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Influence of climate change on saline lakes of the Tibet Plateau, 1973–2010

Lijuan Yan [a,b,*], Mianping Zheng [a]

[a] MLR Key Laboratory of Saline Lake Resources and Environments, Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
[b] Chinese Academy of Geological Sciences, Beijing 100037, China

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ABSTRACT

Levels and surface areas of saline lakes are indicators of climate change and climate variability. The surface extents of 93 saline lakes with areas larger than 20 km^2, excluding dry saline lakes, on the Tibet Plateau were delineated from Landsat images obtained in 1973–1977, 1989–1992, 1999–2001, and 2008–2010 based on remote sensing spatial analysis techniques and GIS. The dynamic changes of the saline lake surface areas from 1973 to 2010 were analyzed. The total surface area of these saline lakes increased, especially since around 2000, and the total surface area increased by 47% during 1973–1977 to 2008–2010. During 1973–1977 to 1989–1992, saline lakes with decreased areas were mainly distributed in the northern and middle parts of the Tibet Plateau, whereas those in other places tended to expand; since around 2000, nearly all the saline lakes expanded. Mean annual temperature, mean annual maximum temperature, mean annual minimum temperature, annual precipitation and evaporation on the Tibet Plateau were analyzed. Over the past four decades, the climate has become warmer and wetter. Rising temperature and dropping evaporation are two dominant factors responsible for saline lake expansion. The salinity of many saline lakes decreased during this climate warming. New analyses included factors responsible for the changes, i.e., tectonics, climate, lake basin shape, glaciers, catchments, open or closed systems and human activities.

1. Introduction

The area and salinity of saline lakes are closely related to the climate and surrounding environment (Zheng et al., 2000, 2004; Liu et al., 2009; Kang et al., 2010). The Tibet Plateau, located in central Asia, is Earth's highest and most extensive highland, with an average elevation exceeding 4000 m; its climate variations are linked to global climate dynamics and the Asian monsoon system (An, 2000; Krause et al., 2010). Lakes play an important role in water circulation and may record regional responses to global climate change (Zheng et al., 2000; Liu et al., 2009). Much of the Tibet Plateau comprises a vast territory with abundant saline lakes and associated mineral resources. The genetic types and recharge sources of these lakes are various and complex, and it is important to monitor their dynamic changes in order to study the climatic and environmental changes of Tibet (Bianduo et al., 2009; Che et al., 2009; Xiang et al., 2011; Yasuda and Furuya, 2013; Song et al., 2014; Yan and Zheng, 2015).

Observations have shown that the global surface temperature rose by 0.74 °C during the 20th century, and the warming trend has accelerated in the last 50 years (Deng et al., 2014; Feng et al., 2014). The annual mean temperature of the Tibet Plateau has increased by 3.7 °C in the last hundred years, much faster than the global average (IPCC, 2013). Thus, glaciers there have melted significantly because of the increased temperature (Ye et al., 2006; Wu et al., 2009; Wang et al., 2011; Yao et al., 2012; Zhang et al., 2012; Yu et al., 2013), and more melt water has been supplied to lakes and rivers (Yao et al., 2004; Ye et al., 2006, 2008; Bianduo et al., 2009; Wu et al., 2009; Kaser et al., 2010; Li et al., 2012). Moreover, since the mid-19th century, disasters caused by glacial lake outburst floods have become more frequent in the Tibet Plateau with consequent losses (Liu et al., 2013a, 2013b, 2014).

The lakes on the Tibet Plateau are rich in common saline minerals such as gypsum, mirabilite, and trona. There are also some special mineral resources such as rubidium (Rb), cesium (Cs), uranium (U), and thorium (Th) (Zheng et al., 1989, 2000, 2004). According to remote sensing images from 2008 to 2010, there are 93 saline lakes with areas larger than 20 km^2 (excluding dry saline lakes) with a total surface area of 7552.30 km^2, accounting for 24.5% of the total lake surface area of the Tibet Plateau (Yan and Qi, 2012). These saline lakes are distributed mainly in northern Tibet, and most of them are recharged by glacier melt water and surface runoff (Zheng et al., 2002; Fig. 1).

Traditionally, water balances of saline lakes are decided based on direct meteorological or hydrological observations (Qi and Zheng, 2006). We can also detect changes in lake water level and shoreline at local spatial and temporal scales. However, this method is limited to a few lakes in the study area; only Zabuye Saline Lake has complete observation data spanning 25 years. The increased availability of low cost

* Corresponding author at: Chinese Academy of Geological Sciences, 26 Baiwanzhuang Road, Beijing 100037, China.
E-mail address: 314219349@qq.com (L. Yan).

