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## APPLICATION OF ELEVATION GEOMORPHOLOGIC CLASSIFICATION FOR CHECKING THE ACCURACY OF DIGITAL ELEVATION MODEL

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**Abstract.** The article deals with the geomorphologic method of classification of the elevation, applying a special overlay of the first and second rate derivative of the elevation. So far in the tests there have been taken into account one or two characteristics for classification. The technique presented suggests the method of joining together some surface characteristics and by summarising as well as associating them together to make one rugged surface of the elevation to be able to reflect the most precisely and comprehensively the elevation changes in the spherical image and it should serve best for selecting the elevation model and parameters of modelling. The errors of the elevation models obtained by means of different modelling techniques have been evaluated. The results revealed that the elevation models errors depend on geomorphologic characteristics. These errors have been calculated by means of different methods. The efficiency of the method has been evaluated calculating the elevation model for each. The possibilities to reduce the standard deviations of the elevation model have been evaluated by selecting the parameters of the elevation modelling.

**Keywords:** digital modelling of the elevation – DEM, zoning of relief, geomorphologic characteristics of relief, method of kriging.

### 1. Introduction

When compiling a digital elevation model (DEM) we come across with different values of standard deviations in locations of digital elevation models. The author has raised and checked the hypothesis that deviations have been arranged not in the random sequence but they depend on the elevation characteristics. The investigation has pointed out that the values of the standard deviations depend on some DEM characteristics [1]. Therefore the author proposes to select the DEM method in accordance with these characteristics. To carry out the task a technique has been compiled for surface geomorphologic zoning, dividing the elevation into zones, grouping the elevation characteristics. The standard deviations of the elevation model have been eliminated by selecting the most suitable technique of elevation modelling and the most optimal parameters.

### 2. Theoretical review of the models

The technique meant for surface geomorphologic zoning has been applied, taking into account the surface characteristics, namely the slope, aspect and roughness, the surface divided into the territories with different geomorphometric characteristics [2, 3].

Within the first stage of the geomorphologic parameter [4] analysis by the universal surface modelling a digital grid elevation model of the selected location has been compiled. After a comparative analysis of the surface modelling, the usual kriging method as the universal method of surface modelling (using circular

semivariogram with 9 neighbouring points) has been selected.

### 3. Computation of the slope by grid data model

The computation technique according to the horizontal or network of irregular triangles (TIN) is not complicated, namely first the slope angle of the vertical connecting two horizontals or by making calculations in the TIN and taking into account the slope angle of the triangle surface is evaluated. When calculating by a network, the task has become more complicated because the cells of the TIN are flat and horizontal. When making computations of the slope by the grid data model, 3×3 cell file [5] (Fig 1) was used. The function for the slope computation for finding out the middle cell values, has enabled to make calculations on the inclined plane set as close as possible to the cell altitude values.

When the cell, the slope of which is being calculated, is situated at the margin of the elevation model, the altitude values of certain cells are missing. Instead of them the computations make use of the altitude value of the middle cell. Therefore the slope of the marginal cells is obtained smaller.

$h_{11}$	$h_{12}$	$h_{13}$
$h_{21}$	$h_{22}$	$h_{23}$
$h_{31}$	$h_{32}$	$h_{33}$

**Fig 1.** Slope calculating by grid data model

The slope is calculated in the aspect of the  $X$  axes [6]:

$$\frac{\delta z}{\delta x} = \frac{(h_{13} + 2h_{23} + h_{33}) - (h_{11} + 2h_{21} + h_{31})}{8 \cdot d_x}, \quad (1)$$

where  $\frac{\delta z}{\delta x}$  – partial derivative quantity of the altitude value to the  $x$  aspect;  $h_{ij}$  – the cell altitude values of the grid model;  $d_x$  – the cell diameter of grid model to  $x$  aspect.

When calculating the slope towards  $Y$  axes aspect:

$$\frac{\delta z}{\delta y} = \frac{(h_{31} + 2h_{32} + h_{33}) - (h_{11} + 2h_{12} + h_{13})}{8 \cdot d_y}, \quad (2)$$

where  $\frac{\delta z}{\delta y}$  – partial derivative quantity of the altitude value towards  $y$  aspect;  $h_{ij}$  – altitude values of grid model;  $d_y$  – cell diameter of grid model towards  $y$  aspect.

