Quantifying Short-term Surface Changes on Recreational Trails – The Use of Topographic Surveys and 'Digital Elevation Models of Differences' (DODs)

Aleksandra M. Tomczyk[1], Marek Ewertowski[2,1]

[1]Adam Mickiewicz University, Institute of Geoecology and Geoinformation, ul. Dziegielowa 27, 61-680 Poznan, Poland
Tel. (+48)-61-8296203 Fax (+48)61-829-6271
alto@amu.edu.pl, http://www.geomorfologia.amu.edu.pl/Aleks_Tomczyk.php
[2]Durham University, Department of Geography, Science Laboratories, South Road, Durham DH1 3LE, UK
Tel. (+44)07999769897 Fax (+44) 01913341801
marek.ewertowski@dur.ac.uk

Summary: The main objectives of this study are: (1) to analyse the spatial aspect of surface changes in microscale; (2) to quantify precisely the short-term rate of soil loss and deposition. Measurements were taken in 12 test fields, located in two protected natural areas in south Poland. The use of precise elevation data provided by the electronic total station and DEMs of Difference allows us to assess the volume of the surface changes. During a two-year period the avenger net volumetric change of the trail surface varied from –0.037 m^3/m^2 per year to +0.005 m^3/m^2 per year.

KEYWORDS: soil loss; erosion; recreational trail; DEM; trail impact

1. Introduction

Recreational trails are one of the key infrastructure elements which enable visitors to enjoy many of the Protected Natural Areas (PNAs). On the one hand, trails provide an easy access to certain places of interest that usually are not spatially concentrated. On the other hand, they limit recreational penetration to designated routes and prevent the scattering of visitors. In this way, areas which, for environmental reasons, should be excluded from direct human impact, can be isolated. However, the restriction of visitors traffic to certain sites (trails or campsites) brings them far more deterioration through wear and tear than the adjacent areas (e.g. Marion et al., 1993; Hammitt and Cole, 1998; Leung and Marion, 2000; Olive and Marion, 2009).

The size of incision in recreational trails has been studied using mainly three methods. The Cross-Sectional Area (CSA) method is based on the measurement along the tight links across the trail, the depth of which is measured at regular intervals, e.g. every 10 cm (e.g. Cole, 1983; Whinam and Comfort, 1996; Hammitt and Cole, 1998; Yoda and Watanabe, 2000; Kasprzak, 2005; Wałdykowski, 2006). Instead of fixed intervals, measurements can be carried out at the characteristic points of the trail surface – as in the Variable Interval Cross-Sectional Area (Variable CSA) method (Olive and Marion, 2009). An alternative to the two aforementioned methods is measurement only at the point of maximum incision to the trail. Depth is measured from the initial level of the earth's surface, which is determined by pulling across the trail measuring tape, sticks or folding car antenna (Dixon et al., 2004; Cakir, 2005; Hawes et al., 2006).

In this paper, we propose a new workflow which allows us to study the spatial and temporal aspects of trail degradation. The main objectives of this study are:

- to propose a new method for studying recreational trail transformation,
- to analyse the spatial and temporal aspect of surface changes in microscale,

- to quantify precisely the short-term rate of soil loss and deposition.

The study area for this research is two protected natural areas: the Gorce National Park (GNP) and Poprad Landscape Park (PLP), located in south-central Poland.

2. Material and methods

2.1. Precise measurements of elevation changes

Twelve segments of trails were selected for the precise measurement of elevation, so as to ensure representation from different types of use, slopes, exposure, and vegetation cover in the vicinity of the route. Test fields' dimensions were about 5 m in length and from 3 to 4 m wide - depending on the width of the trail. Each test field covered a trail tread and its surroundings.

Elevation surveys were carried out using electronic total station. Each of the measurement sessions consisted of surveys of pickets in scattered points around the test field, taking into account the characteristics of microforms. The density of surveyed points was about 80 pickets/m^2. At the end of each measurement session, 30 random checkpoints were surveyed – these would be used to verify the accuracy of surveys in later stages. Moreover, re-measuring the reference points was performed to verify whether the stabilization and level of the instrument have been retained.

Five sessions of measurement were carried out for each test field: August/September 2008, June 2009, August/September 2009, June 2010, August/September 2010.

2.2. Analysis of the microrelief transformation

A total of five digital elevation models (DEMs) using inverse distant interpolation methods and cell size 1 x 1 cm were created for each test field. Checkpoints, which were not used when creating the models, were used to assess the accuracy of DEMs. The difference between the measured elevation of the checkpoint, and the elevation obtained from the DEM, made it possible to identify the error. This difference was interpreted as the total error resulting from the inaccurate measurement and method of interpolation. The root mean square error (RMSE) for each set of checkpoints was used to measure the accuracy of mapping relief within each model. The RMSE for the DEMs was less than 1 cm.

