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Editorial

Geoinformatics and water-erosion processes

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ABSTRACT

Geomorphologists have commonly published conclusions about soil erosion and water movement based on experimental data obtained at the catchment scale. The underlying assumptions were that there exists little spatial variation in conditions at the hillslope scale (the fundamental unit) and that the catchments are representative of other catchments in the same region. These assumptions are unlikely to be tenable in practice. Indeed, we suggest that there is substantial spatial variation in geomorphological properties even at small distances when observed at fine spatial resolution and that modern geoinformatics approaches can be used to quantify and characterize this variation. This introduction reviews the ten papers that comprise this Special Issue on Studying Water-Erosion Processes with Geoinformatics, drawn from across the geomorphological sciences. The water erosion processes studied in these papers include sediment transport, fluvial processes, slope denudation, landsliding, bank erosion and bank line migration. The findings suggest that innovative measurement and modeling approaches such as GPS measurements, geostatistics, image processing techniques, and physically-based models deliver new data with which to study water erosion processes. These findings involve domains that are associated with fundamental aspects of geomorphology. Hence, there are strong grounds for claiming that geoinformatics can contribute to greater understanding of water erosion processes through characterization of space–time dynamics. We suggest that geomorphologists need to use more geoinformatics to collect more data relating to the outcomes of water erosion processes, to seek out and apply innovative processing methods and, finally, model the data to provide greater understanding of processes and to forecast and explore future scenarios.

1. Introduction

Water erosion represents a large threat worldwide, potentially diminishing ecological functionality and food production capability and causing repetitive damage to built infrastructure (Boardman, 1998; Trimble and Crosson, 2000; Valentin et al., 2005). Factors such as climatic changes, anthropogenic land-use changes and intensification of agro technology may increase the damage caused by water erosion. However, we have yet to fully understand to what extent, where, when and how (Vanmaercke et al., 2011).

The increasing utility of geoinformatics for modeling and mapping Earth surface properties (e.g., detailed terrain data — Wilson, 2012) provides an excellent opportunity to help answer the aforementioned questions by providing high quality data at a wide range of spatial resolutions from millimeters to the continental scale. Spatially explicit datasets may increase the representativeness and accuracy of process modeling, increase model parameter space, add process-based model parameters that could not be accounted for before and improve calibration and validation approaches. Furthermore, Church (2010) pointed to enhancing the multi-scale possibilities embedded in computational methods and the ability to explore novel problems for prediction and model confirmation as most important for the emergence of geomorphology as a 'system science'.

The number of research papers in the peer reviewed literature on the use of remote sensing and GIS to study erosion has increased greatly during the last 20 years (Fig. 1). Publications on the use of geoinformatics for erosion modeling reveal that although much progress has been achieved, the potential of geoinformatics has not been fulfilled and several research avenues are still open and awaiting answers. For example, there are questions over the extent to which hyperspectral data can be used to provide maps of soil properties to more accurately predict soil resistance to erosion and how LiDAR data can be used within models of river erosion and deposition. A crucial question is how GIS can be merged into process-based models to create meaningful spatially and temporally explicit modeling of soil erosion in order to explain the formation of geopatterns such as river and gully networks. Another factor that hampers the use of geoinformatics for studying erosion processes is the error that propagates within system layers and increases prediction uncertainty and limits the representation of reality.

The aim of this Special Issue is to demonstrate that geoinformatics has an important role to play, over a wide range of spatial scales, in

