The July 2015 Debris flow in Barsem, Western Pamir (GBAO) Tajikistan: description and causes

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Abstract. Tajikistan is a landlocked country in the Central Asia republics of the former Soviet Union. Tajikistan is prone to many natural disasters. Most commonly in Tajikistan, mudflows occur in the South and North parts of the country. The 2015 Barsem mudflow caused significant damage to the entire village, a territory of the Western Pamir Gorno-Badakhshan Autonomous Region (GBAO), Tajikistan; fortunately, no human casualties. The total volume of debris flow is about 4.9 million m$^3$. Typically, precipitation above 15-20mm per day in arid areas causes mudflow. Accumulated water during the intensive melting of the glacier and snowfields was saturated with water by the moraine sediment blocking its paths (which served as a dam for the lake that formed). Several studies indicate that mudflow triggers excess pore pressure or liquefaction of the soil; consequently, sudden and high shear resistance losses eventually generate a mudflow [5][6]. Although mudflows and landslides occur annually, after the 2015 Barsem mudflow, it becomes clear that the intensity and frequency of new events are increasing. Consequently, the author strongly believes establishing and implementing an early warning system can be essential.

1 Introduction

This article aims to describe potential reasons and geotechnical aspects of the Barsem mudflow in July 2015. Tajikistan is a landlocked country in the Central Asia republics of the former Soviet Union. Barely 10 percent of its territory is suitable for agriculture, and the remaining 90 percent is mountains varying from several hundred meters to 6000-7000 meters above sea level [1].

Tajikistan is prone to many natural disasters, including earthquakes, liquefaction, landslides, mudflow, and avalanches. The primary transportation system between the cities in the country is by roads. Therefore, annual economic loss from mudflow and landslides is growing significantly by thousands of kilometers of road damage, bridges, buildings, and other types of equipment. Especially recently, the last decade, due to climate change and global warming that induces heavy rainfall and glaciers melting. From the perspective of the past, geologists distinguish the main hazard as earthquakes. Thus, more studies in the past focused on earthquake data analysis and damages—however, more studies and investigations are required on mudflow and landslides.

Although landslide hazard analysis has a long history in Central Asia, mainly the earlier publications were in Russian (Fedorenko 1988), eventually stuck around, and were either never published or buried. In addition to that, a large amount of data was stored and never shown due to security requirements. Even if it was published somewhere, most figures were presented without identification, making them almost useless for further studies [2]. Therefore, in this paper author would like to focus on such hazards as mudflow from the geotechnical perspective and as an example of the most extensive and most recent case study, the Barsem 2015.

The increase in rainfall intensities over the past decades and the glacier melting frequency of landslides and mudflows are dramatically increasing. Therefore, for mountain regions like Western Pamir GBAO, it is crucial to implement a monitoring system, as typically, precipitation above 15-20mm per day in arid areas causes mudflow [4].

Fig. 1. Mudflow map of Tajikistan. (Author. N.R.Ischuk 2016).

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Mudflows threaten about 85 percent of the territory, and 32 percent are in the high mudflow risk zone [1]. Figure 1 illustrates “Mudflow hazards and distribution in Tajikistan” on a scale of 1-500,000. The updated map by N.R. Ischuk (2016) and is based on the old maps from Soviet times by Lim et al. (1984) and Tukeev and Uskov (1984).

The existing map was validated through satellite imagery in Google Earth software by further study of the data with Geographic Information system tools N.R. Ischuk (2016).

2 Overview of the disaster

2.1 Location

Village Barsem is located on the right side of Gund river at a distance of 16 km northeastward from the center of Shugnan district (Barkhorog), at the outfall of the Barsemdara gully.

The elevation of the Barsemdara water flow is 2389m above sea level. Inhabitant is located about 90m above the river bed.

Figure 2 is a 3D extracted from a google map image of the Barsem valley in June 2022.

2.2 Weather and precipitation

July is a mild summer month in Barsem with an average temperature of 15.4°C and min 6.3°C.

According to the Navobod hydrometeorological station (Figure 3), the air temperature in July gradually increased from 26°C to 35°C (on July 16, 2015, there was a maximum temperature).

Precipitation was observed only on July 14 in the amount of 1.0 mm. However, rainfall for the rest of the days was July 17.

Additionally, CBC News reported that July 2015 was the hottest day on the Earth. The abnormal temperature increases in all different parts of the world beat the previous global mark.

2.3 Glacier

Pluvial, slope, and glacial deposits represent the upper-quaternary (Figure 4) sediments.

The sediments are composed of boulders’ loose sediments deposited by debris flows. Within the village, the area is composed of alluvial and glacial sediments (pebbles, sand, clay sand) spread in the floodplain and terrace above the floodplain of the Gund river. Boulders and pebble stone materials cover the central and southwestern areas of the village. In addition to that, different constructions cover the surface of the deck.

Snowfields are on the right-hand side of the Barsemdara river (snowfields are an accumulation of permanent snow and ice).

The occultation of four glaciers with an area of 0.23 to 0.37 km² each was observed (Figure 5).

