The Application of Geospatial Technology in Hazards and Disaster Research: Developing and Evaluating Spatial Recovery Indices to Assess Vulnerability and Community Resilience in Austrian Communities

by

Bernhard Kosar

2. Bachelor Thesis

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Carinthia University of Applied Science
Department of Geoinformation

Supervisor:

Internal Supervisor: Dr. Gernot Paulus

School of Geoinformation, Carinthia University of Applied Sciences, Villach, Austria

External Supervisor: Dr. Michael Leitner

Department of Geography and Anthropology, Louisiana State University,
Baton Rouge, USA

Baton Rouge, April 2010

Science Pledge

By my signature below, I certify that my thesis is entirely the result of my own work. I have cited all sources I have used in my theses and I have always indicated their origin.

Baton Rouge, 15.04.2010

Bernhard Kosar

Acknowledgments

At this point I would like to thank my family for their continuous support and understanding throughout my private and academic career.

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Zusammenfassung

Diese Arbeit wurde mit Hilfe von Geoinformations Technologien auf dem Gebiet der Hochwassergefahren und Katastrophenforschung entwickelt um einen spatial recovery index (SRI) zu entwickeln. Dieser dient zur Bewertung der Vulnerabilität und um den Umfang der Belastbarkeit von Gemeinden auf Basis mehreren Indikatoren in Kärnten nach einer Katastrophe zu bewerten. Diese Untersuchung wurde in Kooperation mit meinem Betreuern, Dr. Michael Leitner, Dr. Gernot Paulus und Steven Ward, einem Doktoratsstudenten in der Geographie auf der Louisiana State University in Baton Rouge, USA durchgeführt. Diese Studie ist eine der ersten dieser Art, die einen räumlichen Recovery-Index verwendet, um die Widerstandsfähigkeit für ausgewählte Regionen in Europa zu bewerten. Durch Anpassung und Erweiterungen von bestehenden ähnlichen Untersuchungen im Gebiet der Katastrophenforschung die vor allem in den USA bereits durchgeführt wurden, wurde sowohl das U.S. amerikanische, als auch das europäische Konzept in einem einzigen System der Entscheidungsunterstützung vereint. Das Ergebnis dieser Arbeit ist ein abgewandeltes und einsetzbares Modell für den europäischen ländlichen Raum um räumliche Indikatoren zur Erholung eines Gebietes nach einer Hochwasserkatastrophe zu bewerten. Die Analyse beinhaltet einerseits als Eingangsgrößen spezielle Erholungsfördernde Indikatoren, wie Standorte von Krankenhäuser oder Schulen, sowie Vulnerabilitätsindikatoren wie Hochwasser-, Gewässer- und ein Digitales Höhenmodell. Durch die Kombination beider Komponenten zum spatial recovery index, wird als Ergebnis ein Rastermodell produziert, um eine geeignete Darstellung des Erholungsprozesses in ausgewählten Gemeinden in Kärnten darzustellen. Diese Applikation ermöglicht Krisenstäbe und Experten in der Bewertung von Umweltrisiken, die Vulnerabilität und Belastbarkeit von Gebieten nach langfristigen Schäden zu beurteilen. Ein solch flexibel einsetzbares Werkzeug ermöglicht Fachleuten fundierte Entscheidungen nach Katastrophen speziell im Gebiet der Hochwasserprävention zu treffen.

Abstract

In this study geospatial information technologies are utilized in the field of flood hazards and disaster research to develop a spatial recovery index (SRI) to assess the level of recovery and community resilience for a selected region in Carinthia (Austria). This work was carried out in cooperation with my advisors, Dr. Michael Leitner, Dr. Gernot Paulus and Steven Ward, a PhD student in Geography from the Louisiana State University in Baton Rouge, USA. This research is one of the first that uses a spatial recovery index to assess the resilience for selected regions 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 vulnerability indicators, such as flood-prone areas, rivers, and a digital elevation model. By combining both components to the spatial recovery index, 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 them to make informed management choices regarding disaster recovery.

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List of Abbreviations

CMUA	*Complex Multiple Utility Assignments*
DEM	*Digital Elevation Model*
ESRI	*Environmental Systems Research Institute*
FEMA	*Federal Emergency Management Agency*
GIS	*Geographic Information System*
KAGIS	*Kärntner Geografisches Informationssystem*
LiDAR	*Light Detection And Ranging*
LUCIS	*Land Use Conflict Identification Strategy*
MUA	*Multiple Utility Assignments*
RI	*Recovery Indicators*
SRI	*Spatial Recovery Index*
SUA	*Single Utility Assignments*
VI	*Vulnerability Indicators*

1. Introduction

The following chapters describe the content of the project. The thesis starts with the motivation and the goals of the project. The hypothesis and the structure of the work are provided in the subsequent chapters.

1.1. 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). Geospatial Technologies allow us to simulate certain scenarios of natural disasters to identify and reveal weak spots in certain natural vulnerability areas. The recovery processes of areas after a natural disaster are associated with social, physical, and political factors.

While the WARD et al. (2008) study is based on an urban environment impacted by the major hurricane Katrina in 2005, the research presented in this thesis will seek to develop and evaluate spatial recovery indices for different communities (urban, rural, and suburban) in Austria with regional focus on the Province of Carinthia. Those communities are typically impacted by storms, floods, avalanches, and landslides. This research is a challenging and highly innovative project, since a spatial recovery index (SRI) has never before been developed for any region in Europe, let alone for communities in Austria. The SRI allows identifying the social and non-social factors with recovery aspects in urban post-disaster environments.

It is reasonable to hypothesize that this same technique can be a starting point for developing a spatial recovery index in a European environment in order to provide policy 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. The idea of this project is it to combine, improve, and modify the U.S. model (WARD et al., 2008) and the European concept into one comprehensive spatial decision support system in the field of flood hazards. This system which assess the level of recovery of specific areas in Austria allow planners and public officials to guide post disaster recovery efforts in vulnerable areas of natural disasters based on spatial orientation.

1.2. Goals of Work

Based on the work of WARD et al. (2009), the goal of the project was to develop a spatial index to assess and identify spatial indicators of recovery in an area in Carinthia. Compared with the research of WARD et al. (2009) who utilized a model for the city of New Orleans, Louisiana, this work, in turn, established whether the U.S. model can be used in municipalities in Carinthia. Moreover the work allows, using two different scenarios, a critical comparison of different approaches for developing a recovery index for disaster and hazards analysis. The results of this research will be carried out and implemented with a Geographic Information System. This software allows a visualization and interpretation of the results utilized for several Austrian communities.

1.3. Hypothesis

Spatial recovery indices to assess vulnerability and community resilience developed and evaluated for New Orleans, Louisiana, USA (WARD et al. 2008) can be applied to selected Austrian Communities.

1.4. Structure of Work

Chapter 2 describes the theoretical background of the work. This includes explanations about some terminologies as well as descriptions about the current knowledge of geospatial technologies in hazards and disaster research and a literature review of used sources. Chapter 3 deals with the methodology of the project. This includes a problem definition and suggests a method of solution. The same chapter describes the study area and the data that were used to implement this study. Furthermore subchapters 3.5 and 3.6 illustrate the importance of the parameters and the implementation of the model for this project. To conclude this chapter, all results are listed in the summary in subchapter 3.7. Chapter 4 presents the results and interpretation of two applied scenarios for this work. For the first scenario the model was used for the entire study area. In comparison, scenario two shows the importance of the scale and selected parameters only for the municipality Maria Saal (Austria). The next chapter 5 provides a discussion, and chapter 6 presents a short closing summary of the entire project. The final two chapters of this thesis include the references in Chapter 7 and the list of figures in Chapter 8.

2. Theoretical Background

The following sections describe the terminology of the basic terms in the project. Furthermore this chapter describes background information about hazard and disaster research. At the end of this chapter the current knowledge of the geospatial technologies that are used in this study are explained followed by a literature review of the most important sources used.

2.1. Terminology

2.1.1. Disasters

Generally disasters can be divided into natural and human-made events which have an impact on communities, economies, and environments. Natural disasters are caused by natural hazards (e.g. floods, avalanches, etc.) which affect human areas. Most of the human made disasters are results of failure of technologies (e.g. engineering failures) or sociological aspects (e.g. criminal aspects). PEARCE (2000) defines disaster as follows: A disaster is a non-routine event that exceeds the capacity of the affected area to respond to it in such a way as to save lives; to preserve property, and to maintain the social, ecological, economic, and political stability of the affected region.

2.1.2. Hazards

Hazards refer to a potential harm which threatens our social, economic and natural (flood, hurricane, earthquake, wildfire, etc.), technological (hazardous materials spill, nuclear accident, power outage, etc.) or human-induced events (biochemical, bombing, weapons, mass destruction, terrorism, etc.). Compounded hazards are those that results from a combination of the above hazards types, such as urban fires resulting from earthquakes, failures of dams or levees resulting from flooding, or landslides resulting from wildfires and heavy rains (PINE, 2008). Another definition (MACCOLLUM, 2007) describes that a hazard is an unsafe physical condition that is always in one of three modes: Dormant/latent (unable to cause harm), armed (can cause harm), or active (causing injury, death, and/or damage by releasing unwanted energy, substances, or biological agents, or as a result of defective computations from computer software). The interaction of hazard and vulnerability together creates a risk.

2.1.3. Consequences of a disaster

The consequences of a disaster are closely linked with the consequences after the disaster. ALE (2002) defines the consequences as follows: The consequence is the result of the materialization of the hazard. As such it is always a concrete harm like how many persons are killed or how many million properties are destroyed.

2.1.4. Risk

The term risk has different interpretations because it is depending on the application field; therefore each professional group has its own meaning. The risk of a disaster is typically described in terms of the probabilities of events occurring within a specific period of time, e.g., five, ten, or twenty years, with a specific magnitude or intensity (or higher), or with a range such as low, medium, or high risk. For example, the risk of floods is commonly described by the U.S. Federal Emergency Management Agency (FEMA) in terms of 100- and 500-year floods, in dictating the average frequency of major flooding over these periods of time and the maximum area that has been inundated each time. Risk has the common meaning of danger (inventory exposure to harm), peril (voluntary exposure to harm), venture (a business enterprise), and opportunity (positive connotation, meaning that is worth of attempting something if there is potential for gain) (PINE 2009). PINE (2009) also defines the risk as the product of the likelihood (the probability of a disaster based on the history) of a hazard and the adverse consequences from the event. Risk is a combination of the chance of a particular event, with the impact that the event would cause if it occurred. Risk therefore has two components – the chance (or *probability*) of an event occurring and the impact (or *consequence*) associated with that event. The consequence of an event may be either desirable or undesirable. Generally, however, the flood and coastal defense community is concerned with protecting society and hence a *risk* is typically concerned with the likelihood of an undesirable consequence and our ability to manage or prevent it (SAYERS et al. 2002).

