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The Usability of Contours in Erosion Modelling: A Case Study on ZABAGED, Czech Republic

STANISLAV BEK[1], TOMÁŠ CHUMAN[2], LUDĚK ŠEFRNA[2]

[1] Charles University in Prague, Faculty of Science,
Institute of Applied Mathematics and Information Technologies,
[2] Charles University in Prague, Faculty of Science,
Department of Physical Geography and Geoecology

Abstract

This paper aims to the evaluation of the assessment of topographic potential for erosion and deposition when the contour lines from the Czech Fundamental Base of Geographic Data (ZABAGED) are used. On a hill slope above the Opava River a DEM from field measurements and a DEM from contours were created. The potential for erosion and deposition was computed on the both DEMs and the results were compared. We considered the result based on the DEM from field measurement as a reference. The potential for erosion and deposition based on the contour lines showed large inaccuracies in its spatial distribution. The main drawbacks of ZABAGED contour lines mentioned in literature proved to be significant in erosion and deposition modelling.

Key words: Erosion modelling, USPED, Regularized Spline with Tension, Contour Lines. Modelování eroze, USPED, regularizovaný spline s tenzí, vrstevnice

1. Introduction

The process of soil erosion and deposition caused by flowing water is essentially influenced by terrain geometry which controls the fluxes of mass in the landscape. Topographic potential for erosion and deposition can be measured by the topographic index representing the change in sediment transport capacity in the direction of flow (Mitášová et al. 1996). The topographic index is computed from terrain parameters derived from digital elevation model (DEM). The quality of the DEM is crucial for spatial distribution of the topographic index and its correspondence to reality.

Contour lines are the easiest-accessible source of altitude data for the regional scale and thus frequently used in environmental projects. Conversion of elevation from contours to the regular grid is necessary when the DEM should be used as an input for modelling. The quality of the DEM corresponds then to the precision of contour lines and the quality of the conversion process from contours to regular grid.

The objective of this paper is to verify whether or to which extent the contours are utilizable for the modelling of soil erosion and deposition on field scale. Spatial distribution of the topographic potential for erosion and deposition based on (i) the DEM created from the contour lines and (ii) the DEM created by field measurement will be compared. The DEM created by field measurement is supposed to be more accurate and will be considered as the reference DEM for the comparison.

2. Data and Methods

2.1 Study site

The study site is located on the south-eastern hill slope of the Opava River between the Nové Heřmínovy and Čaková village, in the area of a proposed water reservoir. The area of the study site is 30 hectares, ranging from the floodplain with zero slope to the border of the watershed. The slope reaches maximally 18°. The preserved connection between the dominant area of erosion and the main accumulation area in the floodplain was the main criterion for the study area selection.

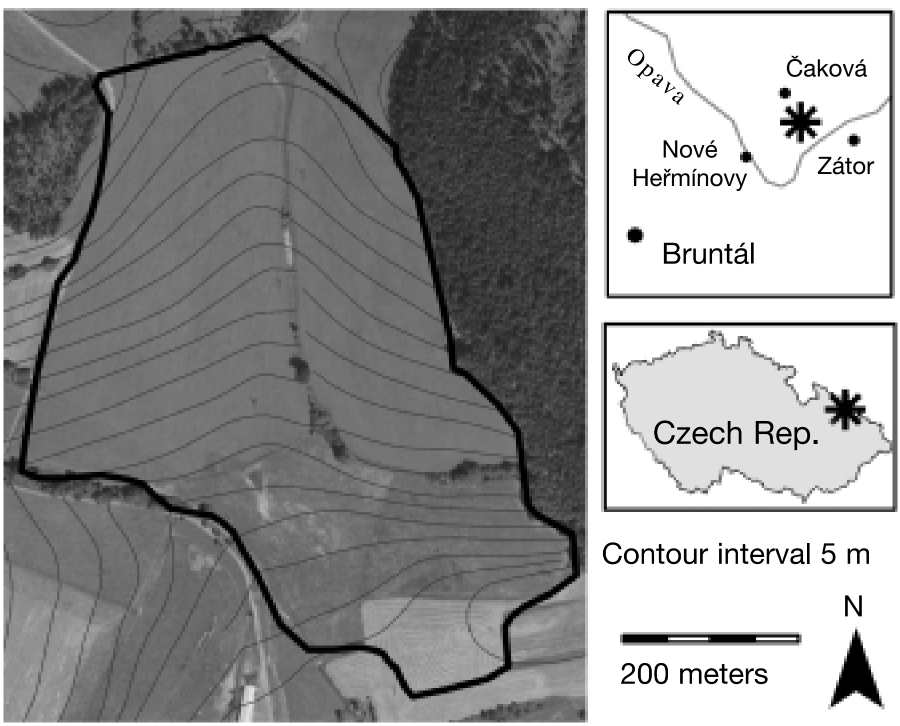

Figure 1: Location of the study site

Land use of the study site has been recently changed from arable land to pasture. However, the area had been used as arable land for centuries as confirmed by historical aerial photographs, Imperial Imprints of the Stable Cadastre and Third military mapping. Evidences of intensive soil erosion and deposition can be observed on geomorphologic features whose genesis was confirmed by checking soil horizon depths on few sites.

