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Spatial-temporal variations and their dynamics of the saline lakes in the Qaidam Basin over the past 40 years

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Spatial-temporal variations and their dynamics of the saline lakes in the Qaidam Basin over the past 40 years

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Abstract. The saline lakes in the Qaidam basin, providing numerous saline mineral resources to the development of China's western region have changed greatly in recent decades. Understanding the spatial-temporal variations of the saline lakes for exploring the dynamics of those changes is not only essential for sustainable development of the region, but also is of significance for scientific studies. By using multi-temporal Landsat and HJ-1A/1B remote sensing data, this study focused on detecting the spatial-temporal variations of the saline lakes concerning with their extent changes with the influence of climate and human activities in the Qaidam basin from 1973 to 2014 based on the normalized difference water index (NDWI) and maximum likelihood supervised classification techniques. The results indicated that most of the saline lakes studied in this paper across the study region had experienced great changes over the past 40 years, and each saline lake differed considerably on extent. The runoff supplies from the surrounding rivers and the large-scale saline resource exploitation were considered as direct reasons for the saline lake extent changes, in which climatic changes characterized by the increase of temperature and slight decrease of precipitation over the region had significant impacts on the lake area variations directly or indirectly.

1. Introduction

As one of the most important lake types, saline lakes, rich in special saline mineral resources such as potassium salt, magnesium salt, boron salt, and lithium salt, are an important strategic resource for the development of countries [1]. Exploitation and resource management of saline lakes require high-precision spatial-temporal variation information of saline lakes concerning with their extents, which are usually difficult to be investigated in China by the conventional means due to the harsh environmental conditions of most saline lakes. Images from earth observation satellites can provide unique data sources rapidly and efficiently for the investigation of saline lakes, and the development of various remote sensing image classification methods also contributes to the application of remote sensing on saline lake researches [2].

Lakes, which constitute the essential components of the hydrological and biogeochemical cycles, are a sensitive indicator of global change [3-7]. An increasing number of studies on the changes of saline lakes in the Qaidam basin where a number of main saline lakes distributed in China had been

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reported [8-10]. The variations of temperature and precipitation and the large-scale saline resource exploitation were regarded as the main dynamics for the various changes of the lakes. Most of such studies focused on the relations of lake area with temperature and precipitation across the Qaidam basin, while the analysis on seasonal extent changes as well as the variations of the saline lakes with runoff supplies was relatively few.

By means of multi-temporal HJ-1A/1B and Landsat satellite images acquired from 1973 to 2014, spatial-temporal extent variations of the saline lakes in the Qaidam basin for the last decades were investigated, annual and seasonal variations on individual saline lake extent with air temperature, precipitation were analysed and meanwhile the driving dynamics for those changes were discussed.

2. Materials and methods

2.1. Study region

Located in Qinghai Province, close to the northern margin of the Qinghai–Xizang Plateau, the Qaidam basin covers an area of 120,000 km^2, situated between 90° 09' - 99° 16' E and 34° 41' - 39° 20' N (figure 1). The Qaidam basin is one of the regions significantly affected by the global change in the Qinghai–Xizang Plateau, and the saline resource exploitation here persistently enhances with the development of the country, especially after 2000. Under the circumstances, some saline lakes there have taken on great changes in the last decades and some of them, as shown in figure 1, were the main research objects in this study.

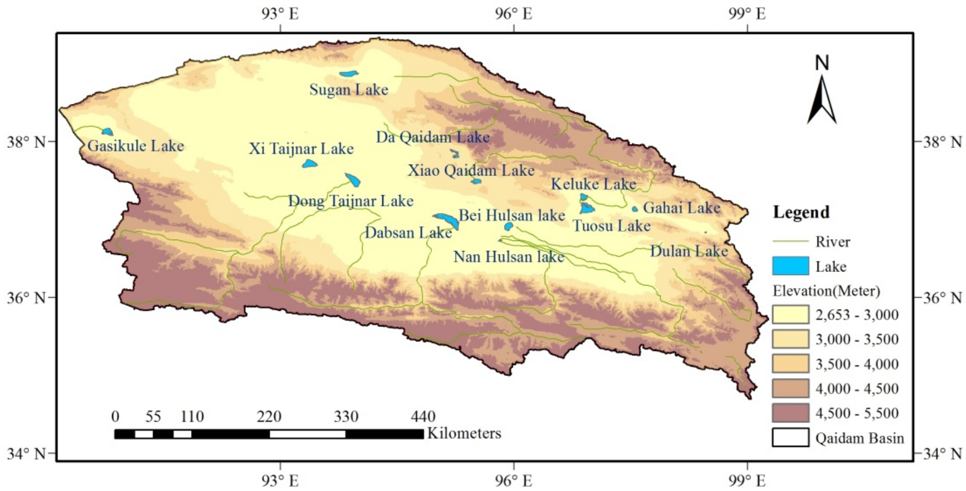

Figure 1. Study region.

