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sUAS and their application in observing geomorphological processes

Jozef Gallik and Lenka Bolešová

Department of Ecology and Environmental Sciences, Constantine the Philosopher University, 949 01, Nitra, Slovakia

Correspondence to: Jozef Gallik (jozef.gallik@ukf.sk)

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Abstract. Methodologies and procedures in processing gained data vary based on possibilities and needs of scientific projects. This paper should help to get a general overview in the choice of small unmanned aircraft systems (sUAS – commonly known as drones) for scientific purposes, namely remote sensing of geomorphologic processes such as soil degradation in high mountainous areas that are hard to access and have unfavourable weather conditions. All high mountain areas in European countries are legislatively protected, and so various permissions and observation of strict procedures are needed in order to not have a negative influence on the environment. Nowadays, several types of UAS exist that could effectively help us in such protection, as well as in full-fledged utilization when answering scientific questions about the alpine lake genesis. We demonstrate it here with selected examples of our photo documentation.

1 Introduction

Soil genesis and soil degradation comprise a worldwide issue that is researched by different strategies (Laudicina et al., 2015; Parras-Alcántara et al., 2015; Saha and Kukal, 2015; Srinivasarao et al., 2014). There is a need for research that will contribute to sustainable soil management (Bisantino et al., 2015; Mekonnen et al., 2015; Ndah et al., 2015; Wildemeersch et al., 2015) and that will assist policy makers in finding a way to apply the findings and achieve the sustainability (Keesstra et al., 2016). The use of remote sensing is today a key strategy to research the soil and the soil processes (Aucelli et al., 2016; Holleran et al., 2015; Kaiser et al., 2015; Van Eck et al., 2016). Throughout remote sensing we can observe the "behaviour" of the environment we live in – changes of soil, vegetation, landforms, land uses, and land management; what is the cause for these changes; and mainly what effects these changes have on the environment (De Mûelenaere et al., 2011; Gong et al., 2015; Islam et al., 2015; Zucca et al., 2014). All these changes – whether natural or anthropogenic – can be effectively and easily monitored with the use of small unmanned aircraft systems (sUAS). For example, the use of this new and very popular technique can research vegetation changes (Cerdà, 1998; Muñoz et al., 2014; Zucca et al., 2015), landforms (De Sy et al., 2013), soil changes (Gelaw et al., 2015; Kiernan, 2015; Mohawesh et al., 2015), changes in fluvial systems (Poeppl et al., 2015; Smith et al., 2015), and land use (Ferreira et al., 2012; Parras-Alcàntara et al., 2013; Shelef et al., 2015; Zhang et al., 2015) in an easier way than getting data directly from the terrain. The research is focused on the most important geomorphological-hydrological phenomena in the High Tatra Mountains, deposition of Čierne Javorové pleso alpine lake. Alpine lakes play a very important role in ecosystem services such as water retention and accumulation, local climate regulation, ecological, and environmental and landscape aesthetic functions (Hreško et al., 2012). Via the monitoring of its environs it is possible to demonstrate effectiveness of remote-sensing technology in the terrain (hardly accessible, dangerous, and legally protected areas).

The high capital cost of satellite, topographic, and aerial photos forces us to find cheaper technology – but of the same quality at the minimum – for scanning of landscape geomorphology. The quality of recording the Earth's surface depends on many different factors when recording the landscape. Recording is used for the analyses of morphological processes, their dynamics, effects, force, hydrology, vegetation cover changes, etc. Henry et al. (2002) described

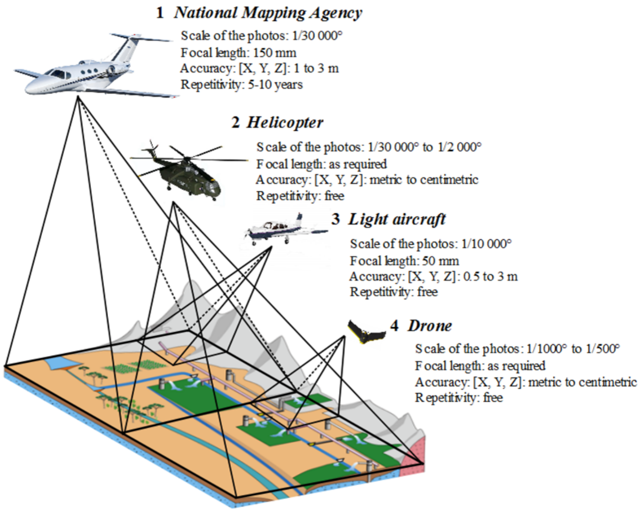

Figure 1. Sketch representing recording scale of Earth's surface according to Henry (2002).

