Earth-Science Reviews 127 (2013) 16–29

Contents lists available at ScienceDirect

Earth-Science Reviews

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

Predicting soil erosion and sediment yield at regional scales: Where do we stand?

Joris de Vente [a,b,*], Jean Poesen [c], Gert Verstraeten [c], Gerard Govers [c], Matthias Vanmaercke [c,d], Anton Van Rompaey [c], Mahmood Arabkhedri [e], Carolina Boix-Fayos [a]

[a] *Soil and Water Conservation Department, Centro de Edafología y Biología Aplicada del Segura, Spanish National Research Council (CEBAS-CSIC), Murcia, Spain*
[b] *Desertification and Geoecology Department, Estación Experimental de Zonas Áridas, Spanish National Research Council (EEZA-CSIC), Almeria, Spain*
[c] *Department of Earth and Environmental Sciences, Division of Geography, KU Leuven, Belgium*
[d] *Research Foundation Flanders (FWO), Brussels, Belgium*
[e] *Soil Conservation and Watershed Management Research Institute, Tehran, Iran*

ARTICLE INFO

Article history:
Received 24 August 2012
Accepted 30 August 2013
Available online 12 September 2013

Keywords:
Soil erosion modelling
Model validation
Catchment scale
Global change
Model accuracy
Scenario analysis

ABSTRACT

Assessments of the implications of soil erosion require quantification of soil erosion rates (SE) and sediment yield (SSY) at regional scales under present and future climate and land use scenarios. A range of models is available to predict SE and SSY, but a critical evaluation of these models is lacking. Here, we evaluate 14 models based on 32 published studies and over 700 selected catchments. Evaluation criteria include: (1) prediction accuracy, (2) knowledge gain on dominant soil erosion processes, (3) data and calibration requirements, and (4) applicability in global change scenario studies. Results indicate that modelling of SE and SSY strongly depends on the spatial and temporal scales considered. In large catchments (>10,000 km^2), most accurate predictions of suspended sediment yield are obtained by nonlinear regression models like BQART, WBMsed, or Pelletier's model. For medium-sized catchments, best results are obtained by factorial scoring models like PSIAC, FSM and SSY Index, which also support identification of dominant erosion processes. Most other models (e.g., WATEM–SEDEM, AGNPS, LISEM, PESERA, and SWAT) represent only a selection of erosion and sediment transport processes. Consequently, these models only provide reliable results where the considered processes are indeed dominant. Identification of sediment sources and sinks requires spatially distributed models, which, on average, have lower model accuracy and require more input data and calibration efforts than spatially lumped models. Of these models, most accurate predictions with least data requirements were provided by SPADS and WATEM–SEDEM. Priorities for model development include: (1) simulation of point sources of sediment, (2) balancing model complexity and the quality of input data, (3) simulation of the impact of soil and water conservation measures, and (4) incorporation of dynamic land use and climate scenarios. Prediction of the impact of global change on SE and SSY in medium sized catchments is one of the main challenges in future model development. No single model fulfils all modelling objectives; a further integration of field observations and different model concepts is needed to obtain better contemporary and future predictions of SE and SSY.

Contents

* Corresponding author at: Soil and Water Conservation Department, Centro de Edafología y Biología Aplicada del Segura, Spanish National Research Council (CEBAS-CSIC), Murcia, Spain. Tel.: +34 968 396349.
E-mail address: Joris@cebas.csic.es (J. de Vente).

