

Soil erosion modeling in terraced landscapes-examples from the Three-Gorges-Area, China

Sarah Schönbrodt, Thorsten Behrens, Stephan Imbery, and Thomas Scholten

Institute of Geography, Physical Geography, University of Tübingen, Rümelinstraße 19-23, D-72074, Tübingen, Germany, Email sarah.schoenbrodt@uni-tuebingen.de (S. Schönbrodt). Tel. +49 7071 29 77504

Abstract

The construction and impoundment of the Three-Gorges-Dam in China fosters an extremely high land-use dynamic. Soil erosion is expected to increase dramatically. In the mountainous landscape farming is mainly practiced on terraced land. Thus, the conceptual *TerraCE* model (Terrace-Condition-Erosion) was developed to assess the spatial variability of terrace condition and the resulting soil erosion risk potential. Our investigations in the Xiangxi catchment confirm the model assumptions. The conditions of terraces were found as a key factor to determine soil erosion. They can be classified in 4 clusters, (a) well maintained (20%), (b) badly maintained (48%), (c) partially collapsed (15%), and (d) completely collapsed (6%). Further, our investigations show that the distance to the inundated area and to the road network are significant covariates to predict the spatial distribution of soil erosion risk. The mean distances to the new shoreline vary between 614 m (well maintained) and 128 m (completely collapsed). The mean distances to the main roads are 588 m and 148 m respectively. A first spatial prediction of the terrace condition of the *TerraCE* model combined with a random forests multi-regression approach show promising results with a spatial accuracy of 70%.

Key Words

Soil erosion, *TerraCE* model, terrace design, quality of terrace maintenance, conceptual model, bench terraces, risk assessment, Three-Georges-Dam, Yangtze river.

Introduction

Soil erosion is worldwide a severe problem and its control a major future challenge (Brady and Weil, 2008). In China, the Yangtze catchment shows the highest rates of soil erosion by water of the whole country (Zhou 2008). 33% (560.000 sqkm) of the catchment area, an area as large as middle Europe, is affected, mostly concentrated on the upper and middle Yangtze river. The world's largest dam project, the Three-Gorges-Dam (TGD) is widely expected to foster soil erosion in an unforeseeable dimension. Due to the river impoundment, large areas became inundated. One consequence is the near and distant resettlement of several million people (McDonald *et al.* 2008; Tan *et al.* 2003; Tan *et al.* 2005). This triggers road construction to improve infrastructure and new land reclamation for smallholder agriculture and cash crop production. Typical natural settings of the scenic Three-Gorges-Area are very steep slopes with shallow soils on various kinds of parent material. Food production takes place on newly build bench terraces as well as on reactivated formerly abandoned terraces. Assuming that the terraces present an equilibrium of geomorphic settings and anthropogenic use (c.f. Brancucci and Paliaga 2006), they are a fairly and sound basis for economic growth and an important engineering tool for water and soil conservation in mountainous areas (Cao *et al.* 2007). However, inadequate construction and mismanagement can lead to a dramatic increase of soil erosion in such areas like the Three-Gorges-Dam in China (Brancucci and Paliaga 2006; Inbar and Llerena 2000; Lesschen *et al.* 2008; Sang-Arun *et al.* 2005). In our study, we try to develop a conceptual model that explains the spatial distribution and quality of bench terraces in the Three-Gorges-Area. The model allows us to understand and to spatially extrapolate the distribution of the quality of terraces in terms of their ability to protect against soil erosion based on data mining techniques. Further, the erosion risk of large catchments can be assessed easily with a high spatial accuracy and resolution.

