Cartographic visualizations of quantitative assessment results for multiple natural hazards

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ABSTRACT
Quantitative results of natural hazards assessments are needed for diverse hazard management activities. Cartographic visualizations have proved to be effective means to communicate these results. However, the large volume of available data, the presence of multiple natural processes and the heterogeneity of the user group pose visualization challenges. In this paper, we analyze results of natural hazards assessments and present cartographic techniques for the visualization of multiple natural hazards. In addition, we discuss how interactive cartographic information systems can facilitate the communication of hazard related data among experts.

RÉSUMÉ
Les résultats quantitatifs des analyses de dangers naturels forment la base de leur propre gestion. Les visualisations cartographiques se sont montrées efficaces pour la communication de ces résultats. La création de cartes est pourtant rendue difficile par le grand volume de données, la présence de multiples phénomènes naturels et l'hétérogénéité des experts en dangers naturels. Dans cet article seront analysés des résultats d'estimations de dangers naturels, on y présentera également des techniques cartographiques pour la visualisation d'une partie de ces dangers, enfin on discutera comment les systèmes d'information cartographique interactifs peuvent alléger la communication des résultats d'analyses parmi les experts.

1 INTRODUCTION

Assessments of hazardous natural processes form the basis of natural hazard management (Kienholz 2005). Hazard maps are among the most prominent products to present the results of such assessments. These maps of suitability indicate areas that are potentially affected by hazardous events and therefore not suited for certain land-use such as residential development. If land-use is aligned with existing natural conditions the damage potential of hazardous events can be efficiently decreased (Zimmermann et al. 2005). Analyses of past events have shown that hazard maps are crucial for effective natural hazards management (Bezzola and Hegg 2008). Standard hazard maps are designed for spatial planners and only reflect information about the hazard levels of the assessed areas. Due to the lack of alternative visualizations, however, other specialists involved in natural hazards management are consulting these maps as basis for their tasks. Consequently, requirements towards hazard maps are increasing and can often not be satisfied. Hence, original quantitative results of natural hazards assessments should be made available to support all experts with their tasks (Bezzola and Hegg 2008).

Modern numerical models for the simulation of natural processes allow for the generation of quantitative hazard assessments in high resolution. Although the spatial and temporal resolutions of the applied models vary, assessment results often encompass large volumes of data. Some areas, such as valleys in mountainous regions, are prone to be affected by more than one hazardous process. The amount of simulation results is consequently multiplied. In addition, some tasks require further knowledge such as information about modeling uncertainties (Pappenberger and Beven 2006). In order to be of use for natural hazards management tasks, all data need to be available in an understandable and interpretable form for all experts and decision makers.

Cartographic visualizations have proved to be valuable means for the communication of spatial data (Merz et al. 2007) and consequently hazard assessment results are often illustrated by maps (Petrascheck and Kienholz 2003).

Apart from the diversity and the volume of available data, communication is further hampered by the heterogeneity of the involved stakeholders; Expert groups encompass engineers, scientists, spatial planners, and many other professionals. In addition, these experts work for different employers (private companies, national or federal offices, or humanitarian organizations) and are assigned different tasks. As maps need to be designed for specific end users and tasks (Slocum et al. 2008), the creation of visualizations for such heterogeneous user groups is difficult.

In response to all these challenges we developed an interactive cartographic information system for natural hazards experts. The interpretation of available hazards data – including uncertainty information – is facilitated by customizable and queryable visualizations through interactive functionality (Kunz et al. 2010). As data about several natural processes are available, the simultaneous display of these processes represents a challenge. In this paper we analyze results of natural hazards assessments, present different cartographic techniques for the visualization of multiple natural hazards, and disclose advantages of integrating these visualizations into an interactive cartographic information system.

2 QUANTITATIVE ASSESSMENT RESULTS

Cartographic representations are chosen according to the characteristics of data we wish to visualize. We therefore conduct hereafter an analysis of an exemplary data set that encompasses results of a detailed hazard assessment of a small mountainous region. Considered natural processes include snow avalanches, debris flows, rock fall, soil creep, and inundations. Except for soil creep, all results represent outputs of numerical simulations.

Table 1 summarizes the analyzed processes, the used assessment method (expert judgement, numerical simulation, or measurement), spatial data format, and spatial resolution. In Figure 1 the different spatial data formats are illustrated.

