UAV Survey for Landslide Hazard Assessment in the Former Min-Kush Uranium Processing Site

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Abstract

In March 2013 a large landslide of almost one million cubic meters happened in the Min-Kush uranium processing site in the Kyrgyz Republic. This hazardous landslide area is connected to radioactive and toxic tailings of mining industry located in the center of Tien-Shan mountain system. The present research represents the results of work done by using Unmanned Aerial Vehicle (UAV) for photographing the landslide area, which was made for monitoring of this potentially hazardous phenomenon. Based on these images and geodetic measurements of the landslide, orthophotos as well as generated Digital Surface Model (DSM) with an accuracy of less than ±5 cm resulted. The application of the UAV in the man-made landslide study has been established as a cost and time effective monitoring tool that provides researchers and engineers with high-resolution geospatial data.

1. Introduction

According to statistical data, in the Kyrgyz Republic up to 70% of present landslides are the result of man-caused activities in mountain areas, mainly related to mining and processing operations. Most hazardous landslide areas are connected to the radioactive and toxic tailings of mining industry located on unstable ground and close to landslide-hazardous slopes, in valleys of narrow mountain rivers (Torgoev et al., 2006). The analysis of the environmental situation in the country shows that high landslide risk has negative influence on environment and population with catastrophic effects of regional and transboundary types under possible combination of the natural hazards, which are typical for mountain regions (earthquakes, mudflows, floods or inundations) (Havenith et al., 2006).

The Min-Kush uranium processing plant (PP) has been actively developed during 1953-1968 at the base of the uranium deposit located in the center of Tien-Shan mountain system. Uranium ore was mined at the Kavak mine located in the mountain slopes adjacent to Min-Kush village (Torgoev et al., 2008). A large anthropogenic landslide on the slope above the former processing plant occurred March 30, 2013 at 04:20. When the dumps collapsed, the sliding masses of dump and burnt clay moved 90-100 meters and were stopped at two dilapidated buildings of the former processing plant (ore grinding mill and the former “Orgtekhnika” Factory), which served as a barrier on the path of further movement of the landslide masses on the plant territory towards the road (Figure 1). The area of the slumped masses immediately after the collapse was more than 20 thousand m^2, and the total volume, according to rough estimates of the Ministry of Emergency Situations of the Kyrgyz Republic, amounted to 800-900 thousand m^3.

According to the Ministry of Emergency Situations of the Kyrgyz Republic, as a result of the PP-2013 landslide, two supports # 211 and # 213 of the 110 kV high-voltage transmission line “Chayek-Minkush”, 6 electrical supports of the 10 kV power transmission line were destroyed and eight settlements were left without electrical power. The total amount of direct economic losses was estimated at 2 million soms (more than 41 thousand USD in 2013 prices). The study of landslide processes, including the type, location, stability, trigger factors, susceptibility and risk, is very important for assessment and monitoring tasks. Several remote sensing methods were applied, including spaceborne synthetic aperture radar (SAR) and optical sensors, airborne light detection and ranging (LiDAR), ground-based SAR and terrestrial LiDAR, combined with in-situ surveying and observations of landslides (Zhao and Lu, 2018, Lissak et al., 2020 and Teshebaeva et al., 2015).

