GLOFCA PROJECT
«Reducing vulnerabilities of populations in the Central Asia region from glacier lake outburst floods in a changing climate»

Report on task 3 part 1: Preliminary comprehensive analysis of GLOF formation conditions for identified critical lakes in the Ala-Archa River basin based on remote sensing data and available special published data.

and

Report on task 5 part 1: Joint lead-authorship together with UZH on the best practice guidance for mapping hazards and risks in the Ala-Archa river basin (GLOF).

Authors: Erokhin S.A., Chontoev D.T., Zaginaev V.V.

Bishkek 2023

Content

Introduction

The Ala-Archa River valley is one of the most mudflow-prone mountain valleys of the northern Tien Shan. The active formation of debris flows in this valley is caused by several factors, including extensive glaciation, high-mountain outburst prone lakes, deeply dissected relief, significant steepness, high elevation of watershed ridges, and a vast amount of loose clastic material that feeds the debris flows. Therefore, the questions regarding the safety of the Ala-Archa Valley area from the impact of floods and debris flows have been and remain highly relevant.

1. The nature of outbursts of moraine-glacial lakes and intraglacial reservoirs in the Ala-Archa River valley

Over the past seventy years, powerful debris flows have shaken the Ala-Archa Valley several times. In 1953, on June 22, there was an outburst of the moraine-glacial lake Tez-Tor. As a result, the outburst flood with a flow rate of up to 50 m^3/sec. rushes into the lower-lying mudflow hot spots of Tez-Tor and Adygene. After charging with clastic material, its flow rate increases up to 400 m^3/sec. (Kroshkin, 1959). The debris flow fronts, reaching heights of 3-4 meters on straight sections and 6-8 meters on bends of the channel, were characterized by exceptional turbulence and wave formation up to 2-2.5 meters high. The flow ejected rocks with noise and roaring sounds, at a distance of more than 5 meters away from the channel. The volume of carried boulders reached 25-30 m^3. The debris flow surged into the Ala-Archa River valley from the side valley of the Adygene River and formed an extensive outflow cone at the mouth of the latter.

It is superimposed on older debris flow deposits, in the composition of which three more age generations are distinguished, indicating the repeated passage of debris flows through the Adygene River valley in the past. One of them blocked the channel of the Ala-Archa River with a temporary dam, the breach of which was catastrophic for the downstream parts of the valley. Not every mountain lake outburst was accompanied by the formation of debris flows. So in June 1988, Lake Tez-Tor filled up again. Its volume reached 150 thousand m^3 (the volume of the lake in 1953 was 80 thousand m^3). The likelihood of a catastrophic outburst was very high. However, the release of water from the lake occurred gradually over a period of 3 days. A flood passed through the valleys of Tez-Tor and Adygene, yet it didn't transform into a debris flow. It caused an increase in the flow of the Ala-Archa River by only 8-10 m^3. A similar gradual release of water from the overflowing basin of Lake Tez-Tor occurred in the first decade of 2019.

Significantly more catastrophic was the outburst of Teztor Lake on July 31, 2012. That outburst drew particular attention to this lake. Lake Tez-Tor belongs to the type of non-stationary lakes, meaning they fill episodically—once every 5-15 years. It filled in the periods 1990 - 1995, 2003-2004 and 2010-2012, 2017-2019, since 1996 and 2001 it filled at 20-30% of its maximum. After the outburst in 2004, the basin of the lake remained dry until 2010. Then its filling began in 2010, 2011 and 2012 (Fig. 1), which continued until August 31, 2012. On that day, the volume of water in the lake reached a critical level. It was about 100 thousand m^3. At 8 a.m., an underground drainage channel located at the bottom of the lake opened, initiating the outburst. The maximum outburst flow rate was 10 m^3/sec. The outburst flow surged towards the mudflow hot spot located downstream in the valley, easily transforming into a debris flow. Its flow rate while moving along the Teztor valley and then along the Adygene valley significantly increased and at the mouth of the Adygene river was about 200 m^3/sec (Fig.2). On the same day at 1:30 p.m., the outburst flow reached Bishkek, passing through it with a maximum flow rate of up to 30 m^3/sec.

At present, the basin of the lake has filled up again. The outburst of the lake is expected in 2024. There's a high probability that the outburst will be catastrophic. Over the past 13 years (after the outburst in 2012), a large amount of loose clastic material has accumulated in the Teztor debris site, which will actively participate in the transformation of the outburst flow into a high-capacity debris flow.

A B

Fig.1. Filling of Lake Teztor: A - in 2011, B - before the outburst of 31.07.2012

Fig. 2. Debris flow following the outburst of Lake Tez-Tor on July 31, 2012, spread across the alluvial fan at the mouth of the Adygene Valley.

An even larger mudflow alluvial fan formed at the mouth of the lateral valley of the Aksai River (see Fig. 3). It is the largest in terms of the volume of carried debris material in the Northern Tien Shan. Its volume is approximately 11600 thousand m^3 (Shatravin, 1978). The middle part of the Aksai Valley represents a substantial mudflow hotspot. Mudflows were recorded here on July 5, 1960, July 29, 1961, August 21, 1965, June 18, 1966, July 13, 24 and 25, 1968, July 24, 1969, July 18 and August 2 1970, July 18 and August 3, 1980, July 21, 2003.

Fig. 3. Extensive mudflow alluvial fan at the mouth of the lateral valley of the Aksai River

The alluvial fan of the Aksai River has been forming over several thousand years. Periods of increased mudflow activity alternated with calm periods when much of the alluvial fan area was covered by spruce forests. Then new powerful mudflows passed through these forest areas, uprooting trees and covering them with a cover of coarse clastic material up to 10 meters thick. The mudflows here were so powerful that they repeatedly blocked the Ala-Archa river bed with temporary dams, the breaches of which were catastrophic for the Ala-Archa Valley. In the center of the cone, thick piles of coarse debris flow material are concentrated.

