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ORIGINAL ARTICLE

Temporal variation of significant soil hydrological parameters in the Yutian oasis in Northwest China from 2001 to 2010

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Abstract In this paper, the temporal variation and causes of groundwater depth, total dissolved solids (TDS), and NO_3^--N in groundwater, as well as salt and water in soil profiles in the Yutian oasis, northwest China from 2001 to 2010 have been studied. The results showed that: (1) during this period, the NO_3^--N in the groundwater showed an increasing trend with the order of mean values at 2010 > 2005 > 2001, while the average values of the groundwater depth and TDS in groundwater were both in the order of 2010 < 2005 < 2001. (2) The geostatistical analysis showed that in 2001, 2005 and 2010, the spatial distribution of the water table and TDS contents in groundwater, and salt and water in soil profiles all declined when going from the northern to the southern region of the oasis, while the NO_3^--N contents in groundwater declined when going from the center to the periphery. (3) Correlation analysis showed that in these three periods, there were obvious correlations between the water table and the TDS in groundwater, the groundwater depth, and the salt content in soil (0–60 cm), and the water table and the water content in soil (0–60 cm). (4) This work found that during recent years, with the influence of natural and human factors, the water table, the TDS, and NO_3^--N in groundwater were significantly increased. At the same time, there was an increase trend in the salt content and a decrease trend in the water content in soil profiles, resulting in increased degree of salinization in the oasis. This deserves much attention and reasonable planning of economic development in the oasis and strict control of the use of water resources should be inspired.

Keywords Oases in arid areas · The depth, the TDS and the NO_3^--N of the groundwater · The salt and water of the soil profiles · Temporal variation characteristics and causes

Introduction

Water resources in arid regions have irregular spatial distribution (Chen et al. 2004; Appelo and Postma 2005). In some places groundwater is the only water source available to maintain the natural plant growth. Therefore, changes in the groundwater levels can directly influence the plant's growth and decay, and control the composition of plant communities (Hu and Sun 2007; Humphries et al. 2011; Kinal and Stoneman 2012). Change in groundwater levels is one of the key ecological factors in arid areas and can influence the formation, development and stability of ecosystems in continental river basins in arid zones (Burnett et al. 2003; Clara et al. 2004). Related studies include Chen et al. (2004) on the influence of groundwater depth below the salinization critical depth on the vegetation succession in arid regions of northwest China. Lü et al. (2009) explored the relationship between the soil salt content and groundwater in Yutian Oasis, and Wang et al.

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(2010) researched the spatial law of groundwater chemical characteristics in this area. However, recent work on groundwater in oases of arid regions has mainly focused on the relationships between the groundwater depth and the ecological environment and also the vegetation.

Recently, the research focus has gradually turned to the studies of groundwater in arid areas (Liu et al. 2003, 2005). In rump oases, the increased salt in the soil profiles, can reflect the salt increase in the groundwater, also can seriously affect the growth of vegetation in the oasis as well as threaten the development of the social economy and ecological security. The development of soil salinization in arid areas is influenced by many factors and the causes of which are closely related the groundwater water levels (Liu et al. 2005; Wahap et al. 2007; Wu et al. 2013). In arid areas, the most direct cause of soil salinization is the rise in the water levels, which can change the depth of groundwater more than the critical depth levels (Kumar and Ahmed 2003; Bauer et al. 2004).

Nowadays, increasing NO_3^--N content in groundwater has become a common phenomenon worldwide (Chaplot et al. 2004; Santos et al. 2012). In drinking water, when the concentration of NO_3^--N exceeds a certain standard, it may cause methemoglobin disease, cancer and other diseases (Du et al. 2011; Wang et al. 2012). Therefore, the concentration of NO_3^--N has become an important indicator in water quality control. In 2011, the world health organization set the concentration limitation of NO_3^--N in drinking water as 10 mg/l. In China, the NO_3^--N concentration standard for drinking water is $\leq$20 mg/l (GB 5749·2006; NEPA 2006).

According to the identification and measurement of nonpoint sources of pollution by the WHO, agriculture is one of the biggest offenders of water pollution with farmland runoff accounting for 69 % of polluted lakes and 52 % of polluted rivers (Stamatis et al. 2011; Howden et al. 2013). In China, the groundwater of many cities has been significantly polluted by NO_3^--N. For example, Changchun in Northeast China has reached a NO_3^--N content in groundwater water as high as 286 mg/l with an area of 126 hm^2 having a NO_3^--N content exceeding the national drinking water standard (Gao et al. 2008). In Xi'an city located in Central China, the NO_3^--N in groundwater reached as high as 189 mg/l with an area of 161 hm^2 having a NO_3^--N content exceeding the national drinking water standard (Qin et al. 2005). In Chengdu city in southwest China, the NO_3^--N in the groundwater was as high as 120 mg/l, which was 55 times higher than the national standard value (Liu et al. 2005).

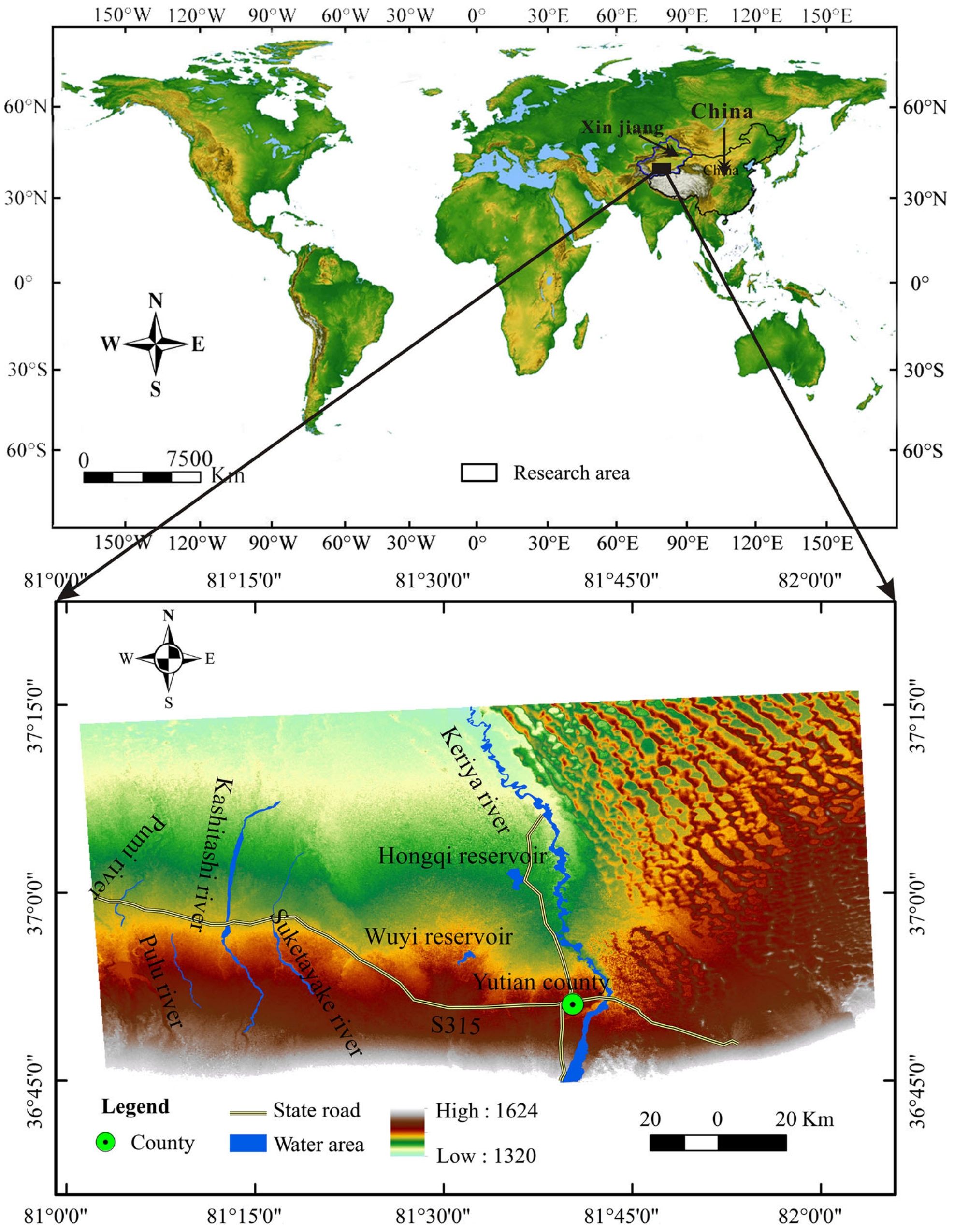
The Yutian oasis is an agricultural region and also one of the most seriously salinized areas in China (Liu et al. 2003; Zhang et al. 2013). Recently, implementation of the "Develop Western" policy by the Chinese government has allowed rapid development of industry and agriculture in this area. This has led to a rapid increase in the population of this region and a subsequent expansion of cultivated land, leading to an increased demand on water resources and the need to mine the groundwater resources. These have caused the local groundwater levels to descend and form a area in the county (Ma et al. 2000, 2002). Furthermore, improper agricultural irrigation and drainage, and the application of nitrogen fertilizers rose annually, resulting in secondary salinization of soil in the oasis and NO_3^--N pollution of the groundwater in the central region. Therefore, research on the depth and NO_3^--N pollution of groundwater as well as the soil salinization of the oasis is necessary for the sustainable use of the soil and water resources in this region. Taking into account both climate changes and socioeconomic development and combining the geostatistical analysis methods with geographic information system (GIS) technology, in this research, the changes and reasons of the spatial distribution of groundwater depth, total dissolved solids (TDS) and NO_3^--N, and salt and water in the soil at 0–20, 20–40 and 40–60 cm in 2001, 2005 and 2010 from the Yutian oasis in Northwest China were analyzed. This research aimed to understand the influence of the development in this region on the soil and water resources, especially the influence of water irrigation, the utilization of the rump oasis groundwater in this region.

