THE QUALITY OF THE BASE DEM AS A KEY FACTOR IN MODELING OF SLOPE AND SOLAR INSOLATION

Jaroslav, BURIAN[1], Jana, SVOBODOVÁ[1], Vít, VOŽENÍLEK[1]

[1]Department of geoinformatics, Faculty of Science, Palacký University, Olomouc, tř. Svobody 26, 771 46, Olomouc, Czech Republic

j.svobodova@upol.cz, jaroslav.burian@upol.cz, vit.vozenilek@upol.cz

Abstract

The results of analysis of spatial conflicts are standard content of territorial planning documents for creating or modifying urban master plans. The paper presents the results of spatial modeling of selected functional spatial conflicts with the characteristics derived from the earth's surface (slope and insolation rate). These two characteristics can be, in terms of comfort and quality of life, considered as very important. The urban planners describe that higher slope affect bigger technical complexity of construction and subsequent maintenance of buildings and technical infrastructure. The insolation rate impacts especially the quality of the environment and has strong influence to the localization of the activities defined as the visual activity (according to standard "CSN 730580").

The main aim of this paper is not just finding the spatial conflicts in the model area. The aim is also to evaluate the differences between slope and insolation rate derived from digital terrain model (DEM) of different quality. The differences for concrete selected area are expressed by numerical quantification. Spatial descriptions (maps) show the qualitative changes of conflicts importance. The results of the analysis show that the quality of the base DEM affects the definition of areas with critical values of observed phenomena very strongly. For use as a content of territorial planning documents is creation of high quality DEM important point of urban planning processes.

Keywords: slope, insolation, spatial conflict, digital terrain model

INTRODUCTION

There most human activities which take place in space, i.e. in a particular area, are to a great extent dependent on the nature of the Earth's surface. The Earth's relief determines suitability of localization of these activities in a particular area or limits of utilization of an area for a given activity (Act No 183/2006 of the Collection of Laws on Urban Planning and Building Regulations, Hyvnar and col. 2007). If those limits and restrictions are not observed, conflicts of various gravity may arise (Dai et al. 2001, Voženílek 2002, Montz a Tobin 2008, Gallay 2010, Pechanec et al. 2011).

Problems of modelling spatial conflicts of functional utilization of an area bearing characteristics derived from the Earth's surface are generally dealt with by urban planning. Significant conflicts always occur when there is a clash of functional areas for housing, sports and recreational activities with other characteristics, specifically gradients of slopes and rate of their solar insolation. To derive these characteristics of the Earth's surface in the environment of geographic information systems (GIS) a digital elevation model (DEM) is used, which substitutes the real Earth's surface. (e.g. Krcho 1990, Tuček 1998, Li et al. 2005). To derive a continuous DEM from input data, (mostly discrete elvation points) it is possible to use various interpolation methods (Mitisová a Mitáš 1993, Longley et al. 2001, Fencík and Vajsáblová 2006), results of which can, however, be outputs of different quality (Desmet 1997, López 2000, Krcho 2001, Hofierka et al. 2007, Li a Heap 2008, Erdogan 2009, Svobodová and Tuček 2009). Therefore the primary objective of this article is an evaluation of influences of DEM quality (from the point of view of the chosen method of interpolation) on results of modelling of the aforementioned spatial conflicts within the frame of urban planning.

Model area for the elaboration of the demonstrations has been placed in Olomouc region (Municipality with extended power Olomouc).

ROLE OF EARTH'S SURFACE IN URBAN PLANNING

Shape and pattern of the Earth's surface can be described by its basic characteristics, the so-called morphometric variables. Wilson and Gallant (2000) have divided them into two basic groups. The first group consists of characteristics derived directly from DEM (of earth's surface) such as slope, aspect or curvature of relief, the second group represents characteristics describing natural processes taking place on the Earth's surface. However, while evaluating suitability of an area for utilization within the frame of urban planning, the most important aspects are gradient and aspect of slope.

Gradient of slope is a property of relief which, to a great extent, influences most human activities in any area. Flatlands and easy slopes were always sought-after and settled sooner than slopes with higher gradients. From the urbanistic point of view, the higher the gradient of slope the more technically demanding the construction and the subsequent maintenance of buildings and public utilities are. The most suitable building sites are flat or gently sloped (with a gradient up to 10%). More detailed limits are stated by Navrátilová and col. (2006) or by Růžička (2000). Consequences of ground shaping in steeper areas have to be dealt with already in the basic urbanistic concept which has to observe not only the aspects of construction and operating economy, balancing moving of earth, concept of local roads and engineering infrastructure but also a general influence it has on landscape (Navrátilová et al. 2006). Especially in protected localities, adjustments resulting in levelling terrain undulations in sloping areas can fundamentally change character of landscape and devastate its present values (Jablonská et 2010).

