THE USE OF VIEWSHED ANALYSIS IN CREATION OF MAPS OF POTENTIAL VISUAL EXPOSURE

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Abstract

We have created software tool that helps to determine Visual exposure of landscape potential (VEP). VEP is determining factor of landscape planning and assessment activities with the visual-aesthetic impact on landscape and its visual quality. VEP value is being determined by the area size the concrete landscape point is visually identified from, or by the area size that can be identified from the concrete point. Potential of landscape visual exposure represents potential of each relief surface point to appear visually dominant in comparison with the other points of terrain surface. Relief point being exposed potentially and visually does not represent its real visual prominence. It stands for the ability to improve visual dominance of landscape element value being situated in the concrete point. The most frequently used GIS software does not offer complex solutions in the process of visual quality landscape evaluation. The main attribute of this process is represented by the potential of visual exposure. Software tool in GRASS GIS has been developed to determine VEP. It uses analytical functions of Visibility as well as functions of region adjustment, input map to ASCII format transformation, map and mask import, and data generation. Program being used for map visualisation has been created. It enables complex solution of landscape visual exposure potential. The output is done by data matrix of the selected area in which each cell of matrix stands for Visibility function converted in km^2. The model testing has been realized for the whole Slovak republic and especially for the Nitra town. Visual structure of land and potential visual exposure are considered in the planning and evaluation processes in the theoretical and proposal level, as well. Examples of use of the visual exposure evaluation approach are system of ecological stability of the territory, environmental impact assessment, urban plan documents, and other activities related to the landscape creation and planning.

Keywords: viewshed analysis, visibility, visual exposure of landscape potential, parallel computations

INTRODUCTION

Definition of main visual landmarks, that mustn't be affected by building-up and at the same time must be visible for citizens mental map to increase readability of urban environment, is necessary for preservation of city's identity. Important aspect in landscaping and city planning is conservation of city skyline, which identifies and makes the city unique. That's why regulations of high-rise buildings, which provide city's historical and aesthetic continuity, are used for this purpose. Equally important is conservation of characteristic landscape panoramas and countryside views, that are signified by the condition of relief and area exposure, but we still don´t have system and regulation for objective assessment. Mentioned landscape panoramas – green skylines are integral aesthetic parts in building green infrastructure and city's environmental image at the same time. But how is it possible to identify this areas? For simple definition of areas with significant visual quality can serve software tool for geographical information system (GIS), that is able to define potentially visually exposed part of landscape. This tool was developed at Constantine the Philosopher University in Nitra and has a wide range of utilization, but especially is usable for land-use, landscape ecology and environmental praxis. This software tool can be practically used for urban planning documentation, especially in green structure plan.

Importance of landscape visual information assessment is associated with landscape planning activities (Clay, Smidt, 2004) and visual impact on landscape regarding environmental impact assessment. Also current assessments are depending on expertise that measures landscape visual quality subjectively.

We realize that exact and automatic landscape assessment, as visual information source, is impossible with software tools. Our ambition was to create objective assessment platform as source of visual identifiable information. Software solution of landscape visual attributes are close to this issue in works of Bishop, Hulse (1994) Shang, Bishop (2000), Bishop, Wherrett, Miller (2000).

Relief is limit factor for visual landscape perception, which defines how every spatial element of landscape is perspective and visible at the same time. This limit is basic starting point for solving issues of landscape visual exposure. We want to create and test model of Visual exposure of landscape potential (VEP), which will be used as objectively measurable platform in case of real or planned activities assessment with visual impact on landscape. This tool will be complement for landscape planning activities.

Visual exposure of landscape potential (VEP) is only hypothetic term, because landscape surface is limited just on relief without landscape structure elements. But reliefs enter like main attribute in process of visual connections determining and assessment. VEP is expressed in values. Value is destined by area size from which we can identify concrete point in landscape (number of points in landscape from which I see one point), or area size which is identifiable from concrete point (number of points in landscape which I see from one point). VEP is main presumption for visual exposure of landscape reality – real part of visual landscape structure. VEP or visual exposure of reality with high values understanding like determining a permanent visual quality factor in landscape planning and visual impact assessment.

