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Fuzzy viewshed, probable viewshed, and their use in the analysis of prehistoric monuments placement in Western Slovakia

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Abstract

Viewshed analysis is used in many fields (e.g. landscape architecture, military, or archaeology) to determinate locations visible from one or more observation points in order to examine suitability of the placement of structures or their visual impact on the environment. The output of this analysis in the GIS environment is usually a binary raster with cells coded as "visible" or "invisible". There are several factors that affect the visibility calculation; in this work we address two of them: (i) the effect of the uncertainty of the DEM, (ii) the non-binary nature of human visual perception. We created two toolboxes in ArcGIS Model Builder: "Probable Viewshed" to consider the vertical error of a DEM, and "Fuzzy Viewshed" to assess the changing visibility of an object due to its size and distance from the observer. Both probable and fuzzy viewshed represents visibility as a value from the interval from 0 to 1. This value represents the probability of a cell being visible considering the vertical error of the DEM for the probable viewshed; for the fuzzy viewshed it can be interpreted as the level of clarity of visibility. We used these tools in an archaeological analysis of seven circular ditched enclosures ("roundels") in Western Slovakia. The results confirmed mutual visibility of two quadruples of roundels, so visibility could be one of the determining factors of their placement.
Keywords: GIS, visibility analysis, fuzzy viewshed, probable viewshed, circular ditched enclosure, roundel

1 Introduction

Visibility analysis seems to be an easy task using built-in tools in a GIS. Only few clicks are needed to get the map of visible and invisible areas, but some issues should be considered to acquire more realistic results, e.g. the ambiguous nature of visibility, which cannot be expressed by binary "visible"/"invisible", and the effect of the inaccuracy of a digital elevation model (DEM).

These problems can be addressed using non-binary viewsheds. We created two toolboxes in ArcGIS ModelBuilder: "Probable viewshed", which calculates the probability of visibility of a cell considering the vertical accuracy of a DEM, and "Fuzzy viewshed", which uses a membership function to assign the value of visibility according to the distance and size of an observed object.

Created toolboxes were used in the archaeological analysis of the placement of prehistoric monuments, circular ditched enclosures (roundels). The analysis of their mutual visibility could partially explain their unknown function.

2 Experimental

2.1 Location and data

The analyzed Neolithic circular ditched enclosures ("roundels") are located in Western Slovakia, information about them was provided by Slovak Academy of Sciences, Institute of Archaeology. From overall seven objects, three have been confirmed by geophysical measurements (Prašník – „P", Šterusy – „S", Borovce – „B") and four have been identified from aerial photographs only ("assumed" roundels: Borovce 2 – "B2", Vrbové – "V", Trebatice – "T", Kočín – "K").

The DEM used in this study was the digital terrain model (DTM) with 10 m resolution. Absolute accuracy of its vertical component (RMSE = 0.84 m, standard deviation = 0.64 m) was specified in the quality assessment [5].

2.2 Fuzzy viewshed

"Fuzzy viewshed" toolbox that we created is using the membership function:

$$\mu_f = \frac{1}{1 + 2\left(\frac{d - b_1}{b_2}\right)^2} \quad \text{for } d > b_1; \tag{2}$$

b_1 is the distance of clear visibility, d Euclidean distance, and b_2 critical distance for an object to be recognized by human eye:

$$b_2 = \frac{h}{2\tan(\beta/2)} \quad , \tag{3}$$

where h is the size of an object (height or width), β is the recognition acuity of human eye. [3, 6]

We computed the fuzzy viewshed to determine the area, where a standing person could be visible, assuming the observer height 1.5 m (the height of eye line) and the size of the target 1.64 m (average height of a Neolithic man [1]).

2.3 Probable viewshed

The computation of probable viewshed is described in [2] using Monte Carlo simulation; it represents the possibility of a cell being visible considering the DEM inaccuracy, which is expressed as a value from the interval [0, 1]. We created the "Probable Viewshed" toolbox using this approach combined

with an option of considering the spatial autocorrelation of the DEM error using low-mean filter, as suggested by [4, 7].

A probable viewshed was calculated for each roundel from 100 random realizations. We used the uniform distribution with low-mean filter. Given the size of roundels and their mutual distance, it wasn't necessary to consider the fuzzy character of visibility in determining the mutual visibility of the objects. To inquire about visibility patterns, multiple probable viewsheds were calculated for two sets of four mutually visible roundels.

3 Results and discussion

The fuzzy viewshed analysis (an example - Figure 1) showed that there is a possibility to recognize a person standing in front of a neighbouring roundel (assuming the roundel itself was visible).