Materials and methods

Study area

Yutian oasis located in the southern margin of the Taklimakan Desert, north of the Kunlun Mountains (81°09′–82°51′E, 35°14′–39°29′N), and has a total area of 4.03 × 10^4 km^2 (Fig. 1). The northern terrain is low, and measures 466 km from the north to the south and 30–120 km from the east to the west. The topography is primarily made up of mountains, hills, deserts and plains, which cover areas of 10,204, 2148, 3326.3 and 2382.6 km^2, respectively. The plains are the agriculture areas, and in the whole oasis, the cultivated land had a total area of 2526.7 km^2 (Wu et al. 2013). The climate of the Yutian oasis is warm temperate desert with an annual average temperature of 12.4 °C, and $\geq$10 °C accumulated temperature of 4340 °C, the rainfall of 44.7 mm, evaporation of 2498 mm and the wind speed of 1.8 m/s. The soils of the whole oasis can be divided into 13 types, 14 subcategories, 26 soil genera and 50 species, and most of the soils are Fluvo-aquic soils, and the second was Brown desert (including for the cultivated land and wasteland,

Fig. 1 Location of study area



solonchak). The plants of Yutian oasis are from 38 families, 112 genera and 112 species, including the *Populus euphratica, the Tamarix ramosissima, the Apocynum venetum, the Sophora alopecuroides, the Cistanche tubulosa, the Alhagi sparisipholia, the Achnatherum splendens* and *the Phragmetis australis* (Liu et al. 2003; Wang et al. 2006; Hu and Sun 2007; Nurmemet et al. 2015).

Sample and data collection

In the research, ArcGIS 10.0 software was used to lay out a grid of sampling points on a digital map of 0.5 km × 0.5 km of the Yutian oasis, which eventually resulted in 89 groundwater monitoring sites (Fig. 2). The depth to groundwater and groundwater samples were acquired in July of 2001, 2005 and 2010 from the whole oasis. At the same time, soil samples were also collected at depths of 0–20, 20–40, and 40–60 cm at each of the groundwater monitoring sites. 500 kg uniform samples of each profile were collected, and then they were blended into a clean cloth, placed in a container, numbered and sealed. The collection position, the sampling date, and the soil quality of each point were also recorded.

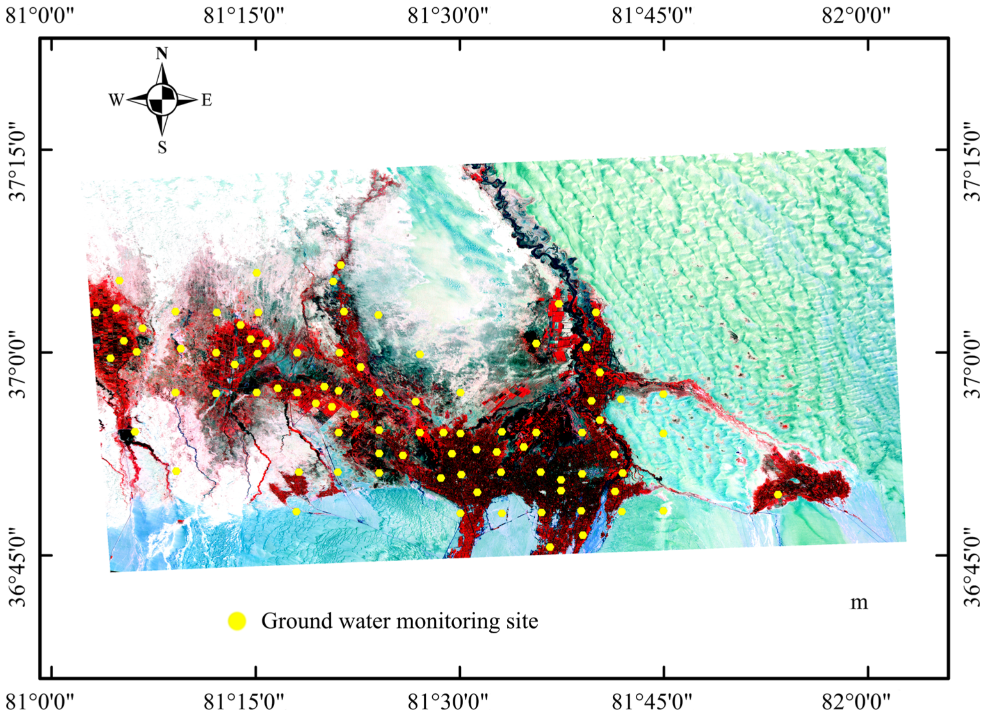


Fig. 2 Locations of sampling sites within the study area

Water and soil sample analyses

The tested indicators groundwater and the soil samples that got, included the depth, the TDS and the NO_3^--N contents in the groundwater, and the salt and water of the soil profiles that taken at the depths of 0–20, 20–40 and 40–60 cm. In this research, all samples were analyzed in the Laboratory of Chemical Analysis of Soil and Water in Xinjiang University, China.

In this research, the water tables of the groundwater were tested as follows: first, a vertical hole. Then, a spade was used when the depth to groundwater was <2 m or mechanical excavation was used when the depth to groundwater was >2 m. Once a depth was reached where groundwater appeared, a leather measuring tape was used to measure the vertical distance from the surface soil as the depth of the groundwater.

The content of TDS in the groundwater was tested as follows: first, the sample bottles were washed with groundwater and a 0.45 μm polycarbonate membrane was placed on the bottleneck. Next, this bottle was submerged into the water body until enough water was collected, the polycarbonate membrane was removed and the bottle was sealed. Finally, the samples were placed in a portable refrigerator with a temperature <4 °C, and shipped to the laboratory, where the gravimetric method was used to determine the content of TDS in the groundwater samples (HJ/T 51. 1999) (Kunkel et al. 2010).

