
The Application of Geospatial Technology in Hazards and Disaster Research – Developing and Evaluating Spatial Recovery Indices to Assess Flood Hazard Zones and Community Resilience in Austrian Communities

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Abstract

In this study geospatial information technologies are utilized in the field of flood hazards and disaster research to successfully apply a Spatial Recovery Index (SRI) to assess the level of recovery and community resilience for a selected region in Carinthia (Austria). This research is one of the first that uses a SRI to assess the resilience for a selected region in Europe. This work expands on current disaster research, primarily carried out in the U.S. to combine both U.S. and European concepts into one single decision support system. The result of this work is a modified and usable model for European post disaster urban environments to identify spatial indicators of recovery. The analysis includes specific recovery indicators, such as hospital or school locations and flood hazard indicators, such as flood-prone areas, rivers, and a digital elevation model. By combining both components into the SRI, the final outcome produces a grid file, which provides a suitable depiction of the recovery process in selected municipalities in Carinthia. This application supports emergency management officials in the evaluation of environmental risk, community resilience, and long term damage assessment. Such a flexible usable spatial tool will allow these officials to make informed management choices regarding disaster recovery.

1 Motivation

If the first decade of the twenty-first century has demonstrated anything, it is that natural disasters and hazards are increasing in number as well as intensity. Given the increasing population of the globe as well as climate change and additional social pressures, this trend shows no signs of diminishing anytime soon (WARD et al. 2008, 2009). Geospatial technologies allow us to simulate certain scenarios of natural disasters to identify and reveal weak spots in certain natural flood hazard areas. The recovery processes of areas affected by natural disasters are associated with social, physical, and political factors.

Based on the study of WARD et al. (2008, 2009), who applied their work on an urban environment impacted by Hurricane Katrina in 2005, the research presented in this paper will seek to develop and evaluate Spatial Recovery Indices (SRI) for different communities

(urban, rural, and suburban) in Austria with regional focus on the Province of Carinthia. Those communities are impacted by storms, floods, avalanches, and landslides. This SRI has never before been developed for any region in Europe. The SRI allows identifying the social and non-social factors with recovery aspects in urban post-disaster environments. The outcome of the analysis is a grid file, which is composed of specific recovery indicators such as hospital or school locations and flood hazard indicators like flood-prone areas, rivers, and a digital elevation model. Based on the results of the analysis the rating of the recovery index allows an interpretation, which areas are more affected and vulnerable to flood hazards. This technique can be used for developing a SRI for natural disasters in order to provide decision makers, insurance companies, and emergency management officials with a tool that will assist in the evaluation of environmental risk, community resilience, and long term damage assessment.

2 Methodology

The entire process of the workflow is shown in Figure 1. It is organized into four main parts, which include all components for the SRI calculation. The first component represents the data collection process which includes the flood data based on a Digital Elevation Model (DEM) and flood zones, natural features (bodies of water), and the recovery indicators (infrastructure, municipal, economy, etc.). After the data collection, the second component handles the categorization of these data.

The framework of this study was employed through the Land Use Conflict Identification Strategy (LUCIS) developed by CARR & ZWICK (2007). Based on the LUCIS data management schema, the data used in this study (shown in Figure 2) were organized into Single Utility Assignments (SUAs), Multiple Utility Assignments (MUAs), and Complex Multiple Utility Assignments (CMUAs) (CARR & ZWICK 2007).

The bottommost level (SUA level) includes all raw datasets of the analysis. As mentioned above the general indicator groups used in this study are based on the UN research (UN 2005). While the basic categories are too general for this study, Figure 2 shows the modified and more appropriate categories for this work. All original layers except the DEM (raster data with a resolution of 25m) are based on a vector file which will be converted into a raster format. Each of the raw datasets, including hospital or school locations is represented as SUA. These SUA can be vector based files like point-, line-, or polygon data types or raster based files. All these SUA's were grouped and classified into a MUA. These MUA's include groups such as care institutions or cultural resources. The model is divided into two main CMUA components. Those components are a measure of Recovery Indicators (RI) and a measure of Flood Hazard Indicators (FH). The RI consists of the MUAs municipality, infrastructure, economy, care institutions, and cultural resources. The flood data and natural features are merged into the FH. For producing the recovery indicator and the flood hazard indicator it is necessary to combine all of the MUAs into a single CMUA, which represents the SRI for the municipalities in Carinthia.

