Applying the EROSION 3D Model to predict the impact of muddy floods in residential areas

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Abstract Flooding and sedimentation can cause significant damages especially if the eroded soil is deposited in residential areas and covers streets, parking areas, gardens etc. A tool to evaluate deposition patterns would be useful in the planning of new settlements or industrial areas and could also be applied for surveys after damage has occurred. In this study the damages in a settlement caused by sedimentation during a flash flood are surveyed and compared to model predictions. The EROSION 3D model is chosen, which is based on a physical description of erosion and deposition processes. Besides, it is able to model single storm events. The special challenge of this study is the small scale of the elements inside residential areas. EROSION 3D requires a digital elevation model (DEM) as input. Generally available DEMs do not represent objects like houses, streets, small ditches etc. in the landscape. A geographic information system (GIS) is used to model the relative height of anthropogenic structures into a DEM. As shown, the modifications of the DEM have a significant effect on surface runoff and deposition patterns. The method developed in this study is easy to apply and yields adequate results in order to evaluate deposition patterns in small scaled residential areas.

Keywords erosion; sediment; deposition; muddy flood; modelling; EROSION 3D; Saxony

INTRODUCTION

The term muddy flood describes large quantities of soil particles suspended in surface runoff from agricultural land (Boardman *et al.*, 2006). Therefore it has to be considered an off-site impact of soil erosion. When these muddy floods reach residential areas damages are produced through inundation and additionally by depositions of sediments on streets, gardens, etc. There are numeral reports of muddy floods in Europe, especially for the Netherlands (Kwaad et al., 2006), South England (Boardman *et al.*, 2003), Belgium (Evrard *et al.*, 2007, Verstraeten & Poesen, 1999, Verstraeten *et al.*, 2006)), France (Morschel *et al.,* 2004, Auzet *et al.*, 2006) and Slovakia (Stankoviansky *et al.*, 2006). These reports prove that muddy floods are frequent and wide spread phenomena with significant financial costs that go to the accounts of private households and municipalities. Additionally the psychological strain for affected residents is not to be neglected.

Boardman *et al.* (1994) named five factors that influence the occurrence of muddy floods:

- land use
- topography and soil
- farm management practices
- rainfall and runoff
- location of property

In addition to the last point the structure of the urbanised area has an extrem effect on the impact of muddy floods. Human constructions may be barriers (houses, walls, etc.) or channels (streets, ditches, etc.) for surface runoff. Thus these elements may define on a small scale, whether some areas are innundated or not. Nevertheless they have never been considered in DEM data for erosion modelling and prediction of muddy floods.

This paper discribes how settlement structures can easyly be implemented in DEMs and that these DEMs can be applied for erosion modelling. The method is validated on a real case of muddy flood in Saxony / Germany. Additionally the modell is applied to predict the effect of active and passive erosion protection measures.

SITE DISCRIPTION AND INUNDATION EVENT

On May 11th 2004 a heavy rainstorm caused inundation in the Saxon village Oberlungwitz. A settlement which is located down slope an agricultural area was flooded by runoff drained from the adjacent field (Fig.1). The mud transported with the runoff was deposited inside the settlement and covered streets and gardens with about 10 cm of mud; it filled up little garden-ponds and entered cellars. The damages of the inundation event were severe for the residents, but also the municipality was charged with cleaning up costs for streets and discharge pipes. The patterns of the occured runoff accumulation and the sediment deposition are indicated in Fig. 1.

