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Assessing The Changes Of The Glaciers In The Karadarya Basin During The Period Of Climate Change

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Abstract. This article analyzes the changes in the existing glaciers in the Karadarya River basin, which begins in the eastern part of the Fergana Valley, from 1970 to 2018 using geographical comparison, historical analysis, and cartographic methods. In particular, the relationship between changes in glaciers on the southwestern slopes of the Fergana Range and the northern slopes of the eastern part of the Aloy Range in the river basin and climate change is assessed. The distribution of existing glaciers in the Karadarya River basin by river tributaries, how many of them have an area larger or smaller than 0.1 km^2, in which tributaries of the river the area of glaciers has decreased or expanded during the studied period, how many glaciers have melted and how many new glaciers have appeared, at what altitude and in what exposure the glaciers undergoing change are located, were analyzed. At the same time, relevant conclusions were drawn based on the above studies.
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Keywords: Climate change; climate change problem; Fergana Range; Alai Range; mountain slopes; mountain glaciers; climate factors; temperature increase; Karadarya River basin; glacier area; large and small glaciers.

1. Introduction

In recent years, climate change has been causing glaciers to shrink around the world. However, this is not the case everywhere in the world. This is because climate change generally has a negative impact on glacier areas in mountains, but the speed and characteristics of this impact vary significantly across the world's mountainous regions. In particular, the object under study, the glaciers of the Fergana Valley, are affected by this phenomenon due to their location in a closed basin and arid region in the center of the continent. At the same time, climate change also affects the distribution of annual precipitation, which is clearly felt in the continental regions of Central Asia. It should be noted that in recent years, the amount of spring and summer precipitation for the region has been increasing compared to the amount of autumn and winter precipitation. This is reflected in changes in mountain glaciers. Analyses of the increase in precipitation in the region can be found in the research works of Kamolov B.A., Soliev E.A., Soliev I.R. and Kariev M.R. (Kamolov B.A et al., 2017; Soliev E.A. 2021; Kariev M.R. 2024; Turgunov D.M. 2022).

According to UNEP, in recent decades, the surface air temperature has increased by about 0.6 °C, and in mountainous areas by 1.6 °C [1]. True, temperature data for the Central Asian region differ from global trends: the highest temperature increases were recorded in the lowlands, while in mountainous areas, in some cases, even cooling was observed [4]. In the studies of D.M. Turgunov, when analyzing the observation data of the Kamchik meteorological station for 1971-2020, it was noted that the air temperature decreased by 0.1 °C to 1.2 °C in January, July, August, September and December. However, the fact of a regular increase in the average annual surface air temperature is not in dispute. Therefore, it is important to comprehensively study changes in glacier area under climate change conditions and assess the impact of climatic factors on changes in their area.

The main purpose of the research work is to determine the changes in the glaciers located on the southwestern slopes of the Fergana Range and the northern slopes of the eastern part of the Aloy Range during the climatic period. To achieve this goal, the following tasks have been set:

1) study the distribution of glaciers along the tributaries of the object and assess changes in them;

2) determine the number of glaciers with an area of more than and less than 0.1 km^2 in the object and changes in them.

2. Material and Methods

In this article, changes in their areas are analyzed using geographical comparison, historical analysis, and cartographic methods based on data from 1970 and 2018.

3. Results

The Karadarya is formed by the confluence of the Tor and Karagulja rivers, which originate in the Fergana Range. The river basin contains numerous glaciers. Glaciers are mainly located along the southwestern slopes of the Fergana Range and the northern slopes of the eastern part of the Aloy Range (Fig.1). The data analyzed were taken from the 1970 glacier catalog [3] and the Central Asian Institute of Practical Earth Research data published in 2018 [2]. In the article, to avoid unnecessary numerical repetitions, glaciers with an area greater than 0.1 km^2 and smaller than 0.1 km^2 are referred to as “large” and “small” glaciers.

