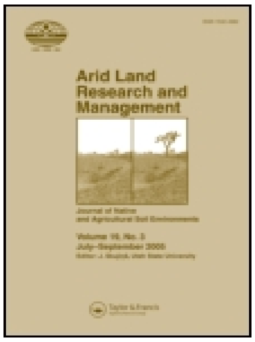

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Hydrochemical and isotopic characters of surface water in agricultural oases of the Tianshan Mountains, Northwest China

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ABSTRACT
For evaluating the status of surface water in agricultural oases of the Tianshan Mountains and discussing the influences of human activities and geographical factors on hydrochemical process, we conducted hydrochemical investigations of surface water in two major agricultural oases: Manas and Yili. The δ^2H and δ^{18}O of surface water in Manas Oasis ranged from −75.4‰ to − 46.2‰ and −11.6‰ to − 5.5‰, respectively, and from −86.4‰ to − 71.8‰ and −12.5‰ to − 10.7‰ in Yili Oasis. Because rivers are mainly supplied by meltwater from ice and snow, the deuterium excess parameter is mostly positive in the oasis surface waters supplied by these rivers. Ca^{2+}-Mg^{2+}-HCO_3^- is the major hydrochemical facies type in Yili and Manas oases. Surface waters of both regions are slightly saturated with carbonate minerals and undersaturated with respect to evaporite minerals, suggesting that the minerals present in the water are mainly produced by calcite and dolomite weathering. Total dissolved solids (TDS) in Manas Oasis are higher than those in Yili Oasis. The δ^2H and δ^{18}O of surface water samples in Manas Oasis are isotopically enriched, which indicates that the evaporation effect on Manas is stronger than on Yili. The relatively high salinity in Manas is also associated with local contamination by soil leaching. Agricultural activities are important to the quality of surface water. If such activity is not controlled, water salinization will be increased. Clarification of the hydrological status of these oases and their factors will be used for water management and protection of agricultural oases.

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Agricultural oasis; China; hydrochemical characters; isotope composition; surface water; Tianshan Mountains

The Tianshan Mountains lie along an east-west axis and extend broadly for over 2500 km across Central Asia (Yin et al. 1998). Many rivers, including the Syr Darya, Yili, Chu, Manas, and Urumqi rivers, originate from the Tianshan Mountains. Large oases are distributed across the alluvial plains of the mountain slopes (Zhang and Lei 2006), which are important in determining not only where people can live, but also their quality of life. Using the historical literature and remote sensing data, former researchers focused on water resource utilization (Zhang et al. 2012b), climatic and hydrologic changes (Cheng

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et al. 2006), and saline soil and soil uses (Feng et al. 2011) in major oases of the Tianshan Mountain region. Owing to the arid climate, the availability of water resource is one of the most important parts of the eco-environmental system in arid regions, and therefore water availability and quality are the key factors restricting the land exploitation and social developments. Meanwhile, large-scale land resource exploitation also intensified the influences on water resources transforming. Therefore, exploring the connection between water resource and land exploitation has important applications to arid lands resource management. In order to effectively manage and protect water resources in the fragile arid ecological environment, a study of the hydrochemical and stable isotopic compositions of surface water in major oases of the Tianshan Mountains will be conducted for the first time. The hydrochemistry and isotopic methods were selected from the literature (Bennetts et al. 2006; Zhu et al. 2008; Dassi 2011) and used to investigate the geochemical evolution of water in the study areas.

The surface runoff in the Manas and Yili oases is mainly supplied by the glacial/snow meltwater from the high Tianshan Mountains (Kang et al. 1999; Ling et al. 2012). According to the hydrogeological Atlas of the People's Republic of China (1979), which was obtained from the Geological Sciences Data Sharing Network (http://www.geoscience.cn), most areas of the Tianshan Mountains belong to a water-bearing formation of clasolite and carbonatite and are moderately water-rich. Hence, the trend of the hydrologic processes, with no anthropogenic influences, should have the same hydrochemical characteristics, as they share a similar background mainly defined by climate change. However, between the Manas and Yili oases, there are anthropogenic differences, including the variety of crops grown, crop planting structure, irrigation methods, etc (Li et al. 2007; Zhang et al. 2012b), which will induce different hydrochemical characters of water resources. In this paper, we chose these two regions for comparison and collected the surface water samples for analysis. The hydrochemical and isotopic composition of the surface water samples are used to evaluate the status of the surface water in agricultural oases of the Tianshan Mountains, Northwest China. Then, the influences of human activities and geographical factors on the hydrochemical characters will be discussed, thereby possibly promoting the management and protection of the water resources of agricultural oases in arid regions.