The amount of NO_3^--N in the groundwater was determined using the Phenol Disulfonic Acid method (Burrough and Mcdonnell 1998). In each of the collected water sample, NaOH was first added until the pH was >10. The samples were then heated at 80 °C until evaporation had occurred and the samples had condensed. The samples were transferred into Kjeldahl bottles, and 20 ml 4×10^5 mg/l NaOH was added, followed by addition of Darcy's alloy as a reducing agent to revert the NO_3^--N to NH_3. 10 ml 4.9×10^4 mg/l H_2SO_4 was used to absorb it, and 3 ml 4×10^5 mg/l NaOBr was added to oxidize NO_3^--N to N_2. N_2 was then collected in a glass tube and an isotope mass spectrometer (Finnigan, MAT252) was used to analyze the samples, the analytical error of which was ±0.2 %.

The salt in the soil profiles was measured as follows: first, the samples were air dried and pushed through a 20 mesh nylon sieve (0.84 mm) to eliminate the plant residue and stones. An agate was used to grind the soil samples through 100 mesh nylon sieves (0.25 mm), to prevent the contamination and then the samples were stored in the plastic bottles. Each soil sample was diluted 1:5 in water to extract leach liquor, and then conventional analysis to measure the salt contents of the soil, and also calculate the soil salt for each of the soil layers (Yao et al. 2006).

The water content of the soil profiles was measured as follows: first, an electric scale (accuracy: 0.0001) was used to obtain the total mass of each soil sample. Then, the weighed soil samples were placed into an aluminum specimen box and dried at 105 °C until the weight remained constant. The water contents within the soil samples were then calculated by comparing the dry weight to the wet weight (Gao et al. 2010).

After all these indicators including the TDS, and the NO_3^--N of the groundwater, and the salt and water contents of all soil samples were tested, 20 % of all samples were chosen to re-tested, the results showed the errors of these indicators comparing with the first test are all within 10 %, indicating that the test results are effective.

Research methods and data processing

In the research, used to analyze the range, the mean, the standard deviation, the coefficient of variation, the kurtosis and skewness of the depth, the TDS and the NO_3^--N values of the groundwater, and the salt and water of the soil profiles. The Kolmogorov-Smicer's test method was used to analyze the normal distribution characteristics of the water and soil samples. The Ordinary kriging method was used to analyze the spatial distribution of the depth, the TDS and the NO_3^--N contents of the groundwater, and the salt and water contents of the soil profiles. Table 1 shows the criteria used to reveal the groundwater quality and soil salinization evaluation of the research area (Table 1).

To detect changes in land use from 2001 to 2010 in the Yutian oasis, a combination of remote sensing and GIS was used. Specifically, Landsat images taken in June 2001, 2005, and 2010 were the data sources with which to evaluate land use changes of the research area. First, we used topographic maps of the Yutian oasis at 1:10,000 to correct the remote sensing images from 2010 and then corrected the images from 2001 and 2005 based on the corrected 2010 images to convert the images from each time point into the same map projection methods. Then the ENVI 4.8 software was used to check the accuracy of the remote sensing image classification results (Mamat et al. 2013, 2014).

Results

Descriptive statistical analysis results

The statistic analysis showed that in all these three time periods, the water table in the Yutian oasis was shallow, with a range of 0.31–6.31 m (Table 2). The mean values in 2001, 2005, and 2010 were 2.52, 2.61, and 2.97 m, respectively. From 2001 to 2010, both the ranges and the mean values of groundwater depth had an increasing trend of $2010 > 2005 > 2001$. The mean groundwater TDS values of the Yutian oasis were 1152.8 g/l in 2001, 1425.7 g/l in 2005 and 2124.8 g/l in 2010, with the maximum values of 3717, 3847 and 4012 g/l, respectively. The NO_3^--N contents in the groundwater ranged from 1.89 to 26.2 mg/l, with the mean values of 6.38 mg/l in 2001, 7.58 mg/l in 2005 and 9.76 mg/l in 2010. Overall, the majority of the water samples from 2001 and 2005 can meet the Drinking Water Standards of the WHO (2011) and China (2006). Across the three periods, the NO_3^--N content of the groundwater showed an increasing trend with the mean values in the order of $2010 > 2005 > 2001$. However, the average NO_3^--N content of the groundwater in 2010 was 1.42 times higher than that in 2001, which exceeded the standard of the WHO (2011), suggesting that in recent years, various factors have led to a dramatic increase in the NO_3^--N content in the groundwater.

As shown in Table 2, there was a significant amount of variation for the water and salt in the soil profiles from all three depths at all three periods, and this trended a decrease going from shallower to deeper in the profiles. The salt content of the soil profiles also showed an increased trend going from 2001 to 2010, and all reached their maximum values in 2010. The mean values of the salt in the soil can be ordered as $2001 > 2005 > 2010$. Based on the analysis, the contents of the salt in the soil profiles ranged from 7.81 to 33.14 g/kg. In 2001 and 2005, the mean salt content in the 0–20 cm soil profile had moderate levels of salinization (>2.0 g/kg), but in 2010, it had reached heavy salinization

Table 1 Indicators used for risk assessment of soil salinization of Yutian oasis

Indicators	Class limits and their ratings score		
	Moderate	Severe	Very severe
Total salt concentration (g/kg)[a]	<2	2–4	>4
	WHO (2011)	NEPA (GB 5749·2006)	
NO_3^--N concentration (mg/l)[b]	<10	<20	
	NEPA (GB 5084-2005)		
TDS concentration (g/l)[c]	<2000		

[a] Agriculture Department of Xinjiang (1996)

[b] WHO (2011), National Standards for Drinking Water Quality of China (GB 5749-2006)

[c] Standards for Irrigation Water Quality of China (GB 5084-2005)

Table 2 Descriptive statistical analysis of of the water table, TDS, and NO_3^--N of the groundwater, and the salt and water of soil profiles in 2001, 2005 and 2010 in the Yutian oasis

Periods	Indicators	Maximum	Distribution pattern	Minimum	*P* (K–S test)	Mean	SD	Coefficient of variation %	Kurtosis	Skewness
2001	Water table (m)	5.11	N	0.31	0.4	2.52	0.46	22.1	25.9	19.7
	TDS (g/l)	3717	N	101	0.2	1152.8	71	85.7	28.1	17.3
	NO_3^-N content (mg/l)	20.2	N	1.89	0.3	6.38	1.2	118.1	27.4	15.3
	Soil salt 0–20 cm (g/kg)	30.92	lgN	0.41	0.16	2.12	0.52	29.7	21.2	11.8
	20–40 cm (g/kg)	25.3	LgN	0.21	0.18	1.5	0.32	25.8	23.6	16.7
	40–60 cm (g/kg)	21.2	LgN	0.11	0.51	0.7	0.28	21.3	29.7	19.7
	Soil water 0–20 cm (g/kg)	23.11	N	9.23	0.3	12.4	0.36	28.3	22.1	11.3
	20–40 cm (g/kg)	26.8	N	11.5	0.4.	17.15	0.22	21.43	19.71	12.22
	40–60 cm (g/kg)	31.1	N	1918	0.6	26.7	0.27	19.81	20.1	13.3
	Water table (m)	5.81	N	0.51	0.2	2.61	0.49	28.1	28.3	16.1
	TDS (g/l)	3847	N	216	0.4	1425.7	81	76.1	33.4	19.7
	NO_3^--N content (mg/l)	23.2	N	2.89	0.3	7.58	0.62	131.1	19.8	13.7
2005	Soil salt 0–20 cm (g/kg)	33.14	LgN	0.36	0.21	2.32	0.33	26.1	18.2	9.82
	20–40 cm (g/kg)	27.13	LgN	0.17	0.12	1.04	0.32	21.18	24.16	15.27
	40–60 cm (g/kg)	22.22	LgN	0.04	0.23	0.81	0.34	17.52	23.27	11.07
	Soil water 0–20 cm (g/kg)	21.35	N	8.67	0.2	11.8	0.31	27.75	20.31	12.17
	20–40 cm (g/kg)	25.3	N	10.8	0.3	15.28	0.32	20.76	14.56	9.76
	40–60 cm (g/kg)	30.7	N	17.7	0.1	24.76	0.31	17.71	22.8	16.5
	Water table (m)	6.31	N	0.71	0.2	2.97	0.42	23.1	22.5	19.5
	TDS (g/l)	4012	N	312	0.4	2124.8	52	97.8	28.3	21.2
2010	NO_3^--N content (mg/l)	26.2	N	3.12	0.6	9.76	0.47	398.1	34.1	27.3
	Soil salt 0–20 cm (g/kg)	36.18	LgN	0.87	0.17	5.62	0.32	53.13	23.21	13.28
	20–40 cm (g/kg)	28.43	LgN	0.62	0.23	3.65	0.23	42.38	21.32	16.37
	40–60 cm (g/kg)	23.22	LgN	0.27	0.16	1.27	0.43	37.43	22.54	15.37
	Soil water 0–20 cm (g/kg)	19.21	N	7.07	0.4	10.14	0.26	65.23	17.21	12.38
	20–40 cm (g/kg)	23.27	N	8.63	0.2	13.58	0.18	52.53	16.71	9.22
	40–60 cm (g/kg)	28.75	N	14.8	0.3	22.27	0.21	38.21	18.21	11.28