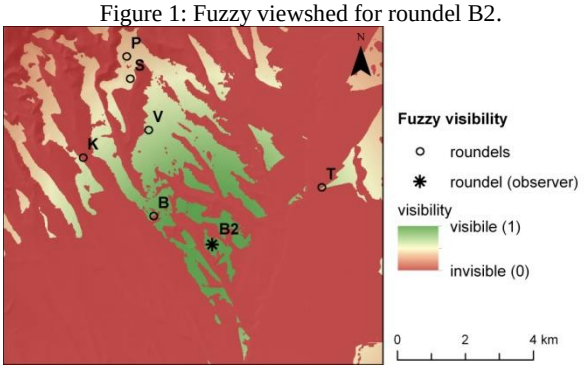
The probable viewshed was used to determine the mutual visibility (Table 1). Two roundels (T, K) are not mutually visible with the others (very low values). In the set of 5 roundels, there are two mutually visible quadruples (P-B-B2-V; S-B-B2-V). P and S, which are only about 660 m distant from each other, are not mutually visible. These two roundels have similar visibility patterns in relation to other 3 roundels (B, B2, V), as can be seen from multiple probable viewsheds (Figure 2, Figure 3). Values of cumulative probability represent sums of single probable viewsheds: a value close to 4 means that this location was probably visible from each observing point. It is thus possible, that one roundel replaced the other because of better position.

Table 1: Probable visibility of the monuments

roundel	B*	P*	S*	B2	V	T	K
B*		1.00	1.00	0.88	0.97	0.00	0.00
P*	1.00		0.20	0.99	0.87	0.99	0.00
S*	1.00	0.40		0.98	0.70	0.00	0.00
B2	0.92	1.00	1.00		1.00	0.25	0.00
V	1.00	0.88	0.70	0.98		0.65	0.00
T	0.00	0.30	0.05	0.25	0.50		0.00
K	0.00	0.00	0.00	0.00	0.00	0.00	

* confirmed roundels

Figure 1: Fuzzy viewshed for roundel B2.



4 Conclusions

Fuzzy viewshed and probable viewshed are tools providing additional information compared to the binary viewshed analysis. Fuzzy viewshed expresses the change of the level of visibility of analyzed object due to its size and distance from an observing point. Probable viewshed provides estimation of the effect of a DEM on calculated visibility; it can be used to confirm that the visibility is not caused by the error of the DEM. We created "Probable Viewshed" and "Fuzzy Viewshed" toolboxes in ArcGIS ModelBuilder; both are published on ArcGIS Resources.

We used these tools to analyze the visibility of prehistoric monuments (roundels). From 7 objects, there are two sets of four mutually visible roundels. The placement of these quadruples of roundels enables to recognize (i) a person standing in the surroundings of at least one neighboring roundel, (ii) all other structures. This suggests possible defense or cult function, because this placement is convenient for signal exchange: to send a warning or participate in a ritual. However, more research is needed to confirm these hypotheses, particularly geophysical measurements to confirm their age and origin and consideration of other factors that affect visibility.

Figure 2: Multiple probable viewshed of roundels P-B-B2-V.

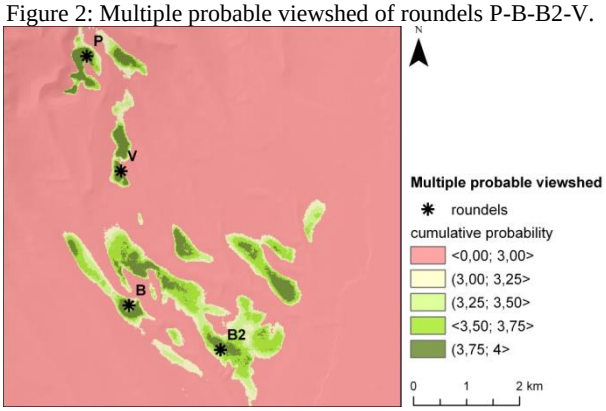
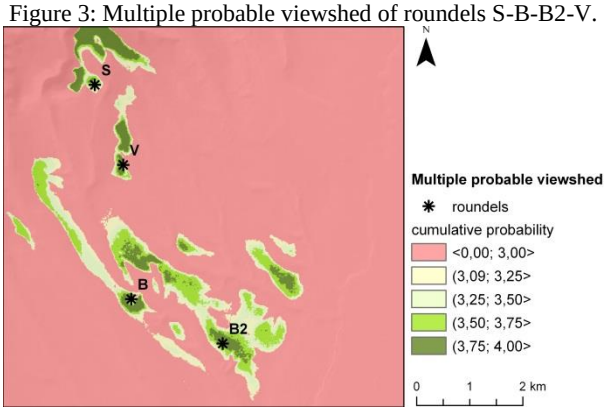


Figure 3: Multiple probable viewshed of roundels S-B-B2-V.



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