General setting

Manas and Yili are the major oases adjacent to the Tianshan Mountains. Manas Oasis is located on the northern slopes of the Tianshan Mountains, adjacent to the southern Junggar Basin (Figure 1). It is the largest artificial oasis and agricultural base in the Xinjiang Uyghur Autonomous Region (Ling et al. 2012; Zhang et al. 2012a). From average, yearly meteorological data, the mean annual temperature (MAT) is about 6.6°C, annual total precipitation (ATP) is 100–200 mm, and annual total evaporation (ATE) is about 1500–2100 mm (Ling et al. 2013). The agricultural acreage of Manas Oasis had increased from 340 km^2 in 1950 to 6590 km^2, and the areas of drip irrigation accounted for 55% of arable land in 2008 (Zhang et al. 2012b). Cotton is the major crop in the Manas Oasis. The total population reached 1.12 million in 2008 (Zhang et al. 2012b). To support artificial oasis expansion and population growth, 96% of the available surface water has been utilized (Y. Li et al. 2007).

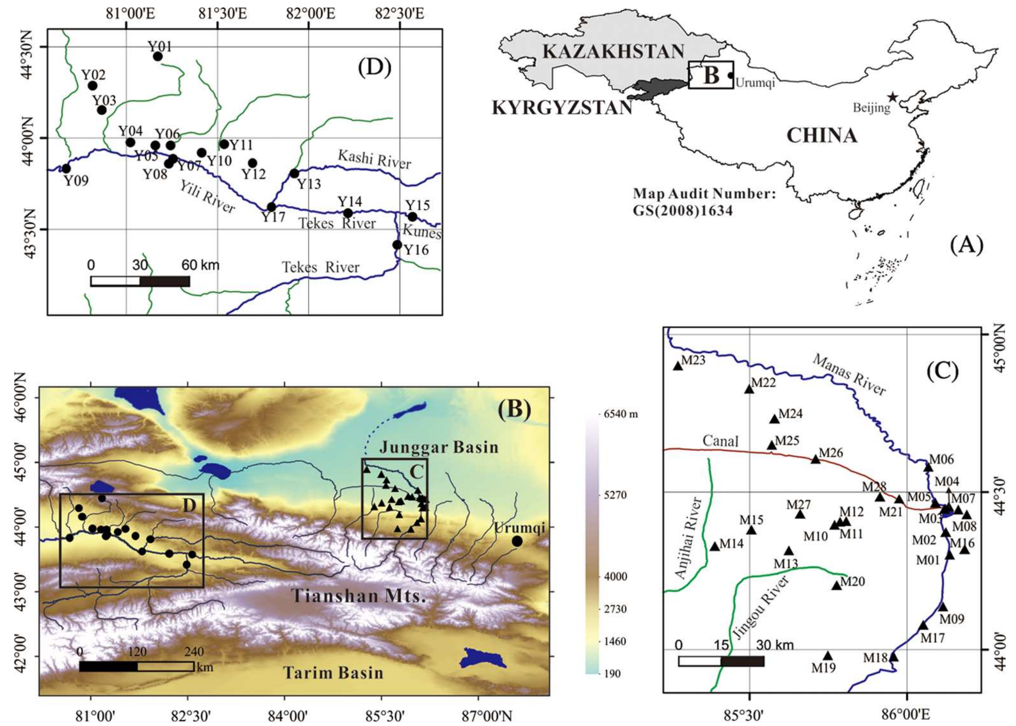

Figure 1. Map of study area with location of sampling sites. (A) The location of the study area. (B) The geomorphic map of study area. (C) The sampling sites in the Manas Oasis. (D) The sampling sites in the Yili Oasis.

