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Runoff processes in the Qinghai Lake Basin, Northeast Qinghai-Tibet Plateau, China: Insights from stable isotope and hydrochemistry

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ABSTRACT

Qinghai Lake is one of China's national nature reserves and supports the ecological security of the NE Qinghai-Tibet Plateau. More than half of the rivers flowing into Qinghai Lake are currently dry due to climate change and human activity. This study was designed to learn more about the causes of environmental problems in the basin, using stable isotopes and hydrochemistry of Qinghai Lake Basin river water to explore runoff processes and their relationship with climate change. Results indicated that the river water was mainly fed by precipitation in the basin, which has undergone weak evaporation. River discharges were generated mainly from the middle and upper basin, due to high precipitation, low evapotranspiration, and alpine swamp land use/cover in those areas. River water in tributaries would experience relatively stronger evaporation than in the main stream. Main hydrochemical types of river waters were Ca^{2+}-Mg^{2+}-HCO_3^-, and river water chemistry was mainly controlled by carbonate weathering in the Qinghai Lake Basin. The effects of human activity on water chemistry were relatively mild in the basin. The interaction between water and rocks was slighter in the river water than in the groundwater. River runoff was more sensitive to precipitation than to temperature. Lake level rises were closely related to increases in river runoff and precipitation. Conversely, Lake level declines were closely related to declines in river runoff and precipitation. Lake level could rise due to increasing precipitation and runoff in the future.

1. Introduction

Qinghai Lake (36°32′–37°15′N, 99°36′–100°47′E) is the largest inland lake in China. It has a surface area of 4400 km^2, a water volume of 71.6×10^9 m^3, and lies at an altitude of 3194 m above sea level. The lake lies in the cold and semiarid region of the NE Qinghai-Tibet Plateau, China (Fig. 1). It is a closed basin, with a watershed area of approximately 29,661 km^2 that has no surface water outflow. The area is one of China's national nature reserves and is important to the ecological security of the NE Qinghai-Tibet Plateau (Tang et al., 1992). In recent decades, more than half of the rivers flowing into Qinghai Lake have dried up due to climate change and human activity (LZBCAS, 1994; Li et al., 2007). The lake level declined from 3196.55 m in 1959–3192.84 m in 2003, an average decreasing rate of 8.4 cm year^{-1} over those 44 years; the lake level rised from 3192.87 m in 2004–3194.08 m in 2012, an average rising rate of 15.1 cm year^{-1} over these 8 years (Li et al., 2007, 2012; Jin et al., 2013). These hydrological processes in part have led to some of the environmental problems in the basin, such as decreases in water supplies, deterioration of water quality, desertification, and the loss of grazing grassland (Qin and Huang, 1998; Zhang et al., 2003; Hao, 2008).

Understanding runoff processes and the water cycle of the river system in the Qinghai Lake Basin should support an understanding of the causes for environmental problems in the basin. However, due to the basin's large area, complex geological and geomorphic conditions (mountain area accounting for 68.6% of the basin area; river valleys and plain accounting for only 17.4%), and few meteorological and hydrological stations (Fig. 1), traditional hydrological research methods face more difficulty and uncertainty in the study of runoff process and water cycle in the basin. Previous published studies concerning river runoff focused on investigating the hydrochemistry compositions of river water, runoff variation, or land use impacts on runoff (Qin and Huang, 1998; Yan and Jia, 2003; Li et al., 2005, 2007,