The total slope of the central cell is calculated by:

$$i = \arctg \sqrt{\left(\frac{\delta z}{\delta x}\right)^2 + \left(\frac{\delta z}{\delta y}\right)^2}, \quad (3)$$

where  $i$  – the slope of the central cell in degrees.

The calculated slope plane (Fig 2) is divided into codes according to the slope value (Table 1).

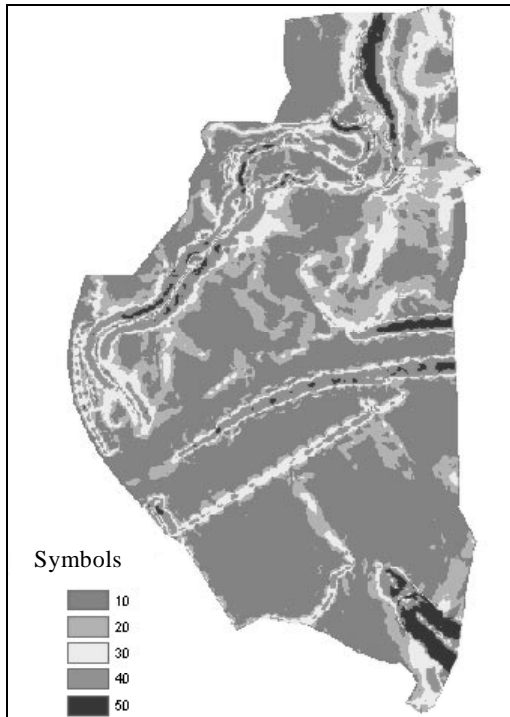


Fig 2. Representation of slope values in the slope model

Table 1. Coding of slope values in slope model

Slope value	Code of slope values
0°–3°	10
3°–6°	20
6°–12°	30
12°–24°	40
24°–60°	50

#### 4. Slope aspect computation by grid data model

DEM is applied as an additional means to evaluate the roughness of the surface [1]. Slope aspect and value overlap (Fig 3) take in itself the information of aspects and slopes. Moreover, it is used to find out the relative variability of the relief.

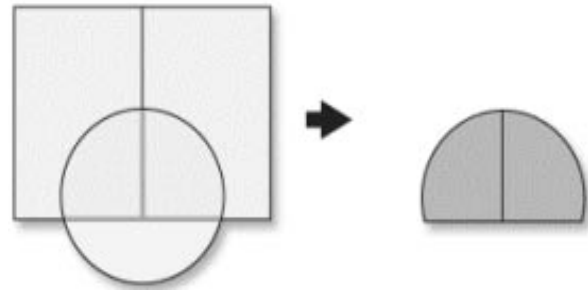


Fig 3. Example of slope aspect and value overlay

While carrying out the analysis of the slope aspects, the surface was divided into 9 categories according to the slope aspects (Fig 4): North, East, Southeast, South, South West, West, North West as well as into territories possessing flat surfaces (Fig 5).

