Towards an Integrated Flood Vulnerability Index – A Flood Vulnerability Assessment

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Declaration

This thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration. The work for this thesis has not been and is not being, in part or wholly, submitted for another degree, diploma, or similar qualification, and fulfils all regulatory requirements.

Towards an Integrated Flood Vulnerability Index – A Flood Risk Assessment

by

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Abstract

Disadvantageous flood plain management makes people living on floodplains more vulnerable to floods. Continuous improvements and changes, investigative and managerial practices, namely the planning instances of city institutions, need to be equipped with easy to use and financially affordable tools to analyse and measure their vulnerability to flood risks. Because changes in the environment are occurring in the form of more severe weather extremes globally, it becomes more important to monitor and investigate the all processes on a local scale where people are affected the most of these hazardous events like floods. In order to steer against probable damage caused by such an event like a flood, it remains important to develop the next generation of flood analysis tools and systems in the face of a probable increase of floods under changing climate conditions. Therefore, it should be apparent that the development of an easy to use tool is most beneficial for communal management departments, to enable these so that they can also conduct flood risk and vulnerability assessments for means of developmental planning and hazard mitigation measures. Hence, the Integrated Flood Vulnerability Index - Tool (IFVI) is developed and the progress described step by steps throughout this thesis.

Key words: Vulnerability, Index, Analysis, Flood Risk, Assessment, Decision Support Tool

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> *"I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the seashore, and diverting myself now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me." (Sir Isaac Newton)*

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> *"May the road rise up to meet you, May the wind be ever at your back, May the sun shine warm upon your face and the rain fall softly on your fields. And until we meet again, may God hold you in the hollow of his hand." (old Irish blessing)*

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1. Introduction

1.1. Preview

The recent changes in timing and hydrologic pattern of floods in Europe (IPCC, 2001a) clearly indicate that there is a growing need to assess the environmental and socioeconomic impacts of hydrological extremes, as all pattern and processes in place most likely caused by both, changes in land use[1] and global climate[2]. In this respect, Benjamin (2008) points out that prior work with the focus of flood analysis has been introduced and conducted by leading scholars like White, 1945; 1974; White and Haas, 1975; Burton et al, 1978, 1993, which had significant impact in the field of disaster risk research (Benjamin, 2008). These thinkers, according to Benjamin, were the first to not only critique, but also present new ways and approaches to flood risk management.

Due to an increasing spread of human settlement and development activities in urbanized areas (Stenchion, 1997), flood hazards and disasters are reported on a growing scale as ever before. This is particular true for urban areas, impacting negatively on socially deprived or financially less well of people like the poor (Alam et al, 2008 in Benjamin 2008) and urban development in general.[3] Many of the flood risk research conducted were mainly influenced by "by the concept of floods within the natural, rural environment" (also see Zevenbergen, 2007 in Benjamin 2008). Therefore there is a growing need to not only revisit the knowledge base of rural, urban and flood risk and vulnerability knowledge base in general to gain a better understanding of all interaction between them, but to also develop the next generation tools, which can be used by local administrative staff and not just by scientists. In this way, the IFVI study aims to inform about the interaction of the physical, social, economic and ecological parameters, but also help to support the

[1]Source: HochwasserAktionsplan Main: http://www.hap-main.de/p1041839368_443.html?SESSION=ijbp890j193vtfit10ltlddvj1#9ad63d90a4899e10b7eaebeb7b4d663e [accessed 23.01.2010]

[2] Source: Munich Reinsurance Company (Munich Re) Heavy losses due to severe weather in the first six months of 2009, Date 27 Jul 2009.
http://www.preventionweb.net/english/professional/news/v.php?id=10619 [accessed 15.10.2009]

[3] Source: GIS-Based Assessment of the Economic and Social Vulnerability of the City of Brantford, Ontario to a 100-Year Flood Event
http://www.uoguelph.ca/geography/research/geog4480_w2007/Group09/index.html [accessed 3.01.2010]

development for the next generation applications for flood risk and vulnerability assessments. The gained insight should ideally help to contribute to appropriate decision making for the local administration for better flood management.

1.2. Identifying the Problem

Because patterns of land use, urban sprawl, population growth, and other factors have an increasing impact on the environment, and thus put more elements at risk (van Westen et al)[4], and consequently increase vulnerability of people and their environment. The vulnerability describes the system in place and the degree to which it can be harmed by an hazard, while the elements at risk

It is hard, however, to identify and understand the exact source and causes of events and processes that impact the risk factors. Emphasis must be given to the combination of all interrelated geophysical processes at work. Moreover, much of the increase in risk seems to come from human behavioural patterns and choices. For example, risk will grow as densely populated areas are growing in flood prone zones and expand their property value. Continuous development in the past is partially the reason for more flood risk in some locations because of processes of population growth and thus urban sprawl because of increased development (Lewis, 1984). That is clearly a risk and it calls for better management. Because floods can occur anywhere, although some areas are more prone to serious flooding compared to others, better management[5] can be supported by insights gained throughout this study.

On the one hand, the vulnerability to socio-economic scenarios is investigated and described as a result of a flood in terms of economic and societal as the percentage necessary for aid distribution on a subdistrict level. On the other hand, floods also have negative environmental consequences to some degree affecting ecological systems. This study aims to look at both the direct physical impacts and the integrated vulnerability to people by combining and overlaying the socio-economic and environmental impacts of floods.[6]

To prevent and mitigate the vulnerability of places to floods before they happen is one of the aims of this study. Introducing an Integrated Flood Vulnerability Index (IFVI) tool, developed around a simplified Environmental Vulnerability Index (EVI) (Kaly, 2005) and Social Vulnerability Index (SVI) (Fekete, 2009) coupled index

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4 Source: Cees van Westen, Nanette Kingma & Lorena Montoya: Guide book Session 4: Elements at Risk
5 "RESEARCH: Floods!: Managing the risks of flooding in Europe."
http://ec.europa.eu/research/environment/newsanddoc/article_3249_en.htm [accessed 24.10.2009]
6 Source: UNESCO http://www.unesco-ihe-fvi.org/ [accessed 30.08.2009]

system, the aim is to simplify the rather complicated indices that are hard to understand for managers and practitioners. These index systems provide a basis in order to construct the IFVI. The outcome ought to give a better picture of vulnerable hotspots of people, including the environments and ecosystems at risk when it comes to floods and their risk or impact analysis. This can help to take into account the delayed effects from impacts on ecosystem functions caused by flood events.

In the prospective study area, the recently occurred century flood in 1999 has caused considerable damage to the environment. Returning floods in 2002 and 2005 have also shown that negative impacts should and can be diminished by precautionary flood protection measures. Conducting a geophysical analysis to depict vulnerable areas and hotspots in the future becomes thus a major requirement to better understand and manage populated places and events.

Flood risks seem to become ever more popular these days all over the world. The recent devastating floods in central Europe (Vogel, 2002) and southern USA (Travis, 2005) challenges current floodplain management practices. These changes in climate may have a contributing factor to more frequent extreme events (Heejun Chang, 2008). “Climatic changes seem to fit the pattern, and people are expected to live with more severe weather and extreme events like severe storms, more heavy rainfall and a greater tendency towards flood risk” according to Prof. Dr. Peter Höppe, Head of Geo Risks Research at Munich Re. because of the steadily rising numbers in losses and damages caused by severe weather over the last years. This is also emphasized by the “HochwasserAktionsplan Main”[7] Munich Re Insurance has emphasized on the importance to consistently adapt to unavoidable changes and thus tackle the causes of climate change. Furthermore, an analysis of the very latest, peer-reviewed science indicates that the majority of predictions made for are more likely to happen, including shifts in the hydrological cycle.

