SELECTION OF APPROPRIATE INTERPOLATION METHODS FOR CREATION DEMs OF VARIOUS TYPES OF RELIEF BY COMPLEX APPROACH TO ASSESSMENT OF DEMs

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Abstract

The main aim of a research presented in this paper is selection of the most suitable interpolation method and its parameter settings for creation of digital elevation models (DEMs) of base types of relief in the Czech Republic (flatlands, hilly areas, uplands and highlands) from the DMÚ 25 database. The suitability of interpolation methods and their settings was explored using the assessment of metric accuracy of resulting DEMs, i.e. difference between estimated data and reference data. The non-spatial indicators (root mean square error – RMSE, total absolute error – AE and hammock index – H) were used to assess the quality of DEM in terms of metric accuracy.

However, complex approach to the assessment of DEMs must contain also evaluation of spatial distribution of errors. For these reason, the spatial cluster analysis LISA has been used. Its sense consists in a possibility to identify the spatial clusters of statistically significant high error values. The next aim of the research was thus using of spatial assessment of metric accuracy of DEMs to verify the results of non-spatial assessment and also to find the differences in spatial behaviour (distribution) of errors in DEMs rated using weighted order as high-quality and low-quality DEMs.

It is evident from the results that if input elevation data are dense enough, non-spatial characteristics of metric accuracy can be viewed as decisive for assessing quality of DEMs and differentiation the high-quality DEMs form low-quality DEMs. The results from local cluster analysis LISA can be than used for verification of non-spatial assessment. However, when using spatial analysis LISA for assessment of DEM quality it is necessary to consider also selected non-spatial indicators in order to avoid misinterpretation.

Keywords: digital elevation models, errors, non-spatial assessment, spatial assessment

1. INTRODUCTION

A relief is a key factor in many environmental processes. It has a significant impact on climate variables like temperature and precipitation. It also influences a degree and spatial extent of weathering, erosion or accumulation on the Earth's surface etc. (Moore et al. 1991, Wilson and Gallangt 2000, Arrell 2005). Within a GIS environment, digital elevation models represent the real image of a relief. The most quality DEM must be used to get best quality of the results from environmental analysis and such DEM it is possible to get only using of suitable interpolation method and setting of its parameters. The main theme of this paper is selection of suitable interpolation methods for creation the DEMs of different types of relief.

The suitability of selected interpolation method or the quality of resulting DEM is commonly described in terms of a metric accuracy of altitude values i.e. a difference between modelled values and real (referential) values. As Arrell (2007) puts it, the applications using DEMs predominantly do not require an overall metric accuracy of altitude, but they rather need accurate illustration of a surface form. In practice, however, there are no limits or definitions which enable to differentiate between DEMs of high or low shape accuracy. A shape fidelity assessment is mostly based only on a visualization of a DEM and its derived morphometric variables. From this reason, the assessment of DEMs will be further focused solely on the assessment of metric accuracy, which can be quantified more easily.

Common methods used for assessment of a metric accuracy of DEMs (like RMSE) are only global non-spatial measures. Their unquestionable advantages are their easy calculation and interpretation. However, as to environmental applications, the knowledge of spatial error variability is very important. Many authors (Desmet 1997, Erdogan 2009, Fischer 1998, Gao 1997, Hofierka et al. 2007, Hunter and Goodchild 1997, Svobodová 2008, Kyriakidis et al. 1999, Wise 2000) claim that the extent of errors in a DMR depends on a character of a terrain and is spatially variable. In the paper, the process of selection the most suitable methods for creation DEMs of various types of a relief is state and also the process of assessment of spatial distribution of errors.

2. SETUP OF MODEL DEMs

In the research were used 21 model areas (4×4 km large) which with regard to their relative roughness height represent four major types of a relief in the Czech Republic i.e. flatlands, hilly areas, uplands and highlands. Three model areas were selected for each type (respectively subtype) of a relief. The outline of selected areas can be seen in table 1.