The length of the glaciers is 0.4-1.8 km, including the genuine part of 0.4-1.8 km. The snow line at altitudes of 4.51-4.66 km. Glacial and diluvial deposits are highly water-saturated with meltwater from snowfields and glaciers due to high soil permeability (Figure 5).
Accumulated water got blocked by moraine sediment during the intensive melting of the glacier and snowfields. Consequently, the formation of the dam appeared.

Further water infiltration pierced through the moraine and diluvial scree sediments, increasing suction and loose shear strength. Therefore, the failure surface accumulates, and flexible saturated material collapses. (Figure 6).

Several reasons triggered the current mudflow. First, abnormally high temperatures during July 2015 consequently caused glaciers to melt. Apparently, not within one or two days but for a month or more. Unfortunately, the precipitation of the previous month of 2015 is unavailable. However, considering the mountainous and rainy seasons, from April to May, the author firmly believes that rainfall is high.

The second reason for mudflow triggers an accumulated dam in the upper part of the glacier, followed by soil erosion.

Several studies indicate that mudflow triggers excess pore pressure or liquefaction of the soil; consequently, sudden and high shear resistance losses eventually generate a mudflow [5][6].

Soil consistency is explained by Atterberg limits, i.e., plastic limit (PL) and liquid limit (LL). If the water level is lower than the LL, the soil is in a plastic state, but when the water content is higher, the ground is in a viscous liquid state.

Figure 7 illustrates the Barsem mudflow path. The red circle line is a glacier at the upper part of the mountain. Further on the bottom side is a snowfield.

Thus, it is assumed that loose soil accumulated during sediment transportation and illuviation over a long time under the snowfield.

Eventually, after the ground reached a viscous liquid state and a large amount of the deposits accumulating for several days started failing after the weather got its maximum temperature, causing the melting of the snowfield that worked as a dam collapse.

Figure 8 demonstrates the consequences of the mudflow. Consequently, the only international road for communication between cities and the entire country was destroyed, including residents' houses.

Further, it created an artificial dam immediately after the mudflow, which soon became an additional threat to downstream villages and the city's center for flooding.

The artificial dam created the “Barsemkul” lake with properties of 2300-2400 m in length, a depth of 13-17 m, and an average width of 128 m. Therefore, the approximate volume of water in the lake is

\[ V = (a \times b \times h) = (2400 \times 17 \times 128) = 5222400 \text{ m}^3 \]

Figure 8.
Fig. 8. Mudflow cone formed as a result of a catastrophic mudflow on July 16, 2015 (Focus Humanitarian Assistance takes photos).

The overall properties of the Barsem 2015 mudflow are listed in Table 1.

Table 1. Some properties of the mudflow.

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mudflow area</td>
<td>71.35 km²</td>
</tr>
<tr>
<td>The total volume of solid runoff is 4994540 m³</td>
<td>4994540 m³</td>
</tr>
<tr>
<td>The estimated volume of the involved solid component is 249727 m³</td>
<td>249727 m³</td>
</tr>
<tr>
<td>Mudflow cone area</td>
<td>308479 m²</td>
</tr>
<tr>
<td>The volume of mudflow mass in the alluvial cone - , with an average mudflow cone thickness (h = 5m) is - 1542395</td>
<td>1542395</td>
</tr>
<tr>
<td>Mudflow velocity from</td>
<td>5-12 m/s</td>
</tr>
</tbody>
</table>

Only the event for July related to climate change in the territory of GBAO, the Rasht region, and the Sughd region led to enormous economic damage to the country. In addition, seven mudflows in various areas have been reported only for July 2015.

4 Conclusion

Several factors triggered the region's current and past natural disasters.

First, climate change is considered the main factor in the resurgent natural disaster - the activation of mudflows, the threat of flooding, and flooding in the Pamirs of GBAO, Tajikistan.

Historically and geologically, due to the lack of land in this mountainous region, all the residential areas (villages, towns, and cities), essential facilities, and infrastructure are located on the alluvial fan of the lateral tributaries of the central valleys. Near the floodplain and low floodplain terraces of the main rivers, at the foot of the slope, and on the surface of ancient landslide bodies, which are very vulnerable to natural hazards with local and remote manifestations.

The ongoing climate change event negatively impacts different areas of life - ecosystem, health, agriculture, water management, transport infrastructure, energy, and gender.

Secondly, the most significant reason is a lake of monitoring data and research.

Although mudflows and landslides occur annually, after the 2015 Barsem mudflow, it becomes clear that the intensity and frequency of new events are increasing. However, the author strongly believes establishing and implementing an early warning system can be essential. Consequently, the early warning system is followed by monitoring soil properties, precipitation, and water content.

Prove of climate change-induced Barsem mudflow must be addressed. However, from a geotechnical perspective, increasing water content is followed by an increase in suction during wetting and a decrease during drying casing slope failure. Therefore, a large number of mudflows and landslides can be eliminated by a proper monitoring system.

The current case study of the Barsem mudflow will be helpful in the implementation of the early warning system in future studies, especially for mountainous regions.

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References