Before continuing to elaborate on the IFVI (Integrated Flood Vulnerability Index) study, a few notions and terms need to be elaborated. The definitions for the vulnerability assessment framework were adapted from the ITC Guide Book on Vulnerability Assessments (van Westen and Kingma, ITC)

[7] Source: HochwasserAktionsplan Main: http://www.hap-main.de/p663651820_395.html?SESSION=ijbp890j193vtfit10ltlddvj1#9ad63d90a4899e10b7eaebeb7b4d663e

1.3. What is vulnerability?

To begin with, the basic concept on vulnerability work comes directly from Hewitt and Burton's Hazardousness of Place (Hewitt and Burton, 1971) and James Lewis work on place-based vulnerability (Lewis, 1979). Furthermore, the basic make up of vulnerability was presented as the Pressure and Release (PAR) model, indicating that vulnerability as a social product, a social; construct (Blaiki, 1994) and Wisner et al. 2004 in van Westen[8])

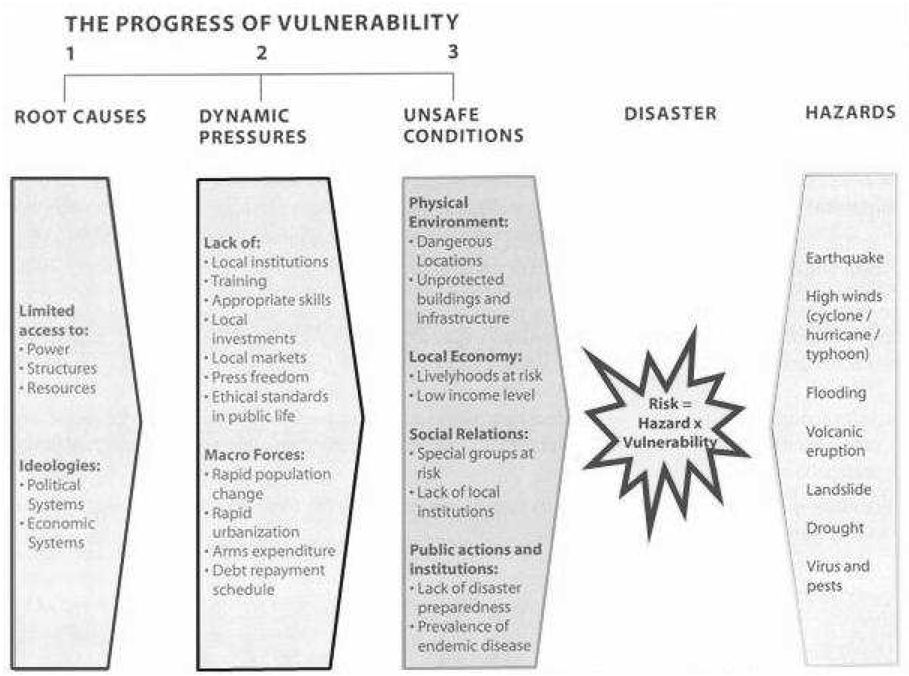


Figure 1-1: The progress of vulnerability (Source: Blaikie, Cannon et al. 1994)

So, the basis of many issues related to vulnerability seem to origin from proc esses related to "economic, demographic, and political processes as a function of economic structure, legal definitions of rights, gender relations, and other elements of the ideological order and reflect the distribution of power in a society (Blaikie, Cannon et al. 1994 in van Westen)." This indicates that the basic ingredient of vulnerability seem to be all major characteristics included about how a society is fabricated, how it works - its current state of being in the moment of a hazardous impact.

[8] Source: Cees van Westen & Nanette Kingma; Guide Book Session 5: Vulnerability assessment, ITC, The Netherlands

This literature review outlines issues and facts related to floods and the conceptual make up of vulnerability. Throughout this document, the focus will primarily be on vulnerability and the role of an individual's socioeconomic status in their state of vulnerability to a natural hazard like a flood. In addition, the likely vulnerability of the people and their environment are taken into consideration, and investigated since it is questionable whether there is a real level of vulnerability to be reported concerning the ecological environment. Saying that, environmental events are "normal and they serve important ecological and societal functions." (Kelman, 2009a). In addition, Kelman (2009a) also refers back to Hewitt who has stated that "such events are termed "hazards" only form a human perspective, and that is particularly true when they cannot cope with them."

As mentioned above, the literature review focuses therefore primarily on the concept of vulnerability but will consider significant matters of individuals, their socioeconomic status as societal construct, and its links to vulnerability in general. We do not engage with a distinct analysis of the issues. The review will further explore economic and ecological factors combined with the socioeconomic relations, their status to vulnerability in respect to food hazards and risks in general. Consequently, the intent of this literature review is to provide background information on how and why socioeconomic status is ultimately linked with issues of risk the highly discussed concept of vulnerability in the light of hazards, 'flood Hazards' and risks in general. There is very good material, but yet, much work is lacking fundamental proof of originality due to missing links to the earlier established vulnerability literature (Kelman, 2008c).

Global processes like that of climate change precede, are driven and also intensified by degrading transnational economic, political and societal interests and thus habits of resource exploitation, causing negative impact on the entire ecosystem affecting humanity. All climate change agents seem to feed the outbreak and intensity of natural hazards like floods on a constant but increasing manner. Therefore, natural hazards like floods, but also others risks tend to revisit human settlements and cause risk to some but less risk to others. This is where the concept of socioeconomic status plays a role and applies. People have different perceptions of hazards and varying options to cope with flood hazards accordingly. This depends on their geographic location, social and political background, values and beliefs, but mainly their economic status within society and thus their coping as adaptive capacity. The key to absolute safety would be first, to live in a fairly safe place, but secondly and much more importantly, to have a good governance system in place, adapting environmental policy measures and manage people's safety as a precaution against severe damage (Olson, 2009). The IFVI should help to improve the planning strategies on an administrative level in the face of all the points mentioned above.

Why is vulnerability defined by so many scientists in so many different ways? Is it due to the scientist’s different origins or backgrounds, their educational influences, or their geographic imagination? (Woodward, 2000) Is it the geography in their mind - their perception? No matter what the reason is, there clearly is a need to find a rather clear and uniform definition for vulnerability, especially for more social descriptive factors for indicator design in and for the realm of the social as well as the natural science. This is important for vulnerability studies and assessments as in ‘thinking geography in relation to define vulnerability’ and making it uniform for a better understanding in an interdisciplinary field in the new age of disturbing natural events to come for the human population. For instance, research on social vulnerability, which remains one of the most important part for the IFVI study will be elaborated and explained in more detail. In addition, there is also a need for a better hydrological understanding in the face of climate change, as well as the need to push forward the understanding of flooding in respect to all vulnerability studies, especially regarding the combination of social and natural aspects alike. This will help to gain more detailed insight into the cause-effect relationships and the derived quantitative description in (flood-) hazard studies in general.

Because to date research on vulnerability, especially social vulnerability, has arisen from a huge variety of different fields in the natural and social sciences, every field or domain of research has defined the concept differently with its specific school of thought. This has lead to an apparently large and diversified set of definitions and approaches according to Blaikie, Cannon, Davis and Wisner 1994; Henninger 1998, Frankenberger, Drinkwater et al. 2000; Alwang, Siegel et al. 2001; Oliver-Smith 2003; Cannon, Twigg et al. 2005. Despite the diversity some common threads, similar assumptions and approaches run through most of the research to date.

The definition of vulnerability emerged after Timmerman's conceptualization in 1981 (Weichselgartner, 2001) and Hewitt’s (1997) later specification on what it means to be vulnerable in disaster literature. However, the concept soon became central for an understanding about what it really means and the condition of people that being struck by a hazard like a flood. Kelman (2009) also emphasizes the importance and the construct of how human actions, behaviour, decisions, and values ultimately lead to the actual state or perception of vulnerability. His analysis of other’s work concludes that disasters, together with the accompanying concept of vulnerability are never “natural”. This concept is now embedded in the disaster literature (e.g. Hewitt, 1997; Lewis, 1999; Mileti et al., 1999; Oliver-Smith, 1986; Steinberg, 2000; Wisner et al., 2004, in Kelman, 2009). Kelman further states that vulnerability refers to a characteristic of society which indicates the potential for damage to occur as a result of hazards (Kelman, 2002). He also writes that Smith (2005) summarizes hazards as follows: “It is generally accepted among environmental geographers that there is no such thing as a natural disaster. In every phase and aspect of a disaster -causes, vulnerability, preparedness, results and response, and reconstruction -the contours of disaster and the difference between who lives and who dies is to a greater or lesser extent a social calculus”. So the construct of the terminology, its perception related to almost every aspect of disaster and vulnerability soon became a hot topic and caused further discourse amongst scientists, and to date it remains a subject of intense debate and controversy, including how to measure hazards and gain estimates from them, while at the same time pushing research into new directions to reduce its often devastating impacts.

The following insights will summarize a large amount of current research literature heavily debated throughout research and its ongoing discourse. Furthermore, insights from several past and recent studies like the “Sixth Framework Study” FLOODsite (FP6 2004-2009)[9] European FLOODsite studies conducted between 2004 and 2009 and the “Seventh Framework Study”: ENSURE (enhancing resilience of communities and territories facing natural and na-tech hazards: FP7 2008-2011)[10]. Both of these EU funded projects have tackled and processed a large amount of these conceptual issues and also provide a very good starting point for the IFVI study. Hence, the following discussion offers a better insight and understanding of different perspectives, concepts and other important terminology of the complex picture related to hazard and links to societal vulnerability.

