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THE CONDITIONS OF THE GLACIAL WATER RESOURCE AND WAYS OF ITS EXPLOITATION AND UTILIZATION IN CHINA

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ABSTRACT: China is one of the countries where there is abundant glacial water resource and glaciers exist in a vast area of mountainous regions. In this paper, a comprehensive discussion is made for the characteristics of glacial water resource, the chemical properties of meltwater and the prospects of future utilization in China. It has found that the glacial water resource is a water resource system based on the effect of a solid water reservoir. Its degree of mineralization is low and it almost does not have any pollution. In particular glacial water is high quality fresh water resource in the inland arid region. It is necessary to reconfirm the value of this water resource and conduct further studies on the fundamentals of its application in order to rationally exploit, utilize and preserve the glacial water resource.
KEY WORDS: glacial water resource, glacier chemistry, water resource exploitation, water resource utilization, water resource preservation

Water is the origin of life and also the important factor influencing economic development. A significant phenomenon is the shortage of fresh water in China with personal average corresponding to about 1/4 of the world average. However glacial water resource is abundant, especially in those inland high mountains.

I. PRESENT STATUS OF GLACIAL WATER RESOURCE IN CHINA

Glacial water resource is a water system based on the effect of solid water reservoir, consisting of snow and ice and its meltwater discharge. Glaciers in China are distributed broadly so that China is one of the biggest countries with glaciers. In China most glaciers exist in the high mountains lying to the west of 104°E, for example between the latitude of 27° and 49° 10'N there are glaciers occupying an area of 58,651 km^2 with ice volume of $51,322.2 \times 10^8$ m^3. The annual amount of meltwater runoff from these glaciers is about the long-term average of the Huanghe (Yellow) River discharge into the Pacific Ocean[1]. The status of glacial water resource in different regions depends on the natural conditions influencing glacier development. Studies indicate that glaciers in China can be divided into continental and maritime types based on physical properties and developing conditions of glaciers[2]. The continental glaciers, the basic type of glaciers, mainly exist in the northwest interior high mountains and the Qinghai-Xizang Plateau, while the maritime type are distributed in the southeast of Tibet and in Hengduan Mountains.

Glacial water resource is much different from those natural water bodies because of its solid phase characterized by motion. Through an equilibrium line a glacier is zoned, the upper part is called as the accumulation area with snowfall accumulating in every year and the lower part is the ablation area with ice and snow melting. The accumulated snow is gradually changed into ice by metamorphism and flows to the ablation area where ice and snow are melted and the melting water flow to the ice-free regions. From this viewpoint glaciers play an important role in the water cycle. The existing glaciers in China have a water storage of 564×10^8 m^3, being 81.2 times of their melting water runoff, therefore they are important nourishment sources of those mountainous rivers in northwest China. In particular abundant melting water can release to rivers in the warm and drought years by strong ablation of glacier ice, while in the wet years with lower air temperature glacier ablation is decreased, snowfall can be kept. This fact demonstrates that solid reservoir of glaciers has a long-time regulation or exert one-century's effect on river discharge. Another characteristics of glaciers in China is that owing to the effect of monsoon ablation season is also main accumulation period, which is different from the "cold season accumulation type" of glaciers. In China most glaciers belong to "warm season accumulation type" except for glaciers in the Mountains, that is usually classified as the subsidiary type of the "cold season accumulation type" of glaciers[3]. In the regions where "warm season accumulation type" of glaciers develop, precipitation in the warm season takes 50% - 95% of its annual total, while July and August are the intensive ablation period in which 80% of annual melting water is formed. This special characteristic surely exerts impact on the water resource patterns. Estimations through field observations indicate that net accumulation is about 28.9% of the total accumulation and seasonal snow melting takes 38.2%, less than the net ablation, of the total ablation on glaciers in the source of the Urumqi River[4]. In the same year, the net glacier accumulation is 36.6% of the total accumulation and seasonal snow melting is 59.0% of the total ablation[5], less than net ablation in the Youyi peak of the Altay Mountains. These evidences display that the subsidiary type of the "cold season accumulation type" of glaciers have a longer accumulation period and the accumulation is bigger in cold season. This results in a longer keeping time of seasonal snow and the formation of superimposed ice in the ablation area as well as a shortened ablation time. On the contrary, glacier melting water presents a significant regulation to river discharge on the "warm season accumulation type" of glaciers because of longer ablation period. Analysis of the concentration of hydrogen isotope shows that glacier ice melting occupies about 51% and 34% of the glacier melting water runoff in July and August. In summary the glacier water resource in the northwest China is characterized by abundant nourishment of glacier melting water with high quality to rivers in summer.

