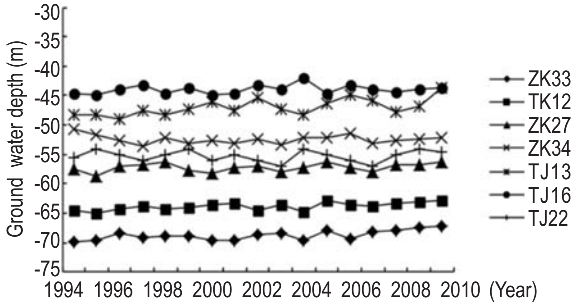

Fig. 4 : Variation of groundwater level in the unclosed hydrogeological unit

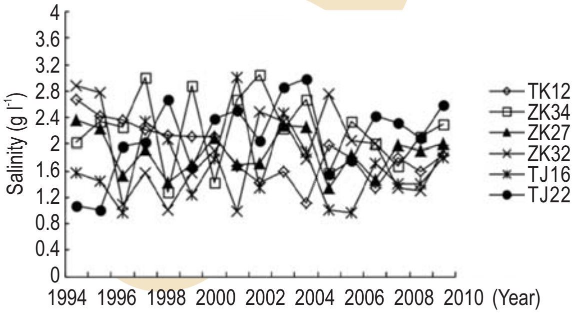

Fig. 5 : Variation of groundwater salinity in the unclosed hydrogeological unit

0.93 g l^{-1} and 3.16 g l^{-1}. The water quality of irrigation-infiltration zone was mainly affected by lixiviation of irrigation infiltration water, and the groundwater salinity of the solute transportation zone and the groundwater drainage zone was mainly affected by the water quality of groundwater.

Table 3 lists the annual average iron milligram equivalent of groundwater in irrigation area. According to monitoring data, transformation and evolution process of groundwater chemistry types in unclosed and closed hydrogeological units is different. In irrigation-infiltration zone and solute transportation zone, the groundwater water quality translates from calcium bisulphate water of low salinity to SO_4^{2-}-Cl^--(K^++Na^+)-Ca^{2+} or SO_4^{2-}-Cl^--(K^++Na^+)-Mg^{2+} water, with salinity of 2.1 to 5.2 g l^{-1}. In drainage and salt accumulation area of closed hydrogeological unit, groundwater salinity and soil salt content are rising year by year, and the groundwater salinity in basin center was up to 172.15 g l^{-1} with the water chemistry type of Cl^--SO_4^{2-}-(K^++Na^+)-Ca^{2+}. In groundwater drainage zone of unclosed hydrogeological unit, the salt content of groundwater was mainly controlled by water quality of deep groundwater and salt content of irrigation-infiltration water, and the chemical type was SO_4^{2-}-Cl^--Ca^{2+}-(K^++Na^+).

Theoretical analysis and field monitoring data revealed that the surface water cycle of arid lift irrigation district is mainly controlled by diversion-irrigation water, seasonal surface runoff of flood-discharge rivers and water discharge of drain ditches in the irrigation area, while the effect of rainfall, runoff formed by groundwater outflow, groundwater irrigation on water-salt cycle are secondary compared with irrigation water and ditch drainage (Xu and Xu, 2011). According to statistical information of JID (1994~2010), diversion-irrigation water was 4.6 times more than the sum of all other water supplies, and the ratio of irrigation-infiltration recharge, rainfall-infiltration recharge and piedmont subsurface runoff recharge in the study area was about 141:30:1. Accordingly, the salt ratio was roughly same.

It was observed that the influence of artificial diversion irrigation on water cycle in irrigation area was far more than that of natural factors. Human activities had significant initiative and directionality, including improving the ecological environment of small artificial oasis, meeting water demand for the growth of agricultural crops and increasing the agricultural production in the arid inland irrigation area. Therefore, properly regulating the quantity relative ratio relationship between surface water and groundwater in the cycle plays an important role in sustainable development of irrigation area.

Table 4 shows the annual average input and output water from 1994 to 2010 in JID. As for the input water, channel diversion was the main source of water in JID, which accounts for about 76.3%, followed by rainfall water which accounts for about 18.6%, and other sources just account for 5.1%. As to the drainage and consumption, agroforestry consumption is the largest, which

Table 3 : Annual average iron milligram equivalent of groundwater in irrigation area

