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Climate Change and Soil Erosion– Results of Comparative Model Simulations for a catchment in Saxony/Germany

MICHAEL, A.[1]; SCHMIDT, J.[1]; ENKE, W.[2]; DEUTSCHLÄNDER, Th.[2], MALITZ, G.[3]
[1]Technical University Freiberg; Soil and Water Conservation Unit, Freiberg, Germany
[2] Meteo – Research, Berlin, Germany
[3] Deutscher Wetterdienst, Berlin, Germany

Abstract

The impact of the expected climate change on the frequency and extent of soil erosion processes is hardly assessable so far. One reason is due to the fact that available models of climate change produce at best mean daily precipitation data, whereas erosion is always the result of extreme but short time events, lasting normally not longer than a few hours. The frequency and intensity of these extreme events are expected to increase in some regions in Saxony/Germany which could lead to increased erosion rates. To explore these processes, the impact of expected increase in precipitation intensities as well as expected changes in land use and socio-economic conditions on soil loss are to be considered.
The use of a new method for the projection of meteorological time series and their extremes using global climate simulations (ENKE 2003, 2005) permits for the first time an approximation of future soil loss. This research is based on simulated, high resolution data for extreme rainfall events in the period of 2031-2050, which reproduces the mean frequency, intensity and duration of future events with high precipitation intensities relevant to erosion within the investigated seasonal period from June to August. The simulations are performed for one exemplary catchment area in Saxony, based on the EROSION 3D model (SCHMIDT et al., 1997), which is a process-based soil erosion model for simulating soil erosion and deposition by water. Simulated precipitation for the 2031-2050 time period is used to model soil loss, and results are compared to soil loss based on 20 year of measured precipitation from 1981 to 2000.
The simulation results allow the impacts of climate change on erosion rates to be quantified by comparing current climate with predicted, future climate. Expected changes in land use due to changed economic conditions, and influences of drought periods are taken into account as exemplary scenarios.

Materials and Methods

Climate simulation

The quality of global climate simulation models and the accuracy of predicted climate changes have steadily increased during the past decades. In spite of this progress, climate simulations still contain a lot of imponderabilities (Schumann et al., 2000). This is also the case for regional climate models, driven by General Circulation Modells (GCMs). Referring to soil erosion prediction, the primary limitation of simulated climate data is the temporal resolution of available outputs which generally consist of daily data. In contrast modern event-based soil erosion models require climate input data of high spatial and temporal resolution, e.g. precipitation data with resolutions from 1 to 10 min which is usually not provided.
Regional scale climate predictions are usually generated by either utilizing statistical methods for the projection of General Circulation Model (GCM) outputs onto local scales, i.e. downscaling, or by application of regional climate models (RCMs) for specific areas of

interest. Statistical methods share the drawback of not being able to produce simulation data with higher than daily resolutions. Especially intensities and patterns of extreme rainfall events are hard to reproduce because they are heavily affected by local (sub-) scale processes (IPCC, 2001a). To overcome this gap, a method developed by Enke (2003) was used to generate time series of rainfall amounts with a resolution of 5 min. In contrast to many other downscaling approaches, the method is capable of preserving the observed statistical structures (e.g. average and dispersion) of the predicted meteorological parameters. In addition, the scheme includes an algorithm for constructing extremes that have not yet been observed within recent climate.

The basic idea is to rearrange time series of observed meteorological data in a way that they reflect climate changes predicted by GCMs on a regional scale. This is realized by applying relationships between large-scale circulation patterns and local scale weather elements derived from historical data to GCM simulations. The first step of the procedure is the application of a circulation pattern classification based on normalized fields of meteorological variables.

Once the different weather types have been determined, the next step is to subdivide the course of the present climate (represented by the time interval from 1981 to 2000) into warm and cool intervals, i.e. into periods with temperatures above and below the seasonal average. Using a random number generator the resulting weather condition periods are rearranged to form a simulated time series optimally reflecting modelled circulation changes. This is accomplished by adjusting the frequency distribution of the circulation patterns pertaining to the temperature regime within the newly generated time series to that resulting from the climate model outputs determined before. Finally, the annual variation of all meteorological elements is appended to the simulated time series in order to restore absolute values.

To allow for extremes that have not yet been observed within recent climate, a regression analysis is performed separately for all objective circulation patterns yielding the general relationships between large-scale circulation conditions and all individual local weather variables except precipitation. By inserting systematic, i.e. mean, changes between the model simulated large-scale conditions during the scenario decade 2001/2010 (representing the present climate within the model output) and the following scenario decades (e.g. 2021/2030) into the derived regression equations, it is possible to estimate the mean changes of the local weather variables. Appending those to the already generated time series allows for extremes of a new magnitude.

