Geoderma 313 (2018) 217–232

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Soil micro-topography change detection at hillslopes in fragile Mediterranean landscapes

Anette Eltner[a,*], Hans-Gerd Maas[a], Dominik Faust[b]

[a] Institute of Photogrammetry and Remote Sensing, Technische Universität Dresden, Germany
[b] Institute of Geography, Technische Universität Dresden, Germany

ARTICLE INFO

Handling Editor: Yvan Capowiez

Keywords:
Soil erosion
Swelling-shrinkage
Roughness
UAV photogrammetry
Terrestrial laser scanning (TLS)
Andalusian marl landscape

ABSTRACT

Measuring soil surface changes at field scale can be an important tool to analyse sediment connectivity and may contribute to a better understanding of processes causing soil detachment and transport. Recent technological and algorithmic developments in high resolution topography measurement techniques enable to capture field plots with high spatial resolution and at varying temporal frequencies using UAV photogrammetry (SfM + MVS) and/or terrestrial LiDAR devices. In this study, three large areas of interest (600–2400 m^2) in Andalusia, Spain, are investigated during an observation period of 2 years. Field campaigns were conducted immediately before and after single intense precipitation events in spring and autumn to capture surface changes caused by torrential rainfall. Accuracies and resolution achieved are below 8.5 and 10 mm, respectively. An approach is used to utilise UAV and TLS point cloud data in a synergetic manner considering surface properties and data acquisition schemes. Besides the calculation of DEMs of difference to measure height changes, isotropic and anisotropic roughness is calculated to measure its influence on across- and along-slope runoff formation. On the one hand, detected surface changes reveal that the estimation of soil erosion is not possible using HiRT methods alone due to processes such as compaction, consolidation, swelling and shrinkage. Surface height shifts due to non-erosive processes amount to 26 mm. On the other hand, the HiRT measurement of these processes with large area coverage enables the detection of spatio-temporally variable micro-topographic changes, not seen before, e.g. plant and soil type influenced circular patterns and rill attenuation as well as re-appearance of former soil tillage tracks due to varying soil bulk densities.

1. Introduction

The application of UAV (unmanned aerial vehicle, 'drone') photogrammetry using Structure from Motion (SfM) in combination with Multi-View Stereo Matching (MVS) can be regarded as an established method in geo-scientific studies to describe the topography with high resolution (e.g. James & Robson, 2012, Smith et al., 2015, Eltner et al., 2016a). The advantages of fast, facile and flexible data acquisition and processing have been demonstrated for various earth surface surveys, e.g. fluvial geomorphology (Woodget et al., 2015, Dietrich, 2016), glacial geomorphology (Immerzeel et al., 2014, Rippin et al., 2015, Westoby et al., 2016), coastal geomorphology (Warrick et al., 2016) and badland observation (Smith & Vericat, 2015) as well as gully monitoring (Stöcker et al., 2015, Glendell et al., 2017).

Applications of UAV photogrammetry are still limited in soil erosion studies of rill and interrill forms (Eltner et al., 2015). This is amongst other due to difficulties to define a stable reference system, which is important to measure surface changes of small magnitudes that are typical for interrill processes. There are studies measuring erosion forms of larger magnitudes (Bazzoffi, 2015, Neugirg et al., 2016), but assessment of interrill changes is yet mostly limited to small (micro-) plots captured with terrestrial imaging sensors (e.g. Nouwakpo et al., 2015, Hänsel et al., 2016, Prosdocimi et al., 2017). However, these measurements are not transferable to hillslope scale (Parsons et al., 2006) or even basin scale (De Vente et al., 2013) due to non-linear process interaction at system boundaries (Cammeraat, 2004) and due to sediment (dis-)connectivity as a function of the distribution of event frequency and magnitude (Fryirs, 2013, Bracken et al., 2015, Faust & Schmidt 2009). Thus, a method is needed to detect surface changes with high resolution covering small to large scales.

High resolution topography (HiRT) methods, e.g. UAV photogrammetry and terrestrial laser scanning (TLS), are a possible approach to perform across-scale erosion measurement. However, soil erosion can be superimposed by other surface changing processes, such as consolidation and compaction or swelling and shrinkage of the soil surface. Consolidation occurs due to raindrop impact and soil weight

* Corresponding author.
E-mail address: anette.eltner@tu-dresden.de (A. Eltner).

http://dx.doi.org/10.1016/j.geoderma.2017.10.034
Received 9 June 2017; Received in revised form 6 October 2017; Accepted 26 October 2017

(Alaoui et al., 2011, Keller et al., 2013), whereas compaction is caused amongst others by passing of agricultural vehicles and surface rolling. Both processes are especially visible at (freshly) ploughed surfaces (e.g. Knapen et al., 2007, Bauer et al., 2015). Swelling and shrinkage, which are other possible influences at soil surface changes, occur due to three-layer structured clay minerals producing dilative soils (Ferber et al., 2009, Lin & Cerato, 2014) that can cause significant height alterations (Fernandes et al., 2015). These processes need consideration if sediment dynamic is to be estimated.

Besides volumetric change detection, HiRT data acquisition approaches enable the assessment of roughness and its change over time, which is another topographic feature important for soil erosion (e.g. Helming et al., 1998). There are many different parameters to describe soil surface height variations, e.g. considering isotropic and anisotropic roughness (Smith, 2014). The application of (close-range) photogrammetry to measure roughness has already been shown by Jester & Klik, 2005, and Taconet & Ciarletti, 2007, who use stereo-approaches. Snapir et al. (2014) are the first using SfM photogrammetry to observe roughness changes at small plots. And Bauer et al. (2015) could link alternating roughness to different soil texture and varying soil moisture, using photogrammetric methods. Thus, a next step should be the evaluation of roughness changes at larger spatial scales with the assistance of HiRT.

