

Determination of Soil Erosion Using Laser Scanners

Ashraf Afana^A, Albert Solé-Benet^B and Jose Luis Pérez^C

^AExperimental Station of Arid Zone, CSIC, Almeria, Spain, Email ashraf@eeza.csic.es

^BExperimental Station of Arid Zone, CSIC, Almeria, Spain, Email albert@eeza.csic.es

^CJaén University, Campus Las Lagunillas, Edificio A3, 23071- Jaén, Spain, Email jlperez@ujaen.es

Abstract

Recent advances in laser scanning techniques have allowed for a wide variety of applications and therefore the adaption of laser scanners (LS), both airborne laser scanners (ALS) and terrestrial laser scanners (TLS), is increasing in many science disciplines. Soil erosion is not an exception, where advances in soil erosion detection and measurement techniques are a crucial step in the reduction of errors and uncertainties in soil erosion models. In this paper, topographic datasets captured by different laser scanning devices were tested in order to quantify the soil erosion by water using different software-types. An experimental protocol based on iterative processes of data capturing and processing on field plots are the essential points of the methodology. In the selected experimental site, five plots were defined and scanned before and after removing manually some soil volume, as would occur during any soil erosion process. Later on, the eroded materials were weighted at the laboratory and their volume calculated considering their bulk density. The scanned dataset (i.e. point cloud) was also adjusted and calibrated at the maximum possible resolution in relation to the device capacity (i.e. accuracy and spot size divergence). Subsequently, soil erosion in each plot was calculated with the available software-types and both laser-calculated and manual-weighted results were compared from each scan using different software-types. Results revealed that soil erosion measured with laser scanning techniques is good when adequate calibration at adequate spatial resolution is performed. Moreover, the combination of hardware and software has led to a variety of results which highlight the importance of the algorithm used by each software-type. Furthermore, soil erosion measured with TLS vary considerably in relation to the software used, and thus the values reported without indication to the software might be doubtful and should be used with caution in hydrological modelling.

Key Words

Laser scanners (LS); Terrestrial laser scanners (TLS); bulk density; point cloud; experimental protocol.

Introduction

In general, and in order to quantify soil erosion by water in the field, different methods are often used, e.g. profile-meter, erosion pins, runoff-erosion plots, etc., according to the dominant hydrological processes and/or their spatial distribution. Methods based on sediment quantification collected by automatic samplers coupled to gauging stations have severe inconveniences when hyper-concentrated flows clog the gauging devices and sensors like those in badlands (Solé-Benet et al., 2003). Whereas classic methods based on microtopographic variations (erosion pins, profile-meters) are precise at local scale, the extrapolation of their results to large scales (i.e. up-scaling) implies errors and/or uncertainties. In this work, we rehearse a non-invasive technique, based on micro-topography surveying by laser scanning techniques (Buckley et al., 2008), scantily used in soil erosion quantification. Precisely, different types of Terrestrial Laser Scanners (TLS) and different software have been tested for their suitability in the volumetric quantification of soil material (e.g. regolith or rock) exported by water erosion.

Materials and Methods

The following TLS types (and makers between brackets) have been used: ScanStation 2 (by Leica), Ilris-3D (by Optech), and LS-800 (by Faro). The datasets captured by these devices were analysed by 5 distinct software-types: Polyworks, I-Site Studio, Cyclone, Faro-Scene and JRC-3D- Reconstructor. The Faro TLS device uses the Phase-based measurement principle, which is a priori more precise but with less range than the other devices that use time-of-flight technology. All the experimental work was performed in the same selected sector of a hillslope in the Tabernas Desert badlands (figure 1). It was a bare marly area with some lichens (Canton et al., 2004) about 30 m x 30 m, with 20° slope.

Experimental procedures

Once the experimental site was georeferenced by specific fixed targets, a first scanning was performed with an horizontal resolution (x,y) of 5 mm (grid spacing), in order to obtain the point cloud used in the