Table 1. An outline of selected model areas

Type of relief	Relative roughness height [m]	Model areas	
		Czech massif	West Carpathians
flatland	0-30	Sadska flatland	Zerotinska flatland Cervenecka flatland
flat hilly area	30-75	Nechanicka table Ostromerska table	Orlovska table
rugged hilly area	75-150	Podjestedska hilly area Radomyslska hilly area	Vlcnovska hilly area
flat upland	150-220	Studenska upland	Divacka upland Uhricka upland
rugged upland	225-300	Bozkovska upland Kozlovska upland	Hostalkovska upland
flat highland	300-450	Ustecke highland	Rusavska highland (RH) Rusavska highland (RU)
rugged highland	450-600	Hornoopavska highland Cernohorska saddlebow Boubinsky ridge	---

A layer of contours from the DMÚ 25 database has been applied as input data in a creation of DEMs in ArcGIS Desktop v. 9.x environment. Selected interpolation methods (see below) require points as an input data. Therefore, the contours with equidistance 5 m had to be translated into points. Resulting file have been divided into two parts, points used in the process of interpolation (85 %) and referential point for calculation of root mean square error and absolute error (15 %). Taking into account the use of geostatic method kriging as one of the main interpolation methods for the creation of DEMs, dependency (autocorrelation), normality of division, and stationarity of input data have been verified.

To create DEMs, four interpolation methods have been selected: inverse distance weighting (IDW), regularized spline (RS), spline with tension (ST), and ordinary kriging (KG). These methods (or their modifications) can be found not only in ArcGIS Desktop v. 9.x software, but also in other easily accessible commercial (e.g. Idrisi, Surfer) and non-commercial software programs (e.g. GRASS GIS, QGIS). The main idea of choosing values of different parameters was to try to cover their basic (in reality applicable) spectrum. For all used methods, two most important parameters were set. Parameter *n*, expressing number of input points from the closest surroundings, was common for all the methods. Parameter *p* (power) was then applied in the inverse distance weighting method, weight parameter in spline methods, and theoretical semivariogram function in kriging (figure. 1). The values of setting of different parameters are outlined in table 2. Kriging method includes also other parameters like range, sill and nugget effect witch are used to modify the curve of theoretical semivariogram. Values of these parameters are counted automatically in ArcGIS Desktop v. 9.x environment from the empirical semivariogram. When kriging method has been used they stayed default. The lag size has been set to 150 m and number of lags to 12. For all used interpolation methods the pixel size has been set to 10 m.

