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EXPERIMENTAL INVESTIGATION OF VISUALIZATION METHODS OF EARTHQUAKE CATALOGUE MAPS

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Abstract. The aim of the study is to find possible solutions to represent earthquake catalogue data and design maps which can help non-professionals to identify those places where earthquakes occurred frequently. The goal is to visualize all available catalogue data sets in a complex way on a single map, displaying the long-term recurrence times of earthquakes. Therefore, raw data and aggregated data were combined with different cartographic visualization techniques to test the applicability of earthquake maps. Preliminary research demonstrates that aggregation can improve the process of retrieving information from earthquake maps and 3D visualization is useful to find the places of earthquakes of highest magnitude. A second result is that 3D visualization is not effective in the comparison of quantities of released energy and the number of earthquakes.

Keywords: cartography, GIS, visualization, earthquake catalogue, 3D mapping, user needs.

Introduction

The catalogue is most valuable for scientists and non-experts as well. The authors in their former study recognized that the recent dataset of the regional earthquakes of Hungary became so large that the necessity of finding various visualization techniques became inevitable. There is a long tradition of representing earthquakes on maps. In a study, the authors gave a brief overview of the difficulties in the cartographic representation of large datasets such as the earthquakes data catalogue of Hungary and the adjacent region was outlined (XXXXXX 2010).

The authors have already made the first attempts to find the optimal visualization technique for representing the data of the Hungarian Earthquake Catalogue (XXXXXX 2011). An effort was made to combine the traditional cartographic symbols system and the possible visualization techniques offered by modern GIS software. The goal was to visualize the whole catalogue in a complex way on one map, as, showing the long-term recurrence times of earthquakes, using all available dataset ArcGIS and 3D Analyst extension can be possible tool in visualization of earthquakes and in finding earthquake faults (Gooding 1998). The seismic source zones are defined from seismicity distribution and seismotectonic criteria, and need a complex data handling on maps (Grünthal *et al*. 1999).

The problems in the visualization of the data sets are as follows. (1) The amount of data is large, representing a catalogue of a 1500-year-period; therefore, the symbolization of all the data on a single map is very complicated. (2) Another problem is the data quality, as data were not gathered two hundred years ago in the same way as today; nowadays, scientists gather instrumental and macroseismic earthquake data and deal with definition of earthquake focal parameters too. (3) The determination of the exact location of the epicentres is not uniform either throughout the Catalogue.
The specific goal of this research was to analyse the usability of various visualization methods for earthquake catalogue data among non-professionals. The questions were: (1) what kind of information can be retrieved by a test person analysing maps created with different methods, (2) which visualization method is the most suitable to show the events, (3) how effectively can non-professionals compare the value of magnitude, energy etc. on the differently designed maps, (4) how one can

estimate the value of magnitude or energy of earthquakes of a specific space. Testing the use of prediction maps was not the task of this study, though the present results can be implemented in the future in preparing such kind of maps. The effectiveness of prediction maps is very much dependent on the fact how the mathematical function of the prediction is working behind. Meanwhile, the findings of the present research would be a good basis in creating high-quality prediction maps helping to choose appropriate visualization methods for the communication.

1. Catalogue of earthquakes in Hungary

As major earthquakes have occurred recently (Stein *et al*. 2012, 2011; Chen, Wang 2010), an extensive discussion developed among seismologists concerning the discrepancy between the earthquakes and prediction maps (Kerr 2011). Researchers analysed the problem and they realized that these maps have to be retested and the communication with the local communities must be enhanced. It is still problematic to predict the place, time and magnitude of future earthquakes. Locations of past small earthquakes are good predictors of the location of future ones (Kafka 2007), so the earthquake catalogues are very important for this purpose. In contrast, according to some scientists (Stein, Liu 2009), these small earthquakes may be the aftershocks of past large ones; therefore, these shocks cannot be automatically considered good indicators of future large earthquakes (Stein *et al.* 2012).
Hungary is at moderate risk of earthquakes, where earthquakes measuring M4-5 on the Richter scale occur every 15–20 years, while those measuring M6.0 or more occur only every 100–150 years. Although Hungary is not typically of the home of large earthquakes, the analysis of the several smaller ones, on which data is stored in the Hungarian Earthquake Catalogue, would be useful to indicate future ones. The earthquake catalogue indicates significantly higher seismic activity on certain areas, where other earthquakes are expected in the future by seismologists (Tóth *et al.* 2008). To analyse the earthquake recurrence times, the use of all of the data of the Catalogue is necessary. Systematic earthquake data collection in the Pannonian region started in the nineteenth century (Zsíros T. 2000; Tóth *et al.* 1995–2001–2011). The Hungarian Earthquake Catalogue contains about 25 000 earthquakes dated from 456 A.D. until present. Earthquake catalogues are also very important in representing the seismic activity in a region. The examination of data stored in a catalogue evidently illustrates the seismically active regions, and provides a strong basis for studying the geological structure responsible for earthquakes and for developing seismotectonic models (XXXXXX, 2010).