The categorization and also the selection processes mean that all recovery indicators (hospital locations, church locations, police stations, etc.) are divided into certain groups. The data categorization includes also the validation of the data quality. In this step the decision is being made, which datasets can be used for the model and which are unnecessary and can be dropped. The criteria for the categorization process are based on the

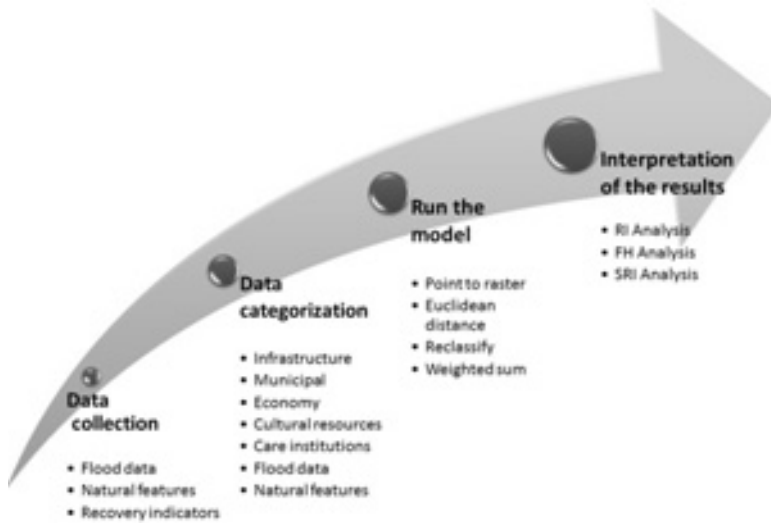


Fig. 1: Schematic representation of the workflow and the most essential components of this research

United Nation's (UN) 2005 Tsunami Recovery project. The categories used by the UN to assess recovery in the countries affected by the Tsunami were designed to be used from a regional perspective and include: Shelter, finance, infrastructure, health, education, and livelihoods (UN 2005). While these basic categories are too general for direct application to this particular study, they were used as a guideline for the development of indicator categories more appropriate for a study at a finer resolution (WARD et al. 2008, 2009). The classification used for the recovery index is a very important part of the entire process because the chosen groups have significant influence on the results. Before the datasets are combined into one single Multiple Utility Assignments (MUA) the datasets have to run through a weighting process.

Due to the lack of specific knowledge or some justifiable basis, all variables are weighted based on subjective criteria chosen by the author's considerations. Those weighting parameters allow the setting of priorities on each of the Single Utility Assignments (SUA) and MUA. The third component describes the model run in ESRI's ArcGIS 9.3 ModelBuilder tool. This automatic process includes the conversion of all raw vector datasets into a raster format with the same grid cell distribution. This homogenizes the datasets and allows the model to produce results, which are more representative of real world conditions (WARD et al. 2008, 2009). Furthermore the model includes a Euclidean distance interpolation technique, a reclassification, and a weighted sum calculation for each of the data groups. The Euclidean distance is calculated from the center of the source cells (e.g. hospital, body of water) to the center of each of the surrounding cells (ESRI 2010).

The last component represents the final results of the analysis as a grid layer with index scores for each of the results. The recovery indicator (RI) map can be seen as a measure of the density of infrastructure, economy, and human life. The flood hazard indicator (FH) map which is calculated based on the flood, the river, and the DEM data can be considered to be a measure of damage. Both results together, computed as a weighted sum, represent the SRI, which assesses the flood hazard zones and community resilience for communities in

Carinthia. The potential of this index and the analysis of its results will then be assessed for incorporation into the emergency management plans of the local government.

2.1 Parameter

The study area includes the municipalities Ebenthal, Klagenfurt, Maria Saal, and St. Veit an der Glan. These communities with their major river Glan are especially affected of flooding and there exists sufficient data about the municipalities. This makes those four communities an appropriate candidate for the project area in this research.