generation of the first Digital Surface Model (DSM). This relief surface forms the base surface level and was named the “a” surface. Later on, all DSMs are filtered in order to generate the Digital Terrain models (DTMs) used to construct the terrain surface using the Triangulated Irregular Networks (TINs). It is important to underline that all scanning processes were carried out from the same reference point, prepared initially in order to minimize the differences between devices due to local factors, e.g. slope, distance, divergence of the laser spot, etc.; that is, equal conditions for all TLS. Next, an artificial (i.e. manual) erosion process was done in five plots using chisel, hammer and shovel, extracting every time between 1 and 2 L of soil or regolith material. The location of plots was chosen to represent variable conditions of the topographic relief (steepness, roughness of surface cover, soil humidity) (Figure 1). The manually-exported materials were stored in bags for further weighting at the laboratory. The extracted volumes were defined in relation to the variable bulk density (BD) of the site, which varies between 1.2 to 1.4 kg/L (measured with both the excavation and the cylinder methods). Consequently field measurements had an error of ± 0.12 kg/L. A second scanning was performed at the same resolution and, once processed it generated the second surface “b”. Therefore, the difference between the two surfaces (“a” and “b”) was assumed to provide a good estimation of the extracted volumes (i.e. eroded plots). This experimental protocol was repeated with every TLS instrument. The generated surfaces (i.e. TINs) by different software-types have provided different values for each plot based on the algorithm used to generate the TIN surfaces and the total number of points in the dataset (i.e. point cloud).

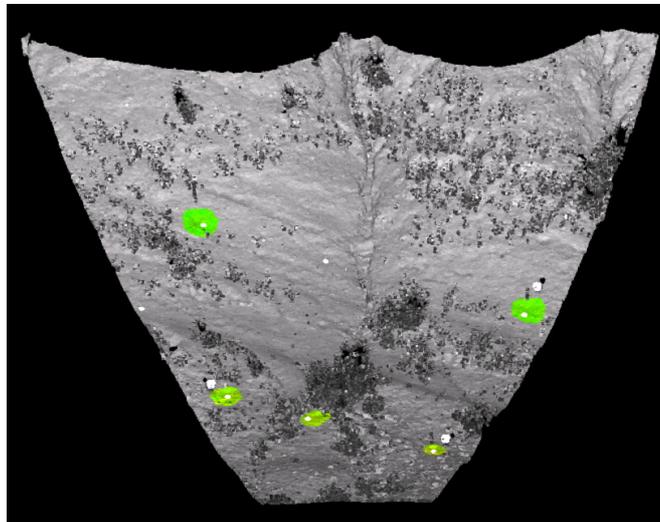


Figure 1. Map of the study area, about 30 m x 30 m, compiled by a TLS cloud of points. Manually-eroded plots are marked in green.

Results and discussion

The TLS measurements generate four types of major error: *i*) errors of the TLS itself, which is related to the TLS maker; *ii*) errors related to the horizontal resolution of the scanning process; *iii*) errors related to the treatment and filtering process; and *iv*) errors related to the algorithm used by each software in the TINs generation. In general, measurement errors produced by different scans of the same instrument (hardware) on the same area and under the same conditions of processing and treatment are minimal, and could be neglected. However, the different algorithms used by distinct software to generate the surface TINs from the same point cloud could lead to significant variations that should be evaluated.

Results revealed that both hardware (TLS) and software types are of paramount importance: results from each instrument vary in relation to the software used, and vice versa. Figure 2 shows the results of the eroded volumes measured and calculated from two devices, ScanStation 2 and Ilris-3D, and 4 types of softwares (Cyclone, Polyworks, Reconstructor, and I-Site). These results reveal a significant variation between real measured volumes (weighted in laboratory) and calculated ones (i.e. defined TINs). In figure 2, the green line of each curve, which represents the calculated values (TINs differences), highlights the clear variations for each instrument and software-type. Theoretically, the best approximation for TLS calculated volumes are achieved when all the points in the green line are located between minimum and maximum laboratory-measured values; this best fit was not achieved in any of the plots. However, the combination ScanStation 2 - Cyclone (figure 2 a) has three points between minimum and maximum values, indicating a good approximation to the laboratory-measured volumes. On the other hand, the same point cloud generated by

the same LS device but processed by another software produced moderately different results (Figures 2 c, d, e and f). It is worthy to underline that all the devices and software-types are quite close to real eroded data, indicating the high capacity and strong potential of this new technology.