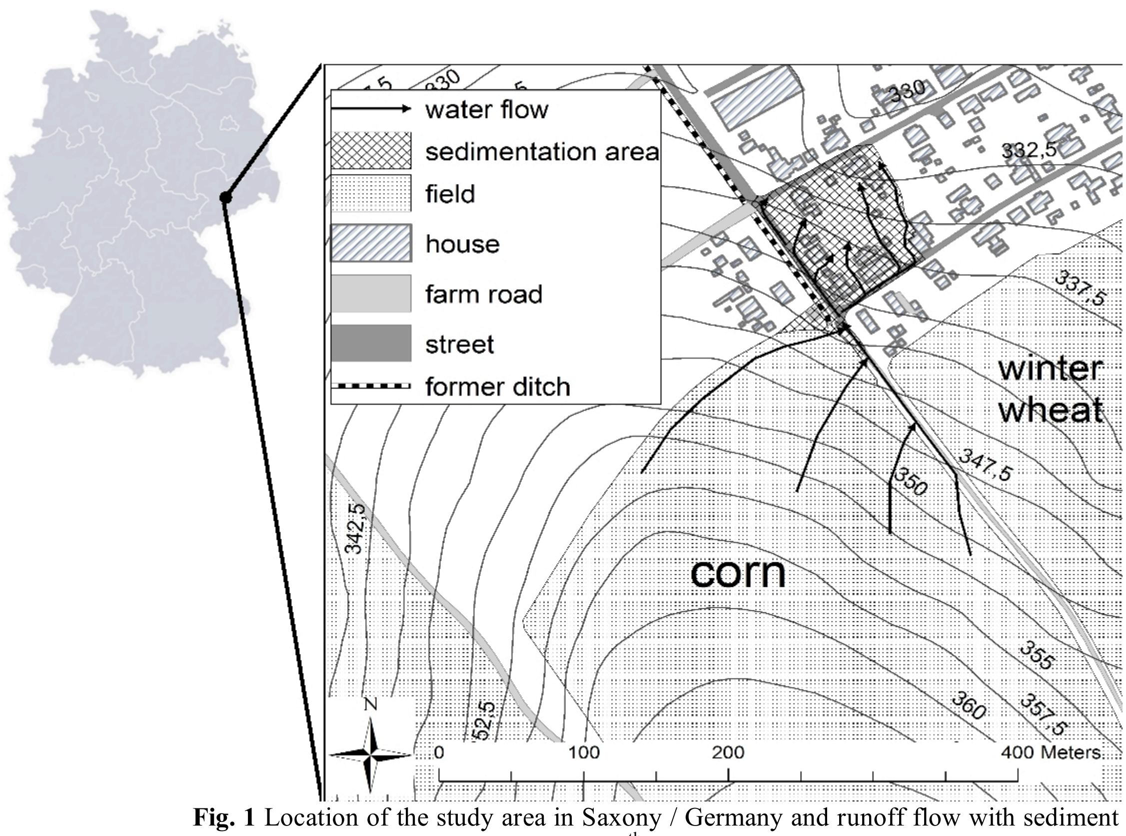

Fig. 1 Location of the study area in Saxony / Germany and runoff flow with sediment deposition areas for the event on May 11th 2004.

The storm event on May 11th delivered 41.5 mm precipitation, registered at the meterological station of Chemnitz, 10 km away from the investigation site. The field upwards the settlement shown in Fig. 1 was cultivated with corn that year and tilled conventionally with a plough. At the northeast border of the field a farm road is located that divides this area from the adjacent field cultivated with winter wheat. During the innundation event it was observed that a lot of surface water ran along this farm road into the settlement.

In former times there has been a ditch alongside the main street of the settlement that started at the north corner of the concerned field. This ditch was removed in the beginning of the 1990´s.

After the innundation in 2004 the farmers cooperation that manage the concerned field changed the management practice from conventionally (plough) to conservative tillage (grubber).

METHODS

To model the impact of muddy floods the above listed factors (Boardman *et al.,* 1994) should be considered. As muddy floods are a phenomena of soil erosion it is requiered to apply a soil erosion model. This model has to be process based in order to discribe detachment, transport and deposition of soil particles for single storm events. The EROSION 3D model (Schmidt, 1991, 1992, 1996, Schmidt *et al.,* 1997, v. Werner, 1995) fits this requierements. The Modell consideres all the above named factors for muddy flood generation in the input parameters (Fig. 2).