Input data for the soil erosion model were generated using observed weather data of the period from 1981 to 2000 including a time series of precipitation data with a resolution of 5 min from the climate station Chemnitz located in the federal state of Saxony. The simulations are based upon the results of the coupled global ocean atmosphere model ECHAM4-OPYC3 operated at the Max-Planck-Institute Hamburg (Roeckner et al., 1996). Specifically, the output of the so-called B2 scenario defined by the Intergovernmental Panel on Climate Change (IPCC, 2001b) was used. To allow for comparison, not only the time period from 2031 to 2050 was simulated, but also simulations of the present climate (1981–2000) were generated.

For statistical evaluation only rainfall events with intensities of >0.1mm/min were selected. This amount has been defined as border for measurable precipitation by the World Meteorological Organization (WMO). Furthermore only the months June, July, and August were considered, because most heavy precipitation events occur during summer. For the following simulations of soil loss, using the comparative model simulation with EROSION 3D, those simulations from each period were chosen within which the minimum and maximum rainfall intensities occurred.

Simulation of soil erosion

The model EROSION 2D/3D, as used for this study, was developed with the intention to create an easy-to-use tool for erosion prediction in soil and water conservation planning and assessment (Schmidt et al., 1999). The EROSION 2D/3D model is predominantly based on physical principles. The model simulates the detachment of soil particles, the transport of detached particles by overland flow, incl. grain size distribution of the transported sediment and the sediment delivery into downstream water courses caused by single events (Schmidt, 1990, 1992). The infiltration rate is estimated by an infiltration subroutine based on the modified approach of Green and Ampt (1911).
At present two model versions are available: EROSION 2D predicts the erosion on single 1-m-wide slope profiles, and EROSION 3D simulates the erosion on catchment scale. The 3D version works on the basis of a regular grid: More than $5*10^5$ grid elements can be processed. The temporal resolution of the model depends on the rainfall data available and can range from 1 to 15 min.
EROSION 3D, the catchment version, was used within this study.

Area description

The exemplary catchment "Hoelzelbergbach" which is situated in the lower "Erzgebirge"-mountains in Saxony is to a large extent agriculturally used. It is a part of a water protection area and discharges into the Saidenbach reservoir. Weathered gneiss formed deep sandy loamy soils with about 20% course silt, fine and middle sand in each fraction, about 6% clay and 1,9 - 2,5% organic Carbon. Table 1 shoes morphometric characteristics of the catchment.

Table 1: Morphometric charakteristics and land use

characteristic value	**Hoelzelbergbach**
catchment area	0,76 km²
length of the receiving water course	1,2 km
average elevation	479 m
average slope gradient	6,6 %
arable land (thereof pasture)	76 % (20%)

The catchment was test site within a former project "Soil erosion measurement program" of the Sächsisches Landesamt für Umwelt und Geologie and the Sächsische Landesanstalt für Landwirtschaft (Michael, 2000). The output of the "Soil erosion measurement program" provides a data base (soil input parameters for EROSION 3D) for soil types in Saxony, which are frequently affected by erosion. The data refers to typical land use and to common tillage practices (conventional/conservation tillage). The compiled data catalogue covers 132 rainfall experiments with a modular rainfall simulator (irrigated area: 22*4 m) on 85 different plots in Saxony, as well in the Hoelzelberg-catchment.
The simulations were accomplished considering:
– soil conditions in June, July, August with simulated drying and re-moisturing,
– crop rotation (corn, spring barley, winter barley, clover over two years, rape, winter barley, potatoes, winter wheat, oat) over a 20-year period,
– crop growth from June to August,
– soil management: conventional tillage.
Soil input parameters refer to the precise date of precipitation. Expected changes in land use due to changed economic conditions, and influences of drought periods are taken into account as exemplary scenarios.

Results, discussion and conclusions

A comparison of the mean cumulative precipitation [mm] of all events with intensities >0.1mm/min for the months June, July and August of both periods from 1981 to 2000 and 2031 to 2050 for the climate station Chemnitz yielded no significant changes. However, the total numbers of events with intensities >0.1mm/min within the month June, July and August decline from period 1981–2000 to 2031–2050 by 38%. As a consequence of that the mean maximum precipitation intensities [mm/min] for the month June, July and August increase in the period 2031–2050 by 23%. So it is to be expected that the precipitation system for South East Germany will change until 2050.
The impact of the expected increase of precipitation intensities leads to increasing soil loss. The amount of soil loss depends on soil, slope and management conditions. Analysis of the impacts of soil loss should include the variation in social and economic conditions, which are unavoidable through the change of the climate. This includes changes in land use and land use structure, soil management and related to that soil structure, cover, roughness, porosity, content of organic carbon, etc. These factors effect soil erosion much more than the impact of the expected increase of precipitation intensities.
This study was conducted as a first approximation of the impact of climate change on soil loss. With improvement in climate research and model concepts of regionalisation of high resolution climate data, the forecasts will become more precise.

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