Bulletin of the Geological Survey of Japan, vol.60 (1/2), p.33-38, 2009

Article

Changes of frozen soil in the Yellow River source region and their impact on water resources

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Zhang Eryong, Gao Cunrong, Han Zhantao and Ding Jianqing (2009) Changes of frozen soil in the Yellow River source region and their impact on water resources. *Bull. Geol. Surv. Japan*, vol. 60 (1/2), p. 33-38, 4 figs.

Abstract: The Yellow River source region is located on the boundary between permafrost and non-permafrost areas, and the former can be subdivided into areas underlying seasonally frozen soil and middle-latitude high-elevation type permafrost. The development and preservation of permafrost are the key factors to maintain ecological balance. The rise of air temperature is the most direct cause for regression of frozen soil. Since the 1950s, there has been an obvious rising trend of air temperature in the source region, and reached 0.28°C per decade during the last 20 years. The shrinkage of the permafrost have occurred on the borders of permafrost area, and followed by remarkable drop of groundwater level and decrease of runoff volume. Impacts of frozen soil changes on regional hydrology are not only related to change of groundwater environment but also to ecological changes in meadow plants, plague of field mice and changes in runoff of the Yellow River.

Keywords: Frozen soil, permafrost, Yellow River source region, Qinghai, regional hydrology, groundwater

1. Temperature and runoff changes, and regression of frozen soil in the Yellow River source region

The permafrost refers to an underground layer (soil and rock) that are at temperatures below 0°C for two continuous years. Warm frozen soil near the ground surface is sensitive to environmental changes. The Yellow River source region is located under a boundary condition between permafrost and non-permafrost areas. The development and preservation of permafrost are the unique natural phenomena of the plateau and also the key factors to maintain ecological balance. The sensitivity of permafrost to the environmental changes results in the vulnerability of the ecology in the source region. The changes in freeze-thaw activity and the structure of the soil affect the surface and subsurface flow and regional ecology.

The rise of air temperature is the most direct cause for regression of frozen soil. Since the 1950s, there has been an obvious rising trend of air temperature in the source region, as can be seen in Fig. 1. From the 1950s to 1970s, slight rise in air temperature was observed at Madoi. The increasing trend became significant after the late 1980s with a large inter-annual variation. The rate of increase in the temperature reached 0.28°C per decade during the last 20 years.

With the rise of temperature, the frozen soil in the source region has shown a regression trend. Such increase in air temperature seems to be resulted in the shrinkage of the permafrost and occurrence of vertically disconnected frozen soil (i.e. talik was formed) on the borders of permafrost area. The boundary altitude of permafrost distribution has ascended 40-80 m. Besides, the seasonally frozen depth decreased and the melting depth increased. For example, in the area around Madoi town, the boundary of permafrost has horizontally shifted 15 km as compared with that of the 1970s.

The presence of permafrost seems to be of great significance to the ecology. In the source region, its regression has possibly resulted in decrease of water content in the plant root zone, drying of surface soil, and drying up of swamps, which caused changes in soil structure and composition, thereby leading degeneration of the alpine meadows and marsh meadows. Consequently, the dominant plant species will have inverse succession, which in turn will cause

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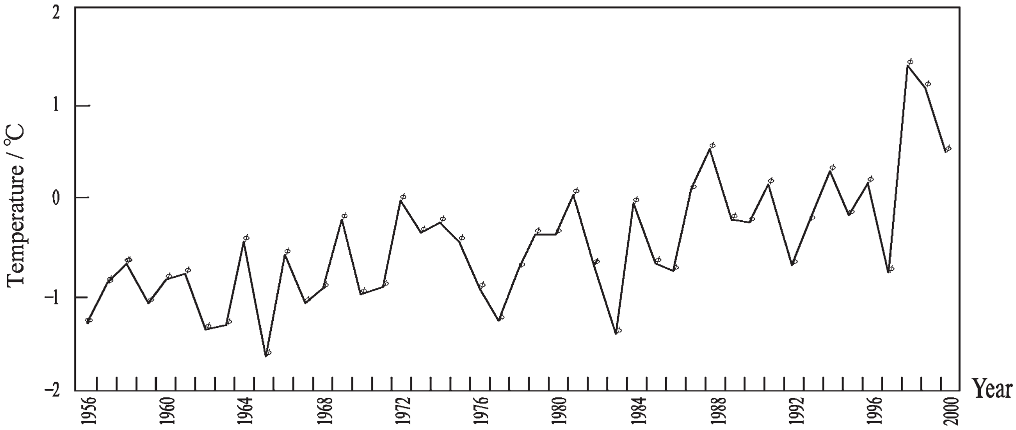

Fig. 1 Mean annual air temperatures at Madoi from 1956 to 2000 (after Chen *et al*., 2006).

