Connectivity and Soil Erosion: How to identify hot spots in the catchments threatened by torrent rainfall

La connectivité et l´érosion des sols : comment identifier les hot spots dans les bassins versants menacés par les pluies torrentielles?

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RÉSUMÉ

Les pluies torrentielles représentent un phénomène météorologique de plus en plus fréquent au cours des dernières décennies, affectant particulièrement les petits bassins versants dont le réseau hydrographique ne dispose pas d'une capacité suffisante pour drainer les eaux de ruissellement et les sédiments mobilisés. Dans ce contexte, la connectivité ou la disconnectivité sédimentaire joue un rôle déterminant pour l´écoulement. Une gestion inappropriée des terres, une perturbation ou, au contraire, une amélioration de la connectivité peuvent favoriser la création de crues soudaines aux conséquences dévastatrices pour les résidents locaux. La collaboration intersectorielle est essentielle pour trouver des stratégies durables et fondées sur la nature pour atténuer l'impact des phénomènes météorologiques extrêmes. Ce travail vise à établir un lien entre les processus d'érosion des terres agricoles et la connectivité du transport sédimentaire, en vue d'identifier les hot spots dans les petits bassins versants ayant connu des épisodes de pluies intenses. L'étude a été conduite sur plusieurs sites en Europe Centrale, où une cartographie détaillée de la connectivité a été réalisée à l'aide de relevés par drone. Les modèles WEPP, GeoWEPP et l'indice de connectivité ont été comparés à la connectivité réelle du terrain et à une base de données d'événements d'érosion. Le principal résultat est la carte des hot spots les plus critiques du point de vue de l'érosion des sols et de la connectivité générale, qui peut servir de base pour améliorer la gestion des petits cours d'eau, et l'utilisation des terres.

ABSTRACT

Extreme rainfall events such as torrential rainfalls are one of the increasingly frequent meteorological phenomena in recent decades. They mostly threaten small watersheds where the drainage/river network does not have sufficient capacity to drain water and sediments eroded by precipitation. In these cases, sediment connectivity and disconnections play a key role. Improper land management, disruption, or, conversely, enhancement of connectivity can support the creation of flash floods with devastating consequences for local residents. Collaboration between scientists, engineers, and local authorities is critical in finding sustainable and nature-based strategies to mitigate the impact of extreme meteorological phenomena. The main goal of our work is to link the issues of agricultural land erosion and sediment transport connectivity to identify hot spots in small watersheds where torrential rainfall occurred in the past. In selected locations in Central Europe, connectivity mapping and soil erosion quantification using UAVs were carried out, and WEPP, GeoWEPP models, connectivity index, and the method of effective catchment areas were used. The WEPP model was validated by comparison with UAV measurement results, and the GeoWEPP and connectivity index results were compared with field connectivity mapping and a database of erosion events. The main result is the map of the most critical hot spots from the point of view of soil erosion and connectivity, which can serve as a basis for improving the management of small catchments, optimizing connectivity, and improving soil protection.

KEYWORDS

connectivity, hot spots, land use management, soil erosion

connectivité, hot spots, gestion de l'utilisation des terres, érosion des sols

1 INTRODUCTION AND AIMS

Climate change affects the functioning of natural ecosystems and human society in various aspects. One of them is the more frequent occurrence of meteorological extremes that cause changes on a local to global scale. The alternation of periods of drought with the occurrence of torrential rainfall results in increased erosion of agricultural land and the occurrence of flash floods with more sediment delivery, which threaten the inhabitants living on the drainage lines. Quantifying erosion events is problematic, because it is not possible to monitor it everywhere. When erosion events occur, a large number of landowners do not report it, so it is impossible to obtain the necessary data for research. Another problem is the financial costs and permits for carrying out measurements.

The concept of connectivity has become the main paradigm in geomorphology and hydrology as a framework for the analysis of water and sediment runoff. In 2001 a general definition of hydrological connectivity as the water-mediated transfer of matter, energy, and organisms within or between the elements of the hydrological cycle was given. Today, we have various definitions based on the type or scales of connectivity, and also lots of approaches for connectivity assessment are currently in use and are still being developed. From field surveys, measurements, and mapping, it moves to indices and modelling. Despite the visible contribution to understanding sediment transport and runoff processes in watersheds, this concept is often neglected in management practice.

This study aims are: i) to integrate soil erosion modeling with the sediment connectivity approach, assess the applicability of WEPP and GeoWEPP in conditions of the Czech Republic, ii) to validate WEPP results using UAV-based soil loss measurements after torrential rainfalls, and iii) to simulate crop impacts on erosion by use of GeoWEPP. We assume that by the analysis of changing crops on agricultural land, sediment connectivity, and runoff routes, it is possible to reduce not only the erosion itself but also modify connectivity and thereby mitigate the consequences of torrential rainfall.