the way and the work methodology of mapping landscape structure with the use of individual flying machines (Fig. 1). From photos gained in this way, it is possible to create three-dimensional (hereinafter 3-D) models by fixing GPS points.

Work with 3-D models of the terrain is commonly used in practice, but still there is a lot to improve on the software and recording level. When using a 3-D model, we focus on the explored surface, i.e. processes in progress and changes in the landscape. Digital terrain data gained in this way can be the material source for geomorphological research and monitoring.

Multi-temporal data can potentially be very valuable for mapping geomorphological features and for the analysis of their changes over time or for the analysis of land management to the landscape development (Anders et al., 2013). That is the reason for collecting of datasets repeatedly, which is sometimes challenged by unfavourable weather conditions in high mountainous landscape. Here we would like to point to great progress in observing geomorphic processes where the lives of direct victims, observers, or scientists are in peril. Geomorphological hazards are understood here as "a probability of occurrence of the geomorphological processes endangering human interests in the affected area" (Minár, 2006). Millers (2012) suggested that we can prevent this by investing billions of dollars into the research where UAS are used. One of our objectives is demonstration of benefits in remote sensing with the use of sUAS (specifically DJI Phantom 1), such as its accuracy in the terrain, easy access to hardly accessible areas, and the possibility to collect data even during unfavourable weather conditions.

Geomorphologists have to make choices and compromises, because acquisition techniques of geometrical information are numerous, depending on the specific complexity of the targeted 3-D objects and the requirements of the end user (Henry, et al., 2002). "Researchers are often forced to make a compromise between what is desirable for their project and what is actually possible" (Whitehead et al., 2013). The second objective is collection of data (creation of a photo documentation) needed before actually entering the environment, for the final statement on whether it is relevant to start planned research or not. The same photos are used for the creation of panoramic photos of alpine lakes, and these photos are used for the monitoring of alpine lake surface changes – comparison of its surface in particular years of our research.

2 Material and methods

2.1 The study area

Mapping of the high mountain environment is grounded in accurate and effective use of all available means. We describe here the principle of the environment recording and work with particular types of sUAS in this paper. We have chosen the alpine lake in Čierna Javorová Valley in Slovakia (central Europe) for direct representation of the methodology and its benefits. The valley is situated in the High Tatra Mountains, located in the northern part of Slovakia. It belongs to the protected area of Tatra National Park (hereinafter TANAP) (Fig. 2). One of the observed objects is Čierne Javorové pleso alpine lake (1493 m a.s.l.), situated at the high altitude. It is quite hard for a single researcher to get there with all needed equipment. Moreover, when we take into consideration the time factor, it is impossible to move all the equipment to one or two more lakes in one single day. Another problem is the fact that the observed area is protected; the necessity of keeping the environment in an unaffected state means total avoidance of any disruption (e.g. entering the alpine lake). That is why we used the quadrocopter in the selected study area.

2.2 Observing of geomorphological phenomena and processes

Due to the problems stated above we had to find an easier way of gathering data needed for research in high mountainous terrain. Based on the observation of the alpine lake, we tried to improve and adjust the methodology of photogrammetric acquisition of data that will be applicable for the research before the sonar observation of the alpine lake.

Sediment transfer and accumulation, observed in the terrain, were captured by recording, and then we made detailed photographic documentation. We used a drone – DJI Phantom 1 quadrocopter – in combination with a GoPro Hero3 waterproof camera and Nokia Lumia 1020 mobile phone for the accurate operation of the quadrocopter. DJI Phantom 1 contains a remote-control unit. It is easy to set it up and fly also for new pilots. The flight time is up to 15 min and can be prolonged by using two batteries. For the controlling of the flight route we used a Nokia Lumia 1020 for the exact

Figure 2. Location of the study area.

location of the quadrocopter position. It was clearly visible whether the object or the phenomenon was captured well or whether there is danger of crashing into the rocks. The GoPro Hero3 camera can be easily attached to the quadrocopter. The frequency of snapshots can be set manually, or there is a possibility to record a video. Data were taken in the summer of 2013 and the winter of 2014.