Hydrology geological units	Monitoring wells		Iron content (me l^{-1})						Chemical type
			Ca^{2+}	Mg^{2+}	K^++Na^+	HCO_3^-	Cl^-	SO_4^{2-}	
Baidunzi ~ Manshuitan Basin	Irrigation-Infiltration Zone	TJ10	18.423	7.645	15.431	5.326	14.344	32.226	SO_4^{2-}—Cl^-—Ca^{2+}—(K^++Na^+)
		ZK09	15.343	8.189	17.149	6.302	22.945	28.736	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
		ZK15	21.544	9.459	18.056	5.447	17.761	32.605	SO_4^{2-}—Cl^-—Ca^{2+}—(K^++Na^+)
	Solute Transportation Zone	ZK12	14.408	8.094	19.664	3.204	20.782	26.302	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
		ZK16	18.435	10.238	20.406	7.376	18.342	21.698	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
		ZK23	12.203	9.437	16.132	9.3245	14.153	24.392	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
	Water and Salt Accumulation Zone	ZK14	18.349	11.476	23.168	5.068	37.358	22.704	Cl^-—SO_4^{2-}—(K^++Na^+)—Ca^{2+}
		ZK21	17.365	11.295	24.356	8.169	28.134	24.348	Cl^-—SO_4^{2-}—(K^++Na^+)—Ca^{2+}
		ZK18	26.764	9.156	21.484	8.285	36.431	27.594	Cl^-—SO_4^{2-}—Ca^{2+}—(K^++Na^+)
Haizitan-Yanghuzitang Basin	Irrigation-Infiltration Zone	ZK33	16.977	10.087	25.358	5.973	15.568	28.324	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
		ZK37	18.638	9.264	20.434	8.578	16.948	32.449	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
		TK12	14.035	10.859	28.496	6.947	18.342	26.895	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
	Solute Transportation Zone	ZK27	10.372	12.083	22.598	9.048	13.489	17.045	SO_4^{2-}—Cl^-—(K^++Na^+)—Mg^{2+}
		ZK32	17.094	12.146	16.762	5.091	20.561	14.945	Cl^-—SO_4^{2-}—Ca^{2+}—(K^++Na^+)
		ZK34	18.694	8.047	20.762	8.338	18.349	21.495	SO_4^{2-}—Cl^-—(K^++Na^+)—Ca^{2+}
	Water and Salt Accumulation Area	TJ13	22.858	8.434	14.323	4.985	12.341	13.452	SO_4^{2-}—Cl^-—Ca^{2+}—(K^++Na^+)
		TJ16	17.668	3.763	13.124	5.347	16.598	18.976	SO_4^{2-}—Cl^-—Ca^{2+}—(K^++Na^+)
		TJ22	18.078	4.372	16.034	2.045	14.339	21.324	SO_4^{2-}—Cl^-—Ca^{2+}—(K^++Na^+)

Table 4 : Annual average input and output water from 1994 to 2010 in JID

Project	Input water ($10^8 m^3$)	Ratio (%)	Project	Output water ($10^8 m^3$)	Ratio (%)
Channel diversion	3.69	76.24	Drain discharge	0.24	6.4
rainfall	0.9	18.57	Agroforerstry consumption (Including evaporation and leakage)	2.42	64.31
Piedmont runoff	0.11	1.96	Wasteland evaporation	0.58	15.37
Lateral ground water recharge	0.08	1.63	Consumption of industry and urban	0.11	3.21
Exploitation of deep ground water	0.08	1.59	Groundwater discharge	0.27	6.97
/	/	/	Leaky drainage	0.15	3.74
Total	4.85	100	Total	3.75	100

accounts for about 64.3%, followed by the wasteland evaporation which accounts for about 15.4% and the drains and underground discharge which account for about 13.4%, while others account for only 6.9%.

Table 5 shows that the annual average input and output salt from 1994 to 2010 in JID. In the total input salt, the salt brought in by irrigation accounts for the highest proportion of about 63.99%, followed by the salt from the use of chemical fertilizers which accounts for about 16.41% and the salt from deep groundwater and rainfalls which account for about 17.14%, and others account for 2.46%. In the total output salt, the salt carried off by the discharge of irrigation water through the ditches accounts for 66.42%, the salt absorbed by the crops accounts for 31.00%, and others account for 2.58%. Therefore, the water and salt balance in JID is mainly controlled by salt input of irrigation diversion and output of ditches. In addition, salt brought by deep groundwater and consumed by agroforestry, industry and town also plays an important role, whereas other shares can be ignored.

In JID, the formation of water and soil salt differentiation mainly depends on four controlling factors of water-salt transportation which are as follows: circulation and distribution of water and salt caused by Yellow River Pumping irrigation; the flow direction and zonation of groundwater; the transportation direction of surface runoff and subsurface runoff caused by atmospheric precipitation; and the geochemical process of soluble salt transportation and differentiation. These controlling factors have different effects on differential distribution of water and soil salt content concentration.

