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COMPARISON OF DIGITAL ELEVATION MODELS BY VISIBILITY ANALYSIS IN LANDSCAPE

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The paper investigates suitability of digital surface model for visibility analysis in GIS. In experiment there were analysed viewsheds from 14 observer points calculated on digital surface model, digital terrain model and its comparison to field survey. Data sources for the investigated models were LiDAR digital terrain model and LiDAR digital surface model with vegetation distributed by the Czech Administration for Land Surveying and Cadastre. The overlay method was used for comparing accuracy of models and the reference model was LiDAR digital surface model. Average equalities in comparison with LiDAR digital terrain model, ZABAGED model and field survey were 15.5 %, 17.3% and 20.9%, respectively.

Keywords: LiDAR, landscape perception, visibility analyses, Lednice-Valtice area

Exploration of the visual properties of space by means of digital elevation models is an integral component of urban planning and practice (Weitkamp, 2011). The first attempts to link GIS and visual perception go back to the 80s and 90s of the 20th century (Benedict, 1979; Steinitz, 1990; Bishop and Hulse, 1994). Visibility analyses in GIS were applied in plans of nature protected areas e.g. for preventive landscape character assessment of municipalities (Salašová et al., 2011) or regions (Salašová et al., 2010). Their application is also in decision processes related to height of buildings in the urban environment e.g. the upcoming Metropolitan Plan of Prague (Koucký et al., 2014). An example might be a case study of Neředín horizon in Olomouc (Štréblová-Hronovská et al., 2013) which deals with the development of periurban area in the Czech 6th largest town Olomouc. An example of analytical applications is the methodology for the identification designed landscape (Kulišťáková et al., 2011), which is based on visibility analysis of compositional elements from past and present and demonstrates their mutual relations proved by the case study of the New chateau near Litovel – composed landscape (Kulišťáková and Sedláček, 2013).

Digital elevation model is the general concept for digital model which describes the surface of certain area. Digital elevation model can be further divided into: digital elevation model (DEM) as a common term for digital elevation raster dataset, digital terrain model (DTM) as a term for bare ground terrain, and digital surface model (DSM) for surface terrain with vegetation and buildings (van Lammeren, 2011).

During the experiment, 3 types of base data were used – digital landscape model with vegetation and buildings, digital terrain model and digital landscape model based on contours and topological objects of the Czech topographic map in scale 1 : 10 000 (ZABAGED) from the Czech Administration for Land Surveying and Cadastre (ČÚZK). DSM and DTM are elevation raster datasets obtained from laser aerial photography. The main reason for evaluating the digital surface model calculated from ZABAGED is that it was often used as a substitute for LiDAR based DSM several years ago (Martínková-Kuchyňková, 2010; Salašová et al., 2010), and its necessity in cases, where historical maps are the only sources of heights.

Material and methods

Methods of creation of digital surface

Preparation of digital terrain model, digital surface model from LiDAR data and ZABAGED digital model.

For creation of DMP there was used the product DMP1G, for DMR there was used the product DMR5G, both provided by the CUZK. For DMP 1G, the average error was 0.4 of heights of buildings and 0.7 for forests and other vegetation. For DMR5G, the mean error was 0.18 and 0.4 m in a wooded terrain (ČÚZK, 2015). Preprocessing of the data was performed in the LASTOOLS software. The outcome was the combined point cloud format exported to LAS (LiDAR data exchange format standard), which is a common data exchange format supported by most GIS applications.

The actual interpolation into a continuous raster digital elevation model and the surface was made based on the creation of the so-called LAS Dataset in ArcGIS 10.2 (Tool Create LAS Dataset), which is an internal format software that allows viewing, filtering and partial data classification of the LAS format. Then, interpolation was performed using the LAS to Raster Dataset, which created a continuous raster terrain models and digital surface at a resolution of 5 meters.

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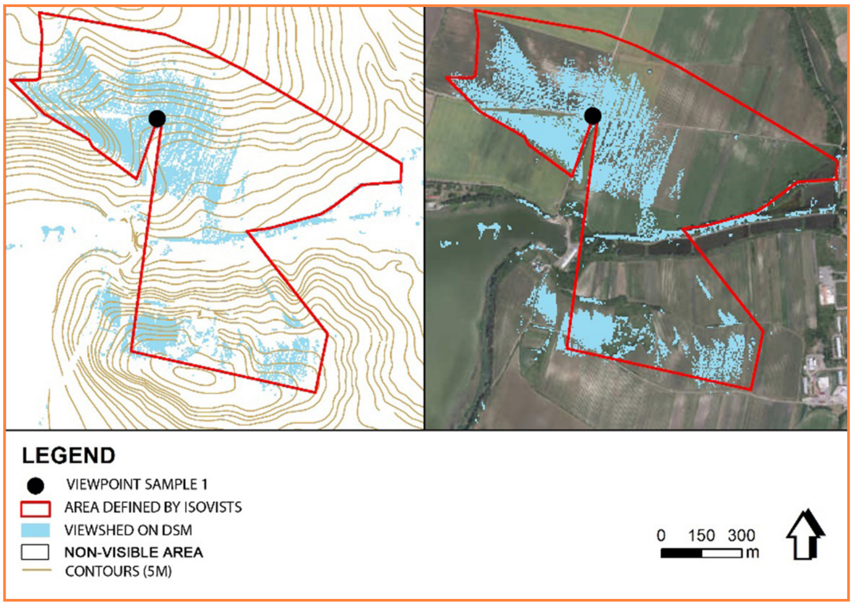