The Yili River valley lies within the Tianshan Mountain system (Figure 1). The Yili River is an international river, flowing from China to Kazakhstan, which is composed of three major tributaries (Kashi River, Kunes River, and Tekes River). In the context of the large spatial-scale desert background of Xinjiang, which only has a long-term average annual precipitation of 130 mm (Zhang et al. 2012), the Yili Oasis has a stable and heterogeneous ecological landscape with significant climate effects. Yili Oasis is one of the largest oases in Xinjiang (Fan et al. 2006). The Yili Oasis is open to the west, so westerly winds bring in moist air, thereby inducing precipitation. Based on average yearly meteorological data, the MAT varies from 9.2°C on the plains to 2.6°C in mountainous areas, and the ATP varies from 200–500 mm on the plains to 800 mm in the mountains (Li et al. 2011). ATE is about 1600 mm (Zhang et al. 2009). The agricultural acreage of the Yili Oasis was 5527 km^2 in 2005, and the irrigated areas accounted for 4600 km^2 (Shi 2008). The total population reached 2.52 million in 2007 (J. Li et al. 2007). Corn is the major crop in the Yili Oasis. Irrigation for crops mainly involves flooding the farms, largely through gravity-based river flow (J. Li et al. 2007).

Materials and methods

Sampling

Water chemistry and stable isotopes (^2H and ^{18}O) were determined for surface water in the Manas (M01-M28) and Yili (Y01-Y17) oases during September 2012 (Supplementary File,

Appendix I) (Figure 1). Samples for isotopic analysis were collected in 20 mL bottles. The bottles were completely filled, so that they were not in contact with air until opened in preparation for analysis in the laboratory.

Laboratory analysis

The pH of the aqueous phase was measured using a pH-meter (pHS-2C; Lida Instruments, Shanghai, China). Electrical conductivity (EC) was measured using a DDS-307-type conductivity meter (Leici Instruments, Shanghai). Total dissolved solids (TDS) were measured using the gravimetric technique, which involves measuring the amount of residue remaining afer a 0.2 μm filtered liquid sample is heated at 105°C until a constant weight is obtained. The dual indicator neutralization method was used to determine the concentrations of HCO_3^- and CO_3^{2-}. Calcium and magnesium were measured by EDTA complexometric titration. A silver nitrate ($AgNO_3$) solution of known concentration was used to precipitate out the chlorides in the water samples. This procedure is complicated by the dense white precipitate silver chloride (AgCl) precipitate. Potassium and sodium ions were measured using flame emission photometry (6410 flame photometer, Shanghai Analysis Apparatus Factory, Shanghai) (State Environmental Protection Administration of China, "Monitoring analytical method for water and waste water" Editorial Committee, 1998). Quantitative analysis of sulfate was conducted by indirect EDTA titration.

Stable isotopes (^2H and ^{18}O) were analyzed using an LGR DT-100 Liquid Water Isotope Laser Analyzer (Los Gatos Research Inc., Mountain View, California, USA) calibrated against the Vienna-Standard Mean Oceanic Water 2 (VSMOW2; IAEA). All hydrogen and oxygen isotope analyses are expressed in the conventional δ notation (δ ‰) referenced to VSMOW. Reproducibility was better than 1.0‰ for δ^2H and 0.15‰ for $\delta^{18}O$. Results of the chemical analyses and isotopic compositions of the oases waters are shown in the Supplementary File, Appendix I.

Results

Hydrochemical characteristics of surface water

In the Manas oasis, we collected nine samples from ditches, eight from reservoirs, and eleven from rivers. Meanwhile, we obtained two samples from ditches and fifteen from rivers in the Yili oasis. Basic statistics for pH, EC, TDS, and major ion concentration of oasis surface waters are shown in Table 1 and Table 2. The coefficient of variation (C_V) is the ratio of the standard deviation (σ) to the average value (μ) (Abdi 2010), which indicates the dispersion of values. In general, the C_V values for the Manas Oasis water have greater dispersion than the values for the Yili Oasis water.

In Manas oasis, TDS varied from 11.6 g L^{-1} to 0.19 g L^{-1}. EC covered the interval between 11.37 dS m^{-1} and 0.22 dS m^{-1} and were correlated with TDS values. Among the major cations (Supplementary File, Appendix I), Ca^{2+} and Na^+ predominated accounting for, on average, 46.5% and 26.4% of the total cation milliequivalents, respectively. Mg^{2+} and K^+ represented an average 24.2% and 2.9%, respectively. Among the major anions, HCO_3^- dominated (average 50.9% of the total anion milliequivalents). Samples from ditches had higher values of EC and TDS (Table 1).

