Catena 114 (2014) 45–58

Contents lists available at ScienceDirect

Catena

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

Modeling soil erosion and river sediment yield for an intermountain drainage basin of the Central Apennines, Italy

Pasquale Borrelli [a,b,*], Michael Märker [c,d], Panos Panagos [b], Brigitta Schütt [a]

[a] Department of Earth Sciences, Physical Geography, Freie Universität Berlin, Malteserstraβe 74-100, Haus H, 12249 Berlin, Germany
[b] Joint Research Centre of the European Commission, Institute for Environment and Sustainability, Via E. Fermi, 2749, I-21027 Ispra, VA, Italy
[c] Department of Agronomy and Land Management, University of Florence, Piazzale delle Cascine 14, I-50144 Florence, Italy
[d] Heidelberg Academy of Sciences and Humanities, ROCEEH, c/o University of Tübingen, Rümelinstr. 19-23, 72070 Tübingen, Germany

ARTICLE INFO

Article history:
Received 2 February 2013
Received in revised form 5 October 2013
Accepted 25 October 2013

Keywords:
Soil erosion risk
RUSLE
Turbidity Unit Index
Landscape sensitivity
Central Italy

ABSTRACT

The overall aim of this research was to investigate the spatial patterns of the soil erosion risk. We focused on accelerated soil erosion processes in an Italian central Apennine intermountain watershed using modeling techniques implemented in a GIS environment. Our thorough literature review revealed a gap in research on soil erosion processes in such forested, intermountain watersheds. To gain a better understanding of the soil erosion processes in such landscapes, we proposed an integrated modeling approach applying a RUSLE model and a Turbidity Unit Index. The model outcomes were validated through measurements of lake sediment deposition. Our findings indicate a potential high soil erosion risk. With 1.33 M t^{-1} yr^{-1} of annual sediment yield, corresponding to an area-specific sediment yield of 32.35 t ha^{-1} yr^{-1}, the Turano drainage basin belongs to the Italian basins with the highest sediment discharge. The outcomes of the RUSLE model showed that, despite the diverse forms of forests that cover about 62% of the drainage basin area, sizable plots of the investigated area are prone to soil erosion. The validation of the model outcomes revealed that the TU Index model performed significantly better than the RUSLE model with regard to sediment yield prediction. Accordingly, we found that even though rill and interrill processes reach very alarming values (RUSLE), they are not the dominant sediment source within the Turano watershed. Other geomorphological processes contributing to the watershed sediment yield – for instance, megarill, gully, bank and channel erosion and re-entrainment of landslide sediments – were very active in the study area. If both models are used in a combined approach, the amount of river load (TU Index) as well as the relative spatial distribution of rill and interrill erosion processes (RUSLE) can be described with sufficient precision.

1. Introduction

In Mediterranean regions, the increasing pressure of human-induced environmental changes together with long dry periods followed by intensive and erosive rainfall (van der Knijff et al., 1999) drives the landscapes towards a stage of irreversible perturbations (Scheffer et al., 2001). According to the Italian Agency for Environmental Protection and Technical Services (APAT, 2009), two thirds of the soils in Italy are affected by degradation problems. Approximately 30% of these soils are potentially prone to erosion rates above the tolerable threshold (Gobin et al., 1999; Grimm et al., 2003).

The current situation of accelerated soil erosion processes in Italy might worsen in the near future when the predicted changes climate (IPCC, 2007) – more precisely, the increase in rainfall in the Italian Peninsula (Brunetti et al., 2000, 2001) – commence. For Italy, Rodolfi and Zanchi (2002) already noticed a progressive lengthening of the summer dry season with a concentration of high-intensity precipitation in only sporadic events.