Making maps of potential visual exposure of landscape eliminates activities that might have negative impact on perception of urban landscape.

MODELING OF THE VISUAL EXPOSURE

At present, the most common GIS software does not posses a direct tool for the determination of the visual exposure of the area.

It offers viewshed operations which are able to derive a new coverage from the DEM of the area. The newly created coverage shows those areas which are visible from one or more locations and which are coded as a binary image, with 1 indicating those areas which are visible and 0 those which are not (Fisher, 1995).

The basic algorithm for generating a viewshed from the DEM is based on the estimation of the elevation difference of intermediate pixels between the viewpoint and the target pixels. The determination whether the target pixels can be seen from the viewpoint is accomplished by examining each of the intermediate pixels between two cells to determine the corresponding 'line-of-sight' (LOS). If the land surface rises above the LOS, the target is invisible. Otherwise, it is visible from the viewpoint. The LOS computation is repeated for all target pixels from a set of viewpoints, and the set of targets which are visible from the viewpoints form a viewshed (Burrough, McDonnel, 1998; Kima et al., 2004).

The solution of the computations in which all of the points (n) on the terrain are used as viewpoints and targets is partially described by Rana (2003). According to this work, it is the exhaustive but time-consuming Golden Case in which the visibility index computation time is of order O(n2).

The map of the visual exposure can be also considered to be the Golden Case solution. Therefore, each pixel of the input DEM carries a value of the visibility index. The map creation process of the potential visual exposure for a specific area requires a number of time-consuming computations.

The main factors that affect the total time of computation, besides the performance of the computer itself, are the numbers of viewpoints and target points in the viewshed computation. The number of points is influenced by the resolution of the input DEM, size of the investigated area, and maximal distance from the viewpoint inside of which the LOS analysis will be performed.

There are several possibilities for speeding up the Golden Case solution. One approach is described by Rana (2003) and Kima et al. (2004) as the reduction of the number of observers (viewpoints), targets, or both. Our approach to speed up the process of the visual exposure map creation is based on using parallel computations.

Parallel computations used in formation of PVE map can reduce the computational time approximately as many times as many processor (or processor cores) are involved in computations (Jakab, Petluš, 2012).

The input map is first divided by a user into the required number of segments. The computation of the visibility in the individual segments can be performed by individual processors. This solution leads to an acceleration of the process, depending on the performance of the employed computer – from 2 or 4 processor-containing desktop computers, through computer clusters with dozens of processors, to supercomputers with several hundreds or thousands of processors.

The created segments present groups of viewpoints of approximately the same size. The number of the viewshed computations obtained by the lines-of-sight projecting within a digital model of relief remains the same, but the computations run simultaneously. Each processor can solve the computations in an individual segment, while the computation of the visibility goes beyond the borders of a segment. In other words, the target points, the parts of the computation, are not limited by the borders of segments; therefore, the computation of the visibility exceeds borders of these segments.

In the case of parallel computations, the source of viewpoints can be the created sectors, and the source of target points can be the whole input map or a map which was derived by including the border zone whose size is equal to the maximal distance from the viewpoint. Inside the newly derived border zone the LOS analysis will be performed towards the borders of the individual sectors. Our parallel algorithm is designed for the distributed memory MIMD architecture. In order to maximize the utilization of the processors, the algorithm distributes its data among the processors and allows each processor to process the data asynchronously. This asynchronous operation ensures that each processor processes the data independently of the other processors and as fast as possible (Lanthier et al., 2003).

The division of the map into more segments and the application of more processors for the computation can lead to a proportional decrease of the computation time. Thus, the developed toolkit can be easily applied, using multi-core processors, computer grids, computer clusters and supercomputers for the computations of large areas in a high resolution.