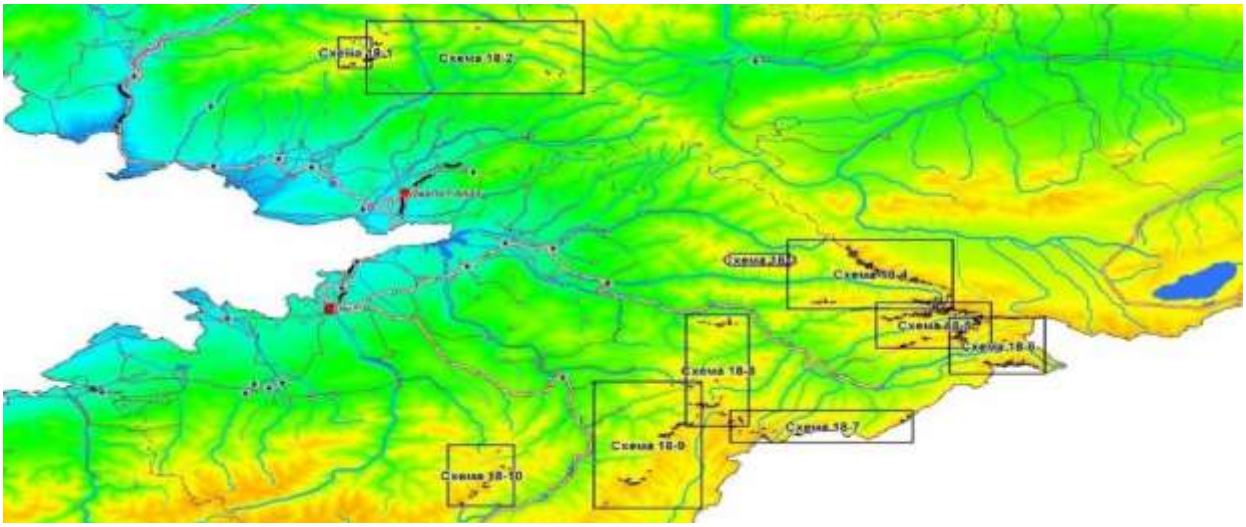

Figure - 1. Map of mountain glaciers in the Karadarya basin. Scheme 18.1 – Moylisuv River Basin. Scheme 18.2 – Karaungur and Kugart River Basins. Scheme 18.3 – Yassi River Basin. Scheme 18.4 – Karagulja River Basin. Scheme 18.5 – Kulun and Terek River Basins. Schemes 18.6 and 18.7 – Alayku River Basin. Scheme 18.8 – Oytol and Tor River Basins. Scheme 18.9 and 18.10 – Kurshab River Basin.

At the beginning of the last quarter of the last century - according to the analysis of 1970, there were 411 glaciers in the Karadarya basin with a total area of 113.5 km^2 (Table 1). Of these, about 72 percent (295 glaciers) had an area larger than 0.1 km^2, and 28 percent (116 glaciers) had an area smaller than 0.1 km^2. Almost half a century later, by 2018, the number of these glaciers had increased by 73 to 484 (Fig. 2). However, a slight decrease in the total area of glaciers is noticeable. For example, their area has not decreased much compared to the previous period (it has decreased by 0.2 km^2). Although the number of glaciers has increased, the slight decrease in their area has occurred due to the disintegration of larger glaciers and the emergence of new ones.

Indeed, while in 1970 there were 295 large glaciers, in 2018 they decreased by 37 to 258 (53%). As a result, the number of small glaciers has increased by 110 to 226 (47%). In particular, in the Karaungur River basin, 2 large glaciers (№ 9 and № 14) have shrunk, and 2 new large glaciers (№ 15-1 and № 19-1) have appeared; in the Yassi River basin, 3 large glaciers (№ 24, № 29 and № 40) have shrunk, and 1 new large glacier (№ 39-1); in the Karagolja River basin, 4 large glaciers (№ 59, № 81, № 85 and № 86) have shrunk, and 5 new large glaciers (№ 43-1, № 70-1, № 71-1, № 72-1 and № 84-1) have appeared; in the Tasryksay and Kulun River basins, 2 large glaciers (№ 87 and № 91) have shrunk; in the Terek River basin, 4 large glaciers (№ 130, № 134), № 142 and № 143) have shrunk and 1 new large glacier (№ 137-1) has appeared, in the basin of the left unnamed tributaries of the Tor River 23 large glaciers (№ 152, № 162, № 163, № 164, № 172, № 182, № 185, № 187, № 188, № 189, № 190, № 191, № 193, № 194, № 195, № 196, № 199, № 200, № 203, № 204, № 206, № 210 and № 213) have shrunk and 4 new large glaciers (№ 174-1, № 174-2, № 174-3, № 186-1) have appeared, in the basin of the left unnamed tributaries of the Tor River 1 new large glacier (№ 243-1) has appeared, 9 large glaciers (№ 249, № 251, № 268, № 269, № 271, № 279, № 285,