3 Results

After the study of the relevant literature and our terrain research we present here a concise survey of characteristics of UAS and show possibilities of their use directly in terrain, where gaining high-quality data is often challenged by exacting terrain and/or weather conditions.

3.1 Characteristics

Two types of UAS are used for mapping relief and landscape field (Fig. 3). "Based on the configuration there are rotary wing (helicopter) and fixed wing (airplane). These two are divided into five categories according to the weight. There is also specified a specific category of sUAS with the weight < 25 kg, that is available for civil operation" (Hugenholtz et al., 2012). These are powered aircraft that evolved from radio-controlled (thereinafter RC) and military "drone" aircraft. They have integrated autopilot technology, which gives them semi- or fully-autonomous navigation, flight control and image acquisition capabilities (Hugenholtz et al., 2012; Stefanik et al., 2011)". "The sUAS have two control modes: remote control and autopilot control. Aircrafts are used mainly for accurate mapping of bigger fields and usually 3-D landscape models are made after that. Aircrafts have accurate flight trajectory that is recounted by its own software, so that no problem occurs in photo-overlapping. Its flight height can be set manually and it ranges from 100 to about 800 m. After it is set, the height is fixed during the whole time of flight" (Hugenholtz et al., 2012).

On the other hand, models with a rotary wing are used for directly observing processes at a specific time, capturing the actual state and actual change of observed phenomena from a bird's-eye view. It means that quadrocopters are better used for detection of an accurate point or its specific part from a different perspective such as detection from an angle (Fig. 4).

Digital photogrammetry has been decreasing in costs. It is becoming accessible to a wider range of users who follow methods allowing non-metric cameras for the accurate calibration (Chandler, 1999; Chandler et al., 2002; Lane, 2000, 2003; Westaway et al., 2003). Initial costs for purchasing cheaper machines are affordable for postgraduates and young scientists. Based on its affordability in the market, it is possible to work with software built in drones quickly, easily, and without any flight training. Creating a new software variation is necessary only in cases of specific projects with specific needs or if we want to assemble a drone on our own. "It is possible to save 1/3 of market price when assembling multipropeller copters. They are often difficult and costly to obtain. Price ranges from c. 1500 € to about 100 000 €" (Koh and Wich, 2012). It is caused mainly by of the differences in duration of flight time, the speed of flight, used camera/recording machine, and specific user demands. The limitations imposed by battery life and the challenges of operating beyond the line of sight impose limitations on the size of the area which can be covered by UAV surveys (Whitehead et al., 2013). When talking about the range of controlling the quadrocopter, it is 300 m.

3.2 Resolution of datasets

Geomorphological projects cannot be done without aerial photos, mainly in their preliminary stage where decisions about the following steps are made and scientific questions and goals are reappraised. Depiction of GPS points from pho-