2 DATA AND METHODS

All five studied catchments are located in the territory of the Czech Republic (Fig.1) and have been affected by torrential rainfalls in the last decade. Four of them are so-called catchments of critical points. This means that they are in the database of watersheds susceptible to the occurrence of flash floods (Drbal et al., 2009). Within these five catchments, overall seven hillslopes were measured by UAV in terms of total soil loss.

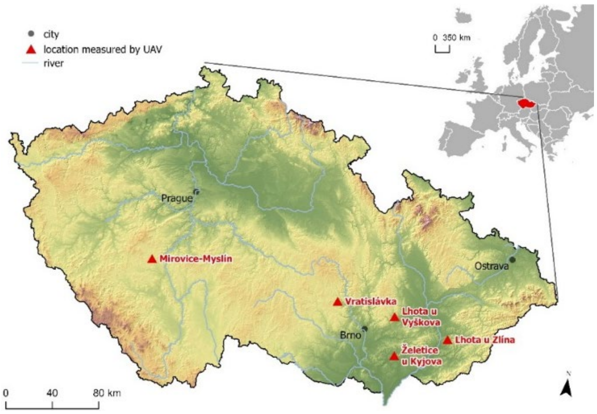

Figure 1. Location of analyzed catchments in the Czech Republic

For analyses in this study were used available general data for the Czech Republic (DEM, soils, climate, and land use). Data were processed in ArcGIS and prepared as shapefiles and rasters in a resolution of 1m and 4m. For the WEPP and GeoWEPP models, some data (climate, slope, soils, and land use) has to be prepared also in a special format. The DEM and orthophoto maps and land use data were obtained from the State Administration of Land Surveying and Cadastre (CUZK). Information about soil properties was extracted from the Comprehensive soil survey (KPP) managed by the Research Institute for Soil and Water Conservation (VUMOP). Climate data from meteorological stations and radar were provided by the Czech Hydrometeorological Institute (CHMI).

2.1 Soil Erosion and Sediment Connectivity

In the Czech Republic, a database of erosion events was established by the VUMOP, which is constantly updated. In the past, 7 locations in the Czech Republic were analyzed using a UAV led by the Water Research Institute

(WRI) to calculate the total sediment loss by the causative precipitation event. These values (Tab. 1) are used to validate the results for total soil loss during single-storm events obtained by the WEPP model (Renschler, 2003).

Table 1 – Quantity of soil loss calculated from UAV measurements results

Catchment	Site	Date	Soil Loss [m^3]
C1	Mirovice-Myslín	8/19/2022	1111
C2	Vratislávka	6/14/2020	909
C3	Lhota u Vyškova – hillslope I	8/28/2022	341
	Lhota u Vyškova – hillslope II		279
C4	Želetice u Kyjova – hillslope I	8/20-21/2022	179
	Želetice u Kyjova – hillslope II		1361
C5	Lhota u Zlína	8/26/2019	398

Connectivity is one of the main factors that affect the runoff from the watershed and the course of the flood itself. Several methods were used for its assessment, starting with connectivity mapping in the field, delineation of effective catchment areas (ECA) (Fryirs et al., 2007), connectivity index (Borselli et al., 2008) and GeoWEPP model (Renschler, 2003).

2.2 Hot Spots Delineation and Best Crops for Agricultural Land

Based on the overlay of the outputs from the individual sediment connectivity assessment approaches and GeoWEPP model, a final map was created showing the most critical *hot spots* from the point of view of erosion and sediment transport for individual catchments. The map shows areas at risk of significant erosion, more than 1t/year, connected to the main drainage line, and represents the primary sources of sediments with a high transport potential during extreme precipitation. Changes in erosion and connectivity were tested by the various types of crops for agricultural land. These analyses are done by GeoWepp, and connectivity index, where the parameter of agricultural land was changed between fallow, wheat, corn, pea, rape seed, grass, and forest. For the Connectivity index, the C-factor from the USLE equation was used as a weighting parameter. All results are analyzed in terms of finding the most suitable land use that can help decrease soil erosion and optimize connectivity.

3 PRELIMINARY RESULTS

The results of the WEPP model validation using measured data showed a difference in the total amount of soill loss within the range of 2 – 48 % at seven sites. The minimum difference was obtained for the Catchment 2 (C2) where GeoWEPP overestimated soil loss by 2.4 %. Areas with an estimated soil loss exceeding 1 t/year, as derived from on-site modeling results, were analyzed. The spatial distribution of these critical erosion zones was further compared with the ECA derived for a 2° slope threshold to assess the degree of spatial agreement. Other tested slope thresholds for the ECA were found to be unsuitable for the studied catchments. In all analyzed catchments, areas with an average annual soil loss greater than 1 t/year account for 70% or more of the total area. Contributing areas delineated by ECA cover more than 50% of the total area in C3, C4, and C5, and approximately 30% in C2. A notably low proportion was observed in C1, where it constitutes less than 5% of the area. A strong spatial correspondence between the contribution areas delineated at a 2° threshold, and GeoWEPP predictions above 1 t/year are evident in C3, C4, and C5, where 75% or more of the area identified by GeoWEPP falls within the area obtained by ECA.