Gradient of slope together with its aspect implicate rate of solar insolation of relief (or angle of incidence of sunbeams) which, within the frame of urban planning, influences, above all, quality of living environment and localization of activities defined by the so-called visual activities. "It is necessary to preserve conditions of visual comfort during daylight irrespective of the amount of clouds (in indoor residential premises in compliance with their function)" (ČSN 730580-2). When designing housing, the values defined by the ČSN 730580 (Czech National Standard) are being observed; these include not only day lighting but also the values of max. hillshade angle of obstacles (i.e. by surrounding buildings) or terrain.

Suitable orientation towards cardinal points in connection with rate of solar insolation has, however, also a very practical effect. In recent years there has been a boom in passive or low energy house construction for which this factor is of vital importance. Most suitable locations for such constructions can be found on south-facing slopes where one can get from 10 to 30% more insolation than on a flatland. Yet a south-facing slope with unfavourable direction of prevailingly cold winds looses this advantage. Formally designed street lines which sometimes do not allow for a sufficient spacing of buildings also decrease the guarantee of a sufficient amount of insolation of dwelling rooms for the whole life duration of a building. This can increase heating requirements by tens of percents (H. L. C. 2011).

The general problems of situating buildings are dealt with in more detail e.g. by Jablonská et al. (2010) who analyses suitable orientation of buildings in relation not only to cardinal points but also to surrounding buildings and roads.

MODELLING OF SPATIAL CONFLICTS IN AN AREA

Elaboration of Background DEM and Derivation of Morphometric Variables

As mentioned above, the objective of this article is an evaluation of influences of DEM quality, from the point of view of the chosen method of interpolation, on results of modelling of spatial conflicts. At the beginning of the modelling process it was therefore necessary to obtain two DEMs of different quality which would be subjected to subsequent analyses and would allow us to monitor changes in the results (Fig. 1). When using identical input data for the DEMs which are being created, the one which achieves the best results when evaluated by non-spatial indicators of metric accuracy is designated as the high-quality DEM. The DEM which achieves the lowest score is then designated as the so-called low-quality DEM. Therefore the selection of the high-quality and the low-quality DEM is conditioned by the elaboration of a set of DEMs which enter the process of accuracy evaluation.

