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A high-resolution soil erosion risk map of Switzerland as strategic policy support system

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ABSTRACT

Soil erosion models and soil erosion risk maps are often used as indicators to assess potential soil erosion in order to assist policy decisions. This paper shows the scientific basis of the soil erosion risk map of Switzerland and its application in policy and practice. Linking a USLE/RUSLE-based model approach (AVErosion) founded on multiple flow algorithms and the unit contributing area concept with an extremely precise and high-resolution digital terrain model (2 m × 2 m grid) using GIS allows for a realistic assessment of the potential soil erosion risk, on single plots, i.e. uniform and comprehensive for the agricultural area of Switzerland (862,579 ha in the valley area and the lower mountain regions). The national or small-scale soil erosion prognosis has thus reached a level heretofore possible only in smaller catchment areas or single plots. Validation was carried out using soil loss data from soil erosion damage mappings in the field from long-term monitoring in different test areas. 45% of the evaluated agricultural area of Switzerland was classified as low potential erosion risk, 12% as moderate potential erosion risk, and 43% as high potential erosion risk. However, many of the areas classified as high potential erosion risk are located at the transition from valley to mountain zone, where many areas are used as permanent grassland, which drastically lowers their current erosion risk.

The present soil erosion risk map serves on the one hand to identify and prioritise the high-erosion risk areas, and on the other hand to promote awareness amongst farmers and authorities. It was published on the internet and will be made available to the authorities in digital form. It is intended as a tool for simplifying and standardising enforcement of the legal framework for soil erosion prevention in Switzerland. The work therefore provides a successful example of cooperation between science, policy and practice.

Introduction

Soil erosion from water is considered one of the greatest threats to soil as a resource. In about one-third of OECD member countries, more than 20% of the agricultural land area is affected by moderate to severe soil erosion from water (OECD, 2008). Soil erosion risk and prognosis maps are an often used instrument for determining the political course-of-action planning in soil conservation. Accordingly, the demand for these maps in Europe has greatly increased within the scope of the Water Framework Directive, cross-compliance regulations and national soil conservation strategies. Soil erosion risk and prognosis maps are usually generated with the use of models. Since a model is always a simplified depiction of reality, however, more complex processes in agricultural reality can only be modelled with a certain degree of vagueness and uncertainty. The number of available soil erosion models has taken on a vast dimension. Merritt et al. (2003) conducted a comprehensive review of 17 soil erosion prediction models. They distinguish between (a) empirical or statistical models, (b) conceptual models, and (c) physically based models. The models differ with regard to complexity, landscape characteristics, data inputs and requirements, processes they represent, scale of intended use, type of output information they provide, accuracy and validity of the model, and objective of the model user. Jetten and Favis-Mortlock (2006) discuss 16 soil erosion models currently used in Europe. Spatial scales range from micro-plot to European scale, and time scales from intervals of less than 1 min over event-based to average

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long-term soil loss over many years. In a comparison of models, the performance in terms of observing long-term soil loss of more simple lumped empirical models such as USLE/RUSLE was of equal quality as that of more complex distributed physically based models, mainly because input errors increase with increasing model complexity (Jetten et al., 2003). Different authors therefore come to the conclusion that there is no 'best' model for all applications (Jetten and Favis-Mortlock, 2006; Merritt et al., 2003; Volk et al., 2010).

Numerous papers address the problem and the importance of scale dependency (De Vente and Poesen, 2005; Parsons et al., 2006; Renschler and Harbor, 2002). Scaling soil erosion rates up or down is almost impossible due to different processes on different scales (Verheijen et al., 2009). Most models therefore focus on a specific spatial scale, e.g. field scale or catchment scale (Lesschen et al., 2009). Volk et al. (2010) present an example for a conceptual framework for scale-specific modelling of soil erosion risk. They use three model approaches of different complexities for large-scale catchments, farms and fields, and designated field blocks. Wickenkamp et al. (2000) present a two-stage procedure. However, each regionalisation has to be developed and validated (Renschler and Harbor, 2002).

Despite criticisms, shortcomings and limitations, the empirical Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1978) remains the most commonly used soil erosion model worldwide (Laflen and Moldenhauer, 2003). It owes its popularity to its minimal data and computation requirements as well as to its transparent and robust model structure. This allows an estimation of extent and distribution of the long-term soil erosion risk with relatively little effort. The Revised Universal Soil Loss Equation (RUSLE, Renard et al., 1997) is replacing USLE in most cases today, but it contains the same factors and has the same formula. Many improvements and modifications to the individual factors of USLE have by now been integrated into RUSLE, making it more process based. In addition, various other USLE derivatives have been developed, e.g. MUSLE (Zhang et al., 2009), MUSLE87 (Bork and Hensel, 1988), USLE-M (Kinnell, 2001) as well as, for Germany, ABAG (Schwertmann et al., 1990), dABAG (Flacke et al., 1990) and ABAG-Flux (Volk et al., 2010).

