Environ Earth Sci (2016)75:383
DOI 10.1007/s12665-016-5287-0

ORIGINAL ARTICLE

Hydrochemical assessment of surface water for irrigation purposes and its influence on soil salinity in Tikanlik oasis, China

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Received: 23 June 2015 / Accepted: 11 November 2015

Abstract The assessment of irrigation water quality and the study of its negative influence on soil are very important, because the soil salinization is one of the most important ecological problems. Water quality parameters such as pH, TDS, EC, contents of SO_4^{2-}, Cl^-, HCO_3^-, CO_3^{2-}, Mg^{2+}, Ca^{2+}, Na^+ and K^+ in Qiala reservoir were determined. This water is used for the irrigation of the soils in Tikanlik oasis. Monthly water sampling was done in 2007. The analysis indicated that major dominant water type was Na^+-Cl^-. For the classification of irrigation properties of the water the following chemical indices were calculated: sodium absorption ratio, residual sodium carbonate, sodium percentage, permeability index and irrigation coefficient. The classifications of Wilcox and USDA Salinity Laboratory were also used. The analysis of all classification methods have lead us to the conclusion that there was a low possibility of sodium or alkalinity hazard in the soils irrigated by the water of Qiala reservoir but there was a big salinity hazard. This negative influence was also confirmed by IWQI, through calculation of which the various quality indicators of irrigation water were generalized and represented by a single value. The salinization degree of the soils in the 14 different areas of Tikanlik oasis and the dynamics of its changes during the irrigation period were studied as well. During the irrigation period TDS and EC values increased abruptly in the upper soil horizon. All this led to the accumulation of high quantity of salts in the upper soil horizon during the irrigation season. Continuous monitoring of surface water by IWQI is the effective way for the complex assessment of irrigation water quality as well as for the control of the soil salinization process.

Keywords Soil salinization · Irrigation water quality · Statistical analysis · Graphical plots · IWQI · China

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Introduction

The soil salinization is considered nowadays as one of the most important ecological problems worldwide (Wang et al. 2008). This big trouble exists in more than hundred countries. Global total area of the salt-affected soils is about 950 million hectares, accounting for 7.26 % of the earth's land area (Wang et al. 1993). The area of the salt-affected soils is about 27 million hectares in China. About 6.7 million hectares of these are farmland, accounting for 7 % of the total farmland in China which is mainly occurs in Xinjiang, Gansu, Ningxia, Inner Mongolia Autonomous Region and eastern coastal areas.

Salinization is a cumulation of soluble salts in the soil profile. This is a soil degradation process, mainly human-caused, which affects the high productive irrigated agricultural ecosystems in the semi-arid and arid regions and can negatively influence on the agricultural production and sustainable development of agricultural regions (Amezketa 2006; Eilers et al. 1997; Ghassemi et al. 1995; Houk et al. 2006; Masoud and Koike 2006; Metternicht 2001; Miller

Published online: 23 February 2016

and Donahue 1995; Mougenot et al. 1993; Semih and Cankut 2008). The salinization reduces the productive capacity of the soil and degrades soil chemical and physical properties. Considering the food shortage problem in the entire world in 21st century, one of the major problems of agriculture is the reduction and control of the soil salinity (Amezketa 2006).

The irrigation water quality has a huge influence on the soil salinization process (Van-Camp et al. 2004; Wu et al. 2014). The influence of irrigation water on the soil salinity was studied by different researchers (Houk et al. 2006; Novikova et al. 2009). The quick development of the irrigation in the last century, mainly performed without ensuring good irrigation water and soil management, brought to the large-scale salinization of agricultural areas (Smedema et al. 2000). Irrigation water constantly have some amount of dissolved substances, which are referred to as salts (Al-Ghobari 2011) and include the dissolved solids obtained from the soils by water and rock weathering. The suitability of water for irrigation, in terms of salinity, directly depends on the type and amount of salts present, the ionic compound of the irrigation water, the kind of soil, concrete plant species and stage of growth, the quantity of water leached below the root layer, or on the leaching fraction (Ayers and Westcot 1976; Bauder and Brock 2001; Hanson et al. 1999; Rhoades 1977; USDA, Natural Resources Conservation Service 2002; Western Fertilizer Handbook 1995). Salts of the irrigation water can influence on the soil structure and crop yield (Fipps 2003). Its toxic elements can menace agricultural plants and decrease the soil suitability for agriculture (Asawa 2008). Many researchers have focused in the last years on the influence of poor quality of irrigation water on the soil degradation and agricultural plants (Pang et al. 2010; Bezborodov et al. 2010; Pedrero et al. 2010).

One of the important tools which promote sustainable development of the agricultural regions and provide important data for the water management is the monitoring of irrigation water quality. Many scientists offer different hydrochemical indices, such as sodium adsorption ratio, sodium percentage, residual sodium carbonate, permeability index and irrigation coefficient to describe the quality of the irrigation water and the practical sides of this water for agriculture (Li et al. 2013; Mkandawire 2008; Fakhre 2014; Cieszynska et al. 2012; Offiong and Edet 1998; Brindha and Elango 2013). Nonetheless, good outcomes can be received by analyzing the chemistry of all ions rather than single parameters of irrigation water (Hem 1985). The more effective solution for this issue is Irrigation Water Quality Index (IWQI), which combines numerous indicators and expresses the quality of the irrigation water in the form of one value (Saeedi et al. 2010; Meireles et al. 2010). In various studies the different ways for the calculation of IWQI were elaborated taking into account the same hydrophysical and hydrochemical characteristics of irrigation water but with different methods of statistical analysis and interpretation of the parameter values (Vahab et al. 2014; Brindha and Kavitha 2015).

Taking all previously mentioned into consideration the aims of this study were (1) the assessment of the Qiala reservoir water for irrigation purposes, and (2) the evaluation of its influence on salinization of the soil in Tikanlik oasis. This research will help local agricultural workers and engineers to implement the necessary prevention and reclamation actions to reduce soil degradation process.

Materials and methods

Study area

The Tikanlik oasis is located in the arid region of Northwest China (40°32′–40°45′E and 87°18′–89°48′N), particularly in the lower reaches of the Tarim River (Fig. 1). This region is in the north of Yuli city and in the south of Ruoqiang city of Xinjiang Uygur Autonomous Region. The ground surface is highly flat. The elevation decreases from north to south. Arid region has climate, which is typical for inner-continental land masses, with a large-scale temperature range, lesser effects of East Asian Monsoon, low humidity and precipitation. The weather is quite windy and dry, the annual precipitation vary from 17 to 42 mm. The potential evaporation in this region could be up to 3200 mm/year (Chen et al. 2012; Shen and Chen 2010). This arid region thereby is one of the droughtiest regions in the universe. Annual total solar radiation ranges from 5692 to 6360 MJ/m^2, cumulative daylight hours vary from 2780 to 2980. Annual accumulative temperature ≥10 °C ranges from 4100 to 4300 °C, the average daily temperature is 13–17 °C.

In the region often strong winds blow. Soils in this region are either salinized meadow soils or alkalized desert soils. In the area the surface groundwater is chiefly supplied from seepage of agriculture irrigation. This region has heavy radiation and heat resources which make it an excellent area for photophilous and thermophilous crops growth, therefore it becomes a good quality as well as high-yield cotton production area (Xu et al. 2011). Thereby, due to climatic characteristics, the main agricultural crop in Tikanlik oasis is the upland cotton (*Gossypium hirsutum*). Through the extreme drought, approximately the 95 % of the total area of 1140 km^2 arable land could be irrigated. June–August is the peak irrigation period. Flood methods and drip irrigation are used for the irrigation of agricultural lands with locally practiced watering norms.

In this region the irrigation water is supplied from the Tarim River, which was extremely consumed in the last 50 years due to intensive social and economic development.

