Scenarios calculations of outburst flood and debris flows

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Abstract. The modelling results of outburst floods and debris flows, which can possibly occur in the Daraisit River Valley, are presented in this paper. The modelling was carried out according to 2 scenarios: the outburst of Lake Sist, the formation of a debris flow on a large tributary of the Daraisist River. The FLO-2D hydrodynamic model and the modernized transport-shear mudflow model developed by Yu.B. Vinogradov were applied in this study. The evaluation of the outburst flood discharge was carried out on the basis of a bathymetric survey. A digital elevation model (DEM) ALOS PALSAR with a resolution of 12.5 m was used as relief data for the valley, and survey data from an unmanned aerial vehicle (UAV) was applied for the debris flow fan. As a result, maps of the spatial distribution of velocities and depths for the rivers Daraisist and Pyanj were obtained. The most vulnerable areas within the Sist village were also identified.

1. Introduction
Degradation of mountain glaciers in Central Asia leads to the intensive formation of glacial lakes [9]. Many of these lakes are subsequently drained during their dams’ destruction. If the outlet stream has a significant slope, and there is a sufficient amount of friable material, then the lake outburst flood can transform into a debris flow. Direct debris flow damage includes loss of human life, destruction of houses and facilities, damage to roads, rail lines and pipelines, vehicle accidents and many other losses that are difficult to quantify [6]. In terms of debris flows distribution, Tajikistan is among the highest in Central Asia [4]. The study of debris flows in this region began in the 60s of the XX century [2]. The last catastrophic outburst flood and the subsequent debris flows took place in 2002 as a result of the breakthrough of a lake with a water volume of about 250,000 m³ [7,11] in the Dasht River Valley. Assessment of debris flow characteristics using FLO – 2D and RAMMS models is given in [7]. The aim of this study was to assess the possible impact of an outburst flood and debris flow in the Daraisist River Valley.
2. Study area
The Daraisist River is located in the Western Pamir. It is the right tributary of the Panj River and flows into it 743 km from the mouth. The watershed is located on the western macroslope of the Ishkashim ridge. The maximum and minimum elevations are 498 and 689 m, respectively. The length of the river is about 9.8 km with the watershed area of 14.5 km². In the upper reaches, there is Sist tarn lake (area - 18 100 m², average depth - 1.15 m, maximum depth - 3.2 m) [3]. The largest tributary of the Daraisist River is located 7 km from the estuary on the right side. In the upper part of this basin, there is a rock glacier a moraine pedestal and a formed debris flow fan in the lower part. The cliff of moraine pedestal is cut by a mudflow trench. In case of intense precipitation, a debris flow can form in this valley. Significant slopes of the Daraisist River and the presence of friable material will lead to a debris flow descent in the main valley. At the river mouth, there is an alluvial fan with a total area of 0.2 km². The Sist village is located on the fan. Also, along the Panj River, there is a section of the P-845 highway connecting Khorog (the administrative center of Gorno-Badakhshan Autonomous Region) and Ishkashim. A bridge was built at the intersection of the Daraisist River.

3. Material and methods
In this study, the modelling was conducted using a two-dimensional hydrodynamic model FLO-2D software package [8] and a transport-shear debris flow process model [1]. The FLO-2D model was applied for the valley zoning. The software is based on the numerical solution of the Saint-Venant equations (viscoplastic fluid) [8,12]. As the input data for modelling, we used the relief based on the digital elevation model (DEM) ALOS PALSAR with a resolution of 12.5 m. For the fan area, a detailed survey was obtained using a UAV with the resolution of 0.13 m. In the mouth area of the Daraisist River, there were a large number of trees, taking into account the height of which led to the peculiar "embankment" emergence. The use of machine learning methods in Agisoft Photoscan Professional software package allowed us to classify automatically a dense point cloud into different classes. In this case, an automatic classification was carried out for the high vegetation class. When constructing the DTM, all classes were used, except for high vegetation. The initial hydrological data included the hydrographs of the outburst flood and debris flow, as well as the average mean discharge of the Panj River. The modelling was carried out for two scenarios: the outburst of Lake Sist and the formation of a debris flow on the tributary of the Daraisist River. A preliminary assessment of the maximum water discharge during the breakthrough of Lake Sist was carried out on the basis of empirical formulas [5]. The water volume component of the outburst flood was set based on the lake possible volume (20 thousand m³) according to the bathymetric survey data in 2020 [3].

