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Exploring the geomorphological processes of Qinghai Lake and surrounding lakes in the northeastern Tibetan Plateau, using Multitemporal Landsat Imagery (1973–2015)

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ABSTRACT

Studies of lake's coastline and shape changes and the influencing factors will contribute to knowledge about the geomorphological and hydrological evolutions of those lakes. This study extracted coastlines of Qinghai Lake and surrounding lakes in the northeastern Tibetan Plateau from multitemporal remote sensing data from 1973 to 2015. The geomorphological processes and the reasons for area and coastline variations were then analyzed. The results showed that: the changes of the total lake area were divided into three stages: the stable decrease stage (1973–1988), the fluctuant decrease stage (1988–2005), and the rapidly increase stage (2005–2015). The changes of Qinghai Lake area and Gahai Lake area showed a similar trend as the total lake area. The Erhai Lake area fluctuated from 1973 to 2004 and then increased from 2004 to 2015. Haiyanwan Lake was isolated from Qinghai Lake in 2003 and was linked into Qinghai Lake in 2006, again. The lakes area variations, excluding Erhai Lake and Shadao Lake, were positively correlated with the variation of the Qinghai Lake level, and estuary area variations were significantly negatively correlated to the lake level, indicating that the higher lake level led to more land being submerged. The evolutionary processes of lakes in the Shadao Region were influenced by aeolian sand and lake water balance experiencing relatively low precipitation and strong evaporation. Erhai Lake was also influenced by river runoff from Daotang River. Sediment loads from rivers flowing into Qinghai Lake, except for Buha River, were relative low and only slightly influenced the estuary. Aeolian sand transported by the lake waves and currents from west coast to east coast will form subaqueous barriers, the Shadao Region land area will increase slowly, and the coastline of the Shadao Region will extend towards the lake. Therefore, the diameter of Qinghai Lake from the west to east coast will become shorter, while the diameter from the south to north coast will become longer in future.

1. Introduction

Lakes make up a relatively small percentage of Earth's water body, but are essential components of the global hydrological system, and influence many aspects of ecosystems and human activities (Winter, 2004; Yıldırım et al., 2011). Inland lakes in arid areas provide scarce but valuable water resources for fragile environments and human beings (Bai et al., 2011). Changes in the lake's area and water levels, especially endorheic lakes in arid areas, respond significantly to climate change and anthropogenic activities (Mason et al., 1994; Yi and Zhang, 2015). Since the 1960s, many inland lakes have been shrinking or drying up (e.g., Aral Sea, Issyk-Kul, Ebinur, and Bosten), and some of them have disappeared (e.g., Lop Nur, Manas, and Taitema). However, declines in lake's area and water level have contributed to a series of environmental problems in the regions (Tatyana and Igor, 2000; Hao, 2008; Lioubimtseva and Henebry, 2009). Inland lakes are also considered to be sentinels, integrators, and regulators of climate changes (Adrian et al., 2009; Williamson et al., 2009a; Williamson et al., 2009b). Therefore, studying the changes of lake's coastline and area and influencing factors are important tasks that contribute to knowledge about the geomorphological and hydrological evolutions of lakes. These studies also inform coastal zone management, coastline erosion monitoring, water resource evaluation, flood prediction, and wetland protection (Lehner and Döll, 2004; Liu and Jezek, 2004; Ouma and Tateishi, 2007; Yi and Zhang, 2015).

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Qinghai Lake, China's largest lake with a closed basin, lies in the Northeast Qinghai-Tibet Plateau (Fig. 1). It lies in a critical transitional zone where the Southeast Asian Monsoon (SEAM), the Westerly Circulation (WC) and the Qinghai-Tibet Plateau Monsoon meet (LZBCAS, 1994; Cui and Li, 2015a). This makes Qinghai Lake very sensitive to climatic changes, and the unique geographical location has made it as an ideal place for global change research, attracting great attention in the international community (An et al., 2012; Li and Liu, 2014). Meanwhile, the lake is one of China's national nature reserves and influences the ecological security of the Northeast Qinghai-Tibet Plateau (Tang et al., 1992). In the past few decades, 50% of the rivers flowing into the lake have dried up as a result of climate change and human activity (LZBCAS, 1994; Li et al., 2007). The lake level elevation has declined from 3196.55 m in 1959 to 3194.26 m in 2012, with a decline rate of 4.75 cm·yr^{-1} over the 53-year period (Li et al., 2012). This has resulted in decrease in the lake's surface area, and the isolation of separate lakes from Qinghai Lake (e.g., Gahai Lake, Haiyanwan Lake, Erhai Lake) (Fig.1). The changes in the lake area and hydrology have contributed to a series of environmental problems in the basin; these problems include desertification, erosion, loss of grazing grassland, and deterioration of water quality and quantity (Qin and Huang, 1998; Hao, 2008; Zhang et al., 2011). These changes have made Qinghai Lake an important research site, and many studies have investigated the hydrological processes of Qinghai Lake, including lake level variation, water balance, evaporation, and the lake water's hydrochemistry (Li et al., 2007; Li et al., 2009; Xu et al., 2010; Cui and Li, 2014; Li and Liu, 2014; Cui and Li, 2015a; Liu et al., 2015; Cui and Li, 2016). Several studies have investigated the changes in the size of the Qinghai Lake area using remote sensing technology (Shen and Kuang, 2003; Yin and Yang, 2005; Feng and Li, 2006; Liu and Liu, 2008; Li et al., 2012; Liu et al., 2013; Shen et al., 2013). However, few studies have focused on the changes of lake's area and coastline of Qinghai Lake and surrounding lakes at high temporal resolution (annual scale) over a long timeframe. In general, these data are of low temporal resolution and cover limited time periods, making research more difficult and creating more uncertainty with respect to the study of geomorphological processes of Qinghai Lake.

