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Correlation of colluvial deposits with the modern land surface and the problem of slope profile description

A.V. Mitusov *, O.E. Mitusova, J. Wendt, S. Dreibrodt, H.-R. Bork

Institute for Ecosystem Research, Christian-Albrechts-University Kiel, Olshausenstrasse 75, D-24118 Kiel, Germany

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ABSTRACT

This article focuses on features of spatial distribution of colluvial (slope) deposits on a micro scale. These features were detected by the non-parametric rank correlation of Spearman (r_S) between thickness of colluvial layers and morphometric variables (MVs) of the modern land surface. The strongest correlation was found between total thickness of colluvial layers and maximal catchment area ($r_S = 0.85$). A negative correlation was observed between thicknesses of younger and older colluvial layers. Additionally, if young colluvial layers have a negative correlation with slope steepness (*GA*), relatively old buried colluvial layers have a positive correlation with *GA*. These facts indicate an inversion of the zones of actual matter accumulation due to transformation of the land surface in profile during long-term sedimentation.

Vertical curvature (*kv*) characterises acceleration and deceleration of surface flow caused by the shape of the slope profile along flow lines. Based on this, it was expected that *kv* would have a direct impact on the accumulation of colluvium. However, in this study, the correlations between the thickness of colluvial deposits and *kv* were low. Functional relationships between colluvial accumulation and the shape of profiles along flow lines were reflected by correlations with *GA*. Based on these observations, it is assumed that the regional nature of surface flow velocity affects the shift between existing accumulation zones reflected by colluvial deposits and potential accumulation zones reflected by MVs.

Signs of correlation coefficients between the thickness of colluvial deposits and curvatures reflect the tendency of increased colluvial depositions at three out of 12 local landforms of Shary's classification. These landforms are located in the valley bottom. The mean thickness of colluvial deposits at these three landforms was 167 ± 18.7 cm (error range = standard deviation); the other nine landforms show a mean thickness of 130.1 ± 34.1 cm.

1. Introduction

In small dry valleys, most of the eroded matter is distributed along downslopes and thalwegs as colluvial deposits (e.g. de Moor and Verstraeten, 2008; Houben, 2012). The investigation of past spatial distribution of colluvial deposits and related soil erosion is an important direction of geomorphology and geoarchaeology (e.g. Rommens et al., 2005; Houben, 2008; Vanwalleghem et al., 2010; Ciampalini et al., 2012). However, thorough literature reviews by Dotterweich (2008) and Dreibrodt et al. (2010) have pointed to one important fact: the low number of investigations based on spatial variability of colluvial deposits at micro scale and based on modern quantitative methods. One of the reasons for this is the insufficiency of information with detailed spatial and temporal resolution on the processes during the Holocene. In this situation, morphometric variables (MVs) are often the only source of additional information for predictive mapping of colluvium (e.g. Ries, 2002; Follain et al., 2006; Reiss et al., 2008; Mitusova, 2010; Schneider et al., 2011). It should be mentioned that land use and climate are important triggers, but the land surface play a predominant role in the distribution of colluvial sediments on a micro scale. The MVs describe different prerequisites of processes that take place on the land surface (Shary, 1995; Shary et al., 2002a, 2005). Hence, the MVs enable us to understand the spatial variability of colluvial deposits that is not visually detectable.

However, the statistical relationships between MVs and colluvial deposits are not well investigated. The specifics of correlations among them are caused mainly by:

1) properties of colluvial layers (type of matter, thickness, density etc.), specifics of deposition and spatial distribution, transformation of the deposits due to soil formation and land use, and;
2) type of MVs and statistical relationships for MVs due to mathematical reasons or strong modification of the land surface e.g. by surface flow and location of sampling points.

MVs can be considered as both prerequisites and indicators of the processes on the land surface. However, not all known processes linked with the land surface can be directly described by the existing MVs. In this case the indirect information from other known MVs can be used

* Corresponding author. Tel.:+49 431 880 4030; fax: +49 431 880 4083.
E-mail address: a_mitusov@mail.ru (A.V. Mitusov).

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(e.g. Shary et al., 2002b). For example, variability of slope steepness along flow lines is the geomorphometrical prerequisite of relative deceleration and acceleration of surface flows. The local zones of relative deceleration and acceleration of surface flows can be defined by the sign of vertical curvature, whereas such an MV for the identification of these zones on a regional scale does not exist because the zones are related to site location in a catchment. This is one of the most important problems of geomorphometry (Shary et al., 2002a).

The impact of the relative velocity of flows on the actual matter accumulation can be logically detected from relationships among MVs, correlations between known MVs, and the thickness of colluvial layers as well as the distribution of sampling points.

In comparison with geological scales, the process of colluvial matter distribution and deposition during the Holocene is usually characterized by relatively small areas, short time of deposition, and low energy. Therefore, the detailed features of spatial and temporal distribution of colluvial deposits cannot be visually detected. Geomorphometrical and statistical techniques have played a major role as the main procedures for investigating spatial distribution of colluvial deposits. The goal of this article is, therefore, the detection of basic statistical properties of colluvial deposits, the calculation of correlations between the thicknesses of colluvial layers and MVs of the modern land surface, and the explanation of the obtained relationships.