FORMATION OF VEP MAP WITH USE OF THE PARALLEL COMPUTATIONS

We developed a GRASS GIS toolkit (Jakab, Petluš, 2012) for solving the Viewshed analysis for a relatively large area, using parallel computations.

The package of our toolkit consists of several modules offering the following functionalities (Grass Development Team, 2011): r.in.gdal, g.region, r.buffer, r.stats, r.out.arc, r.patch, Grass batch job.

The VEP map formation with use of our GRASS toolkit is performed in several steps:

Uploading of input parameters

The created toolkit runs in a GRASS GIS terminal. The input parameters, necessary for r.los module, are uploaded after starting the run:

- the raster map –An input map containing the elevation data (e.g., Digital model of relief) is transformed into the ASCII grid format using the GRASS GIS (the module r.in.gdal). The size of the raster map which enters to the program algorithm must exceed the borders of the area of interest by the distance of the visibility. This condition is necessary for the visibility computation on the territory borders where calculations take into account the area lying outside the borders.
- obs_elev – the value Height of the observer (in meters) above the viewpoint’s elevation,

- max_dist – the maximal distance (in meters) from the viewpoint within which the LOS analysis will be performed.

The VEP maps for the whole area of Slovakia and the cadastre area of Nitra town were the output of the process in our case. We have used the following input parameters to create the final map of the visual exposure potential:

- the raster digital elevation map: the digital map of relief ASTER (© ERSDAC 2011, http://www.gdem.aster.ersdac.or.jp), transformed from WGS84 to S-JTSK and resampled into resolution of 100 m (in the case of whole Slovak Republic) and 30m (in the case of Nitra town)
- the height above the ground of the viewing location: 1.75 m,
- the maximal distance from the viewpoint: 50 km in the case of whole Slovak Republic, 2,5 km in the case of Nitra town
- MASK: the borders of the Slovak Republic, the cadastre of Nitra town

After start of running the toolkit, the GRASS terminal shows a simple guide for users in the form of questions and answers, leading to the specification of the input parameters, such as the units in which the data is recorded (e.g. the number of pixels that are visible from a set point, the area in square meters, square kilometers, in hectares).

Setting of computational region

Two more questions in a new dialog window are used to provide the specification of the computational region in the GRASS. The first one is for the specification of the output map resolution. The second one is important for the specification of the borders of the computation (the border pixels). The most frequently are defined the borders of the region for the calculation base on the MASK.

If we know the map resolution and the border of the computational region, the program will be able to assess how large area is used in the computation, which is reported as the final number of map pixels in the dialogue window (Figure 1).

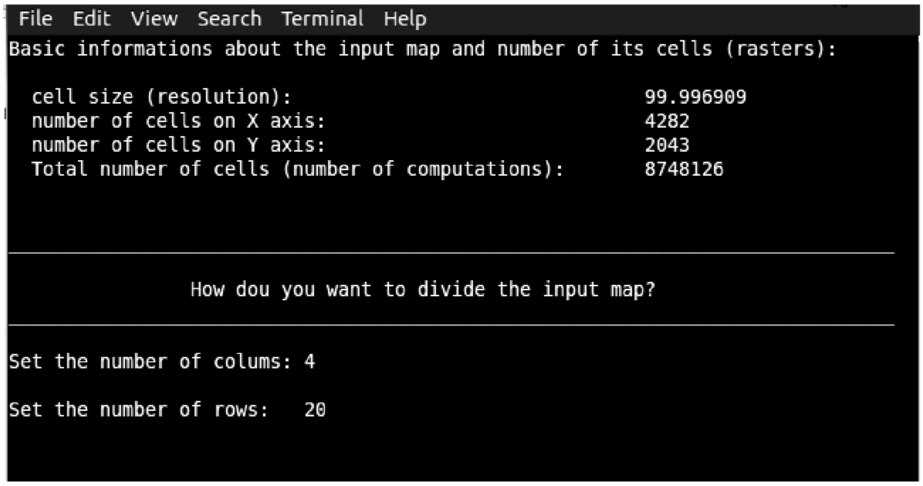

Fig. 1. Segment settings

The report (Figure 1) contains the exact resolution (the cell size), total number of cells, and number of cells on the X and Y axis (the rectangle given by the most outward pixels is taken in account). Whereas the Visibility function has to be performed individually for each pixel, the number of pixels in the computational region is equal to the number of runs of the Visibility function using the r.los module. Therefore, the information from the dialogue window is useful for the users who decide whether they want to use simple or parallel computations of the visual exposure.