The reason for the formation of the Aksai mudflows was the outburst of water accumulated in the intraglacial reservoirs of the Ak-Sai glacier (Fig. 4).

Fig. 4. Lakes and intraglacial reservoirs of Aksai

Water releases from the glacier were particularly frequent in the 1960s. In the 70's there was a transformation of its terminus. The glacier reduced in size, resulting in a decrease in the thickness of its renowned icefall, which is connected to the formation of intraglacial reservoirs (see Figure 4). The conditions for accumulation of intraglacial melt water became less favorable. Hence, during the 1980s, 1990s, and the first decade of the 21st century, the Aksai Valley mudflow hotspot remained inactive. The last time its activation was observed was in 2015. In the last 8 years, the Aksai mudflow hotspot remained relatively passive, but a large amount of debris-forming material has accumulated here, which may be unloaded in the coming years.

In the formation of the Aksai alluvial fan, mudflows from the Sharakatma stream valley, a left tributary of the Aksai River, play a role. The last mudflow from the Sharakatma valley was recorded in July 2004.

In 1974 and 1993, there were outbursts of lakes in the upper reaches of the valley of the right tributary of the Ala-Archa River, Top-Karagay (see Fig. 5). During those events, the outburst flows did not transform into mudflows as there were no substantial mudflow hotspots in the Top-Karagay Valley, unlike the Aksai Valley. The mechanism of these outbursts was underground, and the flow rates reached 10-15 m^3/sec.

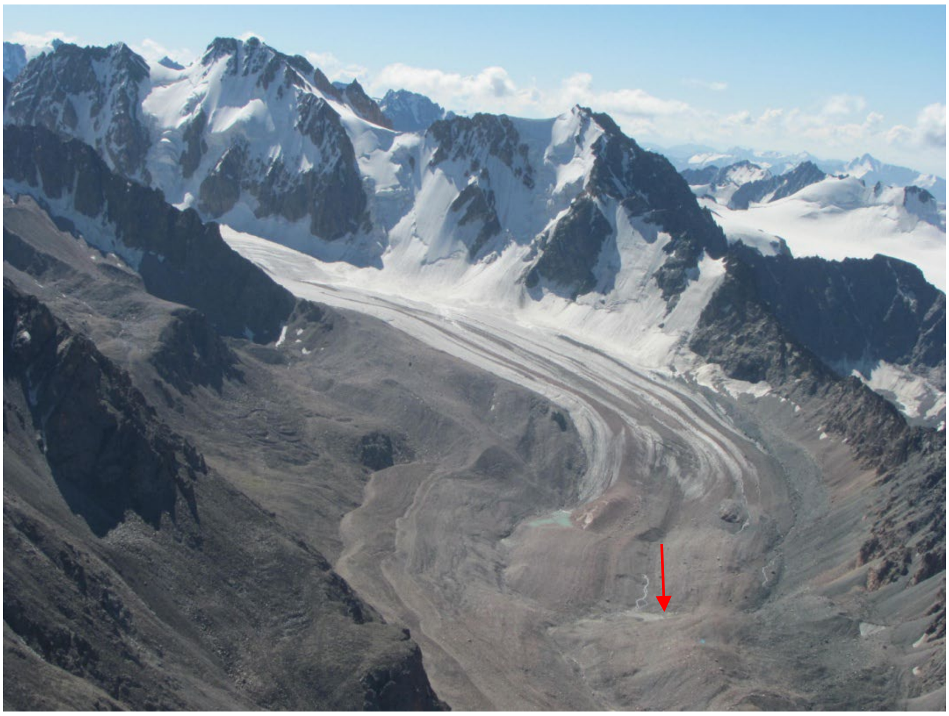

Fig. 5. The basin of Lake Top-Karagai was not filled with water after the outburst of 1993

2. Conditions of mudflow formation in the Ala-Archa river valley. Hazard of formation of mudflow lakes. Types of mudflow catchments

Mudflows and floods originated in the upper reaches of the valleys of nearly every tributary of the Ala-Archa River. They were spilling out onto the bottom of the main valley with the threat of destruction and collapse of its lower sections. The danger increased significantly if the mudflow blocked the channel of the Ala-Archa River. Above the debris blockage, water accumulated, forming a mudflow dammed lake. The lifespan of such lakes is typically measured in hours. As they fill up, the lake level rises above the crest of the debris blockage. Overflow and dam breaches then commence. The water rushes through the breach, creating a powerful flood in the Ala-Archa Valley with catastrophic consequences for the valley's residents.

Apart from the previously mentioned Ala-Archa and Ak-Sai valleys, powerful debris flows capable of obstructing the course of the Ala-Archa River could also occur in the valleys of the lateral tributaries Teke-Tor, and the unnamed tributaries № 5 and № 9 (see Fig. 6). Surveys of the mouth areas of these valleys show that the bed of the Ala-Archa River was blocked by mudflows emanating from them, probably more than once. The last time this occurred at the mouth of valley № 5 was in 1994 or 1995 (a more precise date for this phenomenon could not be determined).