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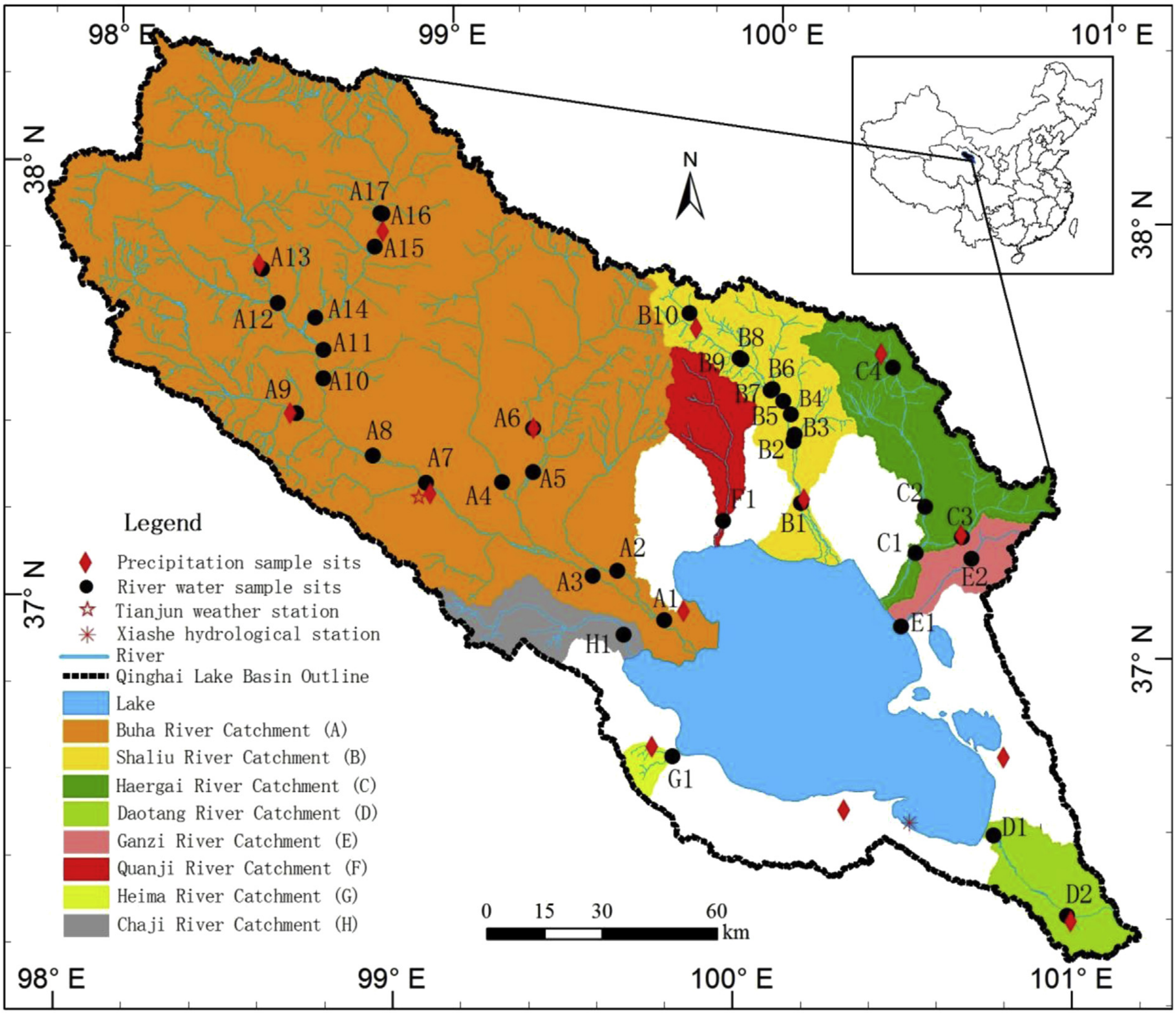

Fig. 1. Location of the Qinghai Lake Basin and sampling sites.

2009; Xu et al., 2010; Yi et al., 2010; Jin et al., 2010; Xiao et al., 2012). Runoff processes in the basin are not fully understood.

The integrated use of isotopic and hydrochemical tracers has emerged as an effective approach to investigate the complex hydrological processes on a range of spatial and temporal scales (Pawellek et al., 2002; Phillips et al., 2003; Song et al., 2006; Ryu et al., 2007; Yuan and Miyamoto, 2008; Liu et al., 2008b; Meredith et al., 2009). Yuan and Miyamoto (2008) analyzed the oxygen and hydrogen isotopic compositions, major ion concentrations, and other physical variables of Mexico's Pecos River water to assess its physical features. The study found that up to 85% of stream flow was derived from local freshwater sources (mainly from Mexican monsoonal rainfall) in the lower valley, and that up to 33% of stream water was lost through evaporation from stream channels and middle basin fields. Halder et al. (2013) investigated the mixing of Rhône River water in Lake Geneva (Switzerland–France) using stable hydrogen and oxygen isotope tracers, and found that the fraction of Rhône River water within the Lake Geneva interflow was estimated to be up to 37% in summer. Fan et al. (2014) analyzed the isotopic composition of river water, precipitation, and ice-snowmelt water of the Tizinafu River, originating in the northern slope of the Kunlun, to investigate the distribution of stable isotopes and sources of river water. This study showed the mean contribution of ice-snowmelt water was 43%, meaning that ice-snowmelt water was a key water source for the Tizinafu River. All these studies demonstrated how isotopes and hydrochemical ions could be used in hydrologic studies.

These studies suggested that investigating the stable isotope and hydrochemistry of the Qinghai Lake Basin's river water could significantly contribute to knowledge of the basin's runoff processes and water cycle. As such, this study's objectives were to: (1) investigate the characteristics of stable isotopes and hydrochemistry of the Qinghai Lake Basin's river waters, (2) study the mechanisms of confluence and segmentation of the basin's river, and (3) evaluate the impact of runoff on the lake level. The study was designed to provide general insights into the hydrological and geochemical processes of cold and alpine rivers, as well as inform water resource management in the basin and the northeastern Qinghai-Tibet Plateau.

2. Methods

2.1. Background about rivers in the Qinghai Lake Basin

There are more than 50 rivers or streams flowing into Qinghai Lake (LZBCAS, 1994). The rivers are mainly located north and northwest of the lake, resulting in an asymmetric distribution in

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