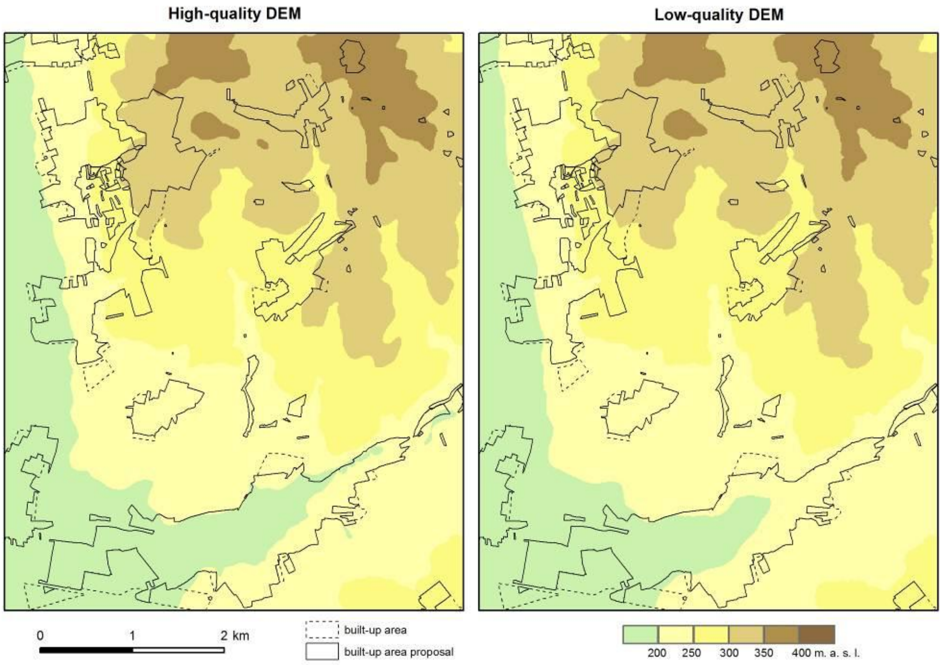

Fig. 1 Vertical situation of the small part of Olomouc region

A number of publications have already been devoted to the topic of evaluation of DEM accuracy (i.e. Desmet 1997, López 2000, Krcho 2001, Hofierka et al. 2007, Li a Heap 2008, Erdogan 2009, Jedlička 2009). The choice of the most suitable interpolation method and configuration of its variables for the specific types of reliefs were dealt with e.g. by Svobodová (2008), Svobodová et al. (2009) or by Svobodová and Tuček (2009). These publications imply that the method suitable for an elaboration of a digital elevation model (from the DLM 25 contours) of the type of relief defined as flat highland is the interpolation method of kriging employing for instance exponential or spherical models of theoretical semivariogram which stress the influence of the closest entry points values on the estimated values; it is also possible to use the tension spline method with a lower value of the weight variable (e.g. 0,1), which results in a high tension of the resulting surface. According to the aforementioned recommendations and a subsequent evaluation of the DEM's metric accuracy, the method of kriging using the exponential model of theoretical semivariogram and the variable n = 20 points has been employed to elaborate the high-quality DEM of the model area. The low-quality DEM of the given area has been created using the IDW method with the values of power = 2 and n = 2. The setup was also based on the results of the aforementioned publications. The contours from the DLM 25 data set with the equidistance of 5 m were used to create the digital elevation models. The size of pixel has been set to 10 m. Since the selected area has a sufficient density of input data the calculation of non-spatial indicators was sufficient to verify the accuracy of both the models (table 1).

Table 1. Values of non-spatial variables of metric accuracy of high- and low-quality DEM

DEM	Interpolating method (settings)	RMSE	AE	H
High-quality	kriging (exponential model)	1,51	1251,39	0,44
Low-quality	IDW (power = 2)	2,50	2343,50	0,45

Accuracy of the quality evaluation of the created DEMs was confirmed also by their spatial visualization using shaded relief (Fig. 2) or by the visualization of the derived morphometric variables – gradient and aspect of slopes (Fig. 3 and 4).

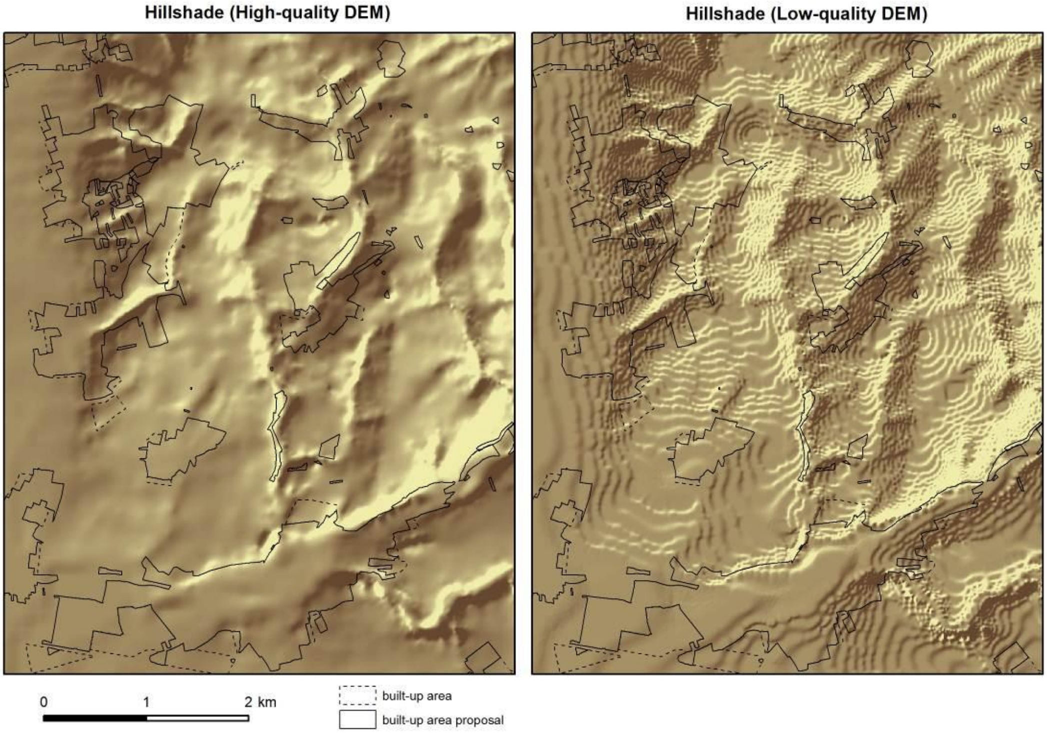

Fig. 2 Shaded relief derived from the HQ DEM and from the LQ DEM The surface of the HQ DEM is smooth whereas in the case of the LQ DEM small terraces occurred on the slopes.