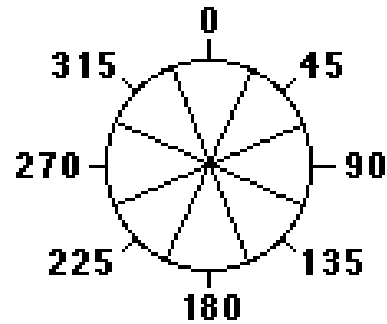


Fig 4. Aspect classification by grid data model

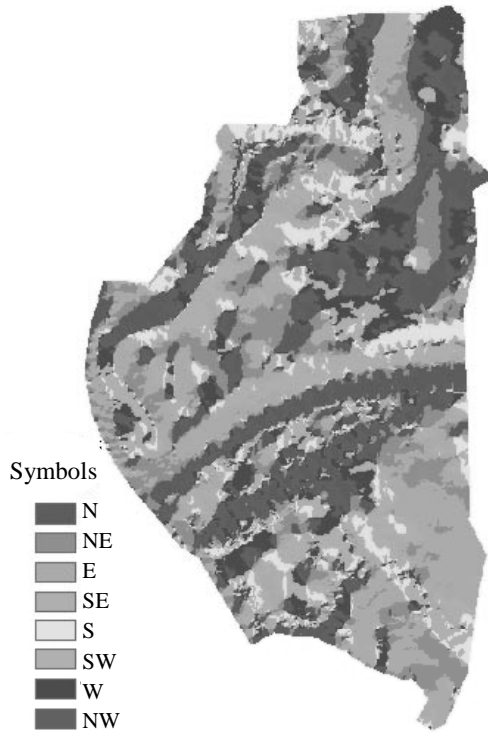


Fig 5. Aspect classification map

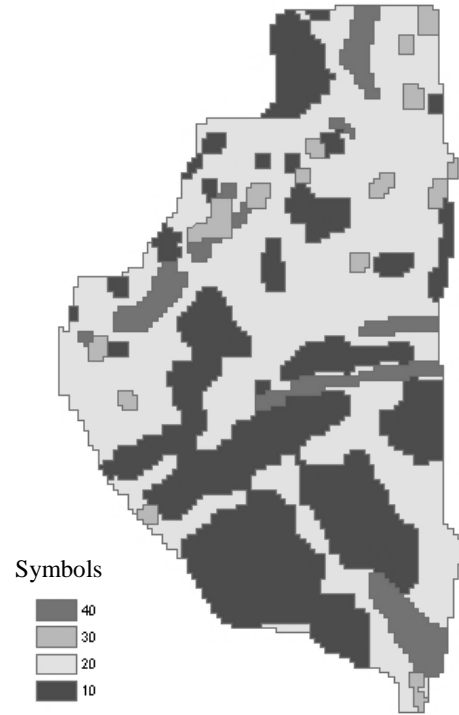


Fig 7. Relief variability map after generalisation

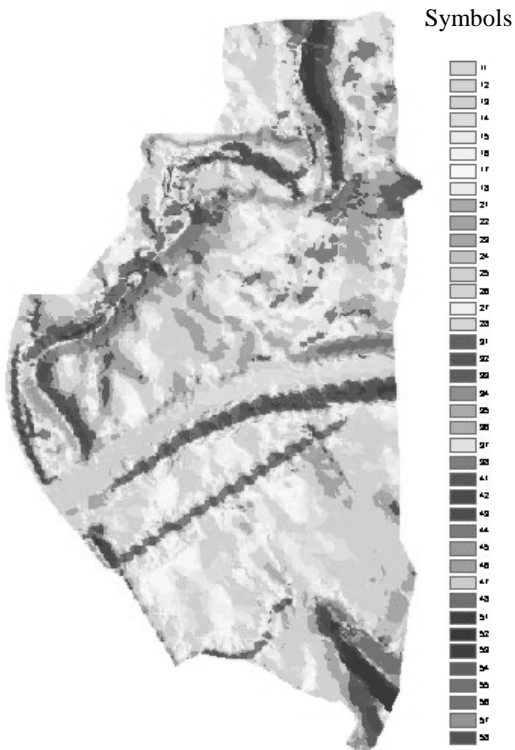


Fig 6. Slope aspect and value overlay map

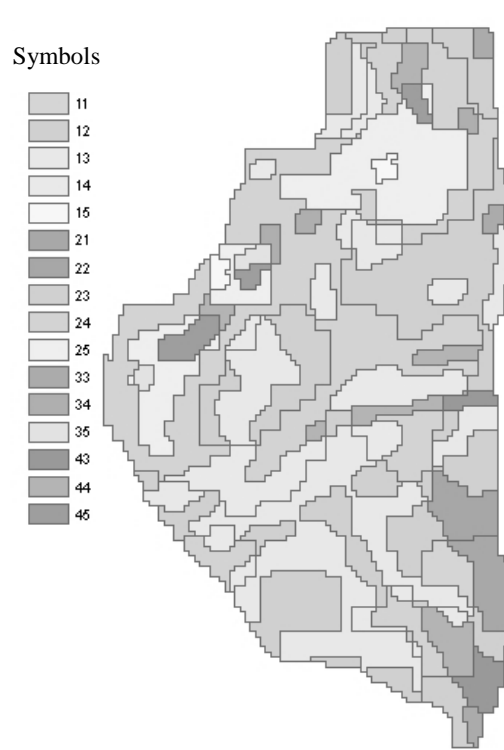


Fig 8. Relief roughness map

## 5. Compiling of the elevation variability map

Relative variability map reflects the variety of horizontal and vertical changes of the surface [7]. While using slope aspect and value overlap map (Fig 6), it is possible to calculate the relative variability of the elevation, which describes the rate of different values in the selected territory with the summed up quantity of different values [8]

$$R = \frac{n}{k} \times 100, \quad (4)$$

where  $R$  – is a relative variability of the elevation;  $n$  – the number of the cells used for analysis;  $k$  – the number of different surface values in the surface model.