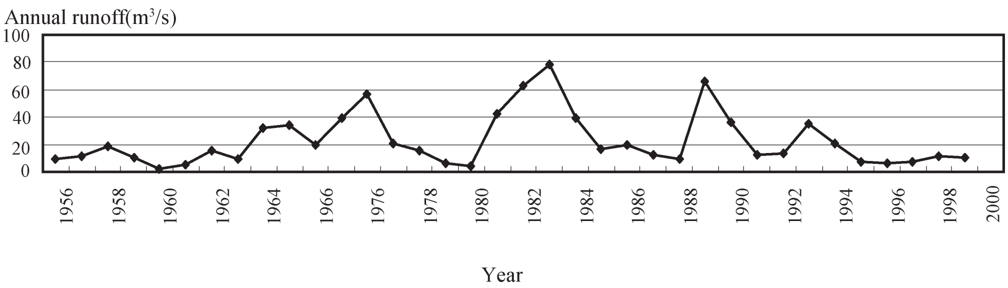

Fig. 2 Changes of runoff in the Yellow River source region.

deterioration of land. In many places black soil has appeared, and even tends to cause desertification. The drop of groundwater level resulting from frozen soil regression will not only cause changes of plants, but also promote explosive increase of plateau rats, thus intensifying the plague of rats. That, in turn, will enhance deterioration of land and plants. The degeneration of plants, rampant plague of rats, deterioration of land and desertification will further intensify the regression of frozen soil, resulting in a vicious cycle.

The regression of frozen soil in the source region may be also one of the causes for the decrease of surface runoff. The source region is one of the main runoff generation areas. Its area accounts for 15.4 % of the whole basin, but its runoff volume is 38.5 % of that of the latter. Since the 1990s, decrease of runoff volume has occurred in the source region, although the runoff in the 1960s was as small as that of the present (Fig. 2). The frozen soil regression resulting from continuous temperature rise during the last 20 years has shifted the aquifers to a deeper position. Remarkable drop of groundwater level occurred in an area of several ten thousand square meters, directly affecting the runoff volume of the source region. In many river sections groundwater levels are lower than river water levels, inverting the recharge-discharge relationship between surface water and groundwater. Since 1960, seven events of drying up of the river have occurred in the source region. That has accelerated the deterioration of ecological environment, causing great economic losses to the local people. Meanwhile, it has directly caused reduction of water resources of the river and intensified the contradiction of supply-demand of water resources, laying some impacts on the economic development of the region.

According to Wang Shaoling, the Qinghai-Tibet Plateau will continue to go warmer in the coming 50 years, and the rate of regression of frozen soil will accelerate. Large-scale regression of frozen soil will have great impacts on the engineering construction, regional water resources, regional ecological environment and ecosystem, and runoff volume of the source region. The last one will especially greatly influence the whole basin. Therefore, it is necessary to carry out investigation, monitoring, and other research on frozen soil in the source region.

2. Types of frozen soil and distribution

The Yellow River source region is a high altitude terrain, with frigid climate and widespread frozen soil layers, and can be divided into areas underlying seasonally frozen soil and middle-latitude high-elevation type permafrost.

In the region, area around Madoi town and the Dêr Qu lower valley are areas of non-permafrost. There are river-lake melting areas along the large river banks and in lake-surrounding zones, and structural melting areas along some regional active faults. Most of the other areas lie in a permafrost zone, which defined as the middle-latitude high-elevation type permafrost. In the study area, the lower boundary of permafrost lies at 4,215 m on the north side of the Bayan Har Mountains, while it lies above 4,250 m on the south side. The permafrost thinner than 38 m is widely distributed in the vally bottom, and the thickness may be greater at a higher location. The upper boundary of permafrost (permafrost table) is constrained by factors such as topography, lithology and elevation, and varies greatly year by year. Under same climatic conditions, the permafrost table is generally deeper on the south side than the north side of mountains, and is inversely proportional to the altitude and proportional to the grain size of the soil.

The seasonally frozen soil is distributed all over the region, the maximum frozen depth of which is about 3 m at a high altitude. Generally, from May, the seasonally frozen soil begins to thaw from ground surface, reaching the maximum depth by the end of September. From the end of October to April in the following year, the shallow ground is fully frozen from the surface. The annual melting period is about 150 days. In the permafrost area, a seasonal freeze-thaw layer (i.e. active layer) normally connects with the underlying permafrost layer. However, in some areas, a talik is formed above permafrost such as in piedmont alluvial plains of Buqing Mountains.

3. Presumed impacts on regional hydrology and ecology by changes in frozen soil conditions

As the global climate is turning warmer and human activities are intensifying, the permafrost table deepens and the seasonally frozen soil becomes thinner. The permafrost distribution is shrinking and some of isolated permafrost area have believed to disappear. All these phenomena of regression of frozen ground may have caused changes in regional water resources and deterioration of the ecologic and geologic environments.