This background highlights the importance of researching the changes in the coastline and area covered by Qinghai Lake and its surrounding lakes. This is important for exploring the geomorphological evolution of the lakes, and may reveal possible solutions to the basin's environmental problems. Therefore, the objectives of this study were (1) to quantify area and coastline changes as well as increase and decrease of Qinghai Lake and surrounding lakes during the period from 1973 to 2015, based on a systematic analysis of multitemporal remote sensing data; (2) to further identify the geomorphological processes and the reasons for the area and coastline variations of Qinghai Lake and surrounding lakes; and (3) to discuss the future possible geomorphological evolutions of Qinghai Lake and surrounding lakes under the impacts of climate and human activity. The results will contribute to knowledge about the evolutions of lakes as a result of global climate change in cold and arid alpine environments, and inform water resource management in the Qinghai Lake Basin and the northeastern Tibetan Plateau.

2. Material and methods

2.1. Study area

Qinghai Lake (36°32′-37°15′N, 99°36′-100°47′E) is a brackish lake with water surface area of 4400 km^2 and a water volume of 7.16

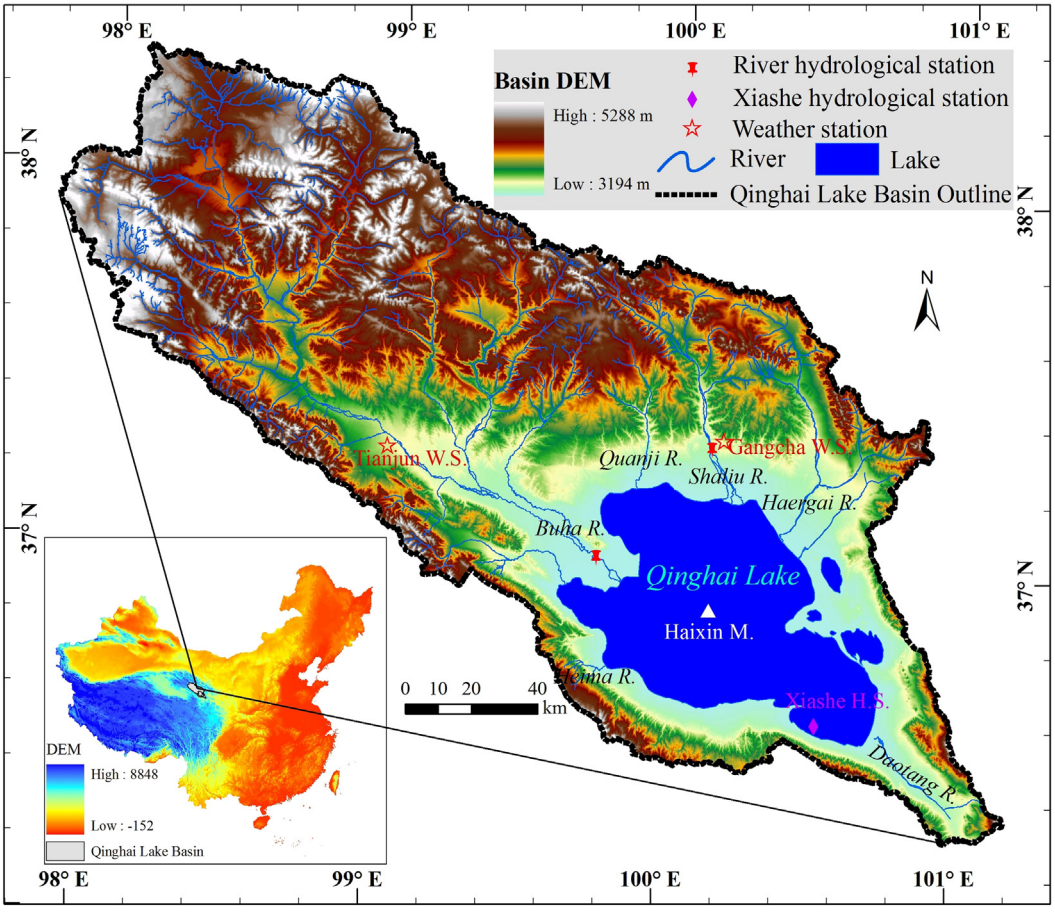

Fig. 1. Locations of the Qinghai Lake Basin and hydrological stations.