Annotation LgN is the logarithmic normal distribution and is in the form of log transformed values. N represents the Normal distribution

levels (>4.0 g/kg) (Agriculture Department of Xinjiang 1996).

In 2001, 2005 and 2010, the content of water in the soil profiles in the oasis all had decreasing trends with the maximum values occurring in 2001. The mean water content can be ordered as: 2001 > 2005 > 2010. In 2001, the mean salt content in the surface soil (0–20 cm) in the Yutian oasis was 1.47 times higher than that in 2005 and 1.28 times higher than that in 2010, indicating a large amount of variation in the amount of water during these years.

According to the variation function, the variability of the soil salinity can be classified into the weak variability when the $CV < 10\ \%$, the medium variability when $10\ \% \leq CV \leq 100\ \%$ and the strong variability when $CV > 100\ \%$ (Yao et al. 2006). As shown in Table 1, the variable coefficients of the depth and TDS of groundwater were significantly lower than that of the NO_3^--N at all three periods. Among these, the mean CVs values of the groundwater depth were 22.3, 23.1, and 28.1 % in 2001, 2005, and 2010, respectively, thus placing them in the medium variation category. Meanwhile, the CVs values of the NO_3^--N contents in the groundwater were 85.7 % in 2001, 76.1 % in 2005, and 97.8 % in 2010, which are all close to 1, indicating that the spatial variations between them are large. Combining with the literature, it hypothesized that the main reasons for this are the unique hydrogeological conditions and landform characteristics that can lead to significantly different hydrologic geochemical zones in the region (Chen et al. 2004).

Based on the analysis, it showed that the contents of salt in all three soil profiles all gradually decreased going from shallower to deeper in the profiles at all three periods, and the CVs values of the surface soil (0–20 cm) taken in 2001, 2005 and 2010 were 29.7, 26.1 and 53.18 %, respectively, suggesting they were all of medium variation.

The analysis showed the CVs for the contents of water in the soil profiles from all three periods gradually decreased going from shallower to deeper profiles (0–60 cm). This analysis showed that the CVs values of the amounts of water in the surface soil (0–20 cm) were 28.3 % in 2001, 27.75 % in 2005 and 65.23 % in 2010, respectively, placing them at moderate levels of variation.

The temporal and spatial variations of indicators

Calculation variation functions require that the data conform to a normal distribution, otherwise a scale effect may occur (Chen et al. 2004). Using the Kolmogorov–Smimov (K–S) method, a normal distribution ($P < 0.05$, two-tailed) was checked and the results showed that in 2001, 2005 and 2010, the groundwater depth, the TDS and NO_3^--N contents in groundwater, and the water contents of the soil profiles in Yutian oasis all had a normal distribution. However, the salt content of the soil profiles did not have a normal distribution and they were therefore transformed logarithmically (Nas and Berktay 2010).

When using the semivariance function model to study the water table, TDS and NO_3^--N in groundwater, the scatter diagram of $r(h)$-h was first calculated, and then the Spherical, Exponential and Gaussian models were used for fitting. Then, three parameters, Nugget (Co), Sill and Range, and the Determination Coefficient (R^2) were obtained from the model. The cross-validation method was used to correct the parameters of the model (Ahmadi and Sedghamiz 2007). In the model, Co represents the spatial heterogeneity caused by random factors, such as the experimental error and was less than the tested sample scales, and Sill represents the total variation within the system. Co/Sill represents the ratio of the heterogeneity caused by random factors for the total spatial heterogeneity. A Co/Sill < 25 % suggests a strong spatial correlation, a 25 % $<$ Co/Sill < 75 % suggests a medium spatial correlation and a Co/Sill > 75 % suggests a weak spatial correlations.

As shown in Table 3 and Fig. 3, for samples obtained at all three periods, the half variance theory models of the water table, TDS and the NO_3^--N content of the groundwater all fit with the spherical models. The salt contents of the 0–20 cm soil profiles all fit with the Gaussian models and the salt and water contents both in the 20–40 and 40–60 cm soil profiles all fit with the exponential model for all three time periods. The effective ranges of all tested variables were among 20–10,403 m, the determination coefficients were all greater than 0.71, and the residual sums of squares were all less than 0.001. These results suggest that the chosen theoretical models can all meet the requirements of the practical situation of the oasis.

The analysis showed there was a large amount of variation of the Co/Sill values. In 2001, the Co/Sill values of the depth, the TDS and the NO_3^--N of the groundwater were all lower than 25 %, suggesting there were strong spatial correlations and obvious spatial distribution patterns for these indicators, indicating they were mainly influenced by the environmental factors, such as the terrain, the climate, the meteorology, the precipitation, the evaporation and the ice and snow supplies (Munoz et al. 2013).

In 2005, the Co/Sill values of the water table, TDS and NO_3^--N of the groundwater all ranged among 25–75 %, suggesting moderate spatial correlations and discernable spatial distribution patterns, indicating they were mainly influenced by the environmental factors, such as the terrain, the climate, the meteorology, the precipitation, the evaporation, and the ice and snow supplies (Wang et al. 2006). Meanwhile the artificial factors, such as the exploitation of groundwater, the use of fertilizers on the farmland and the urban and industrial waste also have some influence. In 2010, the Co/Sill values for the depth, the amounts of TDS and NO_3^--N of the groundwater were all >75 %, suggesting there were only weak spatial correlations and with no discernable spatial distribution patterns, indicating these parameters were mainly influenced by the artificial factors, such as the exploitation of the groundwater, the use of fertilizers on the farmland, and the urban and industrial waste emissions.

This analysis revealed that in 2005, the ranges for the water table and TDS contents of the groundwater were high, but were lower than those of 2001. However, there was little difference among these periods in terms of the spatial distance of the NO_3^--N of the groundwater in the oasis.