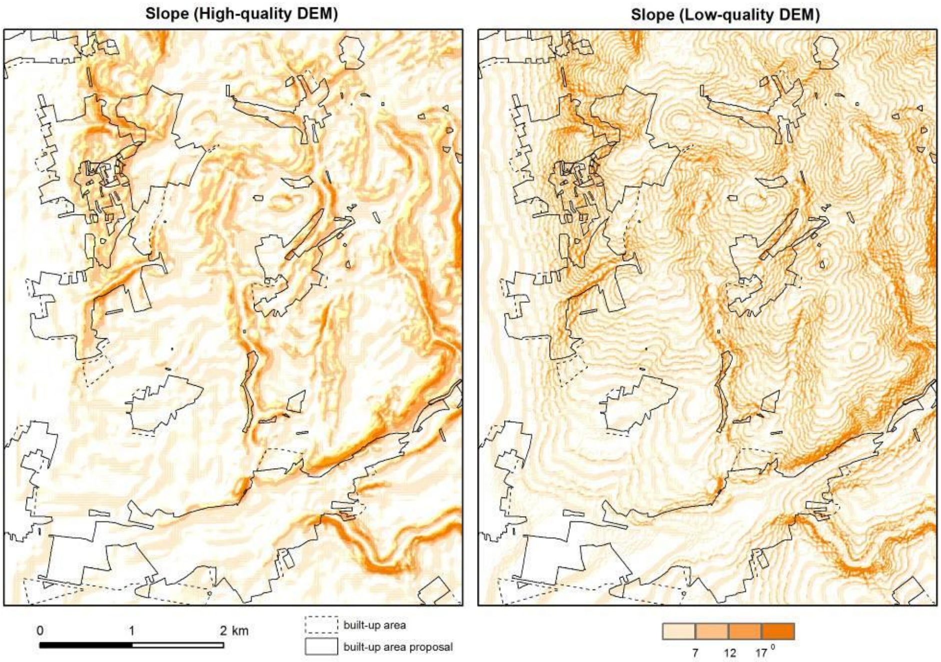

Fig. 3 Gradient of slope derived from the HQ DEM traces the seamless flow of the background DEM and the individual categories of gradient form compact areas. The behavior of the gradient of slope on the LQ DEM traces the existing terraces. The values of gradient of slopes are therefore underestimated in the flat parts of the terraces and overestimated in their slanting parts.

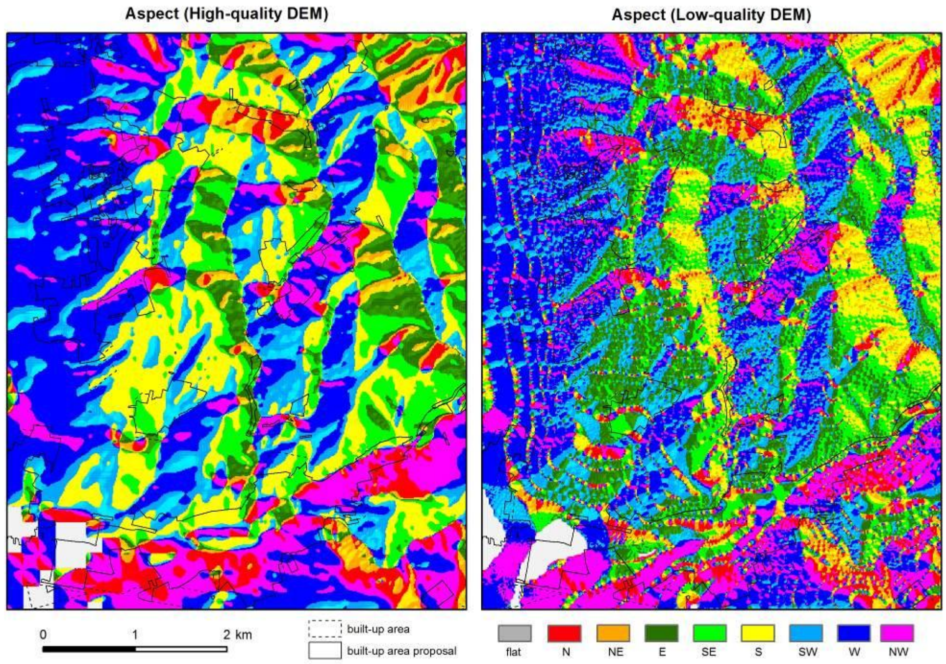

Fig. 4 Values of the aspect of slopes on the HQ DEM form compact areas. More frequent local changes of the aspects of slopes on the LQ DEM are caused by the concentric arrangement of values of altitude around the entry points; this is a result of interpolation using the IDW method, which causes greater planar curvature

When using both the shaded relief and the visualization of gradients and aspects of slopes, the outputs of the DEM created by the IDW interpolation method show so-called artificial terraces which are caused by unrealistic step changes of values. Gradients of slopes are being underestimated in the flat parts of the terraces and overestimated in the slanting parts. When creating a DEM using the IDW method, the interpolated values often create concentric formations around the entry points; these cause greater curvature of earth's surface in the horizontal direction and therefore more frequent local changes in aspects of slopes.

Elaboration of Analysis of Slope Aspect and Solar Insolation

The values of grids of slope gradients derived from the high-quality and the low-quality DEM were divided into 3 categories to suit the requirements of the elaboration of the analysis of conflict with the selected functional areas (residential and recreational). Limit values of gradient are based on limit values of building development which are stated e.g. by Růžička (2000) or Navrátilová et al. (2006).