Also, some of the resulting literature originating from the FLOODsite study has been adopted for the IFVI study to formulate the persisting links between the social, the natural and vulnerability, but also for the economic and the ecological component mentioned later on in the study.

Once again, how do we define vulnerability? Vulnerability can be defined as the state of a system before an event, in our case a flood event, sparks an event. In the IFVI study, four types of vulnerability are included and used to derive the net vulnerability for the study area. These are the social, economic, ecological, and the physical vulnerability, which basically includes all four components. Furthermore, vulnerability can also be defined in terms of the probable likelihood of the losses caused in a system in the case of an event to happen, hence it can and should be measured in the form of socioeconomic losses to derive an adequate knowledge base

[9] Source: http://cordis.europa.eu/fetch?CALLER=FP6_NEWS&QP_EN_QVD=EN_QVD>=date'sysdate-30D';days [accessed 12.09.2009]

[10] Source: http://cordis.europa.eu/fp7/home_en.html). [accessed 12.09.2009]

of where and how to tackle the problem first. Another view of vulnerability is that vulnerability is a combination of a particular state of that system with many different intertwined factors at play, such as the capacity to cope and recover from the flood event, and thus minimizing or even preventing greater damages for future events.

Social vulnerability can be viewed and treated as a rather specific and yet multifaceted entity with many different characteristics and attributes. The characteristics are incorporated to make up the base of the overall degree of vulnerability depending on its geographic location and the socioeconomic web woven into its physical setting. However, its attributes, such as the livelihood of the people, their housing, security, access to services and gender among many others remain the main focus and issue of the IFVI to be analyzed. In addition, and this need thorough consideration for all governance and managerial instances involved, to bring about better planning strategies for the future, all social norms and customs, international, national and private and public law need to be outweighed best to regulate these (Tapsel, 2002). This is where scale becomes an important matter. Fekete (2008) clearly emphasized the different social characteristics and attributes. Hence, it is absolutely essential to think in terms of all these attributes to also depict and differentiate the relationships between them at different social scales since the "social vulnerability is often hidden, complex and nested in various human aspects and contingencies bound to different levels of society" (Fekete, 2008).

Obviously, the social focus does not solely integrate characteristics of people but also their intrinsically and tight interwoven relationship with their closer environment. That is the physical but also the ecological environments besides the societal composition of the place people inhabit and depend on. All components, which are different parts of the puzzle, should be incorporated into defining the social vulnerability together with the other vulnerabilities, and thus it remains an important matter of perception, but also the ability and availability of measurement to be addressed regarding a particular scale (Fekete, 2008; Birkmann 2006).

This is where scale becomes helpful to some degree to depict how exactly vulnerability is or can be defined differently, or in a rather universal manner. Another important point to consider are the different causes and drivers of timescale. Many studies clearly emphasize (Fekete, 2008) that one of the driving factors, and this is what Burrof et al (2005) clearly state that it always depends on whether there is s greater focus set to time and space, and its influences pertaining to the specific hazard, which is closely linked to the overall management of such devastating effects. For example, not only Wisner et al (2004), Blaikie et al (1994)., Weichselgartner (2002), Kelman (2009), and other authors extend the array of vulnerability agents in their wider analysis in relation to societal drivers and their associated processes at hand. Scale for some seems to be the people itself, meaning that according to their perception and the 'value' placed upon them (e.g. females, unemployed, disabled, young and old, and so on). For Polsky et al (2009), as well as Rygal et al (2005) and Yarnal et al (2009), scale is people, and people determine the way in which society perceives them and puts a certain value, significance and importance on others, and thus determine or characterize the effects of a hazardous impact like a flood. However, this brings up new question as to how we could define social vulnerability that is rather hazard specific? Or how is there a need, like stated in the very beginning of the literature review to erode this diversified hotpot of different terms used and applied and derive a rather universal set of terminology in science? Where should the actual focus be, the society or certain groups within? Should it be people, or environment or either of them? Is it thus possible or right to actually combine both the social and the economic to measure vulnerability? Does it make sense to actually sum up all four components at the same time for means of analysis, or should we handle all components separately? However, later chapters in this thesis of the IFVI study investigated each component independently before the net vulnerability was put into perspective and calculated.

In addition, also Fekete's study on scales for vulnerability studies (2009) refers to vulnerability as the level of susceptibility of elements at risk (van Westen et al)[11] from the exposure to an event such as a flood. Kelman (2002) reports in his study that vulnerability, according to the UN DHA (1992) is the "Degree of loss (from 0% to 100%) resulting from a potentially damaging phenomenon". The IPCCs definition of vulnerability (IPCC, 2007a) is also still under scientific debate according to several scientists like Kelly and Adger (2000) , Adger (2004), O'Brien et al. (2004), Bogardi (2005), Füssel (2005), Gallopin (2006), Thomalla et al. (2006 and Clark, et al. (2007). Once again, the starting point therefore is to consider the core concept of vulnerability and how it is embodied not only in the IPCCs work and definition of vulnerability as to how far and to what degree a system is susceptible to, or unable to cope with adverse effects of climate change (IPCC 2001; IPCC (2007b). According to Clark, words like vulnerability have been redefined, transformed and hijacked with such regularity that it is a sign of their inextinguishable practical value and resilience that they survive and prosper in so many attempts to structure and formalise the relationship between impact and response (Clark, 2007).

The concept of vulnerability has been widely treated in the literature and Villagran (2006) and Birkmann (2006) draw together some highlights. In regard to the assessment and reduction of socio-economic vulnerability, they argue, "different

[11] Source: Cees van Westen, Nanette Kingma & Lorena Montoya: Guide book Session 4: Elements at Risk

research and policy communities such as the disaster risk reduction, climate change adaptation, environmental management and poverty reduction community" have taken up the discussion individually (Thomalla, 2006) (Tompkins, 2005). Researchers of the Brahmatwinn working paper (2007) also agree that if a society is highly adaptive, meaning that it can cope or adapt its functions to hazards such as floods, that this can be perceived as the ability in economic strength and social capability. Hence they agree that a "society will be able to withstand even high levels of climate change impact..." like floods "...without serious disadvantage". On the other hand, a society with low levels of adaption (no economic surplus or alternatives; low social capability in terms of skills, technologies, information and governance) will be vulnerable to suffering disadvantage from even a low level of climate change impact (Tompkins, 2005).

Cutter (1996) pointed out that vulnerability "still means different things to different people" which is in accordance with most other researchers, although she neglects the most important literature on vulnerability. An explanation of "the risks involved in disasters" or hazards "must be connected with the vulnerability created for many people through their normal existence", where vulnerability is defined as "the characteristics of a person or group and their situation influencing their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard" (Wisner, 2004). Weichselgartner and Bertens (2000) appear to agree that in applying the term and the overall concept of vulnerability they mean "...the condition of a given area with respect to hazard, exposure, preparedness, prevention, and response characteristics to cope with specific natural hazards." So they are in consent with Cutter (1999) as well as Dwyer et al (2004) and the Brahmatwinn authors, putting a society's perception and initial capability of their analysis as "...it is a measure of capability of this set of elements to withstand events of a certain physical character."

Also Blaikie et al. (1994) clearly separate in their methodology what they call the biophysical and the social dimensions. For that reason they define vulnerability in terms of the human dimension alone as 'the capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard'. Although, Kelly and Adager (1999) emphasize to apply the term 'social vulnerability' in order to underline "the approach on the human dimension which rather neglected in past studies of vulnerability and adaptation" (Adger and Kelly, 1999), they also forget to incorporate more far reaching resources of literature. However, they do emphasize and consider that increasing inequality within a population, like the widening gap between rich and poor through globalization, "can heighten collective vulnerability as all other things being equal. Greater inequality may be associated with a reduction in communal resource allocation and in the pooling of risk and other social phenomena associated with the so-called moral economy" (Scott, 1976). In addition, there are strong links between inequality and a lack of diversification of income sources as well as with poverty, placing further constraints on response options (Reardon and Taylor, 1996) (Kelly and Adger, 2000). However, we are starting to get to the core of some of the literature, which will be further elaborated in the later chapters about the choice of the IFVF indicators.