2.2 Field measurements

The topographic data were obtained using a laser theodolite. The measurements of heights were performed at 449 scattered data points selected by expert judgment in order to characterize detailed variations in terrain morphology. The data were georeferenced into the national coordinates system S-JTSK using GPS with horizontal accuracy 1 m. The vertical accuracy in height measurement was 1 mm.

2.3 Contour lines

Used contour lines are reachable as a part of Fundamental Base of Geographic Data (ZABAGED) provided by the Czech Geodetic and Cadastral Office. It concerns the vectorized contours from basic topographic map at a scale of 1: 10 000. Their elevations range from 375 to 465 m in the area of interest. The contour interval is 5 m, except the contour line of 377.5 m.

Standard error of the contour altitude information in ZABAGED was empirically derived by Kučera (1961):

$$m_v = \sqrt{0{,}88^2} + 4{,}2tg\varepsilon \quad (1)$$

where ε denotes the slope steepness and *tg* is tangent. Boundary error is then about half of contour interval for medium-steeped terrain.

The contour lines were derived from stereoscopic aerial images. During the processing, the detailed terrain features (microrelief) were often smoothed, and smooth character of contours was preferred according to the methodology (Šíma & Egrmajerová 2004).

Except the contours, there is no other altitude information available from ZABAGED (elevation or geodetic points) which could be used as additional information to the contours within the study area.

2.4 Interpolation by RST: Creating regular grid

The conversion of elevation data into the form of regular grid is necessary for their utilization in the spatial modelling. The interpolation method based on regularized spline with tension (RST), constructed by Mitáš & Mitášová (1993), proved to be one of the most appropriate for this task (e.g. Hofierka et al. 2007 or Cebecauer et al. 2002). This method also matches the most important requirements posed on methods which are used to process elevation grid for sediment-flow applications (e.g. direct estimation of derivatives (gradients, curvatures), smoothing for noisy data and applicability to large datasets). The direct estimation of derivatives reduces the problem of the choice of the spatial resolution of the grid.

For good results of interpolation, it is fundamental to optimize the parameters of the method which control the character of the interpolation surface. The two main parameters are: (i) *tension* which tunes the character of the resulting surface from thin plate to membrane, and (ii) Smoothing parameter (smooth*)* which controls the deviation between the given points and the resulting surface. Small values are required for good results. For a good choice of both these parameters, the cross-validation can be used (Hofierka et al. 2007).

The interpolation method RST including the cross-validation is implemented in open-source GRASS GIS. The interpolation with the proper parameters is run by the module *v.surf.rst*.

2.5 Topographic potential for erosion and deposition

Moore & Wilson (1992) have shown that the general form of the sediment transport equation can be used to describe the effects of terrain on soil erosion, which is shown in detail by Mitášová et al. (1996) or Mitášová & Mitáš (1999). Potential of topography for erosion and deposition can be measured by topographic index representing the change in sediment transport capacity (T) in the direction of flow $E = dT/ds$ (Mitášová et al. 1996). In comparison to the LS factor, used to describe topography in traditional USLE-based models, this approach more fully account for topographic complexity by considering both the profile curvature (in the downhill direction) and the tangential curvature (perpendicular to the downhill direction) (Warren et al. 2000). The enhanced capability to handle complex topography using the topographic index was proved by Warren (2005) when USPED model (using this approach) overperformed applications of USLE.

The sediment transport capacity can be expressed as:

$$T = k\,A^m\,(\sin\beta)^n \tag{2}$$

where β is slope, k is a a coefficient expressing factors not directly linked to terrain properties (e.g. rainfall, soil, cover), A is upslope contributing area per unit contour width, m, n are constants that vary according to type of flow and soil properties. For overland flow the constants are usually set to $m = 1.6$, $n = 1.3$ (Mitášová 2001). The change in the sediment transport capacity in the direction of flow is then expressed by a directional derivative:

$$E = \frac{dT}{ds} = T_x \cos\alpha + T_y \sin\alpha \tag{3}$$

$$T_x = \frac{dT}{dx}, = T_y = \frac{dT}{dy}$$

where are the partial derivatives of the function T, and α is the aspect angle computed simultaneously with the interpolation.

