



Landform-related permafrost characteristics in the source area of the Yellow River, eastern Qinghai-Tibet Plateau



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ABSTRACT

The source area of the Yellow River (SAYR) lies in the eastern part of the Qinghai-Tibet Plateau (QTP). Glaciers are absent in the area, but permafrost is widespread because of the high elevations, typically 4200–5000 m a.s.l. Landforms in the SAYR were classified into seven basic types, based on their morphological characteristics and genesis, and further divided into 12 sub-classes based on geomorphic processes. Permafrost development and ground temperature in boreholes were analyzed on representative landforms in the SAYR. Permafrost was discontinuously distributed at 4300–4400 m a.s.l. in fluvial plains because of variations in local topography, sediments, vegetation and water content. In hills and low-relief mountains in the western part of the study area, permafrost is continuous above 4400 m a.s.l. even on unshaded south-facing slopes. In contrast, permafrost in the central part of the study area is discontinuous over this elevation range. Analysis of ground temperature measurements revealed that three macro-scale factors, latitude, longitude, and elevation, explain 72.8% of the variation in the measured mean annual ground temperature (MAGT). The remaining 27.2% can potentially be explained by variations in topography and land cover within the SAYR.

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1. Introduction

In high mountain areas within the low-middle latitudes, topography plays an important role in determining permafrost development and the spatial distribution of periglacial features (Zhao et al., 2010; Etzelmüller, 2013; Haerberli, 2013). In the Alps, the influences of topography on mountain permafrost distribution were empirically concluded to be the combined result of slope, aspect, and elevation (Keller, 1992). In the Qinghai-Tibet Plateau (QTP), where permafrost is widespread, a close relationship exists between topography, especially elevation, and permafrost distribution (Jin et al., 2006; Wu et al., 2012).

The Yellow River is the second largest river in China and the largest in northern China. The “source area of the Yellow River” (SAYR) refers in this paper to the catchment area above Duoshixia (34°46′26″N, 98°20′59″E; 4193 m above sea level) along the Yellow River, where glaciers are absent but permafrost is widespread owing to the cold climate at high elevations (Jin et al., 2010; Luo et al., 2014). The existence of permafrost in the SAYR affects ecological and environmental conditions at the ground surface (Zhang et al., 2004; Liang et al., 2007). Since the

1980s, degradation of permafrost has occurred in the SAYR because of rising air temperatures and increased human activity, as indicated by an elevational rise in the lower limit of permafrost, a decrease in the maximum depth of freezing, and increased permafrost temperatures (Jin et al., 2009). Consequently, a series of environmental problems were triggered in the SAYR, such as vegetation degradation, desertification, lake shrinkage and salinization, wetland degradation, and biodiversity loss (Wang and Cheng, 2000; Wang et al., 2000; Yang et al., 2007). Several qualitative and conceptual studies on permafrost distribution have been conducted, mainly in the eastern SAYR and along Highway 214 (Wang et al., 1999; Luo et al., 2013; Sheng et al., 2015).

Both latitude and elevation contribute significantly to regional variations of permafrost distribution in the eastern SAYR. Variations in the permafrost lower limit (PLL) can be expressed as a function of latitude (Wang et al., 1991, 1999), and spatial variations in ground temperatures can be modeled using a linear equation with latitude and elevation as independent variables (Luo et al., 2012). Previous studies have also indicated that permafrost is distributed continuously in the eastern plains of the SAYR above 4250 m a.s.l. The discontinuous PLL is 4350 and 4450 m a.s.l. on the north-facing and south-facing slopes of the Bayan Har Mountains, respectively (Sheng et al., 2015).

However, permafrost characteristics and distribution patterns throughout the central and western parts of the SAYR are not well

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known. In general, landforms formed by different geomorphic processes are associated with specific topographic characteristics, corresponding deposits, soil properties and vegetation cover, which further changes water and thermal characteristics at the ground surface and in the underlying ground. This study analyzes permafrost characteristics in the SAYR developed in different landforms and summarizes general and regional regularities of permafrost distribution.

2. Study area

The Yellow River’s source area is located between 33°56’N to 35°31’ N and 95°55’E to 98°41’E. It extends approximately 1.5° from north to south and 3° from east to west, and has a catchment area of $2.9 \times 10^4 \text{ km}^2$ (Jin et al., 2009; Luo et al., 2012). The SAYR is a relatively large, semi-enclosed drainage basin surrounded by three high mountain ranges on the north, south, and west sides, known as the Bayan Har, Buqing and Geshigeya Mountains, respectively. The northern Buqing Mountains form the watershed boundary between the inland Qaidam drainage and the southern Yellow River drainage. The southern Bayan Har Mountains form the divide between the Yellow River drainage and the Yangzi River drainage. Two large lakes, Gyaring Lake (34°46’N to 35°05’N, 97°32’E to 98°54’E; 4266–4267 m a.s.l.) and Ngoring Lake (34°49’N to 35°01’N, 97°03’E to 97°27’E; 4289–4290 m a.s.l.), are the catchment centers of the SAYR. Rivers flowing from the north, south, and west sides converge into the two lakes, and then continue to flow eastward (Fig. 1).

Elevations of the SAYR vary from approximately 4200 to 5200 m and the two lakes and their surroundings correspond to the lowest areas. Glaciers are absent in the SAYR, despite the high elevations. Climate is a generally cold and continental type. The only national weather station in the area, Madoi (34°55’N, 98°13’E, 4272.3 m a.s.l.), is located in the northeastern SAYR and has records extending back to the 1950s, from 1953 to 2013. The mean annual temperature and annual precipitation for this period are $-3.6 \text{ }^\circ\text{C}$ and 295 mm, respectively. The annual

evaporation expressed as the amount of water possible to evaporate from an open water surface is 1341 mm, greatly exceeds precipitation because of a drier climate particularly in the western SAYR.