The scatter plot of relationship between component concentration and mass concentration (TDS) of water-soluble salt in drainage channels, and the scatter plot of relationship between component and soil total salt content of water-soluble salt in JID can reveal the component concentration of water-soluble salt in soil and groundwater and the discrete relationship

Table 5 : Annual average input and output salt from 1994 to 2010 in JID

Project	Input salt (10^4t)	Ratio	Project	Output salt (10^4 t)	Ratio
Irrigation diversion	1.56	63.99	Drain discharge	3.6	66.42
Rainfall	0.27	11.07	Agroforestry consumption (including evaporation and leakage)	1.68	31
Piedmont runoff	0.02	0.82	Wasteland evaporation	0	0
Lateral groundwater recharge	0.04	1.64	Consumption of industry and urban	0.12	2.21
Deep ground water	0.15	6.07	Ground water discharge	0.02	0.37
Chemical fertilizers	0.4	16.41	/	/	/
Total	2.44	100	Total	5.42	100

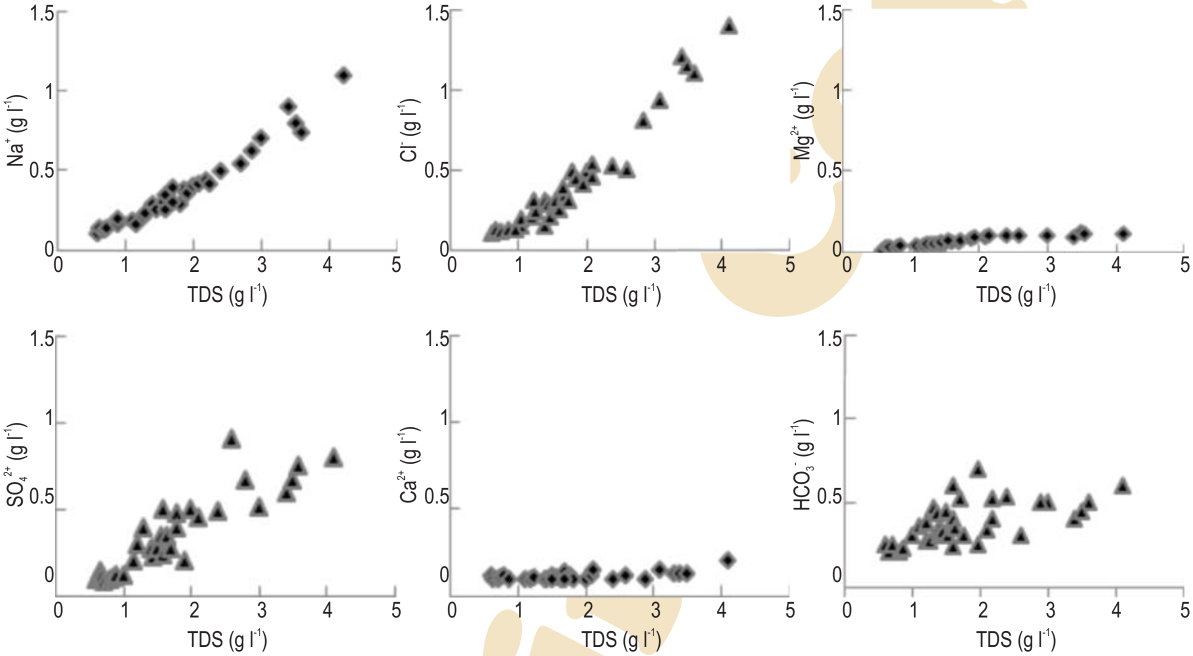

Fig. 6 : Scatterplot of relationship between component concentration and mass concentration (TDS) of water-soluble salt in drainage channels in JID

of total concentration in the process of solute transportation.

Fig. 6 shows the scatterplot of relationship between component concentration and mass concentration (TDS) of water-soluble salt in drainage channels. It can be seen that the scattered median line formed by the concentration of Na^+, Cl^-, SO_4^{2-} and their mass concentration (TDS) in drainage channels approximates to a straight line at an angle of 45° with coordinate axis, indicating positive correlation between component concentration and TDS. These results confirmed that Na^+, Cl^-, SO_4^{2-} were main salt causing increase and decrease in TDS. Relationship between Mg^{2+} and TDS was also similar but the angle between up-line and abscissa was very small. Variation in Mg^{2+} concentration was less along with the increase in TDS. However, the variation trends of Ca^{2+} and HCO_3^- along with the increase of TDS were different from the above four components. With increase in TDS, Ca^{2+} content increased slightly, whereas HCO_3^- variation showed particularity. When TDS was about 2 g l^{-1}, HCO_3^- presented a positive relationship with TDS, and the increment was relatively large. If TDS is >2 g l^{-1}, HCO_3^- concentration decreased sharply, and its reach minimum level of 0.5 g l^{-1}, will not increase until TDS is 5 g l^{-1}. If the range of TDS is 2 to 5 g l^{-1}, HCO_3^- concentration shows negative relationship with TDS, or it will have a greater effect on the concentration of TDS.

