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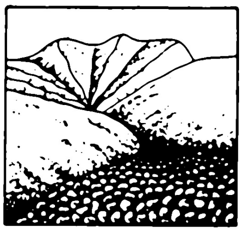

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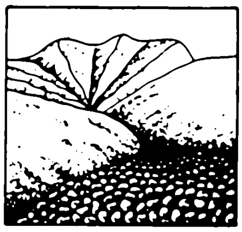

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При создании логотипа конференции использован рисунок из книги С.М. Флейшмана «Селевые потоки» (Москва: Географгиз, 1951, с. 51).
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Debris flows induced by glacier lake bursts in southeastern Tibet, China

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Селевые потоки, вызванные прорывами приледниковых озер, в юго-восточном Тибете, Китай

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Селевые потоки, вызванные прорывами ледниковых озер, относятся к типу турбулентных селей высокогорья, которые часто инициируют последовательность опасных процессов, наносящих ущерб социальному и экономическому развитию. В данной статье обсуждается влияние температуры и осадков. Результаты показывают, что прорыв ледникового озера является последствием аномальных климатических условий. Влажные и холодные условия благоприятны для накопления льда. Селевые потоки могут быть легко спровоцированы, когда климат становится более влажным и теплым или более сухим и теплым, или когда средняя температура резко поднимается на 0,6–1,2°С. В итоге, проанализированы тенденции формирования селей в контексте регионального изменения климата за последние 50 лет.

Debris flows induced by a glacier lake burst are a type of turbulent debris flow in high mountain areas, which often form hazardous chains of events that bring about damage to social and economic development. In this paper, the influences of temperature and precipitation have been discussed; the result shows that the breach of a glacier lake dam responds to abnormal climatic conditions. Wet and cold conditions are favourable to the accumulation of glacier, and debris flows can be easily induced when conditions change to wet-warm and dry-warm, or the temperature abruptly rises by 0.6÷1.2°C. Finally, the trends of debris flows are analysed in the context of regional climate change in the coming 50 years.

1 Introduction

The debris flows resulting from unexpected glacier lake outburst floods (GLOFs) often bring about catastrophic hazards to people and property in alpine glacier-covered regions (Lu et al, 1999; Cheng et al, 2003). Because of the high locations and huge volumes of glacier lakes, the GLOFs can possess prodigious kinetic energy that mobilizes substantial loose materials in the U-shaped valley to form debris flows. These debris flows are generally characterized by high peak discharge, devastating destruction, short duration and extensive range of influence. They can also bring about a series of secondary disasters during the formation, motion and deposition. Typically, a hazard chain resulting from glacier lake outburst can be denoted as below: glacier lake outburst, flood, debris flow, incorporation of loose materials deriving from rock avalanche or landslide, damming in main stream, floods from dam failure, whilst the hazard chain may be more destructive than normal debris flow inspired by rainstorm. For instance, a large debris flow aroused by flood of icefall dam breach occurred in Peilong Valley, Aug. 23, 1984, which lasted 23 h and had the maximal discharge of 5245 $m^3 \cdot s^{-1}$. The materials came from icefalls, moraines, and loose deposits in the valley. It blocked Parlung Zangbo and interrupted the stream for 15 minutes. The total volume was about 1.6×10^6 m^3. And on June 20, 1985, a even larger event occurred, with discharge up to 8195 $m^3 \cdot s^{-1}$, damming the river for half an hour and raising the water headwards up to the Tongmai bridge on the Sichuan-Tibet highway (Zhu et al., 1999); in July 20, 1988, a moraine-dammed lake located in Midui Gully failed and the consequent flood resulted in large-scale debris flow with peak discharge of 1021 m^3/s, which was 5 folds more than the average runoff in Parlong Zangbo. A temporary dam was formed along the cross section of Parlong Zangbo and water level rose up to 10m, the inundation brought about huge losses to people and property (Zhu et al., 1999; Lu et al., 1999).

2 The influences of temperature and precipitation to debris flow induced by GLOFs

The formative processes of debris flows of glacier lake outburst are substantially complex and mainly controlled by the following factors: the accumulative areas and thicknesses of glaciers, sizes and volumes of glacier lakes, configurations and stabilities of ice or moraine dams, channel gradients, magnitudes of loose materials, local temperatures and precipitations. Particularly, the events of debris flow are very sensitive to the temperatures and precipitations. All the events of debris flow occurred in May to September (Table 1). Especially, the debris flows occur most likely in July and August that stand the tiptop of temperature and precipitation in Tibet, accounting for 61 percent of all events in the history.