The optimal number used for analysis is  $n = 7 \times 7$ . The variability relief is divided into categories. After having divided the layer of the slope aspect and value overlap into the categories, there have been received fragmentary scattered data, not useful for accurate analysis of the elevation model. To eliminate data fragments, the layer of the classified overlap has been generalised removing small regions and simplifying the margins of the remaining ones (Fig 7).

## 6. Calculating the elevation roughness by the spherical overlap of the slope and the elevation variability

The elevation variability reflects the variety of surface values, but it does not reflect the intensity of the changes of surface altitudes. The parameter can be possible determined on the surface roughness map, which is possible to obtain by intersecting the special layers of relief roughness and slopes (Fig 8). The relief roughness map reflects the information of the intensity of the relief changes, slope aspects. In order to analyse this information the elevation model is divided into homogenic elevation roughness zones possessing similar geomorphologic characteristics. It is very important to select the optimal parameters of elevation models [9]. The same parameters could be applied only in the elevation territory signified by the same geomorphologic peculiarities, because due to changing elevation it is necessary to change the elevation modelling parameters. The digital elevation model compiled by universal modelling parameters is suitable for the whole territory but it is not able to reflect the elevation peculiarities of some parts of it, that is why when compiling the DEM for the whole territory greater deviations of the elevation might be obtained. That's why, following the roughness levels, the digital elevation model has been divided into separate zones. The first figure of the zone number describes the slope elevation, that is equal to 1÷4, the second figure describes the variability of the elevation

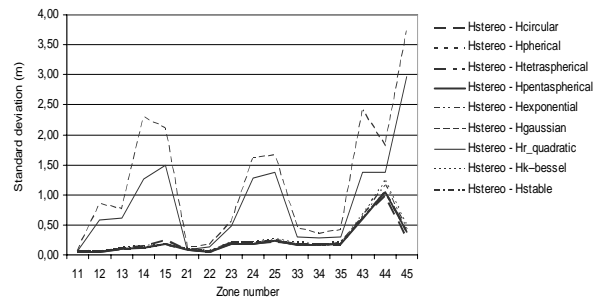
1 ÷ 6 (Table 2). In order to evaluate the elevation model deviations for each zone, the accuracy test was carried out, by which for each separate zone the altitude differences between the grid data model, TIN grid and ordinary kriging method by 9 neighbouring points by means of different semivariograms ( $H_{\text{circular}}$ ,  $H_{\text{tetraspherical}}$ ,  $H_{\text{pentaspherical}}$ ,  $H_{\text{exponential}}$ ,  $H_{\text{gaussian}}$ ,  $H_{\text{r\_quadratic}}$ ,  $H_{\text{k-bessel}}$ ,  $H_{\text{stable}}$ ) of the compiled rectangular grid data models (Fig 9) have been calculated.

**Table 2.** Relief slope, aspect and variability classification

Slope aspect code	Slope aspects
1	N (337,5° ÷ 22,5°)
2	NE (22,5° ÷ 67,5°)
3	E (67,5° ÷ 112,5°)
4	SE (112,5° ÷ 157,5°)
5	S (157,5° ÷ 202,5°)
6	SW (202,5° ÷ 247,5°)
7	W (247,5° ÷ 292,5°)
8	NW (292,5° ÷ 337,5°)

Relief variability code	Relief variability (different value figures, when $n=7 \times 7$ )	Slope elevation code	Slope elevation
1	1–5	1	0° ÷ 2°
2	5–10	2	2° ÷ 8°
3	10–15	3	8° ÷ 16°
4	15–20	4	16° ÷ 60°
5	20–25		
6	25–30		

Table 3 describes the largest standard deviation in zone 44, the one possessing the second largest slope elevation and relief variability. The standard deviations in 45 zones are significantly less though the elevation of the slope and relief variability in this zone is the greatest. This phenomenon could be explained by the fact that the territory has got very few points and the obtained results are not homologous.