Subsequently, by employing the zonal histogram function, the output layers were used to establish the pixel frequency of the selected functional area falling within the individual categories of gradient (gradient after reclassification). Via multiplying the pixel frequency by the surface area of one pixel (100 m2), a specific area has been acquired. The use of the zonal histogram function was conditioned by the conversion of the vector layers of the functional areas into a raster grid. Minimum, maximum and average values of gradient of the monitored functional areas were acquired by applying the zonal statistic function to the original grids of slope gradients.

Derivation of the rate of solar insolation was based on the LANDEP methodics (Department of the Environment of the Slovak Republic 2004). The calculation of insolation was based on the values of gradient and aspect of slopes reclassified into categories according to their respective methodics (table 2). A subsequent combination (combine function) of the reclassified grids resulted in the grids of rate of solar insolation. After that the expanse of the selected functional areas falling within the individual categories of rate of solar insolation was established by means of the zonal histogram function.

Table 2. Solar insolation rate calculated by combination of aspect and slope (created according to methodical by Ministerstvo životného prostredia SR 2004)

Aspect	**Slope [°]**				
	< 3	**3-7**	**7-12**	**12-17**	**> 17**
N	3	3	3	4	5
NE	3	3	3	4	4
E	3	3	3	3	3
SE	3	2	2	2	2
S	3	2	2	1	1
SW	3	2	2	2	2
W	3	3	3	3	3
NW	3	3	3	4	4

1 – best solar insolation rate, 2 – good solar insolation rate 3 – average solar insolation rate, 4 – low solar insolation rate 5 – the lowest solar insolation rate

RESULTS OF MODELLING

Conflict of Selected Functional Areas with Gradient of Slope

Gradient of slope influences technical and financial exigence of construction of housing and recreational facilities. From the point of view of urban planning and housing development restrictions and control, gradient of slopes can be also used to localize potential dangers of landslides or erosion.

In accordance with the LANDEP methodics, Růžička (2000) states the limit values of gradient for the following human activities: complex housing development up to 12°, individual housing construction up to 17°, industrial development up to 7°, gardens up to 3°, farm land up to 7°, orchards up to 17°, production of fodder from 7° to 17°, meadows and pasture-lands from 12° to 25°. Navrátilová et al. (2006) furthermore states the limit gradient for heavy construction assembly and prevailingly repetitive housing (terraced housing) as 5°. Point housing construction can be, according to Navrátilová et al. (2006), carried out up to 12° of gradient (2006); however, problems can be expected concerning construction of utility lines and general access roads. Insolated slopes of up to 15° of gradient can be used for specific types of individual housing construction.

Within the scope of the analysis, the conflict of the values of gradients (derived from both the low-quality and the high-quality DEM) with the functional areas for housing and recreation within the continuous urban development of Potštát was being monitored. The limit values chosen for the analysis are 12° for repetitive and point housing construction and 17° for individual housing construction.

For a typical repetitive or point housing construction, a terrain with a gradient of up to 12° can be used (Navrátilová et al. 2006). When using the high-quality DEM, the limit value of gradient of slope was exceeded only by 1,3 % of the current housing developments and by more than 6,9 % of current recreational and sports areas (table 3 and 4). However, when using the low-quality DEM, the extent of the conflicts with gradient of slopes was by 1-3 % higher. The 12° limit of the gradient of slope was, in this case, exceeded by only 1,9 % of the current housing areas and by ca 10,1% of the current sporting and recreational areas (table 4). The reason for these higher values of gradient of slopes while using a low-quality DEM is the presence of small artificial terraces, upper parts of which are almost completely flat (Fig. 2 and 3).

Individual housing construction can be, according to the LANDEP methodics (Růžička 2000), carried out in gradients up to 17°. It is, however, necessary to take into consideration higher technical and financial expenses. The percentage of the current housing and recreational areas which exceed the limit value of 17° is, again, lower when using the high-quality DEM; in case of the functional areas for housing it is only by 0,04%; yet in case of the sporting and recreational areas it is up to 0,9% (table 3 and 4). In this case it is therefore necessary to verify the type of recreational utility and decide, whether there is a conflict or whether it is an intention.