Table 1. Basic statistical parameters of surface water in the Manas Oasis ($n = 28$).

Sample type	Item	pH	EC (dS m^{-1})	TDS (g L^{-1})	HCO_3^- (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	Na^+ (mg L^{-1})	K^+ (mg L^{-1})
Whole ($n = 28$)	Min[a]	7.2	0.220	0.190	86	7	15	27	4	6	3
	Max[b]	7.9	11.370	11.626	412	3106	4568	440	415	2969	17
	σ[c]	0.208	2.706	2.696	74	756	980	93	95	689	3
	μ[d]	7.7	1.191	1.093	144	242	342	67	39	222	5
	CV[e], %	2.7	227.2	246.7	51.4	312.4	286.5	138.8	243.6	310.4	60.0
Ditch ($n = 9$)	Min	7.5	0.240	0.197	105	9	25	27	6	6	3
	Max	7.9	11.370	11.626	412	2698	4568	290	415	2969	14
	M	7.7	1.628	1.574	162	326	559	64	59	353	6
Reservoir ($n = 8$)	Min	7.2	0.230	0.200	86	12	21	28	4	11	3
	Max	7.8	0.890	0.687	145	99	230	78	20	89	6
	M	7.5	0.451	0.342	115	37	83	43	11	34	4
River ($n = 11$)	Min	7.3	0.220	0.190	97	7	15	27	4	6	3
	max	7.9	9.860	9.348	325	3106	2746	440	329	2288	17
	μ	7.7	1.373	1.245	150	323	353	86	43	251	6

[a]minimum value.
[b]maximum value.
[c]standard deviation.
[d]average value.
[e]coefficient of variation.

TDS and EC in the Yili oasis were higher than those in the Manas oasis. The pH was similar in both oases. The TDS values of all the Yilil samples ranged from 0.65 to 0.21 g L^{-1}. EC values varied from 0.85 dS m^{-1} to 0.26 dS m^{-1} and were also correlated with TDS. Among the major cations (Appendix I), Ca^{2+} and Mg^{2+} predominated accounting for, on average, 49.2% and 31.5% of the total cation milliequivalents, respectively. Na^{2+} and K^+ represented, on average, 17.3% and 2% of the total cation milliequivalents, respectively. Among the major anions, HCO_3^- dominated (68.2% of the total anion milliequivalents), whereas SO_4^{2-} and Cl^- represented, on average, 17.8% and 14%, respectively. The basic statistics for water samples from ditches were similar to the ones from rivers.

Table 2. Basic statistical parameters of surface water in the Yili Oasis ($n = 17$).

Sample type	Item	pH	EC (dS m^{-1})	TDS (g L^{-1})	HCO_3^- (mg L^{-1})	Cl^- (mg L^{-1})	SO_4^{2-} (mg L^{-1})	Ca^{2+} (mg L^{-1})	Mg^{2+} (mg L^{-1})	Na^+ (mg L^{-1})	K^+ (mg L^{-1})
Whole ($n = 17$)	Min[a]	7.4	0.260	0.209	118	12	6	28	6	3	1
	Max[b]	8.3	0.850	0.650	213	83	167	65	26	91	4
	σ[c]	0.243	0.143	0.108	36	16	39	9	7	20	1
	μ[d]	7.8	0.378	0.298	158	21	39	38	15	18	3
	CV[e], %	3.1	37.8	36.2	22.8	76.2	100.0	23.7	46.7	111.1	33.3
Ditch ($n = 2$)	Min	7.9	0.260	0.216	123	12	6	34	7	3	1
	Max	8.1	0.380	0.306	213	18	13	41	22	10	4
	M	8.0	0.320	0.261	168	15	10	38	15	7	3
River ($n = 15$)	Min	7.4	0.260	0.209	118	14	9	28	6	6	2
	max	8.3	0.850	0.650	211	83	167	65	26	91	4
	M	7.8	0.386	0.303	157	22	43	38	15	20	3

[a]minimum value.
[b]maximum value.
[c]standard deviation.
[d]average value.
[e]coefficient of variation.