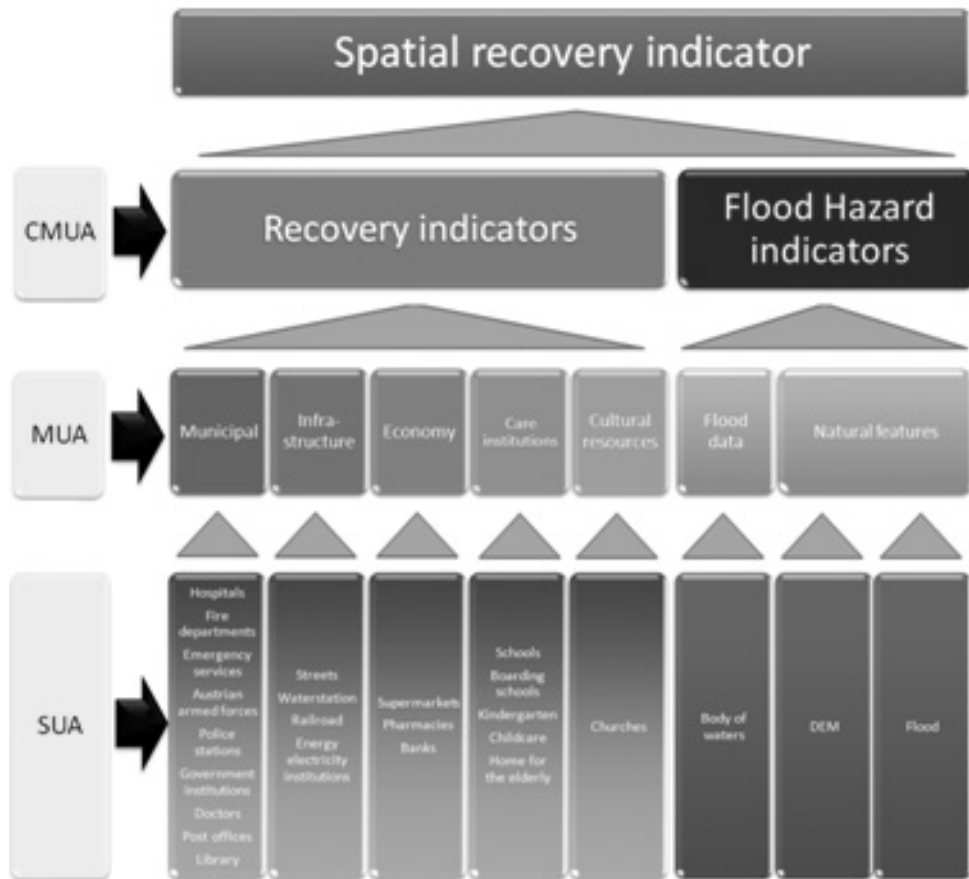


Fig. 2: Overview of the workflow process for developing the SRI

The input parameters of the model for New Orleans (WARD et al. 2008, 2009) have to be adapted to the Austrian model because of different certain foundations regarding the geodata allocation. In contrast to New Orleans this adaption for developing a recovery index is also necessary to minimize the enormous datasets that exists for Austria. For the analysis only the location of the address points and the type of building (e.g., hospital,

police station, church, etc.) will be considered. Spatial modeling techniques should be kept as simple as possible to avoid uncertainty in the analysis and the practicality (HAINING 2003). Figure 2 shows the hierarchy (workflow in direction of the arrow from the bottom to the top) of all components, which are necessary for developing the SRI which is composed of the Recovery Index (RI) and the Flood Hazard Index (FH).

Gray tones show our subjective weighting of the components. In the SUA level the gray tone is illustrated vertically and for the MUA and CMUA levels horizontally. Darker gray tones are an indicator for a stronger weighting.

3 Implementation

After the selection and classification process described in a previous section the data are run through some specific calculation processes by ESRI's ModelBuilder application shown in Figure 3. This process is visualized only for the school dataset which is representative for all other (e.g., hospital locations, police stations, etc.) datasets.



Fig. 3: First workflow segment from the raster conversion, to the Euclidean distance calculation, and finally to the reclassify process.

The first step in the modeling process is the conversion of each of the vector based SUA datasets into a raster file. This selection of a raster based linear overlay technique allows a greater control over the parameters and is also important for the standardization process to guarantee the same grid cell distribution of the existing data. The choice of a raster based analysis as opposed to a vector based investigation allows for greater control over the parameters of the model, and limits the error associated with data resolution and format issues (WARD et al. 2009). After the conversion of the vector based SUA datasets, the raster data utilize Euclidean distances to interpolate raster surfaces from vector files. A distance calculation was used because based on the theory of distance decay this work assumed that the influence of facilities, such as hospitals, streets, etc. to overall recovery is decreasing with distance. Past studies have supported this validation by looking at the relationships between homestead location and visits to hospitals, clinics, and other service facilities based on distance (MULLER et al. 1998, LIN 2002). The selection of the Euclidean distance over Manhattan (rectilinear) or actual street distance measurements is due to the fact that obtaining detailed network distance data at a study of this scale is nearly impossible (LIN 2002). Research has indicated that Euclidean measurements commonly offer distances in the order of 20% less than real network distances, making them an adequate indexing tool based on the scale of the input data (LIN 2002, FRANCIS et al. 1992). After the Euclidean distance calculation, each of the SUA was reclassified into five classes based on subjectively defined distances. These five index values range from 1-5 and represent, low (far from institutions, value of 1), medium-low (value of 2), medium (value of 3), medium-high (value of 4), and high (close to institutions, value of 5) levels of recovery suitability. The index value or recovery level represents a distribution of recovery across the study area.