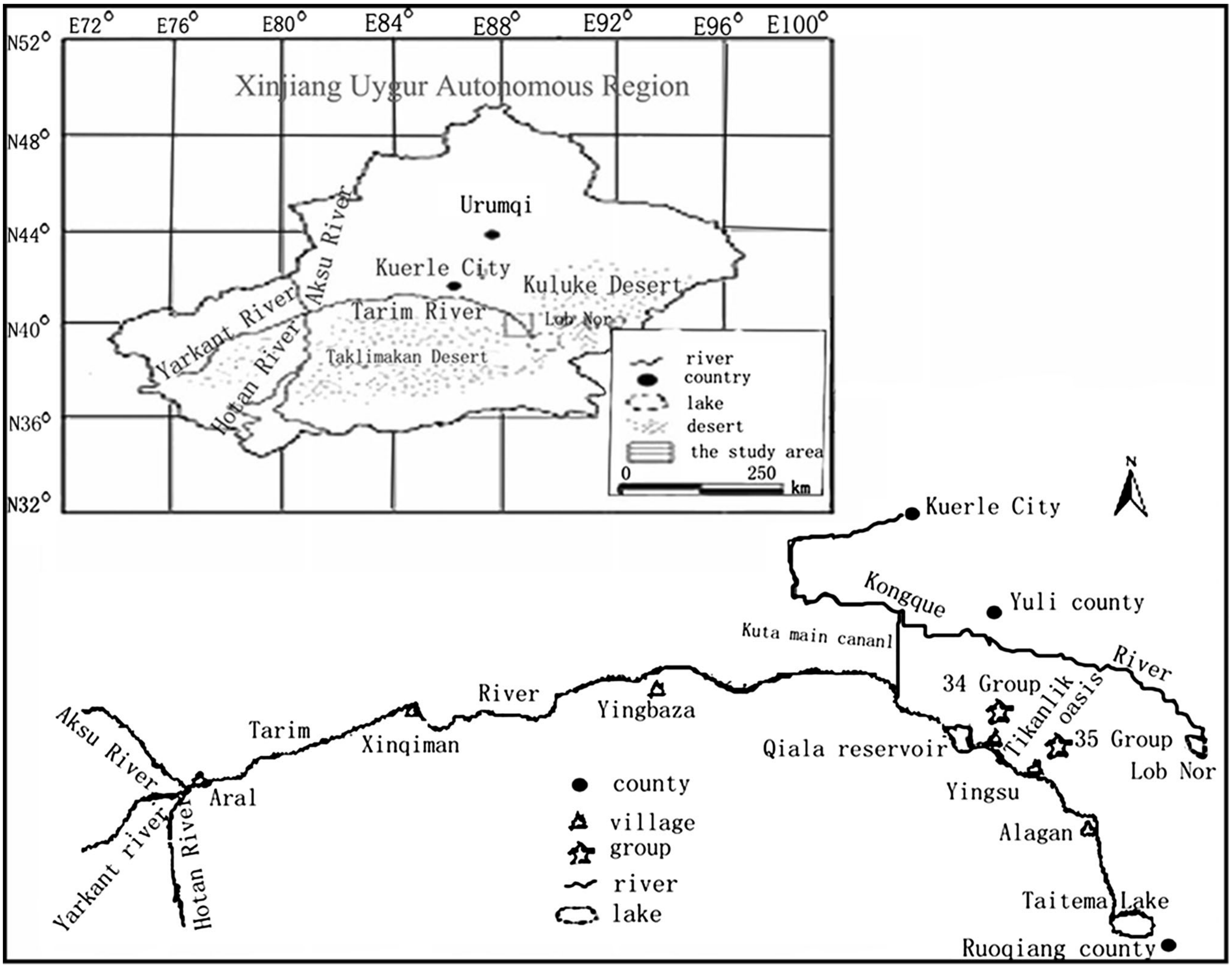

Fig. 1 The sketch map of the study area

It has a big influence on environmental conditions of the Tarim River basin (Liu and Chen 2007). For irrigation of fields the huge quantity of water have been diverting from the upper river. River water quality was permanently decreasing affected by the drainage water discharging back and big salt load to the downstream irrigated places. On the basis of mentioned information, it is supposed that natural salinity accumulation process may occur in this area. Caused by the inconsiderate ways of irrigation and methods of farming, the soil salinization in the Tikanlik oasis is extremely serious. Due to this, the sustainable agriculture development and environment conditions in this part of the Tarim River were seriously violated.

Methodology

The irrigation water for agriculture in the investigated area comes from the Qiala reservoir, which was built on the Tarim River. The studied water samples were taken monthly in 2007. Once the irrigation water samples were collected, they were airproofed momentarily, after which were moved to the laboratory for future analysis. TDS in the irrigation water were measured by weighting, the concentration of Cl^- was measured by the colorimetric methods using a microfluxautoanalyzer, the content of SO_4^{2-} was determined by volume, the concentrations of Mg^{2+}, Ca^{2+} were dignified by the AAS, and the contents of K^+, Na^+ were determined by the flame emission spectroscopy, the value of pH was measured by the acidity meter (PHS-2C), HCO_3^-, CO_3^{2-} and alkalinity were determined by the acid titration method, hardness value was measured by the EDTA volumetric method, and EC was determined by the conductivity meter (DDS-307).

The suitability of irrigation water was assessed using residual sodium carbonate (RSC), sodium adsorption ratio (SAR), permeability index (PI), sodium percentage (Na %), irrigation coefficient (IC), TDS and EC. The classifications of irrigation water, based on these statistical and physico-chemical parameters are reviewed in the Table 1.

Table 1 The irrigation water classifications, according to listed physico-chemical and statistical parameters

Classification pattern	Categories	Ranges	Description
Sodium absorption ratio (SAR) (Richards 1954)	Excellent	0–10	Don't have sodium hazard
	Good	10–18	Low sodium hazard
	Fair	18–26	Harmful for almost all types of soils
	Poor	>26	Unsuitable for irrigation
Percent sodium (% Na) (Wilcox 1955)	Excellent	0–20	Excellent for irrigation
	Good	20–40	Good for irrigation
	Permissible	40–60	Permissible for irrigation
	Doubtful	60–80	Doubtful for irrigation
	Unsuitable	>80	Unsuitable for irrigation
Residual sodium carbonate (RSC) (Richards 1954)	Good	<1.25	Generally safe for irrigation
	Medium	1.25–2.5	Marginal as an irrigation source
	Bad	>2.5	Generally not suitable for irrigation without improvement
Permeability index (PI) (Doneen 1964)	Class-I	>75	Good for irrigation
	Class-II	25–75	Suitable for irrigation
	Class-III	<25	Unsuitable for irrigation
Irrigational coefficient (IC) (Radov et al. 1971)	Good	>18	Water is suitable for irrigation
	Satisfactory	18–6	The water suitable for irrigation after pretreatment of soil or its
	Unsatisfactory	6–1.2	Can use water for irrigation only after deep pretreatment of its
	Poor	<1.2	The water is not suitable for irrigation
Electrical conductivity (EC, $\mu S\ cm^{-1}$) (Wilcox 1955)	Excellent	<250	Low salinity water
	Good	250–750	Medium salinity water
	Permissible	750–2250	High-salinity water
	Doubtful	2250–5000	Doubtful for irrigation
	Unsuitable	>5000	Unsuitable for irrigation
Total dissolved salts (TDS, mg/l), USDA salinity laboratory classification	Excellent	<150	Low salinity hazard
	Good	150–500	Permissible for irrigation
	Fair	500–1500	Doubtful for irrigation
	Poor	>1500	Unsuitable for irrigation
Cl (meq/L) (Doneen 1958)	Class-I	>5	Very good—good for irrigation
	Class-II	5–10	Good—hazardous for irrigation
	Class-III	<10	Hazardous-very hazardous for irrigation

The sodium hazard of irrigation water was definite by the relative and absolute concentrations of cations and was expressed in terms of SAR (sodium absorption ratio). The SAR values were determined by using Eq. 1 (Richards 1954):

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \quad (1)$$

where the given concentrations of ions were reported in meq/l.

There was a considerable relationship between the irrigation water SAR values and the extent to which sodium was attracted by the soil. If irrigation water contains the low quantity of calcium and the high quantity of sodium, the cation-exchange complex could fed up with sodium. The calculation of the SAR value for specified surface water gives helpful information about the water sodium hazard for crops and agricultural lands. The water classification in point of SAR is shown in Table 1 (Bouwer 1978).

The sodium in irrigation water is also expressed in Na %, which was calculated by the formula given in the Eq. 2 (Wilcox 1955):

$$\mathrm{Na\%} = \frac{(\mathrm{Na}^+ + \mathrm{K}^+) \times 100}{(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+ + \mathrm{K}^+)} \quad (2)$$

where the given concentrations of ions were reported in meq/l.

For the determination of the hazardous effect of carbonate and bicarbonate of irrigation water the RSC (Richards 1954) was calculated and decided by the Eq. 3:

$$\mathrm{RSC} = (\mathrm{CO}_3^{2-} + \mathrm{HCO}_3^-) - \left(\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+}\right) \quad (3)$$

where the given concentrations of ions were reported in meq/l.

The permeability of the soil is influenced by the durable use of irrigation water. It is affected by Na^+, Mg^{2+}, Ca^{2+} and HCO_3^- contents of the soil. Doneen (1964) has developed a principle for evaluating the suitability of the irrigation water based on the Permeability Index (PI). PI was defined by the Eq. 4:

$$\mathrm{PI} = \frac{\mathrm{Na}^+ + \sqrt{\mathrm{HCO}_{3^-}}}{\mathrm{Ca}^{2+} + \mathrm{Mg}^{2+} + \mathrm{Na}^+} \times 100 \quad (4)$$

where the given concentrations of ions were reported in meq/l.