The scientific community had, at an early stage, already recognized the loss of topsoil as a principal form of land degradation with ecological as well as economic implications (Bennett and Chapline, 1928; Chapline, 1929; Knapen et al., 2007). In Italy, the process of soil erosion has been subject to scientific investigations since the 1930s (Rodolfi, 2006), when the progressive reduction of cultivable surfaces for agriculture was perceived. Since then, the investigation of geomorphological processes of soil erosion has benefited from cognitive contributions by neighboring disciplines, i.e., geography, soil science, engineering, biology and physics. The numerous approaches presented so far with the intention of gaining a better understanding of this phenomenon vary in terms of temporal and spatial scales, methodologies and research goals and are summarized by Boardman and Poesen (2006). Qualitative and quantitative descriptions of hydric soil erosion have been directly performed through field observations (Bagarello et al., 2011; Della Seta et al., 2009; Porto et al., 2001; Sorriso-Valvo et al., 1995) and laboratory experiments (Leone and Sommer, 2000; Piccolo et al., 1997; Torri and Poesen, 1992). By contrast, indirect estimations of the erosion processes for large areas (global, regional and watershed scales) have

* Corresponding author at: Joint Research Centre of the European Commission, Institute for Environment and Sustainability, Via E. Fermi, 2749, I-21027 Ispra, VA, Italy. Tel.: +39 0332/789072; fax: +39 0332/786394.
E-mail address: pasquale.borrelli@jrc.ec.europa.eu (P. Borrelli).

0341-8162/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.catena.2013.10.007

generally been carried out by estimating the sediments accumulated in artificial lakes, reservoirs and behind check dams or using suspended sediment yield data of rivers (de Vente et al., 2008; van Rompaey et al., 2005; Zeng et al., 2009).

During the past decades, research has primarily focused on the development and application of models able to indirectly predict the magnitude, frequency, scope and temporal spacing of soil erosion. According to current literature, most of these studies are based on the Universal Soil Loss Equation (Wischmeier and Smith, 1978) and its revised and modified versions (e.g., MUSLE — Williams, 1975; RUSLE — Renard et al., 1997; SEDEM/WaTEM — van Rompaey et al., 2001). Several studies report encouraging performances of these models in predicting soil erosion risk and quantifying of soil erosion rates in different environments (among others, Amore et al., 2004; Onori et al., 2006; Märker et al., 2008). However, despite the comprehensive number of variables considered by these models, their capability to predict the sediment yield on the watershed scale is still problematic (van Rompaey et al., 2005). In addition, these models are often less accurate than simple regression equations (Bazzoffi et al., 1996) or semi-quantitative approaches (de Vente et al., 2006).

For Italy, the spatial availability of environmental data necessary for modeling is not homogeneously distributed (e.g., river water discharges, bed load and suspended sediment yields, accurate soil maps, sub-hourly rainfall, high resolution digital elevation models). This situation led to a marked concentration of studies in a very few areas (e.g., Tuscany, Sicily and Calabria), where comprehensive databases are more easily accessible. As inferable from present literature, the processes of soil erosion in some regions of the Italian peninsula have been poorly studied. This is especially the case in the mountainous central Apennine area, where – despite its high potential soil erosion risk (heavy seasonal precipitation and steep slopes) – soil erosion modeling on watershed scale and field observations are lacking.

In view of these serious concerns, this study integrates state of the art approaches to assess accelerated soil erosion processes of the Italian Apennine intermountain watersheds to answer three fundamental questions:

i) Are there hotspots of soil erosion within Central Apennine watersheds and can we identify them using a modeling approach?
ii) Are RUSLE-based approaches and the Turbidity Unit Index equation adequate to simulate and predict soil erosion and sediment yield in complex watersheds of the Central Apennines?

To answer these questions, two soil erosion prediction models were implemented in a GIS environment. Particular attention was paid to the robustness and reliability of the model to predict the watershed's sediment yield. The study area was selected from a watershed of the central Apennine area where no studies on soil erosion have been carried out so far. The selected watershed is located in the upper Turano River drainage basin. Notably, the lack of scientific publications for this area cannot be attributed to the irrelevance of soil erosion risk in this location. Instead, the lack of an efficient runoff and suspended load monitoring network in this region seems to be the major reason why it has hitherto not been considered in soil erosion research.

