Karlsruhe Institute of Technology

How does slope form affect erosion in CATFLOW-SED?

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IWG
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Introduction and Objectives

Erosion is a severe environmental problem in agro-ecosystems with highly erodible loess soils. It is controlled by various factors, e.g. rainfall intensity, initial wetness conditions, soil type, land use and tillage practice. Furthermore slope form and gradient have been shown to influence erosion amounts to a large extent. Erosion models differ in terms of complexity, the processes which are considered, and the data required for model calibration and they can be categorised into empirical or statistical, conceptual, and physically-based models.

We analysed erosion on different virtual hillslopes with varying slope gradient and slope form using the physically-based CATFLOW model[3]. We explored the role of landform, particularly looking for forms that either maximise or minimise erosion.

CATFLOW

- Process-based hydrology and erosion model for catchment and hillslope scales
- Soil water dynamics: Richards equation including effective approaches for preferential flow
- Evapotranspiration: Penman-Monteith
- Overland flow: diffusion wave equation
- Soil detachment: attacking forces of rainfall and overland flow, and the erosion resistance of soil[2]
- Sediment transport capacity and sediment deposition: overland flow velocity using the equation of Engelund and Hansen[1] and the sinking velocity of grain sizes

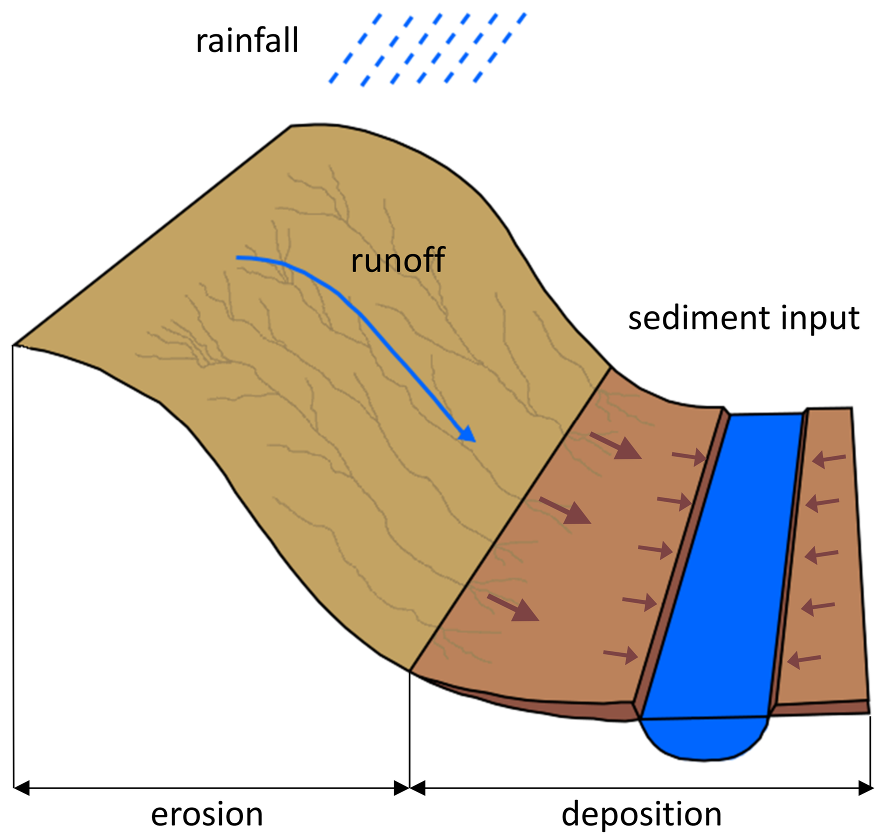

Figure 1: Erosion and deposition on a hillslope.

Methods

- Model runs to analyse the influence of slope forms on the simulated erosion amount using CATFLOW-SED
  - Creating concave/convex slopes

$$\frac{z}{z_{max}} = 1 - \left(\frac{x}{x_{max}}\right)^{\beta}$$

  - Creating sigmoid slopes

$$z = \frac{z_{max}}{1 + e^{-k(x-x_0)}}$$

  - z: elevation, z_{max}: maximum elevation
  - x: distance along slope line, x_{max} : maximum distance along the slope line
  - form parameters: β, k (steepness of the curve) and x_0 (sigmoid's midpoint)

- Variation of form parameters (Table 1)
- Loess soil with vegetation (beets)
- Maximum rainfall intensity: 38 mm/h (for the first 20% of the time it was 22.8 mm/h, after this it was 38 mm/h for 50% of the time and the last 30% of the time it was 15.2 mm/h).