For the water quality characterization, alkali or irrigation coefficient (IC) was also used, which is the ratio of the contents of sodium, chlorides and sulfates (Radov et al. 1971). The irrigation coefficient was determined by the Eqs. 5, 6 and 7: if $rNa^+ < rCl^-$, the Eq. 5 was used; if $rCl^- < rNa^+ < (rCl^- + rSO_4^2)$, the Eq. 6 was used; if $rNa^+ > (rCl^- + rSO_4^{2-})$, the Eq. 7 was used ($rNa^+$, rCl^-, rSO_4^{2-} are the concentrations of the Na^+, Cl^-, SO_4^{2-} in meq/l).

$$\mathrm{IC} = \frac{288}{5r\mathrm{Cl}^-} \quad (5)$$

$$\mathrm{IC} = \frac{288}{r\mathrm{Na}^+ + 4r\mathrm{Cl}^-} \quad (6)$$

$$\mathrm{IC} = \frac{288}{10\mathrm{Na}^+ - 5r\mathrm{Cl}^- - 9r\mathrm{SO}_4^{2-}} \quad (7)$$

For the complex assessment of the quality of irrigation water we used the IWQI (Irrigation Water Quality Index). During the processing of this method we relied on the criteria given by FAO paper No.29 (Ayers and Westcot 1985; Ayres and Westcot 1999) as well as we took into consideration the specifics of the region studied. The advantage of the IWQI is that by the use of it the different quality indicators of the irrigation water are generalized and presented in the form of a single value. That value can vary from 0 to 100 range (Table 2). During the calculation of the IWQI 4 groups of factors which have negative influence on the soil quality and crop yield were taken into consideration. The series of them according to their importance are: (1) influencing on the soil salinity, (2) influencing on the soil infiltration character, (3) toxic ions, (4) factors, that can affect the crops by different ways (Table 3). For each group the Weighting factor (Wf) was determined, the aim of which is to show the relative importance of each group and clarify the interconnections between the different groups. The Weighting factor of each group (Wf_i) was defined by the Eq. 8:

Table 2 Classification of IWQI

IWQI	Class	Categories
>80	I	Excellent
60–80	II	Good
45–60	III	Permissible
30–45	IV	Doubtful
<30	V	Unsuitable

$$\mathrm{Wf}_i = \frac{\frac{1}{K_i}}{\sum_{i=1}^{n} \frac{1}{K_i}} \quad (8)$$

The K_i is a temporary weight value of each group that is varied from 1 (highly important) to 5 (less important). For example K_i of first group is 1 and K_i of second group is 2.

IWQI was calculated by the following equation:

$$\mathrm{IWQI} = \sum_{i=1}^{n} \mathrm{Wf}_i \times \frac{\sum_{i=1}^{m} \mathrm{QR}_i}{m} \quad (9)$$

Where: IWQI is the Irrigation Water Quality Index, Wf_i is the Weighting factor of nth group, QR_i is the quality rating nth group's mth indicator, m is the amount of indicators in nth group.

In the different parts of the Tikanlik oasis the soil profiles were set for the measuring of the salinity of soil, particularly for TDS and EC. From each place, the samples from 0–5, 5–10, 10–20, 20–30, 30–50, 50–80 and 80–100 cm were collected monthly (during the irrigation period: from April to November) in 2007, were categorized and kept in an aluminum box. In each layer three soil samples were analyzed, and the mean value of the analysis results of three samples was taken into account as the representative of this layer.

Results and discussion

The accordant values of some water quality parameters were resumed in Table 4. The values of pH of the irrigation water in the investigated area in different months ranged between 7.7 and 8.28, indicating the type of irrigation water as

Table 3 Groups, weighting factors and quality rating functions for IWQI parameters

Groups of parameters	Hazard group	Weighting factor for a group (Wf)	Parameter	Range (*V*—value of the parameter)	Quality rating function
1	Salinity	0.4922	EC (μS cm^{-1})	$V < 700$	QR = 100
				$700 \le V \le 1500$	QR = 113.13–1.8751 *V*/100
				$1500 \le V \le 3000$	QR = 110–1.6667 *V*/100
				$3000 \le V \le 4500$	QR = 100–1.3333 *V*/100
				$4500 \le V \le 6700$	QR = 182.7–2.7272 *V*/100
2	Infiltration rate	0.2461	SAR <3	EC (μS cm^{-1})	QR = 100
				$V \ge 700$	QR = 6 *V*/100 + 58
				$700 \ge V \ge 450$	QR = 10 *V*/100 + 40
				$450 \ge V \ge 200$	QR = 30 *V*/100
				$V \le 200$	
			3–6	$V \ge 1200$	QR = 100
				$1200 \ge V \ge 700$	QR = 3 *V*/100 + 64
				$700 \ge V \ge 200$	QR = 5 *V*/100 + 50
				$V \le 200$	QR = 30 *V*/100
			6–12	$V \ge 1900$	QR = 100
				$1900 \ge V \ge 1200$	QR = 2.143 *V*/100 + 59.286
				$1200 \ge V \ge 500$	QR = 3.5714 *V*/100 + 42.143
				$V \le 500$	QR = 12 *V*/100
			12–20	$V \ge 2900$	QR = 100
				$2900 \ge V \ge 1700$	QR = 1.25 *V*/100 + 63.75
				$1700 \ge V \ge 500$	QR = 2.083 *V*/100 + 49.58
				$V \le 500$	QR = 12 *V*/100
			20–40	$V \ge 5000$	QR = 100
				$5000 \ge V \ge 3950$	QR = 0.7143 *V*/100 + 64.286
				$3950 \ge V \ge 2900$	QR = 2.381 *V*/100–9.0476
				$V \le 2900$	QR = 2.069 *V*/100
3	Ion toxicity	0.1639	Na^+ (by SAR)	$V < 3$	QR = 100
				$3 \le V \le 6$	QR = 115–5 *V*
				$6 \le V \le 9$	QR = 135–8.3333 *V*
				$9 \le V \le 18$	QR = 80–2.2222 *V*
				$18 \le V \le 26$	QR = 130–5 *V*
			Cl^- (mg/l)	$V < 140$	QR = 100
				$140 \le V \le 175$	QR = 160–0.4286 *V*
				$175 \le V \le 350$	QR = 110–0.1429 *V*
				$350 \le V \le 700$	QR = 120–0.1714 *V*
4	Miscellaneous effects	0.0978	HCO_3^- (mg/l)	$V < 90$	QR = 100
				$90 \le V \le 295$	QR = 106.6–0.073 *V*
				$295 < V \le 500$	QR = 120–0.12 *V*
				$500 < V \le 700$	QR = 135–0.15 *V*
				$V > 700$	QR = <30
			pH	$V = (8–7)$	QR = 100
				$8 < V \le 8.5$	QR = 740–80 *V*
				$8.5 < V \le 9$	QR = 780–85 *V*
				$V > 8.5$	QR = <15
				$V = (7–8)$	QR = 100
				$7 > V \ge 6.5$	QR = 80 *V*–460
				$6.5 > V \ge 6$	QR = 85 *V*–495
				$V < 6$	QR = <15

Table 4 Irrigation water chemistry of Qiala reservoir

Months	EC	pH	TDS	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	K^+	Total salt content
Jan 2007	2080	8.15	1310	**	344	256	388	89	82	225	**	1384
Feb 2007	1770	7.7	1210	**	354	224	322	84	73	199	**	1256
Mar 2007	1650	7.85	1115	**	306	220	314	80	64	194	**	1178
Apr 2007	6360	8	4475	**	488	1153	1340	201	233	902	**	4137
May 2007	3510	7.7	2445	**	291	616	121	121	132	474	**	2370
June 2007	1790	8	1165	**	259	229	355	64	71	209	**	1187
Jul 2007	3960	7.92	2795	**	398	661	817	54	190	550	**	2670
Aug 2007	2580	8.28	1655	**	278	360	498	101	89	293	**	1619
Sep 2007	1280	8.22	885	**	227	178	282	69	56	151	**	963
Oct 2007	1380	8.22	955	**	275	182	239	72	51	157	**	976
Nov 2007	2650	8.25	2430	**	373	593	656	127	117	473	**	2339
Dec 2007	6810	8.05	4160	**	488	1261	1037	188	245	818	**	4037
Max.	6810	8.28	4475	**	488	1261	1340	201	245	902	**	4137
Min.	1280	7.7	885	**	227	178	121	54	51	151	**	963
Mean	2985	8.03	2050	**	340	494	531	104	117	387	**	2010

