



Integrated, spatial distributed modelling of surface runoff and soil erosion during winter and spring

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ABSTRACT

In cold climate regions a significant fraction of annual soil erosion in agricultural land occurs during snowmelt and rain on partially frozen soils. Physically based and spatially distributed soil erosion models have proved to be good tools for understanding the processes occurring at catchment scale during rainfall erosion. However, most existing erosion models do not account for snow in a suitable way. A combination of the UEBGrid snow pack model and the LISEM erosion model was therefore used in this study. The aim was to test and validate this model combination and to assess its utility in relation to quantification and process understanding. Applying this model combination to simulate surface runoff and soil erosion showed that, in principle, it is possible to satisfactorily simulate surface runoff and observed soil erosion patterns during winter. The values for the calibration parameters were similar for the two chosen winter periods when the rainfall and snowmelt episodes occurred. However, the calibration procedure showed that the utility of this combination had several limitations. It is hoped that this study can help to improve existing models and trigger new developments in including snow pack dynamics and soil freezing and thawing in soil erosion models.

1. Introduction

In cold climate regions a significant fraction of annual soil erosion in agricultural land occurs during snowmelt and rain on partially frozen soils (Lundekvam and Skoien, 1998; Deelstra et al., 2009; Su et al., 2011). In particular, the development of snow pack during winter can have a considerable effect on the development of surface runoff in catchments. A snow pack that is not 'ripe', i.e. the internal temperature has not reached 0 °C, can act as a buffer by retaining incoming rain water (Gray and Male, 1981). However, rain falling on a melting snow pack can accelerate the snowmelt process and cause large quantities of runoff (Sui and Koehler, 2001). In addition, partially or completely frozen soil modifies surface runoff generation and also the erodibility of the soil (Ollesch et al., 2005). Soil freezing can reduce soil hydraulic conductivity (k_h) by blocking pores and retaining water in the profile, thereby reducing infiltration capacity during snowmelt (Nyberg et al., 2001). Iwata et al. (2011) showed that a frozen soil layer can significantly impede snowmelt infiltration and thus increase runoff of spring snowmelt water. Water flows much faster over a frozen slope than over a thawed one, as shown by Ban et al. (2016). This runoff water can easily erode soil that has been weakened by repeated freezing

and thawing (Kværne and Øygarden, 2006). In Norway, the occurrence of snowmelt, combined with rain and soil frost, has led to severe gully and rill erosion, even in low risk areas (Øygarden, 2003). Sediment transfer from fields to streams during winter and spring accounts for a major part of the annual loss of phosphorous and nitrogen from agricultural catchments (Su et al., 2011), resulting in loss of the irreplaceable nutrient-rich top layer of agricultural soils. Runoff during winter and spring also needs to be examined with regard to hazardous floods and as a triggering factor for landslides (Bayard et al., 2005).

Physically based and spatially distributed soil erosion models have proved to be good tools for understanding the processes occurring at catchment scale during rainfall erosion (e.g. Bhuyan et al., 2002; Nearing et al., 2005; Starkloff and Stolte, 2014). Such models are widely used to quantify the impact of climate change and tillage, and the efficiency of mitigation measures. To provide reliable tools for researchers and policy makers who deal with the problems caused by runoff and soil erosion during winter and spring, models have to be capable of reproducing winter hydrology processes (Deelstra et al., 2009). However, only few erosion models (e.g. EORSION 3D (Weigert and Schmidt, 2005)) account for snow in a suitable way (Grønsten and Lundekvam, 2006; Ollesch et al., 2006), because it is one of the most

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changeable elements in the hydrological cycle and presents a large range of challenges as regards monitoring and measuring (Doesken and Robinson, 2009).

Spatially distributed snow pack models, using a physically-based one-dimensional mass and energy balance have been successfully used to describe spatial variability in snow pack properties (Luce and Tarboton, 2001; Starkloff et al., 2017a). Combining such a snow pack model with a physically based erosion model could be a solution to quantifying and better understanding the complex processes occurring at catchment scale during winter. A combination of the UEBGrid snow pack model and the LISEM erosion model was therefore used in this study. The first aim was to test and validate this model combination and to assess its utility in relation to quantification and process understanding. A second aim was to evaluate whether this model combination can be a tool for helping to reduce the risk and damage by soil erosion and surface runoff during winter.

2. Methods

2.1. Winter periods

For this study, two winter periods were chosen from the long-term monitoring that has been carried out in the study area since 2008. The winter periods of 2012–2013 and 2014–2015 were chosen because they enabled a comparison to be made between a winter in which erosion was observed (2014–2015) and one in which this was not the case (2012–2013). This made it possible to investigate which processes lead to soil erosion during winter. Hereafter these winter periods are referred to as *winter 2015* and *winter 2013*, respectively.

