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Special Section: Erosion and Lateral Surface Processes

Core Ideas

- This special section is a snapshot of current work and understanding of lateral surface transport processes.
- The particular focus is on soil erosion.
- Soil erosion is a very large and very important topic.
- It must be addressed from both practical and rigorous scientific angles.

Erosion and Lateral Surface Processes

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Erosion can cause serious agricultural and environmental hazards. It can generate severe damage to the landscape, lead to significant loss of agricultural land and consequently to a reduction in agricultural productivity, induce surface water pollution due to the transport of sediments and suspended material to waterways and rivers, and alter the operation of hydraulic structures due to clogging of channels and sediment loading in reservoirs, estuaries, and oceans. The loss of soil due to erosion will also diminish its capacity to store water, which will not only negatively affect plant growth but might also increase the risk of flooding. Furthermore, erosion plays a significant role in the biogeochemical cycles of carbon, nitrogen, and phosphorus as it redistributes significant amounts of these elements across the surface of the Earth. This special section focuses on many of these aspects and gathers studies presenting valuable experimental and monitoring data, recent relevant technologies and measuring tools, and new modeling approaches that allow a better estimate of the intensity of the degradation processes and a better assessment of their multiscale nature and their coupling with biogeochemical processes as well as soil functioning.

Soil erosion is one of the processes that determine the biogeochemical fluxes that occur between the terrestrial biosphere and the atmosphere. The evaluation of these fluxes is crucial for several key issues such as natural hazards, environmental pollution, climate change, agricultural production, and water resources management (Martinez et al., 2017). Experimental data and quantitative estimates of the intensity of the soil degradation process generated by soil erosion are required to: (i) assess the relative importance of its impacts on the soil and water resources on a regional basis; and (ii) evaluate the efficiency and the cost of the proposed alternative solutions of the problems. The multiscale and nonlinear nature of the processes involved in soil erosion and the high spatial and temporal resolution of the required input data create a challenging modeling environment (Hu and Flanagan, 2013). Fundamental knowledge gaps remain, especially hampering moving up and down along the different scales pertinent to the processes involved. These gaps pertain in part to the interaction of dominant processes that are more or less active at different spatial and temporal scales. For example, at the hillslope scale, dominant processes tend to be related first to interrill erosion at the smallest scale and then to rill erosion as slope lengths increase (Cerdan et al., 2006; Meyer and Monke, 1965). Ephemeral gully erosion may also be active but usually at a slightly larger scale associated with small watersheds (Foster, 1986). However, these scale-dependent processes are also temporally variable as well because in the cases of the rare extreme events, processes commonly active at a larger scale may become active at smaller scales (Øygarden, 2003). For example, in an extreme event, an ephemeral gully may appear on a hillslope where under common conditions only interrill and rill erosion would be active.

Furthermore, relatively little attention has been given to the modeling of transport across the landscape of soil material mobilized by erosion. This is important, nevertheless, because it will not only control the amount and quality of the sediment that will eventually reach the stream network and the oceans, but it will also control the fate of the nutrients and carbon transported with this sediment (Carpenter et al., 1998; Lal, 2003). Therefore, modeling tools should not only focus on the prediction of erosion rates but should also investigate the coupling between erosion and soil functioning and biogeochemical cycling in the Critical Zone (Vereecken et al., 2016). A related challenge is the

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assessment of human disturbance on erosion rates and sediment fluxes at larger scales: especially in mountain (Zhou et al., 2008) and wildland areas (Weltz et al., 1998), natural erosion processes contribute strongly to sediment movement, making it difficult to assess correctly the effect humans have on total lateral fluxes of sediment, carbon, and nutrients. Importantly, these issues need to be investigated at different time scales: erosion processes invariably change soils and landscapes, and these changes feed back to erosion processes and rates. Such feedbacks have hitherto insufficiently been considered in erosion research (Kirkby et al., 1996).

This special section gathers studies presenting valuable experimental and monitoring data, recent relevant technologies and measuring tools, and new modeling approaches, allowing a better estimate of the intensity of the degradation processes and a better assessment of their multiscale nature and their coupling with biogeochemical processes as well as soil functioning.

The special section starts with two very different review articles. The first is related to the well-known issue with the Great Barrier Reef of Australia and the complex interrelationship with sediment and nitrogen effects on the health of the reef. This is a problem of obviously huge international interest. Hairsine (2017) lays out current understanding about the modern day accelerated transport of sediment and nutrients to the reef from the terrestrial environment and its negative influence on the marine ecosystem. He then outlines the spatial configuration of the sources and sinks in the system and briefly discusses the scale of interventions that will be necessary to adequately address the problem.

The primary driving force of soil erosion by water at the hillslope scale is generally referred to as rainfall erosivity. It is an important characteristic, highly variable in space and time (Panagos et al., 2016; Assouline, 2009), that determines the soil erosion intensity in most landscapes. Yin et al. (2017) provide a review of the history and active research that addresses this important topic, which will hopefully lead to an improved use of the concept across all parts of the world in applications associated with erosion assessment and soil conservation planning.

New Monitoring Methods

Improved methods for measuring and monitoring erosion rates and processes in the field are critical for improving our understanding of erosion and lateral surface processes. Two relatively new methods, with great potential for improving our understanding of erosion processes and measuring capabilities of erosion rates, are the use of terrestrial lidar and rare earth element tracers. Oz et al. (2017) present the results of a study conducted in northern Israel on the potential for using lidar to monitor soil loss on agricultural plots after rainfall events. In recent decades, the cost of establishing long-term erosion monitoring plots has become prohibitive in many parts of the world. If successful, this method could open up a new, accurate, and relatively inexpensive method for collecting medium- to long-term soil erosion data that would greatly enhance our databases on soil loss as a function of the many various environmental and management factors that are critical to quantifying erosion and developing conservation strategies.