Materials and methods

Study area

The research area covers the Xiangxi catchment (3,200 sqkm) located in Hubei Province, Central China. The Xiangxi originates in the Shennongjia Forest region (about 3,000 m asl) and reaches the Yangtze river almost 40 km westward of the TGD as a first class tributary. 73% of the catchment area has slopes with inclinations above 20° (mean slope angle 39°, standard deviation 22.8°). The soils (Luvisols, Alisols, Cambisols, Regosols, Leptisols, Fluvisols and Gleyisols) are closely linked to the subtropical monsoon climate with an

annual precipitation of 1,000 mm mainly from June to September, and an annual average temperature of 16.9 °C (1961-1990). Land-use is characterized by subsistence farming mixed with cash crop production, typically on terraced farmland with contour cultivation. Crops are oranges, rice, rape, wheat, maize and garden fruits. Due to the TGD project the impoundment of the Xiangxi river reaches from the outlet approx. 25 km northwards to the central catchment. In this backwater area (500 sqkm), resettlement, land use change, road construction, landslides and soil erosion are common features that result in a highly dynamic ecosystem.

Data and Covariates to parameterize TerraCE

In the Xiangxi catchment data are rarely available and access to terrain is limited. This is a typical feature of such mountainous areas, especially in developing countries. Thus, a data-integrative approach is used to apply the conceptual *TerraCE* model (Schönbrodt *et al.* 2009a). Available data (Fig. 1) are the digital elevation model (DEM) based on SRTM Data Version 4 (Jarvis *et al.* 2008) resampled to a resolution of 45 m, a SPOT image (September 2007) in 5 m resolution, and data on terrace conditions, design and soil erosion features from field investigations.

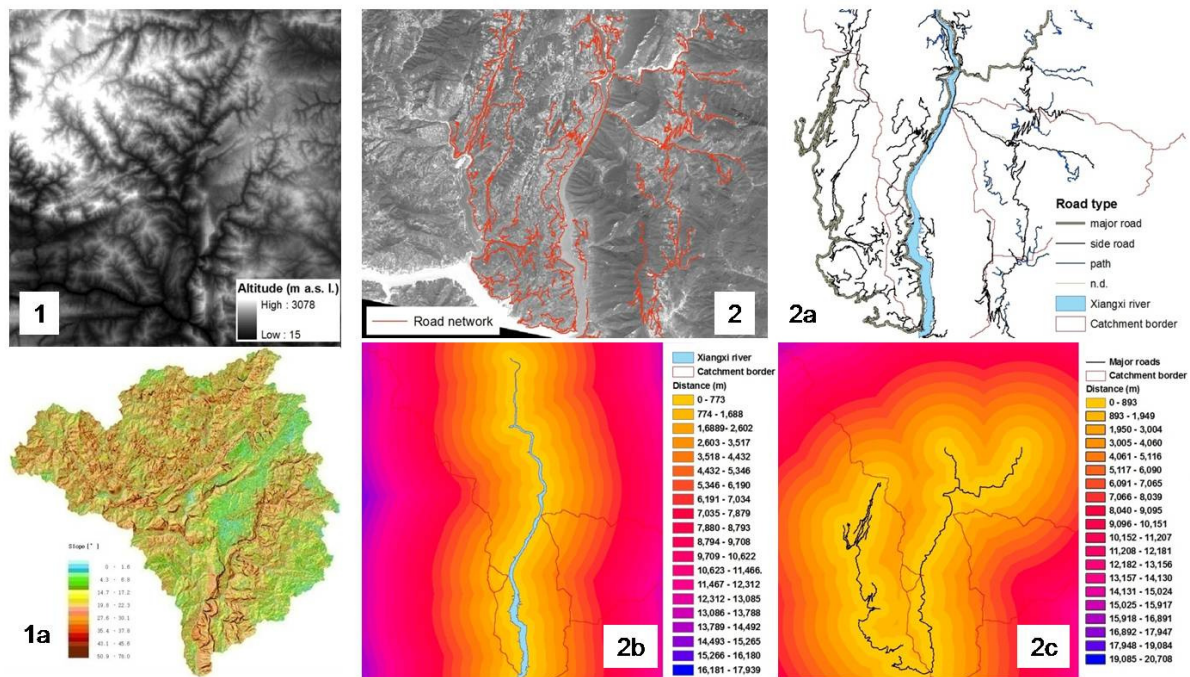


Figure 1. The derivation of covariates for the *TerraCE* model based on the Digital Elevation Model and the SPOT image. (1) DEM of the Xiangxi catchment, and (1a). the slope angle. (2) The SPOT image (5 m), (2a) the road network and new Xiangxi shoreline digitized from the SPOT image with (2b) the euclidian distance (m) from the Xiangxi, and (2c) the main roads.