Also the DEM which is already in a raster format is reclassified into five classes using the natural breaks method and using the same recovery suitability index. This index is scaled into five classes so that reclassified variables are directly related to real world conditions. That classification makes it more comprehensible to assign decreasing input values based on increasing distance for each discrete variable location. All these reclassified SUAs were then grouped into the above mentioned categories and combined into one MUA. In this example the schools are categorized as care institutions (Figure 2). Also the other public facilities like kindergarten, boarding schools, childcare, and home of elderly belong to this category. Before the datasets are combined into one single MUA they are subjected to a weighting process. Due to the lack of specific knowledge or some justifiable basis, all variables in this model are considered subjectively. Those weighting parameters allow the setting of priorities on each of the SUA (color gradient in Figure 2).

The next step was to combine both sides (RI and the FH) that means that the RI MUAs (infrastructure, economy, municipal, care, and cultural resources) and the FH MUAs (flood data and natural features) were combined into two CMUAs. For that reason it is necessary to run the model through a new weighting calculation to model the RI and FH CMUA. Because of the imbalance of the datasets, the data of the flood hazard indicators are weighted more, than the recovery indicators. These two CMUAs represent the recovery indicator and the flood hazard indicator for the study area in Carinthia. After a new reclassification process the outcome is a final grid layer with index scores for each cell unit. Those index values can be used to categorize and assess the level of resilience of the study area in Carinthia. The index will rank each areal unit included in the study based on its potential for recovery as assessed by the input variables in the model. As such, the outcome of this index and the analysis of its results will aid in the assessment of community resilience in Carinthia. This allows efficient broadcasting of results to public officials, and provides decision makers with the ability to make informed management choices regarding disaster recovery (WARD et al. 2008).

4 Results and Interpretation

The result of the two CMUAs is shown in Figures 4 and 5, which visualize in a dark to bright gray tone the level of recovery.

Image (a) in Figure 4 represents the recovery indicators of the model and shows that the highest level of recovery has been achieved in a concentric pattern around Klagenfurt, the capital of the province of Carinthia. The locations of the cities and the names of the rivers are shown in Figure 5. The analysis of the recovery indicators also illustrates a high level of recovery in the area in and around Maria Saal, as well as St. Veit an der Glan. All three cities are located along the river Glan and have experienced varied levels of flooding in the past. These cities are located in a valley and are surrounded by mountains and forest-covered hills. According to the course of the major river Glan, St. Veit sits at a higher elevation (around 480m) than Klagenfurt (center of the Klagenfurter Valley, around 446m), which is also surrounded by the following flood-prone bodies of water: Glanfurt, Viktringerbach, and Zwanzgerbergerbach in the south. The concentric pattern of bright areas in image (a) representing a very high recovery level results from the large increasing number of social and non-social institutions around those cities. It can also be seen that the area in the southern part of the municipality Ebenthal presents the lowest recovery level. This area includes the river Drau.