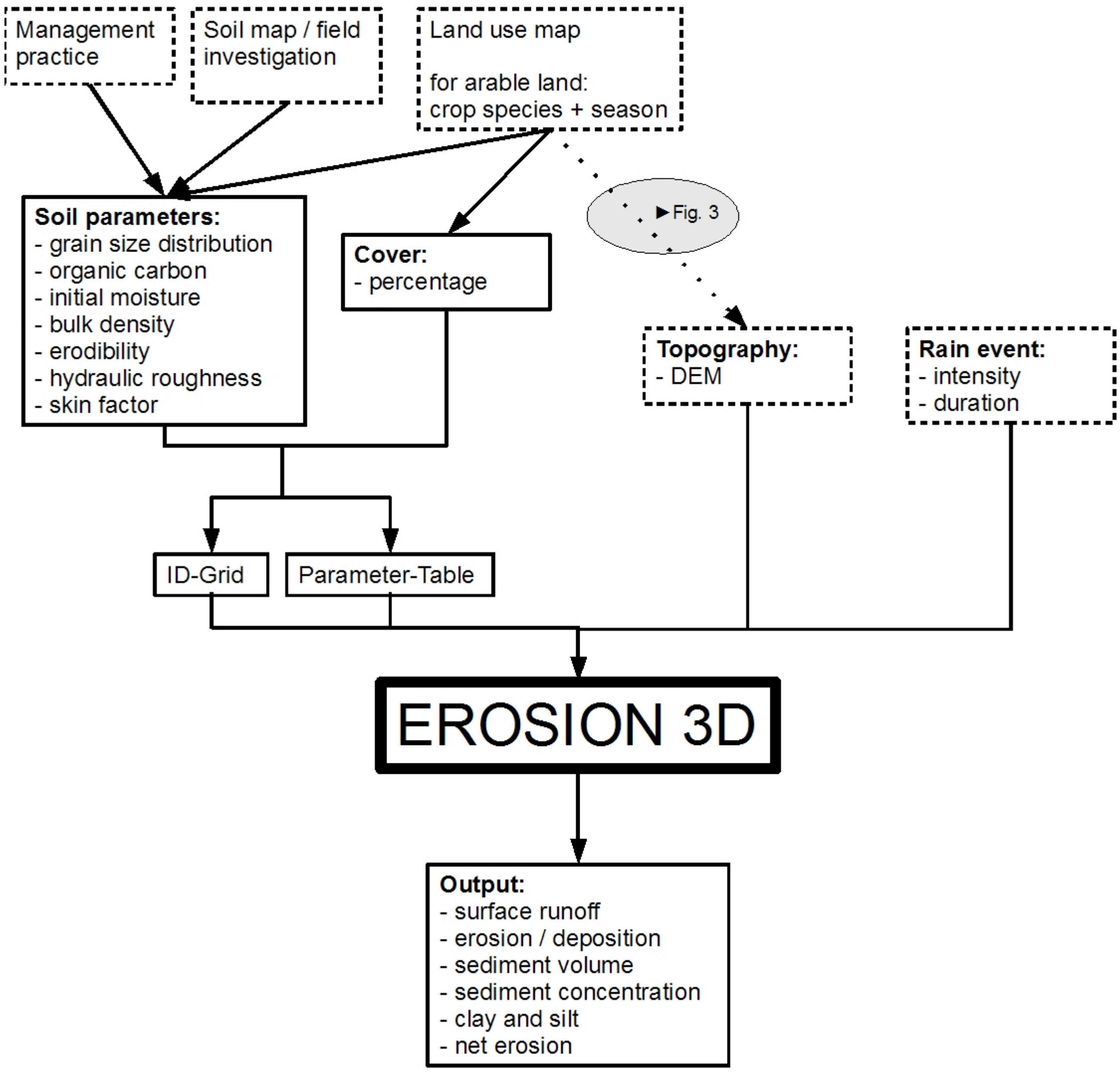

Fig. 2 The EROSION 3D model in- and output parameters.

One of the important input information to discribe soil parameters and surface cover is the land use map. Depending on the scale of this map it is possible to display also elements of a settlement like streets, houses, parking areas, pavements, ditches, etc. Up to now the information of land use has only been applied to discribe soil parameters and surface cover (Michael, 2001, Schindewolf & Schmidt, 2010). In this study it is additionally used to modify topography.

As displayed in Fig. 3 the land use map is digitalised based on ortho-photos. The land use units are used to define soil and cover properties for the EROSION 3D model. The new approach is that the objects of this land use map are also assigned relative height values. When the polygone shape file with relative height values is converted to a raster map, the cell size has to be sufficiantly small to display the objects of the land use map. In this case it is 1 × 1 m. This height raster is then added to a DEM with the same raster size. For this study the DEM has been interpolated from digitalised counter lines of a topographic map. The result is a modified DEM where settlement structures are depressed or raised up in the general surface of the landscape.