2.1.5. Vulnerability

There exist a number of definitions for the term vulnerability. A common use is that vulnerability is the susceptibility to physical or emotional injury to hazards risk. Vulnerability can also be a measure of resilience of the community and environment to hazards. Vulnerability analysis identifies the geographic areas that may be affected, individuals who may be subject to injury or death, and what facilities, property, or environment may be susceptible to damage from the event (PINE, 2008). SAYERS et al. (2002) define vulnerability in the following way: Refers to the resilience of a particular group, people, property, and the environment, and their ability to respond to a hazardous condition. For example, elderly people may be less able to evacuate in the event of a rapid flood than young people.

2.1.6. Recovery

The current notion of recovery is used in different areas with several meanings (e.g. in the field of economic, health, etc.). In this thesis with the issue of disaster management for flooding zones consisting of buildings (e.g. cultural institutions, social institutions) and infrastructure, the common meaning is to return to a normal condition. In more detail VALE et al. (2005) describe the resilience of cities as follows: Cities, intrinsically, are distinguished by the relative density of residents, cultural institutions, and opportunities for commerce, so recovery must also entail some sort of return to normalcy in the human terms of social and economic relations, even if that so-called normalcy merely replicates and extends the inequities of the pre-disaster past. So this thesis measures recovery at different scales in order to assess, based on spatial conditions (social, economic), the level of recovery in particular areas in Carinthia.

2.2. Background in Hazards and Disaster Research

This study has been implemented in order to assess vulnerability and community resilience in several Austrian communities (urban, rural, and suburban) in the field of flood hazards and disaster research. The scarcity of literature seeking to analyze recovery from a spatial perspective suggests that a limited knowledge base exists in the current literature about revitalization following disasters and about the links between vulnerability and recovery. In reality, the science of spatial vulnerabilities is in its infancy, thus making the study of spatial aspects of recovery even further underdeveloped (CUTTER 2001). This study is one of the first to assess the resilience for selected regions in Europe in spite of the fact of the complexity of the relation between vulnerability, risk, and recovery techniques. Lots of work has been done developing tools for estimating potential losses from disasters. The recent state of the art is the U.S. Federal Emergency Management Agency's (FEMA) HAZUS-MH software. HAZUS-MH is a powerful risk assessment methodology for analyzing potential losses from floods, hurricane winds, and earthquakes by using GIS technology. In HAZUS-MH, current scientific and engineering knowledge is coupled with the latest geographic information systems (GIS) technology to produce estimates of hazard-related damage before, or after, a disaster occurs (FEMA 2010). That approach of estimating potential natural disaster losses was also developed in the U.S. and is now being adopted to analyze European datasets. In the German-speaking countries, a prominent data source of direct flood losses is the HOWAS 21 (HOWAS 21 2010) database of the Bavarian Water Management Agency in Munich (FABER 2006). At the moment it contains almost 6000 entries of flood damages in Germany, gathered from 1978 to 2010 but only 88 flood datasets. The problem in Austria is that there exist no systematically collected flood data. Until 2006, each federal province has used a different method for documenting and processing direct flood damages and most systems are not suitable for the development of standardized loss functions (FABER 2006).

Particularly in spring 2006, Austria was affected by numerous serious floods at the river March (Lower Austria). Because of the associated damage of this disaster, the goal of the government for the future was to collect these flood data and damages to make better assessment and evaluation models.

The Federal Ministry of Agriculture, Forestry, Environment, and Water Management and the Federation of Insurance Companies of Austria already implemented in late fall 2002 as prototype the project " Hochwasserrisikozonierung Austria-HORA " a nationwide risk zonal system for natural disasters, focused on flood data (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2010). Since 2006 the ministry published for all citizens a first risk assessment of flood-prone zones along rivers of more than 25.000km^2 on an internet platform (Figure **1**) named eHORA. This important information can be used for example to help people with the planning of their homes or industrially used buildings. Those assessment data are based on 30, 100, and 300 year flood boundaries which are also used for this study. Also Table 1 shows the causes of floods.

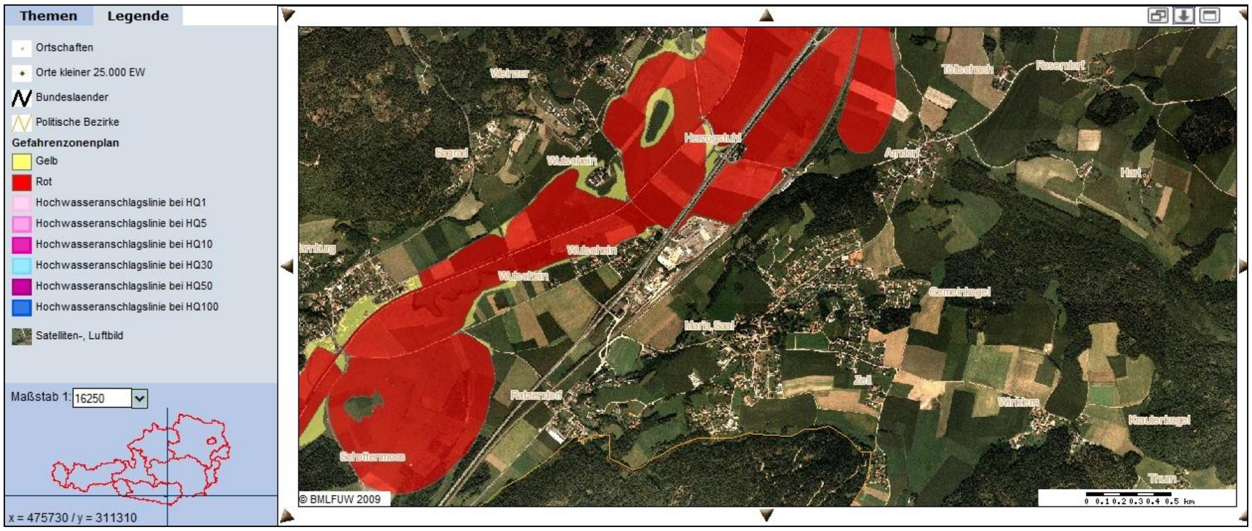


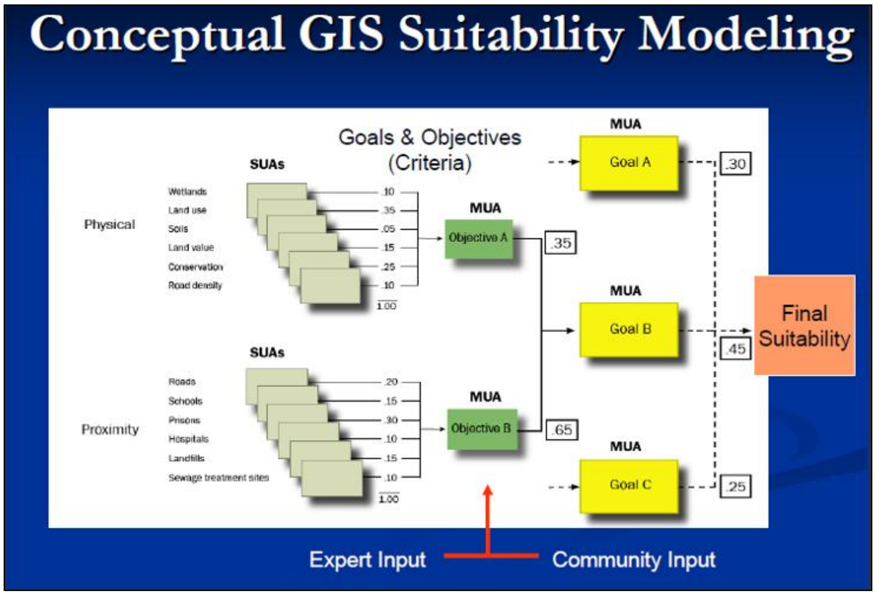
Figure 1: Digital hazard map (HORA) for flood hazard identifications which shows flood-prone zones (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2010)

The eHORA internet platform shows as red and yellow polygons the risk zones for a certain area in Austria. Areas within the red zone are, due to the expected damages, not suitable for permanent use for settlement and transport purposes. Municipalities are encouraged to pronounce a ban for any construction inside these areas. The yellow zone covers the remaining flood plains up to the flood boundary of the 100-year flood event. In this zone damage may occur on any objects (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2010). The advantage of such an internet platform is that citizens have a good outline of flood risk zones in their area. But the disadvantage with this representation is that those maps show only the flood boundaries without any consideration for calculating the affected number of buildings, vegetation, digital elevation model (DEM), population, etc. With this in mind, this thesis utilized a new approach to develop a spatial recovery index including all these parameters.

The study presented in this thesis is in reality a practical tool which may be used to assist in policy development and program evaluation in the future, making the use of this integrated research approach a suitable and necessary technique (WARD 2008). The framework of this study is based on the Land Use Conflict Identification Strategy (LUCIS) model developed by CARR and ZWICK (2007) to assist in the identification of land-use conflicts, and was developed within the modeling environment of Environmental Systems Research Institutes (ESRI) ArcGIS 9.2 Platform. This framework was used as backbone for a new approach of the model of this study to provide and support process steps. The LUCIS model uses the ArcGIS geoprocessing framework, particularly the tool ModelBuilder, to analyze suitability (how suitable is the land for certain uses?) and preference for major land-use categories, determine potential future conflict among the categories, and build future land-use scenarios (ESRI 2010). In the hands of a knowledgeable analyst, LUCIS can provide a reliable projection as to which lands will remain in their current use and which lands will likely change in the future. With this information, various land-use scenarios can be considered by planners. For example, if development continues at its current rate and in the standard fashion, what will a land-use map for any region look like in 35 years? On the other hand, if development policies change, how will things look different (CMC International 2010)? Therefore the model offers a proven data organization framework for the use in this study. The utility assignments (described in more detail in a later chapter) and the way how the model uses structured groupings (Figure **2**) of the data were relatively straight-forward to apply these methods to the development of the spatial recovery index for this thesis.

Floods arise through
Heavy and long-lasting rainfall
Fast melting of snow or thaw with rain
Stream blockages, blockages in rivers caused through debris from inflowing streams
Blockage in river caused by ice floes, usually in combination with floods through precipitation or thaw
High groundwater levels
Overflow of dams caused by landslides in lakes or reservoirs
Failure of structures, e.g. breaching of dams, overflow of ponds

Table 1: Causes of floods (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2006)



Conceptual GIS Suitability Modeling

Figure 2: Structure of the LUCIS model developed by CARR and ZWICK (2007) and (LUCIS 2010)

Guided by the empirical analysis and the framework set forth in the literature, the parameters incorporated into this study represent indicators of spatial vulnerability, as well as, social institutions within the built environment, which lend themselves to the propagation of social networks across the municipalities (WARD 2008). These include: care institutions, cultural resources, infrastructure, economic and municipality data, as well as flood data and natural features.

