Desalination and Water Treatment
www.deswater.com
doi: 10.1080/19443994.2013.827775

52 (2014) 2724–2733
March

Taylor & Francis
Taylor & Francis Group

Salinization of deep groundwater in plain areas of Xinjiang: causes and countermeasures

Qiao Li[a], Jinlong Zhou[a,*], Yinzhu Zhou[b], Ruiliang Jia[a]

[a]*College of Water Conservancy and Civil Engineering, Xinjiang Agricultural University, Urumqi 830052, China*
Tel. +86 13263381574; email: zjzhoujl@163.com
[b]*School of Water Resources and Environment, China University of Geosciences, Beijing 100083, China*

Received 12 July 2012; Accepted 7 July 2013

ABSTRACT

The salinization of deep groundwater is one of the serious geographical environmental hazards. The present study collected groundwater samples from 60 wells with depth over 100 m in the plain areas of Xinjiang from October to November of 2011. The comparison of hydrochemical data obtained in 2011 and 2003 in the same wells indicated that salinization occurred in a spot-like pattern in Xinjiang. Among the 60 groundwater samples, 20 samples were seriously salinized, which made up to 33.3% of the total wells. Through the analysis of the characteristics of salinization of deep groundwater in this region, four causes of salinization and four countermeasures to prevent salinization were put forward.

Keywords: Plain areas of Xinjiang; Deep groundwater; Salinization

1. Introduction

Located in the west of the People's Republic of China and in the hinterland of Asian-European Continent, Xinjiang borders on eight countries with 1/6 of the total area of China. Xinjiang is subdivided into 14 prefectures and cities: Urumqi, Karamay, Bayingolin Mongolian Autonomous Prefecture (Bayingolin Prefecture hereafter), Yili Kazak Autonomous Prefecture (Yili Prefecture hereafter), Altay Prefecture, Bortala Mongolian Autonomous Prefecture (Bortala Prefecture hereafter), Changji Hui Autonomous Prefecture (Changji Prefecture hereafter), Hami Prefecture, Tacheng Prefecture, Turfan Prefecture, Aksu Prefecture, Kashkar Prefecture, Hotan Prefecture and Kizilsu Kirgiz Autonomous Prefecture (Kizilsu Prefecture hereafter). With the constant development of economy and society, the demand for water resources increases and pollution of surface water is aggravated. Such phenomena lead to irrational exploitation of groundwater in some areas. For example, the deep groundwater in Kashkar and Aksu tends to become salinized, which has become an increasingly serious geographical/environmental disaster.

In order to understand the situation of Xinjiang's deep groundwater salinization, we collected 60 sampling wells with depth over 100 m from 283 groundwater samples, while compiling the Planning of the

*Corresponding author.

Presented at the Second International Conference on Water Resources Management and Engineering (ICWRME 2012) Zhengzhou, China, 14–16 August 2012

Utilization and Protection of Groundwater in Xinjiang (revised). Then, comparison with the data of the same sampling wells in 2003 indicated the salinization of deep groundwater in some wells of the plain areas of Xinjiang. Through the analysis of the characteristics of salinization of deep groundwater in this region and its causes, countermeasures to prevent the salinization were put forward.

2. Hydrological and geographical background

Being far away from the ocean and surrounded by high mountains, the terrain of Xinjiang is high in the west and low in the east. Mount Tianshan separates the Junggar Basin from the Tarim Basin. The groundwater in Xinjiang mainly occurs in the alluvial–proluvial plains of violent piedmont sedimentation and Quaternary System accumulation layer in paleoriver plains. The bottom layer of the plains is mainly Palaeogene–Neogene layer and locally the Mesozoic layer is composed of sandstone and conglomerate, which constitute the base of the water-storage basin [1,2].

In this area, shallow and middle-level groundwater occur at depths of <100 m, while deep groundwater usually has a burial depth of >100 m. The groundwater generally has a good quality and is available in large quantity. Therefore, it is being widely exploited.

According to Xinjiang Water Resource Communiques (2005 and 2010), the exploitation quantity of groundwater in 14 prefectures and cities in Xinjiang's plain areas in 2005 and 2010 was 6.71×10^9 and $9.36 \times 10^9\,m^3$, respectively. Except a decrease in exploitation quantity in Turfan, Qomul and Changji Prefecture due to exceeding exploitation limit, the remaining 11 prefectures and cities showed an increase in exploitation quantity (see Table 1).