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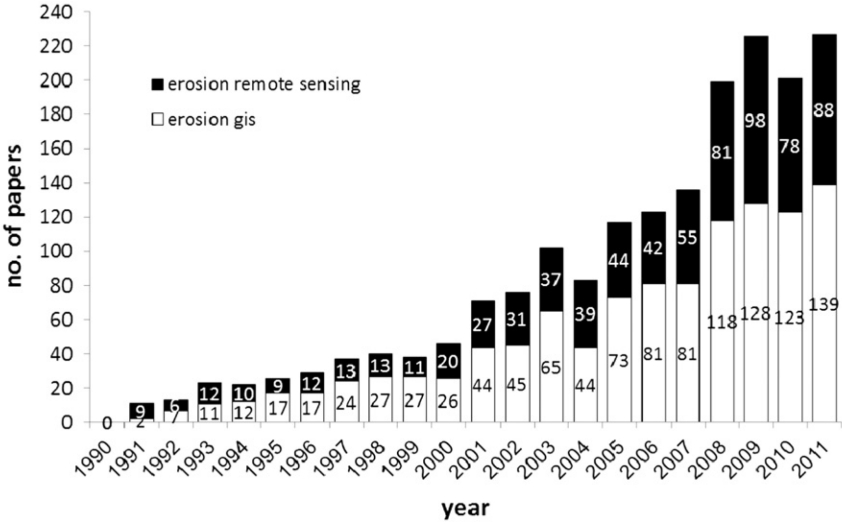

Fig. 1. A plot representing the number of research papers (journal articles only) on erosion and geoinformatics published each year from 1990 to 2011. The plot was created based on a search of the key words "remote sensing and erosion" (black bin) and "GIS and erosion" (white bin) in the ISI Web of Knowledge between the years 1990–2011. The results show a large increase in the number of papers during these 20 years in both fields of geoinformatics.

the study of water erosion. We invited papers that would provide new insights on runoff and erosion processes. Although not all the aforementioned subjects were covered in the Special Issue, it includes representation of a wide variety of approaches and topics within the broad field.

2. Overview of papers

The ten papers in this Special Issue demonstrate the use of geoinformatics tools and methodologies to study the processes at the heart of water and sediment flow over slopes and rivers (Table 1). These processes include sediment transport, fluvial processes, slope denudation, landslides, bank erosion and bank line migration. The research studies gathered in this Special Issue were applied to different parts of the world from France, Italy, Austria and Poland to Bangladesh, Australia, the US and even a study applied to the Martian environment. Based on the geoinformatics methods applied, we divided the set of papers into three groups: field measurement, image processing and spatially explicit modeling.

2.1. Field measurement

Devices such as differential GPS are usually applied in the field when the scale of observation (i.e., spatial resolution) is fine, for example, when 3D analysis of soil movement is the target. These studies usually include point measurements in the field that are assigned map coordinates and interpolated or processed using geostatistics or related approaches. As an example from this Special Issue, Wiegand et al. studied shallow landslides in the small-scale structure of a regolith body on an Alpine slope in the Tyrol, Austria. To quantify the 3D characteristics of the regolith body, they used a 3D volumetric lattice model. In addition, the patterns and variation in the penetration resistance were interpolated using the regularized spline with tension method. These analyses allowed description of the surface and bedrock morphology and the detection of discontinuities in the regolith. In addition, they were able to establish a distinct spatial relation between the derived geotechnical parameters and slope failure.

In another example of 3D analysis, Vergari et al. used differential GPS to perform volumetric estimation of eroded material and to calculate the average erosion rate for large timespans. In addition, an analysis of rainfall time-series facilitated evaluation of the role of critical rainfall events on denudation intensity. Their results show that cropland abandonment increased the erosion rate compared with natural areas characterized by similar conditions. The authors found that, after the abandonment of its cropland, the study site evolved in a manner that was driven by intrinsic thresholds to a greater extent than it was affected by climatic changes.

David et al. investigated the influence on flow resistance of flow structure and turbulence in a mountain channel using 3D velocity measurements and geostatistical analysis. The increase in flow resistance at low flows in a plane-bed reach was not fully explained by grain resistance. Therefore, detailed 3D velocity measurements were made to characterize the spatial variability in velocity and turbulence, and potential controls on flow resistance. One plane-bed reach was surveyed over two stages using a combination of a total station, LiDAR, and a SonTek Flowtracker handheld acoustic Doppler velocimeter. LiDAR data were used to capture bank and channel geometry at low flows, whereas the water surface and bed data were collected with the total station at all flows.