№ 286 and № 289) have shrunk and 5 new large glaciers (№ 274-1, № 277-1, № 284-1, № 291-1 and № 294-1) have appeared in the Kurshab River basin.

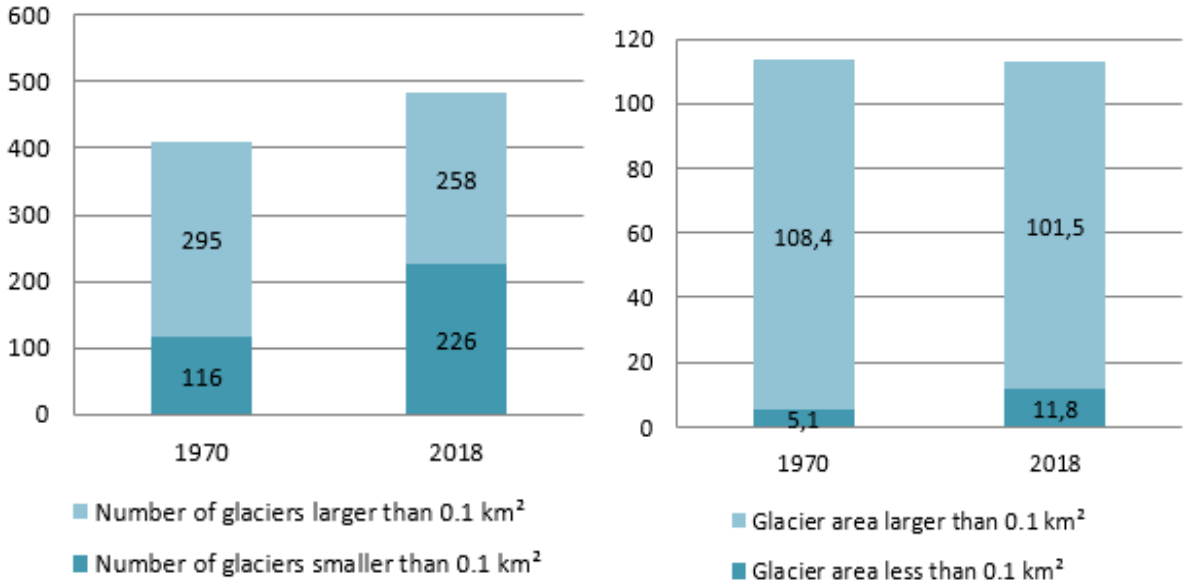

Figure 2. Changes in the number and area of mountain glaciers in the Karadarya basin between 1970 and 2018

In order to determine how the above changes are occurring in the river basins, each river basin was analyzed separately. For example, in the Moylisuv river basin, according to calculations for 1970-2018, the number of large glaciers (8) and their area (2.9 km^2) remained the same. However, there are changes in small ones. In particular, in 1970, the number of small glaciers was 5, but in the subsequent period they reached 10. Accordingly, their area also increased from 0.3 km^2 to 0.6 km^2 (Table 1).

A similar trend of increase can be seen in the Karaungur River Basin. For example, in 1970, the number of large glaciers was 11 and their area was 3.3 km^2, while by 2018 their number had not changed, and their area had increased by 0.4 km^2 to 3.7 km^2. When analyzing small glaciers in the Karaungur River Basin, their number increased from 4 to 21 between the two periods; their area increased from 0.1 km^2 to 1.0 km^2.