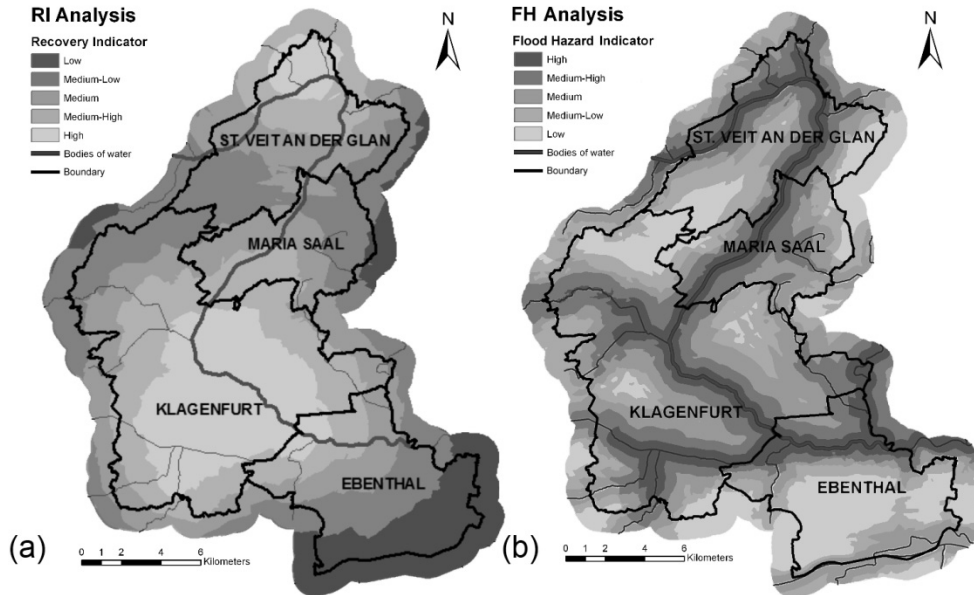


Fig. 4: Image (a) shows the recovery indicator, image (b) the flood hazard indicator of the study area

The reason for this result is the mostly rural environment (farming and agriculture) and the difficult terrain of that area allowing only few economic (in addition to agriculture) and infrastructure activities to develop. This low recovery level in image (a) appears to be consistent with a medium flood hazard swath, which runs from the northeastern part of the municipality Ebenthal, south of the valley to the western border. Exactly the same environment can be observed in the eastern and middle parts of the municipality Maria Saal. The lowest levels of recovery can be found close to the border areas in the east and south of the project area. One reason for that phenomenon is that this work is limited to only four municipalities. The possible problem may be associated with the “edge effect”, that is, surrounding areas, which are immediately adjacent to the study area may exhibit higher recovery indicators (many schools, hospitals, etc.), but are not included in the current calculations. In general, edge effects should be minimized as much as possible, but in this study they were not accounted for, at all. Image (b) shows the results for the flood hazard analysis. Flood-prone areas are shown in dark gray tones. The very high flood hazard areas are a combination of a very low elevation and the proximity to bodies of water. Very characteristic flood-prone zones are around the rivers Glan, Gurk, Glanfurt, and Wölfnitzbach.

The final outcomes of the RI Analysis and the FH Analysis are shown in Figure 5, which presents the final model results, combining both analyses into the SRI. The map of all CMUAs, shown in Image a) represents low to high levels of recovery using dark to light gray tones. The result of the SRI analysis confirms the previously mentioned assumption that the two most significant low recovery levels are located in the municipalities of Ebenthal and Maria Saal. Overall, these two communities in the selected project area in Carinthia possess the lowest level of recovery and the highest level of flood hazard

zones. The analysis shows that there is an uneven distribution of recovery across the study area, which is heavily dependent on the number of recovery indicators for each city or municipality.

Image b) shows the SRI in relation to the population which is stored in 250-meter micro cells. The NoData (white) cells indicate areas without inhabitants. The SRI level is ignored, because in these cells possible flood damage has no effects on human life. Black cells mean a higher risk level for the affected people, because these zones have a lower number of institutions that are in close vicinity. Dark and light gray cells cover areas with a low threat. These areas feature a high number of institutions that are close to the population.

However, this study provides an easy way to interpret visual representation of recovery for a selected region in Carinthia. This analyses and visualizations support government officials and planners to identify such vulnerable areas in order to prevent new flood hazards in those regions.