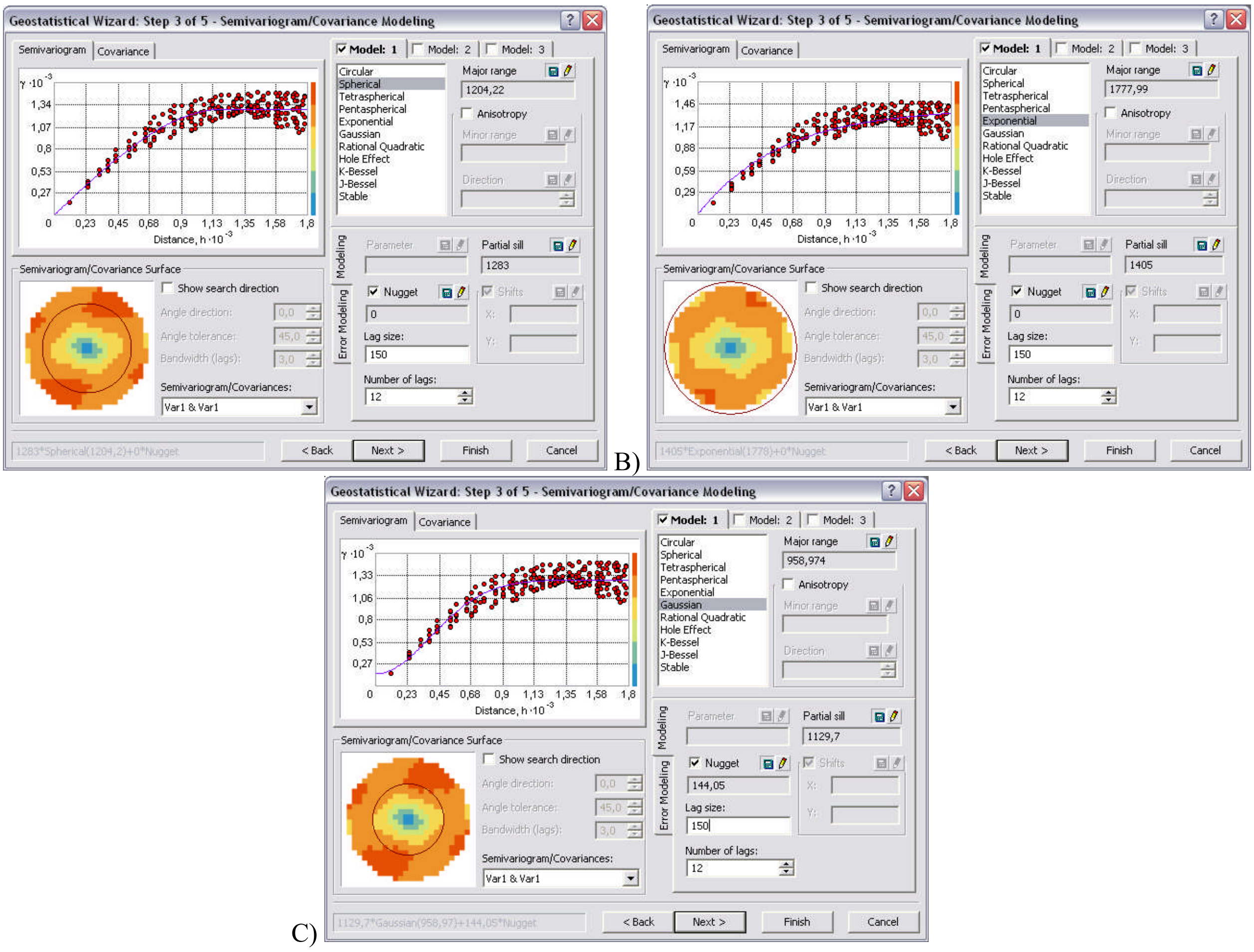

Fig. 1. Empirical semivariogram created in ArcGIS Desktop v. 9.x environment fitted by the curve of Spherical (A), Exponential (B) or Gaussian (C) theoretical semivariogram (the example of the Divacka upland)

Table 2. An outline of setting of parameters for applied interpolation methods

interpolation method: parameter	value		
IDW: power	0,5	2,0	4,0
SR: weight	0,0	0,3	0,6
ST: weight	0,1	5,0	10,0
KG: theoretical semivariogram	spherical	exponential	gaussian

common parameter	value	
number of input points	10	20

The presented values of parameter power, weight parameter and theoretical semivariogram were always combined with two values of input point numbers. This setting was applied consistently in all the tested areas. All in all, 24 DEMs for each area have been created, which means 504 DEMs in total (for all 21 areas). TIN supplemented by ridge lines, valley lines and peaks were used as a reference DMR for assessment of spatial distribution of errors. It was later transformed into a grid.

3. NON-SPATIAL AND SPATIAL METHODS APPLIED IN ASSESSMENT OF DEM ACCURACY

Digital models of relief have been evaluated by using both the global non-spatial and local spatial methods. To draw a comparison between individual DEMs with regard to non-spatial characteristics, a weighted order based on a calculation of root mean square error, total absolute error and hammock index have been used. The root mean square error (RMSE) expresses an extent to which an interpolated value differs from a real value. A higher value corresponds to a greater difference between two datasets (Wood 1996). The total absolute error (AE) shows a real sum of all deviations from reference data in both positive and negative directions (Svobodová et al. 2009). The hammock index (H) examines the regularity of location of interpolated values between the known values, as well as excessive incidence of pixels whose altitude tally with original data values (Wood 1996). In compliance with each of the above mentioned characteristics, the order of DEMs was created. Subsequently, it was multiplied by a selected weight of individual characteristics: RMSE – 2/5, AE – 2/5, H – 1/5. The values of weights were chosen experimentally based on the author's knowledge of predicative values of individual characteristics. Values of weights can be modified by using different characteristics. The total weighted order of DEMs was determined by summing the individual weighted orders (see table 3). It allows for arranging DEMs qualitatively and distinguishing between DEMs of higher and lower quality.