II. CHEMICAL PROPERTIES OF GLACIER WATER

One of the main subjects of studies on glacier water resource is to investigate its geochemical regularity of the distribution of chemical elements during the transformation of glacier water and the chemical properties of various water bodies. Field sampling and chemical analysis demonstrate that the degree of mineralization of glacier water on an average is in the range of 13.09 – 54.11 mg/L, while that of snow on glacier surface is 5.64 – 32.7 mg/L, mountainous precipitation or snowfall 12.29 – 43.67 mg/L and melting water 28.51 – 163.77 mg/L respectively (Table 1)

The degree of mineralization of waters shows different patterns. Snowfall in the accumulation area has the lowest degree mineralization and melting water discharge in rivers is the highest, demonstrating a gradual increase from snowfall, glacier ice , melting snow and ice to river discharge. All water types are the lower mineralized and high quality fresh water and the regional differences of degree of mineralization are obvious.

In glacier areas the concentrations of Na, Mg, K, Ca, Mn, Fe, and Al are higher in meltwater runoff than those in precipitation in the intermediate mountainous areas, snowfall in high mountains has the lowest concentrations of the abovementioned chemical elements. In geochemical words the distributions and constitutional patterns can be described with enrichment coefficient (EF) of the chemical elements, which is defined as the ratio of the concentration of certain elements to Al in a sampled water to its relative mean(element concentration to Al) in the earth surface crust. Chemical analysis (Table 2) shows that Mg (Na) has the higher enrichment coefficient and next is Ca (Na) in precipitation in the glacier area, whilein a sampled water to its relative mean(element concentration to Al) in the earth surface crust. Chemical analysis (Table 2) shows that Mg (Na) has the higher enrich

Table 1 The degree of mineralization of glacier water (mean value)

Glacier area	Sampling elevation(m)	Type of samples	degree of mineralization (mg/L)
Youyi Peak in Altay Mts.	2800 - 3800	Snow	5.64
	2500 - 3200	Glacier ice	13.99
	1400 - 1910	Rainfall	14.81
	1910	Meltwater	25.81
Tumor in Tianshan Mts.	3900 - 5300	Snow	32.50
	3100 - 4400	Glacier ice	35.50
	3200	Rainfall	43.67
	2980 - 3080	Meltwater	146.75
Urumqi River Headwater	3800 - 4100	Snow	20.73
	3800	Glacier ice	22.04
	3700	Rainfall	22.92
		Meltwater	42.26
Lenglongling in Qilian Mts.	4300	Snow	16.62
Dunde Ice Cap in Qilian Mts.	5200 - 5320	Snow	32.71
Namjambawa in Himalayas	3640 - 4100	Snow	10.81
	3000 - 4600	Glacier ice	33.65
	3550	Rainfall	28.78
	2950 - 4130	Melting water	118.19
Hengduan Mts.	4750 - 5780	Snow	7.02
	2780 - 5120	Glacier ice	54.11
	2393 - 4870	Rainfall	12.29
	2300 - 4160	Meltwater	163.77

ment coefficient and next is Ca (Na) in precipitation in the glacier area, while enrichment of Ca is higher than Mg in the melt water runoff. As for the enrichment of chemical elements in different types of glaciers, Mg (Na) is the dominant element in continental type of glaciers, however Ca (Mg) is much rich in the maritime glaciers. These properties demonstrate that chemical elements in glacial waters are mainly from earth surface crust, the precipitation in the glacier area is influenced by moisture transpirtation from oceans. The release of chemical elements from the surrounding bedrock exerts a major impact on the chemical composition of the river discharge.