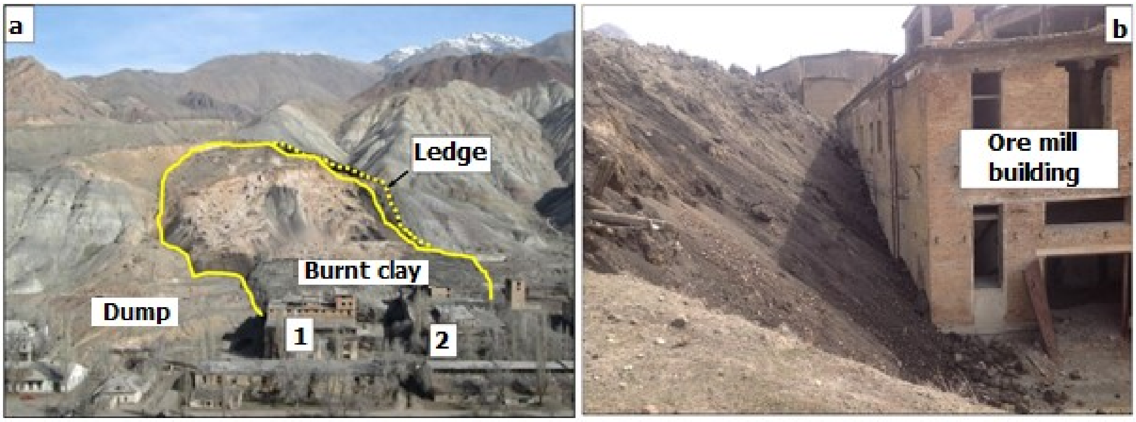

Figure 1: Landslide over the former Min-Kush processing plant: a) photo of the landslide (yellow outline) and the buildings of the processing plant - view from south to north, 1 – Ore grinding mill, 2 - Former “Orgtekhnika” Factory; b) the profile of the landslide tongue - view from west to east

They have been used for generation of landslide inventory maps, monitor landslide deformation, and model landslide susceptibility.

Landslide maps (LMs) are used to show where landslides have occurred and provide information for landslide studies, including susceptibility and hazard modelling and validation, risk assessment, erosion analyses, and to evaluate relationships between landslides and geological settings. The recent spaceborne remote sensing methods and traditional aerial photographs have been used in the large-scale landslide mapping and monitoring as well as to create geomorphological maps, automatically derived elevation models (DEMs), displacement vectors and animations (Li et al., 2016 and Li et al., 2013).

In the last decade, the combination of the rapid development of low cost Unmanned Aerial Vehicles (UAVs) and high resolution optical sensors has started the revolution in the geodetic survey and mapping industry. Aerial surveys and photogrammetric products from high resolution images acquired by drones flying at very low altitudes (from 50 m to 150 m) are becoming very popular. The most important advantages are represented by quick acquisition of low cost, high resolution and detailed morphological data over unstable and difficult accessible slopes, use of best suited sensor, and the possibility to get data even in difficult environmental conditions (Nikolakopoulos et al., 2017 and Karantanellis et al., 2020). The accuracy of the models varies depending on the UAV and sensor types, quantity and on the distribution of GCPs, the applied method of accuracy assessment for the study and would be less than ±10 cm (Peterman, 2015, Lindner et al., 2015 and Tahar, 2013).

2. Data and Methods

2.1 Study Area

The Min-Kush village is located in the southern part of the Zhumgal district of the Naryn region, in the valley of the river of the same name (Figure 2). The Min-Kush valley extends mainly in the latitudinal direction, it is framed by mountain ranges on both sides: from the south of the ridge. Moldo-Too, from the north of the ridge Kavak-Too. These ridges also have a latitudinal strike, and their axial parts are represented by sharp ridges with heights of 3500-4000 meters. The most sharply dissected relief has a ridge named Kavak-Too, the slopes of which are crowned with bizarre forms of weathering. The absolute heights within the area under consideration range from 2040 m in the riverbed to 3600 m on the crest of the Kavak-Too ridge.

In terms of susceptibility to human-induced landslide processes, the Min-Kush mining region ranks second in Kyrgyz Republic after the Mailuu-Suu mining agglomeration (Torgoev and Aleshin, 2009). In comparison with Mailuu-Suu, which shows low-mountainous relief (900-1600 m), the study area of Min-Kush belongs to the middle-mountainous regions (elevation from 2000 m to 2600 m above sea level), which causes differences in the development of landslides. In the conditions of the difficult and cramped mountainous terrain of the Min-Kush mining site, most of the dumps were located as close as possible to mines, quarries to reduce the cost of transporting dump rocks. At the same time, weakly stable mountain slopes were used as sites for storing dump rocks and substandard ore due to the lack of suitable dump areas, on which landslide processes began to develop over time, similar to a landslide happened in the Min-Kush uranium processing plant (PP-2013).