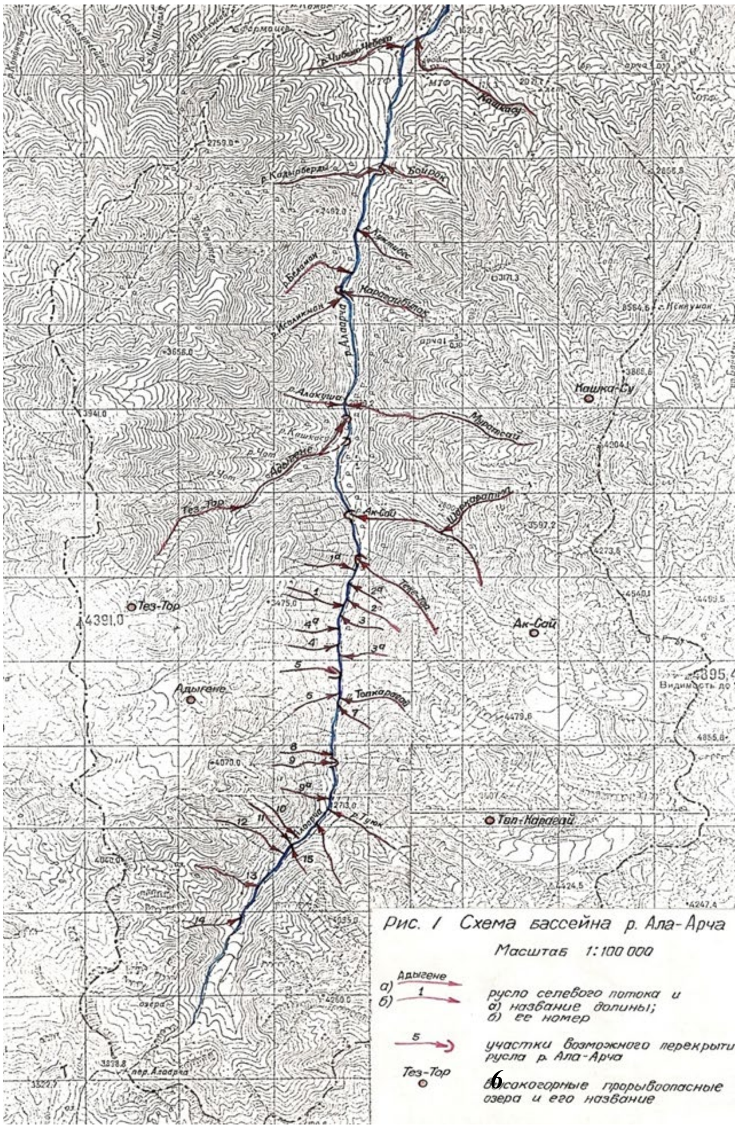

Fig.6. Map of mudflow-hazardous lateral tributaries of the Ala-Archa River

Thus, based on the aforementioned examples of the largest debris flows and floods that occurred in the Ala-Archa Valley in the past, the following conclusion can be drawn. The greatest danger from mudflows and floods in the Ala-Archa River valley occurs when the process of their formation develops according to the following scheme:

1) There is an outburst of a high-altitude lake or an unusually high amount of precipitation;

2) In a lateral valley, a debris flow forms with enough force to block the course of the Ala-Archa River upon reaching the main valley;

3) Above the debris flow barrier, which acts as a dam blocking the Ala-Archa River, a large volume of water accumulates;

4) The debris dam is easily destroyed by the pressure of this water;

5) The dammed-up lake breaks through;

6)A powerful water stream rushes down the valley, catastrophically dangerous for park visitors and residents of the Ala Archa valley.

The valleys of another group of lateral tributaries such as Kashka-Su, Kadyrberdy, Karagaybulak, Top-Karagay, nameless valleys № 4, № 10, № 13, № 14 and № 15 (see Fig. 6) have the potential for the formation of powerful debris flows. Such flows were formed in the Karagai-Bulak and Kashkasu valleys on July 21, 2003 (Figures 6 and 7). Their consequences were catastrophic for residents of dacha settlements located along the Ala-Archa riverbed. In the past, the debris flows from these valleys repeatedly blocked the Ala-Archa Riverbed, that's why the bottom of the main valley has characteristic lake-like expansions above the mouths of these lateral valleys, while opposite these areas, there's a narrowing of the riverbed and a constriction of the valley. The lake-like expansions of the Ala-Archa valley bottom are clearly visible today above the mouths of the lateral valleys of Kadyrberdy, Karagaybulak, Adygene, Aksai, Teke-Tor, № 5, Top-Karagai, № 9, № 10, № 13, and № 15 (see Fig. 8).

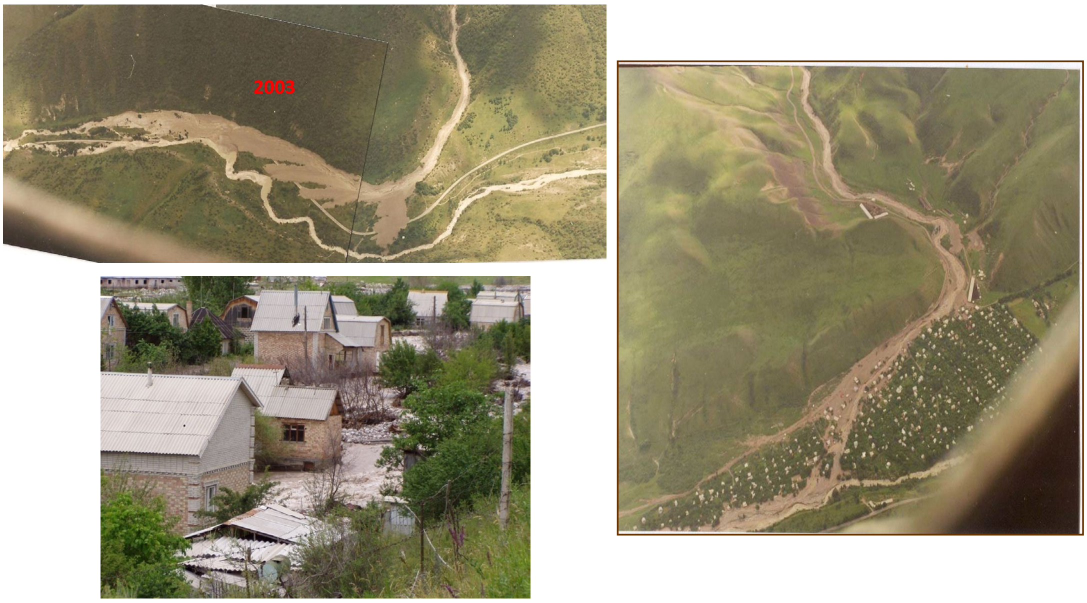

Fig. 7.Debris flows on July 21, 2003 in the Karagai-Bulak and Kashkasu valleys were catastrophic for residents of dacha settlements