Concentrations of all ions (expect pH) and TDS were reported in mg/l, EC in µS cm^{-1}

** Trace quantities

alkaline. The values of EC in different months ranged from 1280 to 6810 µS cm^{-1}. In concordance with the Wilcox (1955) irrigation water classification based on the electrical conductivity, the studied water belong to the following categories: the permissible category within 6 months; doubtful category within 4 months; the unsuitable category within 2 months. During the peak irrigation period (June–August) the quality of the irrigation water fluctuated between permissible-doubtful categories. The huge range in electrical conductivity was essentially specified to geochemical processes and anthropogenic activities dominating in this area. TDS in the investigated area in different months varied in the range of 885–4475 mg/l. The irrigation water in the investigated area fell from fresh to brackish water types. According to the classification of USDA Salinity Laboratory the irrigation water belong to the fair category within 6 months (500–1500 mg/l), and in the remaining 6 months it belong to the poor category (>1500 mg/l). The high TDS increases the osmotic potential in the soil, which complicates the water absorption by plants. Depending on the concentration of Cl^- in the irrigation water and the sensitivity of the agricultural crops, it could have toxicity effect. Amount of Cl^- in the investigated area in different months varied in the range of 178–1261 mg/l or 5.01–35.52 meq/l. According to the Doneen's (1958) classification the irrigation water belong to the Class-II (5–10 meq/l) during 6 months, and in the remaining 6 months it belong to the Class-III (>10 meq/l), and in irrigation period (April–November) in 62.5 % cases—to the Class-III, and in 37.5 % cases—to Class-II, which is the evidence of the potential toxic effects of irrigation water on crops. The allocation pattern of major anions and cations in the irrigation water of the study area, according to the mean annual values (mg/l), was as $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ and $SO_4^{2-} > Cl^- > HCO_3^- > CO_3^{2-}$ accordingly. Totally, the pattern of distribution of all major ions was as $SO_4^{2-} > Cl^- > Na^+ > HCO_3^- > Mg^{2+} > Ca^{2+} > CO_3^{2-} > K^+$.

Correlation analysis

This is a bivariate method which represents the degree of relationship among two random variables. Interpretation of correlation gives an idea of quick water quality monitoring method. For this purpose, Spearman's rank coefficient of correlation between the nine parameters of water quality, namely pH, EC, HCO_3^-, TDS, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+ and IWQI was calculated for correlation analysis as displayed in Table 5. The correlation analysis was obtained from the 12-month study to determine whether the changes of the main hydrochemical parameters of the water quality have identical trend or not during the entire study period. The correlation coefficient of Spearman's rank is expressed by ρ, the value of which is continuously from -1.0 to $+1.0$. A positive ρ matches to an increasing monotonic trend between two water quality parameters whereas a negative ρ matches to a decreasing monotonic trend among two parameters of water quality. A high-level correlation coefficient (nearby -1.0 or $+1.0$) means an effective relationship among two variables. If the value is nearby zero aims no relationship between them (Srivastava and

Table 5 Correlation matrix

	EC	pH	TDS	HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Mg^{2+}	Na^+	IWQI
EC	1									
pH	−0.128	1								
TDS	0.981	−0.109	1							
HCO_3^-	0.874	−0.153	0.886	1						
Cl^-	0.988	−0.090	0.991	0.875	1					
SO_4^{2-}	0.862	0.124	0.884	0.887	0.859	1				
Ca^{2+}	0.850	0.005	0.856	0.760	0.872	0.730	1			
Mg^{2+}	0.981	−0.153	0.980	0.889	0.975	0.875	0.761	1		
Na^+	0.977	−0.109	1.000	0.879	0.989	0.884	0.850	0.979	1	
IWQI	−0.995	0.109	−0.991	−0.876	−0.994	−0.860	−0.846	−0.986	−0.988	1

Ramanathan 2008). A positive correlation was observed in all hydrochemical parameters, except pH. In all months, pH showed the low correlation with most of the variables (Table 5). Between the all remaining eight hydrochemical parameters the strong correlation was observed. This correlation clearly identifies the main ions contribution to the Qiala reservoir's water salinity. Also, these main ions has similar trend of the change that related with geochemical (mineral weathering, ion exchanges, water–rock interaction) and human factors (irrigation of upper river agricultural lands and drainage water discharging back to Tarim River). The strong positive correlation of the main exchangeable ions (sodium-calcium, sodium-magnesium) shows that the similar decline and rise of these ions is the result of the precipitation—dissolution reactions and the effect of concentration (Masoud 2013). The strong negative correlation was observed between IWQI and all hydrochemical parameters, except pH. This means that the increasing of the values of these hydrochemical parameters brings to deterioration of the irrigation water quality.

Irrigation water quality

Sodium adsorption ratio (SAR)

The sodium adsorption ratio values indicate the degree when irrigation water goes into cation-exchange reactions in soil. Sodium replacing changing magnesium and calcium harms structure of the soil by making it dense and impermeable as well as diminishes water and air movement. Hence, the investigation of sodium concentration is necessary when taking into account the irrigation suitability. Irrigation water classification using SAR values is given in Table 1. Sodium adsorption ratio values varied from 3.26 to 10.22 with a middle value of 5.79 (Table 6). Except the April (SAR = 10.22), during the all months, the irrigation water fell in the excellent category. It is also worth mentioning that in April, the irrigation volume was low, and it didn't have any significant impact on soil structure.

Table 6 Statistical representation of irrigation water parameters

Months	SAR	Na %	RSC	PI	IC
Jan 2007	4.12	46.44	−5.64	57.71	7.5
Feb 2007	3.82	45.69	−4.48	58.41	8.5
Mar 2007	3.90	47.47	−4.32	60.08	8.7
Apr 2007	10.22	57.10	−21.47	61.22	1.7
May 2007	7.06	54.72	−12.28	60.52	3.0
June 2007	4.26	49.92	−4.87	61.24	8.3
Jul 2007	7.86	56.34	−12.01	62.35	2.9
Aug 2007	5.10	50.54	−7.91	59.01	5.4
Sep 2007	3.26	44.72	−4.40	57.86	10.8
Oct 2007	3.45	46.51	−3.34	60.98	10.5
Nov 2007	7.25	56.09	−9.99	62.83	3.3
Dec 2007	9.21	54.40	−21.82	58.72	1.6
Maximum	10.22	57.10	−3.34	62.83	10.8
Minimum	3.26	44.72	−21.82	57.71	1.6
Mean	5.79	50.83	−9.38	60.08	6.02

Sodium percentage

The sodium percentage is another important factor to study the sodium hazard, as well as for judging the water quality for agricultural use. Irrigation water with high Na % will rise the exchange of sodium content in soil, affecting the soil permeability and texture. The use of high percentage sodium water for irrigation purposes stunts the growth of plants. The irrigation water classification through Na %, is given in Table 1. The sodium percentage values in Qiala reservoir in different months were 44.72–57.10 % with a medium value of 50.83 % (Table 6). All water samples quality was in the permissible category for irrigation purposes and may have some negative influence on the soil permeability and texture. Therefore, some agromelioration actions such as deep plowing, subsoiling, high leaching, good drainage and the use of farm manure, organic matter, crop residues, are necessary for its control in the irrigated areas.

Residual sodium content (RSC)

Richards (1954) has also defined the hazardous effect of CO_3^{2-} and HCO_3^- on water quality at conditions RSC, and if the concentration of bicarbonate and carbonate is higher than calcium and magnesium, it will influence on suitability of irrigation water. When water has high RSC it has a high value of pH, and the area which is irrigated with this kind of water turn to barren due to deposition of Na_2CO_3. The classification of irrigation water in account of the RSC values is given in Table 1. In the present study, the RSC values were below the 1.25 meq/l in all months. So, the Qiala reservoir water was safe for irrigation use as mentioned in the above discussion.

Permeability index (PI)

The permeability of the soil is influenced by the durable usage of poor quality water, and the affecting ingredients are the Na^+, Mg^{2+}, Ca^{2+} and HCO_3^- and the soil type. The PI values of the Qiala reservoir water in different months ranged between 57.71 and 62.83 with a middle value of 60.08 (Table 6). Hence, the Qiala reservoir water fell within the Class II, which indicated that the water was suitable for irrigation purposes (Doneen 1964; Table 1).

Irrigation coefficient (IC)

In Russian practice, for the assessment of irrigation water the empirical irrigation coefficient (IC) is widely used. Depending on the IC, the water quality was evaluated (Table 1). In the present study, the IC values in different months ranged between 1.6 and 10.8 with a middle value of 6.02 (Table 6). According to the Radov et al. (1971) classification, the irrigation water belong to the satisfactory category (12–6) during 6 months and in the rest 6 months—to the unsatisfactory category (6–1.2). During the peak irrigation period (June–August) the quality of irrigation water belongs to the satisfactory category only in 1 month, which shows the risk of salinization.