Tab1e 1. Historical events of debris flow induced by GLOFs in southeastern Tibet.

Name	Basin	County	Date	Disaster modes
Lumu Lake	Parlung Zangbo	Bomi	8.06.1931	Floods , Non-cohesive DF
Taraco	Pioqu	Nielamu	28.08.1938	Floods, DF
Qiongbixiamaco	Kangbuqu	Yadong	10.07.1940	Floods, DF
Sangwangco	Nianchu River	Kangma	16.07.1954	Floods, Non-cohesive DF
Jilaico	Pengqu	Dingjie	21.09.1964	Non-cohesive and cohesive DF
Damenlakeco	Niyang River	Gongboy yamda	28.09.1964; 15.08.1968	Floods, Non-cohesive and cohesive DF
Ayaco	Pengqu	Dingri	17.08.1969; 17.08.1970	Floods, Non-cohesive and cohesive DF
Zharico	Luozaxiongqu	Luoza	24.06.1981	Floods, DF
Cirenmaco	Pioqu	Nielamu	11.07.1981	Floods, DF
Kungco	Pengqu	Dingjie	27.08.1982	Floods, DF
Peilong Gully	Parlung Zangbo	Linzhi	29.07.1983; 23.08.1984; 20.06.1985	Floods, cohesive DF
Guangxieco	Parlung Zangbo	Bomi	14.07.1988	Floods, Non-cohesive DF
Jialongco	Pioqu	Nielamu	23.05.2002; 29.06.2002	Floods, Non-cohesive and cohesive DF
Degaco	Luozaxiongqu	Luoza	18.09.2002	Floods, Non-cohesive and cohesive DF

Normally, glacier lake outburst relates to unusually high temperature and heavy rainfall of short duration. Since the runoffs of glacier have a exponential relationship with temperature (Xie and Ding, 2006), the magnitude of thawing of glacier and snow could augment rapidly due to local warming; and the rainfalls in glacier covered regions on one hand could accelerate the ablation rate of glacier and snow and on the other hand lubricate glacier bed that increase the probability of icefall or avalanche. All these processes are favorable to moraine or ice dam failures in the terms of overtopping or piping.

2 Debris flow induced by GLOFs and climate change

Generally, since the accumulation and thawing, advance and retreat of glacier are functions of climate, the glacier lake outburst closely relates to the climatic fluctuation and particularly the temporal and spatial combinations of temperature and precipitation. Obviously, relatively wet-cold weather is propitious to the accumulation and advances of glacier; on the contrary, wet-warm and dry-hot weathers increase the melting rate and attenuation of glaciers. It is the most favorable time for glacier lake outburst when the climate turn from wet-cold to wet-hot or dry-hot stage which had been testified by the historic events of glacier lake outburst. There are two hazard-concentrated regions, namely Bomi and Nielamu County, in which the climate changes to some extent indicate the unusually high frequency of such hazards.

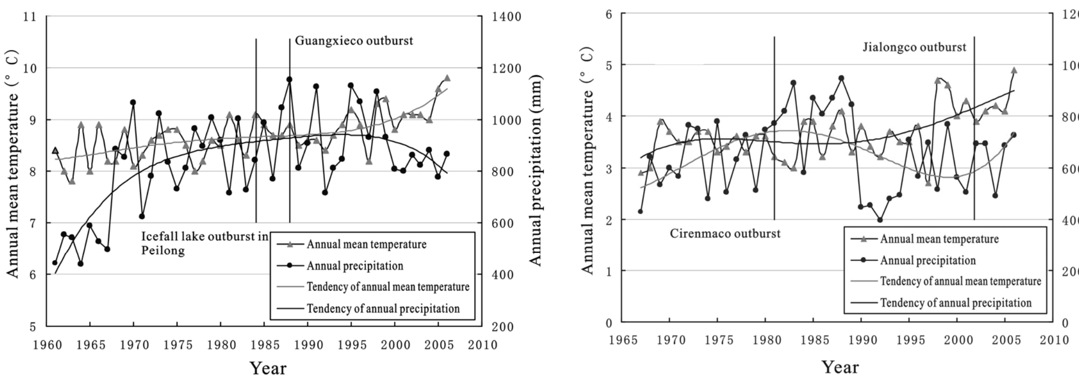

Fig1. Curves of annual precipitations and annual mean temperatures in Bomi (A) and Nielamu (B).

