Geoderma 287 (2017) 116–125

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Multifractal and joint multifractal analysis of water and soil losses from erosion plots: A case study under subtropical conditions in Santa Catarina highlands, Brazil

Ildegardis Bertol [a], Jefferson Schick [b], Douglas H. Bandeira [a,d], Jorge Paz-Ferreiro [c], Eva Vidal Vázquez [d,*]

[a] Soil Science Department CAV/UDESC, CEP 88520-00, Lages, SC, Brazil
[b] Instituto Federal Catarinense, CEP 88965-000, Santa Rosa do Sul, SC, Brazil
[c] School of Civil, Environmental and Chemical Engineering, RMIT University, GPOBox 2476, Melbourne, VIC, Australia
[d] Centro de Investigaciones Científicas Avanzadas CICA, University of Corunna, 15071 Corunna, Spain

ARTICLE INFO

Article history:
Received 28 January 2016
Received in revised form 11 August 2016
Accepted 12 August 2016
Available online 31 August 2016

Keywords:
Soil and water losses
Temporal variability
Tillage
Multifractal analysis
Joint multifractal analysis

ABSTRACT

Understanding and describing the temporal variability of soil surface runoff and the associated production of sediments are required for modeling soil erosion processes. We employed multifractal and joint multifractal techniques to quantify the temporal scaling relationships of water and soil losses measured in standard erosion plots across a period of about 20 years. The time series studied consisted of 795 erosive events, monitored in Lages, SC, Brazil. Water and soil losses were recorded in bare soil (BS) and under crops in rotation, managed by three different soil tillage systems, namely conventional tillage (CT), minimum tillage (MT) and no tillage (NT). All the treatments were replicated twice. Both water and soil losses were multifractally distributed over the study period. Several parameters and indices extracted from the generalized dimension (D_q) and singularity spectra [$f(\alpha)$-α] functions were used to compare the scaling patterns of water and soil losses under the four studied treatments. Temporal distributions of water losses showed a lower heterogeneity, were more evenly distributed, and had a stronger persistence when compared with its soil losses counterparts. The scaling heterogeneity of water losses among treatments increased as: BT < CT < MT < NT, while that of soil losses ranked as: BT ≈ MT < CT ≈ NT. Conversely for water losses, evenness and persistence decreased as BT > CT ≈ MT > NT, while for soil losses ranked as: BT ≈ MT > CT ≈ NT. Joint multifractal analysis showed that the relationships between soil and water losses were scale dependent across the temporal domain studied, and that their respective scaling indices had various degrees of association under different tillage treatments. Therefore, multifractal and joint multifractal techniques have been demonstrated to be useful for assessing multiscale patterns of temporal variability of soil and water losses and for appraising differences among treatments.

Contents

* Corresponding author.

http://dx.doi.org/10.1016/j.geoderma.2016.08.008
0016-7061/

1. Introduction

Soil erosion by water brings about the loss or deterioration of topsoil and increases both, runoff and sediment yield; therefore soil erosion has been worldwide correlated with significant decline of soil quality and reduction of crop yields and has been also considered as a source of sediments that often cause negative downstream impacts (Lal, 2001).

Erosion by rainfall and the associated water and soil losses have been demonstrated to depend on climate, soil type and management, topography, vegetation, and conservation practices. Runoff and soil losses, at the plot scale, have been empirically modeled by the Universal Soil Loss Equation (USLE) as a function of erosivity (rainfall intensity), erodibility (soil susceptibility), slope steepness and length, cropping and management practices and additional support practices (Wischmeier and Smith, 1960, 1978; Brooks et al., 2013). Although rainfall intensity is generally the most important factor determining erosivity, also amount, duration and sequence of precipitation have been recognized as additional factors affecting soil erosion rates (Meyer, 1981). It is also well documented that soil erodibility depends on many other physical and hydraulic soil properties, including texture, aggregation, infiltration capacity, antecedent moisture, surface roughness, soil organisms, etc., that influence soil erosion rates (Römkens et al., 2001; Vidal Vázquez et al., 2005). All these factors are interdependent, and have nested effects on soil erosion rates, varying in space and time. Therefore, the process of soil erosion, commonly described as a sequence of three steps, detachment, transport and sedimentation, is a very dynamic and complex process, which depends on an ensemble of interactions between climate, soil properties, relief, hydrological processes, crop cover and management practices.