Table 1. Exemplary data set of a quantitative natural hazards assessment encompassing multiple processes.

Process	Assessment method	Spatial data format	Spatial resolution
Snow avalanche	Numerical simulation	Regular grid	5m grid
Debris flow	Numerical simulation	Regular grid	5m grid
Rock fall	Numerical simulation	Trajectories	~1 point every 5-7m
Soil creep	Monitoring data	Point measurements	~1 point per 5000m^2
Inundation	Numerical simulation	Triangulated irregular network TIN	2-10m triangle length

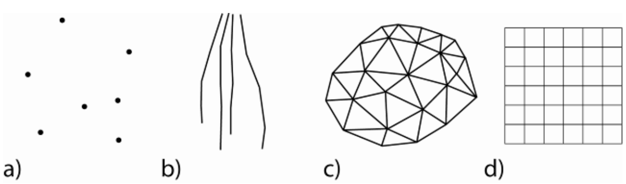

Figure 1. Different spatial data formats: point data (a), trajectories (b), TIN (c), and regular grid (d)

2.1 Data Transformations

The data summarized in Table 1 are raw data; they are not yet reformatted, interpolated, classified, nor altered according to expert judgement. However, in order to merge data sets of different processes and bring them into a uniform format, such transformations are often indispensable. Transformations are also necessary when results have to be presented according to existing standards (e.g. regional or national guidelines). Hazard assessment outputs are usually presented either in the original spatial format or as interpolated areas.

Original spatial data format: If the scale of the representation allows for a detailed reproduction of the assessment results, data can remain in its original format. Examples are the indication of exact water depths at important locations (point data) or the display of intensities in form of a regular grid with the same spatial resolution as the outputs of the numerical simulations.

Interpolated areas: As for some tasks the exceedance of thresholds is of greater interest than small variations, assessment results are often interpolated, classified and presented as discrete areas. Such interpolations can result in areas with jagged borders that make it necessary to smooth these outlines in order to allow for visually appealing representations. Prominent examples of such interpolated and classified areas are hazard zones and intensity classes.

3 CARTOGRAPHIC VISUALIZATIONS OF ASSESSMENT RESULTS

Once all assessment results have been transformed to the required format, available data can be visualized. When assessment results of more than one natural process are available, these data sets can either be visualized as single processes in separate layers or as multiple processes in one layer.

3.1 Visualizations of Single Processes

3.1.1 Classified Data

The most common cartographic representations of assessment results are hazard maps in which results are classified into different hazard levels and presented in form of coloured areas. These hazard zones are determined according to the intensity and frequency (if available) of potential hazardous events. Each affected area within the assessment perimeter is assigned to a hazard class; the levels usually reach from low hazard over moderate hazard to high hazard.

Figure 2 shows a hazard map for potential mass movements where low hazard zones are depicted in yellow, moderate hazard zones in orange, and high hazard zones in red.

Figure 2. Hazard map of mass movements (yellow = low hazard, orange = moderate hazard, red = high hazard) (base map reproduced with the authorization of swisstopo (JD100042; hazard data: courtesy of Canton SG)

Other representations of classified assessment results are intensity maps in which the calculated intensities are usually classified according to regional or national guidelines and visualized in form of coloured areas. Apart from colour fill, the application of textures is used to present areas of different values. In order to avoid the occlusion of underlying data (e.g. base map or further thematic data layers), areas can also be represented by their outlines only. Distinction between classes is accomplished by different line colours or patterns (variations of dashing).

Alternatively, hazard data can be presented in 3D displays. Examples are visualizations where assessment results are mapped to perspective height. Figure 3 shows a prism map with maximum glacier heights during the Würm glaciations as it is provided by the Atlas of Switzerland (AoS 2010).

