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Photogrammetric measurement methods of the gully rock wall retreat in Istrian badlands

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ABSTRACT

Badlands in Central Istria share a very frequent characteristic with other worldwide badland sites, the rapid erosion rate. Rock wall retreat measurement on such a relief is associated with all types of problems because a certain effort has to be put into the measurement equipment design. Spear vegetation and a few previous studies encouraged the testing of different photogrammetric technologies and data acquisition methods for the determination of the denudation rate in Istrian badlands. The main aim of this paper is the establishment of the most suitable methodological combination for the determination of the badland denudation rate, which is the gully rock wall retreat rate.

The photogrammetric approach was tested by measuring and comparing the amount of denudation on the test site, which was established on a gully sidewall. The photogrammetric measurement was used twice within one year. The analysis of the photogrammetric technologies and data acquisition methods focused on the field and laboratory equipment and the accuracy and difference models obtained from the test site measurements. The analysis shows that the combination of digital photogrammetry and fully automatic matching data acquisition provides the most suitable measurement technique of the rock wall retreat in Central Istria badlands and other similar badlands.

1. Introduction

Istria is the largest Croatian peninsula and is located on the northern coastline of the Adriatic Sea and it is also the northernmost part of the Mediterranean. The central part of Istria is characterised by very thick flysch deposits (up to 350 m; Velić et al., 2003), with a highly dissected relief and well-developed gully network. Although the central part of Istria is a region with continental climate, with an annual precipitation of approximately 1000–1400 mm (Gajić-Čapka et al., 2003) and abundant vegetation cover, there are isolated bare parts (approximately 2% of that area) in those gullies, where intense erosion and mass wasting processes occur (Gulam et al., 2014) that are very similar to those in the badland reliefs. There are several definitions of the term badland. All of them refer to an extremely dissected landscape without or with sparse vegetation (Fairbridge, 1968; Bryan and Yair, 1982; Harvey, 2006; Wainwright and Brazier, 2011) with similar lithology such as marls, shales, and silty-clay formations (Bryan and Yair, 1982), which can be eroded rapidly (Howard, 1994; Wainwright and Brazier, 2011). All mentioned badland characteristics can be observed in the Central Istria badlands and are producing several types of difficulties related to the denudation rate measurements, which are similar to the erosion rate measurements on agricultural land (Stroosnijder, 2005). Because of that, researchers are obligated to think through and predict all possible situations and problems that might appear in the period of establishing field instruments, during the field measurements, and in the process of the analysis.

The flysch deposits of the Central Istria badlands have a very heterogeneous lithology (Bergant et al., 2003). The general idea for future investigations is to define the influence of the different lithologies on the gully sidewall retreat. To test that influence, the first step is to define a most suitable method for gully sidewall retreat determination.

Two attempts have been made in the past at measuring the gully sidewall retreat in Central Istria. During the first attempt, investigators used the erosion plot method. The gully sidewall retreat was so great that it damaged the erosion plot during the first research year, so much that the continuation of the study would not give reliable results (Petraš et al., 2007). Hence, the usage of the terrestrial photogrammetry method was recommended. This was a very logical recommendation because the conditions needed for the proper use of the proposed photogrammetric approach are well fulfilled: the area of interest is

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mostly free of vegetation and obstacles are rare and easily avoidable by changing the camera position. The terrestrial photogrammetry method has several advantages such as the scalability of the accuracy, the exact time-stamp of the data collection, complete separation of the data collection process and measuring and data reduction, accessible and affordable equipment with high measuring potential, and light and low-energy consumption equipment can be used during field operations. During the second attempt, the investigators used the analytical terrestrial photogrammetry method and succeeded in an attempt to obtain valid data to determine the annual rock wall retreat (Jurak et al., 2003). The data acquisition was performed twice in 38 months with an annual retreat of approximately 2.1 cm.

More recent investigations, most of which were placed in the Mediterranean gully and badland environment (Martínez-Casasnovas et al., 2003; Marzolff and Poesen, 2009; Martínez-Casasnovas et al., 2009; Gómez-Gutiérrez et al., 2014; Frankl et al., 2015; Stöcker et al., 2015; Aucelli et al., 2016), encourage the use of digital terrestrial photogrammetry techniques to obtain reliable 3D models to measure the gully sidewall retreat. Furthermore, there are several photogrammetric papers dealing with measurements of artificial or archaeological objects (Cardenal et al., 2004; Chandler et al., 2005; Shortis et al., 2006; Wackrow et al., 2007). All mentioned papers were using close range digital photogrammetry for 3D modelling and gained accuracy was overall under 1 cm.