Figure 1 Cartogram shows difference between results of analyses by viewshed tool on raster dataset and terrain survey by isovists method at observer point 1
Source: Author

The digital surface model ZABAGED is created on the basis of topographic data sets ZABAGED and altitudinal set ZABAGED. ZABAGED DSM is made on selection of objects that can act as barriers. These objects are assigned with heights according to the land-use (Table 1). All objects are converted into raster format. The resulting grid contains altimetry of obstacles and terrain as well and resolution 5 × 5 m (Martínková-Kuchyňková, 2010).

Method of exploring the field of vision and visibility of objects

Visible space outside urbanized areas is calculated using Viewshed – field of vision, which is included in most of GIS applications. The principle consists in the calculation of the digital terrain model that defines space (grid cells), connected by an unbroken visible line (Weitkamp, 2011). Viewshed analyses raster digital elevation model or terrain model, resulting in a raster map with a grid of reaching integer values. The result of the analysis may be a binary raster of 0 and 1, where 1 indicates that the location is in the field of view or the incremental visual field, observed from the line and determines movement (Nijhuis and Reitsma, 2011).

Comparison of the accuracy of models for visibility analysis

Overlay method (Maloy and Dean, 2001) was used for comparing accuracy of the evaluated model. This method counts overlay between viewshed in the evaluated model and in the reference model and calculates areas which differ. The area is calculated as a percentage ratio of the sum of viewsheds on both surfaces and shows ratio of equality of compared viewshed datasets. The more percent of equality the more accurate is the model for analysis. The value of 100% means that both viewsheds are identical. The reference model was the field evaluated LiDAR digital surface model with vegetation. The basic premise of the experiment is that the LiDAR digital surface model is the most accurate model compared and thus accurately calculates the area viewed at one place. Therefore, it was used as a reference and the evaluation of other models was calculated by comparison with it. A special investigation was the definition of visibility through ISOVIST in the field, which were also compared with the DMP. All of the compared areas were identified by three codes:

1.1 – the surface is seen on the compared model and the DMT (digital elevation model),
1.0 – surface shown in the DSM (digital surface model), is not visible on the compared model, objects
0.1 – surface is not visible to the DSM, it is seen on the compared models.

Model area

The model area was situated in Lednice-Valtice Area of 142.2 km^2. The digital surface model DSM, the digital elevation model DMT and the ZABAGED digital model were calculated for the entire model area. In order to unify all datasets, all raster models were calculated for resolution of 5 × 5 meters although the DSM and the DTM enable resolution of up to 0.5 × 0.5 meters (ČÚZK, 2015b), the results could not be compared. As many as 14 locations were defined in the area (Table 1) and situated according to the following criteria:

- the observer site must be situated evenly in open country, a country with a high proportion of vegetation (but not inside the stand) and the urban environment,
- minimal visibility in the area must be of 100 meters in one direction,
- the observer site will be at least 1,000 m from the boundary of the model area.

The sites 3, 6, 9, 12 are situated in countryside with high proportion

Table 1 Comparison of overlay of digital surface model with other models. Overlay 1, 1; 1, 0; 0, 1 – mean value of overlay of theDSM (Digital surface model) with other digital models in percent and maximal and minimal values in samples

	Overlay 1.1 (%)	max 1.1 (%)	Min 1.1 (%)	Overlay 1.0 (%)	max 1.0 (%)	Min 1.0 (%)	Overlay 0.1 (%)
DMR	11.5	39.6	0.8	3.3	12.23	0.25	85.2
ZABAGED	17.3	38.3	1.9	21.4	75.6	0.8	61.3
Isovists	20.9	39.4	3.4	36.8	82.2	1.2	42.3