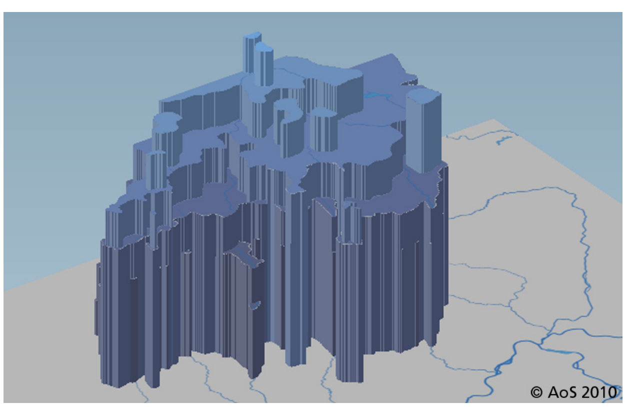

Figure 3. 3D prism map of the maximal Würm glaciation

3.1.2 Original Data Formats

Hazard maps with their areal representations of discrete hazard zones have been developed for spatial planning purposes. Other natural hazards management activities such as the planning of defence structures, however, require more detailed information about the intensities and frequencies of potential events. For such tasks, detailed maps with representations of assessment results in the original spatial data format are needed. Figure 4 shows impact pressures of a snow avalanche simulation with a spatial resolution of 25m presented in a continuous blue colour scheme (light blue = low impact pressures, dark blue = high impact pressures). Exact values can be retrieved by interactive functionality: querying functions (e.g. tooltip windows) provide the calculated values of each data cell.

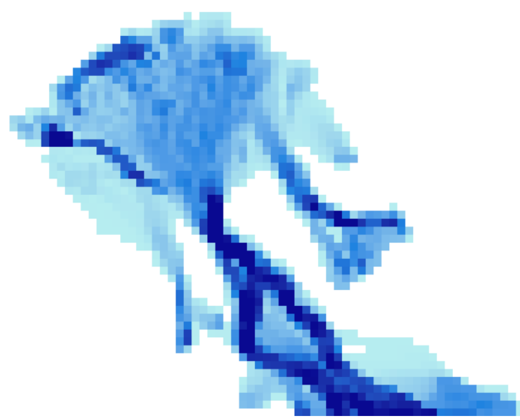

Figure 4. Results of a numerical snow avalanche simulation: Representation of impact pressures in the original spatial data format (25x25m grid)

A potential method for the visualization of detailed intensity data in 3D is the application of bar charts. For this purpose assessment results are adopted as or transformed to a regular grid format. Hazard levels are mapped to perspective height resulting in a bar chart for each grid cell (see Figure 5). The analysis of these bar charts can also be facilitated by interactive queries.

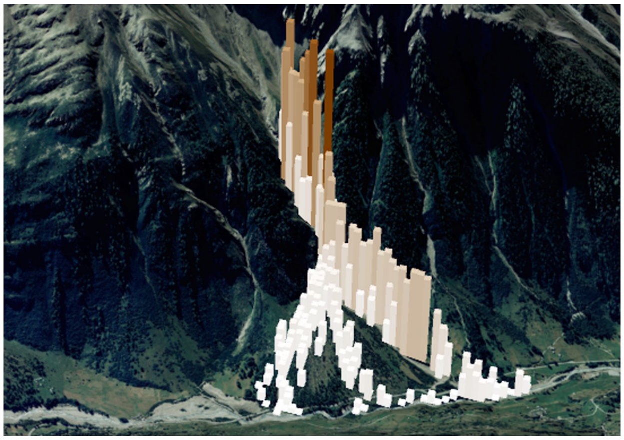

Figure 5. 3D bar chart representation of debris flow heights (aerial image reproduced with the authorization of swisstopo (JD100042))

Perspective height, however, is not restricted to the visualization of data in grid format or to bar chart representations. Data in Triangulated Irregular Network (TIN) format as well as areal vector data (e.g. shape files) can be mapped to perspective height, resulting in prism maps similar to the one presented in Figure 3. Alternatively, heights can be interpolated and represented in form of a smoothed surface (see Figure 6).

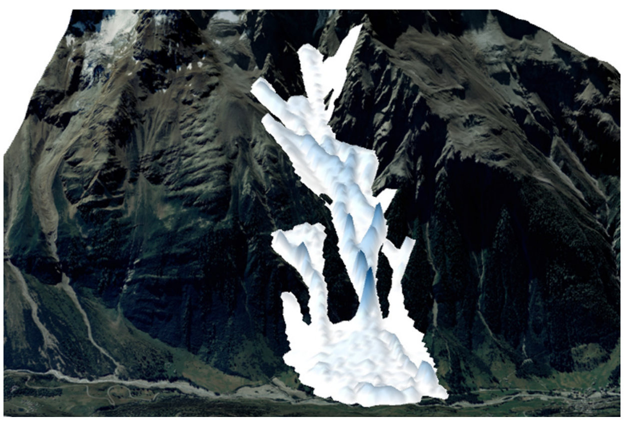

Figure 6. Snow avalanche heights represented by a smoothed surface (aerial image reproduced with the authorization of swisstopo (JD100042))