The transport-shear debris flow formation model was chosen as a research tool to calculate the mudflow hydrograph on the Daraisist River tributary. This model is a one-dimensional and is intended for calculating high-density flows. The model was developed by Yu.B. Vinogradov through the Chemolgan experiments data on reproduction of artificial debris flows in nature [10]. It is based on the equations for calculating the debris flow discharge, the increment in solid flow and the density [10]. It is assumed that the increment in the solid flow along the debris flow origination site is directly proportional to the instability coefficient of the PDFB (potential debris flow body), the elementary potential flow capacity and the index of mudflow mass mobility [1,10]. For the debris flow discharge of the forward wave estimation, the flow discharge in the outlet of the origination site was multiplied by a coefficient close to 2.5 in the first approximation [1]. The velocity was determined by the formula for the maximum debris flow velocity proposed by Yu. B. Vinogradov [1]. The time of wave travel was calculated as the distance between the boundaries of the sections divided by the velocity. Currently, the equations of the model are implemented in a computer program in the Python programming language. The initial information included relief data and parameters of PDFB, as well as initial water discharge in the river.

The static and dynamic angles of internal friction of damp rock composing the PDFB were estimated on the basis of CR 425.1325800.2018 “Engineering protection of the territory from erosion processes. Design rules” and studies by Yu.B. Vinogradov [1] and were set as 45° and 25°.
respectively. The average slope of the debris flow origination site was 27.6 °. The modelling was carried out for the case of an avalanche-like development of a debris flow, while the ratio of the water volume to the solid matter volume was 0.2 [1]. Thus, for scenario I, the maximum outburst flood discharge was estimated as 28.2 m³/s. For scenario II, the debris flow discharge of forward wave was equal to 547 m³/s.

4. Results and discussion

According to two scenarios, modelled hydrographs have several peaks. The maximum outburst discharge for I scenario will be 22.4 m³/s, the travel time from the lake to the fan top will be 2.1 h (figure 1). The flow will pass through the fan in 0.1 h. In scenario I, water flood in the Panj River will exceed the average discharge for about 17 m³/s. According to II scenario, the maximum debris flow discharge will be 369 m³/s, the travel time will be 1.3 h, and the flow will pass the fan section within 0.3 h. The water flood in the Panj River will exceed the average discharge by 156 m³/s.

The Daraisist River Valley has significant slopes, the valley bottom is rather narrow, the course width is on average 5 m. According to the results of two scenarios, the maximum depths in narrowing of the Daraisist River Valley can be more than 3-4 m. The flow velocity in many sections exceeds 5 m/s. The maximum flow velocity for I scenario is 13.3 m/s, for II scenario is 17.7 m/s.

According to I scenario, the lake level will be from 1 to 2 m, the Panj River depth will reach 1-4 m. The velocities for the Daraisist River can vary from 1.5 to 5 m/s and even more (figure 2). At the confluence of the Daraisist River and after along the river course Panj velocity will reach 5 m/s. According to this scenario, in the flood prone zone there are several houses at the fan directly adjacent to the road and the bridge over which it passes the P-45 highway connecting Khorog and Ishkashim.

As for scenario II, there will be the overflow, and almost all houses at the debris flow fan located as well as bridge mentioned before will enter flood prone zone. In this case, the depth in the Daraisist River course will vary from 7 to 15 m, in the adjacent territory – 1-10 m. The depth for the Panj River will be 1-8 m. The debris flow velocity in the Daraisist River course will be more than 5 m/s, on the fan will be up to 1.3 m/s, in the Panj River course – up to 7 m/s (figure 2). It is necessary to mention that along the Panj River the flow will spread it out. So, the opposite bank of the Panj River will not enter the flood prone zone in this scenario.
Figure 2. Simulated on the base FLO-2D model flow velocities in the Daraisist River mouth using a UAV high detail digital terrain model.

However, simulated flood prone zones have an estimate nature. In order to identify the most vulnerable objects of infrastructure, it is necessary to conduct complex field studies, where more accurate debris flow parameters will be obtained.

5. Conclusion
The study provides an assessment of the debris flow hazard for the Daraisist River Valley. The modelling was carried out according to two scenarios: I - the outburst of Lake Sist, based on the lake volume in 2020, and II - the formation of a debris flow on the Daraisist River tributary. In this study, we applied the bathymetric survey data of the lake and a detailed survey of the fan using a UAV, carried out in August 2020. The river valley was zoned using the FLO-2D hydrodynamic model. The hydrograph of the lake outburst was obtained using empirical formulas based on the lake volume in August 2020. The debris flow hydrograph for the Daraisist River tributary was obtained using the transport-shear model. For this, the calculation of the flow velocity and the wave travel time was added to the model. The obtained hydrograph was later used in the FLO-2D model. Thus, maps of the spatial distribution of flow velocities and depths were obtained. According to both scenarios, the bridge and the P-45 highway will be in the flood prone zone. At the same time, according to scenario II, practically all houses on the fan will be located in the flood zone.

Acknowledgments
The research was carried out with financial support from the Branch of the Aga Khan Agency for Habitat in the Republic of Tajikistan and the Russian Foundation for Basic Research (projects No. 20-
35-90006), as well as on topic 1.7 “Hazard and risk of natural processes and phenomena” (GZ) of Lomonosov Moscow State University.

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