Table 2 Contents and enrichment coefficients of chemical elements in glacial water

Glacier area	No. of samples	Water type		Elements							Order of the enrichment
				Na	Mg	K	Ca	Mn	Fe	Al	
Hengduan Mts.	12	Snow in	(1)	0.22	0.92	0.18	0.58	0.0022	0.0161	0.0196	Mg>Ca>Na>K
		glacier	(2)	31.89	181.93	28.70	65.61	10.30	1.31	1.0	
	12	Precipitation	(1)	0.30	1.18	0.26	1.51	0.0026	0.0126	0.0399	Mg>Ca>Na>K
			(2)	21.36	114.63	20.36	83.91	5.98	0.50	1.0	
	8	Glacier ice	(1)	0.37	2.82	0.33	9.50	0.0038	0.0148	0.0964	Ca>Mg>Na>K
			(2)	10.90	113.38	10.70	218.51	3.52	0.24	1.0	
	7	Meltwater	(1)	0.76	12.31	0.47	23.41	0.0007	0.0146	0.1233	Ca>Mg>Na>K
			(2)	17.51	386.97	11.91	420.98	0.52	0.19	1.0	
Mt. Namjambawa	4	Snow in	(1)	0.97	0.96	0.58	0.44	0.0054	0.0676	0.0791	Mg>Na>K>Ca
		glacier	(2)	34.99	47.25	23.19	12.32	6.28	1.35	1.0	
	1	Precipitation	(1)	1.40	2.81	1.08	1.92	0.033	0.1141	0.3771	Mg>Ca>Na>K
			(2)	10.55	28.88	8.95	11.29	8.03	0.48	1.0	
	5	Glacier ice	(1)	0.61	2.99	0.90	2.46	0.0072	0.1383	0.1402	Mg>Ca>K>Na
			(2)	12.36	82.66	20.06	38.91	4.71	1.57	1.0	
	4	Meltwate	(1)	0.99	5.29	4.91	20.94	0.0005	0.0806	2.381	Ca>Mg>K>Na
			(2)	1.18	8.61	6.44	19.50	0.019	0.05	1.0	
Headwater of Urumqi River	5	Snow in	(1)	0.84	1.18	0.38	0.86	0.018	0.018	0.004	Mg>Na>Ca>K
		glacier	(2)	596.5	1146.4	296.8	476.72	412.84	7.17	1.0	
	6	Glacier ice	(1)	9	1	8	2.42	0.006	0.022	0.005	Mg>Ca>Na>K
			(2)	1.27	1.49	0.40	1073.1	110.09	7.01	1.0	
				721.5	1155.0	250.0	7				
				9	4	0					
Youyi Peak in Altay Mts.	4	Snow	(1)	0.33	0.21	0.27	0.13	0.0125	0.06	0.009	Na>K>Mg>Ca
		in glacier	(2)	104.1	90.44	93.75	32.03	127.42	10.62	1.0	
	6	Precipitation	(1)	7	0.45	0.29	0.63	0.0225	0.123	0.0152	Mg>Ca>Na>K
			(2)	0.40	114.75	59.62	91.90	135.80	12.89	1.0	
	6	Glacier ice	(1)	74.76	0.53	0.83	0.24	0.0088	0.0767	0.0052	Na>K>Mg>Ca

Note: (1) contents in mg/kg;
(2) enrichment cofficient (EF)

Except for the above-mentioned chemical elements there are some important trace elements, for example Mo, Co, Sr, Ni, Cu, Zn, V, Pb, As, Cd, Ti, Sn, Hg, Ag, Se and so on in the glacial water. Some of the elements have been identified in certain glacier areas (Table 3). In general their concentrations are relatively unchanged and the variation trend of concentrations in atmospheric precipitation are usually identity with that in the glacier ice, but the contents in snow, rain, hail etc. are higher than those in the glacier ice. This phenomenon displays that these trace elements mainly come from atmospheric precipitation. The concentrations of chemical elements in glacier ice can reflect their status in precipitation at that time, because the process that snow was changed into ice, and then moved to glacier tongue usually takes several decades or even hundred years. In this viewpoint the concentrations of trace elements in precipitation tend to increase during recent years. Field sampling and relevant chemical analysis display that the higher concentration of Sn in glacier ice in Mt. Namjambawa can be identified and next is Co[6]; Sn has biggest concentration Ni takes the second and Co the third in the glacier area of Hengduan Mts[7]. However the concentration of Co in precipitation is the highest, then that of Zn, in Altay Mts., Tianshan Mts. and Qilian Mts[8]. These phenomena may be in relation to moisture sources and regional environment, for instance, southwest monsoon can transport water vapor to Mt. Namjambawa, and southwest and southeast monsoons can reach the Hengduan Mts., while the main vapor source is from the moisture transfered through circulation of westerly.