Table 1. Mountain glaciers located in the Karadarya basin

River names	[2] source data				Total		[3] source data				Total	
	glaciers with an area of more than 0.1 km²		glaciers with an area of less than 0.1 km²				glaciers with an area of more than 0.1 km²		glaciers with an area of less than 0.1 km²			
	number	area	number	area	number	area	number	area	number	area	number	area
Moylisu	8	2,9	10	0,6	18	3,5	8	2,9	5	0,3	13	3,2
Karaungur	11	3,7	21	1	32	4,7	11	3,3	4	0,1	15	3,4
Kogart	1	0,1	1	0,1	2	0,1	1	0,2	-	-	1	0,2
Yassi	20	4,2	6	0,3	26	4,5	22	4,3	2	0,1	24	4,4
Karagolja	45	24,7	37	2,2	82	26,9	44	22,6	18	0,9	62	23,5
Tasryksay	3	0,7	3	0,2	6	0,9	4	0,8	-	-	4	0,8
Kulun	16	9	11	0,5	27	9,5	17	9,5	4	0,2	21	9,7

Terek	41	21,2	14	0,8	55	22	44	22,8	9	0,4	53	23,2
Alayku	45	14,2	31	1,6	76	15,8	64	18,4	14	0,6	78	19
Oytol	18	5	31	1,6	49	6,6	27	7,9	22	1	49	8,9
The left unnamed tributaries	7	1,9	1	0,1	8	2	6	1,4	1	0,1	7	1,4
Total for the Tor River Basin	130	52	91	4,8	221	56,8	162	60,8	50	2,2	212	63
Kurshab	43	13,9	60	2,9	103	16,8	47	14,3	37	1,5	84	15,8
Total for the Karadarya basin	**258**	**101,5**	**226**	**11,8**	**484**	**113,3**	**295**	**108,4**	**116**	**5,1**	**411**	**113,5**

However, this process is not the same everywhere. For example, in the Kogart River basin, there was only one large glacier in 1970, and the number did not change in the next year of analysis. At first glance, it seems that the area has halved, from 0.2 km^2 to 0.1 km^2. In fact, the large glacier has split into two, forming smaller glaciers.

When analyzing the glaciers in the Yassi River basin, in 1970 the number of large glaciers was 22, and their total area was 4.3 km^2. However, by 2018, their number had decreased to 20, and their area had also slightly decreased to 4.2 km^2. The number of small glaciers in the same river basin was 2 in 1970, but in the subsequent period it reached 6.

The change in the total area increased from 0.1 km^2 to 0.3 km^2. It is clear from this that the number and area of large glaciers in the river basin is decreasing, while the number and area of small glaciers are increasing. To be more precise, it can be seen that the number of small glaciers has increased to 4, and their area has increased by 0.2 km^2.

The number of large glaciers in the Karagölja River Basin was 44 (22.6 km^2) in 1970, but after half a century it increased by one to 45 (24.7 km^2). The number of small glaciers in this river basin doubled, from 18 to 37. Their area also expanded by 1.3 km^2 This process, as mentioned above, can be explained by the increasing amount of precipitation in these regions.

The decline in large glaciers in the Tasryksay River basin is noticeable. In particular, their number has decreased by one, from 4 (1970) to 3 (2018). Their area has also decreased by 0.1 km^2, from 0.8 km^2 to 0.7 km^2 On the contrary, if in 1970 there were no small glaciers, then by 2018, 3 new glaciers with an area of 0.2 km^2 were formed. This shows that larger glaciers have broken up and formed new ones, and as a result of glaciological conditions, small glaciers have gradually expanded.