2. Interpreting heterogeneous data

At the beginning of the test, the authors informed the test participants about the special feature of the long-time extension of the earthquake catalogue. The epicentres of several earliest earthquakes were referenced to the middle of the country, which may cause false conclusions. The communication of the earthquakes in education has a basic role. People should understand the risk of earthquake occurrence in their county. They should understand why standards like Eurocode 8 should be followed in engineering. The horizontal peak ground acceleration (PGA) was computed by probabilistic method according to the requirements of Eurocode 8 earthquake safety standard: the result was 90% probability of non-exceedance in 50 years, that is with a return period of 475 years in Hungary (Tóth *et al.* 2006).
For these purpose the authors design to test the possible way of the effective communication of visualization methods of earthquake maps.

3.Test map design

The authors tested 11 different maps based on the dataset of the Hungarian Earthquake Catalogue. These maps only show the previous and recent movements, but the prediction of the possible earthquake-locations is not their task. These maps were tested for visualization purposes and the research concentrated on how well test persons could use them in studying the history of earthquakes of Hungary.

In the fall semester 2012, 97 BSc students from land surveying and 12 BA students from public administration management participated in the Information Technology course and the introductory course of Geographical Information Systems. They took part in the test for the present study. In total 109 students (80 male, 29 female) participated in the test. The age of students was between 18 and 30. For 58% of the students, this semester was their first semester at the University of West Hungary.

The test consisted of 12 maps. The first one showed the municipalities of Hungary to help identify those territories on the other maps which were affected by earthquakes.

In visualizing earthquake data, there are several attributes which can be important: (1) date, (2) coordinate (epicentre or the hypocentre), (3) magnitude or intensity. Traditionally, the magnitude is one of the most important attributes in visualizing earthquakes, but the authors found that showing the released energy and the number of events can be just as important as presenting magnitudes. Examining the possible generalization with a help of a Borland C++ Builder program, the authors divided the study area into small grids (0.1º × 0.1º), and the program counted how many earthquakes occurred within one grid, and how much energy was released during the earthquake (E = 10(1.5M + 4.8) joules, where M = magnitude of the earthquakes).

The aggregated data for these unified cells can be easily drawn on the map. 3D visualization was also implemented as a way of representing the catalogue. This method for aggregation can handle and reduce the problem of inconsistency of the Catalogue (XXXXX, 2011).

The largest number of detected earthquakes happened in the Vértes Mountains region, but a few larger earthquakes produced significant energy release in other areas too.

4. Preparation of the test maps

The earthquakes as natural phenomena are connected to the microplate system and faults in Hungary. This phenomenon is usually displayed on maps by using graduate symbols and isarithmic method.

In earthquake maps, the colour has an important role. Several research papers discussed the optimal usage of colours for statistics (Bertin 1967; Mersey 1990). Mersey tested the hue, intensity and value, and proved that people are able to recognize easier the difference between hues than values, though in a cartographic situation when colours are separated and appear in different environment it is more complicated to recognize them. Potash (1977) stated that only 8–9 values can be recognized. However, according to Robinson (1952), 6 to 10 values can be distinguished by an untrained person. In the case of cold colours, less value can be recognized than in the case of warm colours. Using this theory McCarty and Salisbury (1961) made the first experiment with isarithmic maps, where the different impact of hue, value and intensity was analysed. Cuff's (1973) investigation showed that the progressive sequence of one colour can show the difference between quantities, but some researchers proved that traditional colour sequences are more difficult to use for test persons (Miller 1974; Saunders 1961–1962).

These theories and tradition (graduated symbols, isarithmic method) were fully considered by the authors of the present article while designing the test maps.

Each participant received the same 11 test maps with different designs, and they were asked to answer the same questions. The original database with all the data of the Hungarian Earthquake Catalogue was used on each map, but the data was handled differently. The authors also created and tested maps applying various cartographic methods.