Unquestionably, most authors do use the term social vulnerability together with different terms and meanings (Brooks, 2005) depending on their particular expertise, background, knowledge or geographic imagination (Woodward, 2000) way of thinking and their perception. On the one hand, some authors certainly differentiate or even include, and this is also apparent when looking through the literature, the rather important aspects of the hazard for their conceptual thinking and way of analysis. On the other hand, some would even argue that considering society (the term social can be ambiguous) at different scales and from different perspectives is essential to derive a good understanding of all processes in place as they are part of the entire picture. However, opinions do not always match up and some authors, for instance, like Cutter or Adger do not even take into consideration and acknowledge any of Hewitt’s, Lewis or Oliver-Smith, to cite only three of the forefathers or other important authors for the whole hazard, risk and vulnerability work established out there. Another point here is to acknowledge is that, for instance, Birkmann produced valuable work, also related to indices in general (Birkmann, 2005). However, missing literature from the very beginning of the research is absent and only recent works are cited in some of his work. Brinkmann also indicates that current available literature adds up to about 25 different definition of vulnerability, concepts and methods to systemize vulnerability (Birkmann, 2005): Furthermore, he argues that there seem to be around 20 different manuals and guidebooks on how to estimate vulnerability. As vulnerability can be looked at from different angles, it certainly reveals its multifaceted nature (Bohle, 1994).

Especially in the field of geography, the concept of vulnerability has been in use, or should we say abuse, for nearly two decades since Timmerman's conceptualization (Weichselgartner, 2001). Presently, vulnerability is used in the field of risk, hazard, and disaster management as well as in the areas of global change and environment and development studies. Within the last few years, especially urban vulnerability and the vulnerability of megacities became a focal point (Anderson,1992; Jones and Kandel, 1992; Mitchell, 1998). However, Weichselgartner (2001) as Cutter (1996), both conclude that there is no common conceptualization of vulnerability in general (Weichselgartner, 2001**).** Weichselgartner goes on to emphasize that there is no definite meaning of vulnerability, and thus it remains a rather fuzzy (Weichselgartner, 2001) and multifaceted term or concept throughout science and its different disciplines.

Throughout the analyzed literature, there seem to be four different categories of vulnerability described and these are used in the IFVI study. Later on we describe them as the IFVI components in this document, which make up the different facets of the IFVI index including all variables and individual indicators. First of all, and most importantly, there is the social vulnerability of the people, the social groups within a society who suffer the most from potential losses from flood events or disasters in general. Secondly, there is the economic vulnerability, which captures several different factors as the population size, the remoteness of a place, the merchandise export concentration, agriculture, forestry, fisheries, good and services, manufacturing and so on. Most of these processes can be describes in gross domestic product as source of income of a place (United Nations Committee for Development Policy and the World Institute for Development Economics Research of the United Nations University (UNU-WIDER)[12] in Guillaumont (2008). Third, there is the ecological concerning habitat conservation and degradation, overexploitation, displacement by invasive alien species and global climate change are the main processes currently impacting biodiversity. In particular, it is expected that within the next 100 years, terrestrial ecosystems will suffer the most from land use change, followed by climate change and nitrogen deposition (Sala, 2000, Sala 2000 in Biringer, 2003). Therefore, the ecological component finds its place into the IFVI. Last but not least, there is the physical vulnerability of the built environment, including the infrastructure and so on, but this would also include the people, the population inhabiting the prospective area at risk in case of a flood or hazard.

Finally, there is a potential for loss derived from the interaction of society with biophysical conditions which in turn affect the resilience of the environment to respond to the hazard or disaster as well as influencing the adaptation of society to such changing conditions. Many of the discrepancies in the meanings of vulnerability arise from rather different epistemological orientations and subsequently different methodological approaches and practices.

The FLOODsite study has also shown that so far, most methodologies for the assessment of vulnerability were designed according to social and economic criteria, which can be described in monetary terms, whereas intangible values, social characteristics and ecological values have been widely neglected (FLOODsite, 2009). Some time ago, Lewis (1984) also emphasized “ongoing, cumulating changes which, amongst other things, may lead to chronic conditions that could make a

[12] Source: http://www.wider.unu.edu/publications/working-papers/research-papers/2008/en_GB/rp2008-99 [accessed 04.01.2010]

disaster inevitable. That is, vulnerability is accrued as a long-term process which undermines abilities to deal with new stressors or other changes" (Lewis, 1984).

In addition, the European Union also emphasizes the need to focus increasingly on disaster prevention and risk reduction, which goes hand in hand with "proposed action at community level focuses on areas where a common approach is more effective than separate national approaches, such as developing knowledge, linking actors and policies, and improving the performance of existing community disaster prevention instruments."(UN/ISDR, 2009). This is where the use of the IFVI comes in to support the requirements pointed out by so many instances. Also Barroca, et al., (2006) stresses that future studies on vulnerability should focus on a rather local scale (Comfort, 1999 in Barroca, 2006), Comfort states that "Investment in risk reduction is likely to be most efficient and effective when directed toward improving local capacity to act in coordinated ways to achieve this community-wide goal and the link between policy and practice in disaster mitigation needs to be established at the local level" (Comfort, 1999 in Barroca 2006). Therefore, it becomes interesting that vulnerability can be examined at different levels and scales, as this is the case for the IFVI, and for different issues. For instance, studies have the ability to look at a single issue such as a building, or to assess a complex entity such as a town. The IFVI study focuses on a subdistrict level. (Barroca, 2006)

By having analyzed a wide range of literature, it became clear that there is increasing importance of measuring vulnerability and developing indicators to reduce the vulnerability of societies at risk (Birkmann, 2006). This need was also stated in the final document of the 2005 World Conference on Disaster reduction and repeatedly affirmed in the recently published United Nations on International Strategy for Disaster Reduction (UN/ISDR, 2009) in 2009. Birkmann (2006) goes on to argue that "the ability to measure vulnerability is increasingly seen as a key step, a "key activity" (Birkmann, 2005): forward towards effective risk reduction and the promotion of a culture of disaster resilience." Therefore, in the light of increasing frequency of disaster and continuing environmental degradation, it becomes more than important to measure vulnerability, as it remains a major task to understand all related processes and their origins in place. This will ultimately help to push science, but also administrative and managerial instances to help and support the transition to a more sustainable future (Kasperson et al, 2005 in Birkmann, 2005). Hence, and this is also one of the main concerns in the IFVI study and its indicators used, there is a need to not only focus on purely hazard-oriented approaches (Lewis, 1999) but peoples livelihood must be taken into consideration. Birkmann (2007) also comments that, according to the UN (UN,2005), the development of systems of indicators of risk and vulnerability, that at national, but more importantly on a sub-national scale is definitely essential and requires thorough consideration. It will enable decision makers to assess the impact of floods on all levels (i.e. social, economic, and ecological) to disseminate the results to other decision makers, as well as managers, government, the public and especially the vulnerable population at risk (Olson, 2009).

1.4. Flood Hazard

According to the description of the British Environmental Agency, the notion of flood or flooding is basically a natural event and describes the occurrence of severe rainfalls that fills rivers and streams above their normal capacity. In comparison, the SeaGrantHaznet (NOAA) webpage would refer to floods also as natural events, but they add that "... they have shaped the landscape, provided habitat for wildlife, and created rich soils. Cumulatively, floods have also been our nation's greatest disaster, disrupting lives, and often causing significant economic losses."[13] Other causes for flood are elevated or high river levels, but also tidal or fluvial increase can cause water levels to rise or surge. Both agencies acknowledge in their literature that floods are a hazard, but only the SeaGrantHaznet (NOAA) characterizes it also as positive, as the creator of landscapes, wildlife and rich soils and links the economic loss of a society.

As a result, like in the case of Hurricane Katherina in which heavy rainfall caused excess waters flooding the city, low lying and close to the water settlements areas are more prone to experience floods than any other areas (Travis (2005). Grebner and Richter pointed that out in their literature that floods can also occur when rainwater or melting snow collects on the ground and cannot find a source to drain into (i.e. frozen or solid ground condition). This is a typical example where surface water run-off in sloppy areas (Grebner and Richter, 1991). Consequently, localised flooding mainly happens when the ground cannot absorb any more water in a particular area due to human alternation, increasing risk. And Kelman seems to agree with Grebner and Richter in his article "The Autumn 2000 Floods in England and Flood Management" (2001). He found that vulnerability of people has increased as demographic changes have increasingly put people and property in vulnerable areas like expanding urban areas like in England in 2000. England experienced exceptional levels of rain during autumn 2000, but the resulting flood disaster was mostly caused by society (Kelman, 2001). So, is society a hazard to itself? Kelmans analytic approach like Grebner and Richters argues in "Philosophy of Flood Fatalities"(2004) that "Disasters are sociological, not physical, phenomena. So are disasters, hazards are caused by the people or by nature?