Table 1
Statistics of exploitation quantity of groundwater in the 14 prefectures and cities in Xinjiang plain areas in 2005 and 2010

Name of prefecture and city	Exploitation quantity ($10^6\,m^3$)		
	2005	2010	Variation amount
Urumqi	262.26	496.51	234.25
Karamay	89.89	51.39	−38.50
Turpan	875.86	764.63	−111.23
Hami	608.05	596.18	−11.87
Changji	1673.97	1405.03	−268.94
Bortala	331.63	414.30	82.67
Bayingolin	498.20	900.94	402.74
Aksu	312.97	704.89	391.92
Kizilsu	56.92	100.48	43.56
Kashi	629.75	2095.06	1465.31
Hotan	181.90	374.05	192.15
Yili	266.74	414.51	147.77
Tacheng	878.95	976.60	97.65
Altay	23.95	50.00	26.05
Total	6711.09	9364.67	2653.53

3. Characteristics of deep groundwater salinization

Intense and continuous exploitation has affected the normal recharge and a gradual salinization of deep groundwater. Salinization is featured by increases in SO_4^{2-} and Cl^- concentrations. According to the monitoring data in 2003 and 2011, among 60 deep groundwater samples collected in Xinjiang, 20 were seriously salinized, which made up to 33.3% of the total wells sampled. 31 samples (accounting for 51.7%) showed an increase in total dissolved solids (TDS), 14 samples (accounting for 23.3%) in Cl^- concentration and 20 samples (accounting for 33.3%) in SO_4^{2-} concentration. The results show that the salinization occurred in a spot-like pattern in Xinjiang. The salinization characteristics of deep groundwater in this area could be summarized as follows.

(1) Among the 60 groundwater samples, 20 samples were seriously salinized. The increase in the rates of TDS, Cl^- and SO_4^{2-} was over 20%. These sampling points were located in Aksu Prefecture, Bayingolin Prefecture, Bortala Prefecture, Hotan Prefecture, Kashkar Prefecture, Tacheng Prefecture and Urumqi. They made up to 33.3% of the total wells sampled (see Table 2).
(2) Generally, the salinization occurred as a spot-like pattern. However, the salinization of deep groundwater in Kashkar was significant (Fig. 1). Salinization coefficient is a salinization indicator of groundwater. Salinization coefficient range of fresh water, brackish water and salt water is <1, 1–2, >2, respectively. As shown in Table 3, salinization coefficient varies with areas. A salinization coefficient of >2 was observed in some sampling sites for deep groundwater in the Aksu Prefecture, between 1 and 2 in Bayingolin Prefecture and Turfan Prefecture and <1 in the remaining sampling points.
(3) The salinization of deep groundwater in Akesu, Shihezi and Turfan was more severe among all prefectures and cities. The comparison of water quality data in 2003 and 2011 revealed that the increase rate in TDS of J1-19 Akesu, shiK1 in

Shihezi and J1-87 in Turfan were over 200% (Table 2).

4. Causes of salinization of deep groundwater

Many reasons might cause salinization of deep groundwater and different areas tend to undergo different salinization processes. For example, in coastal areas, seawater encroachment might result in the salinization of groundwater [3]; irrigation using polluted water in agricultural areas and intense evaporation of shallow groundwater in arid areas might also be the reason for salinization of shallow groundwater; mixed exploitation might possibly cause the salinization of deep groundwater. The main reasons for the salinization of deep groundwater in Xinjiang are discussed as follows.

4.1. Years' of intensive exploitation

The movement of groundwater is very slow under natural conditions. The water quality of groundwater in different aquifer systems in the research area is relatively stable. However, as we enter the twenty-first century, the number of deep wells and exploitation quantity go up strikingly (Table 1), and the groundwater level continuously drops. The original hydrological and geographical environment is ruined with significant changes in original recharge, runoff and drainage conditions, which lead to shallow (TDS is commonly 3–5 g/L) recharging of groundwater (TDS is generally less than 1–2 g/L). All these contribute to the changes in the chemical composition of groundwater; for example, the increase in TDS and Cl^- concentration aggravating salinization.