In 2010, the water table and TDS of the groundwater were both significantly lower than those in 2001 and 2005, showing a decreasing trend. Among the indicators

Table 3 Semivariance function model of the water table, TDS, and NO_3^--N of the groundwater, and the salt and water of soil profiles in 2001, 2005 and 2010 in the Yutian oasis

Monitoring periods	Indicators	Theoretical model	Nugget (Co)	Still	Nugget/still (%)	Range (km)	Determination coefficient (R^2)	Residual sum of squares (RSS)
2001	Water table (m)	Spherical	1.06	2.38	44.54	0.57	0.81	0.0001
	TDS (g/l)	Spherical	5.71	5.71	100	0.58	0.72	0.0002
	NO_3^--N (mg/l)	Spherical	4.3	36	11.94	0.01	0.87	0.0001
	Soil salt 0–20 cm (g/kg)	Gaussian	5.9	62.8	9.4	0.45	0.79	0.0008
	20–40 cm (g/kg)	Exponential	4	46.73	8.6	0.51	0.72	0.0001
	40–60 cm (g/kg)	Exponential	2.88	21.59	13.34	0.56	0.96	0.0003
	Soil water 0–20 cm (g/kg)	Exponential	8.9	46.34	19.05	0.02	0.85	0.0002
	20-40 cm (g/kg)	Exponential	5.1	76.03	6.71	0.04	0.93	0.0005
	40–60 cm (g/kg)	Exponential	3.6	66.55	5.41	0.04	0.83	0.0001
	Water table (m)	Spherical	1.07	2.38	44.96	0.57	0.98	0.0004
	TDS (g/l)	Spherical	0.6	5.71	10.51	0.58	0.76	0.0003
	NO_3^--N (mg/l)	Spherical	0.43	3.6	11.94	0.01	0.74	0.0001
	Soil salt 0–20 cm (g/kg)	Gaussian	3.87	31.96	12.11	0.01	0.82	0.0003
2005	20–40 cm (g/kg)	Exponential	1.11	19.94	5.57	0.03	0.77	0.0002
	40–60 cm (g/kg)	Exponential	0.97	9.07	10.7	0.01	0.79	0.0001
	Soil water 0–20 cm (g/kg)	Exponential	17.7	75.61	23.41	0.35	0.98	0.0005
	20–40 cm (g/kg)	Exponential	52.4	140.59	37.27	10.4	0.96	0.0003
	40–60 cm (g/kg)	Exponential	43.3	92.75	46.69	0.42	0.96	0.0001
	Water table (m)	Spherical	1.07	2.38	44.96	0.57	0.99	0.0009
	TDS (g/l)	Spherical	5.71	5.71	100	0.58	0.75	0.0001
2010	NO_3^--N (mg/l)	Spherical	4.3	36	71.67	0.01	0.76	0.0005
	Soil salt 0–20 cm (g/kg)	Gaussian	3.9	32.25	12.12	0.02	0.80	0.0002
	20–40 cm (g/kg)	Exponential	3.45	20.19	17.09	0.47	0.73	0.0001
	40–60 cm (g/kg)	Exponential	0.98	9.21	10.64	0.01	0.79	0.0003
	Soil water 0–20 cm (g/kg)	Exponential	17.7	75.61	23.41	0.35	0.99	0.0002
	20-40 cm (g/kg)	Exponential	52.4	140.59	37.27	10.4	0.96	0.0001
	40–60 cm (g/kg)	Exponential	43.3	92.75	15.75	0.42	0.96	0.0003

measured, the spatial distance of the NO_3^--N contents in the groundwater is at minimum. Combined with the literature and the sampling background, this suggests that the artificial factors, such as the exploitation of the groundwater were the main influenced factors (Rieger et al. 2004; Gilliom et al. 2006). The ranges of the contents of the NO_3^--N in the groundwater further decreased from 2005 to 2010. When combined with the literature and the sampling background, this suggests that the artificial factors, such as the groundwater exploitation and the industrial and urban waste emissions may be the major influential factors (Ahmadi and Sedghamiz 2007).

Out of all three periods, the Co/Sill values of the salt and water contents of the soil profiles (0–60 cm) were all <25 % in 2001, showing a strong spatial correlation between them. Furthermore, there were significant spatial autocorrelation patterns in the soil profiles, indicating they may be mainly influenced by the environmental factors.

In 2005, the Co/Sill values of the salt and water content of the soil profiles (0–60 cm) all ranged among 25–75 %, showing the medium spatial correlations. Also, there were significant spatial autocorrelation patterns, indicating these factors may be mainly influenced by the environmental factors, such as the precipitation, the evaporation and the

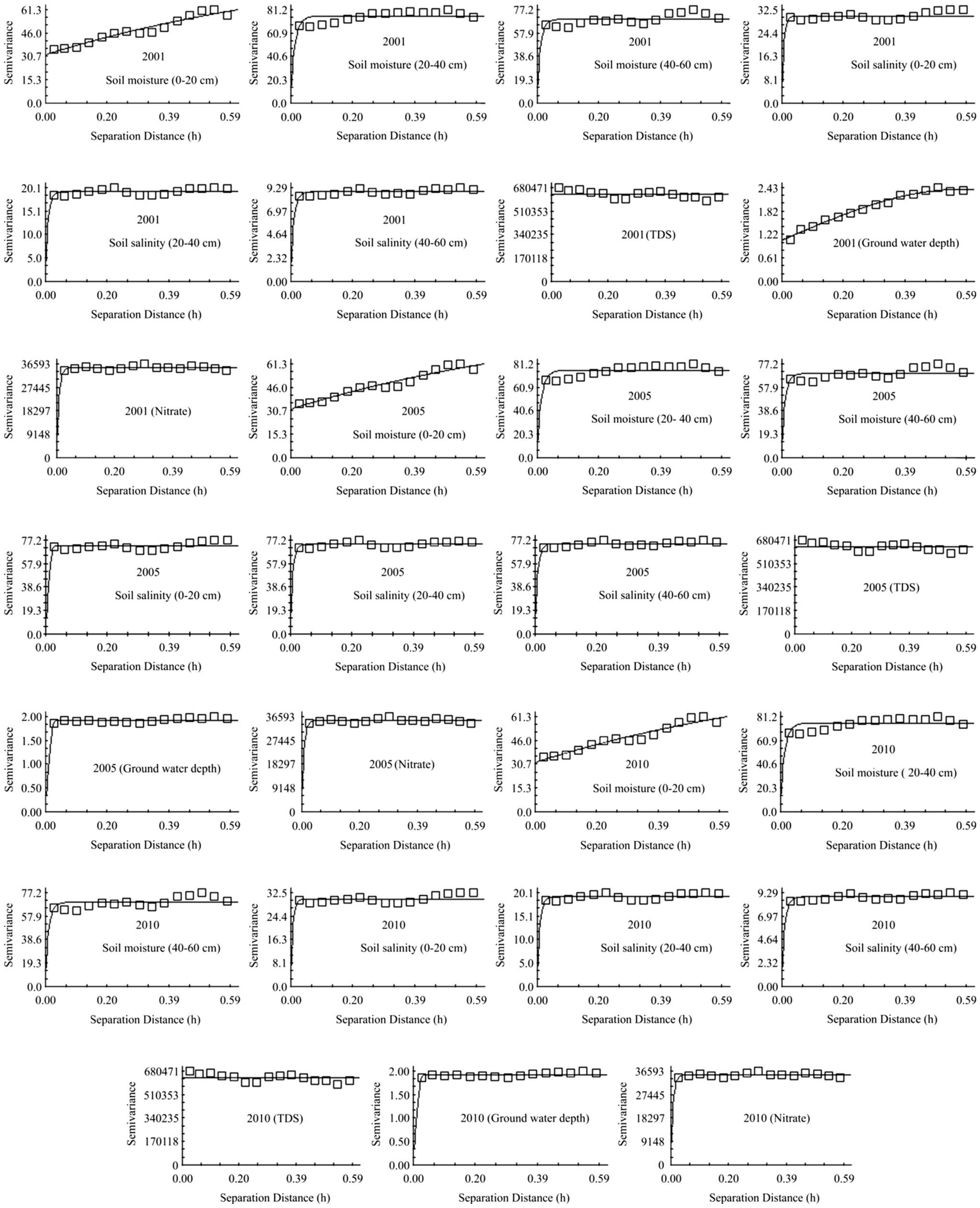


Fig. 3 The semivariance diagrams of the water table, TDS, and NO_3^--N of the groundwater, and the salt and water of soil profiles obtained in 2001, 2005 and 2010 from the Yutian oasis

temperature, as well as partially influenced by the random factors (Zhao et al. 2007).