The index E is positive for areas with topographic potential for deposition where the sediment transport capacity decreases, and negative for areas with erosion potential where the sediment transport capacity increases Mitášová et al. (1996).

We will use pure topographic potential (E_p) obtained as:

$$E_p = E / k \tag{4}$$

which expresses topographic potential without influence of other factors.

Computer implementation of the spatial distribution of the topographic potential for erosion and deposition in GRASS GIS is similar to implementation of USPED model shown by Mitášová & Mitáš (1999).

3. Results

3.1 Creating regular grids

Two regular grids of elevation from ZABAGED contour lines named DEM-cont1 and DEM-cont2, and the regular grid from field measurements named DEM-meas were created using v.surf.rst in GRASS GIS. The proper parameters of the RST method (see Table 1) were found by the cross-validation minimizing RMSE. Simultaneously, grids of slope and aspect were generated. The DEMs are visualized by contours in Figure 2.

Table 1. Parameters of RST interpolation

Name of result DEM	Source	Tension	Smooth	Cross-valid. RMSE (m)	# of points
DEM-cont1	contours	20	0.01	0.439	410
DEM-cont2	contours	20	0.1	0.479	410
DEM-meas	field measurement	30	0.01	0.331	449

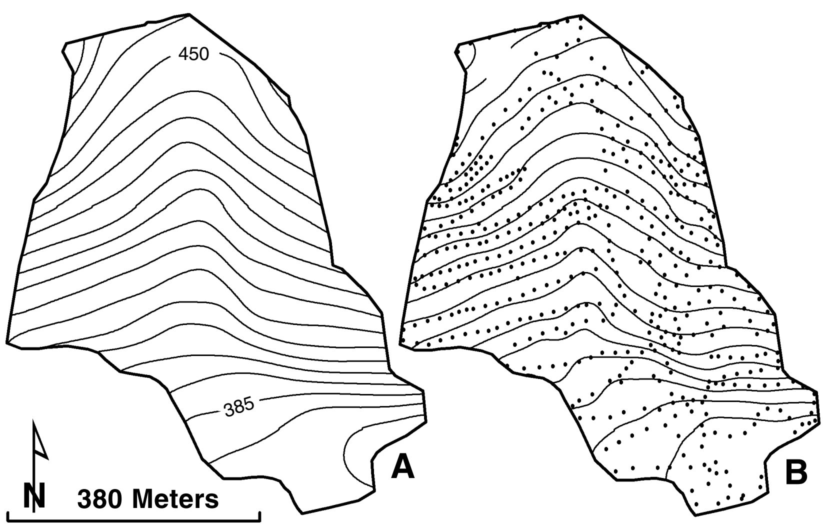

Figure 2. Differences of DEM-cont1 (A) and DEM-meas (B). The contours were generated from the grids using GRASS GIS module r. contour. The points in B show the locations of field measurements.

3.2 Spatial distribution of the topographic potential for erosion and deposition

In the area of interest, we have computed the index E_p for the DEM-cont1 and DEM-meas which represent the change in sediment transport capacity. The result of the E_p computing based on the DEM-meas is considered as a reference one which is due to the higher accuracy of the DEM-meas. The index is represented by raster of spatial resolution 2 m. The distribution summary of the two rasters is given in the Table 2.

Table 2. Distribution summary of E_p-cont1 and E_p-meas

	Ep-cont1	Ep-meas
n	67674	67674
mean	–2.34887	4.08
standard deviation	2389.42	8109.21
minimum	–99014	–176346
10-th percentil	–11.8816	–15.56
1st quartile	–4.56716	–4.20
median	–1.31639	–1.06
3rd quartile	0.0457521	0.89
90-th percentil	6.63784	10.81
maximum	117150	171932

The both variables E_p-cont1 and E_p-meas were specific by low proportion of the interquartile range to the total range. The difference between the 90th and 10th percentile was also low in the proportion to the total range. Extreme values of the variables spatially correspond to the narrow zones of concentrated flow which drains the study area.

