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STREAMFLOW CHARACTERISTICS OF THE EASTERN QINGHAI—XIZANG PLATEAU

Yang Zhenniang (杨针娘)
(Lanzhou Institute of Glaciology and Geogryology, Chinese Academy of Sciences, Langzhou 730000, PRC)
Woo Mingko (胡鸣高)
(Department of Geography, McMaster University, Hamilton, Ontario, Canada)

ABSTRACT: The eastern Qinghai–Xizang (Tibet) Plateau is the headwater area for many large Asian rivers. Permafrost occurs above 4,200 m a.s.l. and glaciers occupy the summits and high valleys of the east–west trending mountain chains. Annual runoff generally increases with precipitation which is augmented southward by the rise in topography. Rainfall, snow melt, glacier melt and groundwater are the primary sources of stream flow, and the presence of permafrost enhances the flashiness of runoff response to rainfall and snowmelt events. Peak flows are concentrated between June and September. And winter is low flow season. Three types of runoff patterns may be distinguished according to their primary sources of water supply: snowmelt and rainfall, glacier melt and snowmelt, and groundwater. Large rivers generally drain more than one environments and their runoff regime reflects an integration of the various flow patterns on the plateau.

KEY WORDS: Qinghai–Xizang Plateau, permafrost, glacial melt runoff, specific runoff

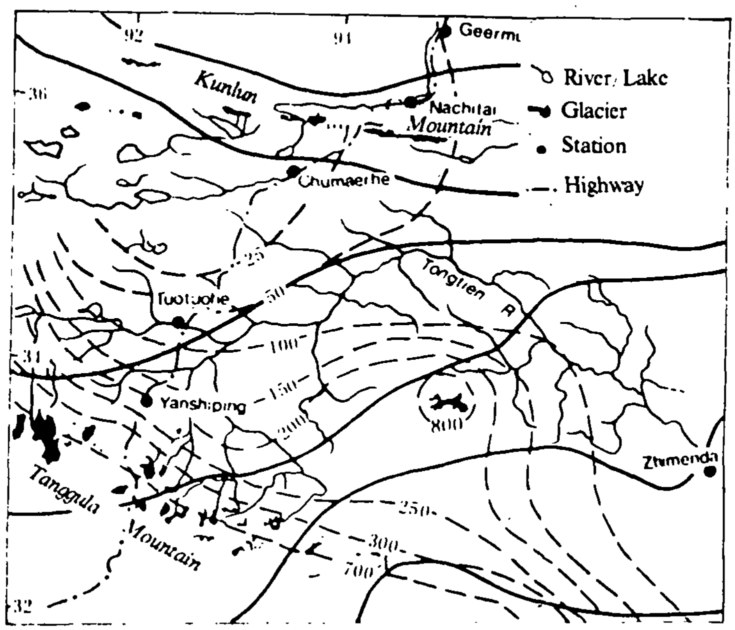
I. INTRODUCTION

The Qinghai–Xizang Plateau covers an area of 1.5 million km^2, most of which is underlain by permafrost. Many large rivers of Asia, such as the Changjiang (Yangtze) River, the Mekong River et al., originate from this plateau. The scarcity of meteohydrologic station and short term data has long prevented the systematic study on permafrost hydrology. Professor Woo Mingko, the Department of Geography, McMaster University, Canada, gave a lecture on cold region hydrology, and went to investigate permafrost hydrology along the Qinghai–Xizang road and the head of the Urumqi River in the Tianshan Mountain from June to August, 1986. Based on the above, streamflow and its effecting elements in the permafrost area of China with low latitude and high altitude had been studied.

II. STUDIED AREA

The Qinghai–Xizang Plateau lies from 32° to 36° N, 90° to 98° E. The range of elevation is 3,500 to 6,621 m. The west is higher than the east, with the highest summit attaining 6,621 m a.s.l. This region is underlain by alpine permafrost and seasonal frozen soil extensively. The lower limit of permafrost lies from 4,150 to 4,200 m a.s.l. The mean annual temperature is −2 to 3℃. Above 4,600 m a.s.l., the air temperature remains below 0℃ for over 8 months in each year. Even between June and September, the minimum temperature of −3℃ has been known to occur.

The annual precipitation averages only 100mm in the northwest, but is about 600 mm in the southeast of studied area (Fig.1). It shows that the precipitation decreases from



— precipitation — runoff

P: Precipitation Q: Discharge A: Area of basin

Fig.1 Distribution of mean annual precipitation and mean annual runoff in the studied area of the Qinghai–Xizang Plateau

southeast to northwest. A semi–permafrost snow cover exists on the high mountains, and glaciers are found on the summits and high valleys. The head water area is the maximum runoff zone, with the runoff depth of 700 to 800 mm. From Fig.1 it can be shown that annual evaporation increases from north to south.