3.1 Impact of frozen soil changes on regional hydrology

The distribution and recharge-runoff-discharge conditions of groundwater on the plateau are probably controlled by the permafrost distribution. Thus, the changes in frozen soil conditions have caused changes in groundwater hydrology, which in turn may have impacted on the former.

3.1.1 Changes in groundwater environment

Vertically, the permafrost layers form regionally stable watertight strata, so that if permafrost develops structure of groundwater changes from the single structure under a non-permafrost condition to double-layered one, which means the potential existence of the water-saturated layer above and below the permafrost. Horizontally, the distribution of groundwater is believed to be constrained by permafrost, although the runoff and discharge conditions of surface water and groundwater are controlled by the other geological and hydrological structures. The geothermally anomaly zones and melting zones by surface water body are channels for groundwater recharge, runoff and discharge in the permafrost area. When the permafrost table deepens, the bottom of the permafrost may ascend at the same time. If permafrost shrinks, the groundwater flow system in the regression zones changes from the frozen soil system into the non-frozen soil system.

3.1.2 Descending groundwater level

The permafrost in the source region has formed widespread suprapermafrost aquifer. In areas of frozen soil regression, the deepened permafrost table (i.e. descending of a watertight layer) probably lowers suprapermafrost water level. In areas where permafrost has disappeared, water level has dropped and is no more restricted near the ground surface.

3.1.3 Impact on the runoff generation of surface water

The areas with shallow groundwater level usually sustain well-developed plateau-swamp meadows. These areas with vegetation coverage generally over 90 % have plenty of water and lush grass, and have a good capacity of water resources. They are one of the main water-producing areas. The regression of frozen soil, which results in lowering of groundwater level in the plateau-swamp meadows, may lead to inverse succession of plants, decrease in groundwater resources, and impact surface flow.

3.2 Impact of frozen soil changes on the ecology

The regression of permafrost seems to have resulted in a series of profound effects on the ecological environment in the Yellow River source region, e.g., deterioration of meadow plants and that of vegetation diversity, rampant plague of rats, deterioration of land and even desertification. Owing to its special geographic location and climatic features, the ecological environment of the source region is vulnerable, and once it is damaged, it will be difficult to recover.

3.2.1 Changes in meadow plants

Being widespread impermeable layers, the permafrost is believed to play a key role for the supply of water and nutrients to the plants of the source region. Its presence can effectively prevent the surface water and soil moisture from migration downward, so that the plant root zones may maintain relatively high water content. As a result, variety of nutrients leached in active layers may accumulate on the permafrost table. The low-temperature condition of soil is also favorable for accumulation of organic matter. Therefore, the low-land basins and intermontane valleys with well-developed frozen soil are areas where the alpine meadow and swamp-meadow vegetation is best developed. The obvious regression of permafrost is accompanied by rise of ground temperature and increase of seasonally thawing depth. This in turn will drive moisture in the active layers to migrate down, and consequently, the near-surface soil moisture is reduced remarkably and the ground surface turns to be dry. Meanwhile, the rise of soil temperature will cause acceleration of decomposition of organic matter and increase effective nutrient contents. Consequently, the nutrition of plants is improved, circulation of nutrients enhanced, growing period of plants lengthened, and the growth space for plant roots is expanded. During the regression of permafrost, some hygrophytes inadaptable to the dryer habitat disappear rapidly, and some other xerophytes begin to invade, resulting in the succession of one plant community by another.

3.2.2 Plague of rats

The lowering of groundwater level caused by the regression of permafrost favors survival of plateau rats. When the groundwater level is as low as 30 cm from the ground surface, plateau moles are able to build nests. The regression of grassland also caused by permafrost regression has led to lowering of soil solidness and large invasion of weeds, thereby providing abundant food and favorable habitat for rats.

The rats not only bite leaves and branches of plants, but also gnaw plant roots, which is especially harmful to the good quality forage grasses that depend on roots for propagation. More importantly, the excavation by large numbers of rats has changed the surface structure of soil. The deep-lying calcic soil is thrown to the ground, which stunts the growth of plants. In addition, the thrown soil is easily blown by wind or flushed by rain, resulting in large-scale reduction of vegetation coverage and serious regression of grassland (i.e. accelerating the desertification process). Such regressed grassland is called "black earth flood plain type" regressed grassland. In a normal environment of grassland vegetation, there are also a variety of rats, but usually not very large in number. However, over 50 % of the "black earth flood plain type" regressed grassland in the source region is estimated to have resulted from plague of rats. The desertification may have in turn exerted impacts on the permafrost of the source region. When desertification began, thin-layered sands cover the ground surface, which may keep the ground temperature lower than before. However, the overlying sand layers thicken and sand dunes increase, ground temperature rises. As a result, frozen soil regresses, so that ground surface turns dry, succession of plant communities occurs, grassland retrogrades, and desertification accelerates. This vicious cycle deteriorates ecological environment in the source region.