Fig. 8. Lake-like expansion of the bottom of the Ala-Archa valley above the Ak-Sai alluvial fan

Finally, the third group of valleys of such lateral tributaries as Chibit, Boirok, Kuntibes, Muratsay, Alakush, Isalikman Tuyuksu, Jindysu forms debris flows of insufficient capacity to block the channel of the Ala-Archa River. This group also includes unnamed valleys with catchment area less than 1 km^2 under numbers 1, 1a, 2, 2a,3, 3a, 4a, 6, 7, 8, 9a, 11, 12 (see Fig. 6).

The magnitude of debris flows is not determined by the catchment area of the lateral valleys. For comparison we give the values of valley areas of different groups. The first group: Adygene-37.9 km^2, Ak-Sai-28.2 km^2, Teke-Tor-3.5 km^2, valley № 5-0.9 km^2, valley № 9-0.7 km^2, valley № 13-2.0 km^2, valley № 14-2.3 km^2. The second group: Kashka-Su-26.0 km^2, Kadyrberdy-20.1 km^2, Karagaybulak-7.7 km^2, Top-Karagay-16.3 km^2, Tuyuksu-14.8 km^2, Jindysu-9.2 km^2 valley № 4-0.8 km^2, valley № 10-1.0 km^2, valley № 13-2.0 km^2, valley № 14-2.3 km^2, valley № 15-0.6 km^2. Valleys of the third group: Chibit (Leskhozny)-6.6 km^2, Boyrok-3.85 km^2, Kuntibes-2.2 km^2, Muratsay-5.9 km^2, Alakush-2.1 km^2, Isalikman-2.3 km^2, Balakhman-2.5 km^2, Tuyuksu-14.8 km^2, Jindysu-9.2 km^2. The above figures show that in each group there are valleys with catchment area from less than 1 km^2 to the first tens of km^2. Consequently, the area of the debris flow catchment is not the main determinant of the valley debris flow hazard.

3. Factors of mudflow formation in the Ala-Archa river valley

The study of the mudflow formation process in mountain valleys showed that:

1) mudflows and floods may form in each mountain valley;

2) The magnitude of debris flows and floods in mountain valleys is determined by the combined action of three factors: 1) presence of debris flow sources in the mountain valley; 2) the possibility of accumulation of a large volume of water in the mountain valley and its subsequent release; 3) the amount of loose clastic material

on the bottoms and sides of the valley and the composition of this material. The first factor is morphological, the second is hydrological, and the third is lithological.

3.1. Morphological factor

A mudflow hotspot is a section of a mountain valley where a water flow can transform into a mudflow. In the Ala-Archa River basin, several dozens of mudflows hotspots were identified and surveyed. Some parameters of the most powerful hotspot areas are provided in the table below. The names of the hotspot areas correspond to the names of the valleys in which they are located.

Table 1

№ п\п	Name of the mudflow hotspot	Upper boundary,m, Нв	Lower boundary,m, Нн	Height, м, Н=Нв-Нн	Length, m			Slope, I= H/L	Coeff. scalability, C=Lск/L
					general, L L=Lсл+Lск	mudflow-forming, Lсл	rocky areas Lск		
1	2	3	4	5	6	7	8	9	10
1	Kashkasuu	3280	2480	800	2325	2092	233	0,34	0,1
2	Boirok	1980	1670	310	1500	1425	75	0,21	0,05
3	Kadyrberdy	3100	1670	1430	7550	6795	755	0,19	0,1
4	Kuntybes	2700	1760	940	2550	2295	255	0,37	0.1
5	Balakhman	2640	1870	770	1850	1757,5	92,5	0,42	0,05
6	Karagaybulak	3200	1920	1280	3700	2960	740	0,35	0,2
7	Isalikman	3100	1880	1220	2500	2125	375	0,49	0,15
8	Muratsai	3600	2020	1580	4700	3995	705	0,34	0,15
9	Alakush	3360	2080	1280	2950	2360	390	0,43	0,2
10	Adygene	2577	2100	477	1500	1425	75	0,32	0,05
11	Tez-Tor	3100	2577	523	1450	1305	145	0,36	0.1
12	Ak-Sai	3200	2880	320	1200	720	480	0,27	0,4
13	Sharkratma	3400	2500	900	2400	1680	720	0,38	0,3
14	Teke-Tor	3200	2280	920	2100	1050	1050	0,44	0,5
15	№4	3200	2500	700	1000	400	600	0,70	0,6
16	№5	3300	2540	760	1100	440	660	0,69	0,6
17	Top-Karagay	3100	2600	500	1250	1188	62	0,40	0,05
18	№9	3440	2740	700	1300	650	650	0,54	0,5
19	Tuyuksu	3100	2710	390	1600	640	960	0,24	0,4
20	Jindysuu	3420	2800	620	1600	1120	480	0,39	0,7
21	№10	3400	2820	580	1000	600	400	0,58	0,4
22	№13	3400	3040	360	970	291	679	0,37	0,3
23	№14	3520	3140	380	810	729	81	0,47	0,1
24	№15	3600	2820	780	1050	945	105	0,74	0,1