2.2. Datasets

Landsat MSS, TM, ETM+ imagery are the most frequently applied remote sensing data in the lake variation detection researches [11], which were also the main satellite imagery sources for this study. Besides, some images from HJ-1A/1B satellites were also used to provide supplementary information. Cloud-free or nearly cloud-free, calibrated and geometrically corrected using ENVI software Landsat images from 1973 to 2014 and HJ-1A/1B images in 2013 and 2014, downloaded from USGS GLOVIS (http://glovis.usgs.gov) and China Centre for Resources Satellite Data and Application (http://cresda.com/en/gywm/zxgk/index.shtml), were applied in this study.

In order to analyse the dynamics of the lake extent variations, annual precipitation and average temperature data during 1973–2013 were collected from China Meteorological Data Network (http://data.cma.cn/). Annual river runoff data in the Qaidam basin were also used in this paper to study the relations of lake changes to runoff. In addition, the 90m-resolution DEM data from Shuttle Radar Topography Mission Digital Elevation Model (SRTM-DEM) and the boundary vector of the Qaidam basin (after slight adjustment by reference to the literatures) from National Science &

Technology Infrastructure of China, Data Sharing Infrastructure of Earth System Science-Lake-Watershed Science Data Center (http://lake.geodata.cn) were obtained to provide the basic geographic information of the study region.

2.3. Water body identification

By means of multi-temporal Landsat and HJ-1A/1B images, the extraction of the saline lakes and retrieval of lake surface area were conducted. Based on the spectral absorption characteristics of water body that differ very much from the other ground objects in visible and infrared spectral bands, several water indices were developed in recent years by combining two or more bands for water body identification, among which the normalised difference water index (NDWI) [12] was a frequently used one, and can be expressed as in equation (1) according to Mcfeeters (1996):

$$NDWI = \frac{(Green - NIR)}{(Green + NIR)} \tag{1}$$

Where Green is the reflectance of green band and NIR is that of near-infrared band.

In this paper, the extent of saline lakes was derived mainly by NDWI methodology, and the maximum likelihood supervised classification method was also applied to the supplementary of variation information. A suitable cut-off threshold was needed when water index methods were used to detect water body. Generally pixels with the water index value greater than 0 represented water bodies. But due to the water index value varied for different lakes caused by environmental factors or lake features, it's necessary to calibrate the thresholds in order to make the lake delineation more accurate and efficient. Hence, the water index values of several sample points classified as water body by the visual interpretation are calculated to adjust the thresholds. It was found that 0.3 was most suitable for water body detection in this study, although slight adjustments in the practical applications were necessary for each image. In this paper, the visual interpretation results referenced with lake area data derived from past literatures were used to evaluate the accuracy of detection and identify the errors in the estimation. Tests showed that the water body identification results matched the visual interpretation perfectly, and also comparatively consistent with the reference data derived from published literatures for the same period.

3. Results and discussions

3.1. Variations of saline lake surface area in the Qaidam Basin

The dynamic changes of saline lakes in the Qaidam basin from 1973 to 2014 were presented in table 1. Because of the lack of suitable images for some lakes in 1973, the 1970s surface area data were derived from images in 1973 or 1976. This table indicated that some saline lakes in the Qaidam basin expanded greatly during the past 40 years, such as Dulan Lake. However, there are also some lakes, like Xi Taijnar Lake, in contrast decreased a lot. Dong Taijnar Lake and Bei Hulsan Lake can't even be detected using satellite images in 2014 probably because their water levels were too low to be detected or they had disappeared at that time. Though the total changes of the saline lakes differed considerably in the past 40 years, their change trends during the period 1970s-2000 and the period 2000-2014 are relatively similar. Most of their area decreased from 1970s to 2000, and increased from 2000 to 2014. As an example, the spatial-temporal changes of Da Qaidam Lake are shown in figure 2.