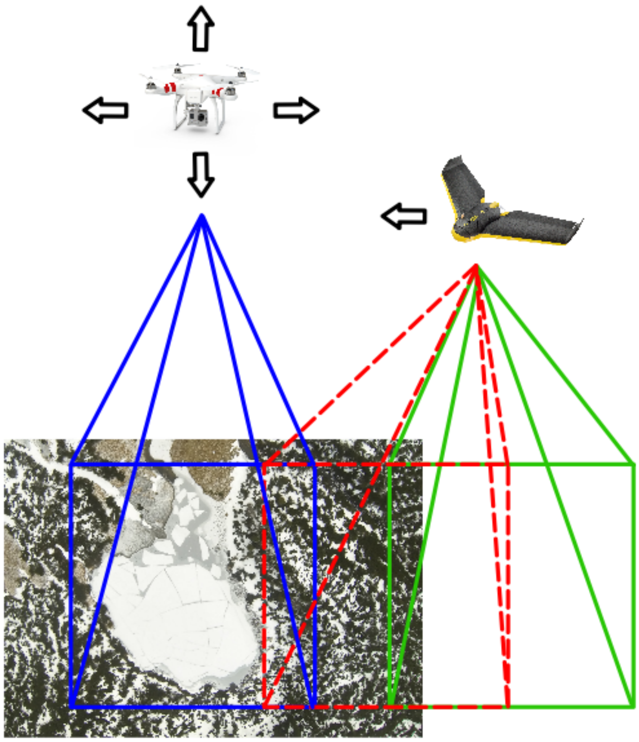

Figure 3. Movement of the quadrocopter and fixed-wing UAS.

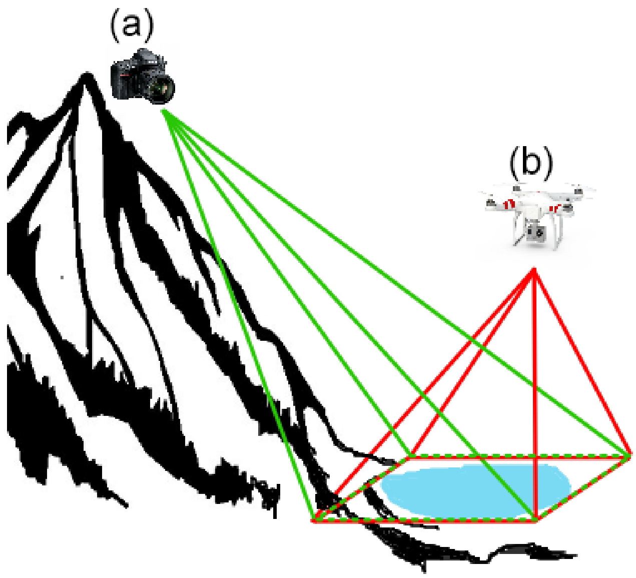

Figure 4. (a) Recording with the camera from an angle; (b) recording of actual state of alpine lake with the quadrocopter perpendicular to the alpine lake.

tos can be challenged in the future because of GPS deviation. In our area of the interest, Čierna Javorová Valley represents an enclosed system. The lower the alpine lake is, and the higher the mountains are that surround it, the bigger are the deviations of cardinal points that the GPS device may show. It is caused by the smaller amount of satellites transmitting the signal that the GPS device receives. On the other hand, if something is captured authentically in the photo, it is needed only to recalculate the measuring scale and then determinate the cardinal point for the possible future comparison.

Recording by satellites and high-flying aircrafts provides us with a big 3-D scene, several square kilometres for one photo. Quadrocopter flies into much lower heights, and the scene captured by the camera narrows to only several tens of square centimetres up to hundreds of square metres. Improvements in the cost and quality of compact and single-lens reflex cameras and methods for their calibration (Clarke and Fryer, 1998; Chandler et al., 2005; Remondino and Fraser, 2006) encouraged a wide range of uses in geomorphology – for example monitoring river bed topography and plan form (Brasington and Smart, 2003; Chandler et al., 2002; Lane, 2000; Tamminga et al., 2015) and gully erosion (Betts and DeRose, 1999; Marzolff and Poesen, 2009) – and in glaciology, for example the quantification of glacier surface change (Keutterling and Thomass, 2006) and also the quantification of soil erosion (Brasington and Smart, 2003; Heng et al., 2010; Lane et al., 2001; Stojic et al., 1998).

"Satellite imagery, mainly used for government map updates, is appropriate for some types of measurements" (Wainstein et al., 2008). In some cases there are some limitations such as its cost, weather conditions, or its resolution. Zooming of a satellite photo makes the photo quality lower, while decreasing flight level does not. This can be achieved by using a drone, so that harshness and accuracy of monitored phenomena is increased. It is possible to create detailed figures and maps of small measuring scales. In the following photos, high quality and very good resolution is visible (Fig. 5; scale: 1 : 1700), in contrary to zoomed satellite photo (Fig. 6; scale: 1 : 2260). Borders of particular herbal covers and their changes in the high mountain environment are separated straightforwardly. If any change of the soil type or of the physical or chemical structure appears, herbal cover changes too (it is clearly visible in the Fig. 5).

