Visualization of landscape changes and threatening environmental processes using a digital landscape model

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Abstract. Visualizations supported by new geoinformation technologies prove to be appropriate tools for presenting and sharing the research results by professional and general public. The object of the research was to evaluate the benefits of visualizations for the non-expert users. The subject of evaluation was: the success rate of interpreting the information; forming of a realistic idea of the unknown landscape; and the preference of the users during selection of the appropriate visualization for the purpose of solving the task. The tasks concerned: assessing the current situation and changes of the landscape; assessing the erosion in the landscape; and the ways of their visualizing. To prepare and process the landscape visualizations, it was necessary to select areas allowing tracking of land use changes and representative environmental processes. Then the digital landscape model was created and a number of visualizations were generated. The results of visualization testing show that the users prefer maps to orthophotos, they are able to formulate correct statements concerning the landscape with the help of visualizations, and that the simulated fly throughs represent a very suitable tool supporting formation of a realistic ideas about the landscape.

1. Introduction

Visualization is one of the ways of analyzing and presenting spatial relationship. Visualizations help form a realistic idea of spatial relations of the presented result, the landscape, its changes and environmental processes. Therefore, they profoundly affect decisions and actions of people, whether from the scientific community, management, or residents of the landscape. It is also possible to visualize the landscape changes. There can be many ways of visualization. Interpretation of visualized information is affected not only by the visualization form, but also by a personal preference (i.e. giving preference to a map or an image) and experience of a user (i.e. expert or non-expert). The object of the research was testing of visualizations depicting situation of landscape, landscape changes, and environmental processes. Among various environmental processes, the erosion was selected as the process suitable for both modelling and user analysis of the causes of its origin or other contexts. It was necessary to prepare reliable data enabling to visualize the landscape changes and to understand the contexts concerning human intervention and existing environmental problems. A great emphasis was placed on selecting a test area where the landscape changes and erosion can be studied. Finally, the agricultural landscape type with the land use that changed completely during the last sixty years was selected. The image of the original agricultural landscape was recorded on the aerial photographs taken in the early 1950’s. These aerial photographs and old military maps enabled a reconstruction of the historical land use. To perform the research investigation the following questions were created: 1. Do the non-expert respondents chose appropriate visualizations to support the set statement? 2. Do they prefer an orthophoto or a map? 3. To what extent they create an appropriate statement with respect to a particular visualization? 4. Is a simulated fly through an appropriate tool for visualizing of the changes in a landscape? 5. Has the name of the

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visualization any effect to its use within a particular task? 6. Which visualizations are preferred in subjective assessments: 2D or 3D? 7. Is a subjective assessment better for map visualizations or for orthophoto visualizations? 8. Are the visualizations being subjectively better assessed used for solving the tasks more frequently?

2. Materials and methods
To prepare testing of visualization it was necessary to find an area complying with a possibility of visualizing the land use change and erosion processes. Concurrently, it was necessary to select the area that was covered with aerial photographs acquired in 1953. Also the existence of other data was verified. Creation of the digital model of the landscape and reconstruction of land use information represented an essential part of preparation of the research investigation.

2.1. Test area - characteristics
The Haraska river basin in the southern part of the Czech Republic met the requirements for both the land use change and the presence of erosion. The area of the river basin is 51 km² and the length of a stream is 15.2 km. The centre of the river basin has the latitude of 49° 00´ and the longitude of 16° 50´. The erosion–accumulation relief is characterized by modelling of Quaternary process in Flyschoid sediments. Rounded ridges and wide valleys characterize the landscape. The erosion processes are significant on 50 % of the area, small landslides can also be found there. The characteristic climate of studied area is very warm with dry summer and very short transition period with warm spring and autumn up to dry winter with short duration of the snow cover. Natural vegetation is almost completely replaced by production forests and agricultural land. Cropland and small fields take 55 % of the test river basin area, forests cover 25 %, vineyards cover 6 %, and gardens and orchards take 4 % of the area. Built-up areas cover 2 % of the area. Cropland lacks vegetation cover for a significant part of the year. That fact together with the cultivating of corn and sunflower and non-contour ploughing increases the risk of soil erosion.