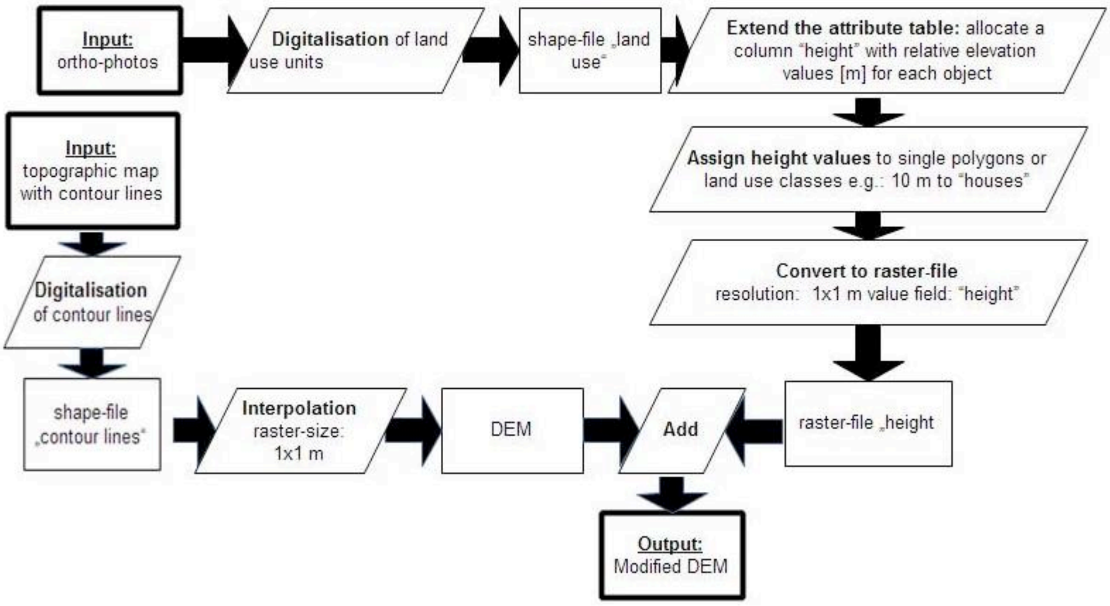

Fig. 3 Workflow for the generation of the modified DEM.

For the discribed investigation site four different simmulations are performed with EROSION 3D. All simulation runs apply the measured rain data of the event on May 11^{th} 2004. The first one uses only the general surface of the area as depicted by the digitalised counter lines. The land use, especially the state of the arable land, is considered in the input data as it realy was. The second simulation uses the same land use map but the modified DEM is applied with the structures of the settlement. A third simulation assumes that the field is cultivated with corn as in 2004, but this time it is tilled conservativly with a plough. The surface is discribed by the modified DEM. The last simulation applies the original land use from 2004, but the DEM is additionally amended with the ditch that formerly existed inside the settlement (Fig. 1).

RESULTS

The effect of the DEM modifications on surface runoff and sediment deposition as predicted by EROSION 3D is shown in Fig. 4. By considering only the general surface

(a) runoff disperses and only a small part of the field drains in direction to the settlement. There is no innundation nor sediment deposition taking place in the settlement (c). In turn figures b and d schow simulation results when surface modifications are considered. In this case the muddy flood enters the settlement and mud is deposited where it was observed during the innundation event in 2004 (Fig. 1). The average amount of sediment deposition on the concerned properties is 126 kg m^{-2}. With an estimated bulk density of 1.4 g cm^{-3} the mud cover would be about 9 cm thick. As the real event produced depositions of an average of 10 cm the modell predictions represent the realtity quite well.

The modell results show how the farm road between the two fields channels the runoff. Inside the settlement it is shown by the modell results at which points the runoff enters the properties (this locations are the gateways where the pavement is lowered). These modell predictions fit with the real case observations very well. Only some properties in the northwest corner are not effected by depositions as much as they were in the real case. Nevertheless, it is shown, that only the anthropogenic constructions that alter the natural surface could explain the observed muddy flood.