Table 3. Calculation of weighted order - the example of the Divacka upland

Interpolation method	Name of DEM	RMSE [m]	Order of RMSE	AE [m]	Order of AE	H	Order of H	Weighted order	Total order
kriging	kg_sf_20	0,96	1	1288,14	1	0,25	10	2,8	1
kriging	kg_ex_20	0,97	2	1290,54	2	0,25	8	3,2	2
kriging	kg_sf_10	0,97	3	1291,04	3	0,25	7	3,8	3
…	…	…	…	…	…	…	…	…	…
IDW	iw_2_20	2,83	20	3932,76	20	0,50	21	20,2	22
kriging	kg_ga_20	4,08	24	5891,65	24	0,25	6	20,4	23
IDW	iw_0-5_10	2,91	21	4072,29	21	0,26	18	20,4	24

To assess DEMs spatially, a local cluster analysis LISA which enables to observe a spatial distribution of errors was applied. In contrast to a mere representation of size of errors in form of an accuracy surface (gained by a mere difference between estimated data and reference data), which does not allow for exact determination of boundaries between high and low error values, a local cluster analysis determines statistically significant high and low error values (or outlying values) accurately enough (figure. 2). The accurate determination can be further used for a research into relationships between occurrence of high error values (or outlying values) in DEMs and values of morphometric parameters derived from these DEMs. For the assessment of DEMs, two DEMs of each area (the highest-quality one and the lowest-quality one selected according to a weighted order) were taken. The two very different DEMs were used in attempt to explore a concordance or difference of spatial location of errors in both high-quality and low-quality DEMs.

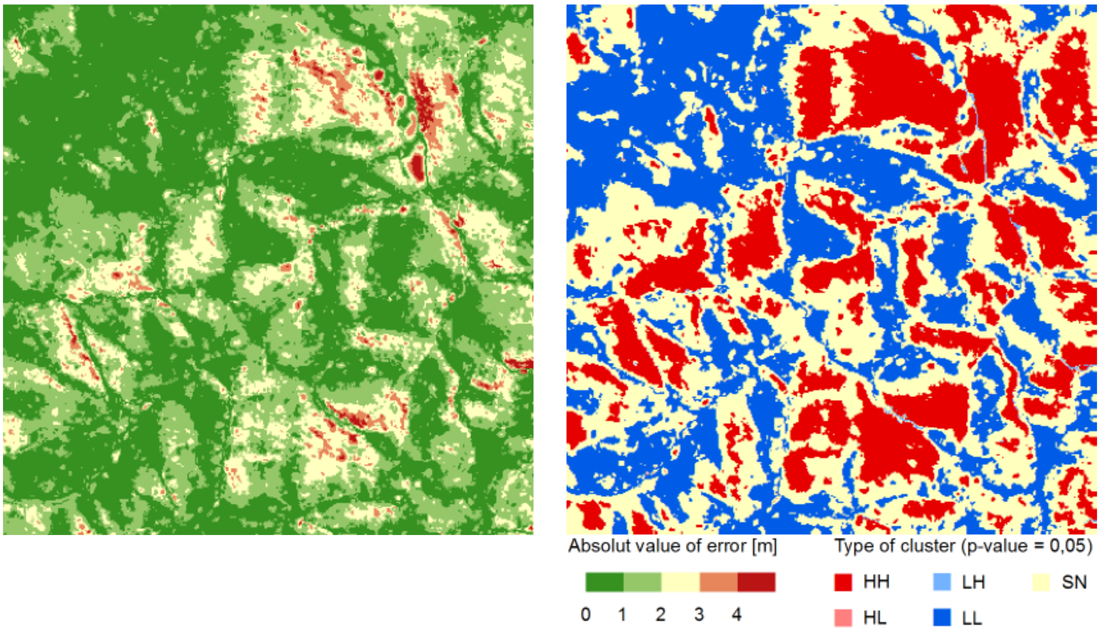

Fig. 2. Comparison of common accuracy surface with absolute error values (left) and localization of statistically significant clusters of high (HH) or low (LL) values gained by LISA (right) - the example of the Rusavská highland

4. COMPLEX ASSESSMENT OF DEM ACCURACY OF MODEL AREAS

Suitability of Interpolation Methods for Creation of High-quality DEMs according to Non-Spatial Indicators of Metric Accuracy