**Fig 9.** Standard deviations of DTM built by different semivariogram models

**Table 3.** Standard deviations of DEM built by different methods in separate areas

Nr.	The DTM was created with ordinary kriging method using 9 neighbouring points								
	$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{spherical}}$	$H_{\text{stereo-}}^{\text{tetraspherical}}$	$H_{\text{stereo-}}^{\text{pentaspherical}}$	$H_{\text{stereo-}}^{\text{exponential}}$	$H_{\text{stereo-}}^{\text{Gaussian}}$	$H_{\text{stereo-}}^{\text{R-quadratic}}$	$H_{\text{stereo-}}^{\text{k-bessel}}$	$H_{\text{stereo-}}^{\text{stable}}$
	Standard deviation $\sigma$ (m)								
11	0,06	0,05	0,05	0,05	0,05	0,07	0,06	0,05	0,05
12	0,06	0,06	0,06	0,06	0,06	0,84	0,59	0,06	0,05
13	0,10	0,09	0,09	0,09	0,09	0,77	0,61	0,14	0,11
14	0,15	0,12	0,12	0,12	0,12	2,29	1,26	0,15	0,12
15	0,26	0,19	0,19	0,19	0,19	2,11	1,50	0,19	0,18
21	0,07	0,08	0,08	0,08	0,08	0,12	0,08	0,10	0,09
22	0,05	0,05	0,05	0,05	0,05	0,17	0,13	0,07	0,06
23	0,20	0,18	0,18	0,18	0,18	0,55	0,48	0,22	0,20
24	0,19	0,18	0,18	0,18	0,18	1,61	1,27	0,21	0,18
25	0,22	0,23	0,23	0,23	0,23	1,66	1,37	0,27	0,25
33	0,18	0,17	0,17	0,17	0,17	0,45	0,30	0,20	0,18
34	0,17	0,17	0,17	0,17	0,17	0,34	0,29	0,19	0,17
35	0,17	0,19	0,19	0,19	0,19	0,41	0,30	0,20	0,19
43	0,60	0,59	0,59	0,59	0,59	2,41	1,37	0,67	0,64
44	0,98	1,05	1,05	1,05	1,05	1,81	1,38	1,22	1,15
45	0,27	0,37	0,37	0,37	0,38	3,74	2,98	0,46	0,43

After the data analysis it has been determined that those standard deviations depend on the elevation roughness. Because the roughness parameter reflects the slope and variability of the elevation (Fig 9), it is possible to conclude that the accuracy of the compiled model declines when the slope elevation or roughness increases. Due to the fact that initial data accuracy within the whole territory is equal and it does not depend on the elevation characteristics, but the accuracy of the compiled model differs accordingly in various elevation zones. It is possible to state that, in modelling all the territory at once, it is not possible to select the universal parameters of modelling. In order to achieve the model of a higher accuracy, an experiment was carried out, which aimed to compile a separate model of the elevation meant for a particular elevation roughness zone. Zone 44 has been chosen because the accuracy of the relief model was the least, namely  $\sigma = 0,98 \div 1,81$  m (Table 4). In order to compile the digital elevation model for that zone, 437 points of measurements, comprising the selected zone and located at the distance of 24 m round it (three times smaller distance between the points  $3 \times 8$ ) were used. It was performed in order to avoid a decrease of the model accuracy in the marginal areas because of the reduced number of points to be used. There are several areas in the investigated territory (close to zone 44). These areas have been modelled in such a way that the effort was made to compile a common elevation model for it. The inspection of this model was performed by using the points of altitudes for modelling, namely such ones that have never been applied yet, but they were measured by means of stereophotogrametric method and found within the zone boundaries. From the TIN there has been compiled and later applied in the experiment the grid data

net which has not been used so far for investigating the accuracy of the relief model of this particular zone because due to the complicated elevation the accuracy of the control model within this territory was less.

**Table 4.** Standard deviations of DEM built by different methods in area 44

Standard deviation $\sigma$ (m)		$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$ 44 zone	$H_{\text{stereo-}}^{\text{circular}}$ 44 zone	$H_{\text{stereo-}}^{\text{circular}}$ 44 zone
		$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$
Ordinary		0,64	0,66	0,68	0,68
Simple		0,64	0,63	0,65	0,66
Universal		0,64	0,66	0,69	0,68
Index method avoided due to rough deviations (>5 m)					
Relativity method avoided due to rough deviations (>5 m)					
Standard deviation $\sigma$ (m)		$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$ 44 zone	$H_{\text{stereo-}}^{\text{circular}}$ 44 zone	$H_{\text{stereo-}}^{\text{circular}}$ 44 zone
		$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$	$H_{\text{stereo-}}^{\text{circular}}$
Regul. spline	$p=0,1$	0,64	0,68	0,69	0,71
Tension spline		0,64	0,56	0,56	0,58
Invert distance weight interpolation	$p=2$	0,64	0,99	0,99	0,99
	$p=3$	0,64	0,73	0,73	0,73
	$p=4$	0,64	0,63	0,63	0,63
	$p=5$	0,64	0,60	0,60	0,60
	$p=6$	0,64	0,61	0,61	0,61

\* Point altitude value obtained by the method indicated on the given line

The investigation has been carried out by using the data in zone 44.