4.2. Leakage recharge caused by thin confining bed in some areas

In the aquifer systems of some areas, the confining bed between the shallow and deep aquifer systems is very thin, or even absent. As a result of intensive exploitation, considerable permeation pressure is generated between the shallow and deep aquifer systems and the leakage recharge of the shallow aquifer system in the areas where the confining bed is thin is intensified. This phenomenon leads to the encroachment of highly mineralized water into deep aquifer system, which results in the salinization of deep groundwater. In order to understand the shallow groundwater (depth <50 m) quality of deep groundwater serious salinization area, we take seven, nine, eight and five shallow ground water samples in Aksu, Bayingolin, Kashgar and Turpan, respectively. Then, we calculate the salinization coefficient as in Table 4. As can be seen from Table 4, partial shallow groundwater of Bayingolin, Kashgar and Turpan are salty, which have the opportunity of leakage recharge to deep groundwater.

4.3. Connection between salt and fresh water layers caused by extensive groundwater extraction well construction technology

With the opening up of the well drilling market, some unqualified well drilling teams having no construction qualification are engaged in groundwater well drilling. Because of the lack in welling techniques, backfilling is common and the quality of water-sealing is poor. If salt water or slightly salt water layer is overlaid, the groundwater in proximity to the well is likely to be salinized.

4.4. Connection between aquifer layers of low-quality wells and out-of-service wells

Under natural conditions, due to the existence of the confining bed, the exchange between shallow aquifer system and deep aquifer system is difficult. However, if the confining bed is damaged artificially, the polluted water in the shallow level will infiltrate and pollute the deep groundwater. Most of the low-quality wells or out-of-service wells are not subjected to proper technological treatment. Generally, 1–3 aquifer groups are drilled. With vertical connection between out-of-service wells and holes, horizontal aquifer layers isolated from each other are connected, which results in the connection between water-bearing structures. The low-quality wells or out-of-service wells accelerate the leakage recharge and connectivity of the salt water layer. As a consequence of this, the more the groundwater pumped, the more severe the salinization.

5. Prevention and control measures against the salinization of deep groundwater

5.1. Strict control of the exploitation of deep groundwater

Deep groundwater is a precious and limited resource. Its formation dates back to the ancient geological age due to extremely slow recharge. Excessive exploitation will inevitably cause a series of geological problems. Therefore, a comprehensive arrangement must be established to achieve a reasonable

Table 2
Assessment indicators of salinization of deep groundwater in Xinjiang in 2003 and 2010 (unit: mg L^{-1})