Table 3. Areas of slope categories for housing (high- and low-quality of DEM)

Aspect [°]	Housing – state						Housing – proposal					
	HQ		LQ		difference		HQ		LQ		Difference	
	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%
0,0-7,0	239047	93,02	235945	91,8	-3102	-1,2	78112	95,9	71800	93,2	-6312	-2,7
7,1-12,0	14517	5,65	15970	6,2	1453	0,6	2934	3,6	4399	5,7	1465	2,1
12,1-17,0	2749	1,07	4209	1,6	1460	0,6	339	0,4	747	1	408	0,5
> 17,0	668	0,26	857	0,3	189	0,1	74	0,1	91	0,1	17	0,1

Table 4. Areas of slope categories for sport and recreation (high- and low-quality of DEM)

Slope [°]	Sport and recreation – state						Sport and recreation – proposal					
	HQ		LQ		difference		HQ		LQ		Difference	
	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%
0,0-7,0	29337	74,4	29055	73,6	-282	-0,71	12826	91,9	12602	90,34	-224	-1,6
7,1-12,0	7377	18,7	6390	16,2	-987	-2,50	1009	7,2	1045	7,49	36	0,3
12,1-17,0	2149	5,4	3049	7,7	900	2,28	106	0,8	273	1,96	167	1,2
> 17,0	592	1,5	961	2,4	369	0,94	9	0,1	30	0,22	21	0,2

Even the areas suggested for housing, sports and recreation are not entirely conflict–free concerning their gradient. Aprox. 0,5 % of the suggested housing areas and 0,9 % of the sporting and recreational areas exceed the limit value of 12° when using the high-quality DEM. The percentage of areas exceeding this limit value when using the low-quality DEM is again higher, which is caused by the occurrence of numerous artificial terraces along contours. The percentage of suggested functional areas which would exceed the limit value of 17° is absolutely negligible.

Conflict of Selected Functional Areas with Rate of Solar Insolation

A sufficient rate of solar insolation is one of the housing area health requirements which are necessary to provide a healthy environment for habitation (see e.g. ČSN 730580-2 Daylighting of Buildings – Part 2: Daylighting of Residential Buildings or Act No 20/1966 of the "On the public health care"). Czech National Standard 730580-2 focuses primarily on establishing a level of daylighting in interiors. Besides that it also defines values of max. hillshade angle of obstacles or terrain for different types of building developments. The nature of developments in the model area can be generally defined as “standard areas of permanent residence“ or "areas of permanent residence in a continuous repetitive developments in city centres" in which the maximal permitted hillshade angle is 30° and 36° respectively. From this point of view, it is appropriate to place the current and the suggested functional areas for housing or sports and recreation in localities with a higher value of angle of incidence of sunbeams, i.e. at least in the category of low rate of solar insolation, or preferably in the category of medium insolation so that, even in case of hillshade by a new obstacle or terrain formation, there is a sufficient amount of direct sunlight in the particular area.

Within the frame of the continuous development of the Olomouc region no significant conflicts arose between the minimal rate of solar insolation and the current or the suggested functional areas designated for housing or sports and recreation while using both the high-quality and the low-quality background DEM (Fig. 5). The percentage of the functional areas being monitored within the scope of this category is null or completely negligible (table 5 and 6).

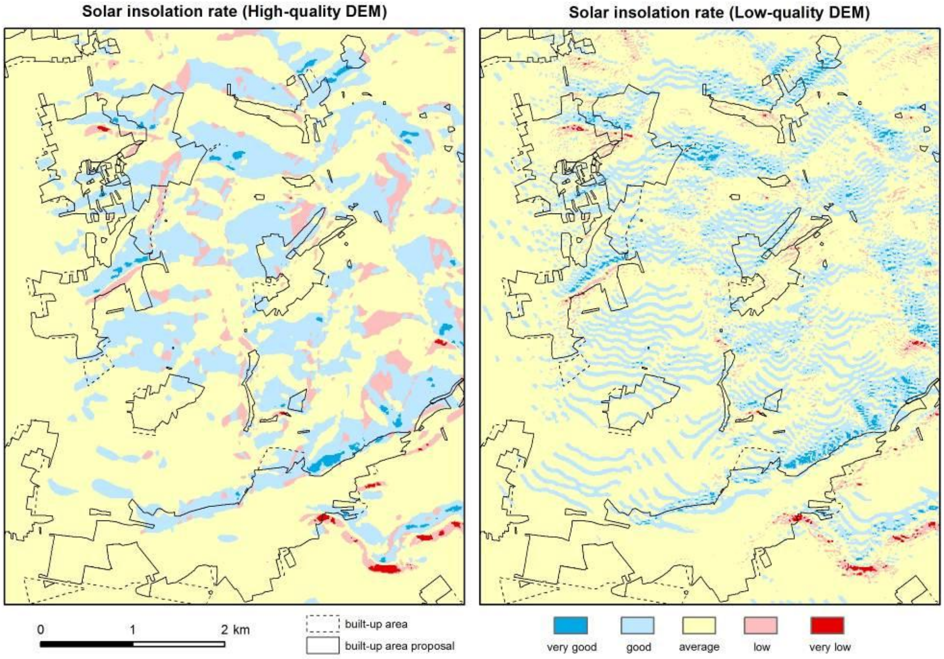

Fig. 4. Values of the solar radiation rate.