[13] Source: http://www.haznet.org [accessed 12.01.2010]

Though triggered by nature, floods are always somehow embedded in a social context when looking to most reports, papers or articles which are available. Floods become negative subject to certain socio-economic, political, and historical situations and constraints (IPCC, 2001b). Hence, floods are cultural and social as well as organizational, technical, communicative, and economic events (Birkmann, 2006). Despite of the risk people may face, most literature stresses the cause of impacts of floods on society depend primarily on how flood reduction is managed in the first place through governance instances. It is convenient to assume that climate change is the start of the impact process like floods, but most research emphasizes yet on externalities, triggering subsequent socio-economic change and adaptation (FLOODsite, 2009).

1.5. Interpreting Vulnerability

The IFVI assessment formula

$$IFVI\ Vul = \sum \quad (SocVul + EconVul + EcolVul) \times PhysicalVul$$

where

IVFI	=	Integrated Flood Vulnerability Index
SocVuln	=	Social Vulnerability factors
EconVul	=	Economic Vulnerability factors
EcoVul	=	Ecological Vulnerability factors
Physical Vul	=	Physical flood factor

The key elements of vulnerability are defined in the mathematical function presented above. The "Physical (Flood) .combinations are defined discretely in intervals from 0.00->4m; The areas at risk (i.e.vulnerable environment), is not completely described due to the limited time-frame of this thesis. Despite the gaps, which exist in fully defining the hazard, the objectives of this thesis (Section 1.3) were focused on the IFVI indicator/index development, and its simplification to be an easy tool to use, and understanding vulnerability through exploring

These references (van Westen and Kingma, ITC Netherlands)[14] indicate that risk is fundamentally a combination of hazard and vulnerability. To mathematically combine hazard and vulnerability to quantify risk/vulnerability as mathematical expectation, quantitative descriptions of hazard and vulnerability are necessary.

[14] Source: Cees van Westen & Nanette Kingma; **"**Guide Book Session 5: Vulnerability Assessment", ITC, The Netherlands

1.6. Governance and the IFVI

Disregarding of the place, governance action, to prevent risk and adapt precautionary principles to protect people is a key component of social capacity, and is thus automatically part of adaptive capacity. In reality, it extends and includes the complete array of a coping system and how it responds to risks according to most literature. However, governance can be seen as pervading every level of social, economic and political interaction including regulations, procedures, practices and expectations (Clark, 2007). However, also local knowledge is repeatedly mentioned in most literature by writers in the light of disaster/hazard management, stressing to enable local communities to participate actively in the decision making process for prevention. That is how local communities could enhance their socioeconomic status by engaging with their own environment and decrease their vulnerability to new hazard like a flood. Consequently, local knowledge is a powerful resource for people and therefore a key element in disaster risk reduction in general (Phong Tran, 2008 in Clark, 2007).

Most literature emphasizes and implies that policy makers, non-governmental organizations (NGOs) and other instances involved in hazard, risk or flood management in governance must pay closer attention to the background of social class and gendered nature of hazard vulnerability. Stressors imply primarily focus on special medical, economic and security needs of weaker citizens in the aftermath of a flood risks. To develop better policies in governance for environmental management will not entirely prevent future impacts of flood hazards and the weaker link in societies where their everyday socio-economic status is low, but better and adaptive policies could, however, reduce the excess hazard risk (IPCC 2001) of those in need as compared to that of the better off people in society.

A number of different literature shows that the varying perception of socioeconomic vulnerability, hazard and risk and other concepts are highly discussed and appear thus more like a social construct, and not only researchers interpreted it in various forms. Like Cutter (1996) puts it, "there is no consensus within the social science community about social vulnerability or its wider connection of meaning. Using the hazards-of-place model of vulnerability, we suggest that social vulnerability..." in a social context "...is a multidimensional concept that helps to identify those characteristics and experiences of communities (and individuals) that enable them to respond to and recover from environmental hazards." (Cutter, 1996), and most of her research colleagues seem to agree. True is that the underlying cultural, social and economic patterns always influence and construct special socioeconomic parameters or status of each society, depending on the place of a risk/hazard like a flood, and thereby generates a specific vulnerability to natural but also socioeconomic disasters like floods. On average, nearly all literature evaluated indicates that natural disasters like floods, disregarding a specific geographic location, increase vulnerability of the weaker as the lack of governance policy and management does not take people into consideration in the first place. Therefore, socioeconomic less well of citizens are mostly disadvantaged to deal with hazards/floods because of their limited option of copping capacity and adaptation.

1.7. Workflow and methodological approach

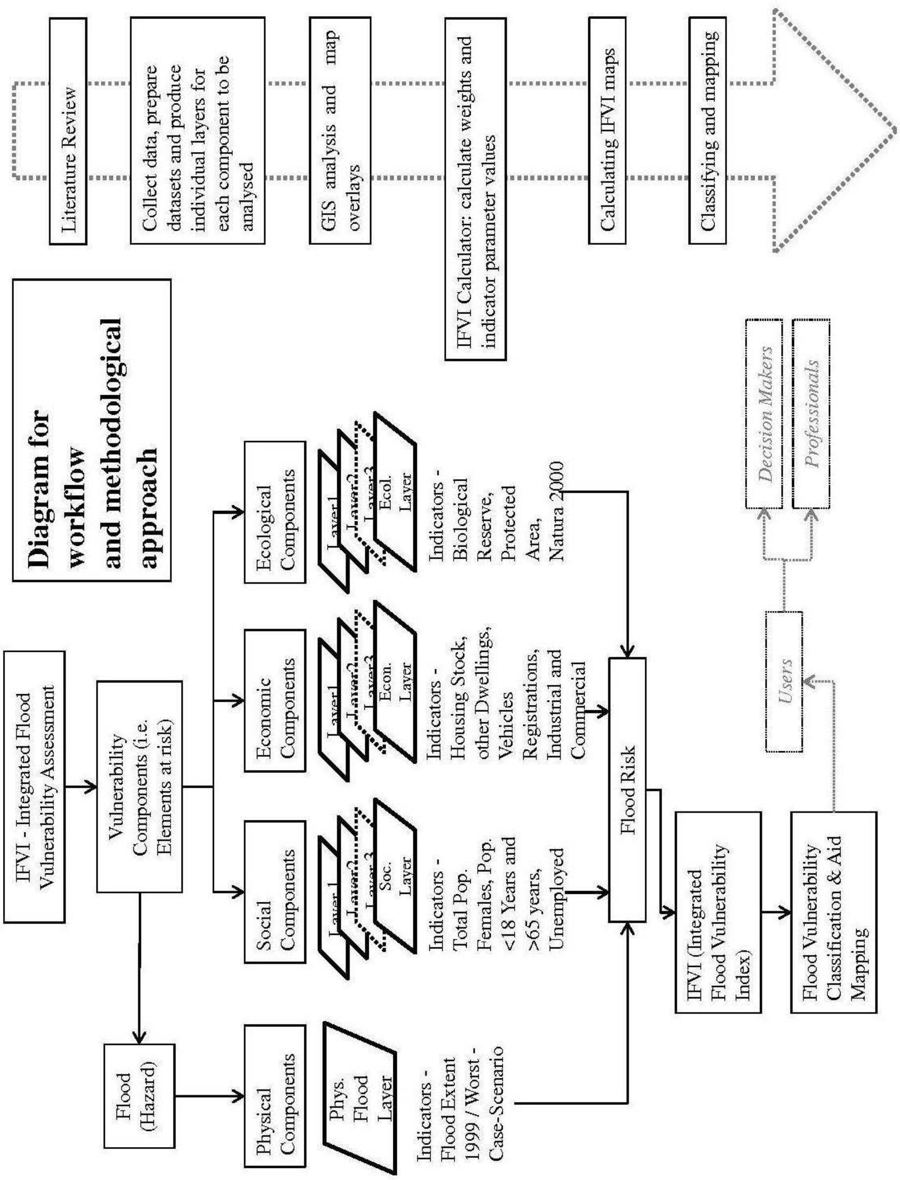


Figure 1-2: IFVI workflow and methodological approach developed for the IFVI study

1.8. Research approach and problem definition

According to literature there seems to be a real demand for continuous monitoring and planning to better cope with flood events in the future. The integration of the social dimension is taken into consideration as a main part of the flood vulnerability assessment. Likely long-term effects that show in the ecological vulnerability are yet another important part to be considered in the vulnerability analysis. The literature evaluated throughout the work of this thesis indicates that many vulnerability index systems were designed in the last decade (Fekete, 2009). Only some of them clearly point out the practical reasoning of the indicators applied. There is obviously a need that the functions of such an index system can be easily understood, as well as applied and utilized by other operators/users besides scientists. Consequently, a vulnerability assessment tool like the IFVI is important to improve probable flood mitigation strategies and activities.