0012-8252/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.earscirev.2013.08.014

1. Introduction

Soil is a valuable natural resource that performs crucial ecosystem functions, and provides many valuable environmental goods and services like food, fibre and fuel production, carbon sequestration, water regulation and habitat provision (Costanza et al., 1997; Swinton et al., 2007). Soil erosion and its impact on ecosystem services receive increasing attention from scientists and policy makers (EC, 2002; MEA, 2005; UNCCD, 2008). To assess the socioeconomic and environmental implications of soil erosion and to develop management plans to deal with them, quantitative data on soil erosion rates at regional and global scales are needed (Boardman and Poesen, 2006). These management plans need to consider *on-site* and *off-site* impacts of erosion. On-site impacts refer to soil loss and the decline of soil organic matter content and soil structure, leading to decay in soil fertility and water-holding capacity, and ultimately to a reduced food security and vegetation cover (Crosson, 1997; Stocking, 2003). The off-site effects involve an increased flood risk and reduced lifetime of reservoirs (Poesen and Hooke, 1997; Boardman et al., 2003). Furthermore, dispersal of polluted sediments and soil organic carbon may cause severe contamination of floodplains and water bodies (Ramos and Martinez-Casasnovas, 2004; Ludwig et al., 2009), and forms a still poorly understood part of the global carbon budget (Quinton et al., 2010).

To deal with these challenges, researchers and policy makers face the question of which model is most effective and efficient to predict soil erosion rates (SE, Mg km^{-2} a^{-1}) and sediment yield (SSY, Mg km^{-2} a^{-1} or SY, Mg a^{-1}) under present or future climate, land use and management scenarios (Walling et al., 2003; de Vente et al., 2008). Over the last decades important progress has been made in the understanding, description and modelling of SE, SSY and SY at various spatial and temporal scales. Yet, most models focus on relatively small spatial units (plots to small catchments), and predict only a selection (sheet-, rill-, ephemeral gully erosion) of erosion processes (Jetten et al., 2003; Merritt et al., 2003; Govers, 2011). Thus, a major limitation for the prediction of catchment SSY is that permanent gullies, mass movements and riverbank erosion are most often not considered. Empirical models are often based on the Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997) that was developed for prediction of mean annual soil loss due to sheet and rill erosion on hillslopes. As sediment deposition is not considered, such models cannot be used to predict catchment SSY (Wischmeier, 1976; Boardman, 2006). While some models do explicitly model sediment transport and deposition, most of these models are evaluated using data from erosion plots, where sediment deposition is negligible (Nearing, 2006; Licciardello et al., 2009). Even if sediment transport and deposition modules would be thoroughly calibrated, their routine application at the catchment scale would remain difficult due to the complexity and interactions between processes and the lack of input data (Merritt et al., 2003; de Vente and Poesen, 2005; Morgan and Nearing, 2011). Furthermore, most SE and SSY models do not simulate the feedback between erosion, deposition and topography. Landscape Evolution Models (LEMs), however, specifically simulate the three dimensional development of landscapes in response to environmental and climatic changes. As they generally operate on timescales of centuries to millennia and over large spatial scales, their equations are typically simple, and compared with erosion models, LEMs have a greater emphasis on fluvial processes (Tucker and Hancock, 2010), although some LEMs simulate erosional processes in coupled systems of hillslopes and fluvial channels (Willgoose et al., 1991; Coulthard et al., 2002; Baartman et al., 2012). Alternatively, several authors have combined SSY modelling with a sediment budget approach, in which those sediment sources and sinks not covered by the model were measured in the field (Trimble, 1999; de Moor and Verstraeten, 2008; Wilkinson et al., 2009).

The main objectives of this paper are to identify the most effective and efficient model or model concept to predict soil erosion and catchment sediment yield under present and future land use and climate scenarios, and to differentiate between dominant soil erosion and sediment transport processes. We evaluate and discuss the strengths and weaknesses of a range of model concepts. Recognising the inherent differences in approach and objectives of different models, the main challenges for interpretation of model results are discussed and suggestions are made for next steps in model development.

2. Model evaluation

2.1. Model and study site selection

Modelling studies included in this evaluation are limited to those that were applied to a selection of study areas to allow a fair model comparison not affected by differences between the study sites. A total of fourteen soil erosion and sediment yield prediction models were selected, most of which had been applied to the same catchments in Spain,