2.2. Study area

The field investigations were carried out in the Gryteland catchment (0.29 km²), located approximately 30 km south of Oslo, Norway. This area (Fig. 1) can be easily reached under all weather conditions. A

monitoring station was installed at the outlet of the sub-catchment in 2008 and enhanced with a weather station in 2013. This station measures precipitation, air temperature, relative humidity, solar radiation, wind direction and speed, and surface runoff and drainage discharge. In addition, five stations (one at the outlet) were installed in the catchment (Kramer and Stolte, 2009) along a transect (Fig. 1) to measure soil moisture and soil temperature at four depths (5, 10, 20 and 40 cm).

The sub-catchment is characterised by undulating landscape (elevation: 106–141 m, slope 2–10%) covered by approx. 60% arable land and 40% coniferous forest. Soil types in the arable land (Fig. 1), are a levelled clay loam (Stagnosol), and silty clay loam (Albeluvisol) (Group 1), and sandy silt on clay (Umbrisol) and sand to loamy medium sand (Histic Gleysol) (Group 2). Hereafter, the two groups are referred to as *clay* and *sand*, respectively.

The mean annual temperature is 5.3 °C, with a minimum average daily temperature of −4.8 °C in January/February and a maximum average daily temperature of 16.1 °C in July. The mean annual precipitation is 785 mm, with a minimum monthly amount of 35 mm in February and a maximum of 100 mm in October (Thue-Hansen and Grimenes, 2015). Winter is usually relatively unstable, with alternating periods of freezing and thawing and several snowmelt events (Kværne and Øygarden, 2006).

Tillage practices were no-till after harvest in 2013, leaving the fields covered in stubble. In 2015, secondary tillage was carried out after harvest with a cultivator on the slopes, leaving the depressions covered with stubble.

2.3. Field investigations

The detailed field investigations carried out during the two winters included spatially distributed measuring of snow water equivalent (SWE) after weather changes that were expected to result in changes in SWE. These measurements were used to calibrate the snow pack model used in this study. A detailed description of the snow measuring set-up that was used can be found in Starkloff et al. (2017a). Changes in soil

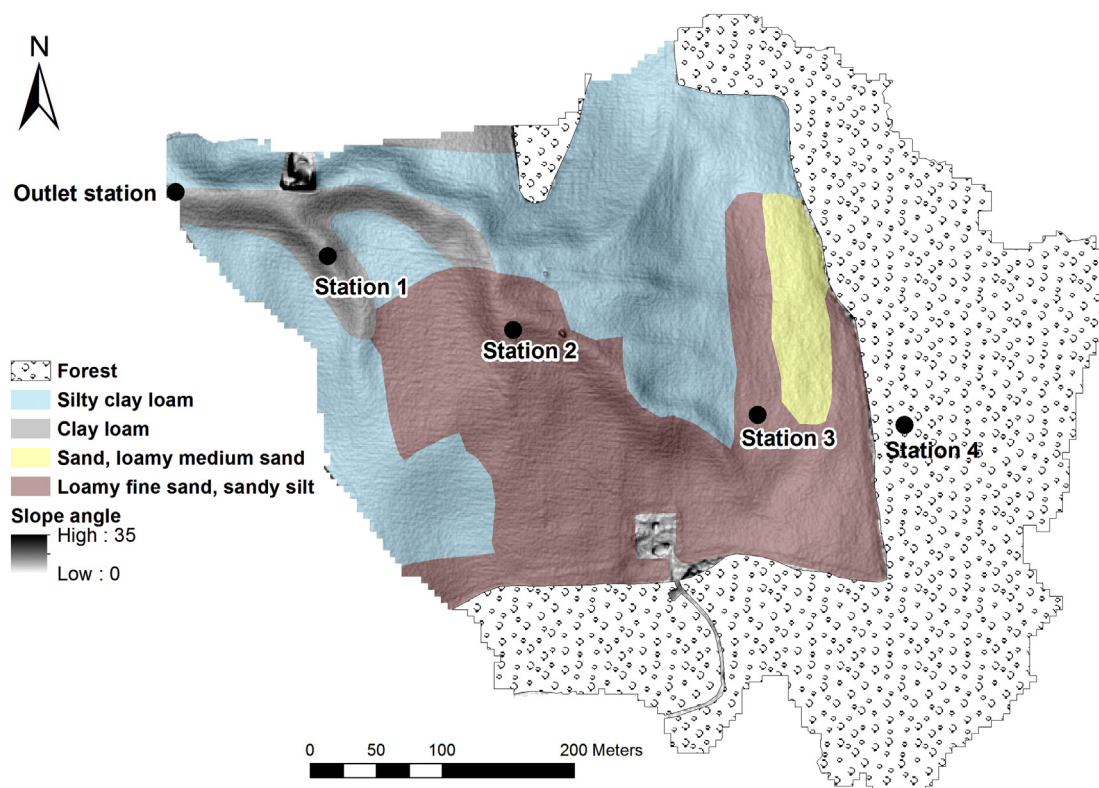


Fig. 1. Map of the study area with slope angles soil types and the location of measuring stations.

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