2.3. Geospatial Technologies

GIS has proven itself to be a viable and reliable tool for the study and analysis of disaster related data (SCOTT & CUTTER, 1996). The software ArcGIS 9.3 from the Environmental Systems Research Institute (ESRI) was used for developing the model for this project. To automate a recurring process, the software allows the creation of models with the tool ModelBuilder. When creating a model, a set of tasks, or a workflow, is preserved that can later be executed multiple times. There are an infinite number of workflows that can be automated using different models. Models can be created by using the ModelBuilder to chain together tools, by using the output of one tool as the input to another tool (ESRI, 2010). The tool Model Builder enables, along with the execution of the process, a documentation of the workflow. This documentation which visualizes a step by step overview provides a broad schematic view of the model.

2.4. Literature Review

The basis for this work was the book chapter by WARD et al. (2008). In that chapter the authors describe in detail how to utilize Geotechnologies to understand post-hurricane Katrina recovery in New Orleans, Louisiana.
Figure 3 represents two interim results of the WARD et al. (2008) model for New Orleans. Another valuable source was the literature of CARR and ZWICK (2007) because the framework of this study is based on the LUCIS model, which they developed.

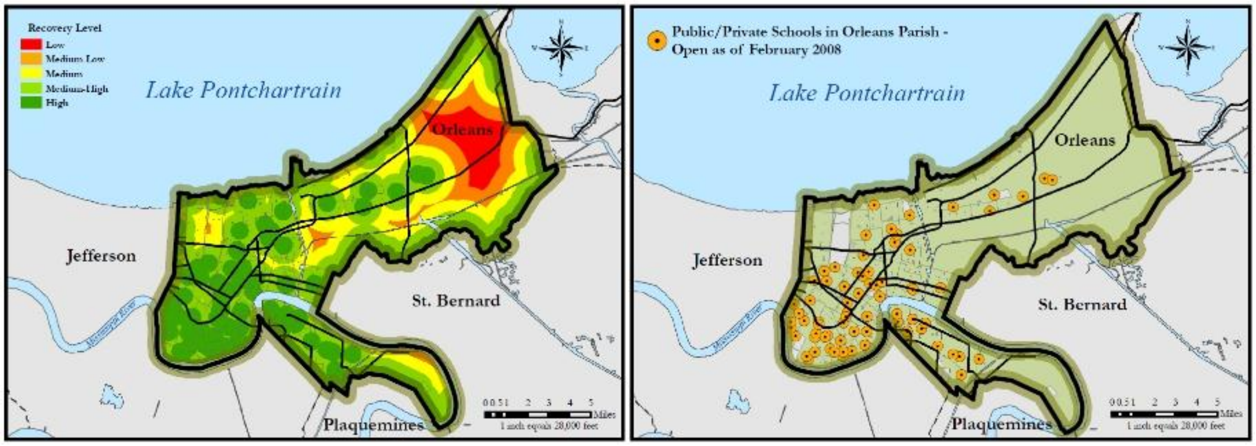


Figure 3: Two interim results of the model for the city of New Orleans (Ward et al. 2008)

A further helpful source was the literature from PINE (2009), who describes in the first chapters of his book a detailed introduction to the topic of natural hazards analysis. Using a cross-disciplinary approach, this book effectively demonstrates how to use the results of GIS tools, spatial analysis, and remote sensing to reduce adverse disaster outcomes and to foster social, economics, and environmental sustainability. In one comprehensive source, this book contains all the information needed to analyze risks and establish successful disaster prevention and relief strategies prior to a disaster event (PINE 2009).
Also the ESRI's ArcGIS Desktop help shows many helpful ideas for the implementation of the research presented in this thesis. Especially the topic around the usage of the ModelBuilder tool gives precise information of all the components of the ModelBuilder application.

3. Methodology

This chapter of the thesis presents the methodology together with the implementation of the project. At first, the chapter discusses the general way of looking at the problem. After that the methodology describes the approach how this project is implemented. The next sections present the study area, data, as well as the parameters that are used for this work. The implementation discusses and interprets the workflow and the results of the model applied to a certain area in Carinthia.

3.1. Defining the Problem

Based on the work of WARD et al. (2009), who presented his work at the GI-Forum 2009 in Salzburg, this research will analyze and create a spatial recovery index (SRI) for a certain area in Carinthia. In this study, the SRI developed for the city of New Orleans (WARD et al. 2008) will be improved and modified to assess environmental risk and community resilience for the selected study area in Carinthia. Based on the results of the analysis the rating of the recovery index allows an interpretation, which areas are more affected and vulnerable of flood hazards. Furthermore, the work determines the differences between the U.S. model (WARD et al. 2009) and the European model. The outcome of the model can be used to categorize the level of resilience of an area or potential for recovery and is heavily dependent on the number of used variables (social and non-social factors) and datasets (e.g. school locations, hospital location, etc.). Two scenarios in this thesis describe in detail, based on the differences of the results, the importance of these parameters in addition to the other important factor "map scale". These results allow emergency teams and the public officials to make decisions regarding disaster recovery.

3.2. Method of Solution

The approach in this work follows the Ward et al. (2008) model, which was used for New Orleans, to develop a SRI for communities in Carinthia. Figure 4 shows an overview of the workflow of the entire process from the data collection to the data categorization, and from the model run to the interpretation of the results. As mentioned in Chapter 2 "Theoretical Background" the framework of the model is based on the LUCIS (CARR and ZWICK 2007) model. To run the model and to produce a model for assessing the resilience of four municipalities in Carinthia some parametric variables were adapted into this system and refined and adapted for use in Carinthia. This adaption will be described at a later time in Section 3.5 "Parameters".

The entire process shown in Figure 4 is organized into four main parts, which include all components for the spatial recovery index calculation. The first component represents the data collection process which includes the flood data based on a DEM and flood zones, natural features (bodies of water), and the recovery indicators (infrastructure, municipal, economy, etc.). After the data collection process the second component handles the categorization of these data. 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 and the classification of the groups are based on the United Nation's 2005 Tsunami Recovery project. The categories used by the U.N. 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 (U.N. 2005). While these basic categories are too general for direct application to this particular study, they were used as a guide for the development of indicator categories more appropriate for a study at a finer resolution (Ward et al. 2008). The classification used for the recovery index is a very important part of the entire process because the resulting groups have significant influence on the results. This research shows, based on two different scenarios, the influences of this classification. Scenario 1 is used to illustrate the SRI with the corresponding spatial analyses with the appropriate categories for this study based on the entire project area. In contrast to this, scenario 2 represents the results only for one municipality. This means that in scenario 2 a different scale as compared to Scenario 1 is applied and consequently different parameters and a different classification and selection process. Those influences based on two different scenarios are illustrated in detail under Section 3. 6 "Implementation".

The next and third component describes the model run in ESRIS's ArcGIS 9.3 ModelBuilder tool. This automatic process includes the conversion of all raw vector based 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). Furthermore the model run includes a Euclidean distance, a reclassification, and a weighted sum calculation for each of the data groups.

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 vulnerability indictor (VI) 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 vulnerability 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.

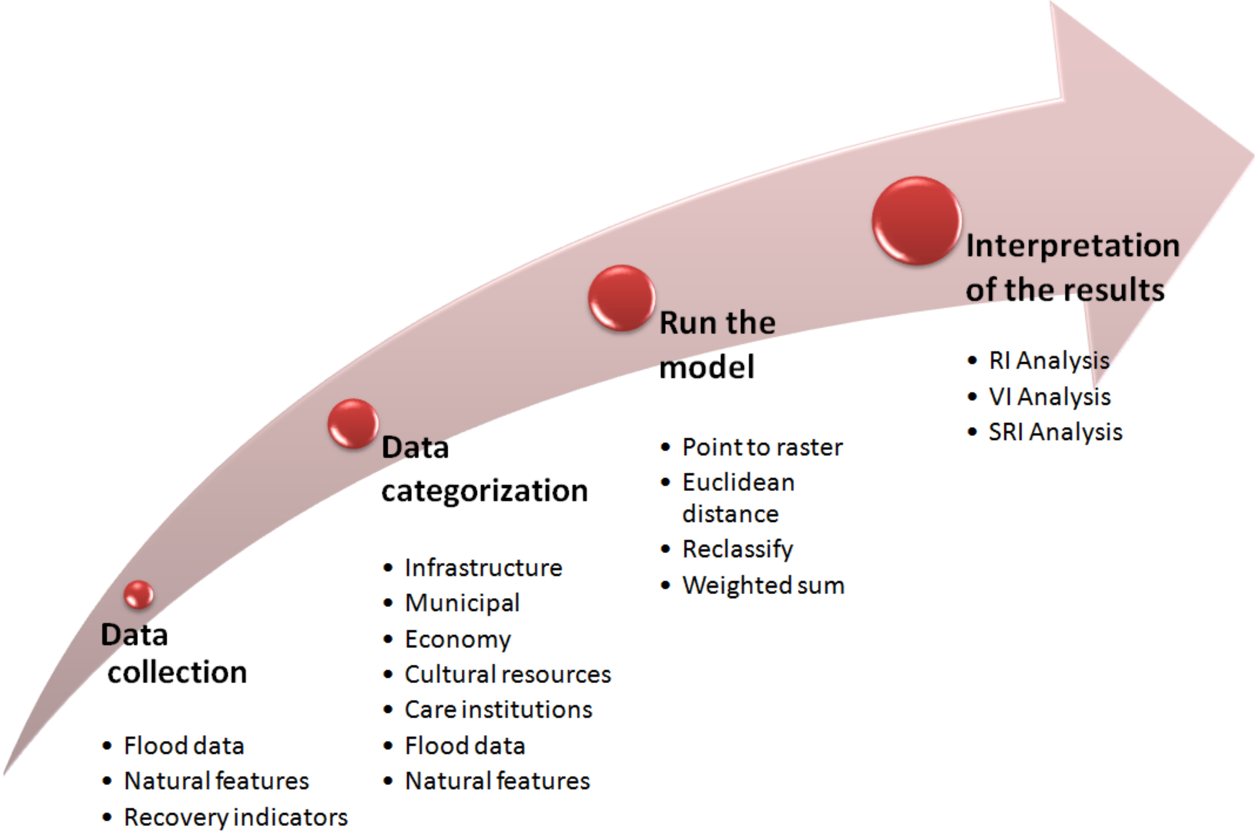


Figure 4: Schematic representation of the workflow and the most essential components of this research

3.3. Study Area

As mentioned above this research will evaluate a SRI for flood-prone urban, rural, and suburban areas in Austria. Especially affected and sufficient data exists about the municipalities Ebenthal, Klagenfurt, Maria Saal, and St. Veit an der Glan. This makes those four communities an appropriate candidate for the project area in this research. The study area of this work includes the portion of the river Glan as the major river from St. Veit an der Glan/Altglandorf to shortly before the confluence of the river Gurk in the region of Ebenthal. And also parts of the study area are all rivers and streams, which flow in and out of the major river Glan. Figure 5 shows all four affected municipalities and bodies of water of the project area.