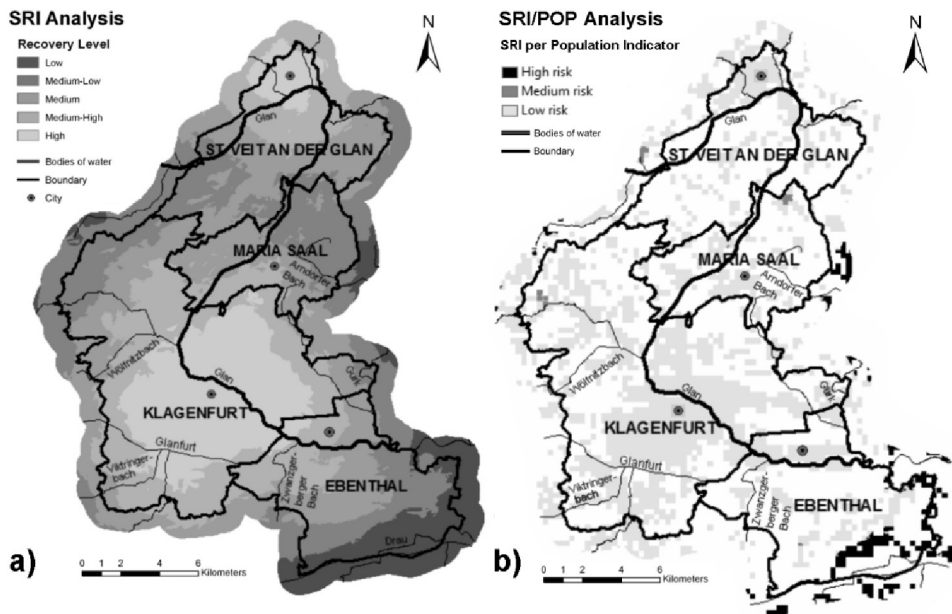


Fig. 5: Image (a) shows the SRI for all four municipalities included in the study area; image (b) illustrates the SRI standardized by population

5 Discussion

The idea of this project is to combine, improve, and modify the previously developed and corresponding U.S. model (WARD et al. 2008), incorporating Austrian concepts into one comprehensive spatial decision support system in the field of flood hazards. A more detailed research on this approach would be important, because recent studies have shown that a limited knowledge base exists in the current literature on the revitalization following disasters and about links between vulnerability and recovery. Previous research validating

the social vulnerability index in context to river floods has already been carried out in Germany (FEKETE 2009) and in Norway (RØD. et. al. 2007). In Austria a lot of knowledge about flood hazards and torrents/avalanches exists, as for example, the Project “Natural Risk Management in Carinthia” (Paulus et al. 2004). While much research has been conducted on hazards, little research has been done on resilience. Existing software applications are either not usable for the European context, because they have been developed for U.S. applications (e.g., FEMA’s HAZUS-MH software) or the software is not very flexible (e.g., HORA Austria). This work expands on current disaster research, primarily carried out in the U.S. to combine both U.S. and European concepts into one single decision support system. The advantage of the model, developed for this study is the inclusion of several indicators, which are necessary to appropriately analyze community resilience in flood-prone zones in several Austrian communities. No previous study has described the importance that these indicators (like population, vegetation, or residential houses) have on the influence of the recovery process for the calculation of the post-disaster environment. The problem of using population as an indicator is to decide in which way population should be considered in the analysis (e.g., as a residential house, as a regional population density, etc.). Some of the indicators are chosen (e.g. schools, kindergarten etc.) because these public institutions are often shelters after disasters. Most of them are important for the U.S. and also for Austria environments. Indicators like churches can have a higher local value for the recovery process in the U.S than in Austrian communities. The model is usable and suitable for other natural hazards like storms, avalanches, or landslides. But when using this model for avalanches or landslides, it is necessary that a large area is impacted and analyzed in order to get valuable information from the analyses. However, this study is one of the first that identifies spatial trends in the recovery process. It has been implemented successfully to serve as a basis for further research in the field of hazards and disaster management for post-disaster environments.

6 Conclusion

It can be summarized that this study developed a model to assess flood hazard zones and community resilience in the field of flood hazards in disaster research in several Austrian communities. Based on the work of WARD et al. (2008, 2009), who analyzed the recovery process for an urban environment impacted by Hurricane Katrina in New Orleans (Louisiana, USA), this research seeks to develop and evaluate SRI for different communities (urban, rural, and suburban) in Carinthia (Austria). While much of the work by WARD et al. (2008, 2009) was focused on U.S. concepts and beliefs, the results of this research was carried out and implemented with a Geographic Information System to combine both U.S. and European concepts into one single decision support system. This research indicates a high potential for the spatial modeling of recovery patterns in post-disaster settings and is one of the first studies that uses a SRI to assess the resilience for selected regions in Europe. The outcome of the analysis is a grid file, which is composed of specific recovery indicators, such as hospital or school locations and flood hazard indicators, such as flood-prone areas, rivers, and a digital elevation model. By combining both components to the SRI, the final results allow emergency management officials and insurance companies in the evaluation of environmental risk, community resilience, and long-term damage assessment. The flexible use of this tool provides responsible persons

efficient broadcasting of results and provides informed management choices regarding the recovery of post-disaster environments.

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