University of West Hungary
Faculty of Forestry

Theses of doctoral (PhD) dissertation

Factors influencing sediment transport on the headwater catchments of Rák Brook, Sopron

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Background and objectives

Sediment transport and soil erosion processes may lead to even more serious environmental and ecological catastrophes due to the global climate changes. According to the precipitation scenarios for Hungary, the change of rainfall distribution leads to the increase of drought and heavy rainstorm frequency (*Bartholy & Pongrácz* 2007).

The intensification of rainfall events contributes to the increase of stream sediment yield. Several news and studies reported on disastrous flash floods and debris flows. Soil erosion, one of the main sources of the sediment in streams, shows also a growing tendency related to the extreme precipitation.

High sediment yield in the streams promotes different harmful ecological and economical changes:

- eroded material as sediment particles can directly impair the life conditions of aquatic organisms;
- alterations of channel morphology modify the aquatic habitats;
- decreasing reservoir capacity and flow section of channels raise the flood levels;
- sediment particles shortens the lifetime of irrigation systems and hydraulic structures;
- suspended particle-bond substances can contaminate the aquatic ecosystems.

To avoid the multiple harmful effects, it is necessary to get detailed information about soil erosion and sediment dynamics. Nevertheless, it is a difficult question to predict sediment motion and to plausibly calculate sediment yield for the future, because the sediment dynamics shows significant spatial and temporal fluctuation, even in the small forested catchments.

The preceding soil erosion researches in forested catchments were performed by the Hungarian Forest Research Institute in the Mátra Mountains (*Bánky* 1959, *Újvári* 1981). They measured soil loss at plot-scale in different forest stands. *Kucsara & Rácz* 1988 and *Gribovszki & Kalicz* 2003 started researches in the Sopron Hills to calculate average soil loss and life expectancy of forest ponds, and to describe the complex dynamics of sediment transport. *Gribovszki* (2000) developed regression equations to determine bedload yield and suspended sediment yield.

The dissertation completes the previous results to better understand the sediment transport and soil erosion processes in small forested catchments. The author examines the variability of sediment dynamics and the sediment control factors at local scale, in the headwater catchments of Rák Brook (Sopron Hills). The main objectives of the PhD-thesis are:

- to demonstrate the spatial and temporal fluctuation of the suspended sediment concentration and its control factors;
- to determine the significant sediment control factors under low and high flow conditions and at different time scales;
- to develop regression equations and to calculate sediment yield at event-scale and annual scale;
- to examine the impact of an outwashing sediment deposit on the sediment dynamics as a stochastic process;
- to identify the role of soil erosion as sediment sources of the stream.

The dissertation synthetizes the results of each research question and makes comparison between annual sediment yield, soil loss and sediment input by an outwashing sediment deposit, in order to point out the main sediment sources and catchment regions threatened by soil erosion in the forested study area.

Data and methods

Dataset are primarily based on the period between the hydrological years 2000 and 2010. The study area are the Farkas Valley and the Vadkan Valley, two small adjacent forested catchments in the Sopron Hills, Hungary.

Table 1 summarizes the applied methods to answer the research questions.

Table 1. Main objectives of the dissertation and the applied methods

Research questions	**Methods**
Which spatial and temporal pattern shows the variability of the suspended sediment concentration and its control factors?	Descriptive statistical analysis
What are the significant sediment control factors at different flow conditions and time scales?	Pearson correlation analysis Factor analysis
Which regression models can describe plausibly the sediment yield • for the selected flood events? • for the hydrological year 2008-2009 in the Farkas Valley?	Stepwise multiple regression analysis Sensitivity analysis
How does an outwashing sediment deposit influence the sediment dynamics between Oct. 2008 and Oct. 2009 in the Farkas Valley?	Geodesic survey and data preprocessing using Geographical Information Systems (GIS) Mass curve and double mass curve analysis
What is the rate of surface soil loss in the hydrological year 2008-2009? Which soil erosion processes contribute to the stream sediment yield in the Farkas Valley?	Soil analyses Geodesic survey and data preprocessing using GIS Erosion modelling • using the empirical Universal Soil Loss Equation (USLE – *Wischmeier & Smith* 1978) • using the physically-distributed EROSION-3D model (*von Werner* 1995)

The author separated the low and high flow periods and low flow periods were also categorized on the basis of the number of days elapsed between the sampling and previous flood event (antecedent days). The following factors controlling suspended sediment concentration (*SSC*) have been examined *under low flow conditions*:

- discharge (*Q*),
- antecedent days,
- water and soil temperature at a depth of 0 cm, 5 cm and 10 cm.

Relations between the sediment variables and control factors have been analysed at different time scales:

- for the entire study period – from 01.11.2000 to 31.10.2010,
- at seasonal scale,
- and for the hydrological years.

The factors controlling *SSC* involved in the analyses *at high flow* are:

- water and soil temperature at a depth of 0 cm, 5 cm and 10 cm,
- rainfall erosivity, antecedent precipitation of 1, 3 and 7 days,
- *Q*, total volume and peak discharge of the flood event.

Reference time scales are:

- the entire study period,
- seasons,
- flood events (18.07.2009 and 04.08.2009).