Administrative area on municipal level	Number of monitored well	Year	Total hardness	TDS	SO_4^{2-}	Cl^-	Salinity level
Aksu	J1-19	2003	125.0	510.0	64.4.0	53.2.0	Serious salinity
		2011	403.8	895	299.6	238	
		Variation rate/%	223.0	75.5	365.2	347.4	
	J2-34	2003	780.6	2533.2	749.3	808.3	Less salinity
		2011	792.2	2690.0	817.7	810.0	
		Variation rate/%	1.5	6.2	9.1	0.2	
	JI-30	2003	231.2	584.5	205.6	136.1	Less salinity
		2011	132.9	570.0	166.8	149.1	
		Variation rate/%	−42.5	−2.5	−18.9	9.6	
	J1-25	2003	133.1	298.2	60.5	78	Less salinity
		2011	132.9	290	61.2	73.1	
		Variation rate/%	−0.2	−2.8	1.2	−6.3	
	J2-29	2003	135.1	201.2	36.5	22.0	No salinity
		2011	92.0	162.4	27.5	15.8	
		Variation rate/%	−31.9	−19.3	−24.7	−28.2	
	J2-39	2003	330.3	792.0	220.9	257.4	No salinity
	XJ-85	2011	265.8	740	216.2	207.9	
		Variation rate/%	−19.5	−6.6	−2.1	−19.2	
	J1-28	2003	376.3	531.1	135.4	99.3	No salinity
		2011	143.1	242.1	64.4	41.6	
		Variation rate/%	−62.0	−54.4	−52.4	−58.1	
	S1-10	2003	288.2	437.7	108.6	75.9	No salinity
		2011	158.4	256.0	61.2	43.0	
		Variation rate/%	−45.0	−41.5	−43.7	−43.4	
	J2-23	2003					–
	XJ-89	2011	327.1	621.1	162.2	116.1	
		Variation rate/%					
Altay	S1-122	2003	989.8	2034.5			No salinity
		2011	279.8	563.1	193.3	69.5	
		Variation rate/%	−71.7	−72.3			
Bayingolin	J1-10	2003	350.3	638.4	234.4	113.4	Serious salinity
		2011	664.4	1134.4	479.5	163.4	
		Variation rate/%	89.7	77.7	104.6	44.1	
	J1-11	2003	33.0	427.2	118.2	90.8	Serious salinity
		2011	30.7	600.1	132.1	157	
		Variation rate/%	−7.0	40.5	11.8	72.9	
	J2-87	2003	428.3	830.0	315.1	170.2	Serious salinity
		2011	419.1	840.0	330.3	164.2	
		Variation rate/%	−21.5	12.1	48.3	−35.3	
	J1-75	2003	342.3	737.9	232.5	172.3	Less salinity
		2011	351.6	792.6	254.5	178.5	
		Variation rate/%	2.7	7.4	9.5	3.6	
	J1-1	2003	157.0	350.0			No salinity
	XJ-61	2011	115.5	230.0	49.7	36. 6	
		Variation rate/%	−264.3	−342.9			
	J2-78	2003					–
		2011	400.7	1040.8	346	279.6	
		Variation rate/%					
Bortala	J1-143	2003	176.1	213.7			Serious salinity
		2011	427.4	547.2	143.3	38.0	
		Variation rate/%	142.7	156.1			
	J2-172	2003	253.2	289.4			No salinity
		2011	236.8	280.3	63.3	15.1	
		Variation rate/%	−6.5	−3.1			
	J1-142	2003	140.1	214.8			No salinity
	XJ-20	2011	133.3	208.1	38.6	28.7	
		Variation rate/%	−4.9	−3.1			

(*Continued*)

Table 2
(*Continued*)

Administrative area on municipal level	Number of monitored well	Year	Total hardness	TDS	SO_4^{2-}	Cl^-	Salinity level
Changji	H13	2003	270.0	510.0			Moderate salinity
		2011	277.2	590.0	152.4	57.1	
		Variation rate/%	2.7	15.7			
	J1-115	2003	300.2	619.2			Less salinity
		2011	308.7	607.4	195.6	86.7	
		Variation rate/%	2.8	−1.9			
	J2-118	2003					–
		2011	245.0	401.1	83	27.2	
		Variation rate/%					
Hotan	J2-75	2003	295.2	611.7	91.3	170.2	Serious salinity
		2011	325.1	710.4	149.5	173.5	
		Variation rate/%	10.1	16.1	63.8	1.9	
	J2-69	2003	433.0	1050.0			Serious salinity
		2011	743.2	1445.6	491.7	261.6	
		Variation rate/%	71.6	37.7			
	J2-77	2003	303.2	660.2	140.3	131.2	Moderate salinity
		2011	304.6	731.8	168.2	123.3	
		Variation rate/%	0.5	10.9	19. 9	−6.0	
	J1-61	2003	640.5	1114.1	405.4	197.1	No salinity
		2011	340.4	711.4	258.4	136.2	
		Variation rate/%	−46.9	−36.2	−36.3	−30.9	
	J1-68	2003	450.4	740.4	348.7	93.6	No salinity
		2011	390.5	706	308.8	93.2	
		Variation rate/%	−0.6	−0.3	−0.4	0.0	
Kashi	J1-49	2003	160.1	560	192.1	108.5	Serious salinity
		2011	207.5	708.9	247.9	132.6	
		Variation rate/%	29.6	26.6	29.1	22.2	
	J2-47	2003	370.3	597.9	254.6	65.2	Serious salinity
		2011	565.3	999.3	427.1	129	
		Variation rate/%	52.7	67.1	67.8	97.9	
	C16	2003	404.8	550.0	295	41.6	Serious salinity
		2011	496.4	790.0	416.6	71.7	
		Variation rate/%	22.6	43.6	41.2	72.4	
	J2-60	2003	380.3	921.3	305.5	250.3	Moderate salinity
		2011	419.1	1021.1	326.4	283.1	
		Variation rate/%	10.2	10.8	6.8	13.1	
	C1	2003	536.8	850.0	418	112.1	Moderate salinity
		2011	575.1	970.0	492.3	104	
		Variation rate/%	7.13	14.12	17. 8	−7.2	
	C35	2003	440	670	341.8	65.4	Moderate salinity
		2011	421.4	790	408.9	65.9	
		Variation rate/%	−4.23	17.91	19.6	0.8	
	C24	2003	579.5	740.0	386	65.4	Moderate salinity
		2011	560.3	840.0	437.6	62.3	
		Variation rate/%	−3.31	13.51	13.4	−4.7	
	C43	2003	541.8	740.0	388.5	68	Less salinity
		2011	545.4	780.0	404.3	65.9	
		Variation rate/%	0.7	5.4	4.1	−3.1	
	J1-51	2003	243.2	814.1	280.5	227.6	No salinity
		2011	97.1	600.0	178.3	136.2	
		Variation rate/%	−60.1	−26.3	−36.4	−40.2	
	J2-46	2003	350.3	623.1	192.1	53.2	No salinity
		2011	199.3	322.8	105.3	21.5	
		Variation rate/%	−43.1	−48.2	−45.2	−59.6	
Karamay	J1-177	2003	185.2	339.3	91.3	39	Serious salinity
		2011	191.7	394.4	102.6	50.9	
		Variation rate/%	3.5	16.2	12.4	30.5	

