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Water Resources of Glaciers in China

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China is one of the nations in the world having the most numerous mountain glaciers in the middle and low latitude. In the western part of China a high mountainous area extends for thousands of kilometers in length and breadth from the Yulong snow mountains (27 °N) in Yunan province in the south to the Altay Mountains (49 °N) in Xingjiang Uygur Autonomous Region in the north. According to preliminary investigation, the contemporary glacier area in China turns out to be about 56,500 km^2 (Ren 1980), nearly 50 % of the total mountain glacial area in central Asia, or 3.5 % of the total glacial cover of the world (16,200,000 km^2) (The USSR National Committee 1978). In terms of magnificence glaciers in Kulun Mountains take the first place, those in the Himalaya the second, while those in the Altay Mountains are the smallest (Tab 1).

Distribution of Glaciers

Glaciers in China can be classified into two types, the continental and the monsoon maritime.

Continental glaciers are those developing under dry and cold climatic conditions with rare precipitation, low temperature (mean temperature near snowline being −6° to −15 °C), high snow-line, weak ablation and low velocity of glacial movement, etc. The distribution of the continental glaciers is mainly on the N slopes of the central and western section of Himalaya, the Kunlun Mountains, the Pamir, the Karakorum Mountains, Tianshan, Altay, the Qilian Mountains and the Tanggula Mountains.

Monsoon maritime glaciers take shape under the climate of monsoon maritime conditions with warm climate, abundant precipitation, high temperature, strong ablation and high speed of glacial movement, etc. The main distributive area of this type of glaciers is in the eastern and central sections of Himalaya, the east Nyainqentanglha and the Hengduan Mountains.

Glacial Water Resources

Geographical Background

Glaciers in China are mainly distributed in the Xizang Plateau (Fig 1). The E and SE margins of the plateau are the main thoroughfare of the SE and SW monsoon with abundant moisture and high temperature, while the W and NW parts of the plateau are hindered by the Himalaya, Kunlun, Karakorum and Pamirs. Therefore, the humid air of the SE and SW current cannot enter the inner part of the plateau, where dry and cold westerlies are prevailing. Hence, the climatic characteristics of the mountain areas in the west of China are continental with rare precipitation. But surrounding the basins, for topographical uplift, "wet islands" in arid regions are formed in the high mountains, where a number of large glaciers and permanent snow covers are developed to supplying a large amount of ice-melt water to the rivers every year and to making them the sources of various large rivers in the mountainous areas of west China. The distribution of glaciers is of significance to water resource systems.

Accumulation and Ablation

The air current of moisture from Pacific, Indian and Arctic oceans is the sources of water vapour in the mountains of west China. Different sources of air current bring about distinct characteristics in precipitation. It is the influence of the air streams from the Pacific and the Indian oceans that makes the annual precipitation in the SE part of Xizang Autonomous Regions to reach 5,000 mm. In the inland arid areas, instead, it is much lower with an annual precipitation of about 700–800 mm or more, originating from either westerlies (Atlantic) or arctic air currents, while at lower areas or basins there is almost no precipitation. Precipi-

