

The mudflow dynamics of the river Gerkhozhan-Su in the section of the mudflow tray and mudslides protection of the city of Tyrnyauz (Central Caucasus)

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Abstract. Based on the data of route inspection and video surveillance of the mudslides of the river Gerkhozhan-Su have been determined the features of the mudslides dynamics in the section of the mudflow tray. Areas of temporary mud accumulation were revealed, over which waves of mudflow periodically passed. Streams rushed through the tray at a speed of 9-12 m/s. The protective role of the mudflow tray and the need for its timely clearing of the mudflow deposits have been highlighted to ensure the anti-flood safety of the city of Tyrnyauz.

1 Introduction

Gerkhozhan-Su basin is known for catastrophic mudslides that repeatedly caused damage to the city of Tyrnyauz, located in the basin of the river Baksan in Kabardino-Balkaria (Central Caucasus). Mudslides of 1999-2000 were the most destructive (Zaporozhchenko, 2002; Seinova и Zolotarev, 2001; Chernomorets, 2005). In the 21st century mudslides occurred in 2011 and 2017. (Dokukin et al., 2012; Dokukin et al., 2018). The mudflow tray was built to ensure the protection of the city of Tyrnyauz from mudflows, which was reconstructed several times after the destruction. In addition, Mudflow-holding dam was built at the distance of 2.3 km from the mouth in the valley of the river Gerkhozhan-Su, which was destroyed by mudslide in 1999.

Thus, at present, to protect the city of Tyrnyauz from mudflows, there is only one anti-mudflow structure – the mudflow tray, the left wall of which has a length of 720 m, while the right wall is 1325 m long with a gabion extension. The distance between the concrete walls on the site above the road bridge is 30-35 m. The tray widens to 120 m below the bridge. The purpose of this article is examination of the functioning of the mudflow tray during the mudflows of 2011 and 2017.

2 Materials and techniques

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In the examination of mudflow processes in the area of tray, a satellite image from Google Earth (25.08.2018), ground photographs and pictures taken from a helicopter of different years, materials of route surveys, videos from the Internet have been used. Ground photos and video footage of the same areas were linked in ArcGIS program to evaluate changes. Videos of mudflow have been analyzed to record mudslide waves on the different sites of the mudflow tray and to determine mudflow speed. The boundaries of the sections of the mudflow waves displayed in the videos have been identified on the satellite image.

3 Research of the mudflow dynamics features of the river Gerkhozhan-Su on the site of mudflow tray in the city of Tyrnyauz

Based on the analysis of route observations and videos, levels of mudflows and mud deposits in the mudflow tray with velocity of the flows on different sites have been determined.

3.1.Measurement of mudflow velocity according to video data

In the work (Zaporozhchenko, 2002) data of the calculated values of speed and spread of mudflows in the section of the mudflow tray have been presented to evaluate capacity of the tray: in the report of the Novocherkassk Engineering and Land Reclamation Institute, the average speed of the mudflow is 6,05 m/s; according to calculations of mudflow in 1977 by V.A. Gerasimov – 6.9 m/s.

The analysis of data from numerous videos of mudflows on August 14-15, 2017 allowed to assess the velocity of passage of mudslides on different sections of the mudflow tray.

In total, three videos were selected: <https://www.youtube.com/watch?v=K10x70gUd3k>, <https://www.youtube.com/watch?v=df6pIO2eEo8>, <https://www.youtube.com/watch?v=8f6R3W0jflE>, on which the passage of mudflows on three sites of the tray, the boundaries of which can be clearly identified on the satellite image, is recorded to evaluate distance traveled by mudflow (Fig. 1)

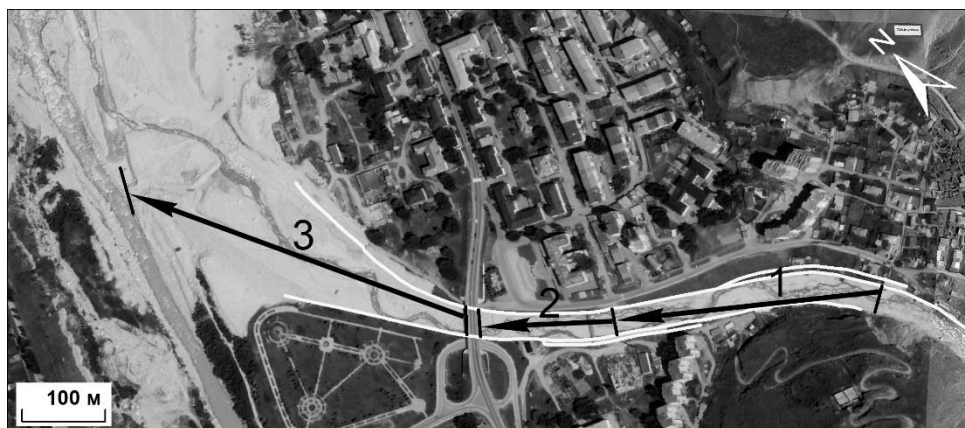


Fig. 1. Sections of mudslide's velocity measurement in the mudflow tray on the satellite photograph 25.08.2018

Results of mudslides speed measurement on sections of mudflow tray are presented in the table.