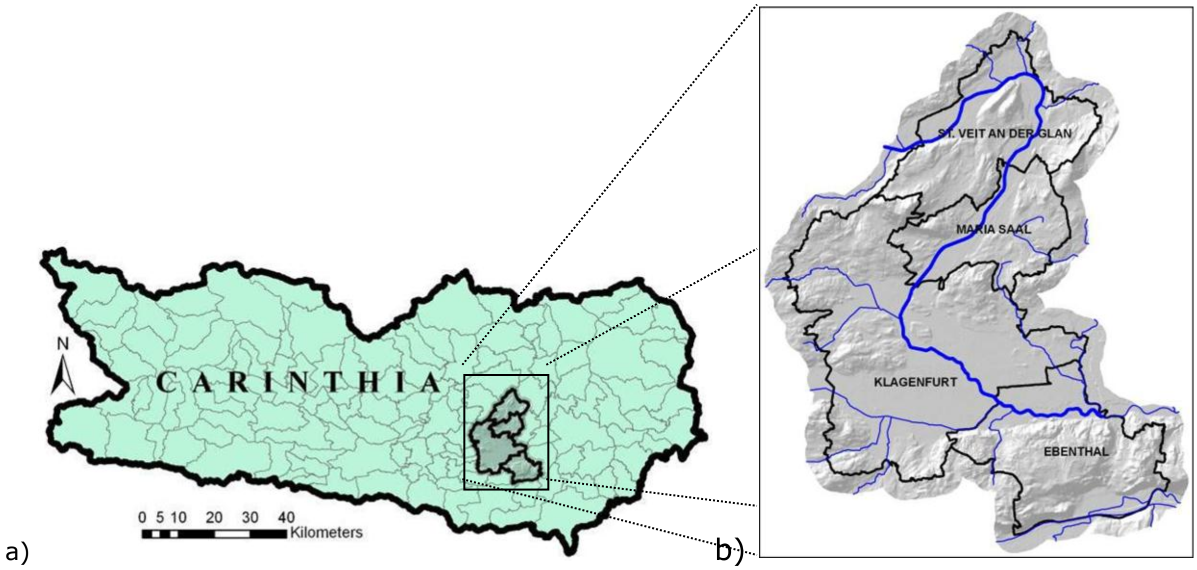


Figure 5: Image (a) shows the project area inside the Austrian Province of Carinthia; Image (b) shows the four chosen municipalities, only with their bodies of water in blue

3.4. Data

The data for this work are provided by KAGIS and the government of Carinthia, Department 18 for Water Resource Management for the municipalities Ebenthal, Klagenfurt, Maria Saal, and St. Veit an der Glan in Carinthia. These data are used in the comprehensive project “Natural risk management Carinthia” for risk assessment for flood hazards (PAULUS et al. 2004). The data used for this project can be classified into three categories:

- Flood data: Digital elevation model (resolution of 25m) and flooded zones
- Natural features: Data about the rivers
- Recovery Indicators: Address points of social facilities

Dataset name	Spatial representation	Geometry Type	Category
Austrian armed forces	Vector	Point	Municipal
Banks	Vector	Point	Economy
Boarding schools	Vector	Point	Care institutions
Body of waters	Vector	Line	Natural features
Childcare	Vector	Point	Care institutions
Churches	Vector	Point	Cultural resources
DEM	Raster		Flood data
Doctors	Vector	Point	Municipal
Emergency services	Vector	Point	Municipal

Energy institutions	Vector	Point	Infrastructure
Fire departments	Vector	Point	Municipal
Flood zones	Vector	Line	Flood data
Government institutions	Vector	Point	Municipal
Home for the elderly	Vector	Point	Care institutions
Hospitals	Vector	Point	Municipal
Kindergarten	Vector	Point	Care institutions
Library	Vector	Point	Municipal
Pharmacies	Vector	Point	Economy
Police stations	Vector	Point	Municipal
Post offices	Vector	Point	Municipal
Railroad	Vector	Line	Infrastructure
Schools	Vector	Point	Care institutions
Streets	Vector	Line	Infrastructure
Supermarkets	Vector	Point	Economy
Waterstation	Vector	Point	Infrastructure

Table 2: Detailed list of the used datasets

All the used data in the study can be shown in Table 2. Most of the data, except the DEM as raster, is represented as Vector data. The fourth column, category shows the data categorization and is described in more detail under chapter parameters. The data of the flood layer (Figure 6, yellow polygons) include the 30, 100, and 300 year flood boundaries. The flood boundary or floodplain is defined as the maximum elevation to which an area can be flooded (Figure 7).

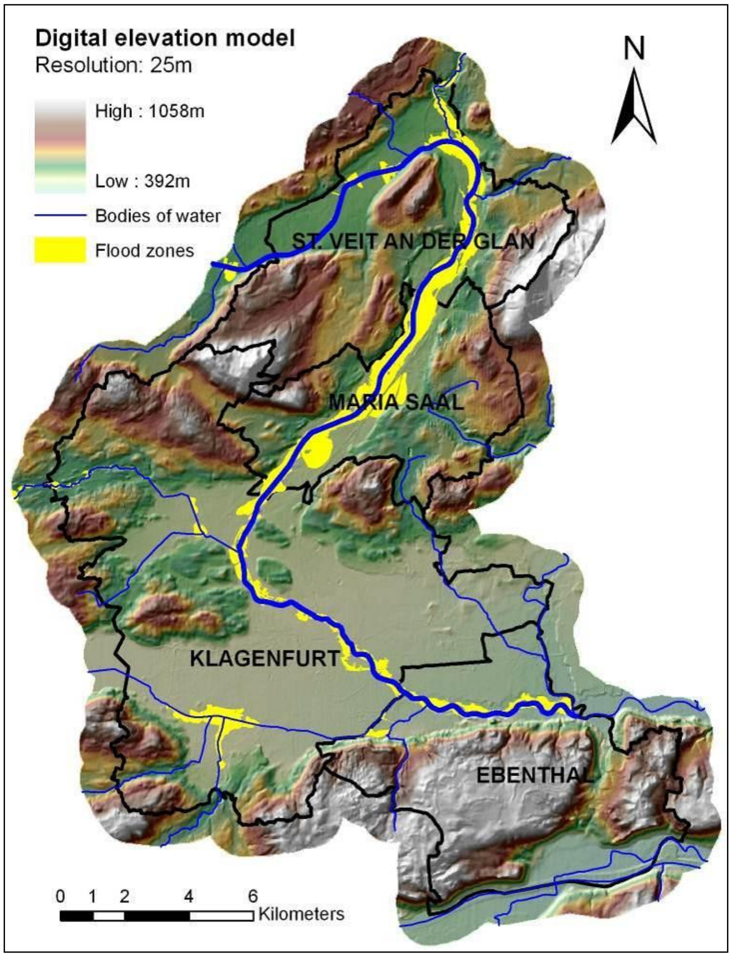


Figure 6: This Image shows the project area in Carinthia with the four chosen municipalities and their bodies of water (blue) with the flood zones (yellow).

The scale of floods is classified according to their return period, which corresponds to the statistical recurrence interval. This means that, for example a 100-year flood (flood of the century) occurs on average every 100 years (100 percent probability). But this does not exclude that a flood can also occur in two consecutive years. For example, one law of the Federal Ministry of Agriculture, Forestry, Environment and Water Management requires a water legal permission, when building a house or a company within the 30 year flood boundary. Those flooded zones correspond to Flood hazard zones with a specific probability/intensity. These are derived from complex hydraulic models based of high resolution Light Detection and Ranging data. LiDAR technology collects high-accuracy elevation data (better than 30cm accuracy) for very large areas very quickly and at lower cost than traditional methods (elevation data was collected manually in the field). LiDAR systems use lasers that pulse tens of thousands of times a second to collect billions of elevation values. With elevation data available for the entire floodplain, flow can be simulated everywhere. This type of simulation, two-dimensional, gives us a much more detailed picture of where water will go during a flood.(USGS 2004) Two additional data sets in this study are all bodies of water (including all rivers and streams) and the digital elevation model with a resolution of 25m. For this work a buffer zone was also drawn around the study area. All four municipalities are bordering other neighboring municipalities and utilize facilities and infrastructure in these neighboring municipalities that are located close to the borders of our study area. In order to account for these so-called “spatial edge effects” it is necessary to create a specific distance buffer around the study area. Based on this buffer zone it is possible to consider the influences of these neighboring facilities and infrastructure on the study area.

Figure 7: Illustration of a flood boundary of the river Pinka in Burgenland (Austria) (Federal Ministry of Agriculture, Forestry, Environment and Water Management 2010)

As mentioned above the recovery indicators are classified and divided into certain categories. For this work the datasets are divided into the categories: care institutions, cultural resources, infrastructure, economy, and buildings belonging to the municipality. This is illustrated in Figure 8. This classification is modified and adapted and includes all necessary data to calculate the SRI for the chosen municipalities in Carinthia.

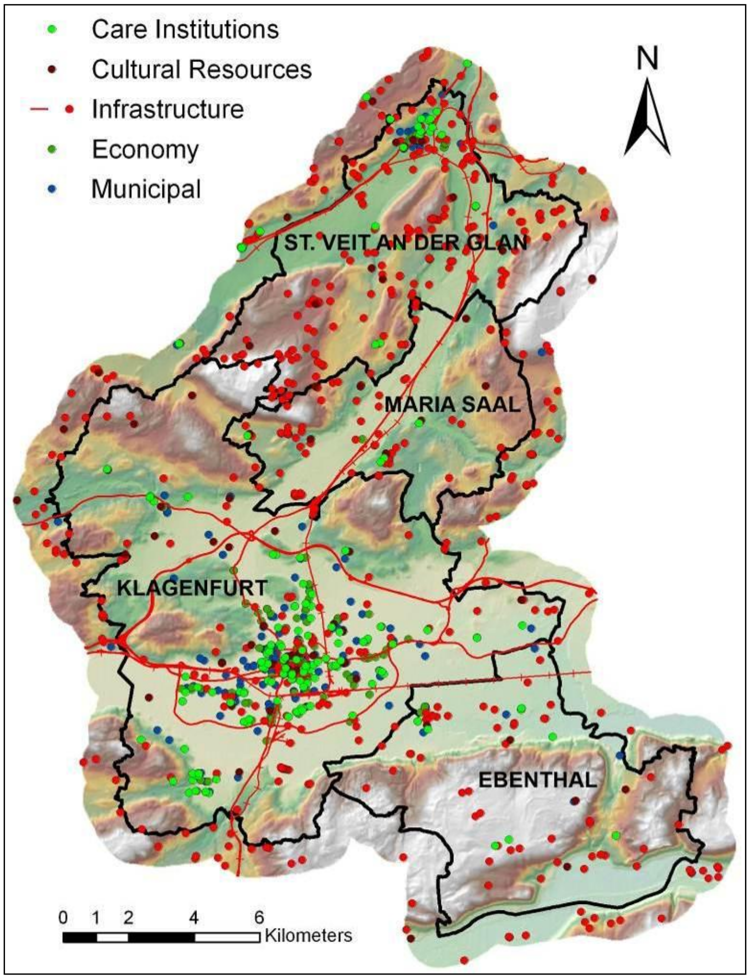


Figure 8: Distribution of different categories of institutions for the four municipalities

3.5. Parameters

While WARD et al. (2008) utilized the SRI for the city of New Orleans it is reasonable to use the same technique for a certain area in Carinthia. This research study will produce a model for assessing resilience of a community which is more complex in nature and in turn more applicable to variable geographic settings. But contrary to the model for New Orleans the input parameters have to be adapted to apply the model to Austria. In contrast to New Orleans this adaption for developing a recovery index is also necessary to minimize the enormous datasets that exists for Austria. An important role in doing the parameterization is to look at the qualitative and quantitative aspects. The qualitative indicators (data quality) include the accuracy of the geocoded points (positional accuracy), actuality (temporal accuracy), and the completeness of the datasets. Those criteria have a significant influence on the entire analysis and the interpretation of the results. For the analysis only the location of the address points and the type of building they represent (e.g., hospital, police station, church, etc.) will be considered and are an important factor in this study. Because the use of too many address points makes the final outcome too homogeneous in nature to draw any significant conclusions. For this research the additional attributes (e.g., number of beds in a hospital, etc.) for each address point have no influence and will not be used for creating the SRI. The accuracy of a model can be inversely related to the number of variables included in a model, which exceed a given threshold (FOTHERINGHAM et al., 2000). Figure 9 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 RI, VI.