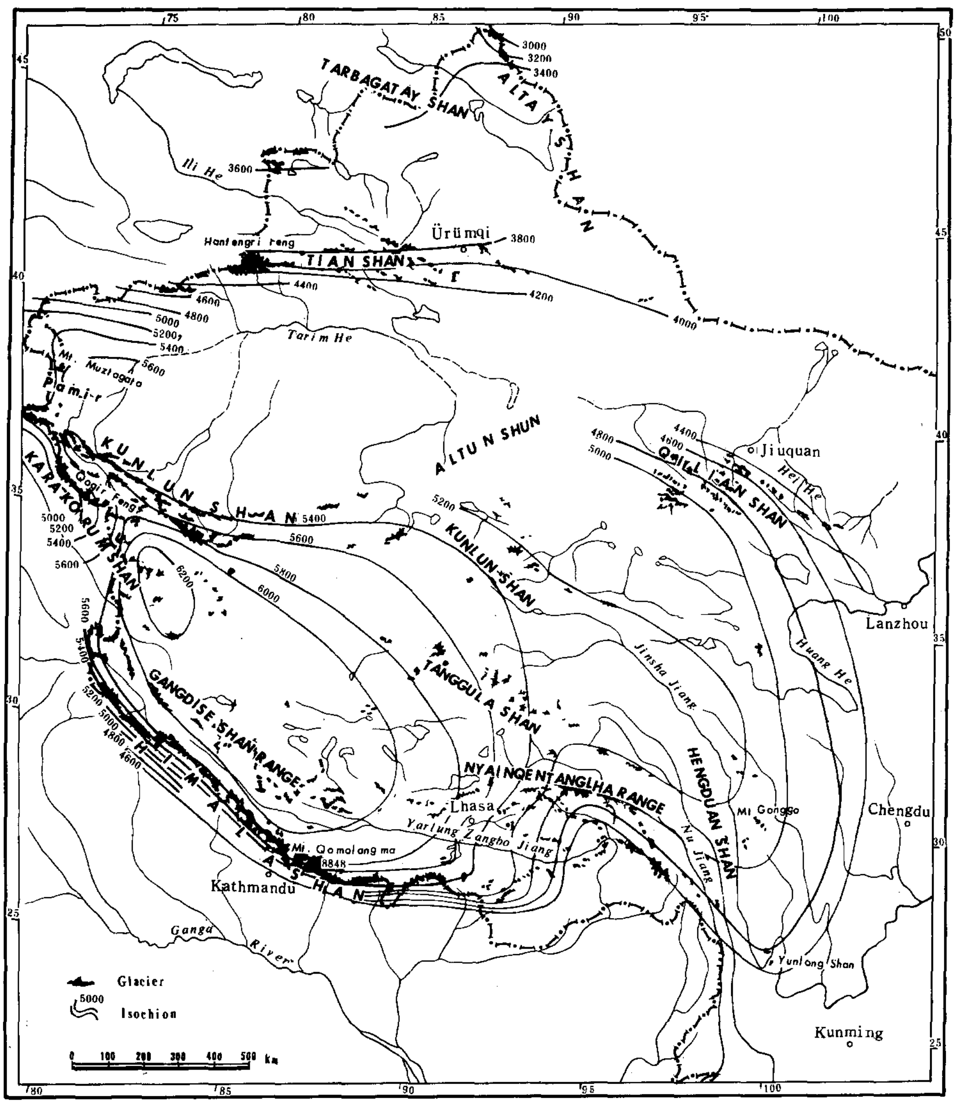

Fig 1 Distribution of existing glaciers and snowline elevations in China

tation in winter is very low, rainfall concentrates on the warm summer season (May to Sept.). In addition, as the snow-line of most glaciers runs above 4,500 m, even in hot summer season the temperature at the snow-line is negative. Low temperature and abundant precipitation in summer render good conditions for the development of glaciers, the ablation area of the glaciers is mainly below the snow-line. During the intensive melting period, large amounts of glacialmeltwater are released to streams and rivers. It is obvious that the summer season is not only a period of ablation but also a period of accumulation for the glaciers.

The heat for glacial ablation is derived mainly from solar radiation, and in a minor degree from the heat exchange of turbulence between the ice surface and atmosphere near the ground. According to the analysis of heat balance measurements, the relative value of net radiation (referring to the percentage by which the heat of radiation balance partakes in the input variables of heat-balance equation on the ice or snow surface during the ablation period) in glaciated areas always increases with decreasing latitude, the upgrade of altitude and the enhancement of climatic aridity, while the melted depth of ice surface increases with the increase of relative value of radiation balance (Yang 1981). Therefore, the distribution trend of melted depth on the ice surface has an obvious regional regularity. Continental glaciers have a short melting period (May to Sept.), but maritime glaciers have a long one (March to Oct.). The precipitation on the latter is higher than that on the former. The result of the above combined influences shows that the melting depth of maritime glaciers is about ten times that of the continental glaciers. Generally, its distribution shows that the maximum melt-water depth (5,000–6,000 mm) is found in monsoon maritime glaciers of SE Xizang, and it gradually decreases towards the W and NW. As for the continental glaciers, such as Rongbuk Glacier, Pamir glaciers etc., their melted depth is only 500–600 mm.

Mountains	Height of highest peak (m)	Height of snow-line (m)	Area of glaciers (km^2)			Runoff of glacier meltwater ($10^8 m^3$)	Data Sources
			Inland river (km^2)	Outflow river (km^2)	Total (km^2)		
Qilian Shan	5826	4300–5240	1931.53	40.97	1972.50	14.45	Glacier inventory of China, Vol. 1, Wang Zong-tai et al.
Altay Shan	4374	3000–3200	0	293.20	293.20	3.87	Glacier inventory of China, Vol. II, Liu Chao-hai et al.
Tian Shan	7435	3600–4400	9549.69	0	9549.69	86.83	1 : 1,000,000 map, Ren Bing-hui et al., 1975.
Pamir	7579	5500–5700	2258.00	0	2258.00	15.79	Landsat images, Mi Desheng
Karakorum Shan	8611	5100–5400	3265.00	0	3265.00	25.90	Landsat images, Mi Desheng
Kunlun Shan	7160	4700–5800	11447.05	191.95	11639.00	67.46	Airphoto maps, Deng Yang-xin
Himalaya Shan	8848	4300–6200	989.40	10065.60	11055.00	79.83	Landsat images, Mi Desheng
Qiangtang Plateau	6547	5600–6100	3566.00	0	3566.00	18.96	Airphoto maps, Li Binyuan
Gangdise Shan	7095	5800–6000	845.90	1342.10	2188.00	11.57	Landsat images and Airphoto maps, Jiao Keqin et al.
Nyainqentanglha	7111	4500–5700	122.80	7413.20	7536.00	151.96	Airphoto maps and Landsat images, Li Jijun et al.
Hengduan Shan	7566	4600–5500	0	1456.00	1456.00	46.05	Airphoto maps, Li Jijun et al.
Tanggula Shan	6621	5200–5800	0	2082.00	2082.00	18.40	Airphoto maps, Zhang Linyuan
Total			33975.37	22885.02	56860.39	541.00	