Formation of segments for parallel computations

If the simple computation is chosen, the sub-program MAP_VPE will run to create the map of visual exposure. When the parallel solution is chosen, it is necessary to divide the input map into smaller parts – segments, and adjust the computation of the visibility for each newly created segment.

The segments present a bordered group of viewpoints, whereas the source of the target points remains the original map DMR. The maximal distance from the viewpoint to the target pixels inside of which the LOS analysis will be performed exceeds the segment borders. In the case of the parallel solution, the user can choose how many segments are necessary to be specified for parallel computations.

We calculated the map of the potential visual exposure using parallel solution. The input map was divided into 20 rows and 4 columns, which led to the creation of 80 individual segments (Figure 1). Creation of VEP map was realized on a computer grid. Number of rows corresponds with a number of computers used and number of columns is adjusted to a number of cores in one computer.

The segments creation produces new input program data saved in external files. The data contain the information about the parameters specified by the user, borders of the individual segments, codes of segments, etc. Therefore, it is important to deal with the organization of the newly created data. Besides the transfer of the data, it is necessary for the parallel computation run to copy the source code and input raster of each segment.

After this question, the above-mentioned data organization is carried out. We then run a further part of the program, leading to the VPE map for the created segments.

Running the parallel computations

Running the parallel computations is performed via a Grass Batch Job application. Grass batch job is an alternative method of easily run jobs in the GRASS with a collection of commands in a shell script file. It is possible to apply it to launch the GRASS in the text mode and in a parallel solution of the GRASS jobs (Grass Development Team, 2011).

Computation of the visibility index within the individual segments

The computation and map creation start in the left top corner of the map segment. The algorithm of the program solves automatically the Visibility function (the module r.los) for each cell of the area of interest. and the viewing position given by the central point of the cell coordinates. The function Visibility is performed for the point determined by the coordinates of the actual cell center and for the specified values of the height above the ground of the viewing location and maximal distance from the viewpoint.

The module r.los generates a raster output map in which the cells that are visible from the user-specified observer position are marked with a vertical angle (in degrees from the ground) required for the cells' visibility (the viewshed). The value of 0 is shown directly below the specified viewing position, 90 is to the right or left of the position, and 180 is directly above the observer. The angle of the cell containing the viewing position is undefined and set equal to 180 (Neteler, Mitasova, 2007; Grass Development Team, 2011).

The creation of the visibility index for a given viewpoint is the next step of the algorithm. The visibility index is obtained by summarizing the results of the r.los module. We use the module r.stats for reporting the area statistics containing the number of the individual cells and the values of their vertical angles.

The following step is the counting of all visible cells with non-zero values. The final number is transformed into the spatial units (chosen by the user during the specification of the input parameters) and written into the output matrix in the corresponding place. It is transferred to the next cell later and the whole cycle is repeated. If the cycle is performed for all cells in the input ASCII grid, the final map in the ASCII grid format is created on the basis of the values in the matrix.

Patching of the individual segments

The results of the parallel computations – particular maps – can be patched by last part of the program into a final output map.

RESULTS AND DISCUSSIONS

Result of the computation process is a map of the potential visual exposure of the landscape in Slovakia, where each cell of the area matrix possesses a value of the Visibility index transformed into selected spatial units (km^2) and where the value of each cell presents a quantitative expression of the visual exposure potential of the land (which is given by the territory visible from the cell). Computations were done by setting of borders of potential visibility to 50 km for the Slovak republic.