III. FACTORS AFFECTING STREAMFLOW

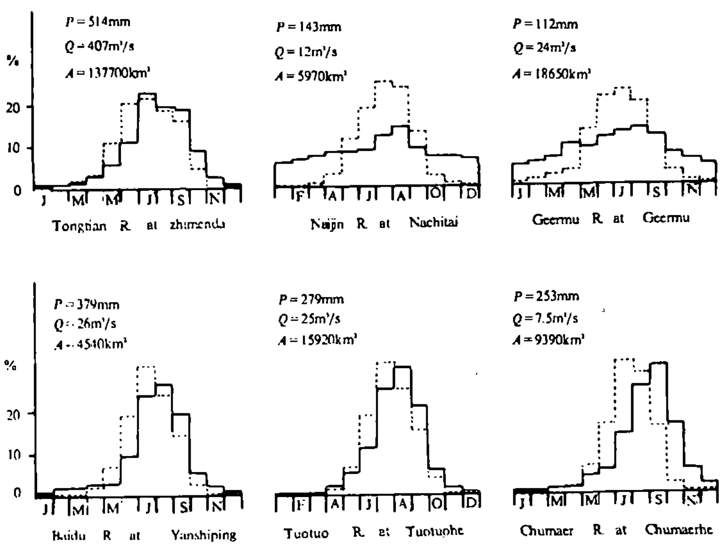
1. Precipitation

The space—time distribution of mean annul runoff (*R*) is governed by water balance: $R=P-E$ where R, P and E are mean annual runoff, precipitation and evaporation respectively. There are very few hydrometric and meteorological stations in the headwater regions of the basins, so neither precipitation nor evaporation can be determined accurately. Fig.1 shows that in the north part of the plateau, much of the low annual precipitation is consumed by evaporation and runoff is very low, particularly in the Chumaer River valley which flows across predominantly arid lands, the depth of runoff is only 21.1 mm. Runoff increases sharply towards the Tanggula Mountains as the increasing of precipitation with elevation and the decreasing of evaporation, for instance, in Yanshiping station the annual precipitation reaches 380 mm and runoff 244 mm. The runoff at glacial zone is much more than that one, the precipitation and runoff can reach 800—900 mm and 700—800 mm, respectively.

Precipitation exhibits pronounced seasonality. The low precipitation period is in winter, during which precipitation is about 10—20% of annual total. Most of precipitation is concentrated in summer (May to Sept.) which is about 90% of mean annual total. Yearly precipitation distribution is more concentrated in the area with higher elevation (Fig.2). Generally, the precipitation measurement is less than the actual precipitation[1] in the high mountain area as the result of the long time of negative temperature and strong wind speed. According to the comparison measurement between the Urumqi River source of the Tianshan Mountain[2] and the Binggou experimental basin of the Heihe River in the Qilian Mountain, the precipitation measurement is 20—25% less than actual precipitation.

2. Glacier Meltwater

The glaciers in this study area mainly clothe the Geladaindong glaciated area at the upper reaches of the Tongtian River. The total glacier area in that river valley is 1,496 km^2, which is about 1.1% of the valley area above Zhimenda Hydrological Station, and the percentage of glacier meltwater runoff is 9.2% of annual runoff. It is found that given similar percentage of glacier area in western mountain area of China, the specific runoff from glacier is less in arid climate zones. For instance, the specific glacier melt runoff in the Nyainqentanglha Mountain at the southeast of Xizang exceeds 180 l/ (s.km^2), while it is only 30—40 l/ (s.km^2) in northern Xizang Plateau[3]. From recent glacial investigation it is shown that Kunlun Mountain is the region with the least specific runoff from glacier melt in China, it is only 20 l/ (s.km^2)[4]. The former one is the maritime glacier with low latitude, high temperature, abundant precipitation, strong glacier melt and long melt season (April to October), while the later two are the continental glaciers with high latitude, low temperature, rare precipitation, weak glacier melt and short melt season (May to September). The peak flow of glacier melt runoff occurs in July to August, and the rain flood is also in the similar period, so the uneven distribution of annual runoff is intensified when the rivers receive the glacier melt water. For example, in Yanshiping Hydrologic Station of the Baidu River and Keermu Hydrological Station of the Keermu River, the glacier coverages are 5.2% and 1.8%, respectively. Between July and August, the former yields 25—30% of its annual flow, the later yields only 10—15% of its annual discharge.