Table 3 Contents of trace elements in glacial water (μg/kg)

Glacier Area	Sample type	No.	Mo	Co	Cr	Sr	Ni	Cu	Zn	V	Pb	As	Cd	Ti	Sn	Hg	Ag	Se
Namjambawa	Precipitation	5	28.1	90.9	11.8	3.7	7.9	33.7	134.1	12.0	16.0	32.8	11.5	0.6	6.5	12.2	19.1	19.7
	Glacier ice	4	18.6	67.9	9.2	2.0	5.4	23.1	101.0	10.1	12.6		9.6	1.5	5.1	10.2	15.5	16.0
Hengduan	Precipitation	14	9.4	35.9	29.9		40.6	28.6	18.1	23.5	18.3	11.3	12.9	4.4	50.4	16.8	4.1	11.2
Mts.	Glacier ice	7	8.2	34.6	31.5		34.7	21.0	10.6	22.6	13.7	13.0	11.8	4.0	48.1	13.7	4.5	6.6
Lenglongling Qilian Mt.	Precipitation	1	21.0	90.3	13.0	8.2		23.8	43.2	12.6	4.2		9.3	0.5	3.0	12.8	17.6	13.6
Tianshan Mts.	Precipitation	5	21.2	56.1	10.5	22.2		14.9	38.4	11.7	7.6	11.8	5.2	0.3	3.1	11.1	16.4	13.4
Youyi Peak, Altay Mts.	Precipitation	3		87.2	4.2	2.6	1.2	5.2	10.1	11.8			0.3					

III. WAYS TO EXPLOIT AND UTILIZE GLACIAL WATER RESOURCE

In the natural water cycles glacial water resource plays a special role in which solid water can be stored in glaciers and glacier ablation can release meltwater in liquid phase. Glaciers are in general developed in high mountains away from pollution sources and were formed before industrialization. Therefore glacial water resource can be referred as the fresh water nearly without pollution in the world. Therefore, the value of glacial water resource should be considered in order to rationaly exploit, utilize and protect glacial water resource.

In China glacial water resource is abundant, with good quality, therefore, has great potentiality in the view of development and utilization, but its distribution is uneven, and the total sum of glacial water is not identical with the sum of glacier meltwater runoff. 61% of the total area of glaciers, about 69% of the total ice volume, exist in interior river basins, but meltwater runoff takes only 40% of the total glacier meltwater runoff. However in the river systems flowing into oceans there is about 60% of glacier meltwater runoff although there are 39% glacier area and 31% of the ice volume. On the basis of regional distribution of glaciers, glacier area and corresponding meltwater discharge are biggest in Tibet Autonomous Region, with 46.7% of the total glacier area and 57.8% of meltwater discharge of the country's total glacier discharge. The remnant area and discharge are distributed in Xinjiang Uygur Autonomous Region, Qinghai and Gansu provinces(52.3% in area and 39.0% in discharge) as well as in Yunnan and Sichuan provinces (1% in glacier area and 3.2% in discharge). The potentiality of developing and utilizing glacial water resource can be seen in the cases that glacier meltwater supply to river can make up about 30% - 40% in the interior northwest China, some rivers even up to 70% - 80%. In particular, glacial water resource plays a significant role in the most drought areas of Tarim Basin, Qaidam Basin and the Hexi Corridor(an important part of Silk Road), because in these regions there are broad land and various valuable mineral mines with more than 100 different kinds of proved mineral. But water supply is the main problem that restrains the development of eco-environment and economy, especially in agriculture, mine excavation and so on. Because annual precipitation in the plain regions of northwest China can never reach to 200 mm while evapotranspiration is about several hundred times of precipitation, therefore it is necessary to rationally exploit and Utilize and protect glacial water resource.

Developing glacial water resource implies to fully utilize this resource, especially the resource of meltwater discharge through constructing reservoir and irrigation system in the mountainous area. Such reservoir and relevant constructions can reduce flood hazards and regulate river runoff, and building multi-purpose water use project, e.g. hydropower. The key construction project is the hydropower which is being constructed at the Yamzho Lake in Tibet Autonomous Region. The establishment of Yamzho Lake Hydropower can greatly abate the tight supply of electricity in Tibet.