Visual exposure of Slovakia landscape

Visual exposure potential´s digital model is a result of software processing with resultant scale of visual exposure values from 0,09 km2 to 2207,1 km2 (Figure 2). Maximum visually identified area takes 7850 km2. Scale is passing from minimal exposure cell (whites) with initial value only 1.25 km2 of possible visibility to maximal exposure cells (reds) with maximum value up to 2207,1 km2 of possible visibility. Visibility of each point was derivated from area of a circle with a radius of 50 km what presents maximum range of visibility. The highest obtained value presents 28,11 % of total value of visibility. Our results showed that the highest value of possible visibility was achieved for the Babia Hora hill (1725 m a.s.l.) The Babia Hora hill belongs to Oravské Beskydy mountain and it is situated in the contact zone of the Slovac republic and Poland in the northern part of Slovak republic (Figure 2).

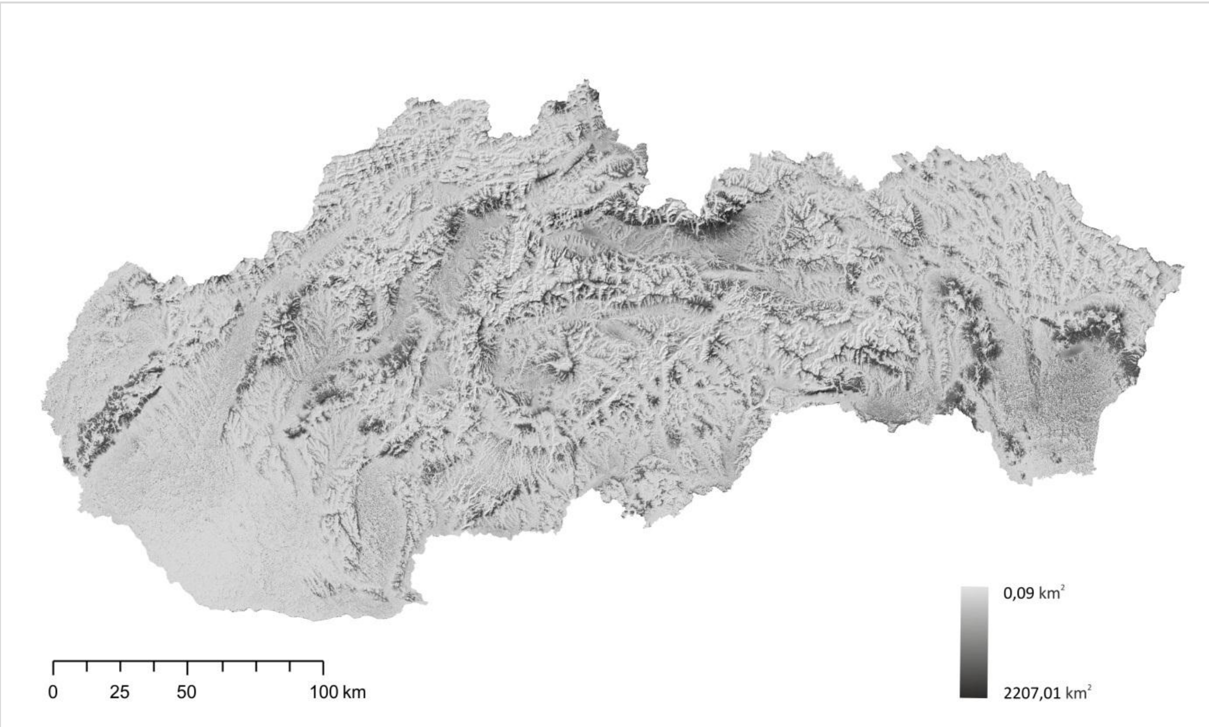

Fig. 2. The potential of the landscape visual exposure of Slovak republic.

