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The relationship between Bedrock geometry and soil solum at a regional scale

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Abstract—**One of the main goals of geomorphometry is to derive the geometry attributes from a topographic surface that can be used as predictive variables in the soil-landscape analysis. In this study, the relationship between geometry attributes of bedrock topography and soil solum in a regional scale was investigated. For this study, seven geometry attributes (slope gradient, slope aspect, plan curvature, profile curvature, cross-sectional curvature, maximum curvature and minimum curvature) of terrain surface (DTM) and bedrock surface (DBM) was calculated. The multivariate adaptive regression splines (MARS) was applied for modeling and Mann-Whitney U test for assessing the statistically differences of the geometry attributes across the groups of DTM and DBM. The results showed that there are remarkable differences between DTM and DBM geometry attributes, especially the slope gradient, profile curvature, maximum curvature and minimum curvature. MARS modeling showed that there is a remarkable difference between the relationships of DTM and DBM geometry attributes and soil solum and the model fitted based on DBM geometry attributes performs better in prediction. In our opinion, the idea of using bedrock topography for geomorphometric modeling of soil properties still needs further investigation, especially in terms of scale issue.**

Keywords— Bedrock topography, Geomorphometry, Soil-landscape analysis, MARS.

I. INTRODUCTION

Topography is the most important pedogenic factor known in a high relief landscape that has a significant influence on the spatial variability of soil properties, especially soil depth, by controlling hydro-geomorphic processes [1, 2]. The relationship between soil and topography can be used to mapping soil patterns of a landscape which this process is called soil-landscape analysis and the development of modern digital techniques such as geomorphometry has led to advances in its methodology [3, 4]. One of the main purposes of geomorphometry analysis is to derive geometry attributes from a digital elevation model (DEM), which can be used as predictive environmental variables in digital soil mapping (DSM) [5]. When the rate of relief in the landscape is reduced, it is often that the ability of geometry attributes to predict soil properties is also diminished, as it becomes much harder to extract topographic information from a DEM. As relief declines, the need for high quality DEM is generally increased, although it is still not accessible in many least developed countries. In a geomorphologic unit such as the plain, because it lacks significant relief, the topography and spatial resolution of DEM will have lower impact on soil-landscape analysis. On the other hand, it seems that in the absence of easy available environmental variables, severe sampling from the soil along with interpolation methods would be an effective method in spatial prediction of the soil properties, which would also require high costs. One idea is that bedrock topography may be used instead of terrain topography for geomorphometric modeling of soil properties. Bedrock is the consolidated solid rock beneath unconsolidated surface materials, such as soil and gravel. The bedrock has been exposed in some areas at earth surface, but in areas it may be more than a thousand meters deep below the surface [6]. Estimating depth to bedrock is an important issue in geophysical science that can be of particular application in many fields of the earth sciences. Depth to bedrock affects energy and water cycles and can be considered as an input parameter for modeling natural hazards such as earthquakes and landslides [7]. This study was conducted to investigate the idea of using bedrock topography for soil-landscape analysis at a regional scale.

II. METHODS

The study was conducted in an area located between the four provinces of Henan, Shandong, Jiangsu and Anhui in western China (114° 05′ to 118° 16′ E and 32° 50′ to 35° 54′ N). The region has an area of 129560 km^2 and the survey of land cover product images (MCD12Q1) of MODIS satellite sensor shows that the major land use of the study area is agricultural. The bedrock elevation map shown in Figure (1) has a spatial resolution of 250 m and is generated from the difference the STRM elevation data and depth to bedrock data that are having same spatial resolution. Depth to bedrock data were obtained from http://globalchange.bnu.edu.cn and details about production and accuracy of this data are discussed in [7]. In this study, it has been

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observed that in areas with high DEM value, depth to bedrock value is low. According to Figure (1), the lowest and highest values of bedrock elevation are -354 and 1096 m, respectively, which are around of these two points the highest and lowest depths to bedrock respectively.

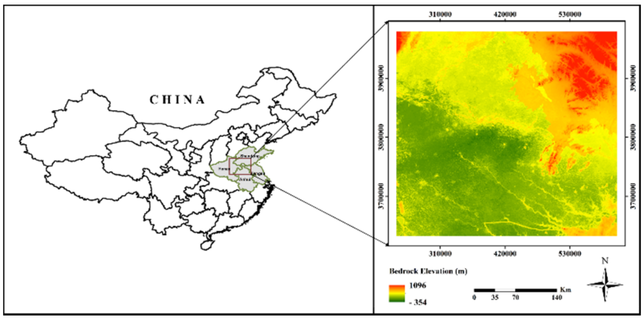

Figure 1. The location of the study area.