Hydrochemical facies and saturation indices (Si) of surface water

Hydrochemical facies for surface waters of the Manas and Yili oases were calculated using the Chadha diagram (Chadha 1999; Kompanart et al. 2005) (Figure 2). Saturation index (SI) Values were calculated using the PHREEQC software (Parkhurst and Appelo 1999). SI = 0 indicates that the water is in thermodynamic equilibrium with respect to the mineral. When SI > 0, the water is supersaturated with respect to the mineral, and if SI < 0, it is undersaturated (Sracek et al. 2004). The SI with respect to anhydrite, aragonite, calcite, dolomite, gypsum, halite, and sylvite are summarized in Table 3 and Table 4.

Stable isotopes of ^{18}O and ^{2}H of surface water

Isotope data for the Manas Oasis showed that values of deuterium (δ^2H) and oxygen ($\delta^{18}O$) in water samples ranged from −75.4‰ to − 46.2‰ with a mean value of − 67.4‰ and from −11.6‰ to − 5.5‰ with a mean value of − 10.1‰, respectively. For the Yili Oasis, δ^2H and $\delta^{18}O$ values varied from −86.4‰ to − 71.8‰ with a mean value of − 80.6‰ and from −12.6‰ to − 10.7‰ with a mean value of − 11.7‰, respectively. The differences in stable isotopic composition are embodied in the different degrees of dispersion degrees between the two oases. Most values of surface water samples from the Yili Oasis are scattered around the local meteoric water line ($\delta^2H = 7.10 \times \delta^{18}O + 2.29$, $n = 130$, $r^2 = 0.94$) (Figure 2), which has been monitored at Urumqi station (43.78°N, 87.62°E) for over 10 years, as part of the Global Network for Isotopes in Precipitation. The ^{18}O and ^{2}H in the Manas Oasis ($\delta^2H = 4.55 \times \delta^{18}O - 21.49$, $n = 28$, $r^2 = 0.94$) is enriched compared to most water samples from the Yili Oasis ($\delta^2H = 6.87 \times \delta^{18}O - 0.20$, $n = 17$, $r^2 = 0.86$) (Figure 3).

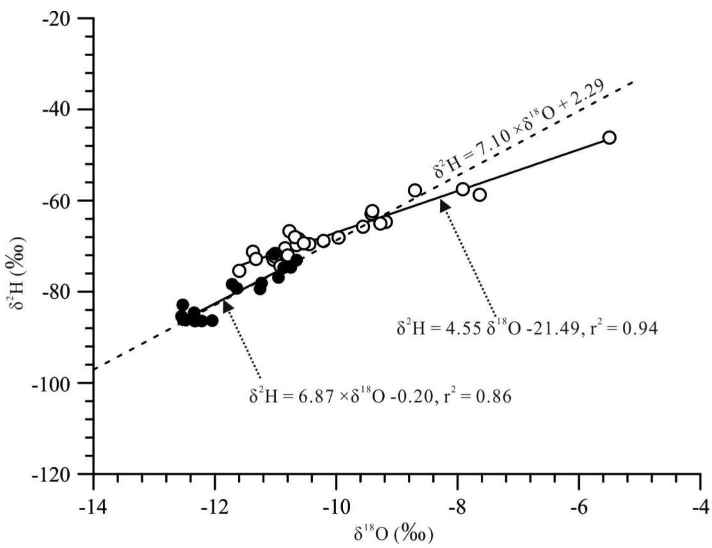

Figure 2. $\delta^{18}O$ and δ^2H for surface water from the Manas Oasis (hollow circles) and Yili Oasis (solid circles) compared with local meteoric water line (dashed line).

Table 3. Mineral saturation indices (SI) and descriptive statistical parameters determined from water chemistry in the Yili Oasis.