Table 1: Parameter values for form parameters

Name	Slope form	Varied parameter	Range	comment
BA01	convex/concave	β	0.32 – 5	-
CA01	Sigmoid	k	-0.05 – -1	x_0=0.5
CA02	Sigmoid	x_0	-10 – 10	k=-0.3
CA03	Sigmoid	x_0	-10 – 10	k=-1

Results

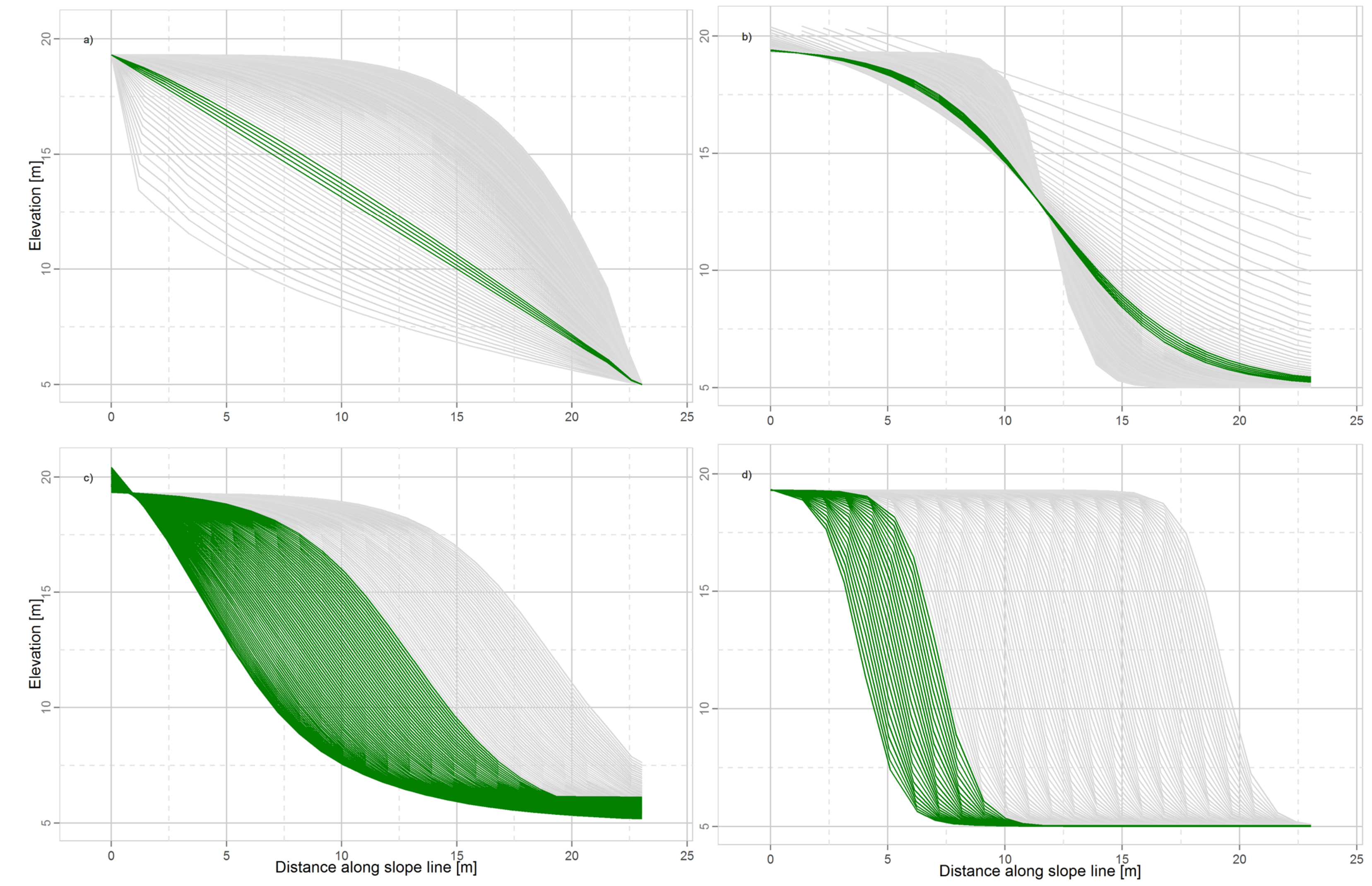

Figure 2: Different slope lines used in simulation (grey lines) and slope lines where simulated erosion is minimised by form parameters (green lines) : a) convex/concave (BA01), b) sigmoid slopes with varied k (CA01), c) sigmoid slopes with varied x_0 and k=-0.3 (CA02), and d) sigmoid slopes with varied x_0 and k=-1 (CA03).

