GUEST EDITORIAL-SPECIAL ISSUE: Mapping and modelling soil erosion to address societal challenges in a changing world

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GUEST EDITORIAL—SPECIAL ISSUE: Mapping and modelling soil erosion to address societal challenges in a changing world

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Abstract

Special issue Mapping and Modelling Soil Erosion to Address Societal Challenges in a Changing World presents advances in interdisciplinary methodologies for the study of the soil erosion/land management/climate change nexus, with a focus on societal challenges linked to land degradation. Contribution of 22 research teams active in 17 countries all over the world provided a global perspective on how soil erosion research contributes to meet societal challenges of our time. The authors conclude that (a) inclusive representation of non-linear system feedback between erosion and land management; (b) combination of mapping, measuring, monitoring, and modelling methods on different temporal and spatial scales; and (c) inclusive, cooperative interdisciplinary research approaches are inevitable to support management aiming for land degradation neutrality.

1 SOIL EROSION RESEARCH IN A CHANGING WORLD

Land degradation, as part of the coupled natural and human system, leads to the reduction of biophysical, sociocultural, and economic functions of the ecosystem. Moreover, it is acknowledged that even regional land degradation has global consequences (Conacher & Conacher, 1995; Leal Pacheco, Sanches Fernandes, Valle Junior, Valera, & Tarlé Pissarra, 2018). Soil erosion is an old phenomenon and the most important land degradation processes (Orr et al., 2017), which has been accompanying human landuse and land management through millennia (Dotterweich, 2008; Hoffmann et al., 2010; Smetanová, Verstraeten, Notebaert, Dotterweich, & Létal, 2017; Teuber et al., 2017).

Over the years, land management has had negative, neutral, or less frequently positive effects on the ecosystem, that is, causing land degradation or not (Vanwalleghem et al., 2017). However, during the last few decades, soil and land degradation related to intensifying land management under increasing population and food production pressure has increased to such an extent that the land's ability to meet the future demand for food production is severely threatened (Brevik, 2013; Gomiero, 2016; Lal, 2013; Lal, 2016; Olivier & Gregory, 2015; Smith et al., 2016). The concept of planetary boundaries helps to define a safe operating space for humanity (Rockström et al., 2009); due to its extent and consequences, the land system change (including change from natural to agricultural system, intensification of land management in existing agricultural areas, and land degradation) was specified as one of these boundaries on regional to global levels (Steffen et al., 2015). Improving the condition of ecosystems and human well-being via maintaining sustainable life on land and access to clean water under ongoing environmental changes are some of the most pressing recent challenges reflected in a governance context within the Sustainable Development Goals Agenda (United Nations, 2015). Healthy, noneroded soils and soil functions are crucial factors for keeping land in balance (Cowie et al., 2018; Keesstra et al., 2016). To this end, scientific knowledge and understanding of non-linear system dynamics of socioecological systems can improve the development and application of land degradation neutral management practices (Cowie et al., 2018; Okpara et al., 2018; Sietz, Fleskens, & Stringer, 2017).

2 SOIL EROSION RESEARCH FOR A CHANGING WORLD

At the same time, a number of approaches have been developed for soil erosion mapping (e.g., field soil and legacy sediment mapping, remote sensing analyses, and sediment fingerprinting), measuring (e.g., laboratory and plot experiments, laboratory soils and sediment analysis, plot to catchment monitoring, and tracer dating techniques), and modelling (e.g., conceptual, statistical, and physically based models). This knowledge base is documented, for example, by more than 19,000 articles published between 1988 and 2018, which are registered in the Web of Science Core Collection (key words: 'soil erosion,' 'sediment dynamics,' and 'land degradation'). The link between the magnitude and frequency of erosion responses to precipitation and landuse constraints and management has been clearly established, both mediated by soil–water–plant interactions and landscape hydrological and sediment connectivity (e.g., Keesstra et al., 2018; Mullan, Vandaele, Boardman, Meneely, & Crossley, 2016; Smetanová, Le Bissonnais, et al., 2018; Smetanová et al., 2019). Furthermore, research has shown that changes in landuse could have a greater impact on long-term erosion rates than changes in climate (López-Moreno et al., 2014; David et al., 2014; Nunes, Jacinto, & Keizer, 2017; Serpa et al., 2015; Bussi, Dadson, Prudhomme, & Whitehead, 2016, Carvalho-Santos, Nunes, Monteiro, Hein, & Honrado, 2016; Rodriguez-Lloveras, Buytaert, Benito, 2016; Borrelli et al., 2017). This has a significant implication for the evaluation of the potential impacts of climate change on land degradation, including necessity to consider the societally driven landuse/land management changes. These studies have improved our understanding of soil erosion process on different temporal and spatial scales, the interactions between erosion and climate or landuse, and the role of soil erosion in land degradation. They have also highlighted the urgent need to study the combined effects of climate change and landuse change on soil erosion and land degradation. Further research is needed on the simultaneous analysis of erosion processes at multiple scales (Poesen, 2018), the relationship between the on-site and off-site consequences of soil erosion, and on improving the understanding of soil erosion by society in general (García-Ruiz, Beguería, Lana-Renault, Nadal-Romero, & Cerda, 2017).