Experience regarding gully sidewall retreat measurements in central Istria and new knowledge regarding digital photogrammetry have directed research elaborated in this paper to test several kinds of photogrammetry methods. Goals of the analysis presented in this paper were to define:

- The best combination of photogrammetry technologies and data acquisition methods;
- The most suitable recording scale for future investigations regarding the impact of different lithology on gully sidewall retreat;
- The smallest adequate time interval between two data set acquisitions, i.e. to confirm that one year is enough time to catch the difference between two derived gully sidewall models realistically.

Additionally, we used well-known profilometer measurement method as a safeguard. Although these two used methodologies are not directly comparable (profilometer = line measurements; photogrammetry = surface measurements) we utilized the acquired profilometer data for verification.

2. Test site

The test site was established in the central part of the Istrian peninsula, approximately 155 km southwest from Zagreb (Fig. 1). This part of Croatia is characterised by very low durable and highly erodible flysch deposits, which mainly consist of marl and sandstone layers with variable thickness (Velić et al., 2003).

The test site was placed on the very steep southwestern side of a gully (Fig. 1) and it was divided into three parts: test plot 1 (red polygon in Fig. 2), test plot 2 (green polygon in Fig. 2), and profilometer plot (marked A and B in Fig. 2). The rock wall cross section (Fig. 2) shows that the materials within these plots are approximately 30 cm thick marls and ~3 cm thick sandstones with one exception, a ~20 cm thick layer of sandstone at the top of the test plot 2.

To provide the plots with Cartesian right coordinate system (red arrows in the Fig. 2) invariant in space and time (at least during the tracking of rock wall changes), control points at each test plots were established. Each control point is stabilized by a metal stick, which was well fixed (drilled into) to the rock. The local coordinates of the control points were determined by polar geodetic measurements (done by geodetic total station: Leica TCR 705).

The areas of the test plots analysed by photogrammetric methods were: (i) plot 1, ~0.7 m^2, with an average slope angle of 55° and (ii) plot 2, ~50 m^2, with an average slope angle of 53°. Plot 2 covers an area which is large enough for future investigations regarding the impact of lithology on gully sidewall retreat, i.e. impact of thickness and share of competent (sandstones) and incompetent (marl) layers on gully sidewall retreat. However, there were some questions whether used scale will provide data of satisfying accuracy for the fulfilment of future goals. Furthermore, plot 1 was placed in the inter-rill area, and plot 2 covers both inter-rill and rill areas. We expected to record some differences in sidewall retreat within mentioned areas. But still, there were some doubts whether small-scale recordings will save those differences. Results presented in this paper cleared those doubts away.

The data acquisition was performed twice for all used methods. The first one took place in October 2008 and the second one in October 2009.

3. Methods

3.1. Terrestrial photogrammetry and the resulting rock wall retreat

The photogrammetric approach was tested by measuring and comparing the amount of the rock wall retreat using several combinations of different photogrammetric data acquisition methods at different photo scales (Fig. 3) and the following analyses were performed:

- Preliminary analysis of field and laboratory photogrammetry equipment and software;
- Accuracy analysis.

3.1.1. Preliminary analysis of field and laboratory photogrammetry equipment and software

All photogrammetric instruments and software used during this research have some pros and cons related to their operation in the field or in the laboratory. In the process of selecting the optimal instrument/software combination, one has to put emphasis on the following:

1) Every in situ measurement has to be optimised for the field usage but should not affect or downgrade the measurement results and laboratory analysis of the acquired data;
2) It is important that the equipment is light and as durable as possible. Especially for geomorphological applications, where the locations that are measured are often hardly accessible by car or foot, the data acquisition methods should be simple and as efficient as possible;
3) Data acquisition instruments and software should be of low cost and affordable.

Fig. 4 gives a short overview of advantages and disadvantages of used photogrammetric techniques and data acquisition methods at field and laboratory conditions.

3.1.2. Accuracy analysis

During the design of the photogrammetric setup, the accuracy that was reached by the simulation of the photogrammetric measuring process is calculated (Fig. 5). This accuracy is called ‘inner accuracy’ because it consists of the potentially highest accuracy of instrumentation and idealised mathematical model of data acquisition. The systematic and subjective errors are not taken into account. The formulation of the ‘normal photogrammetric case’ (Kraus, 1994) is applied here, which was adapted to the horizontal imaging case.

The normal photogrammetric case is the standard approach estimating the impact of major photogrammetric variables, which affect the accuracy of the final result. First of all, the impact of the design of the photogrammetric network, as well as the equipment used to take, process and measure photos is taken into account. That's why the formulae of the normal photogrammetric case are commonly used during the phase of preparing and planning every photogrammetric project, to