- The highest simulated erosion amount on convex/concave slopes in setup BA01 (Table 2)
- The lowest values were found on sigmoid slopes in setup CA02 and CA03
- Mean erosion was lowest for setup CA02
- Values for form parameter were erosion is minimised (Fig. 3).
  - BA01: β = 1.127
  - CA01: k = -0.303
  - CA02: x_0 = -10 … -5.702
  - CA03: x_0 = -10 … -7.765

Table 2: Minimum, maximum and mean simulated erosion amount for different setups

Name	Min. erosion [kg]	Max. erosion [kg]	Mean erosion [kg]
BA01	36.940	360.740	159.660
CA01	0.777	90.548	29.216
CA02	0.000	139.734	20.074
CA03	0.000	125.364	46.336

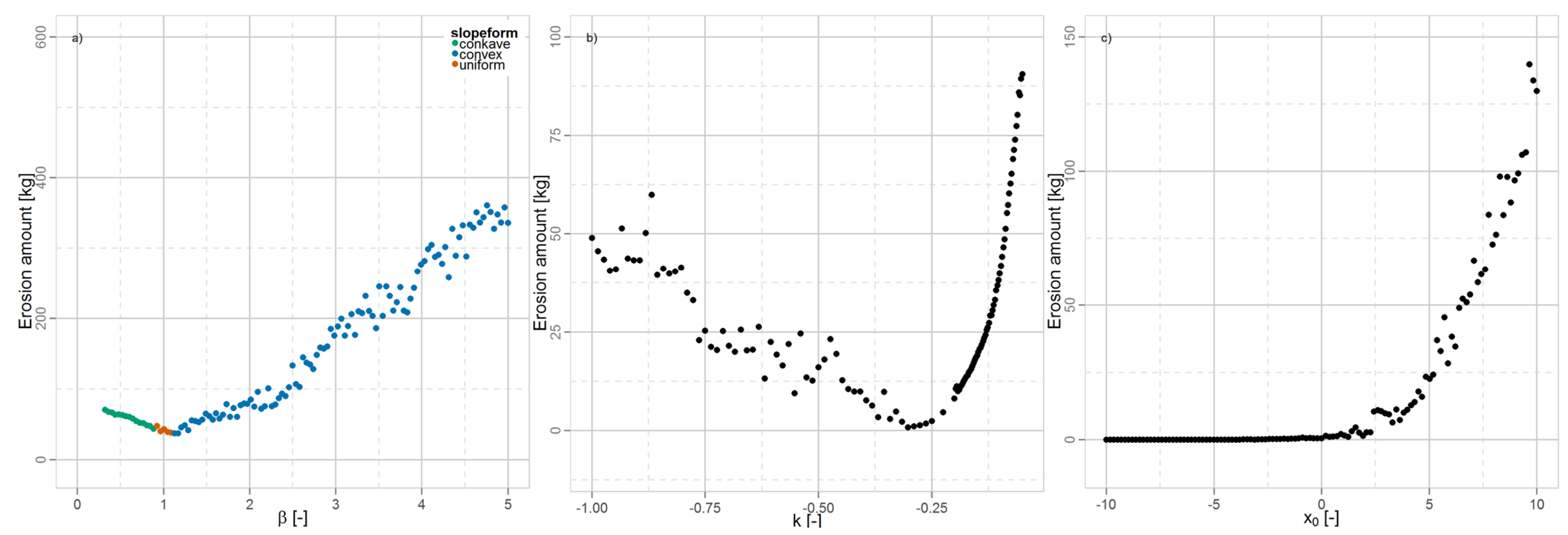

Figure 3: Simulated erosion depending on slope forms on a) convex/concave (BA01), b) sigmoid slopes with varied k (CA01), and c) sigmoid slopes with varied x_0 (CA02).

- More setups where erosion amounts are lower (Fig. 2)
- On convex/concave slopes: Most erosion at slope toe
- On sigmoid slopes: Erosion partly at slope toe but also on the slope shoulder
- Erosion was more distinctive on slopes where we varied the sigmoid's midpoint with higher values for x_0 than on slopes with a smaller x_0 (Fig. 4)
  - Water accumulates over a longer plateau on slopes with a midpoint more to the right side of the slope line
  - The plateau is longer, there is more water on it, and this water has a higher force to erode more soil particles than on those slopes with a midpoint more to the left and a shorter plateau