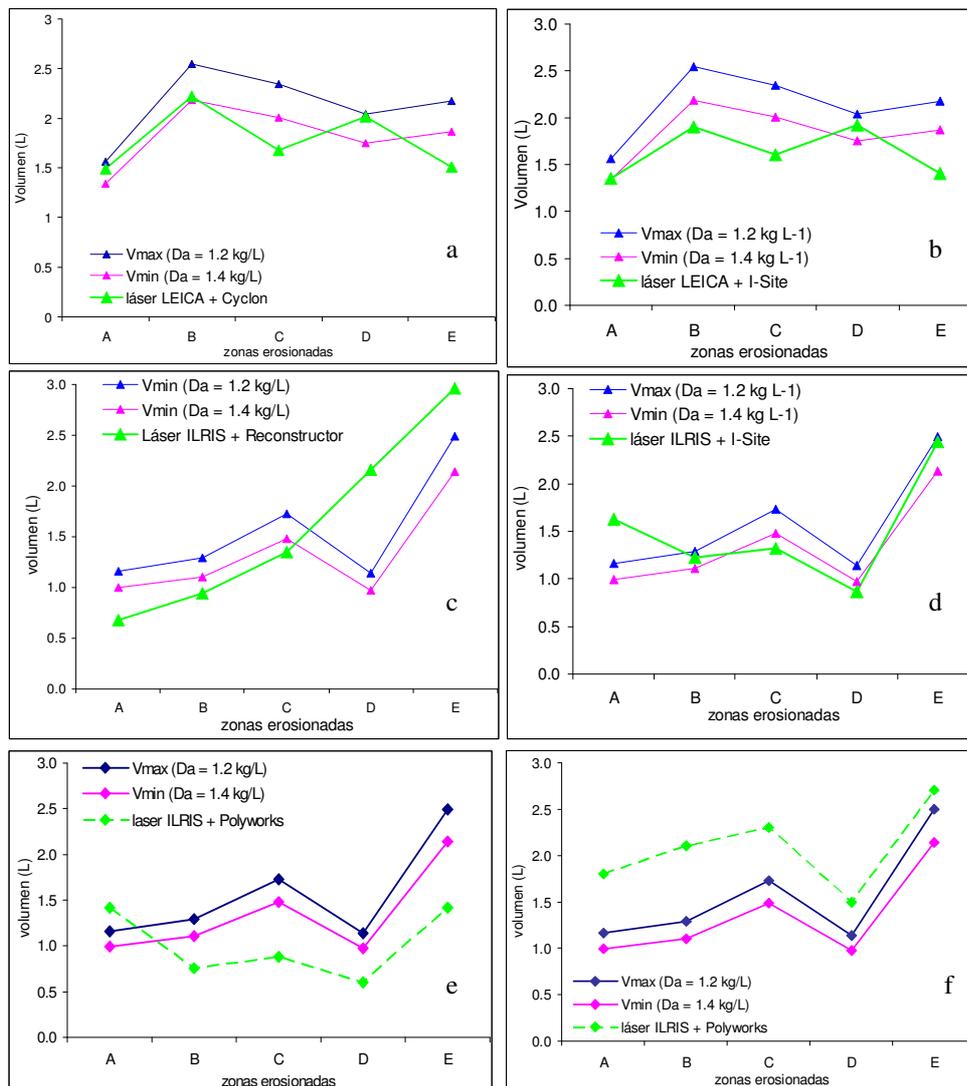


Figure 2. Volumes measured and calculated by different TLS and software-types (green dots linked by discontinuous lines). Blue and red lines dots and lines represent maximum and minimum laboratory-values.

Conclusions

Laser scanners offer a highly effective method for collecting massive volumes of precise, high-resolution 3D information for microtopographic detection, and hence surface variations. Monitoring processes of soil erosion using TLS techniques in specific parts of the landscape susceptible to erosion processes is faster and more precise than other topographic methods. Without any specific pre-evaluation of appropriateness or suitability of the different tested devices, it is possible to emphasize that all TLS achieve a sufficiently dense point cloud to generate a TIN that fit well (with a good precision and accuracy) to minimum landform surface details. However, some combinations of hardware and software achieve better results (better fit to real data) than others. Results revealed that datasets obtained from the same device (LS) but modelled by different software-types are slightly variable, which highlights the importance of the algorithm used in the surface construction process (i.e. triangulation process), a crucial step in the volumetric calculation of the eroded surfaces. When coupling TLS microtopographic data with detailed soil surface mapping in terms of soil type, cover type, etc. the TLS could be an indispensable tool for studying detailed mechanisms of soil surface erosion. Finally, due to its measuring accuracy, its high point density, and its measurement speed, TLS increasingly represents an alternative to and/or an additional option for traditional methods for data capturing and soil erosion detection.

References

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