Table 1. Speed of mudflow on sections of the mudflow tray

<i>№ of section</i>	<i>Distance[m]</i>	<i>Time [s]</i>	<i>Speed [m/s]</i>
1	325	31	10.5
2	160	13	12.3
3	540	55	9.8
3	540	48	11.3

The data in the table shows that the measured mudflow speed is almost twice the estimated one. But this doesn't mean that the calculated data of the mudflow spread should be doubled. Analysis of the video clips and survey materials allowed to reveal the features of the dynamics of mudflows in the sections of the tray, which should be taken into account in calculations and measurements of the mudflows path.

3.2.Features of mudflow dynamics in sections of the mudflow tray

The examination of photographs of different years on sections of the tray before and after mudflows allowed us to identify differences in the dynamics of mudflows. In fig. 2 the upper part of section №1 of the tray before and after the mudflows of 2011 and 2017 is shown. (See fig. 1).

Fig. 2 shows that the level of mud deposits in the tray after the mudflows of 03.08.2011 and 15.08.2017 was almost the same. The marks of passing mudflows on the walls of the tray were at the same level. It can be concluded that mudflow spread in this section was the same, and the height of mud waves was up to 1.5 - 2.0 m. The mudflows passed this section in transit mode. Only closer to the middle of the area at the bottom of the tray a temporary deposition of mud occurred, and the level of marks from mudslides on the walls of the tray became higher.

The video data (<https://www.youtube.com/watch?v=Kl0x70gUd3k>) indicates that the deposits of mud did not exit the liquid phase and was just a mudflow that stopped for a while. The following mudflow waves streak its surface and set in motion the deposited mud. It sways, but remains in place. Subsequently, by the end of the mudflow process, the temporary deposited mud is carried away from the tray by the post-mudflow flood or by an even more powerful mud wave.

In fig. 3 a part of the pedestrian bridge across the mudflow tray (the end of section №1) is shown. From the comparison of photographs and video footage, several conclusions can be made:

- 1) the level of mud deposit in the tray under the bridge after the mudslide on August 3, 2011 (fragment *b*) had increased by 1.5 m;
- 2) after the mudflows on August 14-15, 2017, the level of mud deposits had increased by another 1.5 m (fragment *e*);
- 3) before the destruction of the pedestrian bridge, the thickness of mud deposit was 4.0 m and gap of 1.0 m remained under the bridge (fragment *c*);
- 4) the mudslide, which destroyed the bridge, swept through previously accumulated mud and was 1.5 m high (fragment *d*);
- 5) at the end of mudflow, the level of mud in the tray had lowered by 2.5 m (fragment *e*).

