Permafrost degradation in the Northeastern Tibet: a possible cause of environmental deterioration

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Until 1980s, presence of permafrost was supposed to be common in the northeastern part of the Tibetan (Qinghai-Xizang) Plateau lying between 4000 m and 5000 m asl, which roughly corresponds to the source area of the Yellow River. In this area composed of wide alluvial plains and surrounding hills, which are dominated by grassland subjected to grazing activity, recent studies have emphasized lake shrinkage, decreasing river discharge, lowering groundwater level and changing vegetation. Such environmental deterioration has mostly been associated with permafrost degradation under a recent atmospheric warming trend, although studies on permafrost itself are rare. Thus, we investigated permafrost and associated seasonal frozen ground in 2003-2006 to evaluate the present-day distribution and ongoing degradation of permafrost in the source area of the Yellow River. Distribution of permafrost was examined by seismic, electrical and/or thermal soundings at 18 sites between 3250 m and 4800 m asl. Temporal variations in ground thermal and hydrological regimes were also monitored for two years at Madoi observatory (4273 m asl), by automatic and manual observations of air and ground (0-8 m deep) temperatures, precipitation, snow depth, near-surface soil moisture and groundwater level. Mean annual air temperatures were close to -2 deg. C at the observatory in 2001-2006.

High P-wave velocities (2-3.5 km/s) and relatively high DC resistivities (650-1100 ohmm) below a thin uppermost layer showed that permafrost 10-30 m in thickness occurred above 4300 m asl. In contrast, low P-wave velocities (0.3-1 km/s) throughout the sediments indicated that permafrost was absent below 4000 m asl. On widespread alluvial plains between 4200 m and 4300 m asl, permafrost was lacking or significantly degraded. Negative values of the mean annual ground surface temperature (MAGST) also indicated widespread permafrost only above 4300 m asl under the present climatic condition. At the Madoi observatory, the ground between 4 m and 8 m in depth was kept at positive temperatures (0-4 deg. C) throughout the two years, although the presence of permafrost at this site was suggested by a few reports in the 1980s. The seasonal frost penetration reached a maximum depth of 2.6 m, because the dry soil and long snow-free period favored frost penetration. Assuming that the inter-annual variation in MAGST follows that in the mean annual air temperature, permafrost is estimated to have significantly thawed on the alluvial plains at 4200-4300 m asl during the last half-century with drastic local warming up to +0.1 deg. C/a (1981-2006).

Permafrost distribution fitted to the sounding results was mapped by means of GIS. The area of alluvial plains having permafrost (except for relict permafrost), where groundwater hydrology is susceptible to the permafrost, is estimated to be 13600 km^2 in the source area. In addition, distribution pattern including sites reported to have permafrost until the 1980s or 90s requires a boundary elevation 80 m lower than that of the contemporary permafrost. This slight shift in elevation corresponds to 3000 km^2 difference in area having perennially frozen sediment. Since the elevations widely lie under transitional conditions between permafrost and seasonal frost environments, the source area currently faces a rapid loss of the permafrost area under the recent warming trend, which possibly has a significant impact on the regional hydrology. Further 80 m rise in boundary elevation will degrade perennially frozen sediment in additional 4000 km^2 area.