Piper diagram

The general chemical nature of water may be recognized by plotting major cation and anion concentrations on the Piper diagram (Piper 1944; Li et al. 2013). Cations, stated as percentages of total cations (meq/l), are plotted as a single point on the left triangle, anions, similarly appear as a point on the right triangle. Mentioned two triangles are then projected into the central diamond-shaped area parallel to the upper parts of central area. The Piper diagram handily indicates the differences and similarities between water samples in different months as those with similar qualities will tend to plot together as groups. As Fig. 2 shows, during the year, major dominant water type was Na^+-Cl^-. The next dominant water type was mixed Na^+-Cl^--SO_4^{2-}. Plot showed that alkalis (sodium and potassium) exceeded the alkaline earths (calcium and magnesium), and strong acids (chlorine and sulfate) exceeded weak acids (bicarbonate and carbonate).

USSL diagram

The classification system to assess the suitability of irrigation water use can be defined by USSL diagram where SAR and EC values are used (Richards 1954). According to this approach, the irrigation water can be categorized into four types: C1, C2, C3 and C4 according to salinity hazard and S1, S2, S3 and S4 according to sodium hazard. These two the most significant parameters indicate the usability of irrigation water for agricultural goals. The plots of water chemistry of Qiala reservoir in different months on the USSL diagram are shown in Fig. 3. The data of analysis plotted on the USSL diagram illustrated that in 6 months, the irrigation water fell in the field of C3S1, showing the big salinity and the low alkalinity in the water applicable for irrigation use on nearly all types of soil with low danger of exchangeable sodium, but the special management for the control of salinity was needed. The water samples in 3 months fell in the field of C4S2, indicating a medium alkalinity and a very high salinity hazard. The samples in 3 months fell in C4S3, indicating an extreme salinity and a big alkalinity hazard (Fig. 3), and one of them was in July, which is considered as the peak irrigation

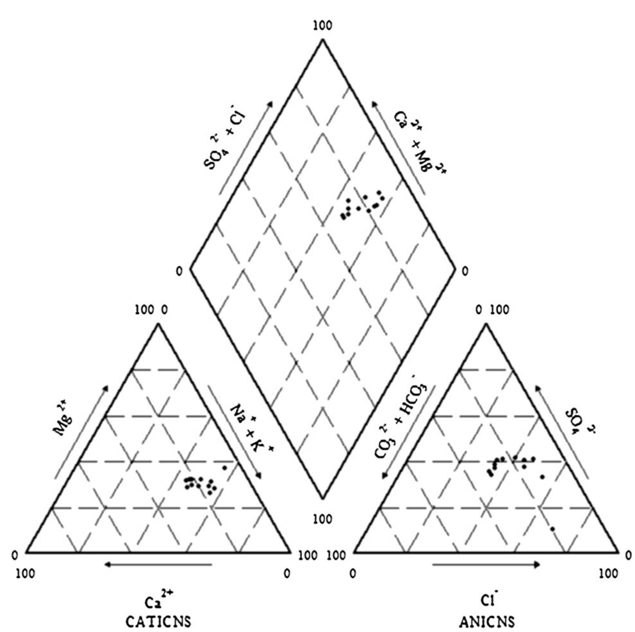

Fig. 2 Piper trilinear diagram for the Qiala reservoir water

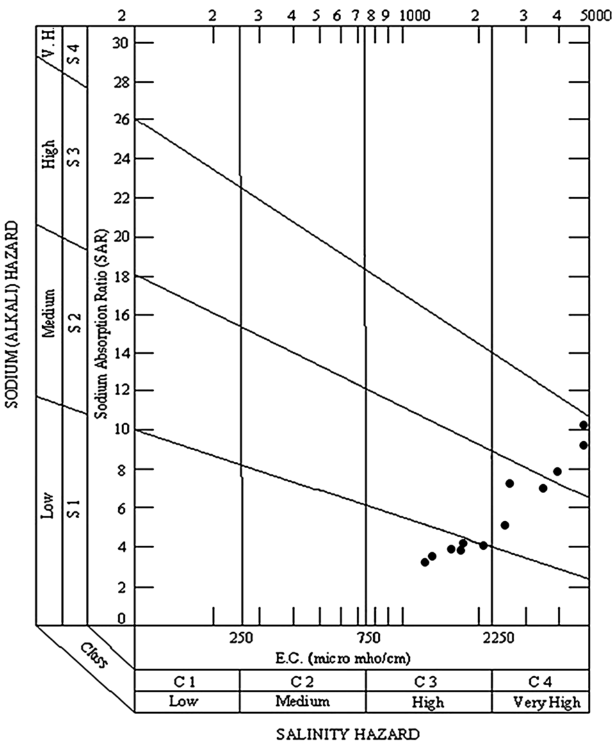

Fig. 3 Classification of irrigation waters using U.S. salinity diagram

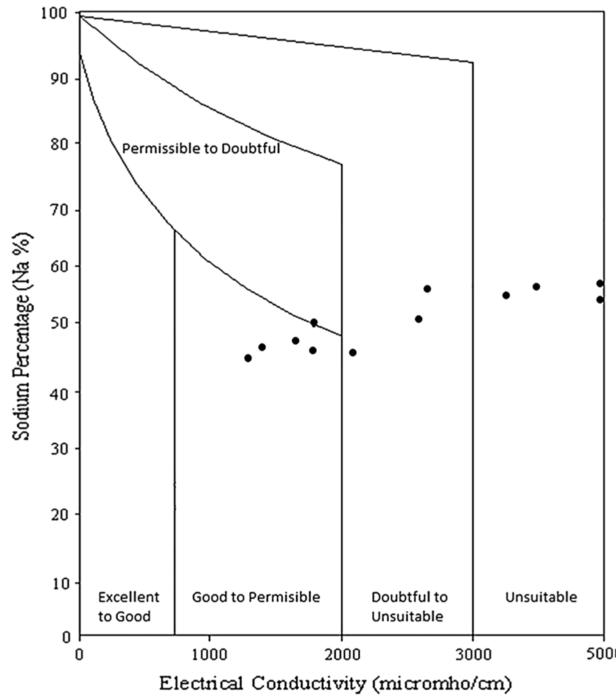

Fig. 4 Classification of irrigation waters using Wilcox diagram

period and could have had dangerous consequences to soils irrigated by this water.

Wilcox diagram

Wilcox (1955) used Na % and EC for estimating the suitability of water for irrigation use. According to the Wilcox classification method, the irrigation water in 4 months fell under "good to permissible" category, the water samples in 4 months fell under "unsuitable" category, the water samples in 3 months fell under "doubtful to unsuitable" category, and the water samples in 1 month fell under "permissible to doubtful" category (Fig. 4). During the Tikanlik oasis irrigation (April-November), the usable water in 37.5 % of cases fell under "unsuitable" category, in 25 % of cases fell under "good to permissible" category, in 25 % of cases fell under "doubtful to unsuitable", and in 12.5 % of cases fell under "permissible to doubtful" category. In more than half of the irrigation period, the water used for irrigation could have had dangerous impact on soil quality. In some months, such fall of water quality may have been caused by both climate and geographical characteristics of the region and the large-scale agricultural activities in the upper stream of the Tarim River, particularly as a result of large-scale irrigation, drainage water outlet to the river causing a drop of the water quality and could have led to a higher salt load to the downstream irrigation places.

Irrigation water quality index

One of the most important issues agricultural workers are constantly confronted with is how to analyze a variety of water quality data and choose the correct conclusion for the optimal irrigation norms. The ideal solution for this problem could be the IWQI, which is the accurately calculated complex indicator of the water quality in a wide range of complex data and may give a clear description of the irrigation water quality by one value.

In Table 2 the water suitability scheme by IWQI is offered. Our research results are presented in Table 7: according to IWQI scheme, the irrigation water belong to the Class-I (>80) during 6 months, in 4 months it belong to the Class-III (60–80), and in 2 months it belongs to the Class-IV (30–45), and in irrigation period (April–November) in 37.5 % of cases—to the Class-I, in 50 % of cases—to the Class-II, and in 12.5 % of cases—to the Class-IV. The maximum value (91.93) of IWQI was observed in September, the minimum value (37.24)—in December, which is out of irrigation period and could not threaten agricultural areas.