These observations are in agreement with our assumptions, because of adjacent lowlands (Podunajská nížina and Záhorská nížina - lowland in the contact with Malé Karpaty on the west and Východoslovenská nížina - lowland in the contact with mountains of Slanské vrchy and Vihorlatské vrchy on the east of Slovakia). Similarly, Zoborské vrchy with the peaks Zobor (585 m a.s.l.) and Žibrica (617 m a.s.l.) are surrounded by a wide Podunajská pahorkatina – hill land, what enables wide view on the localities. Smaller areas with the relevant value of 25% from possible maximum are scattered over the whole area of Slovakia with culmination on hilly and mountain parts Zoborské vrchy – Zobor (586 m a.s.l.), Štiavnické vrchy – Sitno

(1009 m a.s.l.), Pohronský Inovec – Veľký Inovec (901 m a.s.l.), Považský Inovec – Marhát (748 m a.s.l.), Inovec (1042 m a.s.l.), Malá Fatra – Veľká lúka (1476 m a.s.l), Veľký Kriváň (1709 m a.s.l.), Považský Inovec – Marhát (748 m a.s.l.), Nízke tatry – Chopok (2023 m a.s.l.), Kráľova Hoľa (1948 m a.s.l.), Kráľova Hoľa (1948 m a.s.l.), Vysoké Tatry – Gerlachovský štít (2664,4 m a.s.l), Lomnický štít (2632 m a.s.l.), Poľana – Poľana (1458 m a.s.l.), Slánske vrchy – Šimonka (1092 m a.s.l.), Makovica (981 m a.s.l.), and Vihorlatské vrchy – Vihorlat (1076 m a.s.l.).

These localities are identical with the scenic and cultural-historical symbols of Slovakia. Further investigations were focused on identification of localities with relevant value of 25% from possible maximum and we made new visual exposure potential's digital model with good readability of High visual quality (Figure 3). This digital model defines areas with visibility from 25 % to maximum value. By visualization of the data, a map with the most potentially visually exposed areas in Slovakia landscape was created. The mountain areas in Malé Karpaty, Slánske vrchy and Vihorlatské vrchy.