The most crucial factors determining debris flow hotspot from the parameters mentioned above are two: 1) the debris flow hotspot length and 2) the slope. When comparing mudflow hotspot zones based on these two parameters, the most hazardous and active among them should be Kashkasu, Kuntubes, Karagaybulak, Isalikman, Muratsai, and Alakush. In fact, mudflow-hazardous and active hotspots aren't solely determined by the maximum values of the mudflow-determining parameters. These include Aksai (Fig. 9), Sharkaratma, Teztor, Teke-Tor and unnamed mudflow hotspots № 5 and № 10. Mudflows in these hotspots are formed much more often than in others, and their power can be so great that they are able to block the channel of the Ala-Archa River with a temporary dam. Consequently, the mudflow hazard of a mountain valley is determined not only by the magnitude of the mudflow hotspot, but also by hydrological and lithological factors. The most significant of these is the hydrological factor. It determines the possibility of formation of powerful water flows in the mountain valley. Lithological factor is also very important. It determines the susceptibility of deposits composing the valley bottom and sides to debris-forming. By deposits, we mean loose clastic materials that accumulate at the bottom of the valley and at the foot of its slopes after destruction by weathering of its bedrock. A well-known mudflow scientist Yu.B.Vinogradov (1980) calls these deposits as potential debris flow material, abbreviated as PDFM. In engineering geology these deposits are defined by the term debris-forming deposits.

3.2. Hydrological factor

The formation of mudflows in a mountain valley depends on three conditions: 1) the active melting of glaciers and snowfields; 2) heavy rainfall; 3) the formation of temporary reservoirs in the valley, either open or closed, accumulating water with its subsequent outburst.

Fig. 9. Debris boulder-stone pavement in the Aksai Valley.

The most powerful debris flows appear in valleys after the outburst of mountain lakes and intraglacial cavities filled with water. In the basin of the Ala-

Archa River, in the upper reaches of the lateral tributary valleys, there are several lake basins, the filling of which can create a hazardous situation of outburst (Fig. 10).

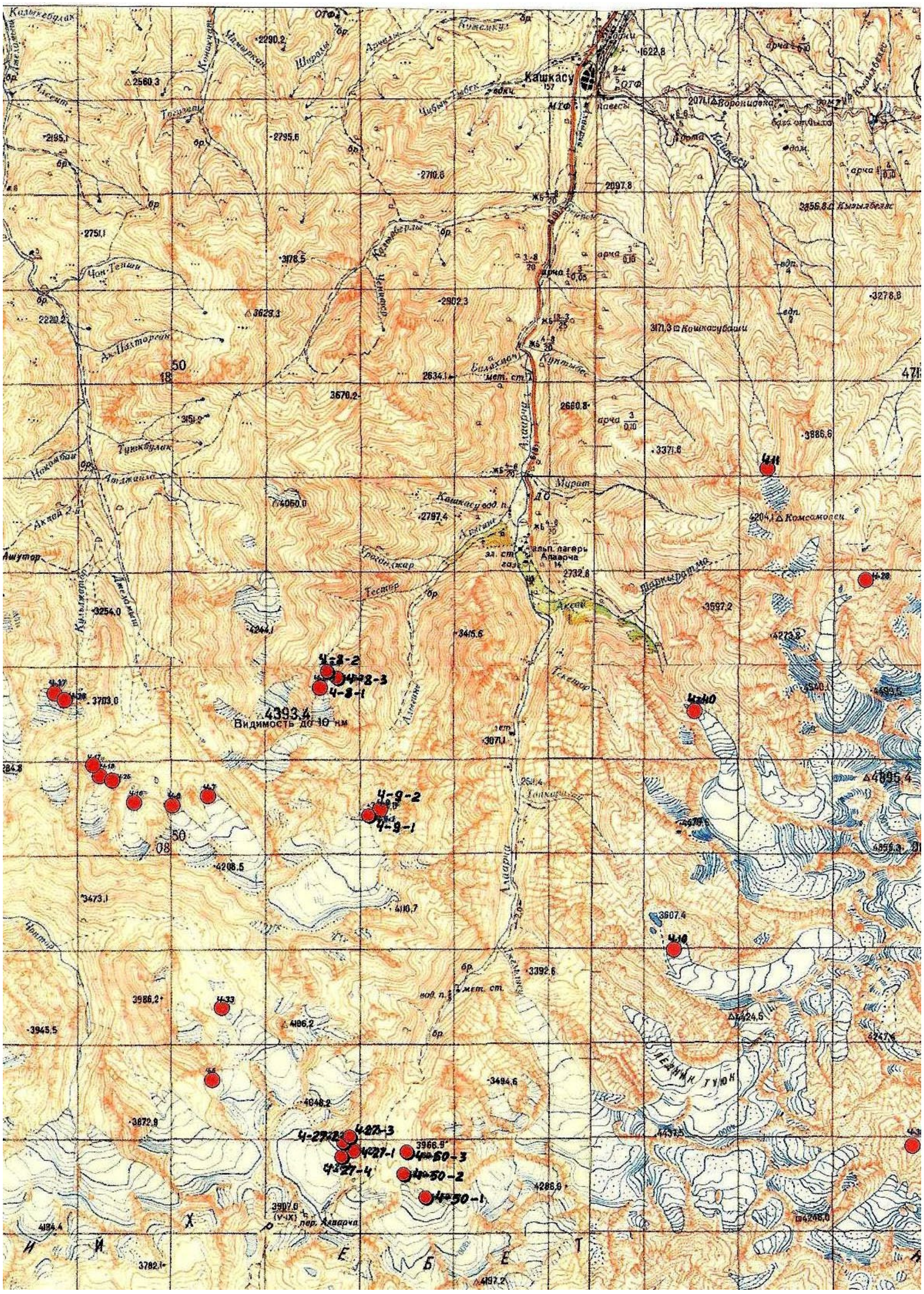

Fig.10. Map-scheme of lakes location in the Ala-Archa river valley

In the past, lake outbursts in the Ala-Archa River valley occurred repeatedly. This is evidenced by the data in Table 2 below.