The weighted order (see chapter 3) was used as a basis for the assessment of quality of DEMs according to non-spatial characteristics. Table 4 shows the interpolation methods with concrete setting of their parameters which were evaluated as the best ones for gaining high-quality DEMs of individual relief types. The selection was carried out with regard to their occurrence in the first three places of a weighted order within a given type of a relief. The main condition of the selection was that the same setting of a decisive parameter was applied at least twice in one interpolation method. A parameter of weight was decisive in case of spline methods. As to inverse distance method, a parameter power was taken into account. As for ordinary kriging method, a parameter representing an applied model of theoretical semivariogram was considered. A common parameter of a number of input points (n) was not regarded significant when testing values of ten and twenty points were in use. Concrete vales of the decisive parameters must be viewed as approximate since they were chosen experimentally and thus do not cover the extent of the decisive parameter values elaborately enough. Their significance lays in showing a certain area of values (area of higher and lower values from an interval of real values) from which it is advisable to choose a concrete setting of interpolation method for a given type of a relief.

Table 4 shows that ordinary kriging is the most suitable interpolation method for rough terrains like highlands, uplands (both flat and rugged) on condition that the spherical or exponential model of theoretical semivariogram are used. The suitability of these two types of mathematical functions for modelling a surface by ordinary kriging was expected and later was proved to be successful. The above mentioned theoretical models intensify the influence of the closest points to the place of estimated value and at the same time, a calculation does not cover the values of more distant input points. Thus final surfaces are not too flattened which is by rough surfaces undesirable.

In the case of highlands and uplands, interpolation method spline with tension with low value of weight parameter (about 0,1) can be used as well. The low value of weight parameter produces a high tension of a surface. Consequently, interpolated values move more within the range of input data and they do not tend to create local extremes. Output values of RMSE and AE are thus low for these DEMs.

As for flatter surfaces like hilly areas and flatlands the choice of a suitable interpolation method differs significantly. Especially for modelling of flat hilly areas and flatlands, regularized spline with weight values around 0,3 (or 0,6) has been considered the most appropriate interpolation method. Preference of weight values around 0,3 and than 0,6 signifies that these types of relief require the use of a method, which creates flattened surfaces. Flattening, however, cannot be too great even in the case of lowlands.

Speaking about flatlands, inverse distance weighting method with a high power parameter value appears to be one of the most convenient interpolation methods. It emphasises an influence of the closest points, which is useful mainly when input data are not dense enough. Due to a higher power parameter value, results are not distorted even if more distant points are included. Despite the above mentioned advantage, the use of this method is very questionable since the DEMs created by this interpolation method have been listed at the end of the weighted order covering all types of reliefs (including flatlands).

Selection of interpolation methods for rough hilly areas must be considered individually since this type of relief can be regarded a transition type between rough and flat types of relief (see table 4). Similarly to highlands and uplands, ordinary kriging (using exponential model of theoretical semivariogram) as well as spline with tension with a low weight value were successfully used. On the other hand, regularized spline that is used rather for flatter types of reliefs has been found to be suitable for this type of relief as well. In contrast to flat hilly areas and flatlands, the weight value is zero and therefore there is only a slight flattening.

Table 4. The most suitable methods for interpolation of DEMs of a given type of relief (listed according to frequency of occurrence in the first three places of a weighted order of a given type of relief, the choice was conditioned by the same setting of a decisive parameter at least twice in one interpolation method)

type of relief	interpolation method	value of parameter
rugged highland	KG	sf
	KG	ex
	ST	0,1
flat highland	KG	sf
	ST	0,1
	-	-
rugged upland	KG	ex
	KG	sf
	ST	0,1
flat upland	KG	sf
	KG	ex
	ST	0,1
rugged hilly area	KG	ex
	SR	0
	ST	0,1
flat hilly area	SR	0,3
	SR	0,6
	-	-
flatland	SR	0,3
	IW	4
	SR	0,6

Assessment of Spatial distribution of Errors in DEMs

The aim of spatial assessment of metric accuracy of DEMs was to verify the results of non-spatial assessment and also to find the differences in spatial behaviour (distribution) of errors in DEMs rated using weighted order as high-quality and low-quality DEMs. To assess the spatial metric accuracy of DEMs, the local cluster analysis LISA has been used. It came out during the evaluation of its results that when interpreting results it is desirable to focus not only on a spatial visualization of clusters of statistically significant high or low error values, but also on quantitative (or sometimes global) values of indicators like a range of values in a set of errors, a mean error value or maximal value in the clusters of high error values. On the basis of assessment of spatial extend of statistically significant clusters of errors together with using of above-mentioned quantitative indicators the rules for assessment of quality of DEM (at one area) in the terms of spatial accuracy were made and they are state in table 5.