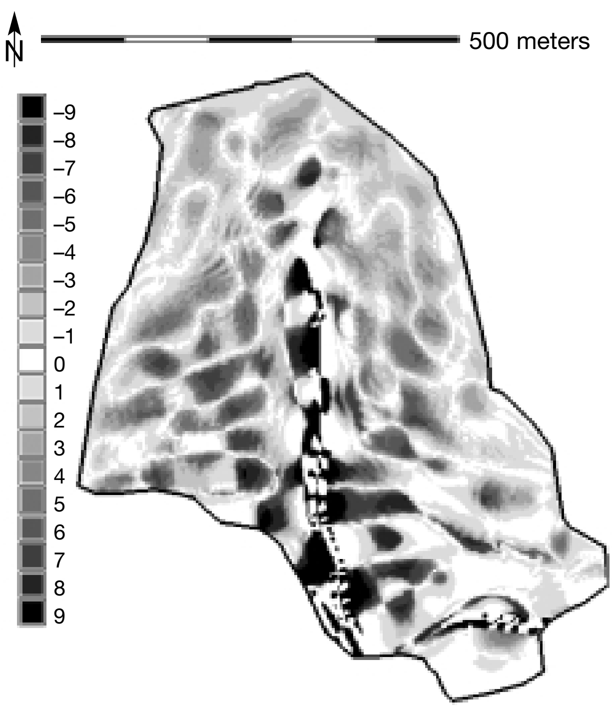

Figure 3. Differences between the classification numbers of spatially overlaid classified variables E_p-cont1 and E_p-meas

The QQ-Plot showed that the both variables E_p-cont1 and E_p-meas were not normally distributed. The relationship of the set of spatially related pairs of variables E_p-meas and E_p-cont1 was examined by the Spearman's correlation coefficient which presented a value of 0.41. Modelling of the direct relationship between the both variables seems to be rather problematic.

Regarding practical issues, the most important matter of interest is to verify whether E_p-cont1 can capture the areas of the highest erosion risk. Therefore, we concentrated on the evaluation of classified data.

In spite of the low spatial autocorrelation in both variables (which does not correspond to reality), E_p-meas and E_p-cont1 were smoothed by averaging in circular neighborhood of each point. The smoothed variables E_p-meas and E_p-cont1 were each classified into 10 classes regarding the $10 \cdot k^{-th}$ percentiles. (Class no. 1 corresponds to the values between minimum and 10^{-th} percentiles etc.) The both classified variables were spatially overlaid and the difference (cont-meas) between the classification numbers computed for each point (see Figure 3.). The root mean square error (RMSE) was 3.38, whereas the expected RMSE of the difference between randomly distributed classes would be 4.06.

The variables E_p-meas and E_p-cont1 were also classified into 4 classes regarding the quartiles values (see Figure 4.), and the spatial differences evaluated in the same manner as for 10 classes. The RMSE of the overlaid classified variables was 1.34, whereas the expected RMSE of randomly distributed classes would be 1.58.

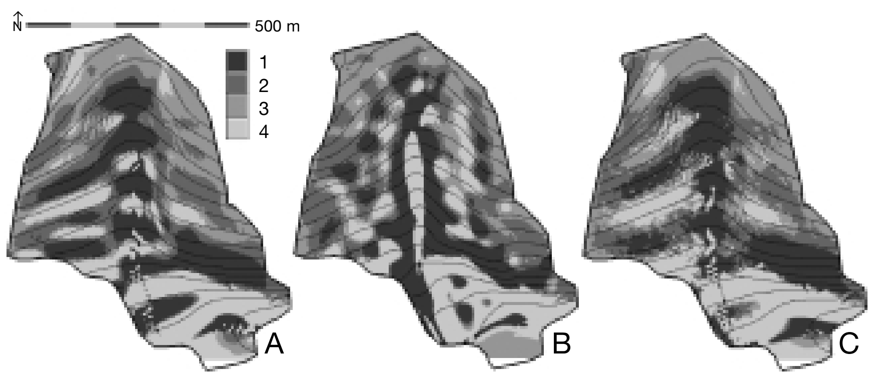

Figure 4. Index E_p of the topographic potential for erosion and deposition classified by quartiles based on (A) DEM-cont1, (B) on DEM-meas, (C) on DEM-cont2

The spatial distribution of the topographic potential for erosion and deposition based on the contours from ZABAGED (E_p-cont1) performed considerable inaccuracies around the whole area (see Figure 3 and 4). Let us divide the detailed description into following two parts:

1. At the bottom of the valley in the axis part of the area the step-like features can be observed which can be addressed either to:

(i) the general problem of undersampling by contours in the valleys and consecutive problem with interpolation (Cebecauer 2002),
and (or)
(ii) the insufficient expression of natural cutting in the relief by the contours of ZABAGED due to the requirement on smoothness posed on the contours by its processing (Šíma 2004).