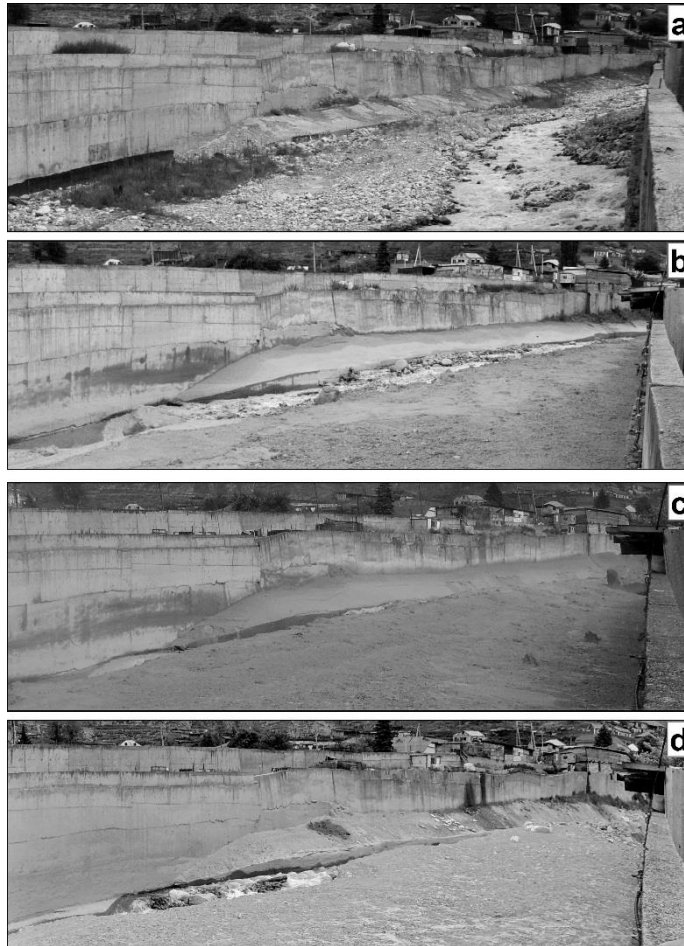


Fig. 2. Condition of the upper section of the tray before and after mudslides:
a – 11.08.2010, *b* – 03.08.2011, *c* – 15.08.2017, *d* – 09.06.2018

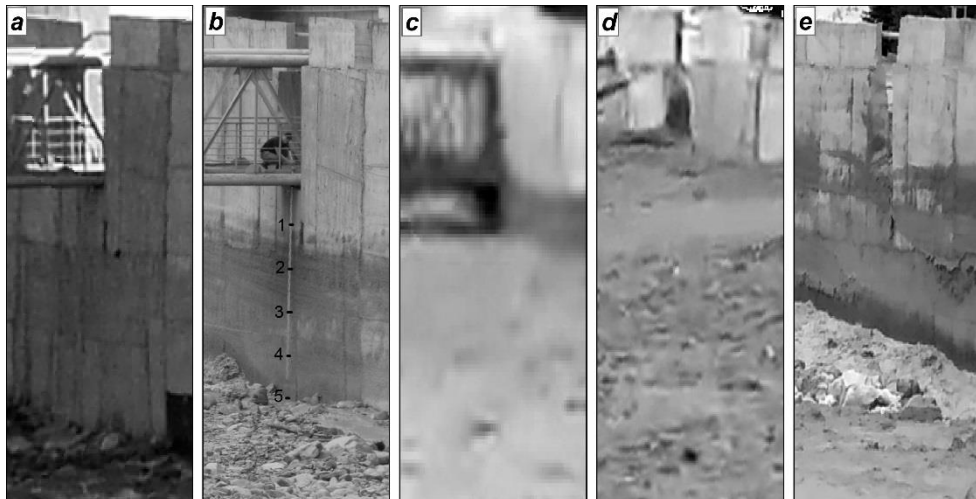


Fig. 3. The right wall of the mudflow tray on the section of the pedestrian bridge:

a - 28.06.2008, *b* - 04.08.2011, *c* - 14.08. 2017 before the destruction of the bridge by mudflow, *d* - 14.08. 2017 at the time of the destruction of the bridge, *e* – 15.08.2017 (*a*, *b*, *e* - photo by M.D. Dokukin, *c*, *d* - frames of the video)

Thus, after each mudflow (according to mudflows of 2011 and 2017) on the end of section №1 of the mudflow tray (see. fig. 1), thickness of the mud deposits increases by 1.5 m. Mud also accumulates in the section №2 of the tray. Part of this section after the mudflow of 2011 and after clearing of the mud deposits (the sediment level is decreased by 2.0 m) is shown in the fig. 4.



Fig. 4. Left wall of the mudflow tray in the middle of section №2: *a* – 04.08.2011, *b* – 31.07.2014 (photographs by M.D. Dokukin, view from pedestrian bridge)

After the mudflows of 2017 in the section of the tray, pictured in fig. 4, the thickness of mud deposits increased a little more after the mudslide of 2011 (fig. 5).



Fig. 5. Section of the mudflow tray with mud deposits 2017 (photo by M.D. Dokukin 22.08.2017)

Due to the fact that the mud mass was deposited in the tray, mudflows with a relatively low front in 2017, by hitting the transverse projection, overflowed through the wall of the tray in the area shown in fig. 5.

4 Conclusions

The research of mudflow dynamics of 2011 and 2017 of the river Gerkhozhan-Su in the section of the mudflow tray in the city of Tyrnyauz allowed to draw the following conclusions:

- 1) the height of the mud waves mainly doesn't exceeds 1.5-2.0 m;
- 2) the speed of mudflow can reach 12 m/s and more;
- 3) the mud mass can temporary accumulate in the mudflow tray by a layer of up to 4 m and higher and later be involved in the mudslide process again;
- 4) mud waves by moving along the surface of temporary accumulated mud can reach the height of the tray's walls and overflow through it;
- 5) with each mudslide (data of mudflows of 2011 and 2017) thickness of deposited mud in the tray in the section above the road bridge increases by 1.5-2.0 m;
- 6) to ensure the protection from the mudflows it is required to timely remove from the mudflow tray deposited mud after each mudflow in every section of the tray.

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