Catena 74 (2008) 119–126

Contents lists available at ScienceDirect

Catena

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

# A pragmatic approach to modelling soil and water conservation measures with a catchment scale erosion model

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ARTICLE INFO

*Article history:*
Received 7 August 2007
Received in revised form 17 March 2008
Accepted 20 March 2008

*Keywords:*
Soil erosion modelling
Soil and water conservation
Kenya
LISEM
P-factor

ABSTRACT

To reduce soil erosion, soil and water conservation (SWC) methods are often used. However, no method exists to model beforehand how implementing such measures will affect erosion at catchment scale. A method was developed to simulate the effects of SWC measures with catchment scale erosion models. The method was implemented by applying the LISEM model to an agricultural catchment on the slopes of Mt. Kenya. The method consisted of a field scale calibration based on P-factors, followed by application at catchment scale. This calibration included factors such as saturated conductivity, Manning's *n*, roughness and slope angle. It was found that using data on P-factors, such models can be calibrated to give acceptable predictions at pixel scale. However, P-factors were also found to vary with land use type and storm size. Besides, more data on the physical effectiveness of SWC measures are needed. At catchment scale, the effect of SWC was found to be different from that at pixel scale. Most SWC were simulated to be more effective at catchment scale, indicating additional infiltration during transport through the catchment to the outlet. However, slope corrections in case of terraces were found to be less effective at this scale. Nevertheless, a simulation for current land use with current SWC measures indicated that these SWC measures decrease runoff by 28% and erosion by 60%.



## 1. Introduction

For conservation planning it is imperative that the effect of soil and water conservation (SWC) measures on runoff and erosion is known. Such data are, for example, necessary to make sensible decisions about land use change and land management. Data on the effectiveness of SWC measures have usually been obtained using plot measurements, in which the effect of different treatments on runoff and erosion is quantified. Erosion modelling can be a tool to predict beforehand what the effect of certain conservation measures would be. However, in erosion modelling the focus has shifted from the plot scale to the catchment scale. The more complex models, i.e. spatially-distributed, process-based erosion models, subdivide catchments into smaller units that are assumed to be internally homogeneous. Such elements might be defined by the user, as for example in EUROSEM (Morgan et al., 1998), KINEROS2 (Smith et al., 1995), WEPP (Flanagan et al., 2001) or might consist of pixels in a grid, as for example in ANSWERS (Beasley et al., 1980) and LISEM (De Roo et al., 1996; Jetten and De Roo, 2001). In either case, the spatial elements are likely to be considerably larger than some of the SWC measures that are being applied in the catchments. A pixel size of 10 m is, for example, quite reasonable for catchments that are several square km in size, but is too large to capture SWC features such as drainage ditches in the digital elevation model (DEM). Since the effect of SWC on runoff and erosion can be considerable, these measures cannot be neglected, and should in some way be incorporated in such models.

One possible way to do this would be to use a much smaller pixel size, e.g. in the order of 0.5 m, which would allow the incorporation of the individual SWC measures into the DEM, and which would allow to include detailed process knowledge into modelling the effects of SWC. However, simulating whole catchments using such very small pixel sizes is impractical, and numerous studies (e.g. Garbrecht and Martz, 1994; Bruneau et al., 1995; Braun et al., 1997; Yin and Wang, 1999; Schoorl et al., 2000; Doe and Harmon, 2001; Vázquez et al., 2002; Jetten et al., 2003; Hessel, 2005) have indicated that modelling results depend on pixel size, which means that it would not be possible to develop a model for SWC using a very small pixel size, and then to apply it using a larger pixel size for the whole catchment. Hence, a method needs to be sought that uses the pixel size as applied to the complete catchment.

In catchment scale physically based models, some changes that are due to SWC are incorporated in the model directly, i.e. the SWC measures result in a change of the value of certain input parameters in the model. However, this is generally not the case for all effects of SWC. Some effects of SWC cannot be modelled directly, but could be

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doi:10.1016/j.catena.2008.03.018

incorporated in the model in a more indirect, pragmatic, way: the expected effect of SWC on runoff and erosion is reproduced by changing input parameters that might in themselves not be directly affected by the change. If for example infiltration ditches are used, not all effects of ditches can be incorporated directly. The main effect of such ditches should be that they store water, increase infiltration and reduce flow velocity. Such effects of infiltration ditches might be achieved in the model by changing e.g. random roughness, saturated conductivity or Manning's *n*, even if the ditch in itself does not affect those input parameters (Hessel et al., 2003). Obviously, if such an indirect method is used, data on the effectiveness of SWC are needed since those data determine by how much the actual input parameters should be changed. For that, information is needed about the ratio of runoff and erosion for areas with SWC to areas without SWC. This corresponds to the P-factor of, for example, the RUSLE model (Renard et al., 1996).

The aim of this study was to use a pragmatic approach to model the effect of SWC measures on runoff and erosion at catchment scale, using a process-based erosion model (LISEM).