3.2 Visualization of Multiple Processes

3.2.1 Classified Data

In order to determine the total hazard of an area, the maps of all occurring single processes have to be aggregated. If the highest hazard level is extracted for each location and visualized in a separate map, this results in a so called synoptic hazard map. In case that not only the total hazard but also its sources are of interest all present processes need to be symbolized as well. Existing methods for the visualization of multiple processes include the application of textures (see Figure 7a in which the different processes are represented by a variation of hachures), labels (in Figure 7b each process area is marked by a label with abbreviations of the process and a figure for the intensity level), and coloured outlines (in Figure 7c process areas are bounded by lines in different colours: green = soil creep, red = rock fall, purple = flooding and yellow = snow avalanche).

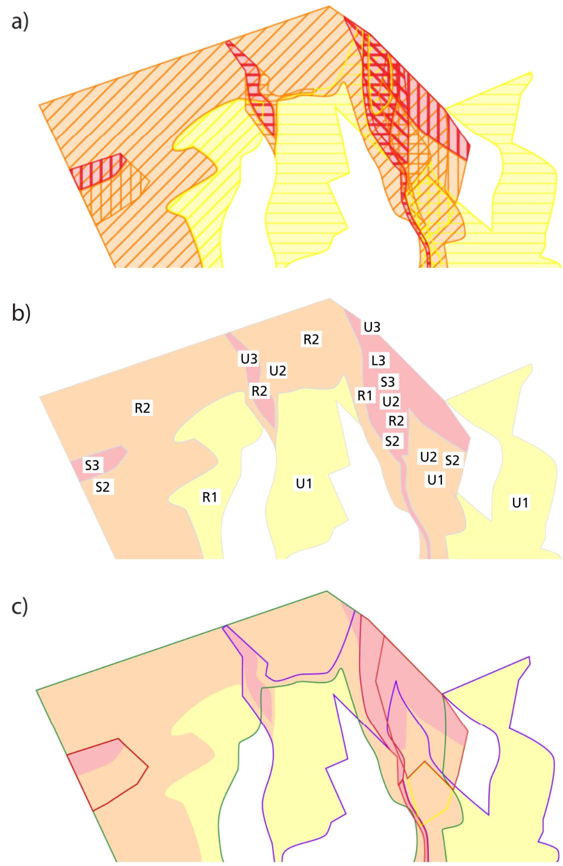

Figure 7. Symbolization of different processes by application of texture (a), labels (b), and coloured outlines (c) (hazard data: courtesy of Canton SG)

If too many processes occur in one location this leads to congestion of symbolization and consequently to occlusion which lead to an unbalanced map appearance (see e.g. Figure 7a). In order to reduce occlusion, gridded patterns can be applied. This method retains the application of a coloured area fill representing the highest hazard level. In addition, the single processes are represented by point symbols that are regularly distributed within the process area. To render the symbolization intuitively interpretable, the forms of these symbols illustrate the processes (snowflakes for snow avalanches, squares for rock fall, arrows for soil creep, and water drops for inundations) and their colour stands for the hazard levels of the single processes (Romer, 2009). As the point symbols are arranged on a regular grid, no overlay occurs (see Figure 8).

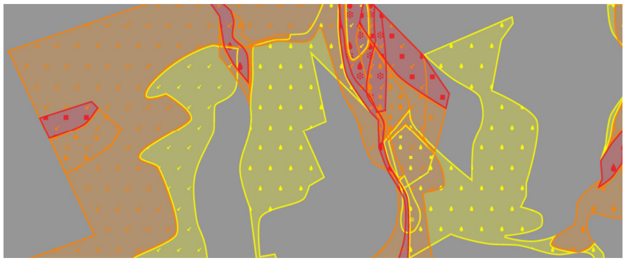

Figure 8. Reduction of occlusion by gridded textures (hazard data: courtesy of Canton SG)

In case of many small areas even the application of gridded texture does not lead to a satisfying result (either due to the cropping of symbols or because of a confusing appearance due to too many symbols). In this case it is suggested to gather information about the total hazard from a synoptic map that does not contain information about the single processes and then look up data about the individual processes in separate maps. This layer-based approach may be quite inconvenient for paper maps, however, interactive functionality of digital information systems often offer layer structures that facilitate the adding and removing of layers from the display.