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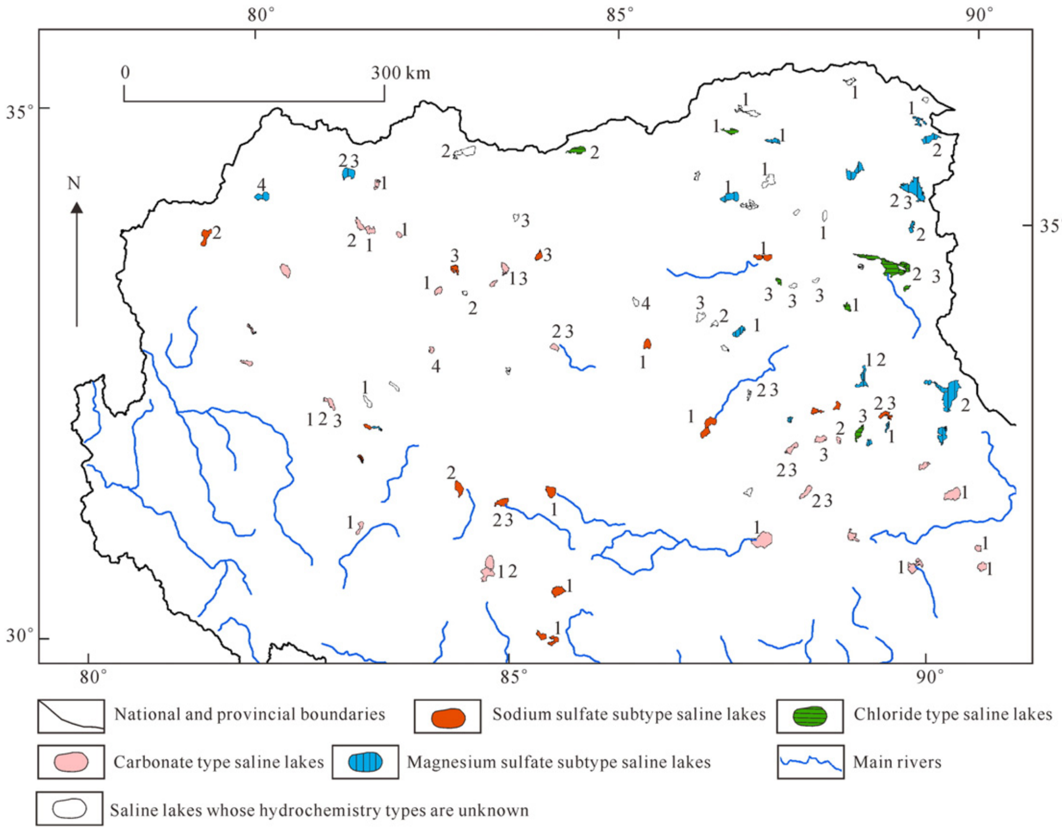

Fig. 1. Distribution and hydrochemical types of saline lakes on the Tibet Plateau. Lake boundaries are derived from remote sensing images of 2008 to 2010 using ArcGIS. The hydrochemical type of saline lakes was determined from Zheng et al. (1989); the main recharge sources are after Zheng et al. (2002). Main recharge sources: 1—surface runoff, 2—glacial melt water, 3—spring water, 4—groundwater runoff.

Table 1
Details of remote sensing images used to derive saline lake extent.

Time	Image type	Number of images	Data source	Level	Spatial resolution/m
1973–1977	Landsat 5 MSS	82	(1)	2	80
1989–1992	Landsat 5 TM	76	(1)	2	30
1999–2001	Landsat 5 ETM	76	(1)	2	30
2008–2010	Landsat 5 TM	76	(2)	4	30

Notes: (1) USGS, 2012; (2) Center for Earth Observation and Digital Earth, Chinese Academy of Sciences, 2013. Level 2 data products of Landsat have been processed using radiometric correction and systematically geometric correction, and have been adapted to map projection; Level 4 data are Digital Terrain Model (DTM) based correction products with radiometric correction and systematic geometric correction using ground control points (GCPS) and the DTM for terrain parallax correction.

remote sensing images with moderate spatial and temporal resolutions allows us to observe lake water environments at larger spatial extent and longer timescales, particularly in remote and inaccessible areas where in-situ observations are lacking.

The levels of many saline lakes in the study area have risen based on recent field investigations (Yan and Qi, 2012; Yan and Zheng, 2015). This study analyzed the dynamic variation characteristics of the saline lakes and their response to the climate, based on spatial analysis of remotely sensed imagery and meteorological data. Besides, some factors responsible for the saline lake changes were analyzed.

2. Materials and methods

2.1. Remote sensing images

We used 310 Landsat MSS/TM/ETM images covering the study area to retrieve data on the saline lake surface extent for 1973–1977, 1989–1992, 1999–2001, and 2008–2010. Details of the sources and other information are provided in Table 1. All of the images selected are cloud free or have only slight cloud cover (less than 5%).

2.2. Meteorological data

Annual mean temperature, annual mean maximum temperature, annual mean minimum temperature and precipitation from 1973 to 2012 of 25 weather stations were obtained from the China Meteorological Data Sharing Service System (http://cdc.cma.gov.cn/home.do).

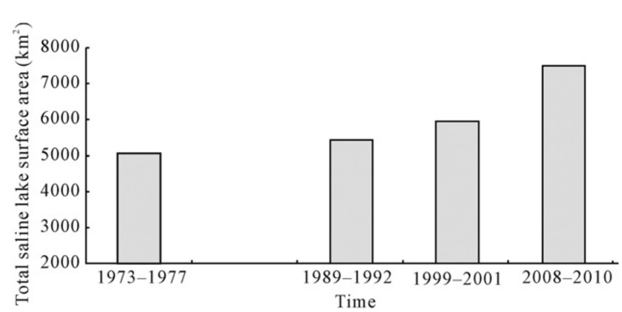

Fig. 2. Dynamic changes of the total saline lake surface areas in this study.