The topsoil data were obtained by laboratory test method (Liu and Yang, 2001). The samples were collected from the topsoil with the depth of 0 ~ 30 cm within the spring irrigation period (each April) from 1994 to 2010.

As evident and shown in Fig. 7, with increase in total salt content, the concentrations of Na^+, SO_4^{2-} and Cl^- increased while Mg^{2+} and Ca^{2+} concentration increased slightly, but HCO_3^-

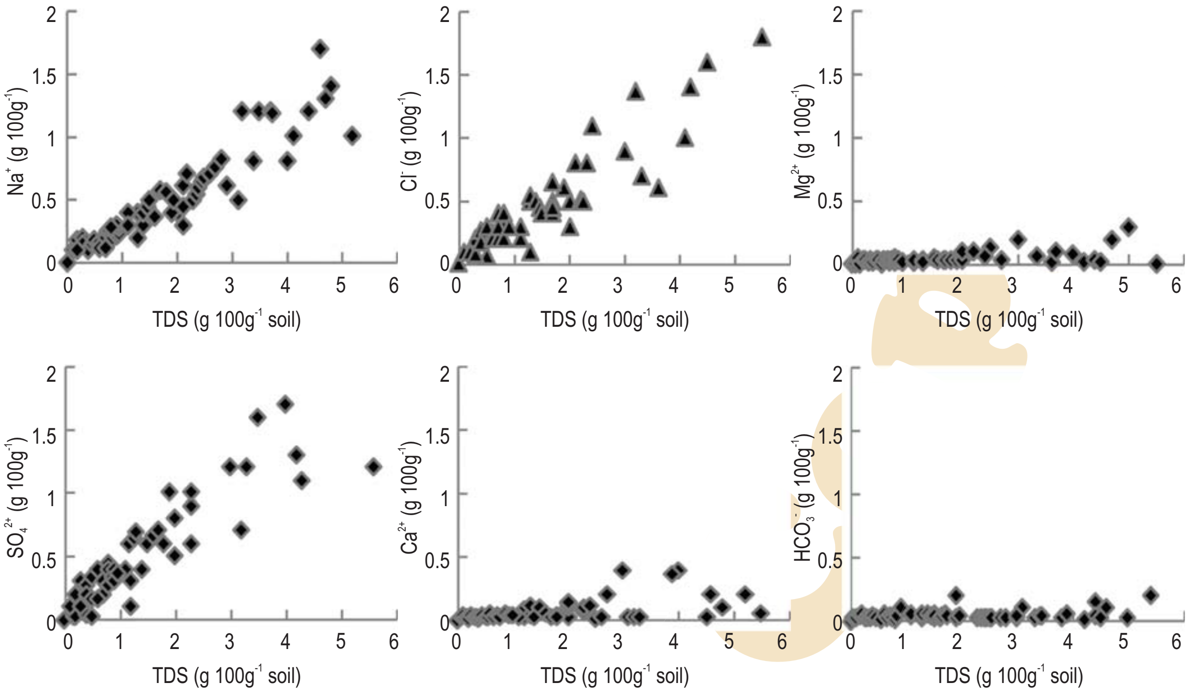

Fig. 7 : Scatterplot of component and soil total salt content of water-soluble salt in JID

concentration almost remained unchanged.

The above analysis showed a symbiosis aggregation regularity in transportation of water-soluble salt in water and soil in JID. Components of soluble salt and relative soluble salt in water and soil have the characteristics of transportation and symbiosis aggregation, which decides the increase and decrease of TDS and total salt content; while differentiation with components of insoluble salt is significant in the process of transportation, especially transportation of Na$^+$ and Ca^{2+}. With increase in TDS and total salt content in the groundwater and soil, concentration of Na$^+$,Cl$^-$, SO$_4^{2-}$ and Mg^{2+} all increased and the concentration increment was relatively large except that of Mg^{2+}; while the variations of HCO$_3^-$ and Ca^{2+} concentrations both presented a complex process of increasing and decreasing alternately. Essentially, symbiosis aggregation and differentiation of these above-mentioned components in the process of transportation are mainly controlled by the transportation activities of the soluble salt in water and soil, *i.e.*, stability, transportation rate and flow direction.

In artificial irrigation oasis of inland desert district, irrigation and drainage pattern belongs to the way of diversion outside and drainage inside, mainly controlled by the irrigation infiltration and the return water discharge. Variation in groundwater and soil salt content has obvious symbiosis aggregation regularity, while the differentiation with insoluble salt components is significant in the process of transportation.

Acknowledgments

This work was financially supported by the Natural Science Foundation of China (51279064; 31360204) and Program for Science and Technology Innovation Talents in Universities of Henan Province (14HASTIT047).

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