(*Continued*)

Table 2
(*Continued*)

Administrative area on municipal level	Number of monitored well	Year	Total hardness	TDS	SO_4^{2-}	Cl^-	Salinity level
Shihezi	004	2003	104.1	210.0	64.4	22.7	Serious salinity
		2011	195.1	310.0	82.2	23.4	
		Variation rate/%	87.4	47.6	27.6	3.1	
	Shik1	2003	82.1	180.0	42.3	14.9	Serious salinity
		2011	472.3	900.0	325.9	142.8	
		Variation rate/%	475.3	400.0	670.5	858.4	
Tacheng	J1-131	2003	271.2	465.4			Serious salinity
		2011	350.6	652.0	241.4	28.7	
		Variation rate/%	79.4	186.6			
	J2-150	2003					–
		2011	727.8	1607.7	599.7	152.7	
		Variation rate/%					
	J2-154	2003					–
		2011	239.9	325.2	107.6	50.2	
		Variation rate/%					
	J2-147	2003					–
		2011	121	127.5	14.9	17.2	
		Variation rate/%					
	J1-127	2003	179.1	331.7			Moderate salinity
		2011	199.9	367.8	80.9	28.7	
		Variation rate/%	11.61	10.88			
	J2-163	2003					–
		2011	298.3	750.6	283.8	46.6	
		Variation rate/%					
Turpan	J1-84	2003	296.0	570.0			Serious salinity
		2011	644.0	1102.5	313.3	301.1	
		Variation rate/%	117.6	93.4			
	J1-87	2003	85.0	220.0			Serious salinity
		2011	1124.4	2048.9	968.1	316.1	
		Variation rate/%	1222.8	831.3			
	J1-81	2003	516.4	767.9	258.4	195.7	No salinity
		2011	253.5	373.5	82.4	82.4	
		Variation rate/%	−50.9	−51.4	−68.1	−57.9	
	J2-89	2003	641.5	1,343	628.2	120.5	No salinity
		2011	108.4	432.2	149.5	76.0	
		Variation rate/%	−83.1	−67.8	−76.2	−36.9	
	J1-86	2003	254.2	1833.7	291.1	822.4	No salinity
	XJ-49	2011	202.4	275.6	88.6	21.5	
		Variation rate/%	−20.4	−85.0	−69.6	−97.4	
Urumqi	J3-2	2003	216.0	400.0			Serious salinity
		2011	500.9	839.7	295	113.3	
		Variation rate/%	131.9	109.9			
	J3-10	2003	205	280			Serious salinity
		2011	286.2	416.4	133.1	41.6	
		Variation rate/%	39.6	48.7			
	J3-1	2003	200	470			Serious salinity
		2011	265.8	582.9	152.4	57.3	
		Variation rate/%	32.9	24.0			
	J3-9	2003	175.0	350.0			No salinity
		2011	147.9	342.0	75.1	18.7	
		Variation rate/%	−15.5	−2.3			