— precipitation — runoff

P: Precipitation Q: Discharge A: Area of basin

Fig.2 Monthly distribution of runoff and precipitation as recorded at the selected hydrometric station

3. Permafrost

The seasonal frozen ground is distributed in the low elevation area on the plateau fringe, while the permafrost is absent there. This rapidly change with height, giving rise to a transitional zone with sporadic permafrost, and finally to the continuous alpine permafrost that underlies most of the high plateau. Being relatively impermeable[5], permafrost encourages flashy basin runoff responses to rainfall in summer[6] and sheds much of the melt water as surface flow in spring[7]. A basin in the permafrost area will generate a higher concentration velocity and a higher runoff ratio of R / P than in the lower zone. An example is provided in Fig.3 to contrast the streamflow responses to rainfall events in the Baidu River

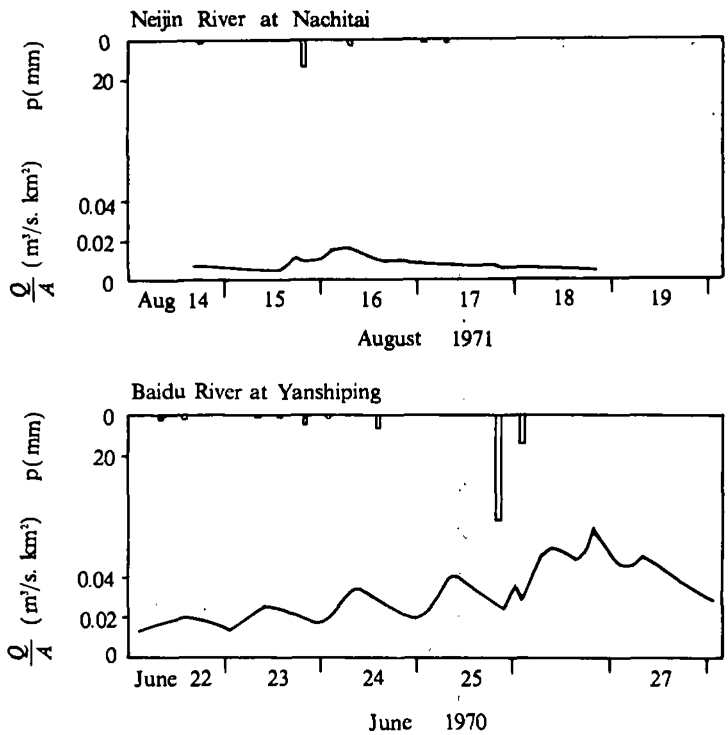


Fig.3 Stream flow response to rainfall in basins underlain continuously (Yanshiping) and sporadically (Nachitai) by permafrost

basin underlain continuously by permafrost and in the Neijin River basin occupied sporadically by permafrost. Based on the runoff measurement in the permafrost area without glacial cover in the Tianshan Mountain and the Qilian Mountain the runoff ratio is 0.7—0.8.

4. Groundwater

The basins fed by subterranean spring along major fault zones or in carbonate terrain receive significant amount of groundwater throughout a year. In lower altitude, rivers mainly fed by spring water, such as the Neijin River, are kept open in winter, while in high cold region, because of high elevation and low temperature, spring flow formed ice cone, river ice and ground ice in winter, and the frozen season is so long. For example, in the Baidu River and the Tuotuo River, from October to November, ice bank or ice flower are formed, and ice covered for about five and half months (from mid November to April). In Alaska, rivers are ice—covered for about one half a year[8].

IV. RUNOFF CHARACTERISTICS

Streamflow characteristics to be examined are mean annual flow, maximum annual flow and minimum annual flow. Based on hydrometric data from 1962 to 1982, all flow values are reduced to specific discharge ($m^3/(s.km^2)$) to permit comparisons without the interference of basin size.