Table 2 gives the seasonal changes of some saline lakes in the Qaidam basin from Jan 2013 to July 2014, from which it can be found that these lakes didn't change greatly during different seasons compared with the inter-annual changes.

3.2. Dynamics of the variations of saline lake surface area

3.2.1 Climate changes in the Qaidam Basin. The river runoff feeding by the glacial and snow melting, as well as precipitation, is the main water supply of saline lakes in the Qaidam basin [10], so the temperature and precipitation have significantly influences on the surface area of the saline lakes. However, the relations of the saline lake changes to the temperature and precipitation were not so direct according to the study results. Figure 3 shows the inter-annual variations of the average data of precipitation and average temperature derived from six meteorological stations across the study area. Compared with precipitation, the temperature had an obvious increasing trend, which may accelerate glacier and snow melting to provide more water resource to the lakes. However, while studying on the area changes and temperature in specific years, it was found that there was no strong correlation between the variations of temperature and the extent changes of saline lakes. It was the same with precipitation. In addition, the relationship between lake area and climate factors took on strong regional features when using the nearest meteorological station data to analyze the variations of specific lakes, which was also presented by Wu (2014). For example, compared with Da Qaidam Lake, the variations of Gasikule Lake area had a stronger correlation with the changes of temperature.

Table 1. The area changes of the saline lakes in the Qaidam basin over the past 40 years.

Saline Lake	Area（km^2）			Change（%）		
	1970s	2000	2014	1970s-2000	2000-2014	1970s-2014
Gahai Lake	32.17	28.32	33.05	-11.98%	16.71%	2.73%
Tuosu Lake	157.15	133.56	147.54	-15.01%	10.46%	-6.12%
Da Qaidam Lake	42.01	21.23	34.12	-49.47%	60.73%	-18.79%
Xiao Qaidam Lake	44.06	51.34	81.51	16.50%	58.77%	84.97%
Gasikule Lake	81.03	118.30	109.49	46.00%	-7.45%	35.13%
Sugan Lake	105.16	102.03	104.53	-2.98%	2.45%	-0.60%
Dong Taijnar Lake[a]	133.04	202.19		51.97%		
Xi Taijnar Lake	113.04	18.79	33.62	-83.38%	78.93%	-70.26%
Nan Hulsan Lake	3.37	0.51	11.33	-84.87%	2120.28%	235.89%
Bei Hulsan Lake[a]	88.21	52.55		-40.43%		
Dulan Lake	7.94	1.84	22.44	-76.83%	1119.67%	182.65%
Dabsan Lake	238.36	167.13	226.15	-29.88%	35.31%	-5.12%

[a] The lakes can't be detected using satellite images in 2014.

Table 2. The seasonal area changes of the saline lakes in the Qaidam basin from Jan 2013 to July 2014.

Saline Lake	Area(km^2)						
	Jan-13	Apr-13	Aug-13	Oct-13	Feb-14	May-14	Jul-14
Tuosu Lake	151.97	149.27	149.11	149.31	153.91	149.29	147.54
Gahai Lake	35.91	34.98	33.95	34.02	36.09	34.69	33.05
Keluke Lake	54.87	53.03	51.35	52.48	56.05	53.03	50.51
Xiao Qaidam Lake	99.23	91.77	88.77	87.77	95.97	85.59	81.51
Dabsan Lake	305.10	321.93	235.88	194.09	198.08	226.15	157.06
Nan Hulsan lake	44.40	63.88	32.58	27.44	25.71	91.94	11.33

To analyze the relationship between the lake area and river runoff, according to the annual runoff data of the main supply rivers of these saline lakes acquired from seven hydrological stations during the period 1956-2012, the annual runoff design values of typical hydrological years were calculated using the annual runoff frequency curve means, where the runoff values at the frequencies 25%,50%,75%,90% were chosen as the design values of wet year, normal year, dry year and extra ordinary dry year. By the calculated annual runoff design values, the typical or nearly typical hydrological year from 1973 to 2002 (due to the large scale saline recourse exploitation started from 2000, the area variations before 2000 are more related to climate changes) were chosen and the lakes area were derived from satellite images in these years, presented in table 3. The table shows that compared with temperature and precipitation, the variations of lakes seemed more directly relative to the runoff supplies from the surrounding rivers, probably due to the situation that the influences of temperature and precipitation on the lake area in the Qaidam basin were always cross-regional, lagged and more complex, not as obvious as that of the river runoff. In spite of that, temperature and precipitation were still ones of the primary dynamics of the saline lake variations in the Qaidam basin, because the river runoff was also significantly affected by them.