2.2. Creating the digital landscape model of the river basin
The digital landscape model was created for the test river basin. [2] defines the model as "at least three-dimensional computer-generated scheme of a selected segment of the Earth landscape capturing its fundamental structural and dynamic features in a simplified but integrated form". Digital landscape model is a digital representation of a particular area of the landscape depicting its natural and anthropogenetic condition. According to Kovařík in[3] preparation of the model comprise the following five phases: preparation of the source material and data; creation of the landscape model; verification of the model; exploitation of the model; visualization of the model. Integrated synthetic geodatabase of the landscape model of the Haraska river basin was created using the method of the landscape synthesis from the individual layers such as relief, geology, soils, drainage, climate, humidity conditions, biota, current land use, original land use in 1953, current aerial photographs, aerial photograps from 1953, digital terrain model

2.3. Reconstruction of land use and landscape processes in the river basin
To visualize the changes in a landscape it was necessary to create a current land use and to reconstruct a historical land use. This reconstruction methodically follows the works of Bouma J and Varallyay G and Batjes N H in [4] and Boltižiar M and Brůna V and Křováková K in [5], related to reconstruction and analysis of historical land use in the Central European region Historical land use of the test river basin was created using data obtained from the aerial photographs that were acquired in 1953 and from the military maps coming also from 1953. Vector layer showing the land use in 1953 was created by manual digitizing using a mosaic of the orthorectified aerial photographs. Current land use was obtained from mapping in the terrain; an appropriate vector layer was created by digitizing of a terrain sketch and the current orthophotographs. Comparing sixty-year old way of using the intensively exploited agricultural landscape with the current one shows the features that would be possible to present using visualizations and to test them. Forests were preserved in both the area and locations. Sloping lands in many places were adjusted as terraced and they were further used for planting of vineyards. Overall, the biggest change of the landscape was joining of originally small fields into the large pieces of land. This is apparent from the aerial photographs and also from the visualizations of both current and historical land use. Erosion was chosen as an example of landscape
processes. For the test river basin and both epochs (2013 and 1953) it was determined the following: areas potentially prone to erosion due to a terrain slope (slope greater than 15 \%) and a high-risk land use category (arable land, vineyards and orchards).

3. Visualization of the landscape changes and environmental processes
Visualizations using new geoinformation technologies are used for presenting and sharing of geographic information about a landscape. When considering a general visualization for decision making, it is by [6], always necessary to take into account the particular user and a task that has to be sorted out An evaluation of visualizations was presented by [7,8].

3.1. Processing of visualizations
To test the user assessment of visualizations of landscape changes and environmental processes the visualizations of the Haraska river basin digital landscape model were created. A total of 9 visualizations were selected for testing - 5 in 2D, 3 in 3D, and one 4D simulated fly through. The 2D visualizations were the following: the river basin landscape on a current colour orthophoto and on a historical black and white orthophoto acquired in 1950's; current and historical land use; and areas affected by erosion. The digital terrain model generated from the 10 m spacing contours was used as a background for 3D visualizations. The 3D visualizations depicted a view of a current orthophoto; historical orthophoto; and a result of erosion modelling. The video sequence with a simulated fly through showed the views of current and historical orthophoto. The fly through starts above a current landscape in a form of a colour orthophoto that is smoothly changed into the landscape as it was in the past. A gradual transition of views is important for the spectator - a transformation of the landscape takes place before his or her eyes as the current orthophoto gradually fades and the historical orthophoto comes out. Large areas of joined fields transform into small fields, modern built-up areas transform to the original form of housing, a view of terraced slopes transforms to the original shapes of slopes. This fly through shows directly the changes in time therefore it was labeled as the 4D visualization. An overview of the visualizations is shown in table 1.