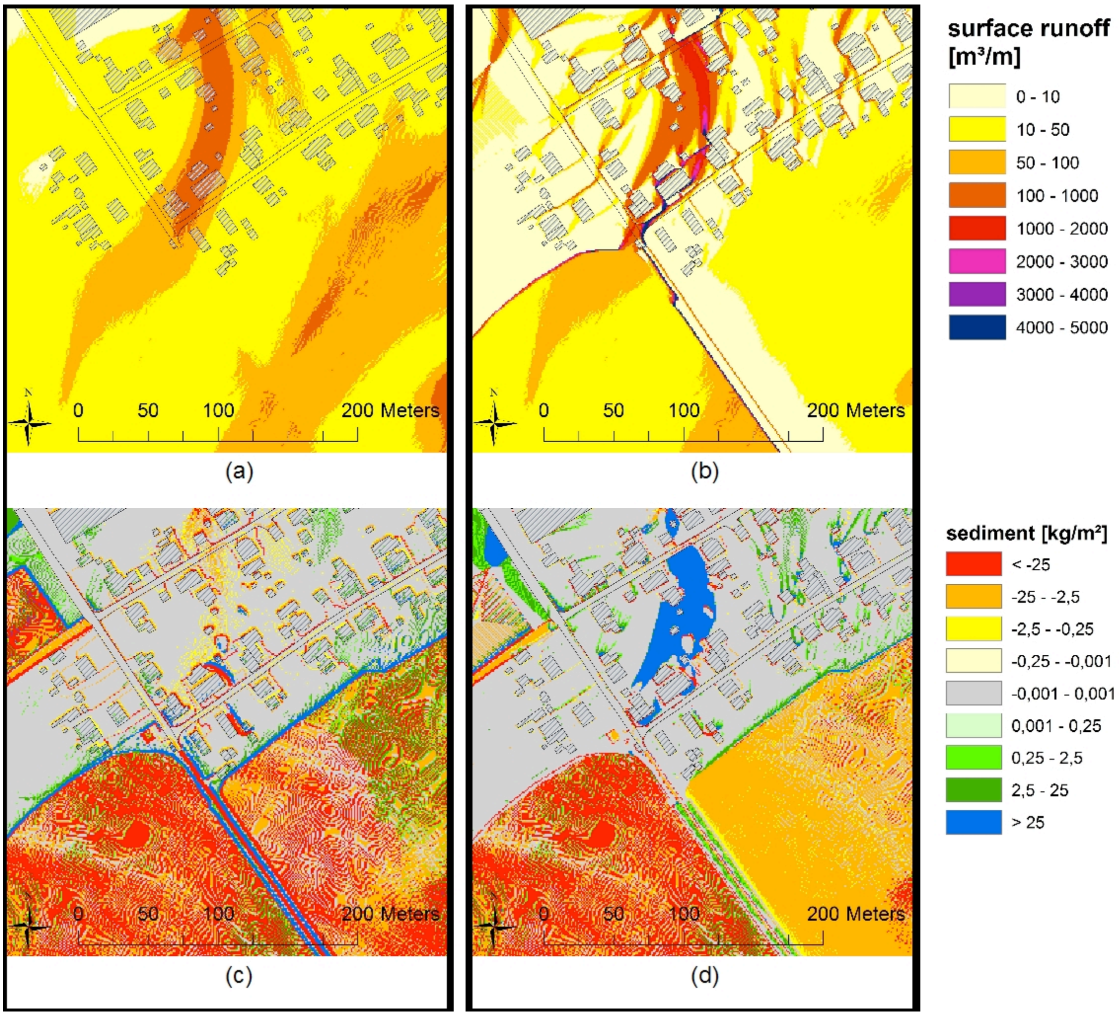

Fig. 4 Effect of the DEM-modification on surface runoff and sediment deposition modelled with EROSION 3D (a) surface runoff, interpolated DEM (b) surface runoff, modified DEM (c) erosion and sedimentation, interpolated DEM (d) erosion and sedimentation, modified DEM.

In Fig. 5 the effect of passive and active protection measures on the occurence of muddy floods are investigated. Figures a and c show the simulation results when the soil on the field is not treated with a plough but with a grubber instead. This treatment improves the infiltration capacity of the soil, so that less runoff is produced, furthermore the resistance of the soil to erosion is increased. As a consquence of both the mud transport to the settlement is significantly reduced.

As mentioned before there has once been a ditch inside the settlement. Structural changes in the surface like this ditch can easyly be implemented in the DEM. The effect of this ditch on the runoff and deposition patterns is depicted in Fig. 5, b and d. The model results show how this ditch takes up the runoff and as a consequence no mud is transported into the settlement.

Both simulation runs in Fig. 5 prove how EROSION 3D can be applied to evaluate on- and off-site protection measures in order to minimise the risk of muddy floods.