Hancock et al. examined soil organic carbon concentration along pasture transects in a catchment located in southern Western Australia. An erosion assessment using ^{137}Cs and also a numerical soil erosion and landscape evolution model found low and comparable erosion rates at the site. The results demonstrate that organic carbon concentration in this specific site is relatively uniform and that a transect scale assessment can provide a measure of hillslope and catchment scale soil organic carbon in this environment.

In the last paper of this group, Tomczyk & Ewertowski applied a new method to quantify short-term dynamics in recreational trails. The trails measured were located in different environments and types of use. The use of high resolution DEM provided by electronic theodolite allowed to assess sediment budget of surface changes. The short-term dynamics were high and several test fields had a predominance of deposition in one period and predominance of soil loss in another. Local geomorphic conditions, morphology of the trail tread and soil properties seemed to be the most important factors contributing to the relief transformation. The authors did not find connection between the number of visitors or type of use and the amount of soil loss or deposition.

2.2. Image processing

Remotely sensed data have been used for water erosion assessment through a variety of approaches as the review paper of Vrieling (2006) illustrates. In this Special Issue, we received contributions on

Table 1
The ten papers published in the *Geomorphology* Journal Special Issue on "Studying Water-Erosion Processes with Geoinformatics". These papers exemplify studies from different parts of the world (and beyond), focusing on different processes of water erosion at several scales, using a variety of geoinformatics methods.

Authors	Study site	Aim	Process	Scale	Geoinformatics method
Wiegand et al.	Tyrol, Austria	To understand how the structure of the regolith can be captured with penetration test, how the data can be spatially interpolated within a voxel model and whether it is possible to find evidence of discontinuities in the regolith as an influencing factor for the small-scale variability of shallow landslide occurrence.	Shallow landslides triggered by extreme rain or snowmelt.	m	Geostatistical modeling from data collected by Dynamic Cone Penetration Tests (DCPT)
Vergari et al.	Bargiano, Central Italy	To better understand the applicability of DGPS surveys to the computation of erosion rates over long time periods and to better understand the effects of land-use changes on erosion rates.	Slope denudation.	Multi-scale — m, cm, mm	Erosion pins and DGPS used for volumetric estimation
David et al.	Colorado, USA	To understand how flow structure varies as a function of flow stage within a plane-bed channel and to determine how bed roughness affects flow structure.	Flow structure and turbulence.	m	3D velocity measures and geostatistical analysis.
Hancock et al.	Young River, Western Australia	To better understand the factors regulating the spatial distribution of soil organic carbon at the hillslope and catchment scales.	Soil erosion and deposition patterns.	Multi-scale — m, cm, mm	DEM and SIBERIA model.
Tomczyk & Ewertowski	South-central Poland	To apply a new method for detailed surveys of short-term dynamics in the surface of recreational trails.	Soil loss and deposition.	Microscale — cm	Electronic theodolite and DEM analyses
Wierzbicki et al.	Vistula River, Poland	To find out if it is possible to use geomorphological analysis of a floodplain to predict extreme flood effects in a large river valley with an artificial levée system.	Geomorphological effects of a floodplain.	Multi-scale — m, cm	Manual GIS analysis of remotely sensed (DEM, DSM, LiDAR) and hydrological data.
Mount et al.	Jamuna River, Bangladesh	To explore the potential of Continuous Wavelet Transform for quantitative characterisation of temporal sequences of downstream bank line migration patterns.	Bank erosion and bank line retreat.	Multi-scale — km, m	Continuous wavelet transform.
Nicholson et al.	Paranna Valles, Mars	To determine the geological history of Mars for use in planning future Mars exploration.	Fluvial processes.	km	DEM analysis to find geomorphic and hydrologic catchment descriptors
Mukundan et al.	New York, USA	To examine how changes in precipitation and streamflow translate into changes in soil erosion and sediment transport.	Soil erosion and sediment transport.	Multi-scale — ton/ hectare/year, mm	Soil and water assessment tool-water balance (SWAT-WB) model
Couturier et al.	Seine Maritime, Northern France	To improve soil erosion modeling by allowing the model to account for the effect of tillage operations on surface water flow direction.	Soil erosion through surface water Flow.	Hectare	DEM analysis and STREAM (software) used to extract a flow line network.