3.3 Ease of access

"The acquisition of the high quality terrain data still remains challenging in remote, hostile high alpine environments, where steep and unconsolidated slopes and poor satellite coverage hinder the application of ground surveys by GPS or total station. Other alternatives such as terrestrial laser scanning (TLS), airborne surveys are also restricted because of the high three dimensionality of mountainous landscape" (Westoby et al., 2012). Flying with the quadrocopter may be demanding in its operation. That is why another technical aid, a Nokia Lumia 1020, was used. The mobile phone was connected with the GoPro camera through Wi-Fi, which enabled us to watch the whole operation of the quadro-

Figure 5. Quadrocopter photo – Čierne Javorové pleso alpine lake.

Figure 6. Zoomed satellite photo – Čierne Javorové pleso alpine lake (Google Earth, 2002).

copter's flight. This can prevent the quadrocopter crashing into the rock. Another reason for such an operation with the possibility to see the track of the quadrocopter is better control of the flight and so better recordings. It helped us to record the exact area of monitored processes and to control the flight height by the observer, so it is possible to approach observed processes.

Collecting of datasets may pose significant challenges in some glaciated areas where stable reference points are unavailable. Using remote-sensing technology here has significant advances, and it provides new options to researchers (d'Oleire-Oltmanns et al., 2012; Hugehnholtz et al., 2012). The same is applicable to the study area where stable reference points are difficult to be set. "In Slovakia, one of the most significant advantages of sUAS compared to aeroplanes is, that owner of the quadrocopter does not need to have pilot licence for operating it. Moreover, the size of the quadrocopter is not bigger than radiocontrolled models of aeroplanes and helicopter" (Gallik and Bolešová, 2014).

"sUAS enable us to effectively monitor ongoing processes such as ice flow, marginal recession or seasonal drainage on an ongoing basis" (Whitehead et al., 2013). In this photo from the quadrocopter (Fig. 5), the shoreline (littoral zone) of the alpine lake is clearly visible. Such photos made over the whole lake basin serve to create a panoramic photo that is used for the research of alpine lake genesis. According to the colour scale it is possible to determine depth of the alpine lake in its constituent parts without any use of sonar technology needed for getting it into the alpine lake (Lejot et al., 2007). As for the shoreline and water surface that are changing in particular seasons (Hreško et al., 2012), not even the best-quality sonar systems would provide information about these changes because they are limited in depth measuring. It is possible accurately to detect the actual state of vegetation, which gives us a depiction of sediments and their extension without any necessity to go through the observed area several times and locate the area with other technical machines (e.g. GPS).

3.4 Weather conditions

One of the main advantages of using unmanned aircrafts is the analysis and the documentation of the actual condition of the environment and processes in progress. This way it is possible to record each geomorphological process individually, under what weather conditions it arose or what effects preceded its genesis.

Although there exist various photogrammetric methods for 3-D topographic modelling (Fraser and Cronk, 2009; Mathews, 2008; Remondino and El-Hakim, 2006), when it is important to catch the effect of processes (such as backfilling of the alpine lake) in the mountainous landscape, using the drone is a better option. The first decision was to take photos from one point (Fig. 4), because Čierne Javorové pleso alpine lake is situated in an enclosed valley with precipitous slopes that surround it. Since it is observing the water surface and its immediate environs, photo documentation from an angle gave us partly misrepresented information about changes in the alpine lake environs. It was caused by the sunlight reflecting from the water surface and by the image of the opposite slope (Fig. 7). With the use of the quadrocopter, an optimal perpendicular look to the water surface of the alpine lake was set, and an image of sediment dispersion was clearly visible on its bottom (Fig. 8). Shadows of surrounding peaks, based on the sun position and seasons, do not disrupt the picture. Another advantage of the quadrocopter is its movement and stabilization at one point, which is easy to programme in the case of expensive versions, making the observer's work easier. The flight time ranges from 20 to 50 min according to

Figure 7. Photo of Čierne Javorové pleso alpine lake from an angle, with reflected images of mountains surrounding it.