3.2.2 Original Data Formats

The visualization of detailed multiple intensity data in their original formats is a challenge because of the limited space that is available to simultaneously depict multiple results. If only few data sets are overlaying accumulations can be represented by the combination of different colour hues. Possible 3D representations are the accumulation of bar charts; each process is assigned a colour and the dingle bars are placed on top of each other. Figure 9 shows such accumulated bar charts.

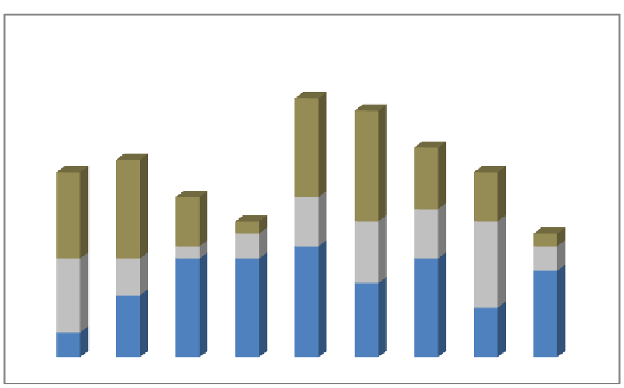

Figure 9. Accumulated bar charts for the representation of multi-hazard data sets

4 INTERACTIVE CARTOGRAPHIC INFORMATION SYSTEM

The integration of the presented visualization techniques into an interactive cartographic information system can facilitate the interpretation of the data. A big advantage of such systems is thematic and spatial navigation allowing users to inspect available data, choose the ones of interest, and to freely adjust their visualizations in order to get the desired viewpoint. In addition, users can choose from different visualization methods and customize them according to their needs (described in detail in Kunz et al. 2010).

A major advantage in respect of multi hazard representation is the possibility to interactively query the data and retrieve detailed information about the assessment results.

A further issue that is facilitated by interactive systems is the inclusion of uncertainty visualizations. A complete list of the advantages of interactive cartographic information systems can be found in Hurni (2008).

In order to benefit from these advantages we developed an interactive cartographic system for natural hazards experts. Figure 10 shows the graphical user interface (GUI) of the system which is characterized by its lean design without many buttons and menus.

Our system offers a layer structure from which users can select the data they wish to explore and therefore remove disturbing or confusing information from the display. Apart from different 2D visualization methods, a block diagram mode with 3D symbolization is offered. Interactive functionality allows for zooming and dragging of the maps and in case of 3D visualizations also for rotating and tilting. This navigation is either possible with the help of the navigation tool (top right in Figure 10), by mouse actions or by keyboard.

Data can be queried by the provision of tooltip information; whenever the mouse is moved over symbolization detailed information can be displayed in a window next to the cursor. Concerning multiple natural hazards, this information contains results about the total hazard as well as about the single processes. Additional information such as details about the assessment methods, input parameters, or used interpolation algorithms can be provided in additional windows or status bars.

Furthermore, the system provides information about uncertainties that are present in natural hazards assessments. Uncertainty information is included in the tooltip windows and can also be visualized in the same way as any other assessment results by 2D or 3D representations. At this point uncertainty is represented by standard deviations, ranges and variation coefficients for assessment results originating from numerical modeling.