Secondly developing glacial water resource means that glacial water goes to the market. In recent years international beverage market has been broadened, for example there are several hundred brands of mineral water produced in the Chinese market, due to the increased concern of human health. At present many countries have paid much attention to studying the influence of environmental pollution on the daily diet. It is found that glacial water is the better beverage for daily life, nearly not be polluted because it is in the high mountains away from human activities and formed before the industrialization. It is necessary to construct plants to produce glacial water beverage. Investigations in the Qilian Mts. show that the mineralized glacial water is nourished by the nearby glacier meltwater, which has the value of development. Now many such kind of plants have been established to produce glacial water beverages.

To develop glacial water resource needs to research the distribution, evolution of present glaciers, because glaciers are the product of important climatic events and fluctuate with climate change. In the geological time many times of alternations of glacial and interglacial or glacier advances and retreats have occurred. It is accepted that glacier fluctuations reflect the intensity of climate change. Based on ice coring in Qilian Mts. glaciers have more than 4700-year ice layer[9]. Glaciers in China, like that around the world are still in the Little Ice Age, which is generally in the retreat state. Studies on fluctuations of several hundred glaciers display that 44% of glaciers were in the retreat state, 30% basically in steady state and 26% showing advance during the 1950s and the 1980s[10,11]. Glacier fluctuations are impacted by climatic changes which appear in the pattern of wet and cold/drought and warm or wet and warm/drought and cold. Researches indicate that it was in wet and cold climate from the beginning of this century to the 1940s, after the 1960s drought and warm trend occurred[12]. Because of glacier fluctuations delaying climatic change, glacier fluctuations in China was in the decreased state of retreat which responded the wet and cold change of climate before the 1960s. After the 1980s retreat glaciers showed a increased trend which might be triggered by the "Greenhouse Effect" from increasing of atmospheric CO_2 release. Therefore to monitor glacier fluctuations should not be ignored while developing glacial water resource, and relevant measures are also necessary to protect the glacial resource. To intensify such sense of referring glaciers to a kind of resource, corresponding studies should be carried out to increase glacier accumulation based on synoptic and climatic conditions as well as the properties of atmosphere in the glacier areas.

REFERENCES

I[1] Yang Zhenniang. Glacial meltwater runoff and its nourishment to rivers in China. In: An Introduction to Glaciers in China. Beijing: Science Press, 1988. 187-204. (in Chinese)

[2] Shi Yafeng, Xie Zhichu. The basic characteristics of glaciers in China. Journal of Geography. 1964, 30 (3): 184-208. (in Chinese)

[3] Wang Lilun, Liu Chaohai, Wang Ping. The modern glaciers in Altay Mts.. Journal of Geography, 1985, 40(2): 142-154. (in Chinese)

[4] Zhang Jinghua, Wang Xiaojun, Li Jun. The variations of glacier mass balance of Glacier No. 1 and its relation to climate. Journal of Glaciology and Geocryology, 1984, 6(4): 25-36. (in Chinese)

[5] Wang Lilun. Precipitation in the Altay Mts. China and its influence on glacier development. In: The Second National Glacier Symposium of chinese soliety of Geography. Lanzhou: Gansu People's Publishing House, 1987. 64-71. (in Chinese)

[6] Zhang Wenjing, Wang Ping. The geochemical properties of glacier ice, snow and water in Mt. Namjambawa. Journal of Mountain Research, 1984, 2(2): 155-164. (in Chinese)

[7] Wang Lilun, Wang Ping, Su Zhen. Glaciogeochemical properties in Hengduan Mts.. Journal of Geographical Research, 1989, 8(3): 66-77. (in Chinese)

[8] Wang Ping. Analysis of trace elements in Halasi Glacier in Youyi Peak of Altay Mts.. Journal of Glaciology and Geocryology, 1983, 5(1): 63-70. (in Chinese)
[9] Wu Xiaoling, Song Guoping, Zhang Huixing. Map of glaciers in Mt. Dunde, Qilian Mts.. Xi'an: Xi'an Map Press, 1989. (in Chinese)
[10] Wu Guanghe. Observations of neoglacial moraines in the Qilian Mts.. Journal of Glaciology and Geocryology, 1984, 6(2): 53-59. (in Chinese)
[11] Ren Binghui. Recent fluctuations of existing glaciers in China. In: An Introduction to Glaciers in China. Beijing: Science Press, 1988. 171-186. (in Chinese)
[12] Wang Zongtai. Glaciers and environment during the Little Ice Age in the central section of Tianshan Mts. and Qilian Mts.. Journal of Geography, 1991,46(2):160-168. (in Chinese)