Connectivity Index maps show the spatial distribution of more/less connected areas within the whole catchments. In the case of C2 and C4, the lower connectivity is caused by the low proportion of agricultural land and higher forest cover. Connectivity in C2 is affected by a small water reservoir that retains water and sediments. In the case of C4, connectivity is significantly affected by the presence of dense road infrastructure and settlements. These man-made structures disrupt the natural flow of water and can lead to increased sedimentation, thereby affecting the connectivity of the basin.

A series of maps that show mapped connectivity features obtained during fieldwork and also results from the GeoWEPP (GW) model for each Catchment was created. In C3 (Figure 2), the drainage lines identified in the field are mostly similar to those that were delineated by the model. The grass lawn on the main drainage line in the middle part of C3 appeared on GW as a feature with deposition on its edges or decreasing soil loss. A similar situation is for parts with the forest and grassland. Most of the deposition is modeled around features that influence connectivity. C3 is used mainly for agriculture, so the erosion potential here is high. For 70% of the area, the average annual soil loss is 1t/year or more, and 37 % is in the category of 4t/year and more. A total of 22 hot spots were identified in C3. 15 represents potential sediment delivery to the main drainage line from the left side.

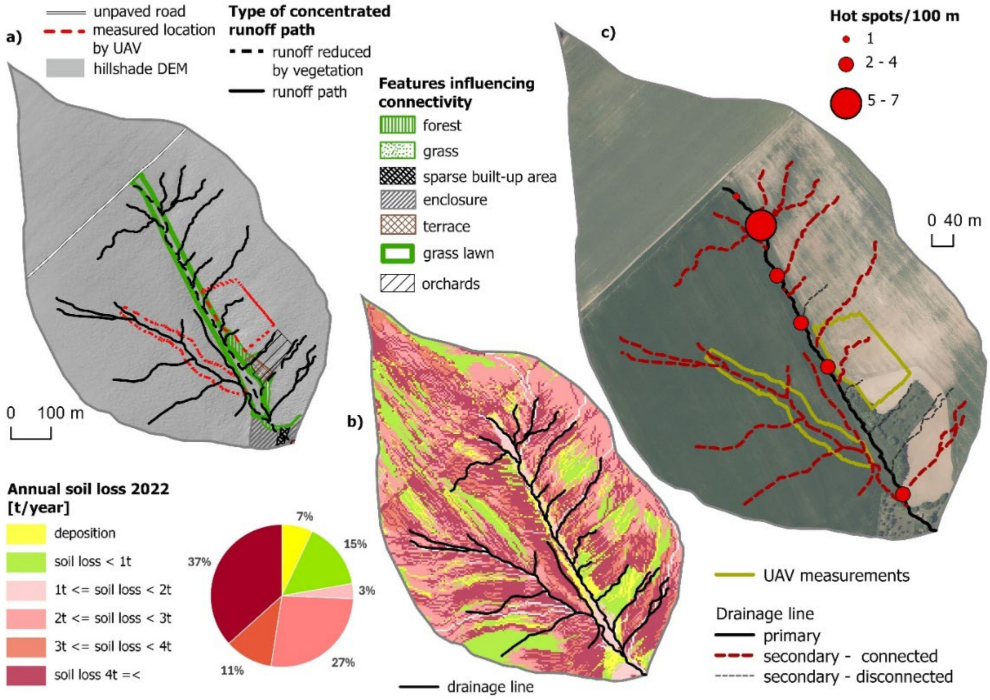

Figure 2. Catchment C3: a) Connectivity mapping, b) GeoWEPP, and c) map of *hot spots*

4 CONCLUSION

Human society faces an increasing challenge in the field of adaptation to climate change, which brings more frequent extreme meteorological phenomena. These include torrential rainfall, which can cause enormous damage to infrastructure, property and human lives. To protect natural ecosystems and sustainability, it is necessary to look for effective measures close to nature that help reduce the effects of extreme hard-predictable rainfall events. However, this is only possible with more detailed regional and local analyses that deal with natural conditions. By identifying *hot spots* we can make land management more efficient, reduce the consequences of flash floods, and improve the infrastructure in the catchments. Proposed coupled methodologies provide good results in identifying hot spots, but they must be applied appropriately to the scale of the studied catchment/basin. We cannot influence when and where torrential rainfall will occur, but we can learn from the past. Knowing the watershed's physiographic features, landscape connectivity, and water-sediment transport can help mitigate flash flood impacts and protect people and infrastructure.

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