Then the elevation model (compiled by means of ordinary kriging technique applying the circular semivariogram with 9 neighbouring points) for the whole territory was compared with the elevation models compiled using the points from zone 44 (Table 4). The results showed that the elevation model for the whole territory did not weaken the accuracy of the models compiled for zone 44. First of all it is possible to conclude that modelling only one zone is not efficient. After having investigated the elevation in zone 44 the conclusion was derived that a separate elevation model should be compiled for each area of the zone. In order to justify the speculation an additional test was made. Two models of elevation for different areas from zone 44 have been compiled. The accuracy test of these areas was made as well. The evaluation of the accuracy of the elevation models for this area by means of stereophotogrammetrically measured points was performed. The obtained standard deviation semivariogram was compared with the semivariogram of the standard deviation for the elevation model of the whole area under this territory. The results showed that the elevation models compiled for the whole territory as well as separate areas are almost the same as concerns their accuracy. In order to achieve a more accuracy in certain areas it is necessary to take into consideration the regularities of the surface changes within these areas. This becomes possible due to the usage of anisotropic parameter for compiling elevation models of each area, then the received accuracy for the elevation model must close to the accuracy of the initial data. Within the first area where the elevation structure is simpler, the value of the standard deviation was reduced by 5 cm (Table 5). In the second area, where due to the complicated structure of the elevation, the standard deviation was the largest within the whole territory being modelled ( $\sigma = 0,85$  m) by means of the anisotropic parameter. Undoubtedly, it has

become possible to specify the relief model more than twice ( $\sigma = 0,34$  m). The achieved result has proved the efficiency of the suggested method which was targeted for splitting the territory into zones. In order to apply this method more widely for practical purposes, it is necessary to compile the whole system, to have criteria evaluation, enabling us to select, in accordance with the peculiarities of the surface, the most suitable modelling method and the most optimal parameters.

**Table 5.** Standard deviations of DEM in different territory of area 44

Investigated area	Ordinary kriging type of semivariogram, using 9 neighbouring points	Standard deviations $\sigma$ (m)
		Without anisotropic / with anisotropic parameters
I	circular *	0,33 / 0,33
	circular	0,34 / 0,29
	spherical	0,34 / 0,29
II	circular*	0,90 / 0,89
	circular	0,85 / 0,34
	spherical	0,85 / 0,34

\* In order to compare the accuracy the relief model has been compiled for the whole territory

To find out if a more precise accuracy might be achieved by different surface modelling methods for elevation models into other zones than in cases of modelling all the territory by the same methods was an experiment carried out to test the accuracy of the compiled elevation model for each separate zone. The calculated standard deviations were compared to the elevation models, that have been worked out by different methods of surface modelling prepared for the whole territory at once (Table 6).

**Table 6.** Standard deviations of DEM in different areas

Method \ Zone No	Number of points in the zone	Kriging	Cokriging	Spline	Invert distance weight	Local polynomial
		$\sigma$ (m)				
11	9	0,16	0,25	0,17	0,21	0,18
12	91	0,14	0,18	0,26	0,17	0,15
13	267	0,26	0,24	0,37	0,30	0,37
14	164	0,44	0,39	0,77	0,47	0,34
15	10	0,19	0,28	0,29	0,25	0,27
21	13	0,14	0,20	0,13	0,32	0,16
22	25	0,22	0,19	0,24	0,38	0,18
23	440	0,53	0,52	0,78	0,65	0,44
24	895	0,43	0,41	0,60	0,64	0,47
25	461	0,45	0,56	0,58	0,73	0,63
33	29	0,60	0,83	0,67	1,13	0,53
34	38	0,64	0,52	0,64	0,79	0,49
35	26	0,43	0,59	0,94	0,59	0,74
43*	12	3,17	1,65	6,10	4,41	1,38
44	63	1,32	1,72	1,02	2,34	1,30
45	53	1,15	0,96	1,35	1,88	0,99

\* Because of the rough errors the zone is not presented in the diagram

The test results have shown that while compiling the elevation model for only one zone, which consists of several areas disconnected in between, the received accuracy was less, than in case of modelling all the territory at once (Fig 10). To achieve the maximum accuracy in modelling the whole territory at a time, it is necessary to compile the model by different methods used for the territory elevation, to split the territory into zones according to the type of the elevation and to evaluate in each zone the accuracy of elevation models. The fragments of these models in which the highest accuracy has been obtained, are to be connected in between and the elevation model should receive the accuracy which is higher than that of the elevation models compiled by means of a single technique of relief modelling.