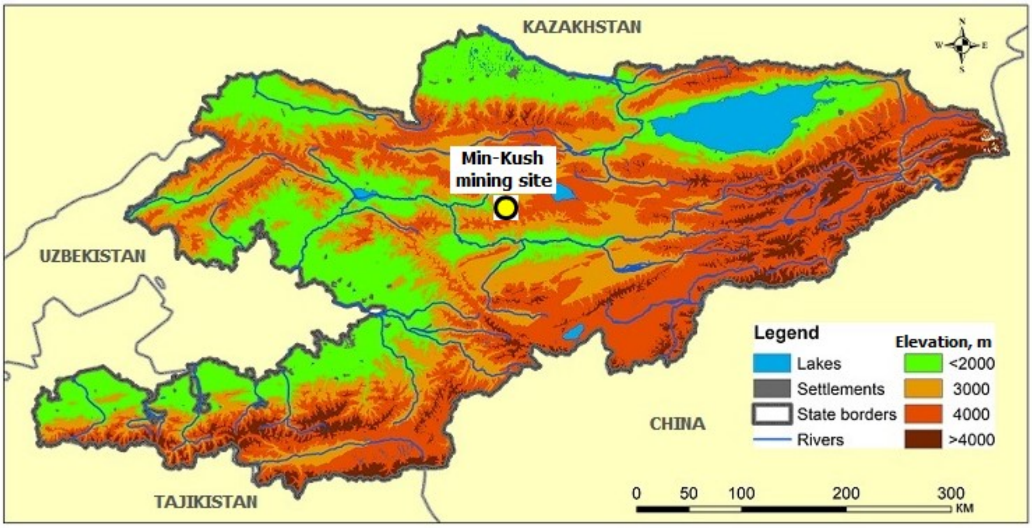

Figure 2: Study area in the map

2.2 Remote Sensing Data

Based on the analysis of available very high resolution satellite images of different years displayed in Google Earth, it can be argued that back in 2003, on the considered slope, a scarp and cracks were clearly visible. They outline the deformation zone of subsidence of deposits, which later became the head part of the landslide, which was unloaded on March 30, 2013. It is possible that this zone began to form even before 2003, since we do not have earlier high-resolution satellite or aerial images of this area. One thing can be confidently asserted that this subsidence zone is related to the groundwater discharges, pinching out from the eastern side of the subsidence zone. Along with this, a stream flowed from the upper parts of the slope along a narrow ravine on the eastern side of the PP-2013 landslide, which also contributed to the watering of the fractured subsidence zone, reducing its stability (Figure 4).

To assess the changes in the relief, on November 24, 2020, we carried out aerial photography of the slope and the territory of the PP using an UAV (DJI PHANTOM 4 type). After computer processing of aerial photographs for landslide risk assessment, three-dimensional digital surface models were built, as well as a number of surface profiles at different parts of the slope. When performing aerial photography and processing images, the following steps were performed:

- Reconnaissance of the area and the construction of a mission plan for UAV.
- Placement of GCPs (photogrammetric Ground Control Points) on the object and satellite positioning of them by using a Network RTK GNSS receiver.
- The photographic acquisition at the study area was performed according to the UAV flight plan at a flying height of about 90 m above ground level, achieving a mean ground sampling distance (GSD) of about 2 cm/px (Figure 3).
- Survey data processing.

Figure 3: UAV photography of the PP-2013 landslide

The above procedure provides up to 5 centimeter horizontal accuracy of images. Obviously, the larger and more complex the survey object, the longer this operation will take for placement and shooting. GCPs are placed not evenly due to inaccessibility of the part of dumps and burnt clay surface. UAV survey data processed in Agisoft Photoscan - photogrammetric package, a widely used image-based 3D modeling and rendering package. This method allows us to obtain very high resolution orthophoto plans and 3D data from a variety of images taken from different points for small areas as in our case. The open source Quantum GIS software is used in order to collect, storage, manage, process, analyze and visualize the complex geospatial information. The current state of landslides in the study area realized by developing very high resolution Digital Elevation Models (DEMs), visual interpretation of aerial photography and in-situ inspection. Regular landslide monitoring activities by the combination of UAV survey and field work will be implemented as a main method of surveying. Judging by the satellite images of different years (2014, 2016, 2019), available from Google Earth and an aerial image dated November 24, 2020, changes in the topography of its surface occurred on the slope under consideration (Figure 3), caused by geodynamic processes, erosion and denudation. Without going into detail, we can identify the following significant changes:

- The area of the deformation zone gradually increased, the outlines of which are highlighted in Figure 4 with a red outline. By analogy with the PP-2013 landslide, this deformation zone can become the head of a new landslide.
- In the 2016 satellite image, a crack appeared parallel to the ledge (Figure 4b, 4c) above the PP-2013 landslide scarp and the deformation zone, which indicates the spread of the landslide process up the slope; that is, in this case, we are dealing with a so-called "delapsive" landslide that occurs in the lower part of the slope and grows up the slope with the formation of new creep cycles.
- On the high-resolution aerial photo dated November 24, 2020, in the deformation zone with an area of about 5000 m^2, which can become the head of a new landslide, concentric cracks are visible, which are likely to form as a result of a slow downward displacement (Figure 4d).