the use of LiDAR and multispectral satellite sensor data. Wierzbicki et al. used LiDAR and very high resolution multispectral remote sensing to predict extreme flood effects with an artificial levée system. They identified floodplain landforms from palaeofloods visible in multispectral satellite sensor imagery and outlined a modern flood event (on the basis of river stage data and Acoustic Doppler Current Profiler measurements) and provided a detailed study of its geomorphologic effects on the floodplain on the basis of aerial imagery and LiDAR data. They provided a comparison of the landforms created in the palaeofloods and in the 2010 flood event. Their results show that geomorphological effects of recent catastrophic flooding are similar to palaeoflood landforms developed before the construction of the artificial levée system.

Mount et al. used continuous wavelet transforms to study the spatio-temporal patterns of multi-scale bank line retreat of the Jamuna River, Bangladesh. A sequence of eight bank line retreat snapshots, derived from remotely-sensed imagery for the period 1987–1999, was transformed using the Morlet mother wavelet. Local erosion and bank line retreat were shown to occur in short, well defined reaches characterized by temporal persistence at the same location, and separated by relatively stable reaches. In contrast, downstream propagation of bank line retreat patterns was evident for larger areas. The intensity of localized bank line retreat was strongly related to the magnitude of monsoonal peak discharge.

Nicholson et al. used a multifaceted remote sensing and morphometric approach to investigate if the surface of subcatchments on Mars is reflective of geomorphological processes and, specifically, sediment transport by water. Using DEM data obtained from the Mars Orbiter Laser Altimeter, three nested subcatchments were examined using a suite of terrestrial geomorphic and hydrologic statistics to determine if their shape and form lay within the known range of fluvial catchment properties on Earth. Further, an examination of statistical accuracy via an innovative pixel-by-pixel solution of two statistics established that despite mineralogical homogeneity confirmed by the Compact Reconnaissance Imaging Spectrometer for Mars spectral survey, erosion processes were likely to be variable across the study site.

2.3. Spatially explicit modeling

Catchment-scale soil erosion has been modeled in a spatially explicit manner through various approaches including fuzzy logic coupled with a GIS (Cohen et al., 2008), multicriteria methods (Jabbar and Chen, 2006) and the very well-known USLE on a GIS platform (Desmet and

Govers, 1996). But among these approaches, two have received a lot of attention in the literature: channel network extraction (Tarboton, 1997) and the application of physically-based models with GIS (Flanagan et al., 2007). In the current Special Issue, two papers address these avenues of research.

Mukundan et al. used a physically-based semi-distributed model to study the source area of suspended sediment and simulated potential climate change impacts on soil erosion and suspended sediment yield. Their simulations show a sharp increase in the annual rates of soil erosion, although a similar result in sediment yield at the watershed outlet was not evident. The effect of climate changes on soil erosion and sediment yield appeared more significant in the winter due to a shift in the timing of snowmelt and due to a decrease in the proportion of precipitation received as snow.

Couturier et al. addressed the long standing challenge of automated delineation of the surface flow path. Flow network data are critical for important uses such as flood forecasting and watershed management. They propose a 5-step procedure to account for human-made features such as tillage lines in agricultural fields. The procedure was implemented in a GIS and increased the accuracy of the prediction of surface flow and water erosion modeling at the watershed scale.

3. Summary

Soil movement by water is a highly variable and dynamic process, in space and time, varying in scale from millimeters to continents and from milliseconds to millennia. Erosion processes have the potential to impact on society through effects on agriculture, infrastructure and built areas. With progress in measurement techniques, including remote sensing, image processing algorithms and computational models, the road is open to increase the use of geoinformatics by geomorphologists. This Special Issue of *Geomorphology* aims to encourage this use as a means to explore the space-time dynamics of water erosion. Although this Special Issue does not cover all aspects of using geoinformatics for studying water erosion, we hope that it will help in demonstrating the use of modern geoinformatics for studying water erosion processes.

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