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Water Flow and Sediment Transport in Paddy Cascades in Vietnam and their Representation in a Landscape-Scale Model

Schaufelberger[a*], Rebecca, Carsten Marohn[a] and Georg Cadisch[a]

[a] Inst. of Plant Production and Agroecology in the Tropics and Subtropics, University of Hohenheim, Germany

Introduction

Deforestation and continuous maize cropping without fallow increase erosion in mountainous watersheds in SE Asia. Eroded material from the uplands is deposited in paddies in the lowlands influencing their soil fertility (Schmitter et al., 2011). The dynamic and spatially explicit model LUCIA (Land Use Change Impact Assessment tool) simulates erosion, water, nutrient cycles and plant growth on landscape-scale (Marohn and Cadisch, 2011) . Topography as represented in the current model does not account for paddy terraces. Further, sediments are assumed to reach the end of the watershed within one day. But in paddy cascades sediment transport is retarded and discontinuous owed to the paddy bunds.
The scope was to develop a paddy module for the LUCIA model that simulates water and sediment flows in a semi-distributed manner and to test the module based on field measurements. The research area was in Chieng Khoi, Son La, North West Vietnam. The climate is subtropical with a unimodal rainfall distribution. The landscape is dominated by steep slopes mainly planted with annual crops while the valley are covered with paddy fields.

Material and Methods

Model concept

Both models are written in PCRaster (Van Deursen (1995), run on a daily time step and user-defined pixel size. Within each cascade, routing of water flows in the paddy model is directly based on elevation as drain directions in the field may vary frequently and field data be difficult to obtain. At each time step, potential water volume for every pixel is updated for inflow, evapotranspiration (ET), percolation, bund percolation (BP) and cross flow (CF). After dry periods water needed to saturate the bund is accounted for. Having

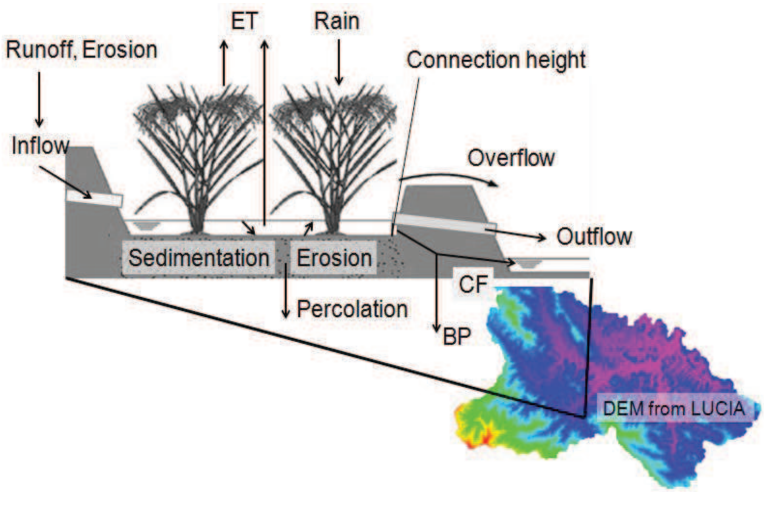

Figure 1 Important stocks and flows in the paddy module as a part of LUCIA.

*Corresponding author: rebeccaschaufi@aol.com

calculated the highest pixel, remaining water is routed through the cascade towards the pixel of lowest elevation. Each paddy fills up until the connection height is reached and outflow starts. Water flow between the paddies is limited by the connection capacity. When the bund height is reached, overflow starts.

Water flowing in from the uplands transports sediments into the paddies. Particles in the water remaining in the paddy are assumed to settle during one day. Erosion in the paddies is calculated using the Rose equation (see Marohn and Cadisch, 2011). A distinction between sediment classes is not implemented, so that only sediment concentration, not the average particle size changes from inlet to outlet due to erosion and sedimentation.