Input data for the soil erosion modelling are:

- a 5·5 m raster resolution digital elevation model,
- a 1:10000 scale georeferred rasterized topographic map,
- aerial photographs in 0.5 m/px resolution,
- forestry management plans (1994, 2004),
- a soil map based on the soil samples from the Farkas Valley,
- 1-min resolution rainfall time series.

Soil dataset for the EROSION-3D consists of the bulk density, organic matter, initial moisture, erodibility, cover, roughness, skin factor for the corrections and nine particle fractions. In the absence of own soil parameters, the *Parameter catalogue for Saxony* (1996) have been used.

Theses of the dissertation

1. The author introduced a new variable “antecedent days” (*AD*) which represents the number of days elapsed between the water sampling and the previous flood event. This variable refers to the sediment-outwash effect of previous flood events and the sediment supply processes during dry periods. Since the correlation is significant between *AD* and suspended sediment concentration (*SSC*) under low flow conditions, *AD* is a useful variable to better understand the low flow suspended sediment dynamics in small catchments. Freeze-thaw effect has also been identified as another significant impact on the low flow sediment dynamics: significant correlation was only obtained between *SSC* and temperature variables in spring **[1]**.

2. The author identified three types of hysteresis loops relating the relation between suspended sediment concentration (*SSC*) and discharge (*Q*): clockwise, counterclockwise and eight-shaped loops. These phenomena refer to the temporal fluctuation of *SSC*-*Q* ratio during a flood event and the fine material availability in the channel. Knowing the conditions of sediment availability in a stream for different *Q*-ranges, it is also possible to identify catchment regions which contribute to the sediment load into a channel. These findings can be considered as novel results in the Hungarian forest hydrological researches related to small catchments **[1][2][3]**.

3. The author found significant correlation between the suspended sediment concentration (*SSC*) and rainfall, runoff and climate parameters, such as discharge, water temperature, soil temperature, antecedent precipitation index, rainfall erosivity, peak discharge and total volume of the flood event depending on the examined time scale and flow dynamics under high flow conditions. Based on these relations between the *SSC* and its control factors, regression equations have been developed to calculate suspended sediment yield.

Temporal variability of *SSC* reduces the strength of correlation between *SSC* and environmental parameters and the reliability of regression equations as well. The strongest relations have been obtained at event scale. Separation of rising and falling limb provided even higher Pearson's correlation coefficients. Thus, regression models were developed for single flood events or for the rising and falling limb of each flood. These models are suitable to calculate suspended sediment yield for high flow periods at annual and event scale **[1][2][3][4][8]**.

4. The author developed a four-part workflow in the ArcGIS Model Builder in order to implement the empirical Universal Soil Loss Equation (*Wischmeier & Smith* 1978) into GIS-environment. The model accelerates and makes uniform the calculation of surface soil loss in small catchments. Soil loss prediction confirms the soil protection role of forest vegetation, as the predicted average surface soil loss remained under the tolerance limit in each subcompartments, and surface soil loss was not the major source of the sediment load in the small forested catchment **[5][6][7][8]**.

5. The author pointed out that other sediment sources determine the annual sediment yield in a forested catchment beside the surface erosion. Despite of the expressive quantitative overestimation of soil loss, application of the physical erosion model EROSION-3D (*von Werner* 1995) for a small forest catchment, as novel results for the Hungarian forest hydrological research, demonstrated the outstanding impact of unpaved forest roads on stream sediment budget. Geodesic survey, geoinformatical calculations and mass curve analysis were suitable methods to determine another sediment source of small forest streams, that is, an outwashing sediment deposit behind log jam. This experiment is a good recommendation to analyse stochastic processes of the sediment delivery **[3][4][5][8]**.

[X] References relating the theses are listed among the publications of the author.

Application of the results

Recognizing the relations between suspended sediment concentration and hydrological, hydrometeorological and climate variables helps the development of further regression models for sediment yield predictions in small forest catchments.

Sediment yield forecasting is useful and important, if we would like

- to determine the life expectancy of forest ponds and reservoirs;
- to protect aquatic ecosystems from the harmful effects of increased turbidity –
  – Knowledge of the expected suspended sediment conditions in a water body makes possible to create suitable habitat for different fish species, or to avoid damages to irrigation systems.
- to eliminate the damages by high bedload yield –
  – Knowing the sediment trapping effect of log jams enables to manage the bedload transport which could destroy the hydraulic structures.

The workflow in the ArcGIS environment enables to calculate and classify surface soil loss with the USLE in a fast and uniform way in small forest catchments. The USLE-implementation has also been tested in the Apátkút Valley (Visegrád Mountains), and the model was capable for determining zones which are sensitive to soil erosion (*Kiss* 2013). Hysteresis analysis also gives information of the regions which may contribute to the stream sediment yield. Knowing the erosion-active zones within a catchment promotes to adapt soil protecting forestry technologies, in order to avoid more soil loss.

In the knowledge of rainfall, land use and land cover, soil erosion risk projections for the future provide an important basis to the soil protection strategies for the climate change, such as the increasing frequency of heavy rainfalls.

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