Figure 8. Photo of Čierne Javorové alpine lake where disruptive, reflected images are missing.

the quality of batteries and the air temperature. Size of the quadrocopter is not crucial when observing in free space, but it is needed to make a choice based on the study area characteristics. It does not need to be too small, but it should have the optimum size so it is easy for one person transfer.

Aerial photos acquired in common weather conditions are accurate. Shade represents a big problem when detecting the landscape parts. That is the reason why accurate area detection is not possible. These are examples of places with poor visibility and places where there is constant shade in normal conditions. As soon as we descend under the boundary of light and get into shaded places, it is possible to detect the actual state of the mountain rock face, i.e. changes that are in process and rockfall in source areas of sedimentary rock. Then it is possible to delimit steady places with almost no change – and if so, then in a very long time period (once in the geological period) – from zones that are rapidly destroyed. The rockfall also represents an important role in the monitoring of alpine lake genesis, namely backfilling of the alpine lake.

sUAS, which have smaller size and weight, are highly dependent on favourable weather conditions. According to Hugenholtz (2013), they are inherently less stable than larger piloted aircraft. This instability of the platform changes the roll, pitch, and yaw of the aircraft, and it can affect accuracy of a digital terrain model (DTM). But in the case of the quadrocopter used for collecting photo documentation of ongoing processes, there still is a benefit of changing the height of flight, which enables going under the level of clouds and avoiding them in the frame of the photo or getting very close to the monitored phenomena.

Using drones for recording of the high mountainous environment enables us to record the alpine lakes each day in case of good weather conditions. It is possible to observe the state of backfilling of the alpine lakes in different seasons of the year, so it is possible to determine its actual and gradual changes (Fig. 9 on the left – winter – scale: 1 : 1000; Fig. 9 on the right – summer – scale: 1 : 1000). The quadrocopter can be used to explore the monitored phenomenon in real conditions, real time and space, and so secondary influences can be eliminated. "They can be easily and cheaply used before and after a natural event or also in order to offer a basis for understanding the evolution of the investigated process" (Tarolli, 2014).

4 Discussion

For today's conditions of scientific knowledge, satellite and aerial photos do not suffice for the accurate determination of the magnitude of geomorphic processes and phenomena. The free satellite photos taken from the Google Earth program, even if there is visible improvement in their resolution, do not reach the level of the GoPro camera photo quality needed for the research of the alpine lake genesis. Many differences between the real state of observed phenomena and the available photos occur almost in all preliminary analyses, and only directly in the terrain is it possible to state exactly whether preliminary assumptions were correct. The high quality of photos and good resolution are outcomes of flying and recording at lower heights with the use of the quadrocopter.

Since the research area belongs to the protected area of TANAP, the use of the quadrocopter is the best way to observe this area without any encroachment into the environment. After the pre-investigation stage of research it is possible to decide whether there really is substantiated need to enter and affect such a protected area. This paper points to the protection of the environment by using remote-sensing technology – mainly for immediate observation, transportation

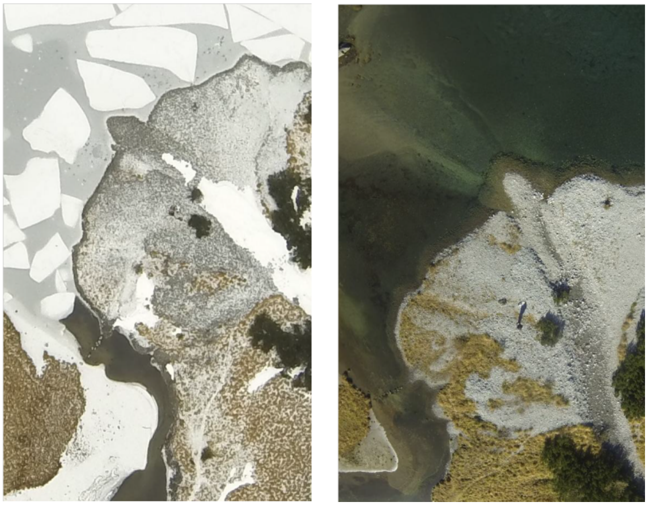

Figure 9. Deluvio-fluvial sediments depositing Čierne Javorové alpine lake in winter 2014 (on the left) and in summer 2013 (on the right).

to the observed location, and operation of sUAS – without harmful substances being released to the environment.