The first level (in violet) includes all raw datasets of the analysis. As mentioned above the general indicator groups used in this study are based on the U.N research (U.N. 2005). While these basic categories are too general for this study, Figure 9 shows (in green) the modified and more appropriate categories for this work. These vector files of the analysis, which represent the density of human institutions, will be converted into a raster format with 9m for each pixel. All original layers except the DEM (raster data with a resolution of 25m) are based on a vector file. This modeling process will use a raster based overlay technique with the advantage in comparison with the vector technique that the produced raster files allow more control options over the parameters. Converting all of the datasets to a raster based format with the same grid cell (9m) distribution will homogenize the data and allow the model to produce results, which are more representative of real world conditions (WARD et al. 2008). The advantage of utilizing smaller grid cells for the index recovery rates will significantly improve the final outcome and the efficiency of the algorithm. As mentioned above the framework of this study was employed through the Land Use Conflict Identification Strategy (LUCIS) developed by CARR and ZWICK (2007). Based on the LUCIS data management schema, the data used in this study (shown in Figure 9, yellow column) were generalized into Single Utility Assignments (SUAs), Multiple Utility Assignments (MUAs), and Complex Multiple Utility Assignments (CMUAs) (CARR and ZWICK 2007). The model is divided into two main CMUA components. Those components are a measure of Recovery Indicators (RI) and a measure of Vulnerability Indicators (VI).The RI includes the MUAs for Care Institutions (Kindergarten, Boarding schools, Home for the elderly, Schools, Childcare), Cultural Resources (churches), Economy (banks, pharmacies, supermarkets), Infrastructure (streets, railroad, energy electricity institutions, water stations) and Municipal (hospitals, fire departments, governments institutions, library, Austrian armed forces, police stations, post offices, emergency services, doctors). The second component, the VI includes the MUAs for Natural Features (bodies of water) and the Flood data (DEM, flood zones). The study used the technical term vulnerability indicators (and not e.g. hazard indicators) for the natural features and flood data because these indicators are the reason for vulnerability for an area affected by natural hazards. As mentioned above the selection and the classification is based on the U.N and the LUCIS model but some selected indicators are also based on subjective criteria. Each of the raw datasets (in violet), including kindergarten locations or school locations are represented as SUA. These SUA can be vector based files like point-, line-, or polygon data types or raster based files. Also, the organization of the parameters into logical groups was employed through the framework of the LUCIS. The green row in Figure 9 shows that through a raster calculation process. All these SUA's were then grouped and classified into a MUA. These MUA's include groups such as care institutions or cultural resources. For producing the recovery indicator and the vulnerability indicator (in red) it is necessary to combine all of the MUA's into a single CMUA, which represents the SRI (in blue) for the municipalities in Carinthia. This final process includes a weighting sum calculation with the tool ModelBuilder. The data of the vulnerability indicators are weighted heavier, then the recovery indicators because of the imbalance of the datasets. The study uses clearly more data inputs on the recovery side, therefore a ratio of 0.6 to 1 was chosen. That means that the vulnerability grid file was less weighted than the recovery grid file. The calculation processes (vector to raster conversion, Euclidean distance, reclassification, and the weighting sum processes) between each of the components are discussed in detail in the "Implementation" Section.

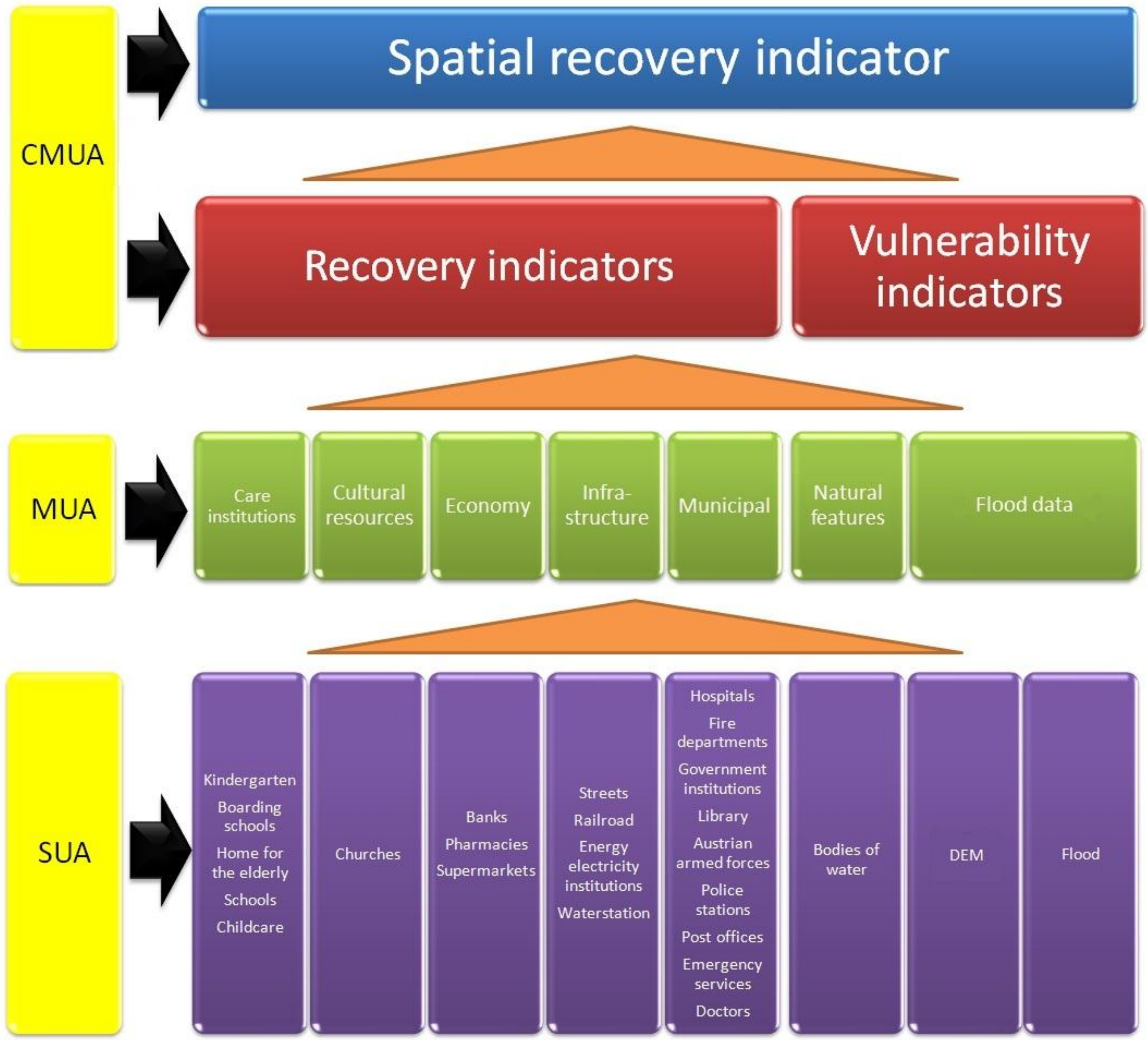


Figure 9: Overview of the workflow process for developing the SRI

The classification of the final standardized raster files of the variables into certain groups and the organization into separate SUA's, MUA's, and CMUA's allows measuring the influence of each individual level on the results. Also the high influence and significance of using different scales to determine the most appropriate recovery index can be visualize in the final outcome. The scale of this type of study is extremely important. If the study area is too large, recovery trends may be disguised or diluted, if it is too small, many issues may be overlooked (SOPAC, 2005).

3.6. Implementation

For developing and evaluating the SRI based on a final raster file to assess the resilience vulnerability and the community resilience in several Austrian communities, additional calculation processes are necessary. It was important for the evaluation, interpretations, and analysis to utilize a simple index to visualize and quantify the results and final outcomes of the model. Spatial modeling techniques should be kept as simple as possible to avoid uncertainty in analysis and practicality (HAINING, 2003). The accuracy of a model can be inversely related to the number of variables included in a model which exceed a given threshold (FOTHERINGHAM et al., 2000). After the selection and classification process described in a previous section the data are run through some specific calculation processes shown in Figure 10. All these processes in this chapter are visualized only for the school dataset which is representative for all other (e.g., hospital locations, police stations, etc.) datasets.

Figure 10: 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 (9m cell size). 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 conversation of the vector based SUA datasets, the raster data utilize Euclidean distances (Figure 11 , Image a) 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 using natural breaks assigned to each cell. These five index values (Figure 11, image b) ranged from 1-5 and represented, low, medium-low, medium, medium-high, and high levels of recovery suitability. The index value or recovery level represents a distribution of recovery across the study area.