(*Continued*)

Table 2
(*Continued*)

Administrative area on municipal level	Number of monitored well	Year	Total hardness	TDS	SO_4^{2-}	Cl^-	Salinity level
Yili	J1-160	2003	250.2	323.6			Serious salinity
		2011	279.8	454.1	126.2	35.1	
		Variation rate/%	11.8	40.3			
	J2-181	2003	430.3	471.2			Less salinity
		2011	254.2	493.2	112.3	45.9	
		Variation rate/%	−40.9	4.7			
	J1-156	2003	260.2	347.6			No salinity
		2011	130.2	169.5	23.8	8.6	
		Variation rate/%	−50.0	−51.2			
	J1-158	2003	200.2	230.8			No salinity
		2011	179.4	222.9	24.8	14.3	
		Variation rate/%	−10.4	−3.4			
	J2-140	2003	216.2	338.3			No salinity
		2011	118.9	168.8	32.6	10.8	
		Variation rate/%	−45.0	−50.1			

Note: Serious salinity refers to increase rate of one of the indicators surpassed 20%; moderate salinity, less salinity and no salinity refer to increase rate of one of the indicators between10 and 20%, between 0 and 10%, and less than 0%, respectively.

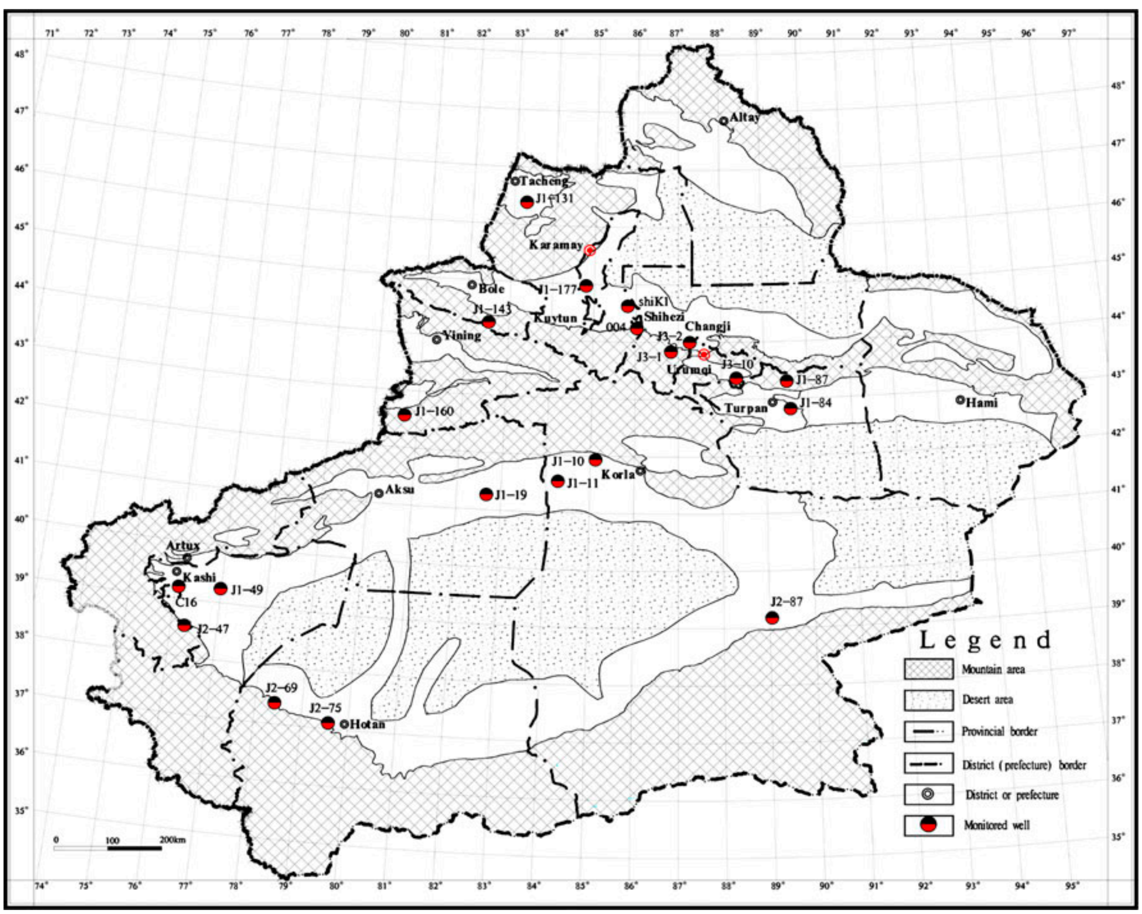

Fig. 1. Location of sampling points of serious salinized deep groundwater in Xinjiang plain areas.