On body of the PP-2013 landslide, one can also notice changes caused by the erosion of its loose sediments and fragmented rocks exposed to atmospheric precipitation and surface waters of the slope runoff. At the same time, it can be argued that the probability of a repeated displacement in its contours is small. Accordingly, when carrying out reclamation work on the territory of the processing plant in 2021, it is practically possible to ignore the risk of landslides associated with the unloading of landslide masses.

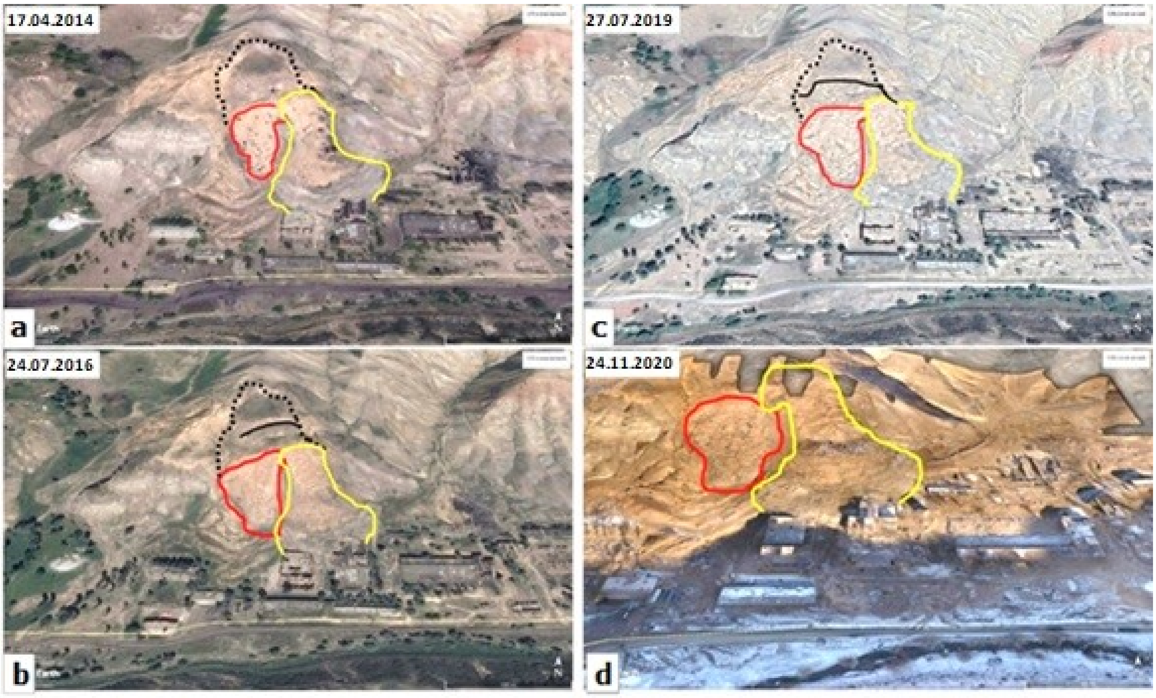

Figure 4: Multitemporal remote sensing images of the PP-2013 landslide (yellow outline), deformation zone (red outline), crack lines (black outlines) above the slope. a) Google Earth imagery from May 17, 2014, after one year from the PP landslide; b) Google Earth imagery from July 24, 2016, after three years from the PP landslide; c) Google Earth imagery from July 27, 2019, after six years from the PP landslide; d) UAV aerial photography from November 24, 2020