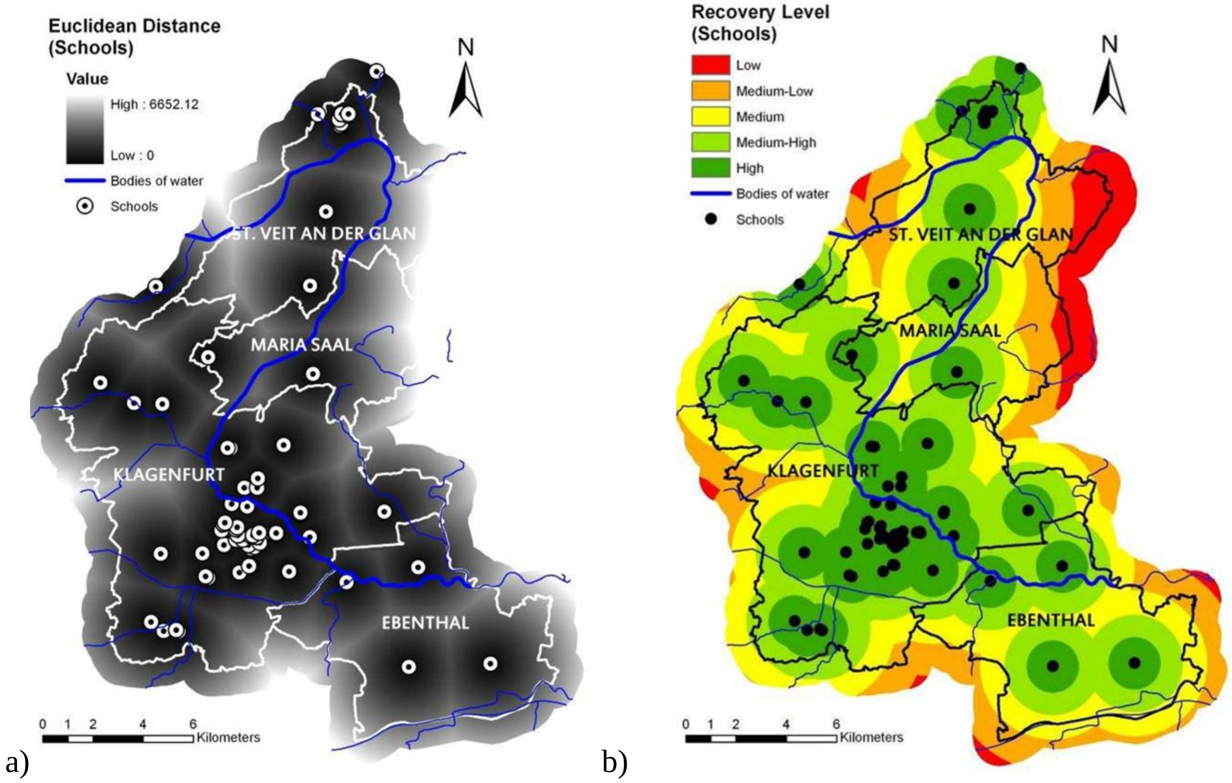


Figure 11: Distribution of recovery levels with only schools included in the calculations. Image (a) represents the region of influence for each school using the Euclidean distance decay interpolation technique and Image (b) is the reclassified interpolated school raster

Also the digital elevation model 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 means that areas with a high elevation have also the highest recovery suitability index (value of 5), while areas with a very low elevation, especially in the city of Klagenfurt, are assigned a value of one. That classification makes it more comprehensible to assign decreasing input values based on increasing distance for each discrete variable location. All these reclassified SUA's were then grouped into the above mentioned categories and combined into one MUA. In this example (Figure 12, image a) all care institutions (kindergarten, boarding schools, childcare, and home of elderly) are combined through a raster calculation into the MUA named “care”. The recovery level of all datasets of care institutions are illustrated in Figure 12, Image b.

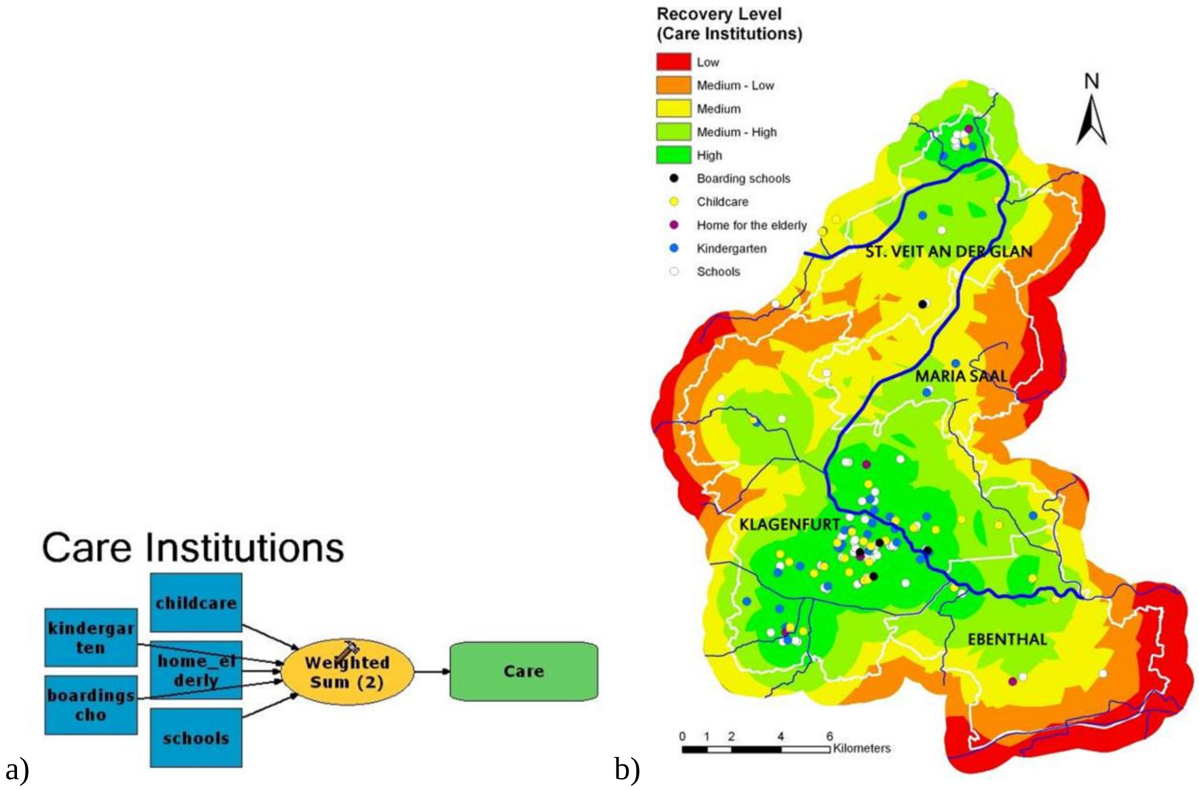


Figure 12: Image (a) shows a workflow segment after the Euclidean distance calculation and reclassification process to combine the care SUAs to one single file. Image (b) represents a distribution of recovery levels with only the care institutions

Before the datasets are combined into one single MUA the datasets have to run through a weighting process. Due to the lack of specific knowledge or some justifiable basis, all variables in this model are considered equally. As a result, no weighting differences were applied to any of the parameters used for this study (WARD et al. 2009). Those weighting parameter would allow the setting of priorities on each of the SUA. But there are no previous representative studies in which objective criteria were applied to weigh parameters. Figure 13 shows as an overview the second workflow process after the Euclidean distance calculation as well as the reclassification procedure were completed. The next step was to combine both sides (recovery indicators and the vulnerability indicators) that means that all of the MUA’s (infrastructure, economy, municipal, care, and natural features) were combined into one single CMUA. For that reason it is necessary to run the model through a new weighting calculation to model the RI and VI CMUA. As mentioned above because of the imbalance of the datasets, the data of the vulnerability indicators are more weighted, than the recovery indicators. These two CMUA’s represent the recovery indicator and the vulnerability 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).

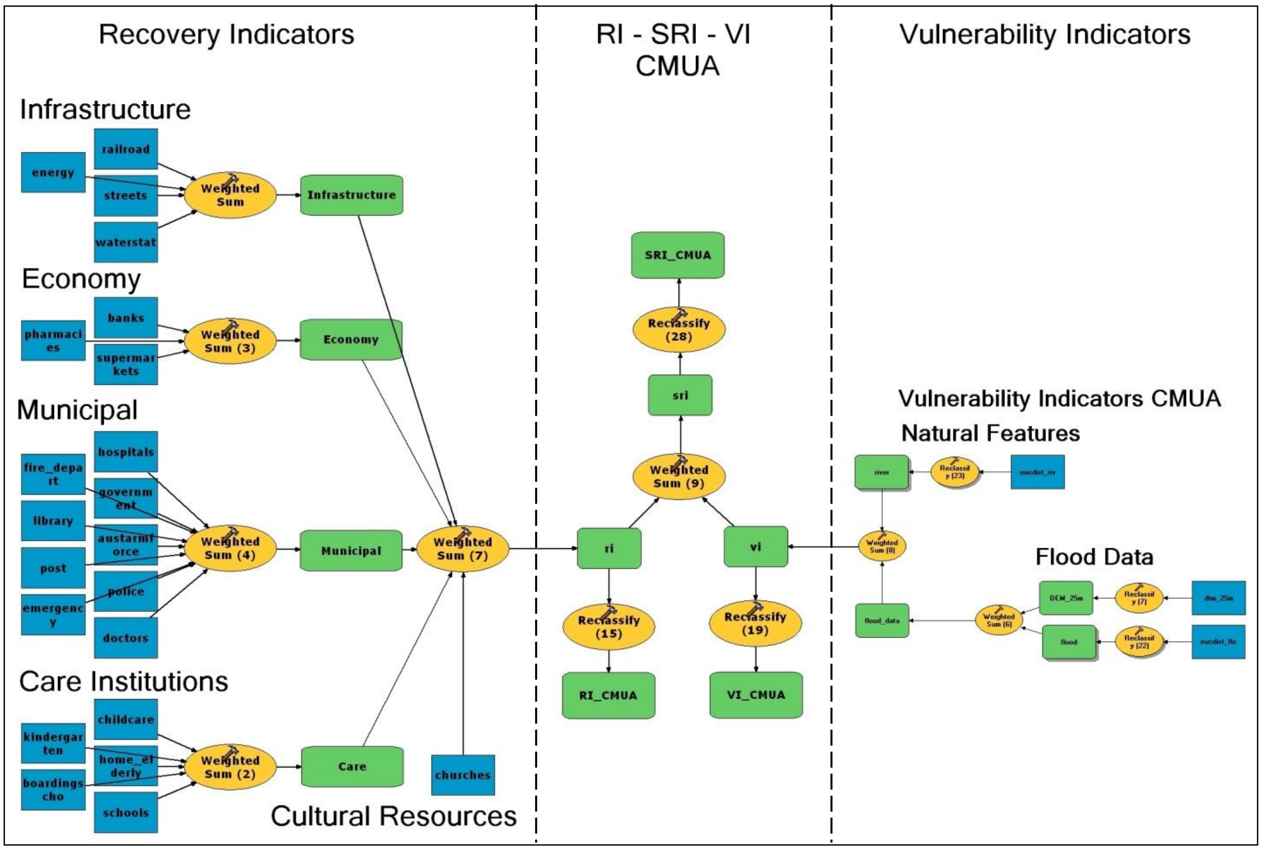


Figure 13: Second workflow model after the Euclidean distance calculation to determine the RI, VI and SRI

3.7. Summary

The previous chapter "Methodology" discussed at the beginning the way of looking at the general problem how geospatial technologies in hazard and disaster research can assess vulnerability and community resilience in several Austrian municipalities. The next section explained the method and represented a schematic representation of the workflow with all essential components of the research. All components, as well as the workflow description are described in detail to understand the creation of the model for developing the SRI. The subsequent parts of Chapter 3 discuss the study area or project area, the used data, and also the modified parameters compared to the New Orleans model (WARD et al. 2008) in a very explicit way. The major part of Chapter 3 dealt with the implementation and calculation processes to produce the results in the desired quality.

