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Timing of erosion and satellite data: A multi-resolution approach to soil erosion risk mapping☆

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Abstract

Erosion reduces soil productivity and causes negative downstream impacts. Erosion processes occur on areas with erodible soils and sloping terrain when high-intensity rainfall coincides with limited vegetation cover. Timing of erosion events has implications on the selection of satellite imagery, used to describe spatial patterns of protective vegetation cover. This study proposes a method for erosion risk mapping with multi-temporal and multi-resolution satellite data. The specific objectives of the study are: (1) to determine when during the year erosion risk is highest using coarse-resolution data, and (2) to assess the optimal timing of available medium-resolution images to spatially represent vegetation cover during the high erosion risk period. Analyses were performed for a 100-km^2 pasture area in the Brazilian Cerrados. The first objective was studied by qualitatively comparing three-hourly TRMM rainfall estimates with MODIS NDVI time series for one full year (August 2002–August 2003). November and December were identified as the months with highest erosion risk. The second objective was examined with a time series of six available ASTER images acquired in the same year. Persistent cloud cover limited image acquisition during high erosion risk periods. For each ASTER image the NDVI was calculated and classified into five equally sized classes. Low NDVI was related to high erosion risk and vice versa. A DEM was used to set approximately flat zones to very low erosion risk. The six resulting risk maps were compared with erosion features, visually interpreted from a fine-resolution QuickBird image. Results from the October ASTER image gave highest accuracy (84%), showing that erosion risk mapping in the Brazilian Cerrados can best be performed with images acquired shortly before the first erosion events. The presented approach that uses coarse-resolution temporal data for determining erosion periods and medium-resolution data for effective erosion risk mapping is fast and straightforward. It shows good potential for successful application in other areas with high spatial and temporal variability of vegetation cover.

Keywords: Soil erosion; Vegetation; Risk assessment; Multi-temporal; Multi-resolution; Validation; Brazilian cerrados

1. Introduction

In many regions around the world, soil erosion by runoff is one of the main processes reducing the soil productivity by removing fertile topsoil layers, thus decreasing levels of organic matter and nutrients. Furthermore, it often causes negative downstream impacts, such as the sedimentation of soil material in

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reservoirs or damage to infrastructural facilities like houses, roads and canals (Morgan, 2005). Because soil erosion has a high spatial variability, it is useful to obtain knowledge on where erosion is occurring, for example for the planning of mitigation measures. Many efforts have been made to map erosion at different scales and in different regions around the world. Sometimes maps are constructed with deterministic erosion models describing the erosion processes and resulting in quantitative outcomes. A major difficulty is the validation of resulting erosion rates, as accurate measurements are generally expensive and time-consuming, standard equipment is hardly available (Stroosnijder, 2005), and measurement results may be highly variable under similar circumstances (Nearing et al., 1999). For larger regions (>50 km^2) it is therefore more common to construct erosion risk maps. Erosion risk usually indicates the relative probability that erosion will occur at a certain location as compared to other locations in the region mapped. Erosion risk maps are constructed using either erosion models or more qualitative approaches (e.g. Vrieling et al., 2002). Although erosion models yield absolute soil loss values, their outcome is generally used in qualitative terms.

Satellite remote sensing can offer important inputs for the mapping of erosion risk (Vrieling, 2006). Some options exist for direct detection of erosion, but these are mostly limited to semi-arid environments (Liu et al., 2004) or detection of large features such as permanent gullies (Vrieling et al., 2007). High-resolution imagery like QuickBird (<1 m) may however detect smaller features such as rills and signs of overland flow, but neither the price of these data nor the data volume would currently allow timely erosion detection over large areas. Therefore, the most important role of satellite data for erosion risk mapping is the assessment of erosion controlling factors. Although in semi-arid areas soil properties may be assessed with satellite data, for more vegetated (tropical) areas the use of satellite data is generally limited to assessing slope (from DEMs) and particularly vegetation (Vrieling, 2006). However, depending on the region this limitation need not be a constraint for erosion risk mapping, as some factors may be assumed spatially constant or directly related to vegetation cover. For example, Vrieling et al. (2006) showed that for a mountainous region in northeast Tanzania, erosion risk could be accurately mapped using only information on slope and vegetation cover.

Erosion is a process that mostly occurs during high-intensity rainfall events. Given a certain slope and soil type, much erosion occurs when high-intensity rainfall coincides with limited soil protection. Vegetation cover is one of the most important factors offering protection of the soil against erosion. Vegetation cover, and thus erosion risk, can however be highly variable during the year, depending on seasonal effects and land management. Using satellite data, different ways exist to deal with the spatial and temporal dynamics of vegetation cover. One approach is to create a land use map and apply a vegetation growth model for the different mapping units (e.g. using WEPP: Laflen et al., 1991). However, growth models cannot account for within-class spatial variability, nor for the effects of varying management practices and ad-hoc changes by land users, like for instance land clearing, burning, late sowing, or mismanagement. In many land use systems and ecosystems, such variability cannot be discarded.

A different approach is the use of spectral vegetation indices. Unlike land use, a vegetation index is a continuous variable which allows detailed spatial and temporal comparison. Vegetation indices like the NDVI (normalized difference vegetation index) can easily be derived from data acquired by a variety of satellites operating at different spatial resolutions and long time series are available. Although the NDVI is affected by soil reflectance (Escadafal, 1994) and vegetation vitality (De Jong, 1994), it can give a proper relative indication of the spatial and temporal variability of vegetation cover (e.g. Carlson and Ripley, 1997; Purevdorj et al., 1998). NDVI has therefore often been used for assessing the protective vegetation cover within erosion studies (e.g. De Jong et al., 1999; Jain and Goel, 2002; Symeonakis and Drake, 2004).

Time series of NDVI images, combined with temporal rainfall data, allow determining where and when erosion can be expected to occur. Erosion risk is high, if low NDVI values coincide with high rainfall intensities. However, a problem for detailed temporal analysis of NDVI is the persistent cloud cover, which especially in humid (tropical) regions hampers frequent observation of the land surface. In these regions, cloud cover is particularly problematic during periods of high-intensity rainfall. At coarse resolution (250-m and above) images are acquired frequently and thus good opportunities may exist for obtaining cloud-free scenes (either individual scenes or composite products), also during difficult periods. However, at medium (10–30 m) resolution image acquisition is far less frequent, often only once every 14 days and hence cloud cover often reduces image availability to less than five scenes per year. For mapping at the regional scale (50–10,000 km^2), medium-resolution data is required.

A detailed quantitative description of spatial and temporal changes of vegetation cover is not always