3.2. Testing
A test group was composed of 39 students of geography teaching aged 19 and 20 years. There were 25 women and 14 men. Tested persons worked independently on a computer with all the visualizations and the fly through. There was no time limit set for the task.

Table 1. Overview of the test visualizations.

| Visualization label | Description                                      |
|---------------------|--------------------------------------------------|
| A                   | 2D view - current orthophoto                      |
| B                   | 2D view - current land use                        |
| C                   | 2D view - historical orthophoto                   |
| D                   | 2D view - historical land use                     |
| E                   | 2D view - results of erosion modelling            |
| F                   | 3D view - current orthophoto                      |
| G                   | 3D view - historical orthophoto                   |
| H                   | 3D view - results of erosion modelling            |
| I                   | 4D simulated fly through                          |

To assess the visualizations, there were four types of tasks focused on interpretation, preference, and subjective assessment of individual visualizations.

The first task consisted in selecting the two most suitable presentations supporting a particular statement related to the landscape, its exploitation, and the land use change. With a consideration of the visualization order (i.e. selection at the first or the second place) the user's preference was assessed. The statements were phrased in such a manner to correspond with existing visualizations and it was possible to select at least one suitable visualization. Table 2 shows the phrasing of the test statements.
Table 2. Test statements.

|   | Statement                                                                                           |
|---|---------------------------------------------------------------------------------------------------|
| 1 | Forests cover one third of the test river basin                                                     |
| 2 | Forests cover primarily slopes and hills                                                             |
| 3 | Total area and locations of forests are the same for both 1950’s and today                          |
| 4 | Forests in the landscape have evolved significantly over the last 60 years                          |
| 5 | Method of today’s land use has changed considerably since 1953                                      |
| 6 | The original landscape comprised small fields, today’s landscape comprises large pieces of land     |
| 7 | Potential erosion areas are distributed primarily on the slopes                                     |

The goal of the second task was to determine whether the test persons formulate correctly - using visualizations - the three statements related to the erosion. They were asked to match the statement and the visualization label supporting that statement. The term ‘erosion’ was used in the names of two of the visualizations and the preference of that particular visualization compared to other visualizations was assessed.

The third task was focused on assessing the level of concept of a landscape created by the respondents. The test persons watched the simulated fly through and their task was to describe aptly the landscape. The fourth task consisted in a subjective assessment of the visualization, i.e. how the respondent likes it. The test persons marked the visualizations using a scale of values between 1 and 5 where the mark 1 meant the assessment of „excellent, I like it“ and the mark 5 the assessment of „bad, I do not like it at all“.

3.2. Evaluation

Evaluation of the task 1. Respondents were selecting among the available visualizations. Success rate assessed by a selection of at least one suitable visualization achieved 62 % or more. Considering a preference of visualizations it was shown that the respondents preferred a map to an orthophoto. When determining a distribution of erosion on the slopes, the respondents evaluated correctly (62 %) the need to employ either the 3D or 4D visualizations. Evaluation of particular tasks is shown in detail in table 3.

Table 3. Evaluation of the Task 1 - selecting visualizations suitable to support the statements

| Statement | Appropriate combination of visualizations | % of respondents selecting two suitable visualizations | % of respondents selecting one suitable visualization | Visualization preference |
|-----------|------------------------------------------|------------------------------------------------------|-----------------------------------------------------|--------------------------|
| 1         | B, A                                     | 32                                                   | 53                                                  | B – 42 %                 |
| 2         | F, I                                     | 29                                                   | 64                                                  | F – 51 %                 |
| 3         | A, B, C, D                              | 71                                                   | 12                                                  | B – 23 %                 |
| 4         | A, B, C, D                              | 11                                                   | 11                                                  | A - 18 %                 |
| 5         | A, B, C, D, F                           | 79                                                   | 13                                                  | F – 16 %                 |
| 6         | A, C, F                                 | 34                                                   | 29                                                  | F – 17 %                 |
| 7         | H                                        | -                                                    | 62                                                  | H – 57 %                 |