The use of powerful GIS techniques allows feasible soil erosion estimates and their spatial distribution with reasonable costs and better accuracy (Bartsch et al., 2002; Lu et al., 2004). The availability of increasingly better digital elevation models allows a very high spatial resolution of the topographical factor. Examples of high-resolution soil erosion risk maps on the basis of USLE/RUSLE models are shown by Brandhuber (2010) for Bavaria, Germany (5 m × 5 m grid); Onori et al. (2006) for Sicily, Italy (20 m × 20 m); Tetzlaff et al. (in press) for Hesse, Germany (20 m × 20 m); Martín-Fernández and Martínez-Núñez (2011) for Spain (25 m × 25 m); Deumlich et al. (2006) for Brandenburg, Germany (25 m × 25 m); Park et al. (2011) for South Korea (30 m × 30 m). The spatial range for modelling reaches from the individual plot (Volk et al., 2010) to catchment areas (e.g. Amore et al., 2004, for three Sicilian basins, Italy; Chen et al., 2011 for Miyun watershed in Northern China), regions (Lu et al., 2004, for Rondonia, Brazilian Amazonia; Terranova et al., 2009, for Calabria, Italy), states (e.g. Park et al., 2011, for all of South Korea) and entire continents (Bui et al., 2011, for all of Australia). Most European countries (Austria, Belgium, Czech Republic, Germany, Hungary, Italy, Norway, Portugal, Spain, Sweden, Switzerland) have applied adjusted versions of the USLE/RUSLE approach, as shown in Boardman and Poesen (2006). There also are large variations in time resolution of the USLE/RUSLE models. Originally designed for the long-term average soil loss, USLE/RUSLE is now also used on a monthly basis (Nigel and Rughooputh, 2010), for individual events (Kinnell, 2010) and for calculating future scenarios (Park et al., 2011).

Compared with process-based research and modelling there are only few studies about the interplay between soil erosion and socio-economic and political parameters (Boardman et al., 2003). Fullen et al. (2006) have reviewed the soil conservation policies of 10 European countries. They conclude that the interest in and the perception of soil erosion have increased, mainly in connection with off-site damage such as water contamination through nutrients and pollutants or downstream sedimentation. This includes the use of a wide range of instruments: legal rules, subsidies, agri-environmental measures, soil erosion control plans, promotion of participatory approaches, education programmes and the development of advisory services. Successful examples but also problems for the implementation of different soil erosion prevention measures are shown by Deumlich et al. (2006) for Brandenburg, Germany; Lundkvam et al. (2003) for Norway; Prager et al. (2011a) for Uckermark, Germany; Schuler and Sattler (2010) for north-eastern Germany; Veihe et al. (2003) for Denmark; Verstraeten et al. (2003) and Verspecht et al. (2011) for Flanders, Belgium. Prager et al. (2011b) summarise the results of 10 different case studies. They classify policy measures as:

1. mandatory policies (command-and-control);
2. voluntary, incentive-based policies (e.g. agri-environmental schemes);
3. consultation and awareness-raising measures.

A comprehensive overview of the implementation of EU27 policy measures that are relevant for soil quality and a classification system for analysing policies are provided by Kutter et al. (2011). They found that a wide range of soil conservation policies exist, but with different ones being implemented in every country. Louwagie et al. (2011) analysed the EU legislation and found that only nine EU member states have specific legislation on soil protection. However, the most important EU-wide environmental directives for soil quality, surprisingly, are the Nitrate Directive and the Water Framework Directive. Despite numerous efforts, there still is no soil conservation directive analogous to the Water Framework Directive.

In Switzerland soil erosion on agricultural land has been systematically studied by scientists since the mid-1970s and was recognised by policymakers as a problem – within the framework of the discussions about the introduction of environmental protection legislation – as early as 1973. At least since the publication of the studies and results by Mosimann et al. (1990) about the extent and distribution of soil erosion in Switzerland, the issue has also registered with the general public and been recognised as a problem. In addition to numerous field studies on soil erosion (see compilation in Prasuhn, 2011), there have been several subsequent attempts to model the extent and the spatial distribution of soil erosion extensively for the whole of Switzerland (Prasuhn et al., 2007; Schaub and Prasuhn, 1998). However, until recently the existing basic data and models allowed only rough overview maps which are unsuitable for users. High-resolution digital elevation models and numerous other available digital basic data for soil, climate and land use as well as freely available soil erosion models have recently permitted soil erosion modelling which can be used on a plot level, making it suitable as a practical tool.

The first part of this paper presents the scientific foundations and results of a high-resolution and highly precise soil erosion risk map for the agricultural area of Switzerland. A modified USLE/RUSLE model calculation with a 2 m × 2 m grid serves as the basis for this (erosion risk map 2 m × 2 m, ERM2). The second part demonstrates the utilisation of the ERM2 for implementing the legislation in Switzerland. A successful example for linking science, policy and practical application is presented.