Soil solum data used in modeling have been extracted from the ISRIC's global database of soil profiles [8]. Solum is the upper part of the soil profile where soil formation processes are active. Solum in the soil consists of the A, E and B horizons. The activities of soil fauna and flora are largely limited to the solum [9]. In this study, the geometric attributes of slope gradient, slope aspect, plan curvature, profile curvature, cross-sectional curvature, maximum curvature and minimum curvature of DEM raster and bedrock surface raster was calculated in SAGA software (v.7.5.0) by fitting the quadratic function parameters in a locally moving neighborhood analysis window (NAW) (via least squares) as described by Wood (1996) [10]. In this paper, we call the geometry attributes group of the terrain surface and the bedrock surface DTM and DBM, respectively. Mann-Whitney U test was used for assessing the statistically differences of geometry attributes across the groups of DTM and DBM. The Spearman correlation test and the multivariate adaptive regression splines (MARS) were used to investigate the relationship between soil solum and DTM and DBM geometry attributes. MARS is a nonparametric modeling technique developed by Friedman (1991) [11] and can be viewed as generalization of stepwise linear regression or a modification of tree regression (CART) [12].This technique does not impose or consider any underlying assumptions about the functional relationship between explanatory and response variables, and model the nonlinear relationships between these variables by a set of separate piecewise linear segments (splines) of differing gradients (slope). This method divides the space of the explanatory variables into smaller pieces and fits a spline function at each piece, which the breakpoints between the pieces and these functions are called knots and basic functions, respectively [13]. In order to develop an optimal model that has a more accurate estimation, the MARS modeling was performed with different settings including maximum basic function in the first step, maximum degree of interaction between the independent variables and the penalty parameter. Evaluation of the MARS fitted models was performed using k-fold cross validation (k = 10).

III. RESULTS AND CONCLUSIONS

The results of descriptive statistics of the soil solum data are presented in Table (1). The skewness and kurtosis coefficients indicate that the solum property of soil does not have a normal distribution. In geomorphometric modeling of soil properties it is appropriate not to normalize the data because it reduces the effect of hot spots in the modeling. Soil solum has a coefficient of variation (CV) of 80.80 %, which seems that the large extent of the study area and its land use type are the main reason for the increase in CV.

Table 1. Descriptive statistics of Soil Solum Depth (n = 74).

Soil Property	Minimum	Maximum	Mean	Median
Solum Depth (cm)	12.00	150.00	37.80	26.00
	S.D.	**C.V. (%)**	**Skewness**	**Kurtosis**
	30.55	80.80	2.38	5.17

S.D. = Standard deviation. C.V. = Coefficient of Variation

After geomorphometric analysis, the values of each of the DTM and DBM geometry attributes were extracted for the location of the sampling points. The statistical analysis results of the extracted values of geometry attributes are shown in Figure (2) and Table (2). When geometry attributes, especially curvatures, are derived from topographic surface of the bedrock, a relatively wide range of positive and negative values can be observed which indicating a high variability in topographic surface bending among sampling areas. But in the DTM geometry attributes, the values range and hence the bending variability is significantly reduced. Mann-Whitney U test results (table 2) showed that the difference between slope gradient, profile curvature, maximum curvature and minimum curvature was significant across the DTM and DBM geometry attributes.