Evaluation of the task 2. The respondents' own statements concerning erosion processes within the test river basin and selection of visualizations supporting that statement were evaluated. Statements related to the erosion processes were formulated correctly in 66 % of cases. However, selection of a suitable visualization was facilitated by the fact that the name of an appropriate visualization contained the term "erosion", that is it suggested itself as a suitable selection to formulate the statement related to erosion. The test persons selected correctly the visualization of erosion that was usually supplemented with other visualizations depending on the content of their statement. Success rate of selecting the suitable visualization was 85 %. Here are the examples of responders' answers: "Erosion affects agricultural areas (visualization E)"; "Erosion affects the slopes, especially those sloping towards the watercourses, i.e. the steep slope (visualization H)"; "The reason for the
accelerated erosion affecting some slopes might be a wrong ploughing, i.e. that non-contour one (visualizations E, G, and I)."

Evaluation of the task 3. After the respondents described the landscape and its changes, it was evaluated whether they expressed the typical attributes of the landscape: land use condition, land use change, hilly character of the test river basin, distribution of forests, and slope terracing. It was discovered, that 70 % of descriptions was very apt (minimum of 3 attributes), 17 % was apt (minimum of 2 attributes), and 13 % was little apt (only one or no attribute). Here is an example of the description: "The most significant changes are (1) the cultivation of fields that were small private fields in the past but today, there are large pieces of land; (2) forestation, especially at the peaks and the steep slopes; (3) expansion of built-up areas, i.e. bigger areas, formation of new settlements; and (4) building of new roads."

Evaluation of the task 4. The arithmetic mean and the mode were computed for the subjective assessments of particular visualizations. The current maps, the historial land use, and the simulated fly through were the most appraised visualizations. The 2D visualizations, such as both historical and current orthophotos, were well appraised. The 3D visualizations were less appraised than the 2D visualizations. Respondents did not give reasons for their evaluation. The average values of marks are shown in table 4.

Table 4. Subjective assessment of the test visualizations

| Visualization label | Description                              | Assessment Arithmetic mean | Assessment Mode |
|---------------------|------------------------------------------|----------------------------|-----------------|
| A                   | 2D view - current orthophoto             | 2.3                        | 2               |
| B                   | 2D view - current land use               | 1.7                        | 1               |
| C                   | 2D view - historical orthophoto          | 2.1                        | 2               |
| D                   | 2D view - historical land use            | 1.9                        | 2               |
| E                   | 2D view - results of erosion modelling   | 2.4                        | 2               |
| F                   | 3D view - current orthophoto             | 3.6                        | 3               |
| G                   | 3D view - historical orthophoto          | 3.8                        | 3               |
| H                   | 3D view - results of erosion modelling   | 2.3                        | 2               |
| I                   | 4 D simulated fly through                | 1.9                        | 2               |

4. Results
A comprehensive presentation using visualizations supported by geoinformation technologies is a necessary component of geographic research. Testing of visualizations showed that (1) respondents - even those without a deep experience with geoinformation technologies - aptly selected a suitable visualization to support the particular statement; (2) respondents preferred a map to an orthophoto; (3) respondents formulated correctly the statements based on presented test visualizations; (4) after watching the fly through, the test group aptly described the landscape and its changes; (5) a name of the visualization affected selection of visualization meant for dealing with a task; (6) the 3D visualizations were less appraised than the 2D visualizations. The visualizations being subjectively better appraised were also employed more often for solving the tasks. On the basis of presented research it is possible to recommend to the non-expert users to use simulated fly throughs and the 2D visualizations, especially digital maps. The testing of visualizations and their capabilities to provide necessary information to the public shows a very good efficacy of visualizations as the communication means. The research works currently continue with a test group of primary school children in order to express the relationship between the age of a user and his or her ability to interpret visualizations and also to test the visualizations adapted to various user groups differing in age, gender, and specialization.
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