Table 5. Evaluation of quality of DEMs according to a spatial assessment of LISA results supplemented with quantitative non-spatial indicators

Area of clusters at comparison of two DEMs by visual evaluation	Range of error values, mean value of errors, max. value in HH* clusters	Quality of DEM
bigger	higher	less-quality
	lower	more-quality
smaller	higher	less-quality
	lower	more-quality
comparable	higher	less-quality
	lower	more-quality
	comparable	comparable

*cluster of high values (high error values)

It is possible to demonstrate a need to supplement spatial assessment of quality of DEMs with quantitative non-spatial indicators by the results of local cluster analysis of highland relief (Rusavska highland RH). The results of LISA are in case of the high-quality DEM compact and aerially more extensive clusters of high or low errors. As for the low-quality DEM, the clusters are aerially less extensive and their types vary in areas more often (see figure 3). Interpretation by visual evaluation only could lead us to the conclusion that there are more statistically significant errors in the DEM which is considered to be high-quality one than in the lower-quality DEM (figure 4). Nonetheless, this way of differentiating between high-quality and low-quality DEM is not correct.

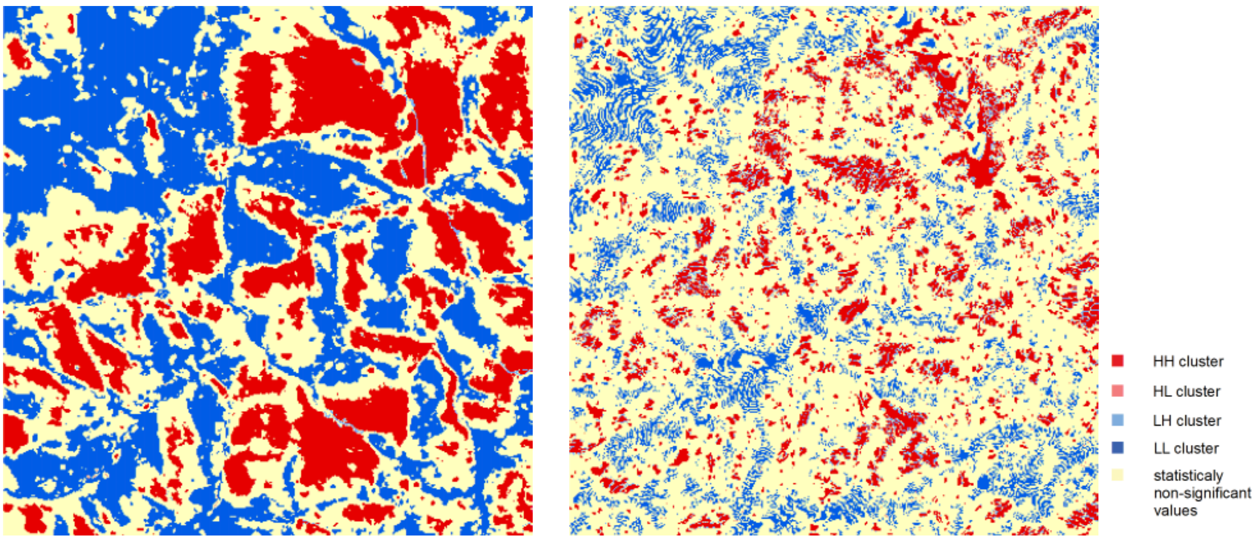

Fig. 3. Typical structure of clusters in results of LISA derived from the high-quality (left) and low-quality (right) DEMs of highlands (the example of the Rusavska highland)