The rare earth element tracer work (Zhang et al., 2017) tackles a different problem—that being our ability to understand and measure the spatial distribution and movement of sediment within, across, and out of landscapes. This contribution addresses a potential weakness of the method, which is that of sediment enrichment in fine particles during the transport process, and hence the associated enrichment of the rare earth elements that bind preferentially to these fine particles. This study suggests an easy and effective way to address this conundrum in a quantifiable and reliable manner.

Field monitoring of sediment and the associated chemical and organic components that move with the sediment is another critical part of improving our ability to understand processes and improve conservation outcomes. The various monitoring and measuring studies in this issue cannot hope to cover the nearly infinite situations present around the world, but they do illustrate examples of how such studies might be performed and what types of information might be gained from them.

One often overlooked but important aspect of such monitoring is associated with the movement of fine sediments in subsurface drainage tiles. Grangeon et al. (2017) conducted monitoring of sediment from a nested drainage tile network in France to illustrate the importance of continuous monitoring needed to accurately quantify the losses of sediment through drainage tiles in lowland, agricultural areas. Two other measurement studies presented here address other important environments and situations that illustrate examples of the usefulness and importance of monitoring.

Abandoned agricultural lands tend to alter environmental function in many parts of the world under a wide variety of situations, sometimes for the better and sometimes for the worse. Rodrigo Comino et al. (2017) looked at the impact of abandonment of vineyards (*Vitis vinifera* L.) in Germany. The results illustrate the significant changes, in this case improvements in water holding capacity, that may occur in the hydrologic functioning of the soil after such abandonment.

Biogeochemical Fluxes

The fate and transport of organic matter and P are closely associated with the movement of sediment, and in particular fine particles, in many ecosystems. Both of these constituents have importance for ecological functioning from a local scale (e.g., eutrophication) to a global scale (carbon storage and emissions). Gómez et al. (2017) studied runoff and sediment discharge from three olive (*Olea europaea* L.) orchards in Spain and analyzed the dissolved organic carbon, reactive phosphorus, total organic carbon, and total phosphorus. From these data, they were able to develop a statistical model of these processes, applicable for evaluating conservation alternatives.

Even after decades of research, through which we have gained a generally comprehensive understanding of the physics and chemistry of the processes, we still have a lot to learn. One topic that has come to light is how the surface morphology of the soil changes as erosion occurs, and how this change in turn impacts flow velocities (Govers et al., 2000; Assouline and Ben-Hur, 2006). The change in flow velocities then in turn impact the erosion, bringing the system full circle in a feedback loop of processes referred to as slope–velocity–equilibrium (Nearing et al., 2017). This general process appears to be relatively universal across many types of soil surfaces and erosion conditions. Di Stefano et al. (2017) investigated the process of step-pool formation in eroding rills, offering a new theoretical approach and adding another layer of information regarding this important process of slope–velocity–equilibrium.

Modeling and Scale Issues

Models play an important role in the scientific field of lateral transport processes, particularly relative to soil conservation planning and practices used to minimize the detrimental effects of erosion. One important aspect of modeling erosion is the ability to evaluate the validity of models using comparisons of model estimates to measured field data. One such quantitative criterion was suggested by Nearing (2000) based on the idea that the physical model represented by a replicated plot functions as the best possible, unbiased, real world model to predict plot soil erosion. Bagarello et al. (2017), using data from Sicily, suggest an improvement on the original mathematics of the method that results in less restrictive criteria for acceptance of model results.

The issue of crossing temporal and spatial scales presents several particularly thorny problems for the field of soil erosion. Scaling up or down in time is never a straightforward matter of linear interpolation because of the variable but intertwined sets of processes that must be considered. For example, moving from a hillslope to a watershed scale is not a simple matter of linear additions of soil loss, in part because of the interactive nature of soil detachment and sediment transport. Furthermore, understanding or measuring sediment loads at watershed outlets or other specific points within the landscape is not generally indicative of the soil erosion that is occurring within a watershed boundary, particularly on the hillslope.

Another particularly interesting property of understanding scaling is related to the relative dominance of a few major rainfall events that tend to drive the system. This effect and others were studied in an ambitious study from Tunisia (Inoubli et al., 2017) using a 7-yr set of monitoring data at four nested spatial scales. To complicate the problem further, these researchers were dealing with a soil that experiences cracking during the dry season, which is a very difficult problem to address using traditional modeling techniques.

Back to Sicily, Bagarello and Ferro (2017), used data from experimental plots of varying lengths under natural rainfall to investigate slope length effects on soil losses and runoff volumes.

From a modeling approach, Lisle et al. (2017) used the popular Hairsine and Rose (1992a, 1992b) model of soil erosion to better understand, from a mathematical perspective, the inherent time scales involved in the process of erosion at the hillslope scale. Their analysis considers particle entrainment, transport, deposition, and potential re-entrainment, all of which are variable as a function of sediment particle sizes.

Concluding Remarks

The purpose of this special section is to introduce a snapshot of the current work and our modern understanding of lateral surface transport processes, with a particular focus on soil erosion. We attempt here to show several of the important lines of research as well as the techniques commonly used. Obviously, it is impossible to address every important matter of interest or line of research. For example, the current use of watershed-scale modeling using geographical information systems linked with either statistical (e.g., Universal Soil Loss Equation) or process-based models is not addressed here. We also did not attempt to address in a significant way the application of soil conservation methods, either from a physical or social perspective. The topic of lateral surface transport processes and soil erosion is a very large and very important topic that must be addressed from both practical and rigorous scientific angles. We hope that this special section contributes to that goal.

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