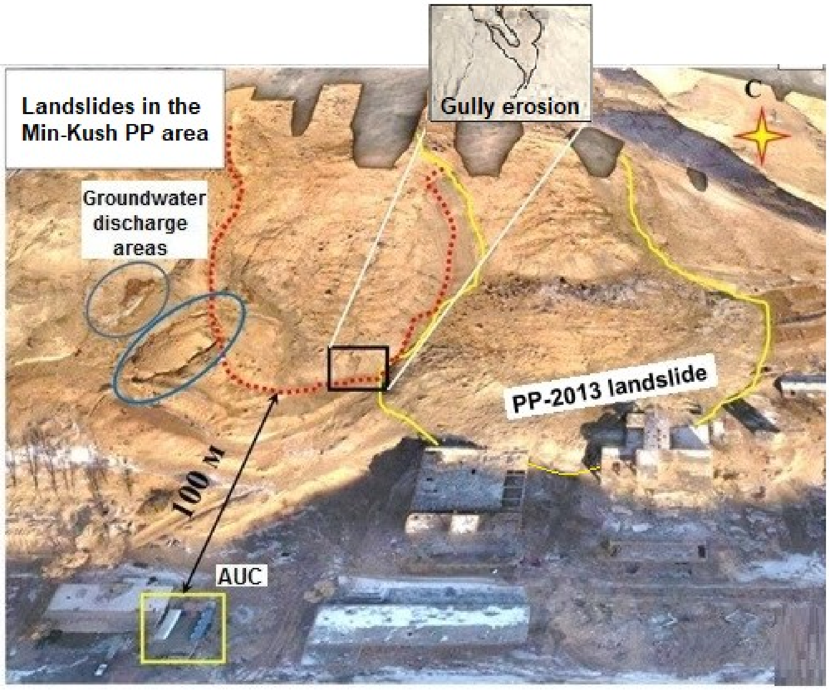

Figure 5: Landslide situation on the slope above the Min-Kush PP: UAV photography based 3D image of the slope and PP-2013 landslide (yellow outline); red dotted outline - the zone of active deformations of a new potentially dangerous landslide with a threat to the AUC; the gully areas are shown in the lower part of the dump in the black rectangle

3. Results and Discussion

One of the obtained three-dimensional images is presented in Figure 5, in which the deformation zone is highlighted with a red dotted line, which can become the head part of another landslide on the considered slope. The western flank of the deformation zone of groundwater outcrops, as well as gullies, shown in the blue ovals. Due to negative air temperatures at the time of shooting, a piece of ice is formed in the place where the water wedged out.

At present, in the deformation zone, the process of preparing the slope for the main displacement towards the Administrative and Utility Containers (AUC) is developing, which can occur with a combination of high moisture content of the rocks in the deformation zone in spring and a strong earthquake within a radius of up to 100 km from Min-Kush. It should be noted that after the descent of the landslide from the deformation zone, a significant volume of rocks located above it may be mobilized. In Figure 4, the outlines of this zone are shown with a black dashed line.

The high probability of landslides from the deformation zone and the overlying part of the slope is evidenced by the results of radar monitoring of the Min-Kush mining region, carried out by TRE ALTAMIRA Company (Italy) in the period from October 2015 to June 2019 (Bellotti et al., 2019).

4. Conclusion

The study showed that the most dangerous scenario for the collapse of an unstable slope includes the collapse of the slope not only from the recent deformation zone, but also its upper section, outlined in Figure 3 by a black dotted line. Under such a scenario of the development of a landslide process, it is possible that the road to Min-Kush-Dalnyi will be affected. Taking into account the increasing probability of the slope collapse from the deformation zone and then the section above it, the following measures are recommended to reduce the landslide risk and, in particular, to prevent the death and injury of PP personnel:

- Transfer of the Administrative and Utility Containers (AUC) from a potentially hazardous landslide affected area to a safe location.
  Organization of the landslide- monitoring by applying a geodetic method with totalstations at several benchmarks (combined with GCPs) fixed along the profile in the North-South direction. It is advisable to install the total station at the permanent reference point to control the displacement of the fixed benchmarks on the

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opposite left-bank slope of the Min-Kush river valley.
- Installation and satellite positioning of the permanent GCPs on the PP-2013 landslide for the regular UAV survey for monitoring.
- Installation of the contemporary motion sensors.

Moving containers to a safe area seems to be the most reliable measure to prevent the death and injury of workers. Regular geodetic monitoring of the deformation zone will allow early detection of the precursors of slope collapse and thereby introduce an appropriate level of advance warning on the principle of a traffic light, when at the yellow level of alarm it is possible to envisage restricting the access of personnel, vehicles and mechanisms to a potentially dangerous zone of landslide damage. At the red alarm level, the complete prohibition of the stay of people and construction equipment on the territory of the former processing plant.

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