The problem (i) can be partially solved by the choice of higher smoothing parameter of the RST interpolation. For this purpose, the DEM-cont2 was used and the computation of E_p performed. As we can observe in Figure 4c, the problem of step-like patterns were reduced, however, the prediction of erosion in the valley is inadequate. The same result was also achieved by USPED modelling from contour lines (Bek 2007). Regarding this fact, the problem of the incorrect prediction in the valley should be addressed to the insufficient expression of natural cuttings in the relief by input contours.

2. Considering the variables classified into 4 classes excluding the valley are, classes no. 1, 3 and 4 spatially overlapped on 48% of their areas, class no. 2 on 40% of the area. Classes no.1 representing the highest erosion risk matched in the areas of the steepest slopes (more than 15°) in the south-east and also close to the valley in the central part. Classes no. 4, representing predominantly the deposition areas, matched in the areas adjacent to the areas of match of classes no. 1 at the lower concave part of the steep slopes. The border between these erosion and deposition patterns was modeled by E_p-cont1 accurately. The E_p-cont1 shows usually lower absolute values than E_p-meas in the areas of match.

The erosion and deposition patterns on slopes < 10° were not captured by E_p-cont1. That illustrates the parallel belts of erosion and deposition in the eastern part, for example. On the contrary, the high erosion and deposition patterns, predicted in the western (lower) part by E_p-cont1, are unjustified and do not express the true structure.

Conclusion

The results demonstrated that in the area of interest, the topographic potential for erosion and deposition computed from ZABAGED contour lines shows large inaccuracies in its spatial distribution. The drawback of ZABAGED contours in the insufficient representation of small valleys, mentioned by Šíma (2004), revealed significant for erosion and deposition modelling. Excluding valley areas, the contours could correctly capture only areas of the highest topographic potential for erosion and deposition. Therefore, the erosion and deposition modelling on the field scale based on the ZABAGED contour lines seems to be very limited.

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Résumé

Využitelnost vrstevnic v modelování eroze: případová studie o využití ZABAGED

Tvar reliéfu podstatně ovlivňuje prostorové rozdělení vodní eroze a depozice půdního materiálu. Cílem článku je zhodnotit využitelnost vrstevnic Základní mapy (Zabaged) pro modelování topografického potenciálu eroze.

V povodí Opavy byl vybrán modelový svah o velikosti 30 hektarů. Byly použity vrstevnice Zabaged, které byly převedeny na body dostatečně vystihující průběh vrstevnic. Totální stanicí bylo zaměřeno 449 bodů, které byly použity pro tvorbu referenčního modelu. Pro počítačové modelování se zpravidla používají gridové digitální modely terénu (DMT). Tvorba DMT spočívá v konverzi nepravidelně rozmístěných dat do pravidelné sítě. Pro tuto úlohu byla použita obecně uznávaná metoda RST (regularizovaný spline s tenzí). Její vstupní parametry byly optimalizovány a vytvořeny dva digitální modely terénu: i) z vrstevnic a ii) ze

zaměřených bodů. Vzhledem k řádově vyšší přesnosti modelu ii) byl tento považován za referenční. Na obou DMT bylo modelováno prostorové rozdělení topografického potenciálu eroze a depozice. Jedná se o reliéfovou charakteristiku reprezentující změnu v transportní kapacitě ve směru toku. Tato charakteristika zahrnuje profilovou i tangenciální křivost reliéfu a tím, v porovnání s často používaným LS faktorem, lépe popisuje komplexitu reliéfu.

Z porovnání prostorového rozdělení topografického potenciálu eroze a depozice na DMT z vrstevnic a referenčním DMT plyne, že topografický potenciál eroze a depozice modelovaný z vrstevnic dobře odpovídá referenčnímu modelu na prudkých svazích (kolem 15°), a to jak v jejich konvexních částech (vysoký potenciál eroze) tak i v konkávních (vysoký potenciál depozice). Naopak na svazích nižší sklonitosti (< 10°) a v oblasti úpadu ve střední části modelového území je potenciál eroze a depozice modelován z vrstevnic neuspokojivě. Je známo, že vrstevnice Zabaged nedostatečně vyjadřují malé zařízlé reliéfové tvary. Tato skutečnost se zřejmě negativně projevuje i při modelování eroze.

Stanislav Bek
Charles University in Prague, Faculty of Science,
Institute of Applied Mathematics and Information Technologies,
Albertov 6
128 43 Prague 2
Czech Republic
e-mail: bks@centrum.cz

Tomáš Chuman, Luděk Šefrna
Charles University in Prague, Faculty of Science,
Department of Physical Geography and Geoecology
Albertov 6
128 43 Prague 2
Czech Republic