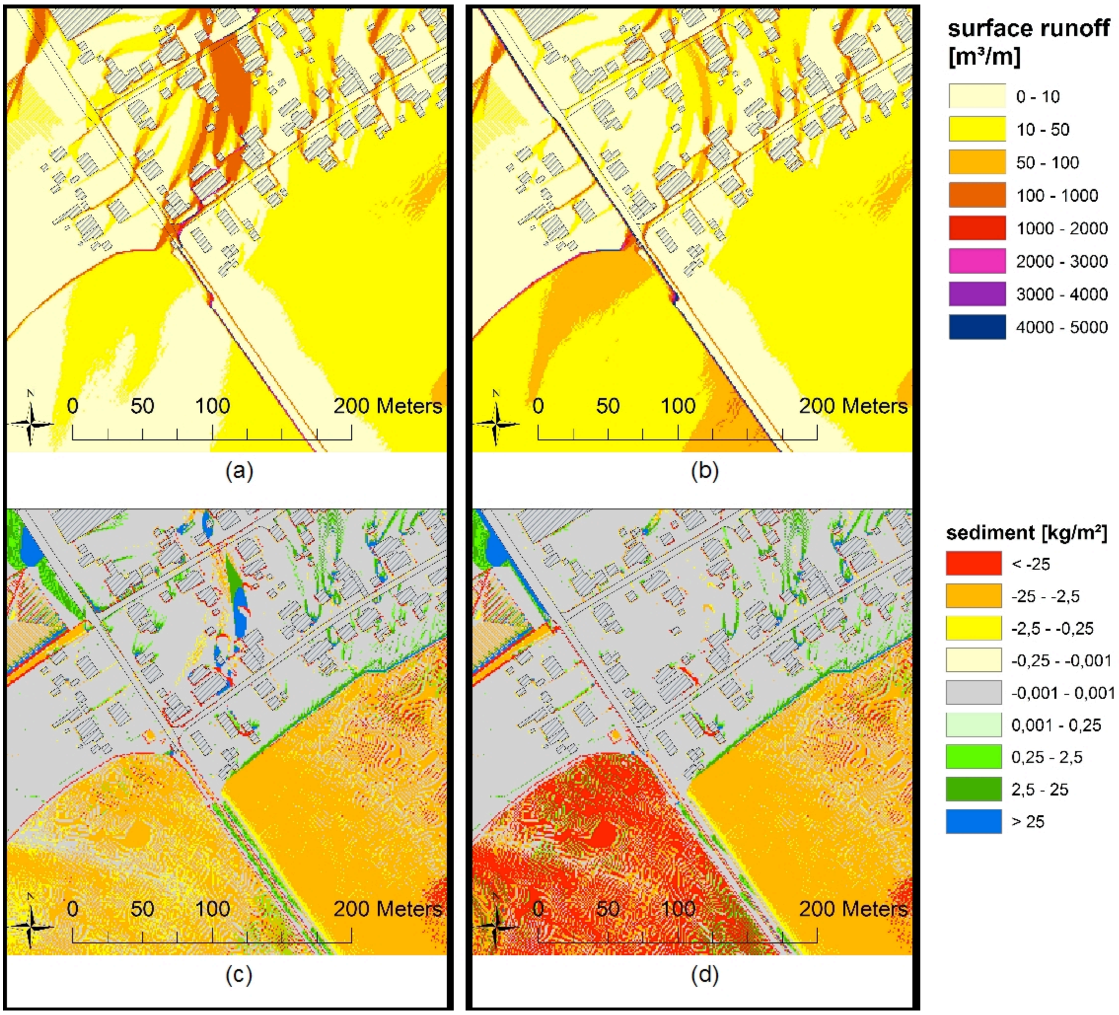

Fig. 5 The impact of active and passive protection measures on muddy flood occurence modelled with EROSION 3D (a) surface runoff, conservative soil treatment practice (grubber) (b) surface runoff, ditch inside the settlement (c) erosion and sedimentation, conservative soil treatment practice (grubber) (d) erosion and sedimentation, ditch inside the settlement .

CONCLUSIONS

It is proven that settlement structures can easyly be added to a DEM and that the resulting DEM can be used for soil erosion modelling within the process-based erosion modell EROSION 3D. The results show that certain structures act as barriers or channels and thus direct surface runoff and produce flooding. The occurred inundations and mud depositions in Oberlungwitz can only be explained by considering the settlement structures in the DEM for modelling. Using the modified DEM the model EROSION 3D predicts runoff an depositions as they were reported for the real event.

The method can be applied for planning processes of new settlement or industrial areas or for the evaluation of protection measures. In this case it was shown that the farm road between the two fields as well as the streets inside the settlement and the gateways contribute to the occurence and the extend of the muddy flood. These effects have formerly been annihilated by the ditch in the settlement. The consequent change from a conventionall to conservative soil tillage will reduce the risk of muddy flood significantly.

As the presented method of DEM modification is still timeconsuming there will be further investigation on the enhancement and fastening of the procedure. This could be achieved through the automatisation of the procedure, e.g. with a GIS-implemented tool. Additionally the implication of further data-sources will be tested.

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