Generated DEMs were subtracted from each other, enabling us to obtain a spatial picture of the loss or deposition of soil in each cell of the model from one survey session to another. The subtraction of DEMs from subsequent time periods (DEMs of Differences – DoDs – e.g. Wheaton et al., 2010) gave the amount of soil which was transported within the test fields and showed the spatial distribution of earth-surface changes as well. Then the value of changes was multiplied by cell size, and thus the volume of relocated mineral material was obtained. Cells whose value of changes was within the limits of the RMSE were treated as such, where there has been no change or the transformation of relief was smaller than the model error; in other words, the value 0 was attributed to them.

3. Results and discussion

The examined test fields differ in dimensions. In order to compare them with each other, we used standardized data - the total change in volume of the soil (the loss of soil + deposition) in a given field divided by its surface. The analyzed test fields are characterized by great diversity. There were test fields in which the soil loss in two years was greater than 25,000 cm^3/m^2 (0,025 m^3/m^2). There were also those where the volume of material removed and deposited was either similar or the deposition slightly dominated. Only on one of the field in two consecutive years, the direction of change was radically different; in the first year a large quantity of material was deposited, in the second year significant loss of material was recorded

In our opinion, soil properties, morphology of the trails (cf. Bryan, 1977; Cakir, 2005) and local geomorphological conditions (especially slope length above the test field) are factors which have the most influence on the amount of soil loss. These three factors are often linked together. Examined sections of the trails whose surfaces are overgrown by tree roots and berries or are covered with numerous fragments of rocks show the least transformation. Roots act as sediments traps and cause the deposition of fine grained material. Similarly, rocks can also harden the soil, which protects against excessive water erosion. When the trail tread is even, the pressure of hikers' boots cause soil compaction as well as soil hardening, which make water erosion difficult. Uneven trail tread can affect trail development in two ways. First, when the trail is hard to walk on, visitors start to bypass the deteriorated section which leads to the trail widening. Moreover, a rough trail tread also favours significant soil erosion. In case of an uneven tread, hikers destroy microforms and cause soil to loose, and in such a way facilitating water erosion and transport. Accelerated soil erosion is also facilitated by being located in the bottom part of the local slope. In such cases, the volume of flowing water after rain is high; this provides greater erosional and transportational power. The impact of soil is also variable and depends on other factors. Clay soil texture is homogenous and compacts tightly which ensures that in dry conditions it is more resistant to trampling. However, in the case of rain, such textures cause greater runoff on steep sections and creation of muddy puddles on gentle sections. Moreover, in humid conditions, boots and tyres easily slide and relocate soil particles. Soils with coarser grains and generally wider range of particle sizes are more prone to soil erosion due to boots and tyres in a dry state. However, in case of light rains, due to greater permeability, they are less prone to creation of muddiness.

3. Conclusions

The main conclusions that can be drawn from this study are the following:

- This study has developed a new method for assessing the dynamic of surface transformation in recreational trails. It incorporates precise topographic surveys and digital elevation modelling to quantify soil loss or deposition from specified areas, and not only profiles. Digital elevation models of differences (DODs) were found to demonstrate a good representation of microrelief features and their transformations. The proposed method was applied to 12 test fields in two PNAs and provided an efficient procedure for assessing soil dynamic on recreational trails.
- The magnitude of recreational trail transformation in the case of studied PNAs can be quite significant. The amount of soil loss was even up to 37,000 cm^3/m^2 per two-year period. This amount of soil loss may be visualized as the equivalent of a half-full average garden wheelbarrow.
- The spatial and temporal aspect of soil loss or deposition is vastly diversified and is for the most part related to local geomorphic conditions. Moreover, those most prone to significant soil erosion are trails with an uneven tread surface.

4. Acknowledgement

Funding for research at Gorce National Park was provided by the Polish Ministry of Science and Higher Education as a projects: N N 305 3625 33 and National Science Centre as a project: N N305 066940.

5. Biography

Aleksandra Tomczyk is a Lecturer in the Faculty of Geographical and Geological Sciences, Adam Mickiewicz University, Poznan, Poland. She completed her PhD at June 2011. Her research focuses on human impact in mid-mountain and arctic environment. She uses an approach that links field work, GIS-based modeling and geomorphometry.

Marek Ewertowski is on research fellowship in Durham University founded by PMSHE. He completed his PhD at June 2009. His research focuses on glacial geology and geomorphology with the vast use of GIS and Remote Sensing.