Remarks: a) Figures for Qilian and Altay Mountains are latest values, others are published figures,
b) The glacial areas for inland and outflow rivers in Xizang and a part of Qinghai are roughly estimated figures.

Tab 1 Glacial area and runoff of glacial meltwater in China

Water Resources

The so-called glacial reserve refers to the water storing capacity of glaciers. Because of the extent of the glaciers and the limited number of measurements of their thickness, a rough estimation of the glacial reserve in China gives the figure of around 50,000 km^3. Water resources of the glaciers refer to the replenishment of water i.e. the renewable part of glacial meltwater in a year.

Hydrological and meteorological measurements at more than a dozen temporary sites and permanent stations in high mountains show that glacier runoff modulus increases with the increase of glacial coverage, but when the glacial coverage is the same, glacial runoff modulus decreases with the increase of climatic aridity. Thus the glacial meltwater of both the measured and unmeasured areas can be calculated with this tendency of distribution of glacial runoff modulus. The preliminary figure calculated by means of the above-mentioned method is about $550 \times 10^8 m^3$, or about 2.0 % of the total runoff of the whole country, which is equivalent to the average amount of runoff of the Huang He River. The proportion of glacial meltwater in inland rivers reaches 45 % of the total glacial meltwater or 20 % of the runoff in inland rivers. If only the ice-melt runoff is taken into account, the water amount per capita in inland river basins equals the average runoff per capita in the whole country. Obviously, glacial water resources in inland river basins of China are plentiful. Although the area of glacial coverage in external drainage basins is only 40 % of the total glacial coverage, the glacial meltwater is about 55 % of the total glacial meltwater. However, the percentage of glacial meltwater in external drainage basins is much lower than that in inland rivers.

The share of meltwater from the glaciers in the rivers surrounding the Qinghai-Xizang Plateau is about 10 %, and it increases towards the center of the plateau with increasing climatic aridity. For instance, it makes up about 30–40 % in Kokosily, Qiadam basin and Dalimu Basin. With increasing rainfall the share of glacial meltwater decreases in the SE part of the Xizang Plateau.

Some effects on Rivers

The glacial meltwater varies from season to season. The runoff is made up by rain water and glacial meltwater in warm season, because of both increase of rainfall and increase of ablation. Melting of glacier ice releases a large amount of water to supply the rivers. In spring stream-flow is very low because streams are frozen and so is the soil in the high mountain areas. Although annual stream-flow varies widely, the long-term fluctuation of runoff is very small. This is because in a dry year with low rainfall, the glaciers may melt intensively and supply more meltwater to the streams than in a normal year, thus inhibiting the rapid decrease of runoff for the scarcity of precipitation. Whereas, in the years of low temperature with abundant rainfall, glacial ablation is restrained and glacial meltwater decreases. Consequently the material nourishment of glaciers increases. The discharge of streams does not rise abruptly when precipitation is abundant. The regulating effect of glaciers on stream-flow in the mountains of W China can be found in providing meltwater in dry years and in reducing the share meltwater in wet years with low temperature. Thus the variation coefficient of stream runoff (C_V) is small, in other words, the stream-flow is steady. This is the unique peculiarity of the water resources in the mountains of W China.

The glaciers can not only provide an excellent quality of water but also a stability of water supply for industry and agriculture in wide areas of West China. So far, the glacial meltwater has been used mainly for irrigation in China's arid West for example on the S and N slopes in Tian Shan in Xinjiang Uygur Autonomous Region and in the Hexi corridor of the Gausu Province. The stability of water supplied by the glaciers plays an important role in high and stable yields of agricultural production. In addition, a small portion of glacial meltwater in Xinjiang and Xizang Autonomous Regions is used to generating electricity. Apparently, glacial water resources can be considered as one of natural resources for industrial and agricultural development in the mountainous areas of arid West China.

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