	Anhydrite	Aragonite	Calcite	Dolomite	Gypsum	Halite	Sylvite
Samples	$CaSO_4$	$CaCO_3$	$CaCO_3$	$CaMg(CO_3)_2$	$CaSO_4{:}2H_2O$	NaCl	KCl
Y01	−3.39	0.39	0.54	1.01	−2.98	−8.99	−8.98
Y02	−3.22	0.30	0.45	0.81	−2.81	−8.56	−8.56
Y03	−2.79	−0.10	0.05	0.23	−2.37	−8.32	−8.62
Y04	−2.83	−0.38	−0.23	−1.06	−2.42	−8.39	−8.30
Y05	−2.69	−0.14	0	−0.14	−2.39	−8.23	−8.42
Y06	−2.43	−0.29	−0.14	−0.26	−2.02	−7.87	−8.27
Y07	−2.63	−0.28	−0.13	−0.33	−2.22	−7.96	−8.28
Y08	−2.39	−0.30	−0.15	−0.53	−1.98	−7.83	−8.27
Y09	−2.36	−0.43	−0.27	−0.80	−1.95	−7.90	−8.27
Y10	−3.01	−0.22	−0.07	−0.42	−2.59	−8.39	−8.43
Y11	−3.10	−0.28	−0.13	−0.59	−2.69	−8.39	−8.43
Y12	−3.06	−0.10	0.05	−0.38	−2.65	−8.28	−8.19
Y13	−3.18	−0.19	−0.04	−0.31	−2.77	−8.43	−8.60
Y14	−2.38	0.02	0.17	0.32	−1.96	−7.66	−8.33
Y15	−1.89	0.27	0.42	0.61	−1.47	−6.70	−7.57
Y16	−2.91	0.20	0.35	0.41	−2.50	−8.54	−8.43
Y17	−2.68	−0.11	0.04	−0.30	−2.27	−8.23	−8.26
Min[a]	−3.39	−0.43	−0.27	−1.06	−2.98	−8.99	−8.98
Max[b]	−1.89	0.39	0.54	1.01	−1.47	−6.70	−7.57
Average	−2.76	−0.10	0.05	−0.10	−2.36	−8.16	−8.37

[a]minimum value.
[b]maximum value.

Table 4. Mineral saturation indices (SI) and descriptive statistical parameters determined from water chemistry in the Manas Oasis.

	Anhydrite	Aragonite	Calcite	Dolomite	Gypsum	Halite	Sylvite
Phase	$CaSO_4$	$CaCO_3$	$CaCO_3$	$CaMg(CO_3)_2$	$CaSO_4{:}2H_2O$	NaCl	KCl
M01	−2.71	−0.34	−0.19	−0.71	−2.29	−8.55	−8.37
M02	−2.73	−0.35	−0.20	−0.63	−2.31	−8.59	−8.41
M03	−2.89	−0.43	−0.28	−0.70	−2.47	−8.38	−8.19
M04	−2.68	−0.35	−0.20	−0.87	−2.26	−8.24	−8.32
M05	−2.10	0.04	0.19	0.16	−1.69	−7.33	−7.91
M06	−0.60	0.16	0.32	0.72	−0.19	−3.89	−5.56
M07	−2.20	−0.64	−0.48	−1.25	−1.78	−7.81	−8.06
M08	−2.45	−0.41	−0.26	−0.69	−2.04	−7.82	−8.14
M09	−2.67	−0.29	−0.14	−0.50	−2.25	−8.74	−8.62
M10	−2.92	−0.37	−0.22	−0.93	−2.51	−8.27	−8.13
M11	−2.61	−0.71	−0.56	−1.78	−2.20	−8.16	−8.25
M12	−2.52	−0.82	−0.67	−1.93	−2.11	−8.13	−8.25
M13	−3.07	−0.48	−0.33	−1.18	−2.66	−8.43	−8.12
M14	−2.79	−0.32	−0.17	−1.02	−2.38	−8.54	−8.43
M15	−2.92	−0.34	−0.19	−1.01	−2.50	−8.34	−8.37
M16	−2.74	−0.27	−0.11	−0.56	−2.33	−8.80	−8.62
M17	−2.80	−0.33	−0.18	−0.48	−2.38	−8.71	−8.53
M18	−2.75	−0.17	−0.02	−0.44	−2.33	−8.68	−8.49
M19	−1.01	0.48	0.63	0.93	−0.60	−5.58	−6.88
M20	−1.68	−0.27	−0.12	−0.68	−1.27	−6.73	−7.42
M21	−2.62	−0.38	−0.23	−0.46	−2.21	−8.28	−8.31
M22	−0.65	0.66	0.81	1.99	−0.24	−3.86	−5.73
M23	−2.27	−0.09	0.06	−0.07	−1.86	−7.26	−7.69
M24	−2.37	−0.31	−0.16	−0.38	−1.95	−7.29	−7.71
M25	−2.47	−0.41	−0.26	−0.42	−2.06	−7.29	−7.69
M26	−2.03	−0.19	−0.04	−0.60	−1.62	−7.22	−7.62
M27	−2.87	−0.29	−0.13	−0.72	−2.45	−8.46	−8.49
M28	−2.02	−0.66	−0.51	−1.22	−1.60	−6.62	−7.31
Min[a]	−3.07	−0.82	−0.67	−1.93	−2.66	−8.80	−8.62
Max[b]	−0.60	0.66	0.81	1.99	−0.19	−3.86	−5.56
Average	−2.36	−0.28	−0.13	−0.55	−1.95	−7.64	−7.92