Furthermore, as illustrated above, soil erosion and land degradation research has produced data and methods which allow the assessment of trends and their drivers (e.g., Borrelli et al., 2017; García-Ruiz et al., 2015; Wang et al., 2017), and test and suggest sustainable land management scenarios by applying multimethod approaches (e.g., Furlan, Poussin, Mailhol, Le Bissonnais, & Gumiere, 2012; Nunes, Seixas, & Keizer, 2013; Zhao et al., 2018).

Increasing the involvement of soil erosion and land degradation scientists in projects related to decision making or governance and sharing common perspectives with stakeholders active in land and water management (e.g., Nunes, Doerr, et al., 2018, Smetanová, Paton, et al., 2018), with or without SDGs-related initiatives, opens a window of opportunity for policy makers to include scientific knowledge and tools to build holistic sustainable management (Stringer et al., 2018) and to better prepare for the challenges of our changing world (Benton et al., 2018; Kareiva & Fuller, 2016; Lal, 2016).

3 TIMELINESS AND RELEVANCE OF THE ISSUE

This Special Issue presents advances in interdisciplinary methodologies for the study of the soil erosion/land management/climate change nexus, with a focus on societal challenges linked to land degradation. It includes studies on different time (from events to centuries) and spatial (from plots to large catchments) scales, which address this nexus in the past and the present, and try to predict its development in the future. It also reflects the progress that has been made with respect to outstanding research needs (García-Ruiz et al., 2017; Poesen, 2018).

The Special Issue, containing the work of 22 research teams, provides a global perspective studying erosion in 17 countries from Africa, North America, Asia, and Europe. The articles in this issue were built on research presented at the European Geosciences Union (EGU) General Assemblies of 2015, 2016, and 2017, in a homonymous session led by the five authors of this editorial (Smetanová, Nunes, Symenoakis, Schindelwolf, and Ciampalini).

A first group of articles offers a historical perspective on the soil erosion–climate–land management nexus. Balbo et al. (2018) studied legacy sediments in Medieval Menorca; they observed land degradation chronologies to be influenced by both climate and landuse change, with positive feedbacks resulting in amplified environmental change. González-Arqueros, Navarrete-Segueda, and Mendoza (2018) and Kijowska-Strugała, Bucała-Hrabia, and Demczuk (2018) applied modelling and statistical approaches in the Teotihuacan and Aztec Periods in Mexico, and the last 160 years in the Polish Carpathians, respectively, and found soil erosion to be more related to landuse than to climate changes. Golosov et al. (2018) modelled run-off and snow-melt erosion, recognized abandonment of agricultural land to be responsible for decreased erosion rates in the last 30 years in the Russian plains, and suggested that snow-melt erosion is influenced by changing winter air temperature patterns.

The larger share of articles analyses the effect of landuse on erosion, including the role of soil conservation measures. Nunes, Naranjo Quintanilla, et al. (2018) evaluated the effects on afforestation and subsequent forest fires on erosion and sediment export in mountainous Portugal, suggesting that fires have led to an increase in erosion and extreme sediment yield episodes and recommending post-fire management practices. Raclot, Le Bissonnais, Annabi, Sabir, and Smetanová