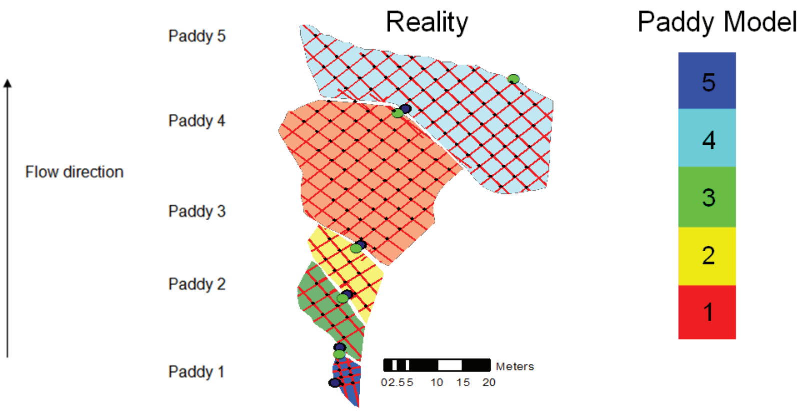

Figure 2 Paddy cascade in Chieng Khoi, Vietnam with soil sampling points (black points, n=150), paddy inlets (blue points) and outlets (green points).

<u>Field measurements and laboratory analyses</u>

Pipes were installed at every connection, plus inlet and outlet. Water flows between the paddies, in and out of the cascade were measured with water clocks. Turbidity (sediment loads) measurements in paddy water flows was conducted during base flow conditions with portable sensors (NEP160 and NEP 260, McVan Instruments) Soil samples were taken shortly before rice harvest along a grid (Figure 2). Every 10 m² a grab sample was taken from the first 1 cm of the topsoil characterise the sediments and exclude the influence of the parent soil. The samples were dried and analyzed for total nitrogen and carbon (dry combustion using a Vario MAX CN), carbonatic C (Scheibler), and texture (laser diffraction). A training dataset consisting of one third of the soil samples was analyzed using the aforementioned methods. This dataset was used to calibrate for measurements on the extended dataset with mid- infrared spectroscopy. Paddy topography was determined using a Garmin GPSMAP 60CS. ArcGIS 10.0 was used for spatial analysis; SAS 9.2 for statistical analysis.

Results and Discussion

An average water amount of 49 m^3 day^{-1} entered the cascade through the inflow while only 24.4 m^3 day^{-1} left it during normal base flow (no rain) (Figure 3a).

The model inflow was also set to 49 m^3 day^{-1}, but resulted in a much higher outflow than measured of 39 m^3 day^{-1} (Figure 3b).

The lower measured outflow might have been owed to an estimated high cross flow and bund percolation of the third paddy while the modeled cross flow and bund percolation (data not shown) were in the range stated by other authors (Janssen & Lennartz, 2009). Measured flows between the paddies could not be directly compared with the modeled data as one pixel in the model got the average paddy size and the sizes of the real paddies varied from 42 m² to 775 m².

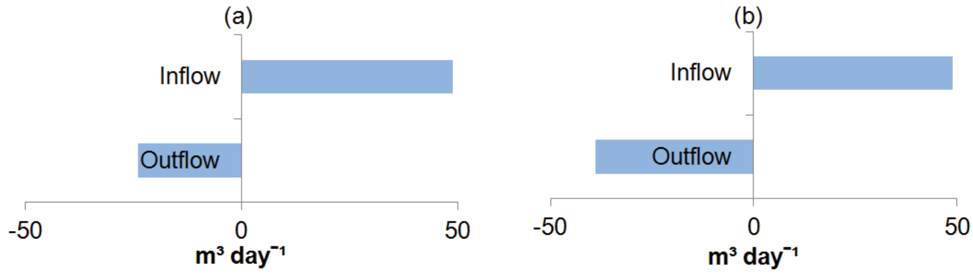

Figure 3 Measured (a) and modeled (b) inflow and outflow of the cascade.

Measured turbidity decreased from the first to the third measuring point but had a peak (340%) at the outflow of Paddy 4 (Figure 4a).
Modeled turbidity slightly decreased (-10%) over the cascade (Figure 4b). One explanation of the difference between measured and modeled turbidity is that the model does not include human activities. Every work inside the field creates a disturbance of the natural erosion and deposition processes. A possible explanation for the smaller unexpected differences (the increase of turbidity from outflow 2 to outflow 3 and to the outlet) is that as no rainfall happened for several weeks the turbidity was near the detection limit of the probes.