In 2010, the Co/Sill values of the salt and water contents of the soil profiles (0–60 cm) were all >75 %, suggesting a weak spatial correlation for them. Due to the lack of significant spatial autocorrelation patterns, these parameters were mostly influenced by the artificial factors, such as the groundwater exploitation and the agricultural irrigation, etc. (Mamat et al. 2013).

From the semivariance function models and the Kriging optimal interpolation, the spatial distribution maps of the depth, the TDS and the NO_3^--N contents of the groundwater, and the salt and water contents of the soil profiles (0–20, 20–40, 40–60 cm) in 2001, 2005 and 2010. In general, the results showed that the water table in the Yutian oasis was shallow with a depth of 1.5–3.0 m, accounting for more than 49.8 % and 20069.4 km^2 of the study area at all three periods. Furthermore, the areas where the water table was <1.5 m, and accounted for at least 21.3 % and 8583.9 km^2 in 2010 and were mainly distributed in the northern part of the oasis, where the vegetation is primarily grass (Liu et al. 2003). In the oasis, the water table was >3.0 m, and accounted for at least 20.1 % and 8100.3 km^2 of the total oasis at all three periods and were mainly distributed in the southern margin of the Kunlun mountains piedmont region. Based on the mean water table, three periods can be ordered as 2001 > 2005 > 2010.

From Fig. 4, it can be seen that TDS contents of the groundwater had discernable spatial distribution patterns across the oasis for all three periods. In general, the contents of TDS increased gradually moving from the south recharge runoff area to the north discharge area, which is consistent with the research of Lü et al. (2009). The contents of the TDS in the groundwater that fell lower than 1000 mg/l tended to be distributed in the southern parts of the tilt piedmont diluvial plain. In the central part of the oasis, the contents of the TDS in the groundwater ranged from 1000 to 2000 g/l and the groundwater was therefore brackish. Figure 4 and Table 3 show that at each period, the areas where the TDS content of the groundwater was lower than 1000 g/l or higher than 3000 g/l accounted for only a small ratio of the total area, which was lower than 18 %. However, in 2001 and 2010, the TDS content of the groundwater ranged among 1000–2000 g/l, accounting for most parts of the oasis and covering more than 50 % and 20270.9 km^2 of each period. In 2010, the area where the TDS content of the groundwater was higher than 2000 g/l covered 38.5 %, and 15515.5 km^2 of the total area, which was significantly higher than that in 2001 and 2005, which were at 12.7 %, and 5118.1 km^2 and 19.1 %, and 7294.3 km^2, respectively.

At each period, the spatial distribution of NO_3^--N contents in the groundwater in the Yutian oasis reduced gradually when going from the center to the periphery with concentrations of >10 mg/l being primarily in the central and south parts of the oasis, which are mostly cultivated land. The accumulation of NO_3^--N was significantly higher in 2010 than in 2001 and 2005. Based on the mean contents of NO_3^--N in the groundwater, in 2001, the areas with NO_3^--N contents >20 mg/l were 9.4 % and 3788.2 km^2, in 2005, the area of that was 11.1 % and 4473.3 km^2, and in 2010 the area of that was 31.9 % and 12855.7 km^2 (Table 4). All of these areas exceeded both the Drinking Water Quality Standard of China (2006) and WHO (2011).

Overall, the analysis revealed that in 2001, 78.1 % and 31474.3 km^2 of the total surface soil of Yutian oasis had low salinity, in 2005 it was 71.7 % and 28895.1 km^2, while in 2010 it was 60.3 % and 24300.9 km^2. In 2010, the moderate salinity was 28.1 % and 11324.3 km^2, and heavy salinity was 11.6 % and 4674.8 km^2.

Discussion

Relationships between the indicators

Correlation analysis results showed that in all three periods, the water table, the TDS and NO_3^--N in groundwater, and the salt and water in the soil profiles were all closely related at $P < 0.01$ or $P < 0.05$ levels (Table 5). Among these, there was a negative correlations between the depth and the TDS of the groundwater, the water table of the groundwater and the salt contents of the soil, and the water table of the groundwater and the water contents of the soil at $P < 0.01$ or $P < 0.05$ levels (Table 5), but there was no correlation between of the water table and the NO_3^--N contents of the groundwater at $P < 0.01$ or $P < 0.05$ levels (Table 5). In 2001 and 2005, little difference was found between the correlation coefficients of these tested indicators. However, these correlation coefficients were significantly higher for samples obtained in 2010 than those of samples obtained in 2001 and 2005. Specifically, the correlation coefficients of the depth and the TDS content of the groundwater, the water table of the groundwater and the salt contents of the soil, and the water table of the groundwater and the water content in the soil were 0.77, 0.82, and 0.73, respectively. At each period, the correlation coefficients of the water table of the groundwater and the salt concentration of the soil (0–20, 20–40 and 40–60 cm), the water table of the groundwater and the water content of the soil (0–20, 20–40, and 40–60 cm) were all at $P < 0.01$ or $P < 0.05$ levels (Table 5). In the mean time, the TDS content of the groundwater and the salt content of the soil profiles (0–20, 20–40 and 40–60 cm) all trended to decrease going from the shallower to the deeper profiles