It should be noted that in almost the all months the first group of the four group factors which influence on the soil salinity was the main reason for the reduction of the IWQI value. The third group (toxic ions) is on the second place of the reduction factors of IWQI value. The second group, which has an impact on infiltration character of the soil, has

Table 7 IWQI of the water of Qiala reservoir in the different months

Months	IWQI	Class	Categories
Jan 2007	83.6	I	Excellent
Feb 2007	87.2	I	Excellent
Mar 2007	88.5	I	Excellent
Apr 2007	41.8	IV	Doubtful
May 2007	67.3	II	Good
June 2007	87.3	I	Excellent
Jul 2007	62.6	II	Good
Aug 2007	77.7	II	Good
Sep 2007	91.9	I	Excellent
Oct 2007	90.7	I	Excellent
Nov 2007	72.3	II	Good
Dec 2007	37.2	IV	Doubtful

no negative effect on the quality of irrigation water throughout the year. Correlation analysis between the IWQI and hydrochemical parameters of the irrigation water showed that the increasing of the EC, TDS, Cl^{-}, Mg^{2+}, Na^{+} values has more negative impact on the quality of the irrigation water (Table 5). Thus, through the IWQI method, it was possible to give an assessment of the water quality of the Qiala reservoir for irrigation purposes by single value and avoid the various values which are derived from the evaluation by traditional single index methods.

Dynamics of soil salinization process

Part of the agricultural lands of the Tikanlik oasis is irrigated by the water of the Qiala reservoir. For the determination of the effect of the Qiala reservoir water on the irrigated soil, the soil salinization degree and its seasonal dynamics in the 14 different areas of the Tikanlik oasis were investigated. It should be noted that the groundwater level in the Tikanlik oasis is about 4 m, so it could not have strong effect on the study area soil salinization process. (Guo and Liu 2002; Fitzpatrick et al. 2003; Qiao and Yu 2003; Franzen 2007; Zhou et al. 2010; Huang et al. 2013). The TDS and EC, as salinization degree indicators, were investigated in the soil. In the soil sampling areas *Gossypium hirsutum* was cultivated and irrigated by the flood method.

The average value of TDS in the different layers of the soil ranged: between 3689 and 6614 mg/l in spring, between 3916 and 6324 mg/l in summer and between 3432 and 11,569 mg/l in autumn. According to the salinization degree classification scale in Table 8, all layers of the soil in spring and summer belonged to the medium categories, in autumn, the high categories of salinization were observed on the top layer of soil, and the medium categories were registered in the rest of the layers.

Table 8 Classification of saline soils by TDS (Camberato 2001)

Categories	Range of TDS value (mg/l)	Description
Low	1300–2500	Soil have low salt level
Medium	2500–7500	Soil have medium level
High	>7500	Soil have high salt level

The dynamics of the change of TDS value in the soil profile in different seasons is given in Fig. 5. The graph clearly shows that the maximum TDS values in spring were observed in 10–50 cm soil layers, and slight decrease in TDS values was observed at a soil section depth of 0–100 cm. In summer, in the middle of the irrigation season, a rise in TDS values was registered in the upper soil horizon. More significant decrease in TDS values was registered at a depth of 0–100 cm. The dynamics of a change in TDS values was strongly expressed in autumn, at the end of the irrigation period. Particularly the large accumulation of salts was observed in the 0–10 cm soil layers. Compared to spring, in autumn, TDS value increased by 2.4 and 1.5 times in the 0–5, 5–10 cm soil layers respectively. During the irrigation season a similar dynamics was observed also in the case of another indicator of the soil salinization level—EC (Fig. 6). The graph shows that during the beginning of the irrigation season (spring) a slight increase of the EC value was observed on the surface to the depth of soil, while the maximum values were observed at 10–80 cm of the soil layers. In the summer the EC value increase in the upper soil layers (0–10) was observed which affected the EC value change tendency of the soil profile. As a result, the contrary, a slight decrease of the EC value on the land surface to the depth was observed. And, at the end of the irrigation season (autumn) these changes became more noticeable, particularly in the upper more strong soil layers (0–30) the increase of EC value was observed and in comparison with the beginning of the irrigation season the EC value increased 2.3 times at 0–5 cm soil layer and 1.8 times at 5–10 cm. All this led to the large accumulation of salts in the upper soil horizon during the irrigation period; a process of soil salinization took place. In the studied soils the accumulation of salts also contributes the soil texture its hydraulic properties, and climatic conditions (little rainfall and high potential evaporation). In the arable lands of the Tikanlik oasis compared to the other lands (residential lands, orchards, grasslands, forests) the clay and silt content is rather high and the contrary the sand has a lower content, which may contribute to water capillary rise and the accumulation of the salts in the upper soil horizons (Zhou et al. 2010; Huang et al. 2013). Also the irrigation method highly influenced on the soil salinization process. As it was mentioned, the flood method was implemented

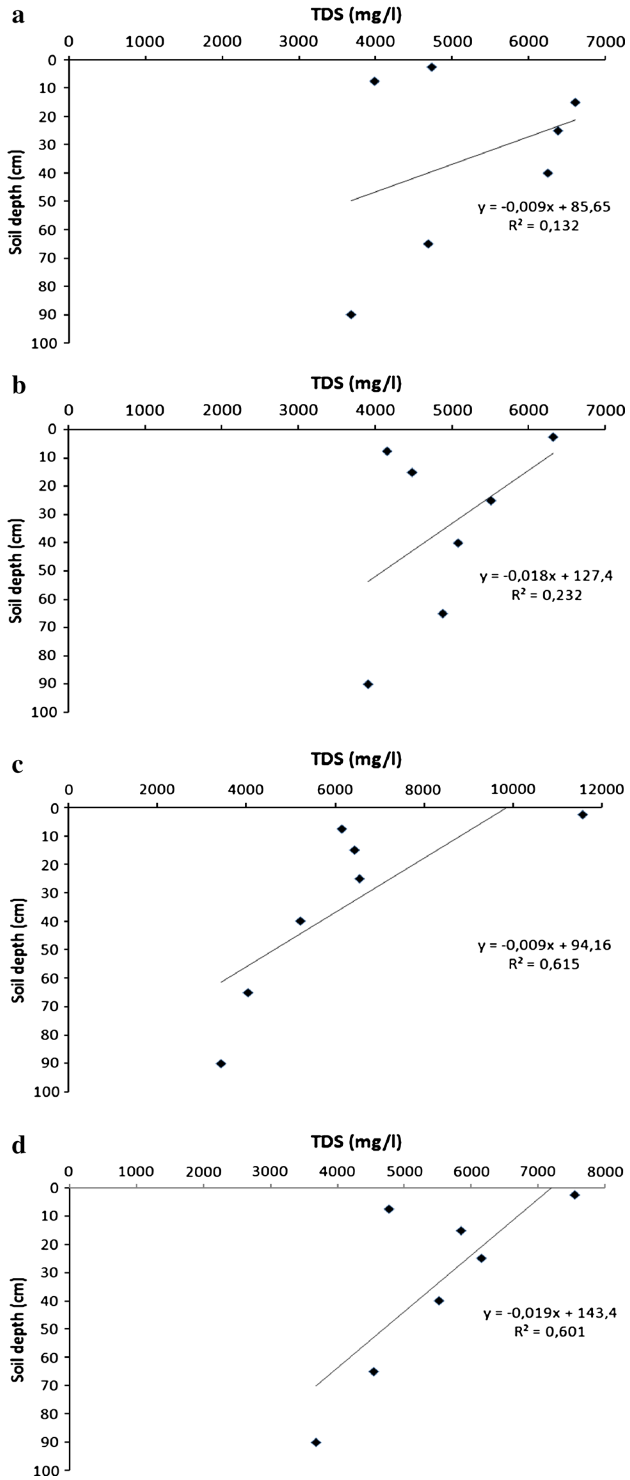

Fig. 5 Change of the TDS value in the soil profile according to the seasons. **a** Spring, **b** summer, **c** autumn, **d** mean