The overall research approach of this thesis will aggregate a number of selected datasets with physical, ecological and societal variables and analyze GIS data layers to depict different ranges of percentage of 'flood vulnerability' (low-high vulnerability). Another reason is to conduct a spatial assessment and identify the elements at risk (van Westen et al)[15] and thus vulnerable hotspots in the event of a flood. Outcomes such as maps can help to improve regional spatial planning and policymaking, but also vulnerability related decision-making and analysis for authorities to make hazard mitigation planning recommendations.

1.9. Scale issues and thoughts on accuracy

There seem to be two major problems with indices. On the one hand, spatial scale is important as it plays an important role to depict more details, and still, many index systems are applied on elevated scales like regional or national scale. This allows the analysis of processes on, for example, a larger scale, but the more interesting small scale micro-level indicative features are left out to aim and improve specific mitigation strategies for the places where floods really occur. Hence, emphasis is given to conduct the IFVI study as it is appealing and important to make an analysis on a limited spatial scale to obtain better results on the sub-country level (Brooks, 2005). As scale can be of limitation to some extent, the temporal scale as in time may also act against the accuracy of the scale of vulnerability analysis as wanted at higher resolution (Fekete, 2009).

[15] Source: Cees van Westen, Nanette Kingma & Lorena Montoya: Guide book Session 4: Elements at Risk

In addition, subjectivity, all personal impression, feelings and opinions rather than external facts involved for such an index will always remain an issue necessary to consider carefully. The only solution for transparency is to use and describe theoretical insights concerning the nature of all components mapped. This helps to guarantee the appropriate selection of variables according to the assumptions made, and the methodology applied in the process to build around the IFVI tool. This can help to make the tool attractive for stakeholders, who should be able to apply the same methodology in their everyday work. Again, that is because stakeholders can thus profit from the described study approach and integrate the IFVI tool in practice.

Further consideration to scale, data and accuracy are given is discussed in the discussion section of this thesis. The next section describes the objectives set out and aims accomplished in the IFVI study.

2. Objectives of research

The study aims to improve already conducted flood vulnerability assessments by designing the IFVI strategy-tool to identify and assess in a more detail how people and the environment are vulnerable to floods. The study draws on a detailed case study on the Danube River in Southern Germany and illustrates the use of an improved Flood Vulnerability Assessment by developing an index system incorporating social, economic and ecologic indicators into an Integrated Flood Vulnerability Index – tool (IFVI). The study contains computed examples, which were mapped to illustrate the assessment process, including data sets, but also provide a detailed description of the data and the tools, which are applied.

Overall, The IFVI study should help to improve planning processes in the prospective study area and respond to a flood hazard/disaster by understanding what the likely vulnerabilities in place are. Thus better managerial strategies can be made and introduced for the city of Ingolstadt.

2.1. Specific research objectives

1. To review current literature related to floods and flood management, indicator design, and especially flood risk literature related to vulnerability issues

2. To comparatively analyze the vulnerability of the Flood 1999 (Pfingsthochwasser 1999) with the worst-case-scenario weather event. Both events will be analyzed to identify the most vulnerable locations in the study area.

3. To undertake a vulnerability assessment of the identified most vulnerable areas in the study area.

4. To integrate the vulnerability assessment findings to derive aid maps for better planning strategies.

Further tasks are the documentation of parameters, data and information for the study area for both the natural and human dimensions. Another aim is to follow the methodological approach (Figure 1.3) in order to assess vulnerability and formulate a concluding statement by making use of publicly available data and GIS technology (ArcGIS9.3) as a decision support tool in conjunction with the developed IFVI. This should help to enhance the understanding of the degree of vulnerability for the prospective study area and both its natural and human dimensions.

2.2. Research questions

1. How to include and combine and ecological and societal factors with a limited amount of indicators for the *Integrated Flood Vulnerability Index* and assessment?

2. How can the computed outcomes of the assessment be used to support and improve administrative planning strategies with the calculated results of the *Integrated Flood Vulnerability Index*?

2.3. Deliverables

1. The IFVI tool, which can be applied anywhere as it is not scale dependant, depending on the data available, and the indicators design for the specific area

2. Flood risk and vulnerability mapping for the city of Ingolstadt in the Danube River floodplain

3. Flood investigation map of the hydrological event and environmental impacts of the different measures

4. Functionality of the IFVI tool developed used and tested in GIS by mapping vulnerability in the study area

5. Vulnerability maps in the form of prospective “aid maps” on an administrative level with the purpose to support planning strategies

3. Study area

The study area of Ingolstadt is situated in the South of Germany, 48,5 degree North and 11,3 degree East, has about 123.000 inhabitants and covers a total area of 133.35km^2 (Figure 3; see also topographic map in Figure 9.1 in appendices) The mean annual precipitation reaches 650mm; the average annual mean temperature is 8.2 grad Celsius. Ingolstadt is situated along the Danube River in a low-lying floodplain; the main topographical features are represented by the Jurassic karst and tertiary terrain near the Danube. The area was chosen because of the following. First, the study qualifies well because of data availability. The data which was required for the assessment was obtainable for the proof of concept. Furthermore, the study area is well suited due to its geographical settings, pointing out that the study area is well suited due to its flood proneness with Natura 2000 areas, protected areas with valuable flora and fauna. The close proximity of the natural environment with settlement and progressing economic activities, also urban sprawl, makes the area interesting for a study. Most importantly, an increased number of flood events in recent years (Table1) make the place interesting and an excellent prerequisite for a vulnerability assessment.

The Danube River became, and still is a focus of attention concerning floods and the consequently high economic losses. In contrast, the Danube River and its basin is an area of high biological diversity, with established protected areas and Natura 2000 sites, that is not only important for activities like tourism, fishery and forestry, but it is also a home for large amount of animal and plant species.[16] These are all reasons for the choice of the study area and its suitability.

Flood events since 1965 (Record Gauge at km 129,7)	**Date**	**Danube water level (m)**	**Discharge Danube m³/s**
Flood June 1965	6/12/1965	7.60	1860
Flood April 1994	4/15/1994	5.85	1470
Flood 1999 (Fathers Day)	5/15/1999	6.14	n/a
Flood 1999 (Whitsuntide)	5/24/1999	7.49	2220
Flood August 2002	8/14/2002	6.12	1607
Flood August 2005	8/28/2005	6.48	1770

Table 1: Table is listing the most recent flood events in the city of Ingolstadt, (Source: Communal Institution and Planning Department Ingolstadt)

[16]Source: http://www.internationalrivers.org/en/node/3658 (Defending the Danube by Susanne Ebert Dec 15, 2008) [accessed 17.10.2009]