Table 3
Salinization coefficient of 20 salinized deep groundwater in Xinjiang

Administrative area on municipal level	Number of monitored well	Cl^- ($mg\,L^{-1}$)	HCO_3^- ($mg\,L^{-1}$)	CO_3^{2-} ($mg\,L^{-1}$)	Salinization coefficient
Aksu	J1-19	238.0	112.1	0	2.1
Bayingolin	J1-10	163.4	261.5	0	0.6
	J1-11	157.0	130.8	6.1	1.1
	J2-87	164.2	139.5	0	1.2
Bortala	J1-143	38.0	368.6	0	0.1
Hotan	J2-75	173.5	246.6	0	0.7
	J2-69	261.6	399.7	0	0.7
Kashi	J1-49	132.6	128.3	0	1.0
	J2-47	129.0	261.5	0	0.5
	C16	71.7	112.1	0	0.6
Karamay	JI-177	50.9	199.3	0	0.3
Shihezi	004	23.4	155.8	0	0.2
	ShiK1	142.8	211.9	0	0.7
Tacheng	J1-131	28.7	286.4	0	0.1
Turpan	J1-84	301.1	224.2	0	1.3
	J1-87	316.1	261.5	0	1.2
Urumqi	J3-2	113.3	199.3	0	0.6
	J3-10	41.6	199.3	0	0.2
	J3-1	57.3	274.0	0	0.2
Yili	J1-160	35.1	264.0	0	0.1

Note: Salinization coefficient = $Cl^-/(HCO_3^- + CO_3^{2-})$.

exploitation and utilization of surface water, shallow groundwater and deep groundwater based on the consideration of the total amount of water resources. Principles of optimized utilization of high-quality water and limited utilization must be respected during the determination of allowable exploitation quantity.

5.2. Reinforcement of water intake authorization and standardization of its approval procedures

Careful control should be imposed on the water intake application, water resources assessment, final inspection, as well as the granting of water intake permit. Law enforcement should be enhanced and illegal water intake should be severely punished. Dynamic monitoring and study of groundwater should be intensified, by establishing layered monitoring system for shallow, middle-level and deep groundwater. Well monitoring network should be improved and the understanding of groundwater quality evolution of different layers should be deepened. Only through strict implementation of these measures can the salinization trend of deep groundwater be effectively controlled.

5.3. Proper treatment of out-of-service wells and holes

First of all, survey should be carried out in villages with wells and holes according to the statistics to locate out-of-service wells and holes. Then, corresponding detection (physical survey, laboratory test of water near the well, etc.) should be executed to make sure whether salinization exists near the groundwater. After that, technological treatment scheme should be formulated based on the specific situation, such as sealing, backfilling and cementing so that out-of-service wells and holes can be prevented from polluting the deep fresh water layer [4–6].

5.4. Full utilization of salt water layer

Currently, there are many ways of utilizing salt water. Firstly, its direct use after exploitation in cooling and washing sanitation facilities is a feasible water-saving measure. Secondly, salt water can be indirectly used in rotational and mixed irrigation of fresh and salt water. Based on the water resources distribution, crop species, their salt tolerance and growth period, salt water and fresh water can be used for irrigation alternately. Thirdly, salt water can be used

Table 4
Salinization coefficient of shallow groundwater in Aksu, Bayingolin, Kashi and Turpan