(2018) discuss the future development of Mediterranean soil resources. Both this and the previous article highlight how landuse changes can have a much greater impact in soil erosion dynamics than in the hydrological cycle. Yang and Lu (2018) applied a water erosion model to assess the efficiency of soil water conservation measures within the Green-for-Grain Program on the Chinese Loess Plateau. Subhatu et al. (2018) used a similar approach for evaluating the efficiency of fanya juu bunds on water and tillage erosion in Ethiopia. Taye et al. (2018) also focused on Ethiopia, assessing the effectiveness of soil water conservation measures by plot monitoring in semi-arid range lands and croplands. They provided time-varying cover-management and conservation practice factors (C and P) of the Revised Universal Soil Loss Equation (RUSLE), commonly applied in erosion-related analyses. The effect of common management practices on erosion by wind is studied by Pierre et al. (2018) in an agro-pastoral landscape in the Nigerian Sahel. They proved that seasonal wind erosion fluxes were triggered by management practices, while interannual fluxes were affected by meteorological conditions in the previous year. Yan, Zhan, Yang, Liu, and Li (2018) also analysed wind erosion and how it is impacted by increased fractional vegetation cover within the Ecological Water Diversion Project in a semi-arid catchment in northwest China.

A third group of articles presents new methodologies for assessing the impacts of landuse on soil erosion. A statistical-based method for calculating the soil erodibility factor (K) of RUSLE was developed by Corral-Pazos-de-Provens, Domingo-Santos, and Rapp-Arrarás (2018), based on more than 300,000 horizon samples from the United States of America. Mapping and measuring techniques applied by Balaguer-Puig, Marqués-Mateu, Lerma, and Ibáñez-Asensio (2018) and Gudino-Elizondo et al. (2018) present state-of-the-art methods for event-scale rill and gully erosion analysis, respectively. The first used lab data, while the latter employed data from rapidly urbanizing catchments in Mexico. A new approach to support dam management in large ungauged catchments was suggested by Le Roux (2018), who combined mapping and modelling to evaluate both hillslope (rill, interrill) and gully erosion under recent climate (last 30 years) in South Africa. This approach allows for the prediction of sediment delivery and, most importantly, the calculation of life expectancies of dams. Borrelli, Meusburger, Ballabio, Panagos, and Alewell (2018) developed a novel spatial–temporal approach to compute an enhanced cover-management factor of the RUSLE. Using a spatially and temporarily variable C-factor in a soil erosion model enabled them to predict, for a Swiss catchment, where and when soil erosion is most likely to occur.

A fourth group of articles addressed the impacts of future climate and landuse change on soil erosion. Rajasree and Deo (2018) addressed the question of how erosion in a coastal estuary could develop under future climate conditions in India. The effect of uncertainty in landuse change projections was addressed by Shrestha, Cochrane, Caruso, and Arias (2018) using an ensemble forecasting of landuse changes for 2060 in the Mekong River Basin, Southeast Asia.

The final group of articles documents examples of successful cooperation between scientists and nonacademic stakeholders in research and management planning. Guzman et al. (2018) used a combination of hydrological and erosion monitoring, soil erosion modelling, and participatory approaches (group discussion, transect walk, participatory mapping) to evaluate the most suitable methods for soil conservation planning in Ethiopia. Waltner et al. (2018) used reports from a farm management system to assess the precision of model-based soil erosion risk maps in Hungary.

Hewett, Simpson, and Wainwright (2018) developed a tool for communicating and visualizing erosion risk to infrastructure in Britain by combining hydrological, geomorphological, and participatory action research principles. Zolezzi, Bezzi, Spada, and Bozzarelli (2018) developed a low-cost, repeatable methodology to quantify gully properties and to suggest appropriate mitigation measures in Uganda, combining observations with stakeholder interviews. They further up-scaled their method to provide a country-scale map of urban areas under the threat of urban gullying and described drivers of evolution of gullies in a sociogeomorphic system.

4 TAKE HOME MESSAGES

The Guest Editors of this Special Issue would like to thank the 22 author teams for their work, and to highlight their scientific contributions. The multiple case studies around the globe provided insights on the soil erosion–climate–landuse change nexus, with several common messages emerging:

The understanding and inclusive representation of non-linear system feedbacks between climate and land management in coupled human–natural systems are fundamental to properly represent soil erosion processes and for effective management aiming for land degradation neutrality.

Scientists operate a powerful toolbox, including a multitude of mapping, measuring, monitoring, and modelling methods, applicable to different temporal and spatial scales: from rainfall events to centuries and from land plots to large catchments/regions. These should be seen as compatible rather than competing and are more effective when combined in land degradation neutrality management efforts.

Inclusive, cooperative, and participatory interdisciplinary science is being applied to address societal challenges related to land degradation. The science-policy dialogue on land degradation neutral management is essential to strengthen the cooperation and inclusion of scientific knowledge in practical management decisions and sustainable development strategies.

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