[a]minimum value.
[b]maximum value.

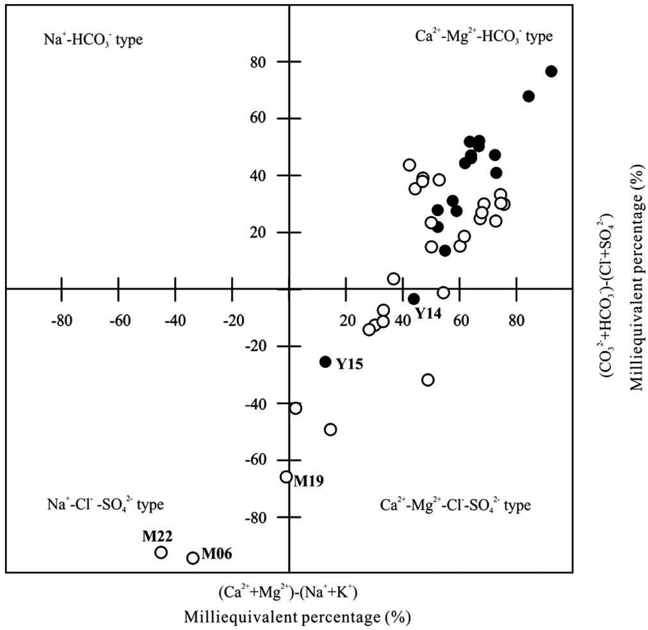

Figure 3. Hydrochemical facies in the Manas Oasis (hollow circles) and Yili Oasis (solid circles) plotted on Chadha diagram.

Discussion

From the aforementioned results, there remain some differences in hydrochemical and isotopic characters of the surface water in the Manas and Yili oases. In order to reveal the influences of human activities and geographical factors on hydrochemical characteristics, a comprehensive analysis of the hydrothermal and isotopic data was conducted and is supported by the geographical background and history of societal development in this area.

The deuterium excess parameter *(d;* $d = \delta^2H - 8 \times \delta^{18}O$) is an important index parameter in the study of surface water (Dansgaard 1964). Here, *d* was mostly positive, with an average of 13‰ and 13.3‰ in the Yili Oasis and Manas Oasis, respectively. It was also found that water, extracted from the base of melting snow, had continuous enrichment of ^2H with a significantly depletion of ^{18}O (Búason 1972; Moser and Stichler 1974). Positive values of excess δ^2H, 3.58‰–21.55‰, also appeared in Tajikistan River waters that is also supplied by glacial/snow meltwater (Zeng and Wu 2013). Site altitude of surface water samples (Supplementary File, Appendix I) suggested altitudinal and latitudinal effects (Dansgaard 1964) were not determining factors in the isotopic composition of surface water. It is very likely the result of natural variations in regional and local climate. Surface waters of the Manas Oasis, with ^{18}O and ^2H enrichment, are strongly affected by stable isotope fractionation during evaporation.