2.1 Bomi County

In Bomi County, the annual mean temperature tended to warming and the annual precipitation obviously fluctuated and comprehensively increased in the last 50 years (Fig. 1, A). The climate in 1970s was dry-hot and debris flow occurred rarely ; in 1980s, the climate tuned to wet-hot owning to sharp increases of temperature and precipitation that led to frequent debris flows, for instance, the three events resulting from icefall dam failures in Peilong Gully. The annual mean temperatures ascended considerably and exceeded the perennial mean value when entering into the new century, and it reached its maximum of 8.9°C of the last 40 years, in which detailed weather records were commenced. Since 2000, the weather has turned to wet-warm stage that is favorable for large-scale debris flows even when the precipitation decreases.

2.2 Nielamu County

The annual mean temperatures and rainfalls fiercely fluctuated during 1967-2006, and the tendency of weather changes could be characterized by the continuous increase of temperature and precipitation as well as frequently extreme weathers (Fig. 1,B). E.g. the Ciremaco glacier lake outburst and resulting debris flow in July 11, 1981 due to extreme accretion of rainfall in 1979 and 1980 successively.

Generally, glacier lakes break in dry-hot and wet-warm conditions and result in debris flow. And such events are often controlled by the combinative effects of temperature and rainfall.

3 Developing trends of debris flow

It is susceptible to form glacier lake outburst and debris flow incorporated with masses of loose materials when the temperature and precipitation increase simultaneously, and the processes of debris flow can be represented as follows: warming, fierce thawing of glacier, raising of water level in glacier lake, icefall or glacier tongue plunging into the lake, ice or moraine dam failure, floods, debris flow.

According to Ding, the air temperature and precipitation in Tibet would respectively rise ranges of 0.8÷1.2°C and 7÷17% in 2003 comparing to 1990 (Ding, 2002), and other meteorologic data in tow hazards severely suffered counties (Fig. 1 and Fig. 2) had proved the so-called forecast. The average value of annual mean temperature in Bomi County was 8.69°C during 1961 to 2006, and the annual mean temperature reached 9.80 °C and increased by 12.7% after successive 6 years' warming; and the average value of annual mean temperature in Nielamu County was 3.67°C during 1969 to 2006, and the annual mean temperature reached 4.9 °C and increased by 33.5%. The precipitations in the tow region take on the tendency of fluctuation and helical ascending.

The amounts and occupied areas of glacier have changed substantially during the few years due to the increase of temperature and rainfall in Tibet, and the glacier runoff will increase by 50% and glacier covered areas will decrease by 50% in 2050 (Qin, 2002). According to glacier survey and interpretations of RS image in Tibet (Wang et al, 2003; Che et al, 2004; Chen et al, 2007), the total areas of 24 glacier lakes in Pengqu Basin in 2000 and 2001 enlarged from 42.032 km^2 to 47.509 km^2, increased by 13 % since 1980; the glacier covered areas in Bioqu Basin decreased by 10% and the amounts of glacier lakes (areas bigger than 0.02 km^2) increased by 11 % with increases in areas by 47 % from 1987 to 2005;

The climate warming and increase of extreme events certainly enhance the probability of glacier lake outburst whilst accelerating the weathering processes of bedrocks that produce more loose materials in the gully, which in turn would be ready to form debris flows at the stimulus of the GLOFs. Thereby such type of debris flow will be intensely active from now to 2050. Since the climate warming would sharply shrink the occupations and total volumes of glacier, the increasing of meltwater in glacier areas is not limitless, however the meltwater may decrease and reduce the probability of glacier lake outburst and resulting debris flow when exceeding the critical points. Namely, the developing trend of debris flow induced by glacier lake outburst in Tibet will take on reverse "U" shape, and the occurrences of such debris flow mainly depend on the abrupt increase of precipitation.

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