4. Results and Interpretation

The following chapter discusses the results and interpretations of the final outcome of the spatial recovery index. The individual subchapters compare two different approaches for developing the spatial recovery index and illustrate the importance of the parameters applied to at different scales.

4.1. Scenario 1: Spatial recovery index based on the entire study area

For assessing the resilience of flood hazards in Austria it is necessary to enhance and modify the existing parameters of the existing hurricane hazard model developed from WARD et al. (2008). In Austria the greatest potential hazards are floods, avalanches, torrents, and landslides. Scenario 1 of this work uses flood disasters as hazard type to create the SRI for all four municipalities in Carinthia. Because the WARD et al. (2208) model is based on hurricane hazards, the input variables have to be modified for a flood disaster, which was discussed in the previous chapter. Through these enhancing and modifying processes it is very easy to organize the input variables into separate SUA's, MUA's, and CMUA's to see how each of these indicators influences the final outcome. If a particular SUA or MUA has negative or unexpected levels of influence on the model, it could be reevaluated for quality and comprehensiveness prior to inclusion in successive model runs. This model structure also made it easy to manipulate and calibrate the model based on a post evaluation sensitivity analysis (WARD et al. 2008). The result developed with ESRI's ArcGIS software produces as a final outcome a grid layer with index scores for each grid cell. The score illustrates the level of resilience for each the four municipalities based on the previously mentioned criteria. The results model the combined influence of all three different components, the recovery indicator (RI), vulnerability indictor (VI), and the spatial recovery indicator (SRI). The final result gives some indication that assesses the vulnerability and the community resilience in several Austrian communities, which allows efficient broadcasting of the results to public officials.

The result of all three CMUA's can be shown in Figure 14, which visualizes in a red to green color scheme the level of recovery or recovery suitability. Image (a) presents 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 analysis of the recovery indicators illustrate also 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 several mountains and forest-covered hills. According to the course of the major river Glan, St. Veit sits at a lower 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, Steiner Bach, and Zwanzgerbergerbach in the south. The concentric pattern of green areas in image (a), representing a very high recovery level results from the large increasing number of social and non-social institutions around those big cities. It can also be seen that the area in southern part of the municipality Ebenthal presents the lowest recovery level. The reason for that result is on one hand the mostly rural environment (farming and agriculture) and on the other hand the difficult terrain of that area allowing only few economic (besides agriculture) and infrastructure activities to develop. This low recovery level on image (a) appears to be consistent with a medium vulnerability 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. And especially close to the border areas the lowest levels of recovery can be found. 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 not within the study area but may exhibit higher recovery indicators (many schools, hospitals, etc.), are not included in the current calculations. In general, edge effects should be minimized as much as possible. Image (b) shows the results for the vulnerability analysis. Flood-prone areas are shown in red. The very high vulnerability areas are a combination of a very low elevation and the proximity to bodies of water. Very characteristic flood-prone zones are around the bodies of water Glan, Gurk, Glanfurt, and Wölfnitzbach. The final outcomes of the RI Analysis and the VI Analysis are shown in image (c), which present the final model results, combining both analyses into the spatial recovery index. Also, this result of all three CMUA'S represents low to high levels of recovery or recovery suitability using a red to green color scheme. The result of the SRI analysis confirms the previously mentioned assumption that the two most significant high 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 vulnerability. The analysis shows that there is an uneven distribution of recovery across the study area heavily dependent on the number of recovery indicators for each city or municipality. The WARD et al. (2008) model and also this study comes to the conclusion that both results are not groundbreaking in nature. However, this study provides an easy way to interpret visual representation of recovery for a selected region in Carinthia.

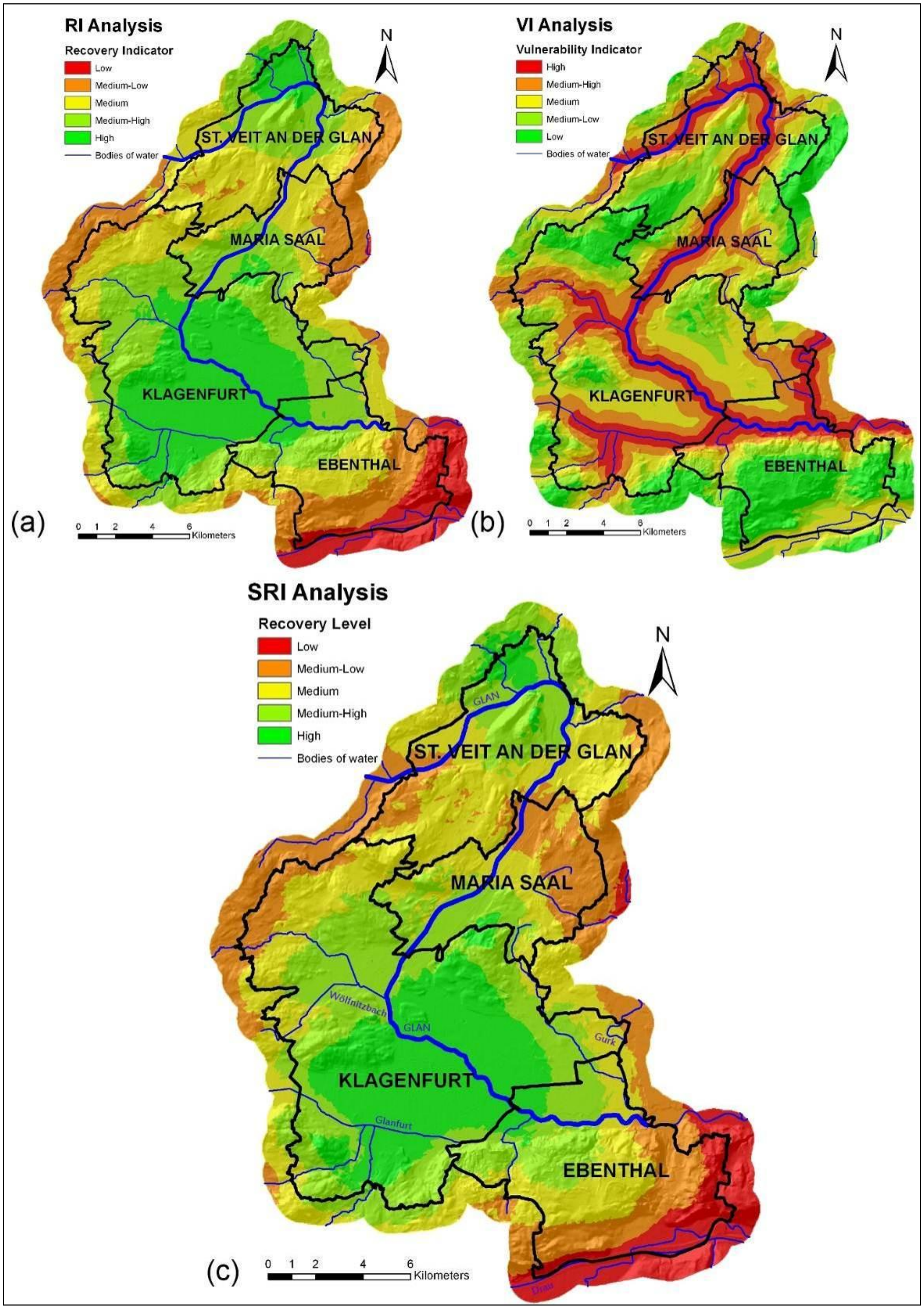


Figure 14: Image (a) shows the recovery indicator, image (b) the vulnerability indicator and image (c) the spatial recovery index for all four municipalities of the study area

4.2. Scenario 2: Spatial recovery index based on one municipality

As mentioned in the previous sections the scale of analysis and the selection of the parameters are a very important factor of this study. For a better illustration of that significance, scenario 2 demonstrates the same calculations as for scenario 1, but on a smaller scale only for the municipality of Maria Saal (Figure 15). A comparison of image (a) from Figure 14 and Figure 15 shows the differences of the very low recovery level in the northern and in the western parts of the area around Maria Saal. By simplifying (some recovery indicators or SUA do not exist) the data from the SRI CMUA to one municipality level, a better understanding of the geographic influences on recovery than the previous discussion focused on individual parameters can be gained. This would suggest that recovery can be better understood, when interpreted over a larger area (WARD et al. 2008). Analyses on a larger scale illustrate which big influence several parameters have on the selected area. Through the use of a larger scale the recovery indicators of the surrounding bigger cities are not being considered in the Euclidean distance calculation and have thus no influence on the final outcome for the municipality Maria Saal. Due to this fact the two images (Figures 14a and 15a) show a different dispersion of the recovery level for the same area. As mentioned above due to the lack of specific knowledge, all variables in this model are considered to be equal. That means that this study does not apply any differential weights, since it cannot be demonstrated, whether any one parameter is more important than any other. But Figure 15 makes clear that results for the same study area using a different scale are significantly different. So in general, overall recovery of a certain area appears to be much higher and is more informative when using the smaller scale. But both Figures (Figure 14 and Figure 15) illustrate that the northern area of Maria Saal is a very flood-prone zone that is indicative of moderate recovery indicators (sparsely populated region) and of a very high vulnerability value. Another very significant detail shows the inverse relationship between the RI and VI indicators. That means that areas with a very high recovery level also possess a very low vulnerability level and vice versa. This analyses and visualizations support government officials and planners to identify such vulnerable areas in order to prevent new flood hazards in those regions.