Lakes and rivers account for approximately 5% of the total study area. In addition to the two large lakes, there are many small lakes such as Galala Co (Co = “small lake” in Tibetan), and the Xingxinghai and Xingxiuhai lake clusters. To the west, Yueguzonglie Qu (Qu = “river” in Tibetan) and Kari Qu originate from the northern slopes of the Geshigeya Mountains. To the south, Beimin Qu, Re Qu, Lena Qu, and Duo Qu originate from the northern slopes of the Bayan Har Mountains. These rivers also have numerous small tributaries. However, ground surfaces are very dry because of good infiltration of arenaceous sediments and the dry climate. Alpine steppe dominated by gramineous species and alpine desert dominated by cushion-like vegetation are widely distributed in the lowlands. The presence of a permafrost layer can effectively sequester abundant water in shallow soil, contributing to the locally developed hygric- and mesic-meadow vegetation communities. The alpine meadow is dominated by *Kobresia* and *Carex* species, and the alpine swamp meadow by paludal *Kobresia tibetica*. In addition, the so-called black soil land, formed as a result of permafrost degradation, is another important landscape type, whose area increased by approximately two-thirds between the 1970s and 1990s (Wang et al., 2002).

National Highway 214 (G214), starting at Xining, Qinghai Province, and ending at Jinghong, Yunnan Province, extends across the eastern part of the SAYR from north to south. Population density is low in the SAYR. Madoi County has a total population of <15,000 and population density is approximately $0.5 \text{ person km}^{-2}$. Another sparsely populated settlement is Madoi Village, located in the western SAYR.

3. Data and methods

Field investigations on the distribution and thermal characteristics of permafrost were conducted in the summers of 2013 and 2014. Data

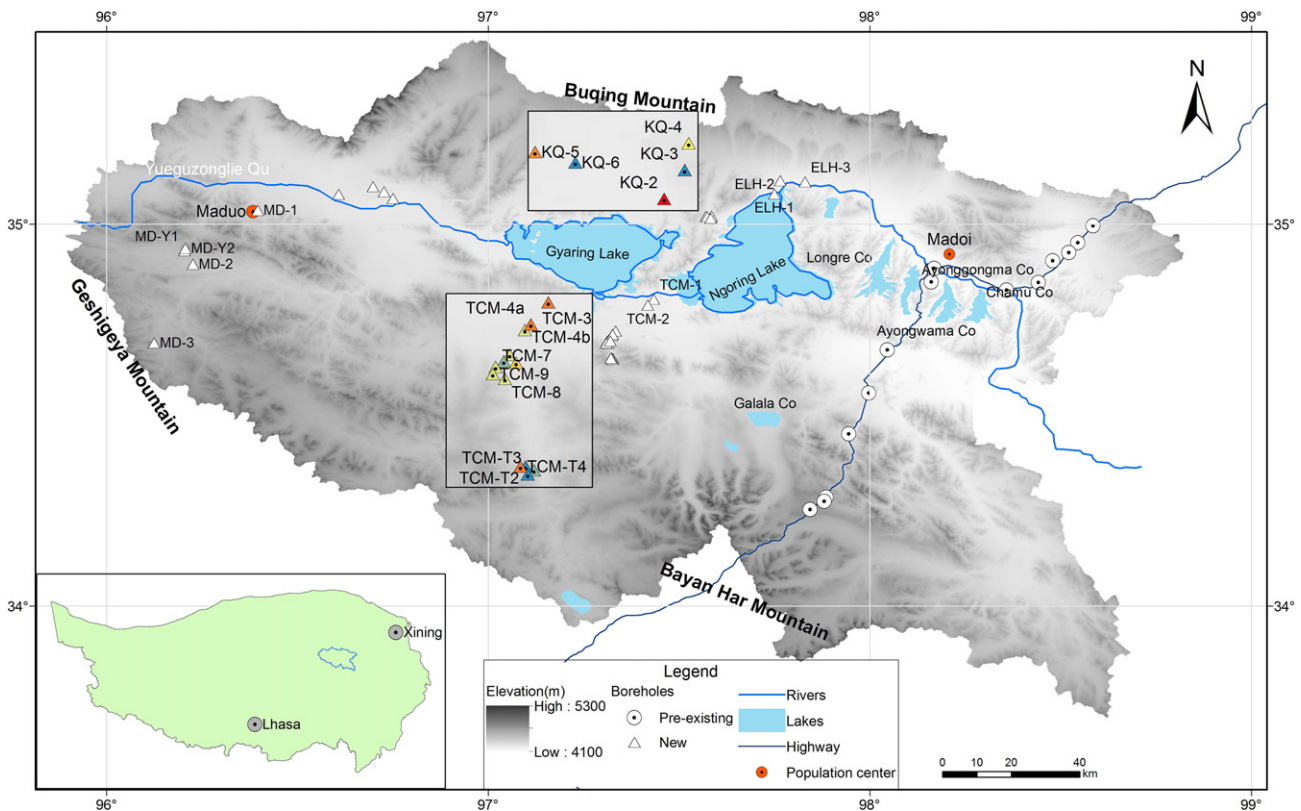


Fig. 1. Map showing topography of the source area of the Yellow River (SAYR) and borehole locations. The inset map indicates the location of the study area on the Qinghai-Tibet Plateau.

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