Table 2

№	Name of lake or intraglacial reservoir	Location	Date of outburst	Water volume, thousand m^3	Outburst flow rate m^3/s	Mudflow rate, m^3/s	Current volume of the lake, thousand m^3	The current risk of lake outburst
1	Kashka-Su	Upper reaches	4.08.75	70	30	40-50	30	insignifica

		of the Kashka-Su valley						nt
2	Top-Karagay	Upper reaches of the Topkaragai valley	10.07.74 7.08.93	130 160	10 5	- -	10	insignificant
3	Tez-Tor	Upper reaches of the Adygene valley	22.06.53 6.08.88 07.2005 31.07.12 6-9.08.19	80 150 60-70 70 60-70	5-8 4-6 2-3 7-8 2-3	200 - - 300 -	40	significant
4	Glacier Lake №234	Upper reaches of the Adygene valley	07. 2010	100	3-4	50-60	1	insignificant
5	Aksai intraglacial reservoir	Ak-Sai Glacier	9.07.61 18.06.66 10.08.68 25.07.69 13.07.75 3.08.80 4.07.2015	- - - - - - -	4 5,5 7,5 5 8 3,6 4	100 260 925 80 120 45 150	1-10	insignificant

Powerful mudflows capable of even blocking the Ala-Archa River channel also form after prolonged rains, torrential rains, and during the active melting of snow piles that accumulate on the bottoms of deep canyon-like valleys. Among the most powerful rain-triggered mudflows in history are the following.

Table 3

№	Name of the side valley	Date of debris flow passage	Debris flow rate, m^3/sec
1	2	3	4
1	Kashkasu	20.07.54 14.07.66 14.06.72 21.07.03	6,9 12 10 60
2	Boirok	27.05.67	0,5
3	Kadyrberdy	14.07.66	3,.3
4	Karagaybulak	14.07.66 21.07.03	2,4 15
5	Muratsay	06.85	3
6	Sharkaratma	06.99	10
7	Valley-4	1994-95	10

8	Valley-5	1994-95	20

Transition (transformation) of the water flow into a mudflow is accompanied by a sharp increase in its discharge. Table 4 below contains data on those rare cases when it was possible to measure the flow rate before and after its transformation into a mudflow.

Table 4

№ п/п	Name of valley	Catchment area, km^2	Date of passage of the mud flow or flood	Flow rate, m^3/sec			Discharge module $l/s\times km^2$	
				max.. long-term	outburst	mud flow	max. Aquatic long term	maximum mudflow 1
1	Teztor -	25,9	22.06.53 6.08.88 31.07.2012	3,5 3,5 3,5	50 25 30	400 - 300	135	15440
2	Adygene	37,9	22.06.53	4,9		220	129	5805
3	Top-Karagai	16,3	10.07.74 7.08.93	2,5 2,5	10 5	15 10	153	920 613
4	Ak-Sai	28,2	18.06.66 10.08.68 18.07.80 3.08.80	5,5	5,5 76 3,3 3,6	70 925 40 45	195	2482 32801 1418 1596
5	Kashkasu	26	4.08.75 14.06.72 14.07.66 20.07.54	3,1		30 10 12 6,9	119	1154 385 462 265
6	Muratsay	5,9	06.85	0,3		3	51	508
7	Kadyrberdy	20,1	14.07.66	1		3,3	50	164
8	Karagaybulak	7,7	14.07.66	0,33		2,4	43	312
9	Boirok	3,85	27.05.67	0,1		0,5	26	130

Table 4 shows that the discharges of outburst and rainfall streams increase tens and hundreds of times when transformed into mudflows. Glacial mudflows, in particular, can be extremely powerful (up to 925 m^3/s). They are capable of moving enormous rock masses measuring 5×4×27 meters and weighing 1400 tons (Fig. 11). Valleys where glacial debris flows occur are characterized by high values of water (119-195) and debris flow (from 920 to 32801 $l/sec\times km^2$) discharge modules. Valleys where mudflows form due to rainfall have significantly lower discharge module values: water - from 50 to 156; debris flow - from 130 to 2308 l/sec×km^2.

Fig. 11. A glacial debris flow in 1968 dragged a huge block measuring 5×4×27m and weighing up to 1400 tons

Thus, in the lateral valleys of the Ala-Archa river basin, there are conditions for two types of mudflow formation: 1) through glacial processes, and 2) due to torrential rainfall. Under these conditions, each of the two primary mudflow-forming factors (hydrological and lithological) manifests in a particular way. So, the hydrological factor in the formation of glacial mudflows manifests in all three forms: 1) outburst; 2) actively melting; 3) torrential. The action of the first two forms is due to the presence of modern glaciers in the valleys. During the formation of torrential mudflows, the effect of the hydrological factor manifests itself in only one form - torrential rainfall. These conditions occur in valleys where there is no modern glaciation. Consequently, modern glaciers play the role of accumulators of significant volumes of water, which are periodically released down the valley in the form of outburst or flood (caused by the melting of snow and ice) flows. As shown by the data in Table 4, their flow rate significantly exceeds that of the rainfall runoff (by tens of times). However, this superiority still does not provide an answer to why the discharge of glacial mudflows can exceed that of rainfall-induced mudflows by hundreds of times. To answer this question, it's necessary to study the influence of the third factor contributing to mudflow formation - lithology.

3.3. Lithological factor

Lithological factors in the process of debris flow formation manifest in two forms:

1) the quantity of loose clastic deposits on the bottom of the mountain valley;

2) the composition of these loose clastic deposits.