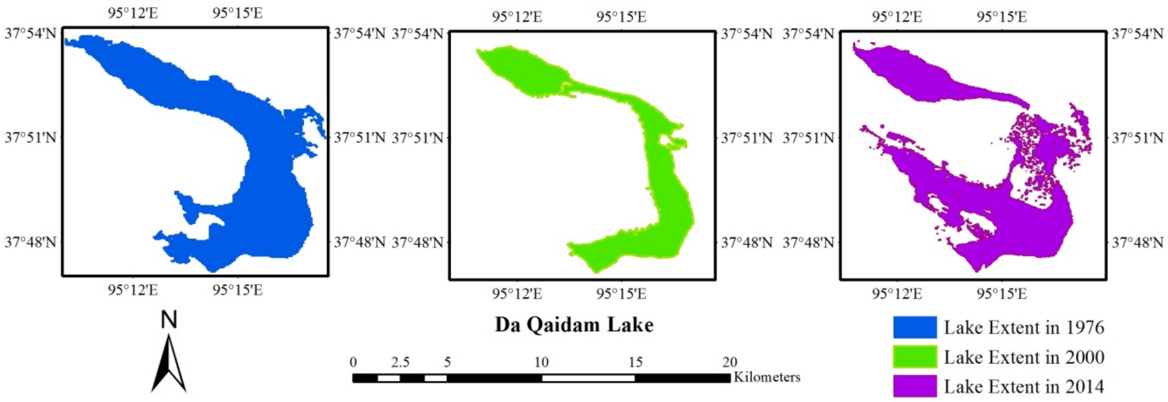

Figure 2. The spatial-temporal changes of Da Qaidam Lake from 1976 to 2014.

