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Glacier change in the Poiqu River basin inferred from Landsat data from 1975 to 2010

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ABSTRACT

The Poiqu River basin is a transboundary basin that is highly prone to glacial lake outburst floods. This basin is located in the middle of the Himalayas between China and Nepal. Fieldwork investigating nearby glaciers has indicated that glaciers in this region have ablated quickly in recent decades. A new glacier database for the Poiqu River basin was generated for the phases 1975, 2000, and 2010 using automatic classification and manual visual interpretation based on long time series Landsat data. In 2010, the Poiqu River basin had 124 glaciers with a total area of 203.4 ± 5.3 km^2. Eleven glaciers have debris-covered tongues, with the debris covering a total area of 51.0 ± 1.5 km^2. During the period of 1975–2000, the area change rates of all glaciers in the basin, clean ice and debris-covered parts were −0.45%/y, −0.71%/y and 0.96%/y, respectively. From 2000 to 2010, these area change rates were −0.82%/y, −1.24%/y and 0.73%/y, respectively. The number of glaciers and area change of clean ice within various size classes indicate that the large glaciers shrink into small glaciers and smaller glaciers retreated faster. The mean size of the glaciers in this basin is within the size class 1.0–5.0 km^2. The area change rate for 1.0–5.0 km^2 glaciers was similar to that of all glaciers in the Poiqu River basin. The altitude of the Region with the Fastest Change (RFC) uplifted from 5200 m to 5500 m, and the area change rate of glaciers in the RFC accelerated from −0.17 km^2/y to −0.21 km^2/y between the two periods, 1975 to 2000 and 2000 to 2010. Aspect analysis indicates that for a long time period, glaciers with southward aspects (including south, east, southeast and southwest) in the Poiqu River basin retreated faster than glaciers with northward aspects (including west, north, northeast and northwest). At the decade-scale, changes in areas of glaciers were more influenced by composition than aspect. Additionally, the retreat rate of the glaciers in the Poiqu River is in a state of accelerating ablation since 2000, despite elevation and aspect.

1. Introduction

There are vast mountain glaciers in the Himalaya region of the Tibetan Plateau. Glacial melt water is an important source of surface runoff that supports life and agricultural production in this region (Yao et al., 2004; Immerzeel et al., 2010). Changes in the melt rates of the glaciers not only change the downstream runoff but also increase the chances of geological hazards such as landslides and glacial lake outburst floods (Benn et al., 2012; Fujita et al., 2013). Glaciers are known as indicators of climate change because of their very sensitive response (Haeberli et al., 2007; Bhambri et al., 2012). Many studies have demonstrated that most glaciers in the Himalayas have been shrinking since the 1980s, concurrent with climate warming (Bhambri and Bolch, 2009; Bolch et al., 2012; Yao et al., 2012). Meanwhile, glacier change differs by region, and controversy about the speed of glacial melting in this region continues (Yao et al., 2007, 2012; Kaab et al., 2012; Gardner et al., 2013). Hence, there is a need for monitoring and evaluating of glacier change in the Himalayas, especially in regions where glacier retreat is greatest.

The Poiqu River basin is located in the middle of the Himalayas and contains numerous glaciers and glacial lakes on both sides of the river. Recent studies have involved fieldwork on nearby glaciers. The Kangwure Glacier, which is located in the northwest of the basin, lost approximately 48.3% of its volume from 1970 to 2008, as calculated using geodesic radar data and mapped area (Ma et al., 2010). The Yala Glacier which is located in the southwest of the basin, lost mass at a mean rate of 800 kg m^{-2} over the last 10 years (Fujita and Nuimura, 2011). These results indicated that

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glaciers in the Poiqu River basin may be ablating quickly. The melting glaciers caused several glacial lake outburst floods, as recorded in recent decades (Chen et al., 2007; Shrestha et al., 2010). These disasters caused great loss of life and property to the downstream residents. Therefore, it is important to study glacial changes in the Poiqu River basin and to identify the variation and trend in the background of global warming in recent decades.

Remote sensing is an effective means to monitor the wide range of glaciers and to extract information on glacial variation. Due to the rapid development of remote sensing and the application of high-resolution optical sensors in recent years, glaciers that are difficult to access for fieldwork can now be effectively observed. Previous studies have verified the reliability of glacial parameters extracted from remote sensing data by comparison with field data (Bhambri et al., 2012; Negi et al., 2012). The use of remote sensing data to map glaciers is now one of the primary methods for constructing glacier inventories (Raup et al., 2007; Racoviteanu et al., 2010).