Loose clastic deposits are the basis of debris flow-forming deposits (DFD). When surveyed, it was determined that the deposits responsible for debris flow formation are primarily created through the influence of mountain glaciers on rock formations. Under the influence of mountain glaciers, it's not just glacial exaration that occurs, but rather an entire set of processes related to mountain glaciation that aim to erode mountain rocks and transport them to lower parts of mountain valleys.

These processes are referred to as glacial processes. As a result of their action, deep and wide cirques, valleys, and troughs are formed, filled with a thick layer (several tens of meters) of loose-clastic glacial deposits, which serve as the primary source of debris flow-forming material. In the Ala-Archa River basin, the valleys containing thick strata of glacial deposits are characterized by the greatest mudflow activity. These are the Ak-Sai, Adygene, Top-Karagay valleys, valleys № 5, № 10, № 11, № 12, № 13, № 14, № 15. To a lesser extent, these are Teke-Tor, Kashkasu, Jindysu, valleys № 4, № 8, № 9. In these valleys, debris flow hotspots penetrate the layers of glacial deposits, involving them in the process of debris flow formation. This results in debris flows with a discharge of several tens or even hundreds of cubic meters per second. A number of valleys do not contain thick strata of glacial deposits. These are the valleys of Boirok, Kadyrberdy, Karagaibulak, Muratsai, valleys № 1, № 2, № 3, № 7. In these valleys, the sources of debris flow-forming deposits are colluvial and deluvial deposits from mountain slopes, as well as alluvial and proluvial deposits from the bottoms of mountain valleys. The thickness of slope and floodplain-channel deposits is not significant, ranging from 1 to 10-15 meters. Therefore, the formation of debris flows in these valleys is limited. This results in a lower density (1.1-1.3 g/cm^3) of local debris flows and a smaller discharge (up to 10 m^3/s) compared to glacial flows (see tables 3 and 4).

Loose clastic deposits accumulating in mountain valleys are not equally susceptible to mudflow formation. The activity of debris-forming deposits depends on their composition, which is determined by their genesis. Thus, in the process of studying debris-flow forming deposits it was established that the most favorable for their formation are glacial and proluvial deposits, less favorable are slope dealluvial and colluvial deposits, unfavorable are alluvial and alluvial-proluvial deposits. The granulometric analysis of deposits of different genetic types revealed that active debris flows are characterized by an increased content of dusty and clayey particles in the composition of fine grains (fine grains consists of particles with a diameter of less than 10 mm). Thus, in glacial deposits this content reaches 23-24%, and in poorly selective alluvial deposits, it is about 5% (see table 5).

The natural slope angle was used as a criterion for quantitatively assessing the deposit's mudflow-forming activity. This criterion was used to determine the possible saturation of the debris flow with coarse material during its contact with various stratigraphic-genetic types of deposits. In this case, the well-known Takahashi-Bagnold equation (Stepanov, 1985) was used, transformed with respect to the C_T. parameter. C_T is the weight concentration of debris in the mudflow mass. The equation is as follows:

$$C_T = \frac{\rho_0 \times tg\alpha}{(\rho_T - \rho_o) \times (tg\varphi - tg\alpha)} \qquad (1)$$

where ρ_o and ρ_T - density of water and solid component of debris flow mass; for practical calculations it is possible to accept ρ_o= 1,0 g/cm^3; ρ_T= 2,65 g/cm^3;

φ - is the angle of internal friction of loose-clastic sediments under water, deg;

α - Angle of inclination of the base of the mudflow hot spot, deg

The density of debris mass in the flow was determined by the formula:

$$\rho_C = (1 - C_T)\rho_o + C_T\rho_T \qquad (2)$$

The designations in the formula are the same.

The table below presents the calculation results (using formulas (1) and (2)) for the parameters C_T and ρ_c and for the debris flow-forming deposits of the Ak-Sai mudflow hotspot. In this case, the value $tg\alpha$ of is assumed to be equal to the average slope of the mudflow hotspot, which is 0.27 (see Table 1). The content of dusty and clay particles, as well as the angle of internal friction φ of deposits of different genetic types, are provided in the table as the average values from the analysis results of samples taken from the debris flow-forming deposits in the valleys of the Northern Tien Shan Mountains.

Table 5

№	Stratigraphic-genetic complex	Number of samples	Average content of dust and clay particles, %	Average value of the angle of internal friction, deg.	Possible concentration of debris flows	Density of debris flows, g/cm^3
1	2	3	4	5	6	7
1	alluvium Q_{IV}	30	4.7	34	0.41	1.68
2	alluvium Q_{III}	30	8.9	29	0.58	1.96
3	alluvium-proluvium Q_{IV}	36	5.8	32	0.47	1.78
4	alluvium-proluvium Q_{III}	30	4.6	34	0.41	1.68
5	colluvium Q_{IV}	50	6.9	30	0.53	1.87
6	deluvium Q_{IV}	38	5.8	32	0.47	1.78
7	glacial Q_{IV}	60	9.4	28	0.63	2.04
8	glacial Q_{III}	30	24.1	24	0.91	2.50
9	glacial Q_{II}	30	23.9	24	0.91	2.50
10	colluvial-glacial Q_{IV}	30	8.5	29	0.58	1.96
11	proluvial Q_{III-IV}	30	15.8	25	0.82	2.35

The values of debris flow-forming parameters given in Table 5 very clearly indicate that debris flows of high, almost maximum, density (2.50 g/cm^3) are formed during the erosion of glacial deposits of the Middle-Upper Quaternary age. A less active role in debris flow formation is played by modern glacial and proluvial deposits (2.04-2.35 g/cm^3). Even less active are colluvial-glacial and upper Quaternary alluvial deposits. In terms of activity, colluvial deposits are close to them (1.87-1.96 g/cm^3).