3.2.3 Changes in runoff of the Yellow River

We believe that the regression of permafrost is the main factor for deterioration of ecological environment in the source region, which has in turn results in changes of runoff volume of the Yellow River. The drop of groundwater level, degeneration of vegetation and desertification have lowered water storage in the near-surface ground, which appears to decrease the runoff volume of the source region. As can be seen from the diagram showing the changes of precipitation and runoff (Fig. 3), the amount of precipitation is not closely related to that of runoff. The correlation coefficient between the annual precipitation and the average annual runoff volume is only 0.3766. It means that from the beginning of the 1980s, precipitation is no longer the main factor affecting the runoff volume

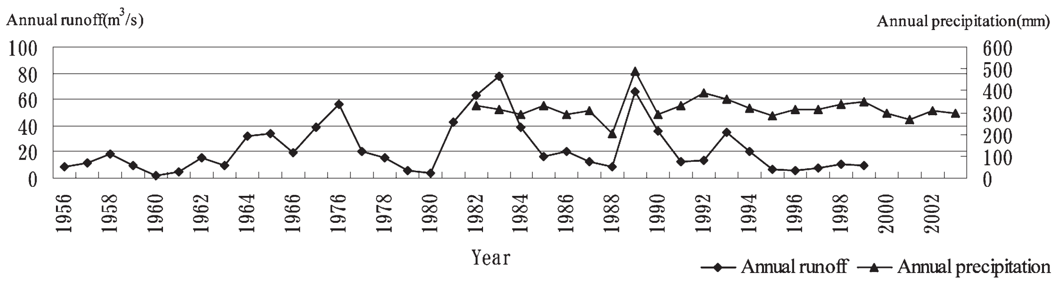

Fig. 3 Annual runoff and annual precipitation in the Yellow River source region

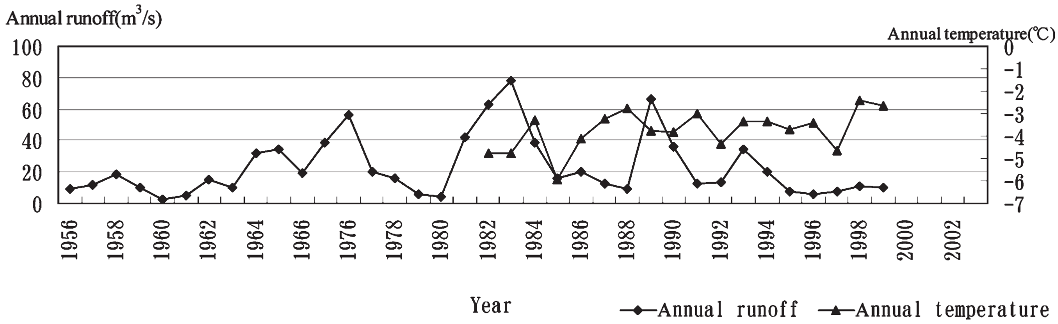

Fig. 4 Annual runoff and annual temperature in the Yellow River source region

of the source region. Figure 4 shows that the decrease in runoff volume after early 1980s weakly correlates with continuous rise of temperature in the region. Since the temperature has been significantly rising during this period, we think that serious regression of frozen soil resulted in the runoff decrease.

4. Closing remarks

If permafrost regression is taken into account, the deterioration of ecological environment in the source region can be well explained. In addition, feedback from the changes in hydrological and ecological conditions may cause further permafrost regression.

References

Chen Liqun, Liu Changming and Hao Fanghua (2006, ed.) Changes of the baseflow and its impacting factors in the source regions of Yellow River. *Journal of Glaciology and Geocryology*. vol.28, no.2, p.141-148.

Received December, 15, 2008
Accepted December, 19, 2008

黄河源流域の凍土の変化とその水資源に与える影響

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要　旨

黄河源流域には凍土地帯と非凍土地帯があり，凍土地帯は季節凍土の卓越する地域と中緯度高山帯永久凍土地域に分けられる．永久凍土地域の開発あるいは保全は，その地域の生態系バランスを左右するが，凍土を後退させる最も直接的な要因は気温の上昇である．1950年代以降，黄河源流域では明らかに気温の上昇傾向が認められ，過去20年間で10年当たり0.28℃上昇の割合となっている．その結果，凍土地帯の縁辺で凍土が縮小し，地下水位の低下と河川流量の減少を招いている．凍土の変化は地下水環境に影響するばかりでなく，草原の変化，野ネズミの異常発生，黄河流量の変化に関連している．