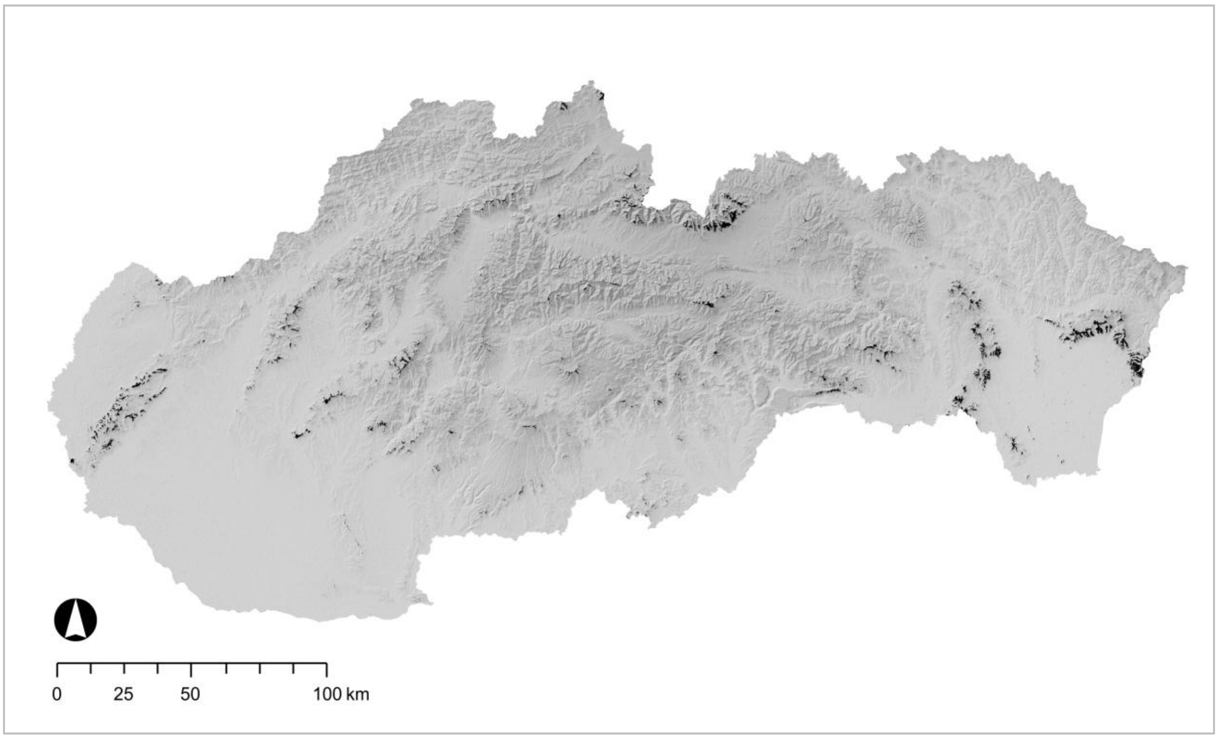

Fig. 3. The identification of the potential visible areas exceeding 25% of the possible maximal area.

Use of VEP map in urban land

The town of Nitra was chosen as an area of interest. The input map (ASTER © ERSDAC 2011, http://www.gdem.aster.ersdac.or.jp) with resolution 30 x 30 m was used for computation of visibility with the radius of 2.5 km. Town Nitra is situated on border of Danube plain (in town is the lowest point 138 m a.s.l) and Tribeč mountains (in town is the highest point on top of Zobor hill at 587 m a.s.l.). Landscaping dominants are well readable in field research for these reasons. The old town was established on seven hills like we used to say about Rome. Zobor, Hradný vrch (Castle hill), Kalvária (Calvary), Čermáň, Borina, Vŕšok and Martinský vrch (Martin´s hill) are hills in different heights but most dominant is massif of Zobor. Visual exposure potential´s digital model is a result of software processing with resultant scale of visual exposure values from 0.1 km^2 to 14.6 km^2.

Reclassification of Nitra city VEP was performed for identification of the most visual exposed areas in the city. The scale of five grades for VEP was set based on how large area can be identified from the each point of terrain. We divided the area into the categories of visibility as followed: category 1 (0-15%), category 2 (15 – 30%), category 3 (30– 45%), category 4 (45– 60%), category 5 (60 – 75%), category 6 (over 75%, this category was not observed in the area of interest), Table 1., Table 2., Figure 4.

Table 1. Area of individual category of visual landscape exposure

Category of visual landscape exposure	Area in square meters	Number of pixels
1	52,926,648.119034	58,795
2	41,435,727.747613	46,030
3	6,086,181.953113	6,761
4	205,243.231077	228
5	7,201.516880	8

Table 2. Univariate statistics of the non-null cells

n	111822
minimum	22
maximum	16245
range	16223
mean	3349.77
standard deviation	1941.13
median (even number of cells)	3133

The urban plan defines the primary dominants, which have importance in identification and orientation. These dominants are usually buildings. We propose an universal platform, based on relief, which creates potential of visual exposure.

We have prepared the model of VEP of Nitra town with good readability of high visual exposure. Figure 4 shows dominants of relief. This digital model defines areas with visibility from 25 % to 74.6 % (maximum value – Table 2).

We can say that results from this digital model and field research are same, but digital model points directly at results on exposure areas, which are the most sensitive places on interventions.