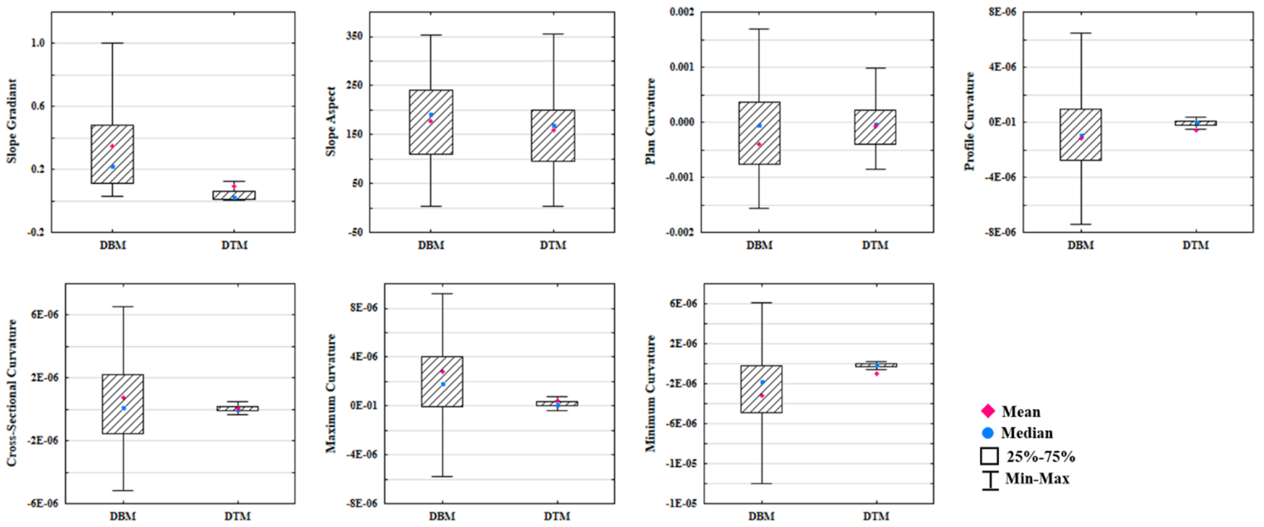

Figure 2. Descriptive statistics of DTM and DBM geometry attributes.

Table 2. Mann-Whitney U Test results used for assess a statistically significant differences between DBM and DTM (n = 2).

Geometry Attributes	Chi-square	df	P-value
Slope Gradient	64.98	1	0.00
Slope Aspect	2.62	1	0.11
Plan Curvature	0.13	1	0.72
Profile Curvature	4.27	1	0.04
Cross-Sectional Curvature	0.19	1	0.66
Maximum Curvature	11.81	1	0.00
Minimum Curvature	18.15	1	0.00

There is a difference between the correlation of DTM and DBM geometry attributes with soil solum. So that none of the DTM geometry attributes have significant correlation with soil solum but the plan curvature (at the 5 % level), cross-sectional curvature and minimum curvature (at the 1 % level) that are derived from bedrock topography have significant correlation with soil solum (table 3).

Table 3. Spearman correlation coefficients among soil depth and geometry attributes of bedrock surface (DBM) and terrain surface (DTM) at the study area (n=74).

DBM	Solum Depth	DTM	Solum Depth
Slope Gradient	-0.155	Slope Gradient	0.219
Slope Aspect	0.022	Slope Aspect	0.172
Plan Curvature	-0.277	Plan Curvature	-0.127
Profile Curvature	0.163	Profile Curvature	-0.1
Cross-Sectional Curvature	0.301	Cross-Sectional Curvature	0.145
Maximum Curvature	0.165	Maximum Curvature	0.187
Minimum Curvature	0.337	Minimum Curvature	-0.146

Correlation is significant at the 0.05 level.
Correlation is significant at the 0.01 level.

The results of soil solum modeling by DTM and DBM geometry attributes using MARS are presented in Table (4). The MARS models based on DTM and DBM were able to justify 31 and 45% of the soil solum depth variations in the study area, respectively, which this may indicate that DBM geometry attributes are better predictors for soil solum. Test results of the fitted MARS models by k-Fold cross validation show that the prediction accuracy of the two models is low, but the DBM-based model performs more accurate than the DTM model. MARS has fitted 5 basic functions based on DBM geometry attributes for soil solum modeling, some of which result from the multiplying of two or three basic functions due to the degree of interaction being set to 3 for modeling. The basic functions and the final formula for calculating the soil solum depth which developed based on DBM geometry attributes are presented in Table (4).

Table 4. Results of modeling between soil solum depth and geometry attributes of bedrock surface (DBM) and terrain surface (DTM) Using MARS.

Model	Learn R-Sq.	Test R-Sq.
DBM	0.45	0.14
DTM	0.31	-0.19

Solum depth model based on DBM :

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BF4 = max( 0, 0.756769 - SLOPE);
BF9 = max( 0, MAXIMUM_CU + 8.98505e-007) * BF4;
BF15 = max( 0, SLOPE - 0.460765);
BF18 = max( 0, ASPECT - 303.408) * BF9;
BF20 = max( 0, ASPECT - 164.834) * BF9;

Solum depth = 35.4004 + 18.071 * BF15 + 1.3763e+006 * BF18 - 101313 * BF20;
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The overall results of this study show that there are remarkable differences between DTM and DBM geometry attributes and their relationship with soil solum. Although geometry attributes of bedrock surface are more correlated with soil solum and the MARS model fitted based on them has a higher accuracy in the prediction soil solum, this issue still needs further investigation. Preparing a high spatial resolution bedrock topography map requires specialized tools such as Ground Penetrating Radar (GPR) and is costly, but it is recommended that a fine-scale study be conducted to examine more accurately the relationship between bedrock topography and soil properties in different geoform units.

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