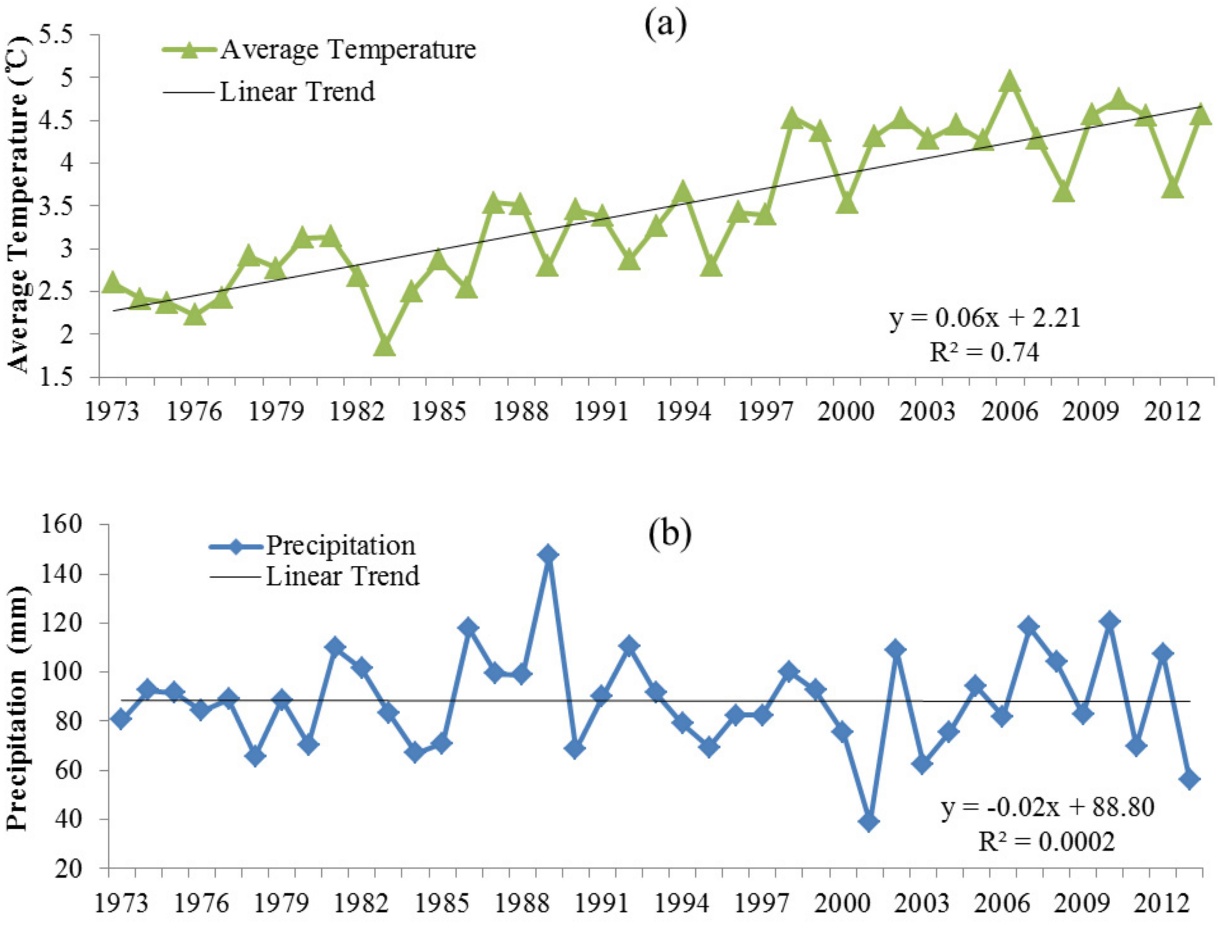

Figure 3. The variations of average temperature (a) and precipitation (b) in the study region from 1973 to 2013.

Table 3. The area changes of the saline lakes in the Qaidam basin in typical hydrological years.

Saline Lake	Wet year		Normal year		Dry year		Extra ordinary dry year	
	Year	Area (km^2)	Year	Area (km^2)	Year	Area (km^2)	Year	Area (km^2)
Dabsan Lake	1976	238.36	1987	212.03	1991	263.92	1998	121.71
Gahai Lake	1987	28.41	1991	29.71	2000	28.32	2001	27.97
Tuosu Lake	1987	147.13	1991	146.04	2000	133.56	2001	132.32
Da Qaidam Lake	1987	34.47	1988	33.88	2000	21.23	2001	20.57
Xiao Qaidam Lake	1987	55.17	1988	50.68	2000	51.34	2001	45.19
Gasikule Lake	2000	118.30	1992	115.13	1990	115.70	1973	81.03
Sugan Lake	2000	102.03	1998	101.72	1987	99.89	1990	101.19
Dong Taijnar Lake	2000	202.19	1992		1990	164.71	1973	133.04
Xi Taijnar Lake	2000	18.79	1992	127.16	1990	129.42	1973	113.04
Nan Hulsan Lake	1976	3.37	1988	6.41	2000	0.51	2002	7.59
Bei Hulsan Lake	1976	88.21	1988	69.79	2000	52.55	2002	62.95
Dulan Lake	1991	11.50	1995	1.30	1999	1.37	2000	1.84

3.2.2 Impact of human activities on changes in lake area. The large-scale human activities, especially the saline resource exploitation, have considerable impacts on the area changes of these saline lakes. As shown in table 2, Dong Taijnar Lake had decreased greatly after 2000. From the satellite images, it was found that Dong Taijnar Lake had a large area in 1970s and 2000, but with the salt pans building nearby, the area of the lake decreased rapidly. In 2014, the main water body of the lake can't be even detected based on remote sensing, and instead the salt pans were still obvious on the images and had increased compared with before. The expanding of Dabsan Lake and Nan Hulsan Lake after 2000 was also thought to be related to the 400-ton potash fertilizer product project in Qinghai Province by Lu (2014).

4. Conclusion

The present study showed that most of the saline lakes studied in the Qaidam basin had great changes in the past 40 years, and the changes of the saline lakes differed considerably. Half of them had significantly decreased in surface area, while there are meanwhile several lakes expanding considerably during the period. The trends of the lake changes were distinct across different regions, and the relations of the changes to temperature and precipitation also took on strong regional features. The results illustrated that although temperature and precipitation had significant impacts on the lake area directly or indirectly, the runoff supplies from the surrounding rivers were more directly correlated to the area of these lakes, the variations of which may be one of the main dynamics of the lake changes. The analysis based on remote sensing images in this paper also indicated that human activities especially the saline resource exploitation, had considerable impacts on the area changes of these saline lakes, which were considered as one of the main reasons of the decrease of Dong Taijnar Lake. Accordingly, it is important and necessary to control the scale of saline resource exploitation for the protection of saline lake resource in the Qaidam basin.

Acknowledgments

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