remote sensing

Editorial

Quantifying Landscape Evolution and Erosion by Remote Sensing

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1. Introduction

Remote sensing techniques have been part of the geomorphologists' toolkit practically since their initial advances, and used to describe, quantify, and model landscape evolution. Linked to aerial photography, and with its subsequent developments over the last 20 years, remote sensing has become one of the main tools used to obtain information about present-day topography and active landscape processes. Worldwide digital elevation models (DEMs) obtained from radio detection and ranging (RADAR), local DEMs constructed using unmanned aerial vehicles (UAVs) and photogrammetry, light imaging detection and ranging (LIDAR), and terrestrial laser scanner (TLS) techniques are the main sources of our information about present-day topography at regional and local scales. Multi-temporal studies based on series of optical images, interferometric synthetic-aperture radar (InSAR) techniques, and DEMs of difference approaches (DoD) [1] provide powerful information that is used to detect, quantify, and model changes in topography and understand its underlying processes. Simultaneously, we have witnessed a tremendous development of LIDAR-TLS techniques during this century, which has significantly increased the accuracy and spatial resolution of topographic data [2]. The cost, size, and weight of LIDAR sensors have decreased notably, facilitating their use in UAV platforms flying close to the Earth's surface, resulting in very dense point clouds and ultra-high-resolution DEMs. Similarly, photogrammetric techniques have evolved from classic photogrammetry, which had significant requirements (metric and calibrated cameras, geometrical constraints to camera location and orientation, user knowledge, ground control points or GCPs, etc.), to modern automated digital photogrammetry, known as structure-from-motion (and multiview stereo) or SfM-MVS. This automatic digital photogrammetry allows for the production of 3D models from images taken with consumer-grade cameras, with minimal user supervision. As a result, geomorphologists can generate detailed 3D models of any surface inexpensively [3], i.e., the SfM-MVS technique has democratized the production of high-resolution 3D information previously limited to a few research institutions with substantial budgets.

Other factors contributing to the extensive development and application of remote sensing techniques in the assessment of topographic changes are the advancement of UAVs and the decreasing size and cost of global navigation satellite systems (GNSSs) and inertial measurement units (IMUs). Both instruments are interrelated; while UAVs capture close-to-surface aerial perspectives and cover significant areas, GNSSs and IMUs are used to guide UAVs precisely and almost automatically during data acquisition. Even some of the most sophisticated systems have direct georeferencing capabilities, making GCPs unnecessary [4].

The changes introduced by these new technologies and datasets are related to spatial scale, spatial coverage, and temporal resolution, as we can monitor processes in almost real time, i.e., 4D monitoring at unprecedented spatial and temporal scales [5]. This allows us to, for example, elucidate the role of individual rainfall events on soil erosion and accurately quantify frequency–magnitude relationships. The production of all this high-resolution spatial information (point clouds and DEMs) has led to its integration with modern machine learning and artificial intelligence (AI) technologies, which have advanced our understanding of certain processes and the factors involved in their genesis. For example, erosive processes, and particularly erosion due to concentrated flows of water, have been a typical application of these methods and techniques, particularly in rills and gullies [6].

All of the reasons above justified the proposal of this Special Issue of *Remote Sensing*, in which we aim to compile works that have employed these techniques to enhance our understanding of the recent dynamics of the topographic surface. We have compiled 10 papers that demonstrate state-of-the-art research that specifically addresses how remote sensing is being used in landscape evolution studies to monitor, quantify, and model landscape evolution and erosion.

2. Contributions to the Special Issue

The call welcomed papers describing new methodologies, as well as outstanding case studies and reviews. Ten manuscripts were definitively accepted for publication, demonstrating these techniques' wide-ranging applications (Table 1). High- or medium-resolution topographic models and data from high-resolution satellites have helped us to (a) carry out efficient neotectonic investigations in Canada; (b) execute a spatially explicit analysis of ephemeral channels in Spain, revealing sediment sources and sinks at the event scale; (c) quantify differences in the uplift, denudation rates, and accumulated uplift between Mediterranean and Atlantic slopes in the Gibraltar Arc; (d) develop a dynamic model of divide migration in the Zhongtiao Shan (North China); (e) study and forecast land area changes due to tectonic plate movements; (f) quantify the soil erosion in vineyards in Hungary in detail; and (g) automatically extract surface and width measurements of rivers in mountain areas.

Table 1. Contributions in the present Special Issue.