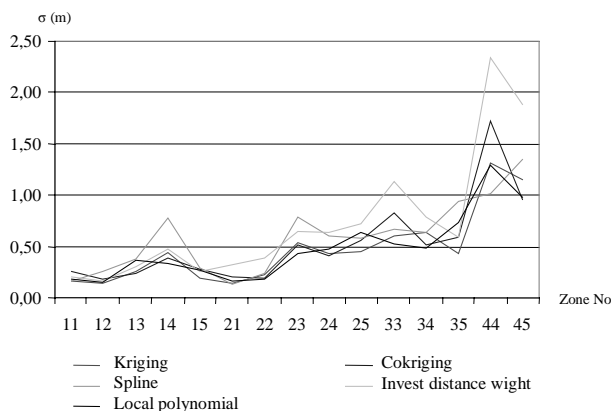


Fig 10. Diagram of standard deviations of DEM in different areas

## 7. Conclusions

1. The accuracy test has been carried out by splitting the elevation model into separate zones according to the elevation roughness. By applying the above-mentioned method of elevation zoning, several characteristics at a time have been evaluated. Compiling elevation models for each zone did not result in a visible improvement of the accuracy, because, when compiling DEM common for the whole zone and consisting of some separate areas, it was difficult or even impossible to find the elevation change regularities.

2. The test has disclosed that in order to receive a greater accuracy of the elevation model for the separate DEM areas which make the same zone, it is necessary to compile separate models by means of anisotropic parameter. This parameter allows to evaluate in each separate area the regularities of the elevation and to achieve a more precise accuracy. Within the area of complicated elevation, in zone 44, after the application of

the mentioned-above method, the accuracy had a tendency to be improved from  $\sigma = 0,85$  m till  $\sigma = 0,34$  m, namely the standard deviation of DEM has been reduced by more than twice.

3. To implement the advantages of splitting the elevation into zones and to apply it within a large territory, it is necessary to compile the system of criteria evaluation which would allow each area to be modelled so as to select the most optimal method of surface modelling taking into account the relief parameters as well as the most suitable parameters.

## References

1. Travis, M. R.; Elsner, G. H.; Iverson, W. D.; Johnson, C. G. VIEWIT: Computation of seen areas, slope and aspect for land-use planning. U.S. Dept of Agriculture Forest Service General Technical Report PSW 11/1975. Pacific Southwest Forest and Range Experimental Station, Berkeley, California, 1975.
2. Skidmore, A. K. A comparison of techniques for calculating gradient and aspect from a gridded digital elevation model. *International Journal of Geographical Information Systems*, No 3 (4), 1989, p. 323–334.
3. Chang, K.; Tsai, B. The effect of DEM resolution on slope and aspect mapping. *Cartography and Geographic Information Systems*, No 18 (1), 1991, p. 69–77.
4. Zevenbergen, L. W.; Thorne, C. R. Quantitative analysis of land surface topography. *Earth Surface Processes and Landforms*, No 12, 1987, p. 47–56.
5. Jones, K. A comparison of two approaches to ranking algorithms used to compute hill slopes. In: Proc. of Fifth National Conference of GIS Research UK (GISRUK 97), Leeds, UK, 1997, p. 79–82.
6. Burrough, P. A.; McDonnell, R. A. Principles of Geographical Information Systems. Oxford University Press, New York, 1998. 333 p.
7. Evans, I. S. An integrated system of terrain analysis and slope mapping. *Zeitschrift für Geomorphologie*, Suppl-Bd 36, 1980, p. 274–295.
8. Turner, M. G. Landscape Ecology – The Effect of Pattern on Process. *Rev. Ecol. Syst.*, No 20, 1989, p. 171–197.
9. Wood, J. The geomorphological characterisation of Digital Elevation Models. PhD thesis. University of Leicester, UK, 1996. 213 p.

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