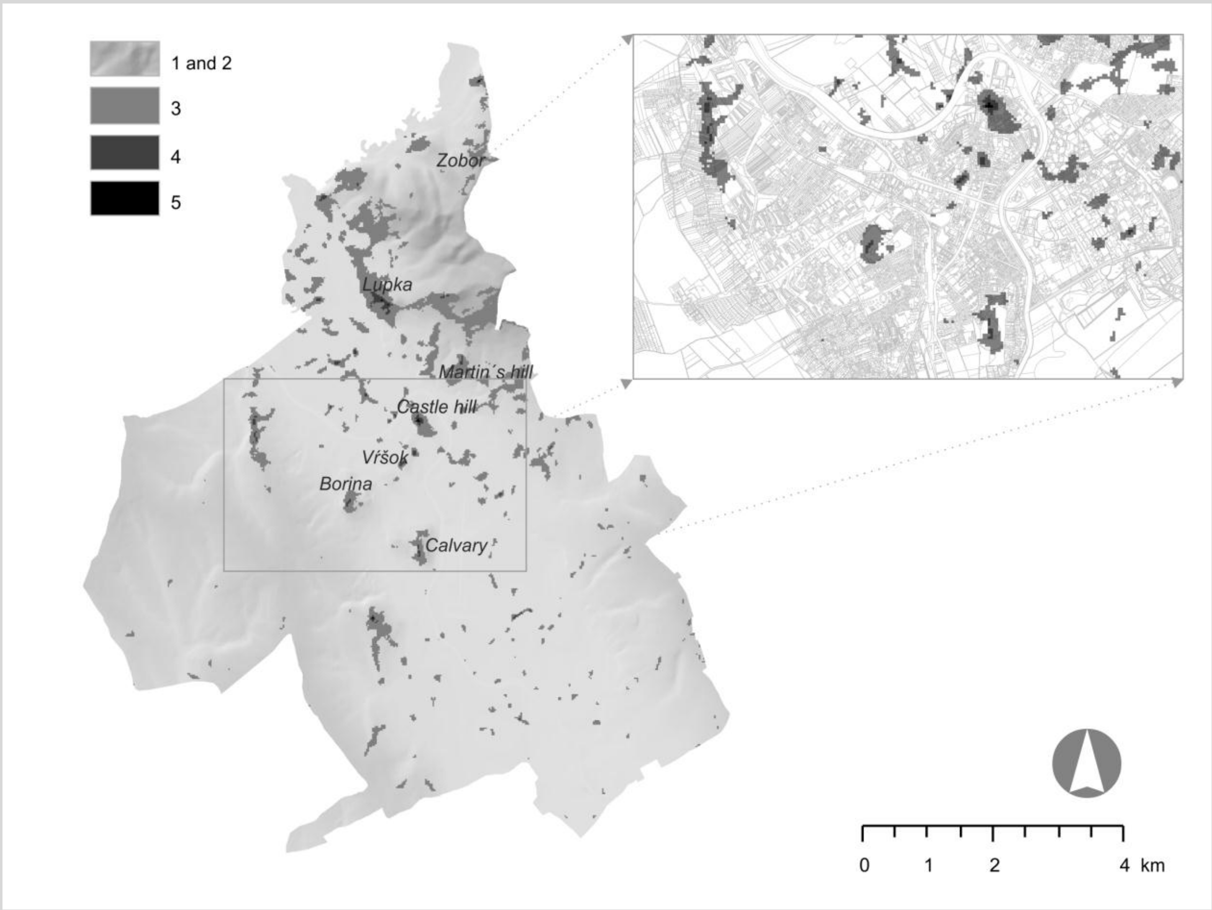

Fig. 4. Category of visual exposure of landscape potential in Nitra town. 1 and 2 – without significance, 3 – less significant, 4 – more significant, 5 – the most significant.

CONCLUSIONS

Our contribution was aimed at the use of the GIS software to develop a toolkit for modeling the visual exposure of landscape. The output of the process is a map of the visual exposure in which each pixel of the raster map carries information on the visibility index. The importance of the landscape visual information assessment is associated with the landscape planning activities and a visual impact on landscape. The current assessments depend on expertise which evaluates the landscape visual quality subjectively.

We wanted to create and test the model which would be used as an objectively measurable platform in the case of the assessment of real or planned activities with a visual impact on landscape. This would be a complementary tool for landscape planning activities. This method is applicable in landscape planning documents, in our conditions in green structure plan of residences. Software GIS solution is good choice for urban landscape visual quality assessment and making green horizons core for traditional urban landscape character of towns.

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