High-quality field research is hardly feasible without quality technical support. Each project, its realization, and procedures depend on exact measurements and gained data from the terrain. Observation of different morphodynamic processes in the high mountain landscape is exacting mainly because of rapidly changing weather conditions. Methodology of observing the field–environmental relief has made great progress in the last few years, mainly in the way of remote sensing of the Earth and the most modern technical aids used directly in the terrain, for which it was necessary to use the laboratory in the past. sUAS constitute the source of the new point of view on the observation of animate and inanimate components of the environment and give higher scientific value of research where they are used. "An emerging technology – unmanned aerial vehicles – offers a viable alternative to conventional platforms for acquiring high-resolution remote sensing data with increased operational flexibility, low cost and greater versatility. Usage of sUAS is transferred to the civil and the research applications where these tools are capable of acquiring high-quality geophysical measurements" (Hugenholtz, 2012). Conventional applications of photogrammetry in geomorphology mainly involved piloted aircraft. But there are a number of other platforms that have been tested: balloons (Boike and Yoshikawa, 2003), kites (Marzolff and Poesen, 2009), telescoping masts (Hauet et al., 2009), and small unmanned helicopters (Niethammer et al., 2009).

All geomorphological processes are best determined via direct terrain research and measurements in the landscape. That is why application of the production of high-resolution topographic datasets is rapidly increasing in the geomorphic sciences (Bird et al., 2010; Butler et al., 2001; Fonstad and Marcus, 2010). Satellite and aerial photos used in the research of the alpine lake genesis will not achieve such accuracy so that clear conclusions can be deduced. Based on this, it is possible only to point to the changes that have been happening during particular years of terrain recording sequence, made in one and multiyear repetition intervals. It is necessary to summarize digital data from different time and different technical devices in order to compare them. This process of working with different formats of photo material could be made easier by selection of one quality technical device that will provide data from different time periods of the same format for easier work. It is possible with the usage of the chosen quadrocopter.

Because the price of some models is too high, it will take some time to reach the standard when it would be affordable also for economically weak countries. But still, this technology is much cheaper than the purchase of satellite photos needed for determination of landscape elements and phenomena. After all, purchase of sUAS can be funded by a project.

Last but not least, the created photo documentation needed for our research of the alpine lake serves for the calculations; it helps to state the deposition level of the alpine lake or to find the source of the deposited material. All of this is possible without any disturbing encroachment into the alpine lake environment.

5 Conclusions

The use of UAS technology for bearing out the hypothesis in science projects still requires scrutiny and testing to fully understand the opportunities, limitations, and drawbacks. sUAS make work much easier, because there is no need to carry too-heavy equipment or to take up too much space (the best example of this is the sonar technology for mapping the alpine lake bed). This is a great advantage mainly for scientists who often need to get to hardly accessible terrain. The study area is in a protected area, where scientific research has to be permitted. As earlier stated in this paper, sUAS are small machines. We do not need any flying permit, because there is no encroachment into the environment, and so it is not necessary to spend too much time waiting for such permission.

The irreplaceable quality of using sUAS in a high mountainous landscape is the possibility of recording areas with poor visibility and constant shade; what is more, it helps to lower inaccuracy of GPS coordinates of the point which is measured.

With gained photos, the creation of more accurate digital elevation models (DEMs) is possible (in comparison to DEMs derived on the basis of satellite, topographic, and aerial photos), because of the higher accuracy of photos gained by the use of the DJI Phantom and with the GoPro Hero3 camera.

Remote-sensing technology in observing the alpine lake genesis enables looking at the water surface without any disturbing elements (e.g. sunlight reflecting from the water surface, image of opposite slope on the water surface). This paper points to possible and great use of the sUAS in locations with limited access and with limited conditions.

6 Data availability

All gained data can be assessed by asking for them the author via an e-mail (jozef.gallik@ukf.sk).

Author contributions. Jozef Gallik designed methods and procured all needed equipment. Jozef Gallik and Lenka Bolešová collected all data in the terrain. Jozef Gallik processed them. Lenka Bolešová prepared the manuscript.

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