1. Mean Annual Flow (Q/A)

Fig.4 shows that under the same probability, the Baidu River which lies in the Tanggula Mountain has the maximum annual flow, while the rivers in the more arid zone

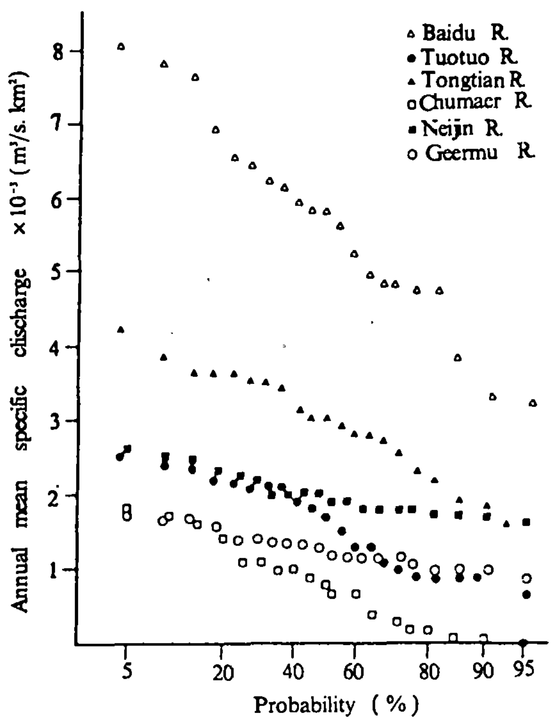


Fig.4 Probability distribution of mean annual flows of selected rivers on the Qinghai–Xizang Plateau

of the northern plateau, such as the Chumaer River has the minimum annual flow. In addition, the interannual variation of the former is lower ($Cv=0.24$) than that of the later ($Cv=0.73$). The mean annual discharge values of remaining rivers are intermediate. The largest different value of specific discharge from sporadic permafrost to continuous permafrost can reach eight times. It shows that the specific discharge in continuous permafrost is much larger than others. And its distribution is the same as in glaciated area, which decreases with the increasing aridity.

2. Maximum Annual Flow (Q_{max} / A)

Maximum annual flow, defined as max (Qi), i = 1, ... 365 days of a year, often occurs in summer (July to August) for the rivers in the Qinghai–Xizang Plateau (Fig.5). These peaks are usually related to intense storm events. Annual peak flows are similar to mean annual flows, with the highest for such mountainous rivers as the Baidu River, and the least for the Chumaer River. The occurrence of peak flows usually lagged 1 or 2 days behind the occurring of the maximum precipitation. The peak flow in continuous permafrost is 8 to 10 times of the peak flow in sporadic permafrost. The encouragement of peak flow is as a result of the impermeable layer of permafrost preventing the infiltration water into the ground.

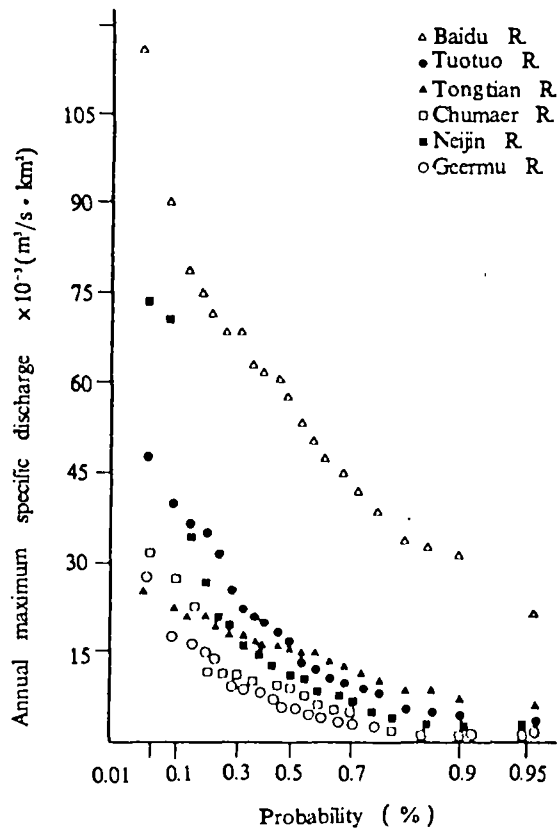


Fig.5 Probability distribution of maximum annual flows of selected rivers on the Qinghai–Xizang Plateau

3. Minimum Annual Low Flow ($Q_{min.}$ / A)

The minimum annual flow, defined as min. (Qi), i = 1, ... 365 days of a year, usually occurs in the period from November to March, or October to April. The occurrence of minimum annual flow during this period is due to low precipitation as well as low temperature. Rivers such as the Chumaer usually have zero flow in the winter. Others maintain a positive flow (Fig.6) fed by groundwater from non–permafrost zone (e.g. Geermu River) or from taliks (e.g. Baidu River). The Neijin River is fed mainly by groundwater, so its minimum annual flow is the largest. Because of the error of measurement in frozen period, the relation between $Q_{min.} / A$ and probability is not so good.