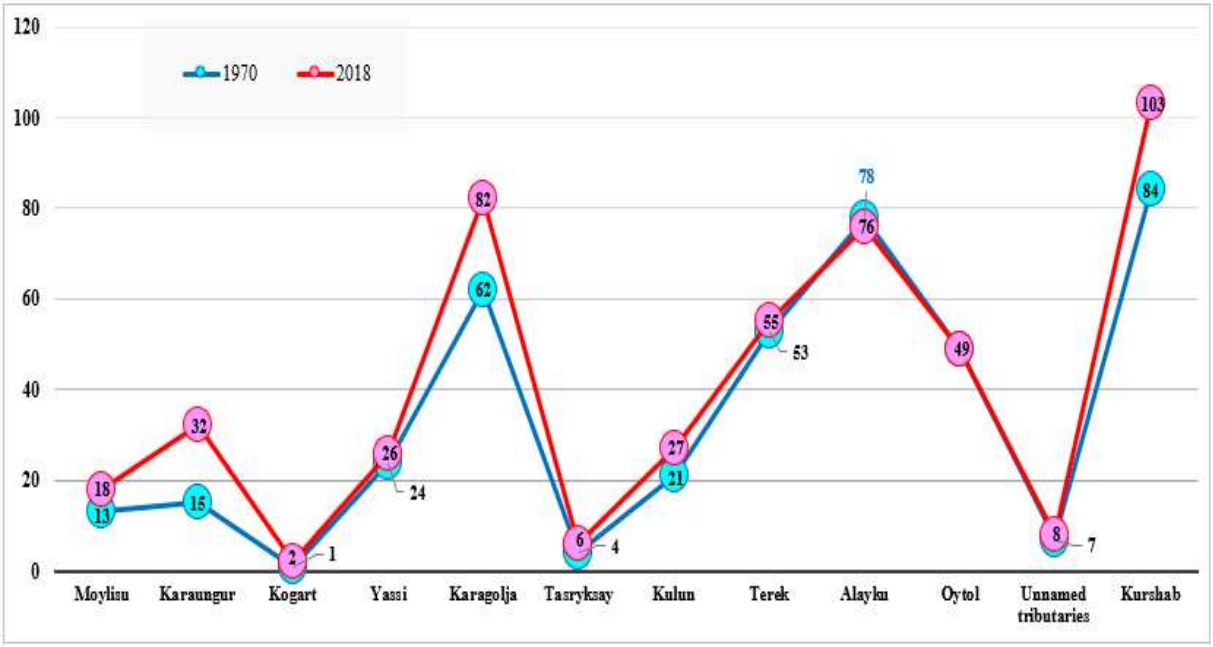

Figure - 3. Total number of glaciers in the Karadarya basin for two periods

A similar process is observed in the Kulun River basin. For example, in 1970, there were 17 large glaciers with a total area of 9.5 km^2, but in the subsequent period their area decreased by 0.5 km^2 and their number decreased by one. As a result of the division of larger glaciers into smaller ones, the number of glaciers with an area of less than 0.1 km^2 increased from 3 to 11 during the two analyzed periods. Their area also increased by 0.3 km^2 From this, it can be concluded that the number and area of large glaciers in this basin is decreasing, while small glaciers are increasing.

Changes in the area and number of glaciers are directly related to their geographical location. Depending on the location of the mountain range and the influence of climatic changes, large glaciers in some ranges shrink and small glaciers increase, or vice versa. The situation in the Tasryksay and Kulun river basins is also similar for the Terek River basin since it is located in the Fergana Range, particularly its southwestern slopes. That is, in 1970, the area of large glaciers was 22.8 km^2, with a number of 44, but after half a century their number decreased by three and their area by 1.6 km^2. As a result of the disintegration of large ones and the formation of new ones, the number of small glaciers increased from 9 to 14. Their area also almost doubled (Table 1).

When analyzing the glaciers in the Alayku River Basin, in 1970 the number of large glaciers was 64, and their area was 18.4 km^2. However, climate change has had a significant negative impact on the large glaciers of this region. In particular, their number has decreased by 30%, and their total area has also decreased by 20%. As noted earlier, the number of small glaciers has doubled after this process, from 14 to 31. As a result of the increase in number, the area of small glaciers has changed from 0.6 km^2 in 1970 to 1.6 km^2 in 2018.