In this study, a multi-temporal HiRT method is introduced and favoured, which combines TLS and UAV-photogrammetry data to measure soil surface changes with cm-resolution at large field plots. The measured plots, all situated in the landscape of western Andalusia, have different soil types and underwent different tillage practices over a maximum 2-year observation period, allowing for the measurement of diverse processes that influence soil surface dynamics. Soil erosion and further surface height and roughness alternating processes are analysed, thereby detecting inter- and intra-annual cycles and non-linear variations as well as local features of surface changes.

2. Methods

2.1. Study area

Three different locations in the Mediterranean were chosen to analyse the influence of internal (e.g. soil type) and external (e.g. precipitation) forces at the magnitude and form of surface change. UAV photogrammetry and TLS was used to identify surface changes with high resolution and accuracy at field plot scale. The observed fields, called campo sandstone, campo blue marl, and campo white marl, are situated in Andalusia, Spain (Fig. 1). Two plots, campo sandstone and blue marl (referred to as northern plots), are located close to each other, solely distanced about 1 km. The third plot (campo white marl) is located about 50 km south of the northern plots. All field plots have a minimum size of 600 m^2 with the longer plot sides oriented towards the main slope direction.

The field plots were ploughed or harrowed before the first field campaign to generate a pre-event surface. Furthermore, the soil surface was kept free of vegetation during the entire observation period. At the northern plots additional wheel tracks in the middle of each plot had to be accepted to cover the entire investigation plot with herbicides. In contrast, campo white marl has not been processed anymore after initial ploughing. The surfaces were (at most) observed for two years to evaluate inter- and intra-annual changes. Apart from those similarities each field plot is characterised by distinct features unique to each chosen location (Table 1).

Rain gauges were setup nearby the plots to measure daily precipitation values. During the entire investigation period it was intended to measure the soil surface immediately before and after torrential precipitation to evaluate the impact of single events on soil erosion. Field campaigns were conducted at the end of summer and winter due to the climatic characteristic in the Mediterranean, which exhibits high spatial and temporal variability of rainfall (Pilgrim et al., 1988) and reveals dry summers and winters with rainfall events of high intensity during autumn and spring (Renschler et al., 1999). The average annual rainfall at the northern field plots is 540 mm (local rain gauge: ∅ 1981–213) and at the southern plot it is 660 mm (Meyer-Christoffer et al., 2011). Generally, site locations were chosen in fragile landscapes in the Mediterranean (Fletcher et al. 2013) due to shallow soils and torrential rainfall (Poesen and Hooke, 1997) to increase the possibility to capture events that could cause significant and thus detectable surface changes.

2.1.1. Campo sandstone

The first field plot is situated in uppermost Miocene sandstone (Andaluciense) and has a soil type dominantly composed of sand (Table 1). The slope shape is elongated. The plot was divided into separately observed sections with a size of 20 × 50 m, each. First results of surface changes are introduced by Eltner & Baumgart (2015), who used TLS point clouds. However, in this study the focus is on the combined usage of UAV and TLS data to overcome the asserted constraint of limited high resolution surface change detection capabilities, if solely TLS is used due to unfavourable scanning geometry. Furthermore, the authors aim specifically for a comparison of soil surface changes at three different plots.

The fields at campo sandstone as well as at campo blue marl are commonly prepared with conservational tillage practices. Therefore, these locations are assumed to be less affected by soil erosion. Campo sandstone was measured four times between September 2012 and October 2013. Fig. 2 illustrates the precipitation distribution during the observation period, which also applies to the field plot campo blue marl due to their proximity. In total 845 mm rain was falling at campo sandstone during the investigation interval with a daily maximum of 64 mm in September 2012.

2.1.2. Campo blue marl

The second plot is characterised by a soil type with high clay contents above 60% (Table 1).The soil has characteristics similar to an initial Vertisol because of his high clay content and is hence attributed to be dilative. The geologic background of the soil material is Tortonian blue marl. The plot is situated at a local watershed to avoid soil surface changes due to upslope runoff and to attribute potential changes to either rainfall impact and/or runoff generated directly at the plot. The slope shape is convex. As campo sandstone, the field plot was divided into two sides of sizes of 20 × 50 m, whose western half was extended to 20 × 70 m during the winter 2014.

Campo blue marl had been studied during seven field campaigns for the longest period of 19 months from September 2012 till April 2014. Since harvesting in July 2012 the western side of the field plot had not been treated, besides the usage of herbicides to keep it free of vegetation. Therefore, this plot can be investigated in regard to mid-term surface changes. The precipitation amounted 1084 mm during the two-year observation interval (Fig. 2). The event of daily maximum rainfall (64 mm) was the same as mentioned for campo sandstone.

2.1.3. Campo white marl

The third field plot is smaller than the northern plots. It has a size of 20 × 30 m. The soil type reveals high clay contents comparable to campo blue marl (Table 1). Soils are heavily degraded due to erosion phenomena (Faust & Schmidt, 2009). The plot is located in the middle of an elongated slope (Fig. 1) to increase the probability of capturing rill erosion due to increasing catchment area with increasing upslope length.

Campo white marl had been observed three times in five months from September 2013 till February 2014. The common field practice is traditional tillage. Thus, before the first field campaign the surface was freshly ploughed, which is contrary to the less impacting harrowing and grubbing techniques at the northern field plots. The precipitation sum