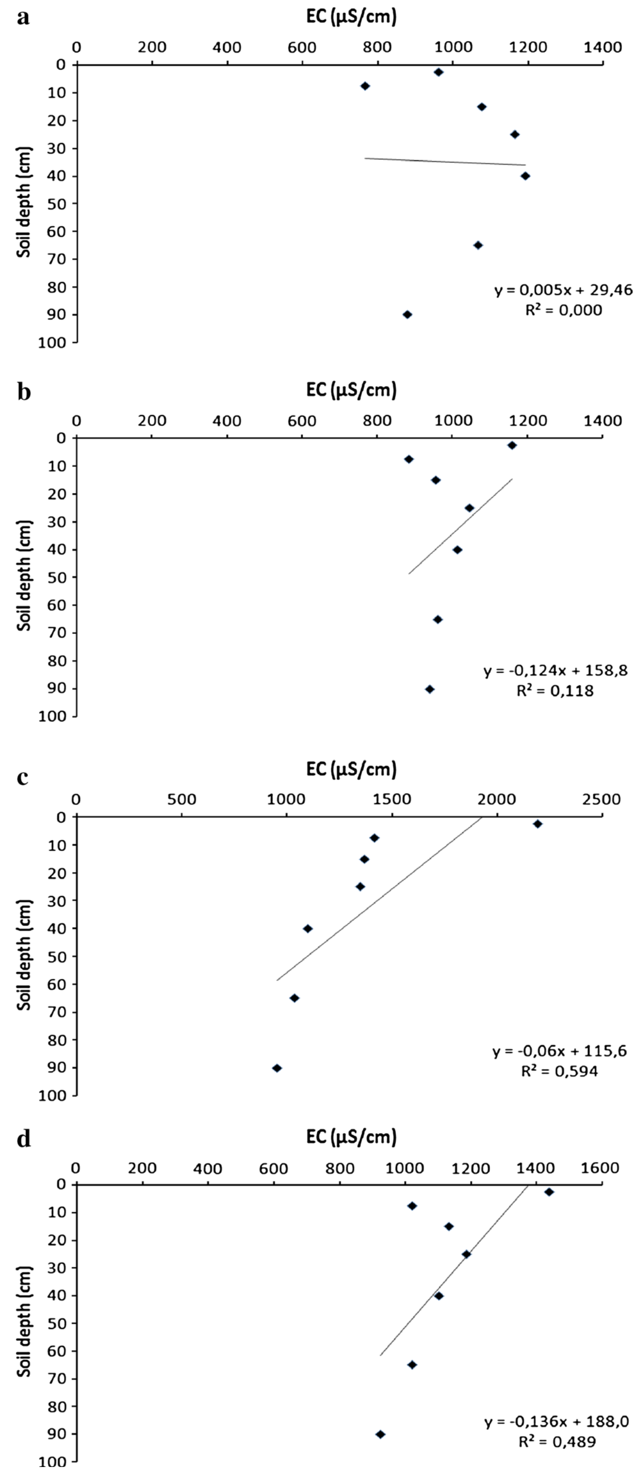

Fig. 6 Change of the EC value in the soil profile in the different seasons. **a** Spring, **b** summer, **c** autumn, **d** mean

for the irrigation of the study area, the efficiency of which in comparison with the drip irrigation is lower, and it caused the rise of the ground water level (about 1 m). Consequently, a high-efficiency irrigation methods usage can somehow mitigate the salinization process reducing the accumulation of the salts in the upper soil layer during the irrigation season.

As during the irrigation season due to intense evaporation, the accumulation of salts is observed in the upper soil horizons, then as a measure directed against the salinization process, the intensive irrigation by flood method is recommended after the vegetation period (Xiaoyu et al. 2015). By the use of it the easily soluble salts will be leached from the upper soil horizons and will be withdrawn from the root zone (similar process may occur by the natural reasons, e.g., heavy rains (Wenjun et al. 2008; Tarchouna et al. 2010), which regrettably lack in the study region). As a result of this the dangerous impact of soils on the crops growing in that area will be softened next year. Also for the maintenance of the salt balance in the soil and for the preservation of the crop yields in arid areas the good drainage is necessary (FAO 2002, 2005, 2007). According to some researchers, the subsurface drainage is more effective for desalination of salty soils and the process of salt cleaning may begin directly after it (Bahceci and Nacar 2008). However, the involvement of local farmers in the activities against salinization is also very important for the achievement of the best results, as they may become the key initiators of the technical solutions of their ecological problems.

Hence, the complex management policy, as a necessary management technique, must be constantly performed.

Conclusions

In 2007 water quality of Qiala reservoir was studied to understand its suitability for irrigation purposes. The EC values in different months ranged from 1280 to 6810 $\mu S\ cm^{-1}$, and TDS value varied in the range of 885–4475 mg/l. The major ions (mg/l) in the irrigation water of Qiala reservoir may have been ranked by concentration as follows: $SO_4^{2-} > Cl^- > Na^+ > HCO_3^- > Mg^{2+} > Ca^{2+} > CO_3^{2-} > K^+$, based on the average annual values. Good positive correlation was observed between EC, TDS values and the major ions. Piper plot showed that during the assessment, the major dominant water type was Na^+-Cl^-.

The suitability of Qiala reservoir's water for irrigation was assessed by EC, TDS, Cl^-, SAR, Na %, RSC, PI and IC classification. For the classification of the irrigation water, the U.S. Salinity and Wilcox diagrams were also used. The analysis of all classification methods have lead us to the conclusion that there was a low possibility of sodium or alkalinity hazard in the soils irrigated by the water of Qiala reservoir but there was a big salinity hazard, and the soil salinization could occur without the implementation of preventative measures. In order to avoid the variety of single index data, IWQI method was used and the various quality indicators of the irrigation water were generalized and represented by single value. IWQI showed that during the irrigation period the water was classified mainly as good and excellent, only in 1 month it was classified as doubtful. The main reason for the reduction of the IWQI value from four group factors was the first group which influenced on the soil salinity. The investigation of the soil salinization degree and its seasonal dynamics in the 14 different areas of the Tikanlik oasis showed that according to changes of TDS and EC values, the large accumulation of the salts observed in the upper soil horizon during the irrigation period, a process of soil salinization took place.

Considering the climate characteristics, irrigation water quality, soil texture, groundwater table of the Tikanlik oasis it is proposed to implement the preventing or reducing measures for the salinization process of the irrigated areas: drip irrigation, soil leaching by intensive irrigation at the end of the vegetation season, ensure good drainage, deep plowing, subsoiling and no less important is the involvement of the local farmers in preventing activities.

Acknowledgments Current research was supported by the CAS (Visiting Fellowship for Researchers from Developing Countries, Grant No. 2013FFZA0010).

References

Al-Ghobari HM (2011) Effect of irrigation water quality on soil salinity and application uniformity under center pivot systems in Arid region. Aust J Basic Appl Sci 5(7):72–80

Amezketa E (2006) An integrated methodology for assessing soil salinization, a pre-condition for land desertification. J Arid Environ 67:594–606

Asawa GL (2008) Irrigation and water resources engineering. NewAge International (P) Ltd., New Delhi

Ayers RS, Westcot DW (1976) Water quality for agriculture. FAO Irrigation and Drainage Paper No, 29 (Rev 1), Food and Agriculture Organization of the United Nations

Ayers RS, Westcot DW (1985) Water quality for agriculture, FAO Irrigation and drainage Paper No. 29, Rev. 1, U.N. Food and Agriculture Organization, Rome

Ayres RS, Westcot DW (1999) The water quality in agriculture, 2nd Campina Grande: UFPB. Studies FAO Irrigation and Drainage Paper No. 29

Bahceci I, Nacar AS (2008) Subsurface drainage and salt leaching in irrigated land in south east Turkey. Irrig Drain 57:1–11. doi:10.1002/ird.400

Bauder JW, Brock TA (2001) Irrigation water quality, soil amendment, and crop effects on sodium leaching. Arid Land Res Manag 15:101–113

Bezborodov GA, Shadmanov DK, Mirhashimov RT, Yuldashev T, Qureshi AS, Noble AD, Qadir M (2010) Mulching and water quality effects on soil salinity and sodicity dynamics and cotton productivity in Central Asia. Agric Ecosyst Environ 138:95–102. doi:10.1016/j.agee.2010.04.005

Bouwer H (1978) Groundwater hydrology. McGraw-Hill, New York

Brindha K, Elango L (2013) Environmental assessment of water quality in Nagarjuna Sagar reservoir, India. Earth Res 1(1):33–36. doi:10.12966/er.05.05.2013

Brindha K, Kavitha R (2015) Hydrochemical assessment of surface water and groundwater quality along Uyyakondan channel, south India. Environ Earth Sci 73:5383–5393. doi:10.1007/s12665-014-3793-5

Camberato J (2001) Irrigation Water Quality. Clemson University, Clemson

Chen YN, Yang Q, Luo Y, Shen YJ, Pan XL, Li LH, Li ZQ (2012) Ponder on the issues of water resources in the arid region of northwest China. Arid Land Geogr 35:1–9

Cieszynska M, Wesolowski M, Bartoszewicz M, Michalska M, Nowacki J (2012) Application of physicochemical data for water-quality assessment of watercourses in the Gdansk Municipality (South Baltic coast). Environ Monit Assess 184:2017–2029

Doneen LD (1958) Quality of water for irrigation. Proc. Conf. on Quality of Water For Irrigation. Water Resources Center, California Doneen LD (ed) 14:208

Doneen LD (1964) Notes on water quality in agriculture. Published as a Water Science and Engineering