Table 5. Areas of solar insolation rate categories for housing (high- and low-quality of DEM)

Solar insolation rate	Housing – state						Housing – proposal					
	HQ		LQ		Difference		HQ		LQ		difference	
	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%
1 – very good	273	0,1	628	0,2	355	0,1	133	0,2	161	0,2	28	0
2 – good	17323	6,7	19503	7,6	2180	0,9	6207	7,6	7316	9	1109	1,4
3 – average	233567	90,9	235190	91,5	1623	0,6	73854	90,6	73597	90,4	-257	-0,3
4 – low	5763	2,2	1594	0,6	-4169	-1,6	1237	1,5	355	0,4	-882	-1,1
5 – very low	55	0,1	66	0,1	11	0	28	0	30	0	2	0

Table 6. Areas of solar insolation rate categories for sport and recreation (high- and low-quality of DEM)

Solar insolation rate	Sport and recreation – state						Sport and recreation – proposal					
	HQ		LQ		difference		HQ		LQ		difference	
	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%	[ha]	%
1 – very good	501	1,3	783	2	282	0,7	987	7,1	1148	8,2	161	1,1
2 – good	9850	25	7800	19,8	-2050	-5,2	0	0	13	0,1	13	0,1
3 – average	27346	69,3	30056	76,2	2710	6,9	12501	89,6	12650	90,7	149	1,1
4 – low	1662	4,2	737	1,9	-925	-2,3	462	3,3	137	1	-325	-2,3
5 – very low	96	0,2	79	0,2	-17	0	0	0	2	0	2	0

As mentioned above, a housing development should be placed at least in the category of low insolation, or preferably in the category of medium insolation. Observing only the minimal health requirements for a housing area is not the best solution; therefore, within the frame of the process of urban planning, a housing or recreational development in an area of low insolation should be considered problematic and conflicting. The influence of either the high-quality or the low-quality background DEM on the resulting values (expanse of the conflicting areas) is, within this category, much more significant. When using the high-quality DEM to derive the rate of solar insolation of the relief, 2,2 % of the current housing areas and 4,2 % of the current recreational and sporting areas were detected as having low insolation. When using the low-quality DEM, the percentage of the current areas for housing or sports and recreation which are in conflict with low insolation decreases significantly lower values (i.e. 1,6 % and 2,3 %). The reason probably being the terrace-like structure of the low-quality DEM elaborated by means of the IDW method, which enables incidence of sunbeams also on northwest, north or northeast facing slopes under a more accurate angles. A conflict with the areas of low rate of solar insolation occurs also within the scope of the suggested areas for housing, sports and recreation. Here too the percentage of conflicting areas is higher when using the high-quality DEM. The expanse of the suggested areas is, however, so small that an evaluation of the differences between the influences of the low-quality and the high-quality DEM has almost no practical value.

CONCLUSION

The primary objective of this article is to evaluate the influences of quality of background DEM (from the point of view of the chosen method of interpolation) on results of modelling of specific spatial conflicts within the frame of urban planning and thus point out potential problems with delimiting necessary measures or further urban development planning. To elaborate the examples, modelling of conflicts of functional areas for housing, sports and recreation with gradient of slopes and rate of solar insolation of slopes was chosen. These aspects, from the perspective of quality and comfort of life, can be considered of an utmost importance. Olomouc region was chosen as the model area.

To evaluate the influence of the background DEM it was necessary to construct so-called high-quality and low-quality DEM. When using identical input data for the DEMs being created, (in this case contours from the DLM 25 data set) the one which achieved the best results being evaluated by non-spatial indicators of metric accuracy was designated as the high-quality DEM. The DEM which achieved the lowest score was then designated as the so-called low-quality DEM. The high-quality DEM for the model area was created through the use of the method of kriging using the exponential model of theoretical semivariogram. The low-quality DEM of the area was elaborated using the IDW method with the weight of p = 2. Subsequently, the background DEMs were used to elicit morphometric variables which were later used in the process of modelling the spatial conflicts. The gradient of slopes was a direct part of the modelling process. It was then combined with the aspect of slopes (according to the LANDEP methodics) to derive the rate of solar insolation.

The results of the elaborated analyses show that in case of employing a high-quality DEM one can always identify places with critical values of a phenomena being monitored (conflicts of functional areas for housing or recreation with values of gradient exceeding 17°, conflicts with a low rate of solar insolation) because such a model creates compact areas. However, when using a low-quality DEM a “fragmentation” occurs and these critical (monitored) values create admittedly larger (in the range of several pixels) but more numerous areas; moreover, they are scattered over a larger area. When using a low-quality background DEM, determination of the necessary measures or planning a further development of a town can become problematical because it is impossible to define “conflicting” parts of a municipality unambiguously. Moreover, because of the scattering of the conflicting places, the whole area of a municipality can become conflicting, which makes any further planning more difficult.