Source: Author

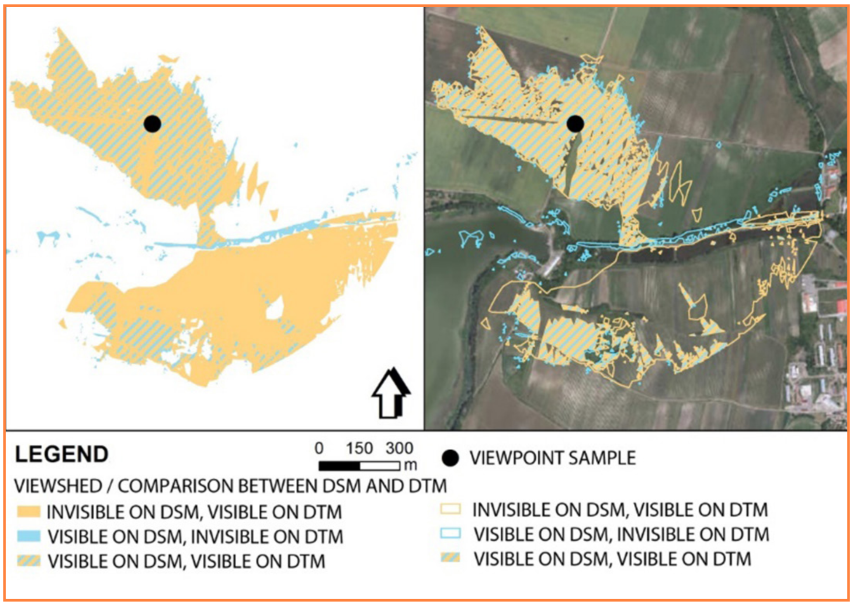

Figure 2 Cartogram showing comparison of viewsheds on observer site one. The figure shows significant difference in southern part of area, where vegetation builds an obstacle which resulted in significant difference in viewshed analyses
Source: Author

of vegetation, the sites 1, 4, 7, 10, 13 are in open countryside locations and sites 2, 5, 8, 11, 14 are in urban landscapes.

For visual analysis there was used the software ArcGIS 10.2.2 by ESRI with extension 3D Analyst, which includes the Viewshed tool. The ArcGIS Model Builder program and the ArcPy Python programming language were used to speed up the working method.

Calculation of the visual field

Viewshed tool allows determining the position of the observer viewing angle (AZIMUTH), the height of the observer (OFFSETA) and the maximum visible distance (RADIUSB). For sites there was set the observer height 1.5 m, the viewing angle 360° and the maximum distance 1,000 meters. The output contains 14 raster files, each representing one observer point. The raster obtains values 0 and 1, where 0 means not visible and 1 means visible. Raster files were afterwards converted to vector format shapefiles and only those values were selected that correspond to the visible surfaces. The conversion used tools Raster to Feature Class and Select. These operations were carried out for the DMP, DMR, ZABAGED and Isovists, which means 4 sets of 14 files.

Comparison of results

The set of the DSM was compared with other sets using Union tools, where viewsheds of evaluated raster were compared with viewsheds of reference rasters of the same observer point. Overlapping areas (value 1, 1) and non-overlapping areas (values 1, 0 and 0, 1) were selected by Select by Attribute tool. Values using CALCULATE VALUES tool were exported to the table, and then the percentage representation was calculated (Table 1).

Results and discussion

The comparison was made on overlapping and non-overlapping viewsheds for the set of 14 observer points. Average ratio of equality in the set of 14 viewsheds was calculated together with minimum and maximum values (Table 1, note: min. and max. Overlays with the values 0, 1 are not relevant, therefore they are not in the table).

The results showed a radical difference in size between the areas of digital surface model and other models. The equality with the digital surface model is only 11%, while this fact is significantly influenced by vegetation. The highest correlation, approximately twice as high, showed identifying the areas using ISOVIST, although the overall equality is low (20.9 %). The highest correlation reached the samples 8 and 13, which were in open landscape scene without significant vegetation. The dependence of the ratio of the viewshed on vegetation is evident; however, the presence of other factors such as the shape of the relief in relation to the position of the viewer does not allow identifying the sample set of unique statistical dependence. The level of accuracy is partly dependent on the raster resolution while higher resolution also increases the difference between the DTM and the DSM (Maloy and Dean, 2001). For better statistical results it would be better to use several samples with different resolutions (Miller, 2011).

Conclusion

The results attempt to prove that analyses carried out on various digital elevation models are not comparable or interchangeable. The possibility to identify the deviation between the measurement models is also questionable, which could be regarded as a standard. Factors influencing the calculation – configuration of the terrain and the presence of vegetation, require that the correlation between them be inferred for higher number of test sites.

The unexpected result is inaccurate definition of the territory through ISOVIST in the open landscape. The reason is smooth curvature of relief that does not precisely define the boundaries of the visible area. This method has certain utilisation in urban areas and at smaller distances, but its accuracy has not been proved in the landscape (equality 20.9% of DSM). With a digital relief model there was confirmed the lowest equality (11% of DSM), which is logical given the presence of obstacles in the form of vegetation. The model for digital data base map 1 : 10,000 – ZABAGED equality is 17.3% and therefore it is not comparable with the DSM at visual analysis.

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