Eilers RG, Eilers WD, Fitzgerald MM (1997) A salinity risk index for soils of the Canadian Prairies. Hydrogeol J 5:68–79

Fakhre A (2014) Evaluation of hydrogeochemical parameters of groundwater for suitability of domestic and irrigational purposes: a case study from central Ganga Plain, India. Arab J Geosci 7:4121–4131. doi:10.1007/s12517-013-1055-6

FAO (2002) Agricultural drainage water management in arid and semi-arid areas. FAO irrigation and drainage paper 61, Rome

FAO (2005) Materials for subsurface land drainage systems. FAO irrigation and drainage paper 60: Rome

FAO (2007) Guidelines and computer programs for the planning and design of land drainage systems. FAO irrigation and drainage paper 62, Rome

Fipps G (2003) Irrigation water quality standards and salinity management strategies. Texas Agricultural Extension Service, Texas A&M University System, College Station, TX. B-1667, 4-03, pp 1–19

Fitzpatrick RW, Merry RH, Cox JW, Rengasamy P, Davies PJ (2003) Assessment of physicochemical changes in dryland saline soils when drained or disturbed for developing management options. Technical Report 2/03. CSIRO Land and Water, Adelaide

Franzen D (2007) Managing saline soils in North Dakota. SF-1087 (revised), North Dakota State University, Fargo, ND 58105

Ghassemi F, Jakeman AJ, Nix HA (1995) Salinization of land and water resources. Human causes, extent, management and case studies. Centre for Resource and Environmental Studies, The Australian National University, Canberra ACT 0200, Australia

Guo ZR, Liu HT (2002) Secondary salinification of soil and dynamic control of groundwater in irrigation area of inland basin, northwestern China. Agro-environment Protection 21:45–48

Hanson B, Grattan SR, Fulton A (1999) Agricultural salinity and drainage. University of California Irrigation Program, University of California

Hem JD (1985) Study and interpretation of the chemical characteristics of natural water USGS. Water Supply paper 2254:117–120

Houk E, Frasier M, Schuck E (2006) The agricultural impacts of Irrigation induced waterlogging and soil salinity in the Arkansas Basin. Agric Water Manag 85:175–183

Huang T, Pang Z, Chen Y, Kong Y (2013) Groundwater circulation relative to water quality and vegetation in an arid transitional zone linking oasis, desert and river. Chin Sci Bull 58:3088–3097

Li P, Wu J, Qian H (2013) Assessment of groundwater quality for irrigation purposes and identification of hydrogeochemical evolution mechanisms in Pengyang County, China. Environ Earth Sci 69:2211–2225. doi:10.1007/s12665-012-2049-5

Liu YB, Chen YN (2007) Saving the "Green Corridor": recharging groundwater to restore riparian forest along the lower Tarim River, China. Ecol Res 25(2):112–117

Masoud EA (2013) Groundwater quality assessment in Wadi Fayd, Western Saudi Arabia. Arab J Geosci 6:247–258

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

Meireles A, Andrade EM, Chaves L, Frischkorn H, Crisostomo LA (2010) A new proposal of the classification of irrigation water. Revista Ciencia Agronomica 413:349–357

Metternicht G (2001) Assessing temporal and spatial changes of salinity using fuzzy logic, remote sensing and GIS. Foundations of an expert system. Ecol Model 144:163–177

Miller RW, Donahue RL (1995) Soils in Our Environment, 7th edn. Prudence Hall, Englewood

Mkandawire T (2008) Quality of groundwater from shallow wells of selected villages in Blantyre District, Malawi. Phys Chem Earth 33:807–811

Mougenot B, Pouget M, Epema G (1993) Remote sensing of saltaffected soils. Rem Sens Rev 7:241–259

Novikova AF, Luo G, Konyushkova MV (2009) Salinization dynamics in irrigated soils of the Svetloyarsk irrigation system Volgograd Oblast. Eurasian Soil Sci 42(13):1479–1486. doi:10.1134/S1064229309130080

Offiong OE, Edet AE (1998) Water quality assessment in Akpabuyo, Cross River basin, South-Eastern Nigeria. Environ Geol 34(2/3):167–174

Pang HC, Li YY, Yang JS, Liang YS (2010) Effect of brackish water irrigation and straw mulching on soil salinity and crop yields under monsoonal climatic conditions. Agric Water Manag 97:1971–1977. doi:10.1016/j.agwat.2009.08.020

Pedrero F, Kalavrouziotis I, Alarcón JJ, Koukoulakis P, Asano T (2010) Use of treated municipal wastewater in irrigated agriculture—review of some practices in Spain and Greece. Agric Water Manag 97:1233–1241. doi:10.1016/j.agwat.2010.03.003

Piper AM (1944) A graphical procedure in the geochemical interpretation of water analysis, Transactions. Am Geophys Union 25:914–928

Qiao YH, Yu ZR (2003) Simulation study on the effects of irrigation on soil salt and saline water exploration. Acta Ecologica Sinica 10:2050–2056

Radov AS, Pustovoy IV, Korolkov AV (1971) Practicum on agricultural chemistry. Moscow, NAS

Rhoades JD (1977) Potential for using saline agricultural drainage waters for irrigation. Proceedings from Water Management for Irrigation and Drainage. American Society of Civil Engineers. Reno, Nevada

Richards LA (1954) Diagnosis and improvement of saline and alkali soils. Agric Handbook 60, USDA: Washington

Saeedi M, Abessi O, Sharifi F, Meraji H (2010) Development of groundwater quality index. Environ Monit Assess 163:327–335

Semih E, Cankut O (2008) Estimating soil salinity using satellite remote sensing data and real-time field sampling. Environ Eng Sci 25:981–988

Shen Y, Chen Y (2010) Global perspective on hydrology, water balance, and water resources management in arid basins. Hydrol Process 24(2):129–135

Srivastava SK, Ramanathan AL (2008) Geochemical assessment of ground water quality in vicinity of Bhalswa landfill, Delhi, India, using graphical and multivariate statistical methods. Environ Geol 53:1509–1528

Tarchouna LG, Merdy P, Raynaud M, Pfeifer H-R, Lucas Y (2010) Effects of long-term irrigation with treated wastewater. Part I: evolution of soil physico-chemical properties. Appl Geochem 25:1703–1710

USDA, Natural Resources Conservation Service (2002) Soil Conservationists. Salinity Management Guide - Salt Management. Available at http://www.launionsweb.org/salinity.htm. Accessed 2002

Vahab A, Mohsen R, Nasim S (2014) Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. Environ Earth Sci 72:3479–3490. doi:10.1007/s12665-014-3255-0

Van-Camp L, Bujarrabal B, Gentile AR, Jones RJA, Montanarella L, Olazabal C et al. (2004) Reports of the technical working groups established under the thematic strategy for soil protection. Volume II Erosion. EUR 21319 EN/2. Luxembourg: Office for Official Publications of the European Communities

Wang ZQ, Zhu SQ, Yu RP (1993) Saline soil of China. Science press, Beijing **(in Chinese)**

Wang YG, Li Y, Xiao DN (2008) Catchment scale spatial variability of soil salt content in agricultural oasis, Northwest China. Environ Geol 56:439–446

Wenjun M, Zhenqiang M, Zhenrong Y, Mensvoort MEF, Driessen PM (2008) Effects of saline water irrigation on soil salinity and yield of winter wheat–maize in North China Plain. Irrig Drainage Syst 22:3–18. doi:10.1007/s10795-007-9027-1

Western Fertilizer Handbook (1995) Produced by the soil improvement committee of the California fertilizer association. Interstate Publishers Inc, Sacramento, California

Wilcox LV (1955) Classification and use of irrigation water. Agriccirc 969, USDA: Washington

Wu J, Li P, Qian H, Fang Y (2014) Assessment of soil salinization based on a low-cost method and its influencing factors in a semi-arid agricultural area, northwest China. Environ Earth Sci 71:3465–3475. doi:10.1007/s12665-013-2736-x

Xiaoyu G, Zailin H, Yining B, Shaoyuan F, Guanhua H, Haibin S, Zhongyi Q (2015) Soil salt and groundwater change in flood irrigation field and uncultivated land: a case study based on 4-year field observations Environ. Earth Sci 73:2127–2139

Xu C, Yang X, Li Y, Wang W (2011) Changes of China agricultural climate resources under the background of climate change III. Spatiotemporal change characteristics of agricultural climate resources in Northwest Arid Area. Chin J Appl Ecol 03:763–772

Zhou H, Chen Y, Li W (2010) Soil properties and their spatial pattern in an oasis on the lower reaches of the Tarim River, northwest China. Agric Water Manag 97:1915–1922