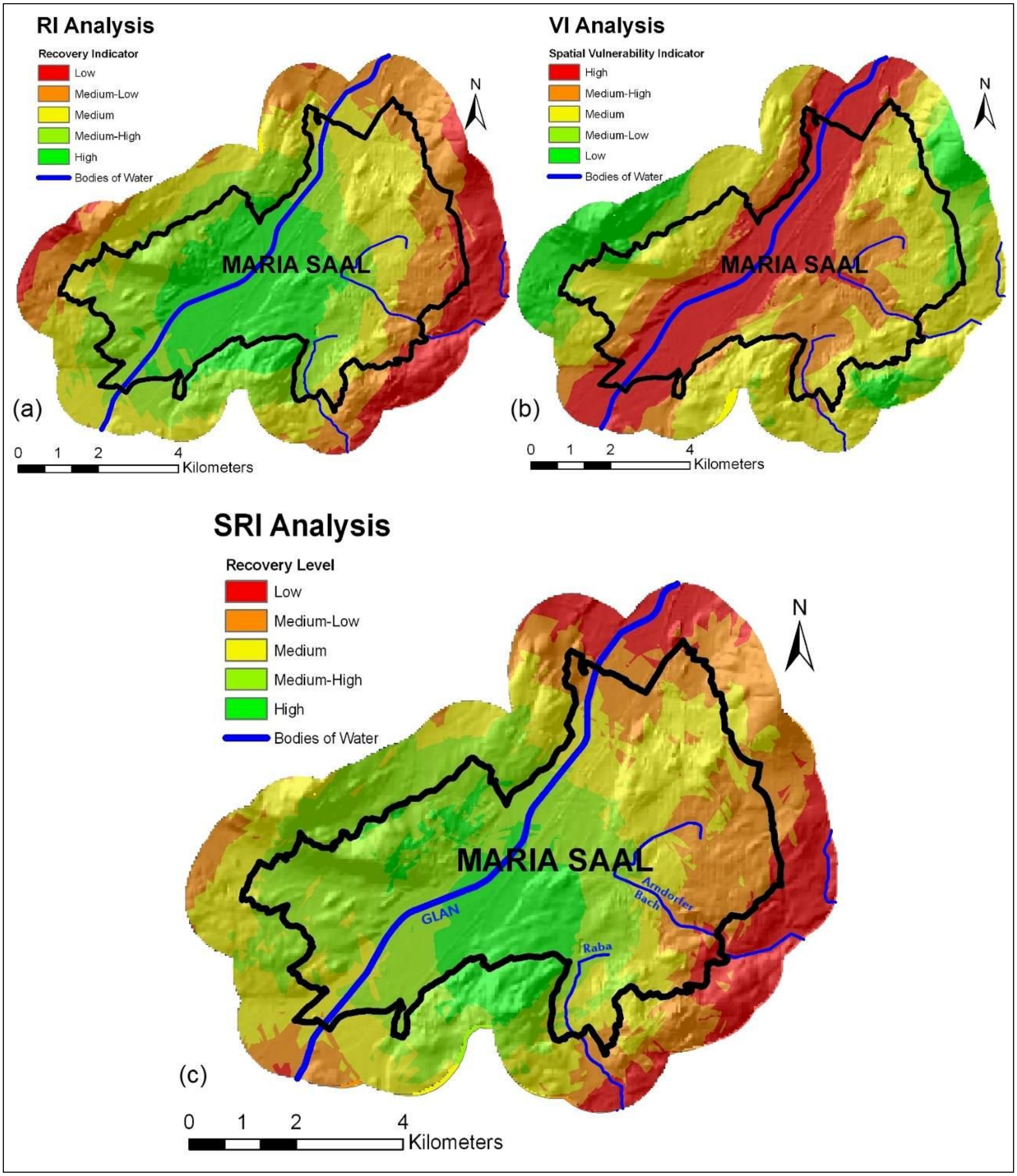


Figure 15: Image (a) shows the recovery indicator, image (b) the vulnerability indicator, and image (c) the spatial recovery index for the municipality of Maria Saal

Figure 16 shows for both scenarios all residential houses as address locations. Image (a) illustrates the density of residential houses with a very high recovery level, especially in the area of the capital city Klagenfurt. Image (b) demonstrates the same calculations as Image (a), but on a smaller scale only for the municipality of Maria Saal. Both images show in a very easy way the distribution of residential houses and demonstrate that areas with a very high density of address locations have a very significant high recovery levels. Also both images illustrate that a number of residential houses are located in the very characteristic flood-prone zones in the northern area of Maria Saal and the southern area of Ebenthal. This study allows government officials and planners to identify such vulnerable areas in order to prevent new flood hazards in those regions.

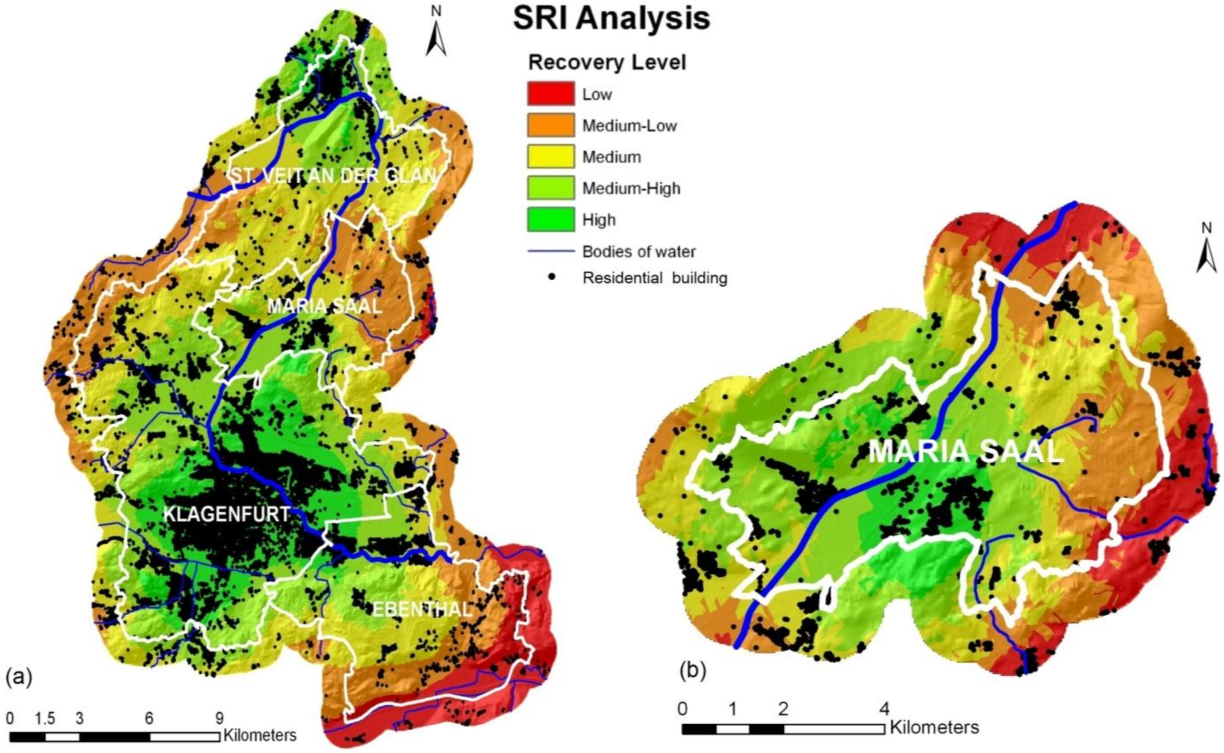


Figure 16: Image (a) shows the spatial recovery index with a distribution of the residential building for all four municipalities. Image (b) shows the distribution of the residential building only for the municipal of Maria Saal

Discussion

To identify spatial indicators of recovery, this study developed a usable model for Carinthia post flood disaster urban and rural environments. The developed spatial recovery index (SRI) helps 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 spatial recovery index to assess the resilience for selected regions in Europe. The idea of this project is it 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. This study is new approach to develop a usable model for European post disaster urban environments to identify spatial indicators of recovery. A more detailed research on this approach would make more sense because recent studies show only that a limited knowledge base exists in current literature about revitalization following disasters and about links between vulnerability and recovery. Especially in Austria for flood hazards and torrents/avalanches a lot of knowledge exists, also the Project "Natural Risk Management in Carinthia (Paulus et al. 2004)" is a successful example, Others are the adapt-alp (AdaptAlp 2010) EU project. There is not much done on resilience, but a lot on hazard research. Existing software applications are either not usable for European requirements because they have been developed for U.S. applications (e.g., FEMA's HAZUS-MH software) or the software is insufficiently 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 make convincing statements about the community resilience in flood-prone zones in several Austrian communities. The implementation and analysis of two scenarios show very clearly the influences of different scales and differently used parameters. Those parameters are selected based on the U.N and the LUCIS model but some selected indicators are also based on subjective criteria. It is very important to note that no study describes the importance that 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 with the population as indicator is that in which way population should be considered in the analysis (e.g., per residential house, per regional population density, etc.). For example, the work by TAKEDA et al. (2003) notes that population alone cannot be relied upon as a sound metric for recovery. After the 1995 earthquake in Japan, "life recovery" based on the population as an indicator for recovery has not been true (TAKEDA et al. 2003). Therefore, the selection process and the weighting of each indicator for developing the spatial recovery index require detailed knowledge and experience in the field of hazards and disaster research. Some of the indicators are chosen (e.g. schools, kindergarten etc.) because these public institutions are often shelters after disasters. Most of them are valid for the U.S. and also for Austria environments. But some indicators (e.g. churches) could have a higher importance/local value in the U.S than in Austrian communities. But this detailed knowledge requires much more investigation in the field of flood hazards and disaster research. But, in general, the development of this modeling process was applied successfully with expected results for selected municipalities in Austria. The work of WARD et al. (2008) developed a model for an urban environment impacted by the major Hurricane

Katrina in 2005. In contrast, this research combines the U.S. and the European concepts into one single decision support system. This adaptation required only a little editing of the used indicators compared to the U.S. model. These modifications were implemented and provided by ESRI's model builder application. The model is usable and suitable for other natural hazards like storms, avalanches, or landslides. But when using this model for disasters, like avalanches or landslides, it is necessary that a large area is impacted and analyzed in order to get valuable information out of the analyses. Anyway, this study is one of the first of that kind that identifies spatial trends in recovery. It has been implemented very successfully to be a good basis for further progresses in the field of hazards and disaster research for post-disaster environments.

5. Summary

The following two subsections describe in the section conclusion a summary of all the work, which has been done for this project. The second subsection titled "Further Perspectives" provides some future research and ideas to be implemented in this project.

5.1. Conclusion

It can be summarized that this study developed a model to assess vulnerability 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), who analyzed the recovery process for an urban environment impacted by the major Hurricane Katrina in New Orleans (Louisiana), this research seeks to develop and evaluate spatial recovery indicators for different communities (urban, rural, and suburban) in Carinthia (Austria). While much of the work by Ward et al. (2008) was focused on U.S. concepts and beliefs, the results of the 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 spatial recovery index 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 vulnerability indicators, such as flood-prone areas, rivers, and a digital elevation model. The inclusion of different parameters and the importance of the scale is demonstrated in this study by using two different scenarios for developing a recovery index for disaster and hazards analysis. By combining both components to the spatial recovery index, 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 leaders efficient broadcasting of results and provides informed management choices regarding the recovery of post-disaster environments.

5.2. Further Perspectives

This study is part of the field of flood hazards and disaster research to develop a **spatial recovery index for** a selected region in Carinthia (Austria). Those communities are typically impacted by **storms, avalanches, and landslides**. Therefore, the focus of this study is the realization of the SRI for these disasters and how the parameters to develop such an index should be modified to appropriately address the recovery of those natural disasters.

Another important point relates to the **expansion** and a better modification of the parameters for such hazards and disaster research in other parts of Europe. That means that for this study **indicators, like population or residential houses** have an influence on the recovery process for the calculation of the post-disaster environment.

As mentioned above, before the datasets are combined into one single final grid file the datasets have to run through a weighting process. But due to the lack of the detailed knowledge, all variables in this model are considered equally. Therefore, no differential weightings were applied. Future research may focus on the **use of differential weighting** of **variables** in order to enable a ranking or to set priorities for each of the input indicators.

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