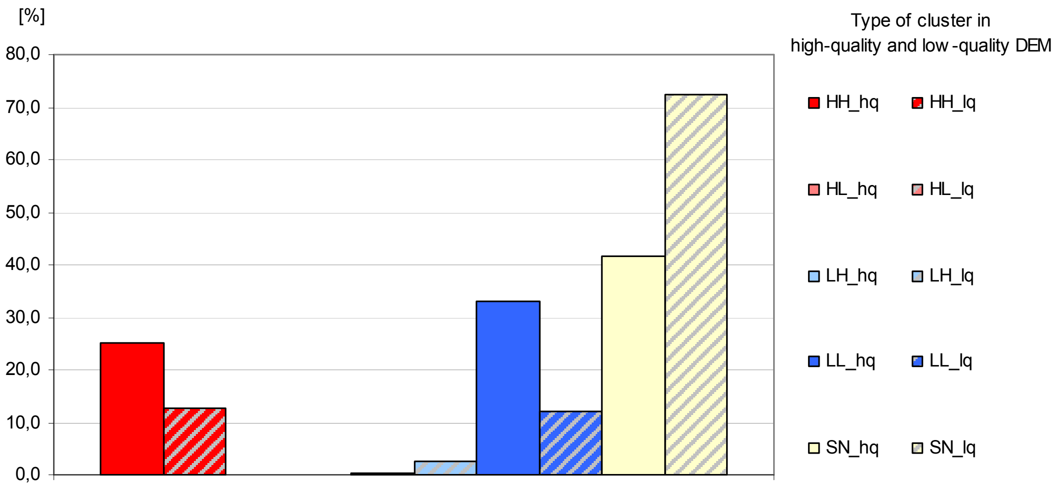

Fig. 4. Percentage rate of features that belong to the individual types of clusters with the use of high-quality and low-quality DEMs (the example of the Rusavska highland)

When considering the various extent of error values, different mean error values in files entering the local cluster analysis and different size of maximal value in the clusters of high error values (table 6), however, we find out that clusters of high errors in high-quality DEM which at first sight appear to be more extensive, in reality cover much lower values of errors than aerially smaller clusters of high errors derived from low-quality DEM. Moreover, taking into account the structure of clusters, it can be supposed that more compact shapes allow for a smoother change of error values, which can preserve shape fidelity of an actual relief. On the contrary, a frequent change of little clusters of low and high errors can bring about occurrence of local minims and maxims in DEM resulting in prevention of fluent outflow.

Table 6. Range and mean value of absolute error values gained by subtraction of high-quality (HQ) or low-quality (LQ) DEM from referential DMR and maximal value of error in clusters of statistically significant high error values (max. HH) - the example of the Rusavska highland

range [m]		mean [m]		max. HH [m]	
HQ	**LQ**	**HQ**	**LQ**	**HQ**	**LQ**
6,53	17,42	1,22	1,53	6,53	17,42

5. CONCLUSION

If input elevation data are dense enough, non-spatial characteristics can be viewed as decisive for assessing quality of DEMs. As for highlands, uplands as well as hilly areas, it is possible to tell apart high-quality DEMs from low-quality ones unequivocally by using a weighted order based on a calculation of RMSE, AE and H. As to flatlands, it is nearly impossible to create a high-quality DEM because of the lack of data (especially speaking about the use of contours). Therefore, the results of weighted order in flatlands seem to be considerably distorted.

For rough terrains like highlands and uplands ordinary kriging (with use spherical or exponential model of theoretical semivariogram) or spline with tension (with low value of weight parameter - about 0,1) are the most suitable interpolation methods according to non-spatial assessment of metric accuracy of DEMs. The default setting of parameters range, sill and nugget of kriging method had not negative influence on resulting interpolation. As for flatter surfaces like hilly areas and flatlands the regularized spline method (with weight values around 0,3 or 0,6) has been considered as the most appropriate interpolation method for creation of high-quality DEM. Selection of interpolation methods for rough hilly areas must be considered individually since this type of relief can be regarded a transition type between rough and flat types of relief. Similarly to highlands and uplands, ordinary kriging (using exponential model of theoretical semivariogram) as well as spline with tension (with a low weight value) is possible to use. On the other hand, regularized spline that is used rather for flatter types of relief has been found to be suitable for this type of relief as well. The selection of interpolation method is thus dependent on a segmentation of the model area.

Importance of local cluster analysis LISA lies especially in spatial determination of occurrence of statistically significant clusters of high error values, i.e. determination of places where the results from environmental analysis have to be more critically evaluated. When using spatial analysis LISA for assessment of DEM quality it is necessary to consider also selected non-spatial indicators in order to avoid misinterpretation. For this reason the base rules for assessment of metric accuracy of DEM using LISA were made. They are summarized in table 5.

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