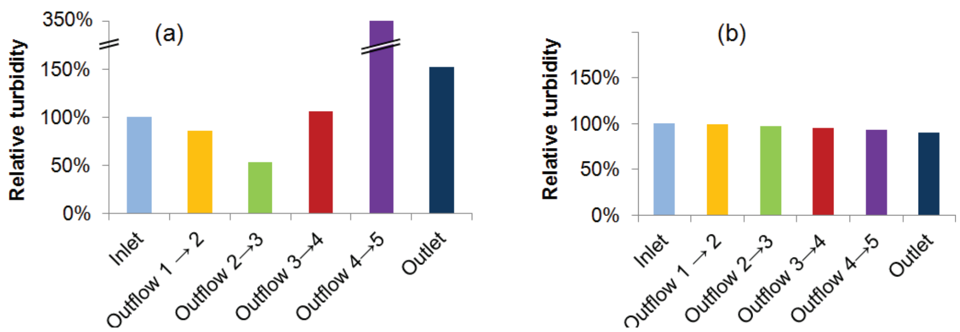

Figure 4 Measured (a) and modeled (b) turbidity at inlet, connections and outlet. Relative values to the measured turbidity at the inlet (100%).

Figure 5 shows simulated values of all the flows during one day. At this time bunds were saturated with water. The pixel and here also paddy area is 361 m² including the bund with a width of 40 cm, the average bund width of the research cascade. The outflow cannot be compared with the measured one as mentioned before. Cross flow (CF), bund percolation (BP) and percolation in the field are in the range of other authors (Janssen & Lennartz, 2009).

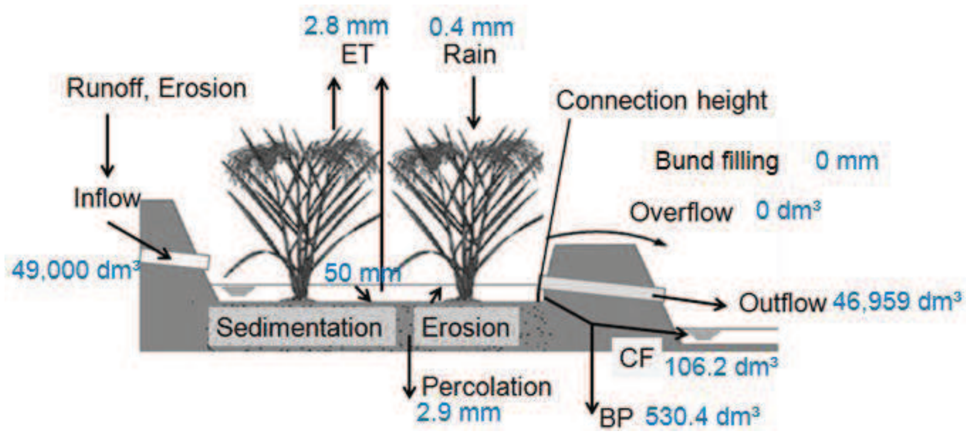

Figure 5 Example for modeled flows in the first pixel at day 84 (first day with both, precipitation and inflow).

Conclusions and Outlook

The new paddy module for LUCIA has the potential to improve the existing model, but further field measurements and data evaluation are needed. To calibrate turbidity dynamics correctly, more measurements, especially during rain events have to be taken. For a better validation of the model also more flow measurements in other cascades should be carried out. To simulate the sedimentation in one paddy and not only between paddies, a higher spatial resolution is needed and the results of the soil analysis could be used.
Further improvement of the sediment modeling could include to calculate not only with one average particle size for all sediments but with average particle sizes of clay, silt and sand. With this it would be possible to model a faster sedimentation of coarser particles compared to finer ones, resulting in a lower average particle size at the outlet compared to the inlet.
The data of the soil analyses (not shown here) can be later used to model the influence of the eroded and deposited sediments on soil fertility and productivity in the paddy cascades.

References

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