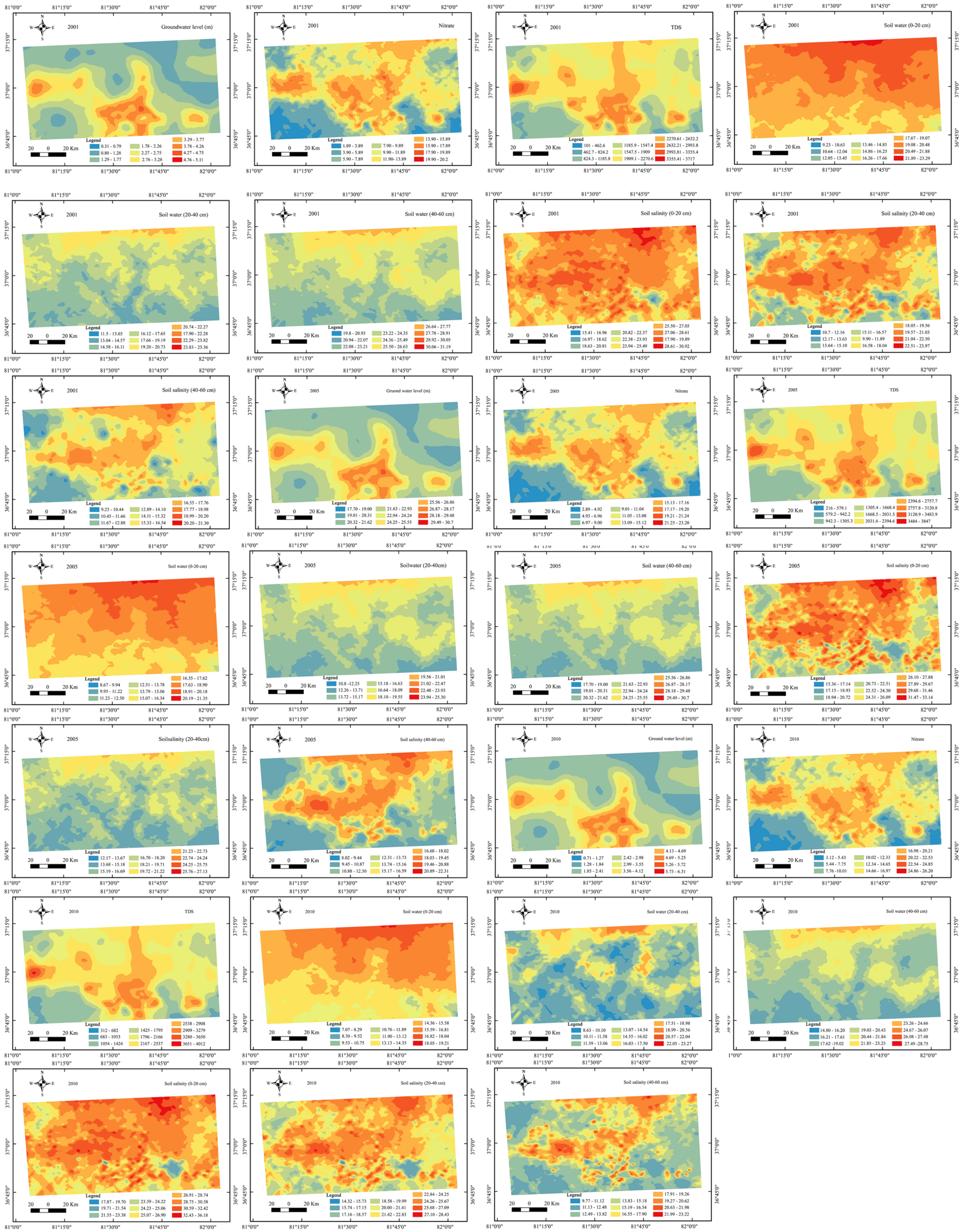


Fig. 4 Spatial patterns of the water table, TDS, and NO_3^--N of the groundwater, and the salt and water of soil profiles obtained in 2001, 2005 and 2010 from the Yutian oasis

(Table 5, $P < 0.01$, $P < 0.05$). This indicates that the water table and the TDS contents of the groundwater were the major factors that influence the salt and water contents of the soil profiles. When comparing between these three periods, it was found that the correlation coefficients were significantly higher in 2010 than in 2001 and 2005, with a large amount of variability.

Reasons for the variability of the indicators

By combining the hydrogeological backgrounds, the average temperatures, the annual rainfalls and the evaporations, amount of groundwater mining, the yearly use of fertilizers, the yearly increase in population and changes in land use (Fig. 5), the spatial distribution and the causes for the water table, the mineralization and the nitrate of the groundwater and the salt and water contents of the soil profiles from 2001, 2005 and 2010 of the Yutian oasis were analysed.

From the spatial distribution, it was found that the water table of the groundwater was significantly higher in the southern part of the oasis than in the northern part, and this reduced gradually going from south to north. Considering the oasis terrain, the south is a piedmont region of the Kunlun Mountains at a high altitude, and it is also the recharge area of the groundwater. Meanwhile, the northern area is near the Taklamakan desert edge, which is flat terrain at a low altitude and is the discharge area of the groundwater. Based on the hydrogeological backgrounds, the south had clastic rock fissure-pore water and magmatic rock class fracture aquifers with strong capacity to contain rich water (Zhao et al. 2007). However, in the north there was fissure karsts water of carbonate with low capacities for enrichment of water. Former analysis showed that in 2010, the salt contents in the surface soil (0–20 cm) were present at a significantly higher level than in 2001 and 2005. So it was hypothesized that this is due to the levels of strong evaporation occurring in an oasis, and in an arid region raising groundwater from the phreatic surface to the soil vadose zone, and this migrate the moisture that led to salt ions moving from deeper to shallower and eventually accumulated in the surface soil (Wahap et al. 2007) and forming the saline-alkali soil in the central and northern parts of the oasis. Recently, as the population of the oasis has increased, the cultivated land reclamation has increased, and the agriculture can cause over irrigation and disordered diversion and drainage of water can cause secondary salinization of the cultivated land (Chen et al. 2004). Concurrently, due to the poor seepage control of the irrigation channel, during the water diversion when the water passed through channels to the farmland as much as 59 % of the total amount was lost, which significantly lowered the groundwater level and led to serious salinization of the soil in the cultivated land of the Yutian oasis.

Table 4 Area and ratios of water table, TDS and NO_3^--N in the groundwater, and the surface soil contents (0-20 cm) in 2001, 2005, and 2010 in the Yutian oasis

Monitoring periods		Water table (m)			TDS (g/l)			NO_3^-N (mg/l)			Salt contents (g/kg) (0–20 cm)		
		0.31–1.5	1.5–3.0	3.0–6.0	101–1000	1000–2000	2000–4012	1.89–10	10–20	20–26.2	0–2	2–4	>4
2001	Area (km^2)	10357.1	20069.4	9873.5	7052.5	28129.4	5118.1	35665.5	846.3	3788.2	31474.3	4956.9	3868.8
	Ratios (%)	25.7	49.8	24.5	17.5	69.8	12.7	88.5	2.1	9.4	78.1	12.3	9.6
2005	Area (km^2)	10075	20673.9	11566.1	6649.5	26356.2	7294.3	30265.3	5561.4	4473.3	28895.1	7495.8	3909.1
	Ratios (%)	25	51.3	28.7	16.5	65.4	18.1	75.1	13.8	11.1	71.7	18.6	9.7
2010	Area (km^2)	8583.9	23615.8	8100.3	4513.6	20270.9	15515.5	16240.9	11243.7	12855.7	24300.9	11324.3	4674.8
	Ratios (%)	21.3	58.6	20.1	11.2	50.3	38.5	40.3	27.9	31.9	60.3	28.1	11.6

Table 5 Relationships between water table to groundwater, TDS and NO_3^--N contents in groundwater, and the salt and water in soil profiles obtained from the Yutian oasis from 2001 to 20 0

Indicators		2001							2005				2010			
		DG	TDS	NO_3^--N	SS	SW	DG	TDS	NO_3^--N	SS	SW	DG	TDS	NO_3^--N	SS	SW
2001	DG	1														
	TDS	0.89**	1													
	NO_3^-N	0.12	0.08	1												
	SS	0.71**	0.85**	−0.11**	1											
	SW	0.72**	0.66**	−0.07**	0.57**	1										
	DG	0.75**	0.67**	−0.12	0.58**	0.67	1									
	TDS	0.68**	0.81**	−0.07	0.47*	0.59**	0.67**	1								
2005	NO_3^--N	0.11	0.03	0.452**	0.04	0.67	0.09	0.11	1							
	SS	0.75	0.67	−0.12	0.58	0.55**	0.65**	0.52**	−0.21	1						
	SW	0.88**	0.87**	−0.56	0.84**	0.65*	0.59**	0.49**	−0.35**	0.76**	1					
	DG	0.81**	0.56**	−0.21	0.66**	0.49**	0.65**	0.85*	0.15	0.61*	0.65**	1				
	TDS	0.67**	0.48*	−0.23	0.53*	0.54*	0.43*	0.58**	0.24	0.47*	0.71**	0.77**	1			
2010	NO_3^--N	0.12	0.12	0.64*	0.05	0.14	0.09	0.13	0.48*	0.21	0.18	0.21	0.19	1		
	SS	0.84**	0.63*	−0.22	0.76*	0.55**	0.59**	0.68*	−0.36	0.57*	0.65**	0.82**	0.68**	−0.39	1	
	SW	0.56*	0.86**	0.07	0.62**	0.71*	0.69**	0.67*	−0.28	0.61*	0.67*	0.73**	0.51**	−0.11**	0.66**	1

DG represents depth to groundwater, *SS* represents soil salt of 0–60 cm, *SW* represents soil water 0–60 cm