There are two glacier inventories for the Poiqu River basin. The first is a Chinese glacier inventory, which reflects the glacier state in the mid-1970s (Shi et al., 2009). The second is the Randolph glacier inventory, which reflects the glacier state in the 1990s (Arendt et al., 2012). However, these two glacier inventories do not reflect the recent condition of glaciers. Several recent studies using remote sensing data indicated changes in the Poiqu River basin glaciers. Chen et al. (2007) found a mean annual change rate of −1.44%/y from 1987 to 2001. Nie et al. (2010) found a mean annual change rate of −0.54%/y from 1976 to 2006. These change rates are higher than the mean annual change rate of −0.40%/y in the central Himalaya region (Yao et al., 2012), which indicates that glaciers in the Poiqu River basin have been melting quickly in recent years. However, there are great differences in the glacial change rates found in these two studies. This finding may be related to the following two factors: study periods and areas were different. The area of the Poiqu River basin defined by Chen et al. in 2000 was 2018.4 km^2, and the glacial area was 183.2 km^2, while the range of the Poiqu River basin defined by Nie et al. in 2000 was 3118.5 km^2, and the glacial area was 538.6 km^2. Both studies investigated changes over the entire glacial area and did not discuss glacier changes of different sizes. Research indicates that glaciers of different sizes respond to climate change differently. Generally, small glaciers are more sensitive to climate change. When the study regions are not the same, the distributions of glacial sizes are also different, such that rates of change over the entire region cannot be simply compared. Also, these studies did not consider regional debris-covered glaciers. The center of the Himalaya contains many debris-covered glaciers (Scherler et al., 2011). Debris-covered glaciers show different rates of change depending on when the debris cover formed. Therefore, the influence of debris-covered glaciers must be considered when studying regional glacier change. Furthermore, recent research has shown that topographic characteristics have an important influence on glacier change (Osmonov et al., 2013). Therefore, this study of glacier change in the Poiqu River basin, a region of the Himalaya range where glacial melt rates are relatively high, includes the following three aspects. First, a new glacier database for the Poiqu River basin is generated and the distribution of glaciers and debris cover is analyzed. Second, glacier changes from 1975 to 2010 are analyzed over different time periods. Third, the influence of glacial composition and topography on glacier change over different time periods is discussed.

2. Study region

The Poiqu River basin is one of the headwater tributaries of the Ganges River basin, which covers latitudes 27°49′–29°05′N and longitudes 85°38′–86°57′E. The basin drainage area is approximately 2160 km^2. The altitude ranges from the highest elevation of 8012 m (north) to the lowest at 1178 m (south), with an average of 4791 m. The basin has substantial relief and displays a typical Himalayan vertical differentiation. The main landforms in the basin are alpine peaks and gorges. The Poiqu River runs from north to south and cuts the southern slope of the Himalaya into two relatively independent geographical units: the western and the eastern parts. The western part contains Shishapangma and surrounding mountains, as well as the Koryagpu River, the Chongduipu River and other tributaries. The eastern part contains the Tongpu River, the Ruijiapu River and other tributaries (Fig. 1).

The Poiqu River basin is affected by the Indian monsoon and experiences high precipitation levels nearly year-round. The Nyalam meteorological station is located at an altitude of 3810 m. According

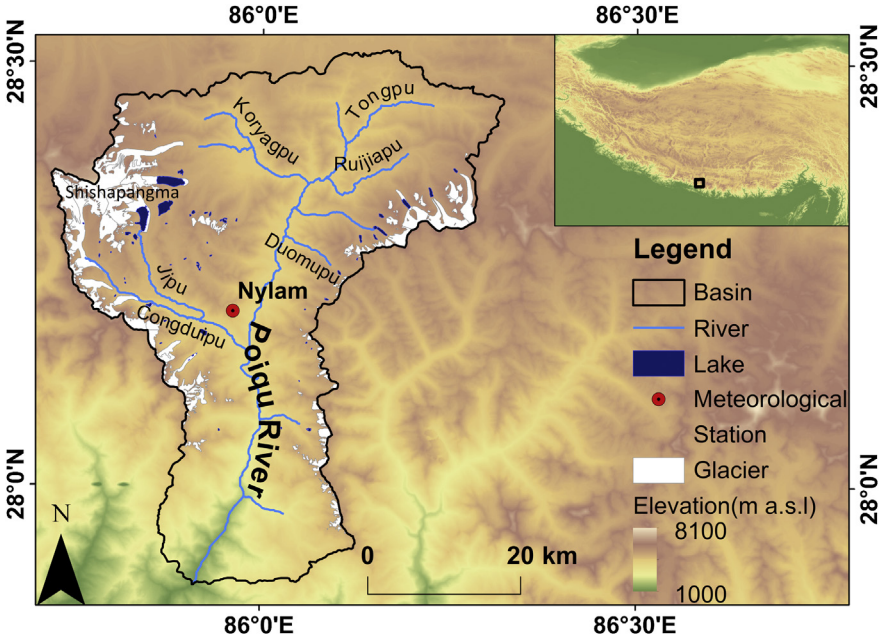

Fig. 1. Distribution of glaciers and meteorological station. Glacier outline is delineated from Landsat images in 2010.