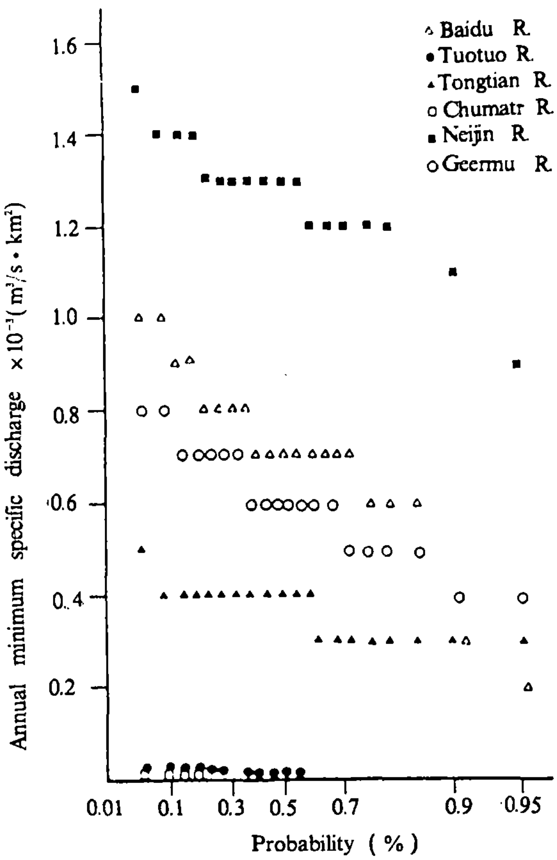


Fig.6 Probability distribution of minimum annual flow of selected rivers on the Qinghai–Xizang Plateau

V. RIVER TYPES

1. River Fed by Rainfall and Snowmelt

This type of rivers is similar to some rivers in high alpine mountain and Arctic region in foreign countries[9]. Their flows are low in winter, and their snowmelt runoffs in spring are smaller than that in Arctic region. The reasons for above facts are small amount of winter precipitation, high altitude, and delayed melting season. Summer precipitation is mainly rainfall at the lower elevations and snowfall at the higher altitude. The study on several Arctic Alaska rivers shows that snow melt runoff in summer is larger than that in the spring season[10]. A similar situation may exist on the Qinghai–Xizang Plateau. The presence of permafrost prevents deep percolation of rain or meltwater, and a sizable portion of the water input is shed as surface runoff. High summer runoff and low winter runoff are formed, so the regulating ability of the basin is weak. Therefore, the annual variation of runoff ($Cv = 0.73$) is higher for the rivers in the permafrost region such as the Chumaer River.

2. Rivers Supplied by Glacier Meltwater

The sources of plateau rivers are occupied by glaciers. In the same climatic zones, the larger the percentage of glacierization, the more obvious the influence of glacier meltwater upon runoff. In summer, July–August is the main rainfall season, as well as the strong glacier melt season with the delayed flood period. Runoff are concentrated from June to August, which is about 60–70% of annual runoff. Glacier melt water has the effect of storage runoff, so the interannual variation of runoff in the permafrost area occupied by glacier is smaller than that in ice free area or in the area with a small glacier percentage, while the peak discharge is much bigger, such as the Baidu River.

3. River Maintained by Groundwater

Rivers along fault zone or in carbonate terrain receive a significant amount groundwater. Spring–fed rivers drain across non–permafrost areas or traverse talik zones. The effects of groundwater discharge include a reduction in interannual flow variation and a more uniform seasonal flow distribution. The most rivers on non–permafrost areas of the plateau fringe belongs to this type, such as the Geermu River, the Neijin River etc.. Valley at low elevation is no ice–covered or has only a short ice–covered period. While in the rivers at high altitude, river ice and ice–cone are formed by the flow of groundwater or spring water, and ground ice or buried ice are also formed from shallow groundwater. These rivers have long ice–covered periods. In fact, it is impossible for any river to receive one source of water, usually the river type is defined by the main water source. From Marsh's[11] study on the rivers in the permafrost area of Arctic Region, it is considered that it is difficult to distinguish snow–melt–fed river from glacier–fed river. While runoff regime is very different between snow–melt–fed river and glacier–melt–fed river in western China.

Large rivers on the plateau zone are located at the different hydrological environments, the basin of the Tongtian River with an area of 137,700 km^2, for example, is fed by snowmelt rainfall, glacier melt and groundwater. There is a large amount of glacier area, so the effect of the regulating storage is strong for large basin, and the annual mean specific discharge is slightly smaller than that of the Baidu River, but the annual maximum specific discharge decreases rapidly (Fig.5). The Tongtian River is fed by rainfall and snowmelt water source.

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