2. Study area and methods

The study area (54° 6′ 31″ N; 10° 15′ 2.76″ E) is located in the dry subcatchment of Lake Belau near the farm "Perdöler Mühle" in Northern Germany, approximately 35 km south of Kiel (Fig. 1). The geomorphological elements surrounding Lake Belau were formed mainly during the Middle Weichselian and later modified during the Late Weichselian (e.g. Piotrowski, 1991; Svendsen et al., 2004). Between the Neolithic period and the Iron Age, soils which had developed during the early Holocene were eroded on agriculturally used upslopes and midslopes, and deposited downslopes in small valley bottoms. On slopes and in these colluvial deposits, Cambisols and Luvisols developed from the Iron Age until Medieval Times. During the Medieval Times and early Modern Times, the upper horizons of Cambisols and Luvisols were eroded again (e.g. Dreibrodt and Bork, 2005).

Four trenches and 18 auger cores (Fig. 1) were made in 2007 (Dreibrodt and Wiethold, submitted for publication). The area, covered by points of measurement, has been used as a permanent pasture for more than 50 years; surrounding areas have been ploughed. Locations and depths of the trenches were defined so that all sequences of colluvial layers could be investigated; individual colluvial layers in auger cores were not distinguished. Structure and characteristics of colluvial layers were described using conventional field methods (Ad-hoc-Arbeitsgruppe Boden, 2005). A digital elevation model (DEM) with 1 m grid spacing from the Land Survey Office of State Schleswig-Holstein was used (Landesvermessungsamt Schleswig-Holstein, 2012). The DEM was prepared from airborne Light Detection and Ranging (LiDAR) data.

The mean thickness of colluvial layers in the trenches was calculated for every grid cell of the DEM (1 m^2). For auger cores, this procedure was not necessary. As a result, the colluvial database consisted of 46 points from trenches and 18 points from auger cores. The points from trenches mainly described the valley bottom. The points from auger cores characterised the slopes.

In contrast to the location of soils, colluvial deposits are restricted in space. Moreover, data obtained from thick deposits is more reliable than those from thin ones, because of their resistance to possible disturbances. Consequently, dense point observations with thick deposits in valleys lead to an optimal ratio between information quality and workload.

Well known statistical methods were used for data analysis (StatSoft Inc., 2013). An overview was made using basic descriptive statistics. For the determination of normality, two different tests (Shapiro-Wilk and Anderson-Darling) were used. Quantitative comparisons were made with the help of the non-parametric rank correlation coefficient of Spearman (r_S). Correlation coefficients with a significance level (p) of more than 0.05 were not considered.

Because colluvial layers have fragmentary spatial distribution, the database was modified for r_S computation. At points where a layer was not found, the thickness was marked as zero. Zero impacts on statistical results but many landscape parameters have fragmentary distribution. Hence, during investigations, this feature must be taken into account. At binary consideration zero means logic variable "NO", whereas other values mean "YES".

The land surface was described by the system of 17 MVs that are divided into four groups (Table 1). Additionally, based on different calculation methods, local and regional MVs can be distinguished (e.g. Shary, 1995). Regional MVs are maximal catchment area (*MCA*) and maximal dispersal area (*MDA*). For calculation of regional MVs, extended terrain portions have to be taken into account (e.g. Tarboton, 1997). Local MVs are curvatures and slope steepness (*GA*). For calculation of local MVs, only a small number of grid cells around the investigated point have

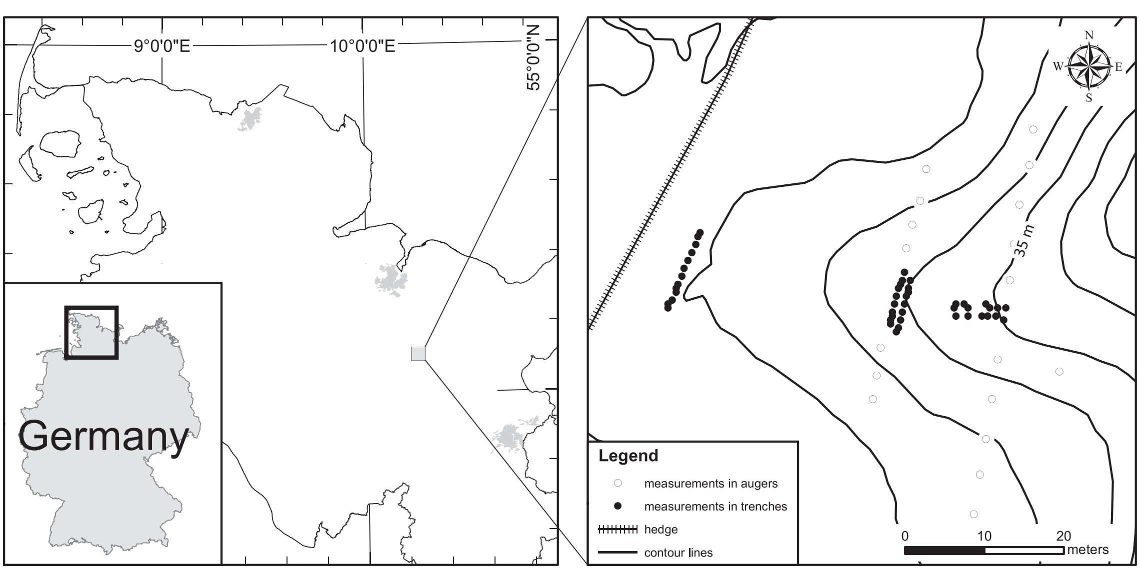

Fig. 1. Location of the study area and points of measurements in trenches and cores. Contour lines have 1 m vertical interval.