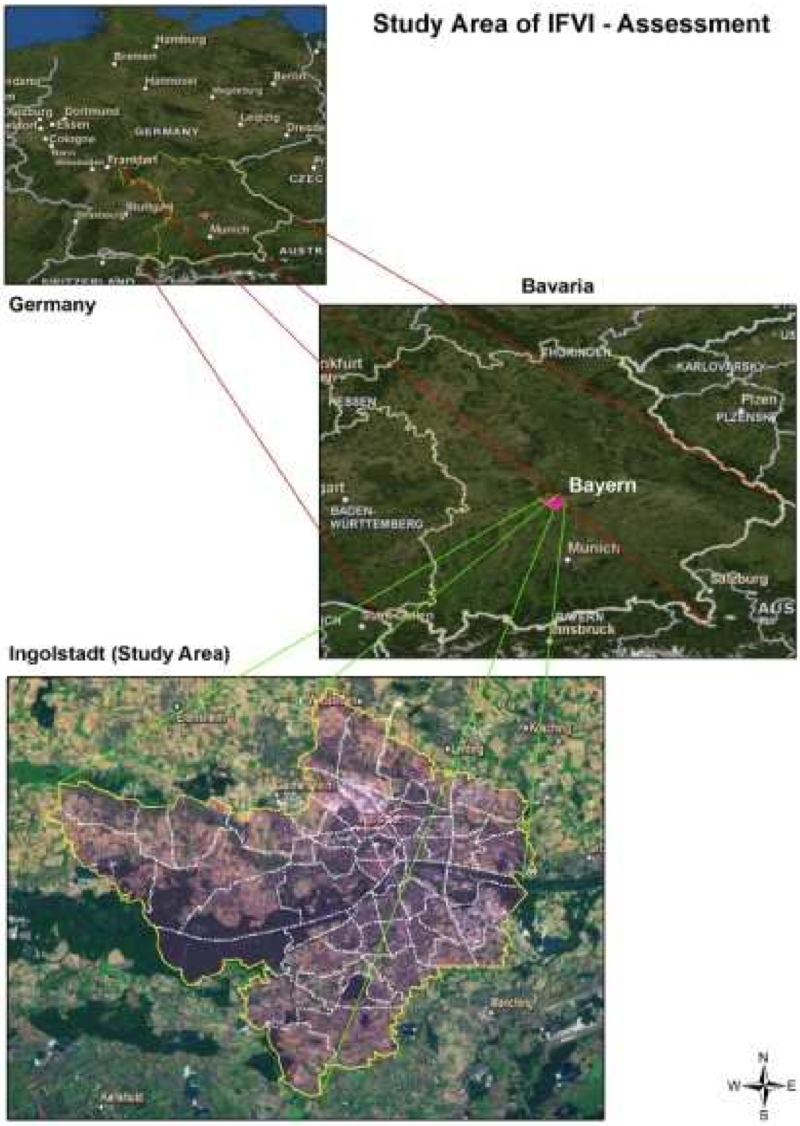


Figure 3-1: Shows the study area of Ingolstadt, Germany

Both, the socioeconomic and ecologic dimension need to be managed adequately in order to prevent future negative consequences or drawbacks, caused by either climate change or due to anthropogenic mismanagement. That may imply the loss of valuable land and its biodiversity. However, there are many economic activities having negative impact on the environments. Therefore, there is no need to add additional pressure to the environment. Since the reoccurring severe weather and floods over the last years have caused a considerable damage, it becomes rather necessary to not only analyze all processes in place, but look at them from a socio-ecological perspective within as well as from outside of the field of science to better understand probable future flood events. All this can help to increase the general understanding of such events, too. Due to the criteria mentioned, the area was chosen for this study.

To further support the choice of the prospective study area with evidence, the following part of section is going to elaborate the analysis and presentation of the results of the Danube River. Flow data of height centimetre and m3/s of quantity discharge were statistically calculated and are presented in Figure 3.2. The obtained data for the analysis was recorded at the gauging station in Ingolstadt Luitpoldstrasse (Table 2).

Water gauge in the Danube area: Ingolstadt Luitpoldstraße/Donau

Catchment area	20.001,00 km²
River Kilometer Index (RKI)	2.457,80 km
Gauge station site **(meters above sea level)**	360,35 (m ASL / m a.s.l.)
Easting (Gauss-Krüger, Bezug 12° Meridian)	4457907,00 m
Northing (Gauss-Krueger)	5402367,00 m

Table 2: Water gauging station Ingolstadt Luitpoldstrasse; Source: Bavarian Environmental Agency

The discharge data for peak and base flow, as well as river level data was analyzed. The data was available as measurements of daily means. The data was sorted and averaged into annual-monthly-mean values for graphical display to be investigated. The results are presented in the next two sections.

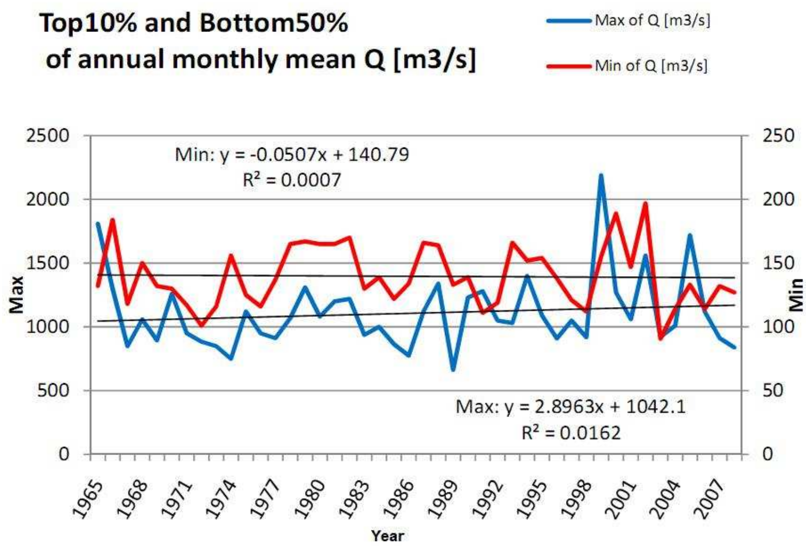


Figure 3-2: Graph showing top 10% peak and bottom 50% base flow

Figure 3.2 show the results of the time series data analysis of discharge [m3/s] from 1965 – 2008. It seems as if, according to the analyzed data that there is a slight trend to report that can be associated with greater likelihood of increased floods in the future. The graph displays an increasing trend of the peak and baseflow, although these are not large. The contrasting trends in the overall peak and base flow can be associated with recent flooding. The trend of greater discharge is easily to depict on the graph in the years 1999, 2002 and 2005 compared to the years before. However, the overall may imply that these events are more frequent due to climatic changes[17], but the analyzed data does not indicate a serious pattern of greater likelihood of extreme events to occur in the future. However, despite the limited evidence of the likely occurrence of probable future flooding events in the study area, the streamflow analysis gives reason enough by showing the recent events within the last decade, which gives enough importance to the situation to carry out a flood vulnerability assessment in the prospective study area

Supportive to the statement made above regarding the stream flow analysis are studies conducted in Southern Germany, which revealed that there is indeed an increase annual mean temperatures from 0.5 to 1.2 degree Celsius from 1931 onward, depending on the particular region. In comparison, records of annual pattern of precipitation changed little within that period. However, scientists report that the

[17] Source: http://www.hap-main.de/p663651820_395.html?SESSION=ijbp890j193vtfit10ltlddvj1#9ad63d90a4899e10b7eaebeb7b4d663e [accessed 23.10.2009]

general pattern of rainfall shifted, showing an increase of precipitation during the summer and less precipitation during spring and winter.18 This may explain the sudden occurrence of flood in 1999, 2002 and 2005 of the Danube river. Nonetheless, in order to estimate future changes in flood flows, water balance models with different regional climate scenarios must be calculated. For instance, the EU project ESPACE (European Spatial Planning: Adapting to Climate Events) for Climate change and river basin planning aims to develop how flood protection schemes can be adapted to a climate change.

[18] Source: http://www.hap-main.de/p663651820_395.html?SESSION=ijbp890j193vtfit10ltlddvj1#9ad63d90a4899e10b7eaebeb7b4d663e [accessed 22.02.2010]

4. Materials and Method

This Chapter describes the necessary steps taken, the data obtained and the use of a SMCA (Spatial Multi Criteria Analysis) method for quantitatively describing the risk and vulnerability of the particular study area, which was subjected to floods in the past and still is today. The principles and methods applied and described can be applied in to areas of interest.