Intensification of soil losses around the world has been demonstrated to be associated to conventional tillage (Lal, 2001). Conversely, conservation-tillage practices have been shown to significantly decrease water and soil losses, when compared to traditional tillage. In particular, rainfall erosion has been demonstrated to produce much greater water and soil losses under conventional tillage than under no-tillage. Moreover, no-tillage was found to be much more efficient in reducing soil losses than in reducing water losses caused by erosive rainfall (Bertol et al., 2005; Engel et al., 2009). Nowadays no-tillage is the most widespread conservation-tillage system and the beneficial effects of this practice in controlling soil erosion have been widely highlighted (Amaral et al., 2008; Engel et al., 2009; Marioti et al., 2013). Worldwide, agricultural land is increasingly cultivated under no-tillage; for example, in Brazil the land surface managed by no-tillage was about 32.10^6 ha (i.e. 86.25% of the total cultivated land surface) during the 2013–2014 growing season (Ziech et al., 2015) and still continues to increase.

Beginning in the 1930s, water and soil losses have been measured in experimental erosion plots with a tank system installed at plot exit by the Soil Conservation Service (now Natural Resources Conservation Service, NRCS) at the U.S. Department of Agriculture, USDA, (Wischmeier and Smith, 1960, 1978; Zhang et al., 1996). Since then, erosion plots have been used around the world to evaluate erosion rates over time under various soil, climate and management conditions. In the USA, the large body of data obtained from erosion plots was used to develop the USLE. Erosion plots have been also frequently used to assess the effect of tillage systems on soil erosion.

The generation of surface runoff and soil losses has been studied not only at the plot scale but also at the field and catchment scales using both, empirical models, such as the USLE and physically based models. Modeling with detail the complexity of soil erosion taken into account a physical description of the mechanisms involved at the field or catchment scale remains a challenging task. Physically based models commonly tackle this challenge by means of simplified, spatially distributed rainfall-runoff models implemented either for individual rainfall events, such as LISEM (de Roo et al., 1996) or for long periods of time, such as WEPP (Flanagan and Nearing, 1995) or SWAT (Arnold et al., 1998). Implicit in these approaches, however, is the hypothesis that runoff generation is inherently linear and time invariant.

Scaling is a distinctive property of geological, soil and environmental systems. Several geophysical, climatological and hydrological processes are known to be extremely non-linear and variable in time and space. In the past, fractal analysis proved to be a useful tool to describe scale invariance in the statistical distribution of hydrological variables such as time series of rainfall, river flow or sediments (Mandelbrot and Wallis, 1969; Olsson et al., 1992). The fractal approach needs a single scaling exponent to describe the statistical distribution of a data set. However, more recently it was shown that multiple scaling exponents were needed to describe statistical scaling behavior in hydrological time series (Lovejoy and Schertzer, 1985; Tessier et al., 1996). The approach based on multiple scaling exponents was termed multifractal approach. Nowadays, multifractal analysis (MFA) is viewed as an adequate framework for investigating scaling properties of complex non-linear processes. The dynamics of soil erosion fits better into this scheme than in the classical linear rainfall-runoff modeling.

Multifractal methods have been applied to assess the inner structure and the variability of time series as, among others, rainfall (Olsson et al., 1993; de Lima and Grasman, 1999), river flow (Pandey et al., 1998), both, rainfall and river flow (Tessier et al., 1996), and runoff in karst catchments (Majone et al., 2004). Joint multifractal analysis of two and three related time series has also been carried out in Earth Sciences. For example, Schertzer and Lovejoy (1987) analyzed the scale invariant interaction of clouds and rainfall. Similarly, Jiménez-Hornero et al. (2010) explored the relationship between ozone and nitrogen dioxin, while Pavón-Domínguez et al. (2015) assessed the joint distribution of temperature, nitrogen dioxide and ozone.

Until now the multifractal approach has been applied to the analysis of water flow or runoff time series from catchments with a wide range of surface scales, and recorded with different time resolutions (Tessier et al., 1996; Pandey et al., 1998; Majone et al., 2004). Also MFA has been occasionally used to analyze the sediment load from river catchments (Sivakumar, 2006). However, to our knowledge there is a lack of research on the variability of time series of water and soil losses obtained from erosion plots using multifractal techniques, and this in spite of the considerable availability of such data series. The objectives of this work were: 1) to apprise how useful the multifractal analysis could be to evaluate the variability of water and soil losses from erosion plots in long term experiments, 2) to asses the effect of different tillage system in the scaling pattern of water and soil losses, and 3) to analyze the association between water and soil losses at a multiple scale through the joint multifractal approach.

2. Material and methods

2.1. Experimental site location, climate and soil

The experimental work was conducted at the research field of the Centre for Agroveterinary Sciences, University of the State of Santa Catarina (CAV-UDESC), Brazil. This site is located in the subtropical Santa Catarina highlands at 27° 49′ S longitude, 50° 10′ W latitude and 923 m asl. The climate has been classified as Cfb following Köppen