REFERENCES

ČSN 73 0580-2 (730580) (2007) Denní osvětlení budov - Část 2: Denní osvětlení obytných budov. Český normalizační institute, Praha.

Dai, F. C., Lee, C. F., Zhang, X. H. (2001) GIS-based geo-environmental evaluation for urban land-use planning: a case study. Engineering geology, 61, 257-271.

Desmet, P. J. J. (1997) Effects of interpolation errors on the analysis of DEMs. Earth surface processes and landforms, 22, 569-580.

Fencík, R., Vajsáblová, M. (2006) Parameters of interpolation methods of creation of digital model of landscape. Proceeding of the 9th AGILE Conference on Geographic Information Science. Visegrád, Hungary, 374-381.

Gallay, I. (2010) Využitie modelovania povrchového odtoku pri hodnotení zraniteľnosti krajiny vo vzťahu k vybraným prírodným hrozbám. Geografický časopis, 62, 2, 109-125.

H.L.C. Zásady návrhu a umisťování pasivních domů, URL http://www.hlc.cz/drevostavby-info/zasady-navrhu-a-umistovani-pasivnich-domu.html, [cit. 2011-4-23].

Hofierka, J, Cebecauert, T., Šúri, M. (2007) Optimisation of Interpolation Parameters Using a Cross-validation. Digital Terrain Modelling, Development and Applications in a Policy Support Environment, Series: Lecture Notes in Geoinformation and Cartography, Springer, 67-82.

Hynvar, V. a kol., Limity využití území,URL <http://www.uur.cz/default.asp?ID=2591>., [cit. 2011-06-13].

Jablonská, L. a kol. (2010) Urbanistická rukověť. Praha.

Jedlička, K. (2009) Accuracy of surface models acquired from different sources - important information for geomorphological research. Geomorphologia Slovaca et Bohemica, 9,1, 17-28.

Krcho, J. (1990) Morfometrická analýza a digitálne modely georeliéfu. Bratislava (Slovenská akadémie vied).

Krcho, J. (2001) Modelling of Georelief and its Geometrical Structure Using DTM – Positional and Numerical Accuracy. Bratislava (Vydavateľstvo Q111).

Li, Z., Zhu, Q., Gold, Ch. (2005) Digital terrain modeling: principles and metodology. CRC Press.

Li J., Heap A.D. (2008) A Review of Spatial Interpolation Methods for Environmental Scientists. Geoscience Australia, 23, Canberra.

Longley, P. A., Goodchild, M. F., Maguire, D. J., Rhind, D. W. (2001) Geographic information systems and science. Chichester.

López, C. (2000) Improving the Elevation Accuracy of Digital Elevvation Models: A Comparison of Some Error Detection Procedures. Transactions in GIS, 4, 1, 43-64.

Ministerstvo pro místní rozvoj ČR (2008) Stavby a zařízení pro výrobu energie z vybraných obnovitelných zdrojů – metodický pokyn k jejich umísťování. Brno (Ústav územního rozvoje).

Ministerstvo životného prostredia SR (2004) Metodický postup spracovania krajinnoekologického plánu v rámci prieskumov a rozborov územného plánu obce [on-line]. [cit. 2006-02-26].

Montz, B. E., Tobin, G. A. (2008) From false sense of security to residual risk: communicating the need for new floodplain development models. Geografický časopis. 60, 1, 3-14.

Navrátilová, A. a kol. (2006) Principy a pravidla územního plánování. Závěrečná zpráva projektu WA-031-05-Z04. Praha

Pechanec, V., Burian, J., Kilianová, H., Němcová, Z. (2011) Geospatial analysis of the spatial conflicts of flood hazard. Moravian Geographical Reports, 11-19.

Růžička, M. (2000) Krajinnoekologické plánovanie – LANDEP I. Systémový prístup v krajinnej ekológii. Bratislava.

Svobodová, J. (2008) Hodnocení přesnosti digitálních modelů reliéfu. Geomorphologia Slovaca et Bohemica, 8, 1, 76-81.

Svobodová, J., Tuček, P. (2009) Creation of DEM by kriging method and evaluation of the results. Geomorphologia Slovaca et Bohemica, 9, 1, 53-60.

Svobodová, J., Tuček, P., Oondráčková, J. (2009) Evaluace digitálních modelů reliéfu metodami statistické analýzy. Geodetický a kartografický obzor, 55/97, 9, 227-231.

Tuček, J. (1998) Geografické informační systémy, principy a praxe, Computer Press, Praha

Voženílek, V. (2002) Radon risk assessment in GIS. NATO Science series IV: Earth and environmental science, 10, 97-107.

Wilson, J. P., Gallant, J. C., eds. (2000) Terrain Analysis: Principles and Applications. John Wiley & Sons.