The first map was intended to help test persons identify the different areas of Hungary (as they were not geographers, it may have caused them problems to identify places). Map 2 showed different magnitudes with graduated point symbols, Map 3 depicted energy release with graduate point symbols. Map 4 used graduated point symbols showing energy, but the data was handled with the aggregation method mentioned in Section 2.1. Maps 5–12 were different heat maps, where IDW interpolation was used to create a surface from the point data. Map 5 showed the distribution of released energy. Maps 6 to 10 showed the aggregated number of earthquakes (see Section 1.) using the result of the aggregation method designed by the authors. On Maps 6 and 10 the authors used different values of the same color (red), but isolines were also applied on Map 6. Cold hue was applied on Map 9; on Map 8. different values and hues were used. On Map 7, different values and hues were used to show the aggregated value of released energy. Maps 11–12 used 3D visualization, where Map 11 showed the aggregated number of released energy as a surface, meanwhile Map 12 gave information on the number of earthquakes.

Fig. 1. Test maps depicting the amount of released energy of earthquakes

Fig. 2. Test maps showing magnitude or the number of earthquakes

5. The experimental tasks

The purpose of the test was to simulate the experimental phases when test persons studying about seismicity.

The participants conducted the experiment in a computer lab. The maps were prepared in ArcGIS at 1 : 3 million scale. This scale allowed participants to analyse the map as a whole on the screen, but the authors experienced that they magnified the map to see the details.

The test generally lasted for 45–60 minutes. It consisted of 39 questions related to 11 maps. Each question was connected to one map indicated at the end of the question. The questions were focused on (1) how well participants could estimate where the biggest earthquakes were, (2) how well they could compare the magnitude and the number of earthquakes and the extent of released energy, and (3) how well they could put the seismic regions in ascending order according to the magnitude of past earthquakes.

The tests were designed on an e-learning platform, and the participants used this platform while answering the questions and examining the maps. Some of the test maps can be seen in Figures 1 and 2.

6. Results

Most of the test participants, 109 students of the University of West Hungary, answered and finished the test successfully, although taking part in the test was not obligatory. Only 2–3 of the participants were not able or not willing to complete the tests properly. All the answers of the 109 test persons were analysed and taken into consideration. Out of 43 questions, 39 meant a task connected to the maps (the first 4 questions were on the age, class etc. of the participants). The test contained both simple and complex tasks for the test persons.

Different questions were applied when the theme of the map (released energy or number of earthquakes) was variant. The same or similar questions were applied in the case of maps where the released energy was illustrated with different aggregation and cartographic methods. Table 1 and Table 2 show the first results of the tests.

The results clearly indicate that retrieving information from the earthquake catalogue map is not a simple process. As the spatial pattern is smoothly distributed in the case of a phenomenon like temperature, the isarithmic representation can be easily interpreted by non-scientists too. However, the earthquakes are connected to fault systems, which are not equally distributed in space. Abrupt value changes in colours are observable only on small parts of the map. However, to recognize these sudden changes may be problematic for the map-reader.

Table 1. The results of tests analysing released energy (percentage of good answers)

Table 2. The results of tests analysing the number of earthquakes (percentage of good answers)

The simplest task proved to be the determination of the location where the largest earthquake occurred. In this task, the best result was connected to the using of 3D map. Preparing the ascendant sequence of energy release was the most difficult assignment for the participants, though 3D maps seem to be very effective in this task also. A second finding is that 3D visualization is not effective in defining the exact number of earthquakes and released energy, so in the visualization of earthquake catalogue one should be careful about applying 3D visualization. These findings clarify that 3D mapping can be an effective tool if scaling and proper visualization are improved.

Analysing the results of each test, it became evident that when the questions referred to a region or the surrounding of a place, participants understood the extent of regions quite differently. In defining exact locations, the authors used a reference data layer showing the municipalities of Hungary. In the test, questions were asked about regions around or near municipalities. It was difficult for the participants to understand which extent or surroundings were connected to the given municipalities. Future research should clarify or mark on the map what extent should be analysed by the participants. Eliminating these uncertainties can improve the results.

Conclusions

Comparing different visualization methods for representing Earthquake Catalogue data, the aggregation method designed by the authors proved to be a useful tool in analyzing and processing large data for the public. The spatial patterns could also be visualized on maps, which provided a clear and well-structured image of the phenomena. Although 3D visualization was also analyzed, the result clearly shows that this method in defining differences of quantities was not very efficient but, on the contrary, in defining the highest and the lowest values and the ascending order of number of earthquakes and released energy proved to be very effective. The findings of the present study would be a good basis of making high quality prediction maps by choosing appropriate visualization methods for communicating earthquake hazards to the community.

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