Finally, the least debris flow-active are alluvial-proluvial, modern alluvial and deluvial deposits. During the erosion of these deposits, the density of the debris flow suspension will be as low as 1.68-1.78 g/cm^3.

Thus, summarizing the analysis of mudflow formation factors we can conclude the following:

1) the effect of morphological factor is manifested in mountain valleys through mudflow hotspots, the larger the hotspot, the more mudflow-prone the valley;
2) the effect of the hydrological factor manifests itself in three forms:

a) the larger the area of modern glaciers in a mountain valley, the more mudflow-prone the valley is;

b) the more intensive rainfall (showers) in a mountain valley, the more active mudflow processes are;

c) the more opportunities for accumulation of melt and rain water in the form of mountain and intraglacial lakes in the mountain valley, the higher its mudflow hazard;

3) The lithological factor manifests in two forms: a) the more loose clastic material in the mountain valley, the more susceptible it is to mudflows; b) the valley with more active mudflow-forming deposits is more prone to mudflows (the most active mudflow-forming deposits are glacial deposits).

4. Typology of mudflows in the Ala-Archa River valley based on their genesis and magnitude

Mudflow formation factors make it possible to assess the mudflow hazard of each lateral valley within the river basin of the Ala-Archa and explain the reasons behind the formation of mudflows of varying magnitude. Based on the analysis of information about past mudflows, the following conclusions can be drawn.

1. Mudflows of the first type, with a flow rate of several hundred cubic meters per second, are formed in valleys where modern glaciation persists, and where a substantial layer of glacial deposits has accumulated. The cause of such powerful mudflows is the outburst of mountain lakes or intraglacial reservoirs. In this case, the flow rate of the outburst flow exceeds the critical one. Similar mudflow-forming conditions are formed in the Ak-Sai and Adygene valleys. The Kashka-Su and Top-Karagay valleys are becoming similar to them. The danger of debris flows from these valleys is aggravated by the fact that debris flow material can block the Ala-Archa riverbeds with a temporary dam. The subsequent breach of the dam will lead to the formation of a powerful catastrophic flood in the Ala-Archa valley.

2. Mudflows of the second type with a flow rate of several tens of cubic meters per second are formed in the valleys already listed in point 1 during the outbursts of mountain lakes and intraglacial reservoirs. However, the flow rate of the outburst flow does not exceed the critical one. Additionally, mudflows with similar flow rates can occur in small valleys (with a watershed area of 1-5 km^2) where there is a significant concentration of mudflow-forming deposits, including glacial deposits. Modern glaciation in these valleys is expressed insignificantly, either in the form of

small slope glaciers or buried ice. The mudflow process begins with the formation of a water flow. This occurs when heavy rainfall is superimposed on the active snowmelt process. This usually occurs in May-July. As a result, a rather powerful water stream with a flow rate of 5-10 m^3/s is formed. As it moves downhill through the valley, this flow breaks through all the snow-avalanche debris on the valley floor, collects debris-forming deposits, and transforms into a debris flow. When reaching the bottom of the main valley, the debris flow can block the bed of the Ala-Archa River with a temporary dam, and the breach of this dam poses catastrophic risks. Examples of such valleys include Kashkasu, Kadyrberdy, Karagaybulak, Sharkartma, Teke-Tor, № 4, № 5, № 9, and № 10.

3. Debris flows of the third type with a flow rate of several cubic meters per second are formed in valleys where there is no modern glaciation and significant accumulations of mudflow-forming deposits. The extended heavy rainfall ranging from 30 to 80 mm per day (as per the Hydrometeorological Service) is the contributing factor to the mudflows in this area. Similar conditions of mudflow formation are formed in the valleys of Chibit, Boirok, Kuntybes, Muratsay. Mudflows from these valleys do not have sufficient power to cover the Ala-Archa river channel, and therefore are not as dangerous as mudflows of the first and second types.

Conclusion

The following conclusion follows from the analysis of the features of the largest debris flows and floods that have passed in the Ala-Archa valley in the past.

The greatest danger from mudflows and floods in the Ala-Archa River valley occurs when the process of their formation develops according to the following scheme:

1) There is an outburst of a high-altitude lake or an unusually high amount of precipitation;

2) In a lateral valley, a debris flow forms with enough force to block the course of the Ala-Archa River upon reaching the main valley;

3) Above the debris flow barrier, which acts as a dam blocking the Ala-Archa River, a large volume of water accumulates;

4) The debris dam is easily destroyed by the pressure of this water;

5) The dammed-up lake breaks through;

6)A powerful water stream rushes down the valley, catastrophically dangerous for park visitors and residents of the Ala Archa valley.

The magnitude of mudflows and floods in the Ala-Archa Valley is determined by the combined action of three factors:

1) Morphological - the presence of mudflow hotspots in the mountainous valley;

2) hydrological, which determines the possibility of accumulation of a large volume of water in the upper valley and its subsequent release;

3) lithological - the amount and composition of loose clastic material on the valley bottoms and sides.

References

1. Vinogradov Yu. B. Studies on debris flows. Leningrad: Hydrometeoizdat, 1980. - 144 p.

2. Kroshkin A.N. Conditions of Formation and Some Calculative Characteristics of Debris Flows on the Ala-Archa River. Proceedings of the IE and WR of the Kyrgyz SSR, Issue 5 (VIII), Frunze, 1959.

3. SP KR 22-102:2001. Procedure for determining flood and mudflow zones during outbursts of mountain lakes on the territory of the Kyrgyz Republic.

4. Stepanov B. S. Transport-shear and shear-erosive mudflow processes. Mudflows. Coll.9. Gidrometeoizdat, M., 1985, p. 3-16.

5. Shatravin V.I. Report on a specialized survey of the Ak-Sai mudflow source. - Funds of the Hydrometeorological Service of the Kyrgyz Republic. 1978-65 p.