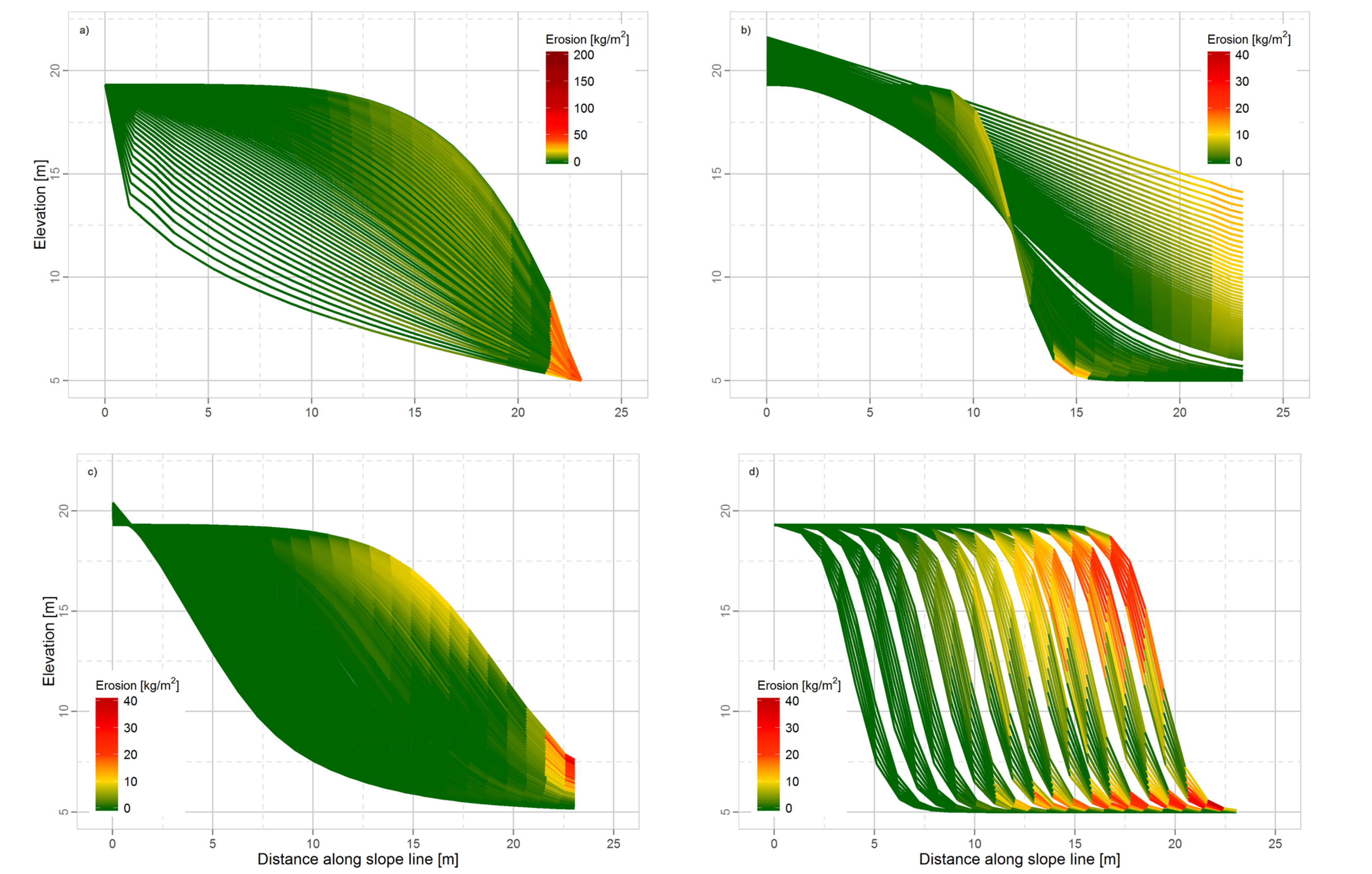

Figure 4: Simulated erosion for the different slope segments on a) convex/concave hillslope forms (BA01), b) sigmoid slopes with varied k (CA01), c) sigmoid slopes with varied x_0 and k=-0.3 (CA02), and d) sigmoid slopes with varied x_0 and k=-1 (CA03).

Conclusions

- The physical-based model CATFLOW-SED allows virtual experiments to explore the interplay of landform and hydrology on erosion processes
- We found hillslope forms that minimise the erosion amounts
- Not only the steepness of the hillslope is important for modelling erosion amounts, but also the length of the plateau on top of the slope
- Importance of performing model runs with physically meaningful parameter ranges

References

1) Engelund, F., Hansen, E. (1967): "A monograph on sediment transport in alluvial streams", Teknisk Forlag
2) Scherer et al. (2012): "Prediction of soil detachment in agricultural loess catchments: Model development and parameterisation", Catena, 90
3) Zehe et al. (2001): "Modeling water flow and mass transport in a loess catchment", Phys. Chem. Earth Pt B-Hydrol. Oceans Atmos, 26

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