The fate of glaciers in the Oytol River basin is similar to the above-mentioned change processes. For example, in 1970, the number of glaciers with an area larger than 0.1 km^2 was 27 (7.9 km^2), decreasing to 9 (5.0 km^2) in 2018. On the contrary, the number of small glaciers increased from 22 (1.0 km^2) to 31 (1.6 km^2). It is clear that during the two analyzed periods, the area of large glaciers decreased by 2.9 km^2; the area of small glaciers expanded by 0.6 km^2.

Due to the geographical location and climatic conditions, the large glaciers in the basin of the left unnamed tributaries of the Tor River, which originate from the northern slopes of the Chakantosh Mountains, are showing an expansion process. After all, in 1970, 6 large glaciers with an area of 1.4 km^2 were recorded. Analysis in 2018 shows that these indications are 0.5 km^2 larger and one more in number. In 1970, there was only 1 small glacier with an area of 0.1 km^2. In subsequent years, there have been almost no changes in it.

When analyzing the total number of glaciers in the basin of the Tor River, one of the largest tributaries of the Karadarya, in 1970 the number of large glaciers was 162, and their area was 60.8 km^2. According to 2018 data, their number decreased by 32, and their area also decreased by 8.8 km^2. Small glaciers in this river basin increased from 50 to 91. They expanded almost twice in terms of area.

When analyzing glaciers in the Kurshab River basin, in 1970 the number of large glaciers was 47, and their area was 14.3 km^2. In the subsequent analytical period, their number decreased by 4, and their area also decreased by 0.4 km^2. However, the number of small glaciers increased from 37 (1.5 km^2) to 60 (2.9 km^2). Thus, according to the

records of glaciers in this basin for 1970-2018, the larger glaciers decreased, and the smaller ones almost doubled.

When analyzing the total number of glaciers in the Karadarya basin, in 1970 there were 295 large glaciers with an area of 108.4 km^2. By 2018, the number of such glaciers was 258 with an area of 101.5 km^2. While the number of small glaciers in the same river basin was 116 with an area of 5.1 km^2 in 1970, by 2018 the number of such glaciers had increased to 226 with an area of 11.8 km^2. It is clear from this that the number and area of large glaciers in Karadarya basin is decreasing, while the number and area of small glaciers are increasing. To be more precise, the number of large glaciers has decreased by 37 and their area has decreased by 6.9 km^2. It can be seen that the number of small glaciers has increased by 110, and their area has increased by 6.7 km^2.

From the above analysis, it can be seen that between 1970 and 2018, the area of glaciers in the Karadarya basin remained almost unchanged, decreasing by 0.2 km^2, but their number increased by 73. In the Karadarya basin, a decrease in the area of glaciers was observed in the Kogart, Kulun, Terek, Alayku, Oytol, and Tor river basins, while an increase in the area of glaciers was observed in the Moylisu, Karaungur, Yassi, Karagulja, Tasryksay, the left unnamed tributaries of the Tor River, and Kurshab.

When analyzing the increase in the area of glaciers in the Karadarya basin for large glaciers, the increase was observed in the basins of the Karaungur, Karagulja, and the left unnamed tributaries of the Tor River.

When analyzing the reduction of the area of glaciers in the Karadarya basin for large glaciers, the reduction was observed in the basins of such rivers as Kogart, Yassi, Tasryksay, Kulun, Terek, Alayku, Oytol, Tor and Kurshab. This reduction is especially active in the basins of the Kogart, Tor, Oytol, Alayku and Tasryksay rivers. In particular, the glaciers in the Kogart river basin in 1970 were reduced by half by 2018. This situation is also relatively rapid in the basins of the Oytol and Alayku rivers. However, the reduction of the area of large glaciers in the Yassi, Kulun, Terek and Kurshab river basins is slower. Their area decreased by only 4.2 percent during the analyzed period. This reduction does not differ much from the general trend of changes in the area of mountain glaciers.

When analyzing the increase in the area of glaciers in the Karadarya basin for small glaciers, growth indicators were observed in the basins of almost all rivers included in the Karadarya basin. Only in the basins of the left unnamed tributaries of the Tor River, no changes were observed (Table 2).