## 2. Study area

The study area is the 5.7 km$^2$ Gikuuri catchment (00° 26′ S, 37° 33′ E) in Embu District, Kenya. The catchment is located on the lower slopes of Mt. Kenya, ranges in altitude from 1300 to 1500 m, and receives almost 1300 mm of rain a year, distributed in two rainy seasons. The long rains last from the middle of March to the end of May and the short rains from the middle of October to early December, and, on average, produce, respectively, 47 and 38% of total yearly rainfall (Okoba, 2005). The major land uses in the catchment are coffee and maize, which cover respectively 46 and 31% of the catchment (Hessel et al., 2006). The soils are deep (>160 cm), well-drained red clay loams of volcanic origin, mainly Nitisols, Cambisols and Luvisols (Wanjogu, 2001; Okoba, 2005). Population density in the catchment is high, with 730 persons per square kilometre (Vigiak et al., 2005). The dominant SWC measures in the catchment are bench terraces, fanya juu terraces and grass strips (Tenge, 2005). Bench terraces are made manually, by creating a series of gently sloping platforms at suitable intervals. Fanya juu terraces are made by digging a trench parallel to the contour; the soil from the trench is put on the upslope side of the trench, and as the ridge that is formed in this way captures sediment eroded upslope, a terrace is formed over time (Tenge, 2005). Grass strips consist of fairly narrow (in the order of 1 m wide) strips along the contour lines, which are planted with different grass species. Fig. 1 shows that the areas in which these SWC measures occur in combination occupy about 50% of the catchment area.

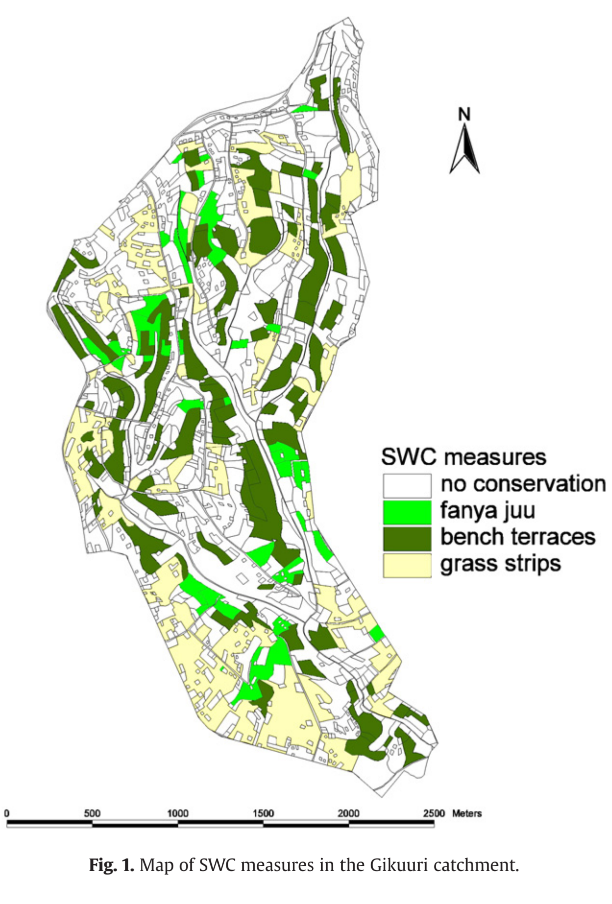


**Fig. 1.** Map of SWC measures in the Gikuuri catchment.

## 3. Methods

LISEM is a process-based erosion model that operates on event basis and that uses pixels to subdivide space (Jetten and De Roo, 2001). A drainage direction map is used to specify to which downstream pixel the water (and sediment) flows. Water is routed using the kinematic wave equation and Manning's equation. The LISEM version used in this study was version 2.154. The pixelsize that was used in the simulations was 20 m and time step length was 15 s. For infiltration, the Green & Ampt equation was used. Simulations were performed for a storm that occurred on November 15th, 2001. This storm produced about 64 mm of rain in 2 h.

LISEM requires some basic data, such as Digital Elevation Model (DEM), land use map and soil map. The DEM was made by digitising contour lines from available topographical maps, while land use map and soil map (Wanjogu, 2001) were made based on data collected during a field survey. Input parameters for the LISEM model were measured in the catchment twice a month between October and December 2001, and included several plant characteristics and soil characteristics, like plant height and cover, leaf area index, cohesion (measured with Torvane), aggregate stability (drop-test of Low, 1954), random roughness (pinboard, Wagner and Yu, 1991; Jester and Klik, 2005) and saturated conductivity (constant head method) (Hessel et al., 2006).

To simulate the effects of SWC measures with LISEM, it was first necessary to obtain data on the effects of SWC on LISEM input parameters and on runoff and erosion.

### 3.1. Effects of SWC

As stated before, the effects of SWC in erosion models can be subdivided in direct effects (affecting input parameters of the model) and indirect effects (affecting runoff and erosion). To be able to model these effects of SWC, data are needed about the effectiveness of the different kinds of SWC measures.

To obtain data on the direct effects of SWC measurements of the LISEM input parameters were carried out on fields with and without SWC measures. During the short rains of 2001 (October to December) and the long rains of 2002 (March to May) the input necessary for the LISEM soil erosion model was measured on coffee and maize/bean fields, with and without bench terraces. The data collected on these fields allow us to determine the direct effect of SWC on the LISEM input parameters, but cannot give data on indirect effects because runoff and erosion from these fields were not measured.

Data on the effect of ten different SWC measures that are being used in the East African Highlands were obtained through literature study of erosion plot results, and they were supplemented with additional plot measurements. P-factors were measured in the Gikuuri catchment and in the Kwalei catchment, which is located in the Usumbara Mountains of northern Tanzania (Tenge, 2005). Runoff and sediment coming from 9 plots in Gikuuri (Okoba, 2005; Hessel et al., 2006) and 7 in Kwalei (Tenge, 2005) were trapped in Gerlach troughs.