The DEM-based parameters such as slope angle, curvature, and exposition refer to the relief-based terrace design. More than 50 parameters were tested. Based on the SPOT image the new shoreline of the Xiangxi after impoundment by the TGD, and the road network were digitized. In a detailed inventory of terrace condition information on the type, frequency and intensity of terrace wall disorders referring to the quality of terrace-maintenance and on the physical infrastructure of terraces (e.g. land slope, terrace slope, height of terrace wall, terrace interval) were taken. Furthermore, an inventory on the type of recent soil erosion forms, its intensity as well as the properties of topsoil and land-use was conducted on randomly chosen plots and tested using a random forest approach. In total, 80 terraces have been assessed in detail and 593 farmland units have been mapped using a simplified documentation scheme along the Xiangxi shoreline.

Results and discussion

As explained above, terraces are common agricultural practice in the Three-Gorges-Area. Preliminary erosion surveys in the Xiangxi catchment close to the TGD (Schönbrodt *et al.* 2009b) have shown a strong connection between the condition of terraces and the occurrence and intensity of soil erosion. Terraces with wall disorders such as failures and a technically poor adapted design show higher soil loss and runoff than well adapted terraces. Another key factor is the quality of maintenance dependent on the human influence. These factors build the framework of the conceptual Terrace-Condition-Erosion model *TerraCE* (Schönbrodt

et al. 2009b). The model is based on the assumption that the erosion frequency and intensity in terraced landscapes depend on the condition of the terraces. The later is explained as a function of (a) the relief-based terrace design and (b) the quality of maintenance depending on the human influence. The distances of a terrace to settlements and roads reflect the farmer's motivation to maintain the terraces well whereas the immediate inundate area is seen to be attractive for rapid land reclamation for cash crop production because of easy access.

Four distinct categories were found that describe the quality of terrace-maintenance: well maintained (20 %), badly maintained (48 %), partially collapsed (15 %), and completely collapsed (6 %). Typically, the worse the condition of walls with an increasing number and intensity of wall failures the worse the quality of terrace-maintenance. While well maintained terraced still show a good and effective structure, the original structure of completely collapsed terraces got lost and the erosive slope length and thus soil erosion risk is increased.

7 % of the farmland was not terraced, although located on steep slopes, and considered as a new class. The mean distance of well and badly maintained terraced from the new Xiangxi shoreline is 614 m (SD 318 m) and 474 m (SD 292 m). Partially and completely collapsed terraces show in average a distance of 209 m (SD 292 m) and 128 m (SD 82 m) to the Xiangxi. Regarding the main roads, the quality of terrace maintenance also increases with increasing distance. The mean distances from the main roads to the well and badly maintained terraces are 588 m (SD 396 m) and 720 m (SD 526 m) respectively. For the partially collapsed and completely collapsed terraces the mean distances to the main roads are 298 m (SD 354 m) and 148 m (SD 217 m). Assuming the backwater area as potentially completely terraced, the terrace condition was modeled using spatial prediction with an overall accuracy of 70 %.

Conclusions

Terraces are typical erosion control measures in the Xiangxi catchment however they strongly differ in their condition. The condition of terraces is regarded as a striking erosion factor and defined by the design of terraces and the quality of maintenance. Four categories of terrace maintenance are identified: well maintained, badly maintained, partially collapsed, completely collapsed. The closer the terraces to the new Xiangxi shoreline and to the main road network, the worse the terrace condition with a higher frequency and intensity of wall disorders. It is concluded that a fast access to potential farming land via main transportation routes within the immediate and highly dynamic inundated area is regarded as reason for the degradation of terraces. Moreover, the seasonal, artificial water level fluctuation of 30 m per year is also regarded to destroy the terrace structure and thus to increase the soil erosion risk potential. Terraced farmland that is more distant from the immediate reservoir area characterized by construction of new infrastructure seems to be less attractive for new land reclamation for cash crops and therefore less influenced by the high land-use dynamic. A first prediction of the terrace condition in the backwater area shows good results (overall accuracy 70%). First results of the *TerraCE* model indicate that in a strongly human influenced area such as the Xiangxi catchment the spatial effectiveness of terraces to protect soil against erosion seems vary with the condition of terraces resulting from an intensification of agriculture.