The collected water samples were undersaturated in several mineral phases (anhydrite, gypsum, halite, and sylvite) (Tables 3 and 4). Carbonate minerals often exist in a nearly saturated state in the Manas and Yili oases, where the host carbonate rocks that dominate in both river basins control water hydrochemical characters. From the Chadha diagram of Figure 2, most water samples from Yili Oasis plot in the field of the Ca^{2+}-Mg^{2+}-HCO_3^- hydrochemical facies type, which can be interpreted as the result of water–rock interactions

(Dindane et al. 2003; Belkhiri et al. 2010), due to the abundance of carbonate lithology in the Tianshan Mountain region. Only two samples (Y14 and Y15, Supplementary File, Appendix I) were in the field of Ca^{2+}-Mg^{2+}dominant Cl^{-}-SO_4^{2-} type water (Figure 3). Overall, waters from the two-aquifer units had significant differences of hydrochemical facies. From the Figure 2, 60.7% of the surface water samples in the Manas Oasis were in the field of Ca^{2+}-Mg^{2+}-HCO_3^{-} type hydrochemical facies. This suggests that the chemical concentration of the water are mainly originated from calcite and dolomite weathering. Another 28.6% of the water samples were in the field of Ca^{2+}-Mg^{2+}-Cl^{-}-SO_4^{2-} hydrochemical facies, and three samples (M06, M19 and M22; Supplementary File, Appendix I) were categorized as Na^{+}-dominant Cl^{-}-SO_4^{2-} type waters (Figure 3). These three samples from rivers and ditches also had high salinity, which may also be the result of dissolution of halite (NaCl) and thenardite (Na_2SO_4) or cation exchange.

Most water samples from Manas Oasis are characterized by relatively higher salt contents in comparison with surface waters from the Yili Oasis. Dissolved ions are enriched along with heavy isotopes during evaporation. If the water chemistry is controlled only by water evaporation, there will be a strong correlation between values of ^{2}H and chloride (Chen et al. 2012), which was not observed for the Manas Oasis or the Yili Oasis. The elevated salinity concentration at Manas can be linked to water evaporation and local contamination, which is responsible for this abnormal concentration. In Manas Oasis, the oasis area expanded from 156 km^2 in 1949 to 5042 km^2 in 2001 and, in 2001, most of the farmland (area 904 km^2) was saline and alkaline (Cheng et al. 2006). Drip irrigation has been widely used since the late 1990s (Zhang et al. 2012b). Drip irrigation in an oasis will cause long-term salt accumulation. In order to slow down the process of salt accumulation and to ensure sustainable cultivation, soil leaching of saline farmland is necessary (Luo 2014). Salt will be washed from the soil to the public ditch, which increases oasis surface water salinity. We conclude that agricultural activities are important to the water quality of Manas Oasis. In Yili Oasis, however, the general geographic background is the factor most responsible for its current water quality.

Following the founding of the Xinjiang Uyghur Autonomous Region in the 1950s, oases have expanded at a rate of nearly 822 km^2 every year (Bai and Ren 2006). Water availability is one of the most important parts of the eco-environmental system in arid regions, as it is the key factor restricting land exploitation and agricultural and social development. Owing to the arid climate in Xinjiang, agricultural activities require large amounts of irrigation water. In addition, drip and flooding irrigation methods in the oasis will cause long-term salt accumulation. In order to slow down the process of salt accumulation and to ensure sustainable cultivation, soil leaching is performed every year for cultivation, which transports pesticide residues and salt from the farmland to the oasis surface water environment. If this is not controlled, surface water salinization will be increased.

Conclusions

For the analysis and comparison of hydrochemical and isotopic characteristics of surface waters from the Manas and Yili oases, the results are as follows:

1. The positive deuterium excess parameters, for surface waters at both the Yili and Manas Oases, inferred that they are mainly supplied by glacial/snow meltwater. Ca^{2+}-Mg^{2+}-HCO_3^{-} is the dominant hydrochemical facies type for both oases, and carbonate minerals often exist

in a nearly saturated state in the Manas and Yili river basins, suggesting that the carbonate rocks that dominate the basins control the hydrochemical character.

2. Most isotopic values of surface water from the Yili Oasis are scattered around the local meteoric water line, with depleted ^{18}O and ^{2}H relative to samples from the Manas Oasis, which is the result of stronger evaporation in the Manas Oasis. The elevated salt concentration in the Manas Oasis was also linked to local contamination by soil leaching for agricultural purposes.

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