** represents significance at <0.01 level; *represents significance at <0.05 level

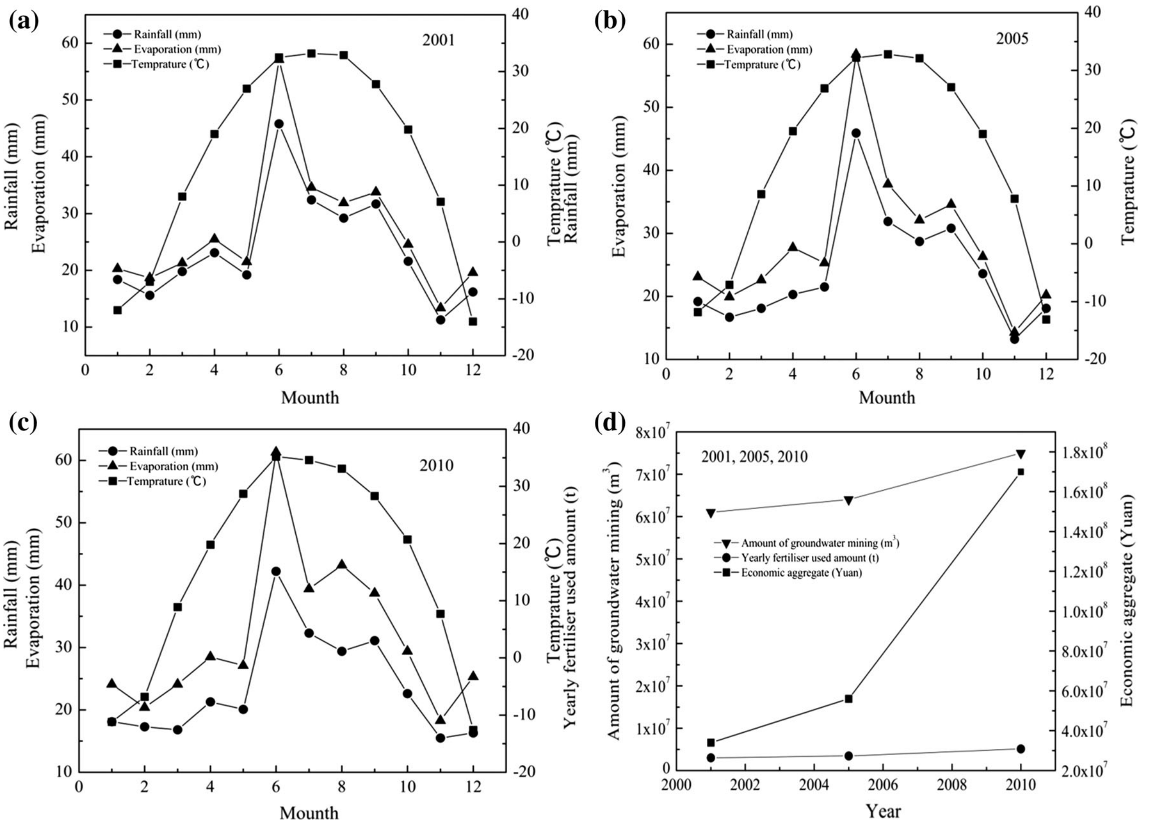


Fig. 5 Meteorological, social and economic data of the Yutian oasis in 2001, 2005 and 2010

The water table, the TDS and the NO_3^--N of the groundwater and the salt concentration in the soil profiles were significantly higher in 2010 than in 2001 and 2005. This was closely related to the climate (precipitation, temperature and evaporation), the amount of groundwater mining, the amount of arable land and the fertilizer usage changes (Fig. 5). In 2010, there were no apparent changes in the precipitation and temperature compared with those in 2001 and 2005, but there were obvious changes in evaporation capacity of the research area, which were most significant from July to November and were more significant than those in 2001 and 2005 (Fig. 5a–c). Meanwhile, the cultivated land size also increased significantly during this period, and reached 193.63 km^2 in 2010, which were significantly higher than those in 2001 and 2005 (Nurmemet et al. 2015). This research also showed the exploitation of the groundwater, which showed the highest value of 0.971 × 10^8 m^3 in 2010 among the three periods (Fig. 5a–c; Wu et al. 2013). This reduced the supplements and increased the water table, which eventually influenced the salt and water contents in the soil profiles (Gilliom et al. 2006; Wahap et al. 2007). Other researchers have also found when the groundwater levels are low in arid regions, the salt in the soil increases and the water decreases (Lü et al. 2009). In this work, the correlation analysis results of the water table, and TDS and NO_3^--N in groundwater all showed strong trends, indicating the depth of groundwater in Yutian oasis can significantly influence the amounts of salt and water in the soil.

Previous research showed that the NO_3^--N contents in groundwater were mainly influenced by the agricultural fertilizer, the industrial "Three Wastes" emissions, the sewage discharge, the vadose zone lithology, and the water table and flow conditions of the groundwater (Hu and Sun 2007). In 2010, the amount of cultivated land of Yutian oasis attained 2651.0 km^2, which was significantly higher compared to those in 2001 and 2005. This led to an increase in the use of fertilizer in agriculture (Nurmemet et al. 2015). Specifically, in 2010, the nitrogenous fertilizer usage in the oasis reached 1.75 × 10^4 t (Fig. 5d) and the annual application levels exceeded 481 kg/hm^2 (Wu et al. 2013). Then, through irrigation and precipitation, the NO_3^--N infiltrated into and polluted the groundwater. In the central oasis, the concentration of NO_3^--N in the groundwater was significantly higher than the surrounding areas, which is consistent with the distribution of the cultivated lands in the study area.

In 2010, the salt contents in the soil profiles were significantly higher than in 2001 and 2005, thus increasing the scale and intensity of agricultural production. Farming activities, such as flood irrigation and soil tillage negatively influenced the accumulation of salt in the soil profiles, especially in the surface soil. By comparison, the water in the soil profiles was also influenced by the increased scale and the intensity of groundwater mining by agricultural activities and urban areas. In 2010, the water content in the soil profiles showed a significant decrease trend. Apart from the increased evaporation, the human population in the research area also discernibly increased during these years (Fig. 5d), which eventually increased the demand for the land and the total area of the arable land (Nurmemet et al. 2015). Additionally, the industries and the urban areas also resulted in an increase in groundwater mining (Jiang et al. 2007), which caused the water table in the Yutian oasis deeper and the water of the soil profiles decreased. In the cultivated land of the central oasis, the moisture contents showed the most significant decreased trend. This is consistent with the correlation analysis results of the groundwater depth and the water contained in the soil profiles (Table 4), indicating that the artificial factors are the important reason for the increase of salt ions contents and decrease of water in the soil in the oasis. In general, over these years, human activity has negatively influenced the water table, the TDS and NO_3^--N contents of the groundwater, and also the salt and water in the soil profiles. This has resulted in a deeper depth to groundwater, and increased the TDS and NO_3^--N contents of the groundwater.

Conclusion

Descriptive statistical analysis showed that the means and CVs of the water table, the TDS and the NO_3^--N of the groundwater, and the salt and the water of the soil profiles in 2010 were significantly higher than those in 2001 and 2005. The increase in salt contents and decrease in water contents in soil profiles amplified the degree of salinization.

Geostatistical analysis showed that all the tested indicators had strong spatial correlations with discernable spatial distributions in 2001, which were mainly influenced by the natural factors. In 2005, they all had relatively strong spatial correlations with obvious spatial distribution patterns and they were influenced by both natural factors and artificial factors. In 2010, these indicators had no obvious spatial correlations or distribution patterns, and they were mainly influenced by the artificial factors.

This work found that combined influence of natural and human factors, the water table, the TDS, and the NO_3^--N of the groundwater were significantly increased recent years. At the same time, there was an increase trend in the salt content and a decrease trend in the water content of the soil profiles, which resulted in increased degree of salinization in the oasis, which deserves much attention.

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