Title	Authors	DOI
• Tectono-Geomorphic Analysis in Low Relief, Low Tectonic Activity Areas: Case Study of the Temiskaming Region in the Western Quebec Seismic Zone (WQSZ), Eastern Canada	Monica Giona Bucci and Lindsay M. Schoenbom	https://doi.org/10.3390/rs14153587
• Spatial Modelling of Vineyard Erosion in the Neszmély Wine Region, Hungary, Using Proximal Sensing	Tünde Takáts et al.	https://doi.org/10.3390/rs14143463
• A New Systematic Framework for Optimization of Multi-Temporal Terrestrial LiDAR Surveys over Complex Gully Morphology	Fran Domazetovic et al.	https://doi.org/10.3390/rs14143366
• Automatic Extraction of Mountain River Surface and Width Based on Multisource High-Resolution Satellite Images	Yuan Xue et al.	https://doi.org/10.3390/rs14102370
• Modelling Gully Erosion Susceptibility to Evaluate Human Impact on a Local Landscape System in Tigray, Ethiopia	Robert Busch et al.	https://doi.org/10.3390/rs13102009
• Combining SfM Photogrammetry and Terrestrial Laser Scanning to Assess Event-Scale Sediment Budgets along a Gravel-Bed Ephemeral Stream	Carmelo Conesa-García et al.	https://doi.org/10.3390/rs12213624

Table 1. *Cont.*

Title	Authors	DOI
• Quantification of Erosion and Uplift in a Rising Orogen-A Large-Scale Perspective (Late Tortonian to Present): The Case of the Gibraltar Arc, Betic Cordillera, Southern Spain	Javier Elez et al.	https://doi.org/10.3390/rs12213492
• A Review on the Possibilities and Challenges of Today's Soil and Soil Surface Assessment Techniques in the Context of Process-Based Soil Erosion Models	Lea Epple et al.	https://doi.org/10.3390/rs14102468
• What Is the Impact of Tectonic Plate Movement on Country Size? A Long-Term Forecast	Kamil Maciuk et al.	https://doi.org/10.3390/rs13234872
• Dynamic Divide Migration as a Response to Asymmetric Uplift: An Example from the Zhongtiao Shan, North China		

Two works in this Special Issue have focused on the study of gully erosion. The first one, with a predominantly methodological approach, attempted to optimize terrestrial LIDAR surveys. The second one included anthropogenic impact in its spatial predictive model of gully erosion susceptibility in Ethiopia, revealing interesting spatial relationships between gully erosion, settlements, and footpaths. An engaging review of 13 process-based soil erosion models is also presented in this Special Issue, emphasizing the potential of evolving data acquisition techniques to enhance soil erosion models.

These studies (Table 1) collectively contribute to diverse areas of geomorphology, remote sensing, and tectonics, showcasing the advancements made in these methodologies and insights into landscape dynamics.

3. Summary and Future Directions

This editorial discusses the significant role of remote sensing technology in geomorphological research, and specifically in landscape dynamics and erosion monitoring. Over the past two decades there has been notable progress in the remote sensing technologies providing high-resolution data, such as RADAR, LiDAR, and UAVs. These advancements have enabled researchers to detect, quantify, and model changes in topography with unprecedented accuracy and at higher resolutions (spatial and temporal). The integration of GNSS, IMU, AI, and machine learning techniques has further enhanced the ability of remote sensing to assess topographic changes. This editorial especially highlights the contributions of ten research papers to this Special Issue of *Remote Sensing*, "Quantifying Landscape Evolution and Erosion Using Remote Sensing", demonstrating the various applications of these advanced techniques, including neotectonic investigations, analyses of ephemeral channels, and the quantification of soil erosion in vineyards. Additionally, it discusses studies focusing on gully erosion and presents a review of process-based soil erosion models. Overall, these contributions showcase the advancements in these methodologies and provide insights into landscape dynamics across a variety of geomorphological and tectonic contexts.

Considering all of the above, as well as a detailed reading of the papers published in this Special Issue and the editors' own experience, we highlight three areas that we believe will form the basis of the future use and application of remote sensing techniques to enhance our understanding of landscape evolution. Firstly, AI and machine learning will support and improve the use of remote sensing for the interpretation, quantification, and modelling of landscape dynamics. In the upcoming years, we will undoubtedly witness an even greater inclusion of AI and machine learning in the solving of complex procedures that previously required a certain degree of supervision, or procedures for which there is not currently a deterministic solution. This includes, among other things, (i) the automation of the co-registration and integration of data from different sensors and platforms; (ii) the management and simplification of 4D data, and the inference of the geomorphological processes responsible for changes using point clouds or DoDs; and (iii) the enhancing of historical datasets (for example, historical archival images) to excute SfM-MVS technologies.

Secondly, real-time monitoring, with high spatial and temporal resolution, will generate a significant improvement in our understanding of the role of individual events and the magnitude–frequency relationships of the processes that control landscape evolution. Consequently, this will result in the better management of risks associated with certain processes (e.g., rockfalls, landslides, floods, etc.).

Finally, the democratization of high-accuracy data acquisition techniques with increased spatial resolution will continue as direct georeferencing techniques become more widespread and integrated into various devices (UAVs, TLSs, smartphones, etc.). In some cases, this will lead to the definitive elimination of GCPs. With the use of UAVs, data collection in hazardous locations will no longer pose a problem and will instead facilitate our improved understanding of the processes and risk management of these areas. We foresee an exciting future for those who work with high-resolution spatial data to understand the operation of the different systems that compose our planet.

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