Administrative area on municipal level	Number of monitored well	Cl^- (mg L^{-1})	HCO_3^- (mg L^{-1})	CO_3^{2-} (mg L^{-1})	Salinization coefficient
Aksu	XJ-87	207.9	510.6	0.0	0.4
	J1-27	37.3	186.8	0.0	0.2
	J1-32	629.4	560.4	0.0	1.1
	J1-21	17.9	242.8	0.0	0.1
	S2-38	152.7	298.9	0.0	0.5
	S2-60	316.8	641.3	0.0	0.5
	XJ-88	460.2	529.3	0.0	0.9
Bayingolin	J2-82	243.7	173.1	0.0	1.4
	J2-6	15.1	224.2	0.0	0.1
	S1-94	416.5	300.1	0.0	1.4
	S1-91	964.1	501.9	0.0	1.9
	S2-8	1569.8	613.9	0.0	2.6
	J1-76	867.3	211.7	0.0	4.1
	31	83.6	251.5	0.0	0.3
	23	551.2	209.6	0.0	2.6
	47	379.9	410.2	0.0	0.9
	303	632.5	645.5	0.0	1.0
	305	388.6	377.2	0.0	1.0
	201	27.1	335.3	0.0	0.1
	202	33.9	234.7	0.0	0.1
	203	52.0	234.7	0.0	0.2
	205	45.2	100.6	0.0	0.4
	206	49.7	209.6	0.0	0.2
Kashi	J2-42	98.9	240.3	0.0	0.4
	S1-51	612.9	645.1	0.0	1.0
	J1-42	759.8	311.3	0.0	2.4
	J2-61	315.4	458.3	0.0	0.7
	XJ-69	512.2	351.2	0.0	1.5
	XJ-70	781.3	287.7	0.0	2.7
Turpan	XJ-71	32.3	151.9	0.0	0.2
	XJ-69	512.2	351.2	0.0	1.5
	XJ-70	781.3	287.7	0.0	2.7
	J1-77	29.4	174.3	0.0	0.2
	3	445.9	137.0	0.0	3.3
	10	21.5	102.1	0.0	0.2
	7	319.7	348.7	0.0	0.9
	8	745.5	85.9	0.0	8.7
	11	98.2	84.7	0.0	1.2

in fish breeding to make economic benefits following the examples of other countries and areas [7–9].

6. Conclusions

According to the analysis of deep groundwater samples collected in Xinjiang, we can know that the salinization occurred in a spot-like pattern in Xinjiang. Among the 60 groundwater samples we collected, 16 were seriously salinized, which made up 26.7% of the total wells sampled. The deep groundwater salinization in Xinjiang is gradually becoming more obvious; we should combine prevention with control to avoid spot-like salinization evolved into regional salinization.

Acknowledgements

The study is financed by the National Natural Science Foundation of China (51069016), the Special Research Funds of Public Service Sectors of the Ministry of land Resources (200911004) and the Key Discipline Construction Fund of Hydrology and Water Resources in Xinjiang (xjswszyzdxk 20101202).

References

[1] Z. Zhang, L. Li (Eds.), China's Groundwater Resources, China Map Press, Xinjiang, 2005 (in Chinese).
[2] X. Dong, M. Deng, Xinjiang Groundwater Resources, Xinjiang Science and Technology Press, Urumqi, 2005 (in Chinese).
[3] A.K. Plappally, J.H. Lienhard, Costs for water supply, treatment, end-use and reclamation, Desalin. Water Treat. 51(1–3) (2013) 200–232.
[4] Y. Wang, Cause analysis and prevention of salinization of deep groundwater in Cangxian county, Groundwater 15(3) (1995) 37–38 (in Chinese).
[5] X. Wang, S. Jiang, Indoor overwinter experiment of sea cucumber seedlings using underground salt water, Shandong, Fisheries 23(10) (2006) 43 (in Chinese).
[6] Y. Teng, R. Zuo, J. Wang, X. Lin, Progress in geochemistry of regional groundwater evolution, Adv. Water Sci. 21(1) (2010) 127–134 (in Chinese).
[7] Z. Zhou, G. Zhang, J. Wang, M. Yan, Risk assessment of soil salinity by multiple-variable indicator Kriging in the low plain around the Bohai Sea, Shuili Xuebao 42(10) (2011) 1144–1151 (in Chinese).
[8] L. Lin, M. Jin, Characteristics of hydrological cycle and salt migration in Yanqi basin, Yellow River 28(5) (2006) 5–7 (in Chinese).
[9] R. Dobhal, D.P. Uniyal, V.K. Gupta, P. Singh, B. Sharma, S. Tyagi, R. Singh, Arsenic speciation analysis and remediation techniques in drinking water, Desalin. Water Treat. 40(1–3) (2012) 231–243.