Acknowledgement

The authors would like to thank the German ministry of education and research (BMBF, grant No. 03 G 0669) for funding the YANGTZE project. Special thank also goes to the Faculty of Engineering of the China University of Geosciences, especially Xiang Wei, for the collaboration and support in organizing the field campaigns.

References

- Brady NC, Weil RR (2008) 'The Nature and Properties of Soil'. (New Jersey).
- Brancucci G, Paliaga G (2006) The Hazard Assessment in a Terraced Landscape: Preliminary Result of the Liguria (Italy) Case Study in the Interreg III Alpter Project. 2006 ECI Conference on Geohazards, Lillehammer, Norway.
- Cai GC, Wang H, Curtin D, Zhu Y (2005) Evaluation of the EUROSEM model with single event data on Steeplands in the Three Gorges Reservoir Area, China. *Catena* **59**, 10-33.
- Cao S, Chen L, Feng Q, Liu Z (2007) Soft-riser bench terrace design for the hilly loess region of Shaanxi Province, China. *Landscape and urban planning* **80**, 184-191.

- Huang Z, Zhou W, Zhou J, Zhou M (2006) Land use of the Three Gorges Reservoir Area and the effect on its landscape in the recent 50 years. *Wuhan University Journal of Natural Sciences* **11**, 910-914.
- Hudson N (1981) Soil Conservation. London.
- Inbar M, Llerena CA (2000) Erosion Processes in High Mountain Agricultural Terraces in Peru. *Mountain Research and Development* **20**, 72-79.
- Jarvis A, Reuter HI, Nelson A, Guevara E (2008) Hole-filled seamless SRTM data V4, International Centre for Tropical Agriculture (CIAT), available from <http://srtm.csi.cgiar.org>.
- Lesschen JP, Cammeraat LH, Niemann T (2008) Erosion and terrace failure due to agricultural abandonment in a semi-arid environment. *Earth Surf. Process. Landforms* **33**, 1574-1584.
- McDonald B, Webber M, Yuefang D (2008) Involuntary resettlement as an opportunity for development: the case of urban resettlers of the three gorges project, China. *Journal of Refugee Studies* doi:10.1093/jrs/fem052.
- Meng QH, Fu BJ, Yang LZ (2001) Effects of land use on soil erosion and nutrient loss in the Three Gorges Reservoir Area, China. *Soil use and management* **17**, 288-291.
- Sang-Arun J, Mihara M, Horaguchi Y, Yamaji E (2006) Soil erosion and participatory remediation strategy for bench terraces in northern Thailand. *Catena* **65**, 258-264.
- Schönbrodt S, Behrens T, Imbery S, Scholten T (2009a) The GIS-based assessment and analysis of soil erosion by water in the Three-Gorges ecosystem – A new approach to model soil erosion on farming terraces by their condition. Annual Meeting of the German Soil Science Society 2009, Bonn, Germany.
- Schönbrodt S, Behrens T, Scholten T (2009b) The GIS-based assessment and analysis of soil erosion by water in the Three-Gorges ecosystem. Geophysical Research Abstracts, Vol. 11, EGU2009-4681, EGU General Assembly.
- Tan Y, Graeme H, Potter L (2003) Government-organized Distant Resettlement and the Three Gorges Project, China. *Asia-Pacific Population Journal* 5-26.
- Tan Y, Bryan B, Hugo G (2005) Development, land-use change and rural resettlement capacity: A case study of the three gorges project, China. *Australian Geographer* **36**, 201-220.
- Zhou P (2008) Landscape-Scale Erosion Modeling and Ecological Restoration for a Mountainous Watershed in Sichuan, China. Academic dissertation, Helsinki, Finland, pp. 81.