The reduction in the total area of glaciers is occurring more rapidly in the Kogart, Alayku, and Oytol basins. The area of glaciers in these river basins decreased by an average of 31% or more in 2018 compared to 1970. These indicators indicate that the area of glaciers in the Kogart, Alayku, and Oytol river basins decreased by an average of about 0.7% per year between 1970 and 2018.

Table 2. Change in glacier area in 2018 compared to 1970

№	River basins with glaciers	Change in glacier area in 2018 compared to 1970					
		Total glaciers		Glaciers larger than 0.1 km²		Glaciers smaller than 0.1 km²	
		km²	%	km²	%	km²	%
1.	Moylisu River Basin	0,3	9,37	0	0,00	0,3	9,38
2.	The Karaungur River Basin	1,3	38,24	0,4	11,76	0,9	26,47
3.	The Kugart River Basin	-0,1	-50,00	-0,1	-50,00	0,1	50,00
4.	The Yassi River Basin	0,1	2,27	-0,1	-2,27	0,2	4,55
5.	The Karaganda River Basin	3,4	14,47	2,1	8,94	1,3	5,53
6.	The Tasryksay River Basin	0,1	12,50	-0,1	-12,50	0,2	25,00
7.	The Kulun River Basin	-0,2	-2,06	-0,5	-5,15	0,3	3,09
8.	Terek River Basin	-1,2	-5,17	-1,6	-6,90	0,4	1,72
9.	The Alayku River Basin	-3,2	-16,84	-4,2	-22,11	1	5,26
10.	The Oytol River Basin	-2,3	-25,84	-2,9	-32,58	0,6	6,74
11.	The left unnamed tributaries	0,6	42,86	0,5	35,71	0	0,00
12.	Tor River Basin	-6,2	-9,84	-8,8	-13,97	2,6	4,13
13.	The Kurshab River Basin	1	6,33	-0,4	-2,53	1,4	8,86
Total for the Karadarya basin		-0,2	-0,18	-6,9	-6,08	6,7	5,90

It is also possible to see that the area of small glaciers is increasing in the basins of almost all rivers included

in the Karadarya basin. In particular, in the basins of the Karaungur, Kogart and Tasryksay rivers, the area of small glaciers has increased by 33.8% between 1970 and 2018. The area of small glaciers in the remaining rivers is increasing by an average of 4.9%. The increase in the area of small glaciers in the basins of these rivers may be associated with the reduction of the area of large glaciers and the location of the glaciers. Because the number of large glaciers is decreasing in some of the river basins analyzed. This, in turn, indicates that large glaciers are breaking up and forming small glaciers.

4. Discussions

Based on the above analysis, the following conclusions can be drawn:

— In the Karadarya basin, mainly large glaciers are shrinking. However, this shrinkage is not typical for all rivers. The reason is that in the Moylisuv river basin, the area of large glaciers has not changed; in the basins of the Kogart, Yassi, Tasryksay, Kulun, Terek, Alayku, Oytal and Tor rivers, there is a decrease in the area of large glaciers. An increase in the area of large glaciers in the basins of the left unnamed tributaries of the Tor river, such as Karagolja and Karaungur rivers, was observed. This may be due to the sun-facing slopes of the mountains and the appearance of new glaciers;

— an increase in the number and area of small glaciers is observed in almost all rivers in the Karadarya basin. In particular, the increase in the number and area of small glaciers is rapid in rivers such as Karaongur, Karagolja, Alayku, Tor and Kurshab. This is happening relatively slowly in rivers such as Moylisuv, Kogart, Yassi, Tasryksoy, Kulun, Terek and Oytol. No change in the number and area of glaciers has been observed in the left unnamed tributaries of the Tor River;

— Among the analyzed river basins, the changes in the area of both large and small glaciers in the Karaongur, Karagolja, Tasryksay, Alayku, left unnamed tributaries of the Tor River, and the Tor and Kurshab river basins are particularly noteworthy. While the increase in area was observed in both large and small glaciers, the increase in number mainly corresponds to small glaciers. This increase can be associated with the position of glaciers in the river basin. It should be noted that the glaciers in these river basins are mainly located on slopes facing humid air.

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