2. Study area

The study site is located in the Upper Turano River Watershed, approximately 58 km northeast of Rome in the Italian Central Apennines (Fig. 1). It is tributary to the Velino River, which drains into the Tiber River. The drainage basin area totals 466.7 km^2 (41° 55′ 20″ N to 42° 14′ 60″ N, 12° 53′ 36″ W to 13° 20′ 20″ W (WGS-84)). With an elongated and irregular shape, the watershed stretches for 47.3 km from northwest to southeast across the Latium–Abruzzi border. The divides (Conca di Oricola) run along the Carseolani (N–E), Simbruini (S) and Sabini (N–W) mountain chains.

The elevations range from 536 m a.s.l. at the lowest point (Turano Lake) up to 1907 m a.s.l. at Monte Tarino. The mean elevation is 983 m a.s.l., the average slope totals 17°, and the prevalent slope exposure is to northwest. The hypsometric curve (Strahler, 1957) shows characteristics of a watershed that has developed up to the point where it reaches an advanced phase in the fluvial cycle of erosion landscapes (hypsometric integral: 0.33).

The annual precipitation in the study area averages 1205 mm yr^{-1} (1961–1990) (Fig. 2) and thus is significantly above the national average of 970 mm yr^{-1}. Within the watershed, precipitation is notably higher in the southern and central-western areas where the annual average totals 1400–1600 mm yr^{-1}, whereas the precipitation values range between 950 and 1200 mm yr^{-1} in the regions near Turano Lake and around the intermountain basin of Oricola (1961–1990). The seasonal rainfall distribution is slightly bimodal. Generally, high monthly rainfall is registered in October, November and December, with maximum values observed for November. Minimum values are measured during July. Average annual temperature totals around 10.2 °C, ranging from 5.8 °C in the mountains to 12.6 °C in the valleys.

The geology is characterized by a significant heterogeneity and complexity of the lithological types (CARG Project — 1:50,000, 2010). The stratigraphic series distinguishes several rock types ranging from the early Cretaceous Berriasian period to the Holocene. On the basis of their lithological characteristics, several lithotypes can be grouped into four fundamental units: carbonate, arenaceous, marly and clastic deposits of predominantly fluvial and mass movement origin (Fig. 3). Owing to the lithological heterogeneity, a great variety of soils can also be identified (Cucchiarelli et al., 2006; Lorenzoni et al., 1995). In the study area, Eutric Cambisols, Calcaric Cambisols and Rendzic Leptosols with silty–loamy to loamy textures prevail.

3. Materials and methods

3.1. Approach overview

The general methodology for modeling soil erosion rates and related sediment yield involved several steps. First, a land use analysis through on-screen visual interpretation of orthophotos was performed. Second, we selected two different prediction models to simulate soil erosion and sediment yield in the study area: the Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997), and the Turbidity Unit Index (Ciccacci et al., 1986). These two models were selected for their complementary nature. The first (RUSLE) performs a quantitative prediction of soil loss due to interrill and rill processes. It is largely employed for risk assessment of human-induced accelerated soil erosion. The second model (Turbidity Unit Index) can well predict the river sediment yield and is considered to be a suitable tool for the estimation of the medium- to long-term denudation rate in drainage basins characterized by fluvial processes (i.e., largely acting in Tertiary sandstones). The combined application of these models can give us useful inputs to better distinguish between the effects of short-term human-induced accelerated soil erosion and long-term geomorphological processes.

For soil erosion modeling, a period of eight years, from September 1997 to October 2005, was selected. For the start and end point of this period, bathymetric surveys of the Turano reservoir were performed (ENEL/E-ON, 2009, personal communication). Thereupon, the required model input parameters were generated: i) land use, ii) silvicultural activities, iii) rainfall, iv) soil maps and v) relief map (Digital Elevation Model). Finally, model validation was performed using the sediment yield predictions.

3.2. Model description

3.2.1. RUSLE model

The Revised Universal Soil Loss Equation (RUSLE) belongs to the class of detachment-limited models. Accordingly, the flow can theoretically