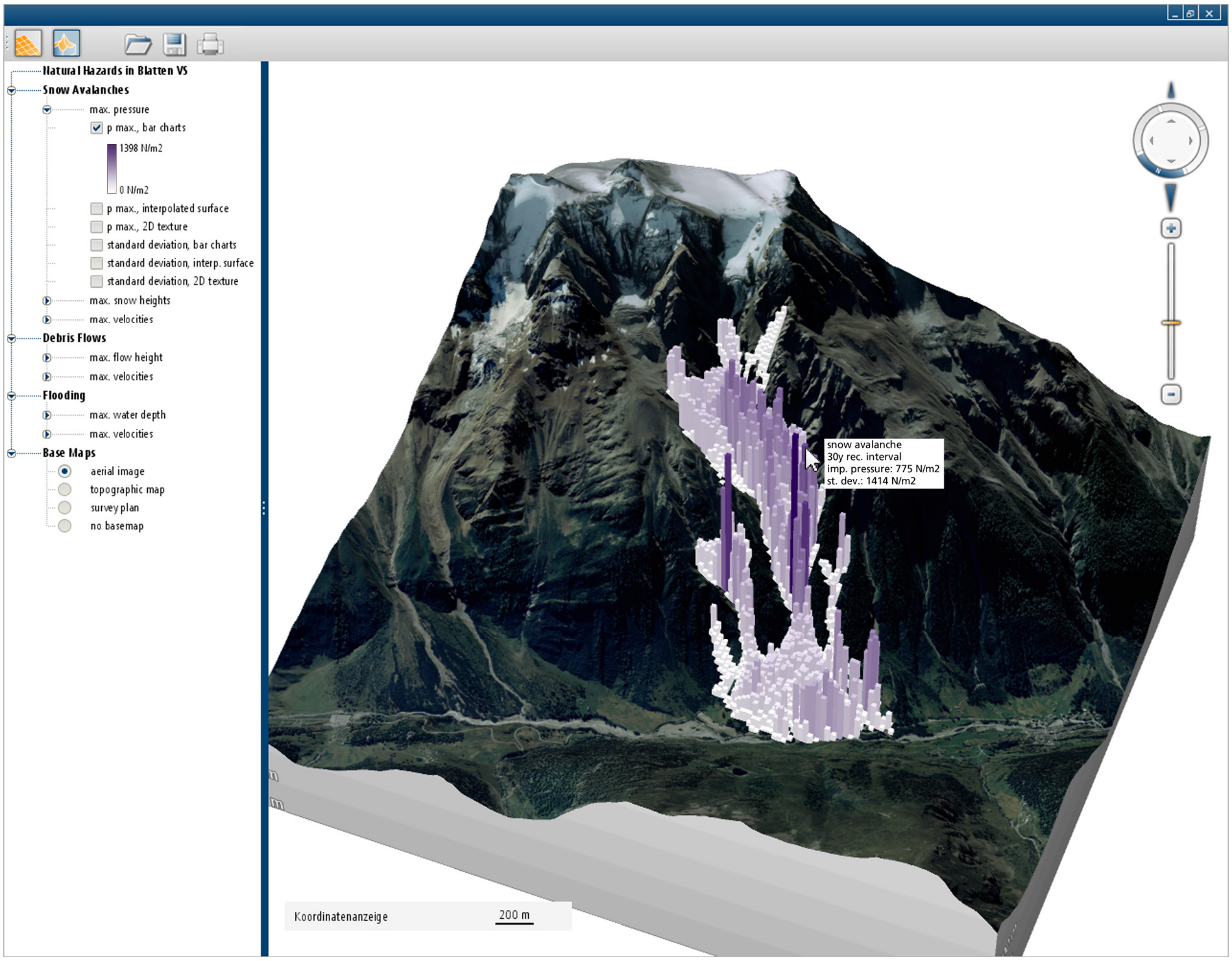

Figure 10. Graphical user interface of the cartographic information system (aerial image reproduced with the authorization of swisstopo (JD100042))

5 CONCLUSIONS

Assessment results for multiple natural hazards can be visualized in their original data format or classified in form of areal symbolization. Various methods in 2D and 3D exist for the representation of single processes as well as for the depiction of the total hazard situation. The aggregation of results for multiple hazardous processes can result in occlusion of symbolization and/or an unbalanced map appearance that can confuse users.

Interactive systems can facilitate the presentation of such multivariate data with the help of interactive functionality. Advantages of cartographic information systems include thematic and spatial navigation, the display and navigation of 3D visualizations, the possibility to query the data (extraction of exact data values), as well as the option to provide different visualization methods (which allows the user to choose the most appealing method).

The provided layer structure and the option to gather detailed information with the help of interactive queries offer an alternative to complicated multivariate maps. This facilitation of the interpretation of assessment results renders interactive systems into valuable tools for knowledge transfer. This supports the communication among experts which is crucial for effective natural hazards management.

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