The conceptual Model – Framework for the IFVI study

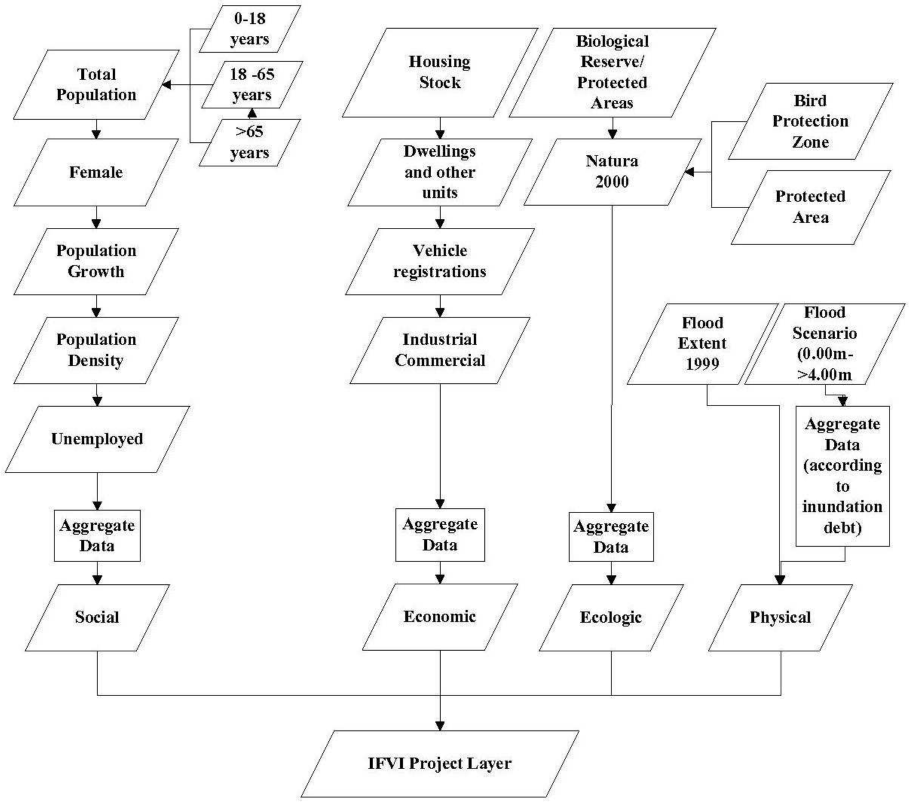


Figure 4-1: Shows the conceptual model to derive the final IFVI project layer

Figure 4.1, displays the conceptual approach and how all components for the IFVI study are going to be aggregated to calculate and evaluate the flood risk and the likely consequence of the flood hazard in respect to the exposure of all elements at risk and their respective vulnerability (Boruff, 2005). Furthermore, the flood vulnerability assessment shows how the IFVI tool is developed and how functions describe the relationship between hydraulic parameters (i.e. flood extent) and the relative vulnerability calculated for the element at risk.

4.1. Spatial Multi Criteria Analysis for IFVI vulnerability assessment.

In order to conduct the IFVI study a multi-criteria analysis approach is necessary. The method allows analyzing several different components and factors. The way the assessment is carried out is based on the Analytical Hierarchical Process (AHP) developed by Saaty (1980) in van Westen and Kingma. The AHP has been extensively applied in other studies on decision-making problems (Saaty and Vargas 2001), and extensive research has been carried out to apply AHP to risk assessment. This will ensure the correctness of the thesis research approach conducted. In addition, within a spatial multi criteria analysis, one extra step is taken into the methodological approach Raaijmakers (2006) and is extensively described in van Herwijnen (1999) and Raaijmakers (2006)**.**

According to Raaijmakers (2006)**.** spatial multi-criteria-analysis (SMCA) can be used in two different ways. On the one hand, the analysis is conducted to identify a certain magnitude and spatial distribution of a flood risk. Literature described in Tapsel et al (2007) analysed implies that most current approaches focus on economic risks only. Environmental, social, or cultural risks seem to be often missing. The assessments enable user to consider all relevant components of risks as needed. Thus, depending on the applied risk or vulnerability criteria assigned to a specific area of interest. Ultimately, results can be compared, and evaluated by GIS based analysis. That also allows the ranking of either the area or a particular indicator to display the level of risk or vulnerability. On the other hand, and that is one aim of the IFVI, once the SMCAs approach identified areas of vulnerability, alternative measures can be elaborated, which help to mitigate high flood risks, the measures of mitigation are to be evaluated to derive a better knowledge base alternative or combination of alternatives. The approach includes components such as non monetary assets, like environmental or social vulnerability, assets and amenities as evaluation criteria into consideration. However, analyzing the spatial distribution of the processed data in GIS is the final step for means of documentation.

Specific indicators are chosen, developed and discussed. Important to note, socioeconomic processes are direct or indirectly linked, and thus inextricably interrelated. It must be considered, and this is especially important for policy and management instances to know, that by using the natural environment for their means, processes of socioeconomic modes are always and certainly affected, diminished or even hindered once the ecological system is affected to some degree. Additionally, and that is indicated by the recently carried out FLOODsite study, so far, most methodologies for the assessment of vulnerability were designed according to economic criteria, which can be described in monetary terms, whereas intangible values, social characteristics and ecological values have been widely neglected (FLOODsite, 2009). Therefore, the IFVI study emphasizes on the integration of social, economic, ecological, and physical components for the assessment.

Kelman (2001) and Penning-Rowsell (2001) also express concern that new developments could factor in negative externalities like (1) the reduction of invaluable wetlands and flood plains which act as water storage areas; (2) accelerated surface water run-off and directing it right away into rivers, thereby intensifying increased flow rates and river levels following rainfall; and (3) changing flow patterns with effects in inundation speed, flood velocity, and flood duration.
Changes in land use practices, such as modes and/or cultivation techniques, have the strong potential to increase flood risk and the types of damage experienced during or after a flood event (Boardman, 2001, in Kelman 2001).

Considering such a wide range of factors, a simplified and fast way to quantify flood vulnerability is important regarding all components cited before. Thus the study approach helps to basically support managers and policy-makers of institutions in the insurance industry, the government, individuals or corporate property owners. Against this background, the IFVI will help to depict those hotspots that are most vulnerable in the case of a flood.

The IFVI is intended to be descriptive, concerning the method for data collection, and processing. However, this offers some sort of flexibility but has both strength and weaknesses. Its strength is to allow different users to use and apply the tool in a variety of computing scenarios and the wanted contexts. Its weakness is that the diversity of data sources and data sets makes comparison to other projects rather difficult and hence limits the potential for drawing more general lessons from the study.

Smaller problems have arisen over the choice of indicators. The IFVI defines its indicators for more comprehension. Evaluating the specific definitions and why they were chosen is yet another important step in the analysis. The indicators received weights are further used to calculate risk and vulnerability in the GIS software ArcGIS9.3, a powerful tool for vulnerability analysis and hazard management (Wang, 1999).

The overall approach is straightforward and keeps in mind the participatory stakeholder approach, thus keeping it simple. Moreover, the lack of more specific guidance of stakeholders on appropriate indicators can wrong outcomes of the complete study conducted. Interviews with local administration departments were conducted for more information.

4.2. Data quality and availability

The data used in this thesis can be put into the following categories listed in Tabel 3: Aerial photography, GIS datasets, and census data. Additional information was acquired in the form of interviews to get the opinions, preferences, concerns of various stakeholders such as environmental organisation, local experts and administrations and citizens, also for means of verification of the data obtained or processed (see also Section 6.1 on validation). The geometrical structure of the data corresponds to the GCS Deutsches Hauptdreiecksnetz Germany Zone 4 projection. The following information is integrated in the base data set:

Topographic data:	Digital Orthographic Photos (DOP); Source: Bavarian Environmental Agency: Land Surveying Department (Munich)
Administrative data:	Political and jurisdictional boundaries; Source: ESRI (ArcGIS9.3), the GIS Data Depot[19], and own generated vector layers
Infrastructure data:	Commercial and industrial; Source: CORINE Land cover 2000[20] [21]
Hydro-meteorological data:	Flood extent layer, river stream flow; Source: Department for Watershed Management, Ingolstadt Communal Institution and Planning Department Ingolstadt; Bavarian Environmental Agency; Land Surveying Department
Socioeconomic data:	Census; Source: Statistical Department Ingolstadt
Natural features:	Biotope, protected areas and NATURA2000; Source: Bavarian Environmental Agency; Land Surveying Department

Table 3: Spatial data for the IFVI study (a detailed data list can be found in appendices)

To note, the index would only be as good as the quality of the data feed into the index system. In addition, obtainable data quantity increases on a national-level but it is rather limited on a local scale and was hard to obtain. The quality of spatial data varied in scale. The following types of data (see Table 3) were received from

[19] Source: http://data.geocomm.com/catalog/GM/datalist.html

[20] Source: http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database-1[accessed 22.11.2009]

[21] Source (Documentation): http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2000-clc2000-seamless-vector-database [accessed 13.12.2009]

authorities: (1) detailed GIS data (i.e. administrative, infrastructure and natural features); (2) digital data (i.e. topographic), georeferenced aerial images and raster data (scanned maps); and (3) analogous maps in pdf (portable document format) Word and Excel of very different scales with different information. There was no land cover descriptive data available, only some 10 per cent of all protected areas was provided. Other freely obtainable land cover data was only available with 1km resolution and thus not suited for the study. Although gaps were evident, about 70 per cent of the required data could be filled in. The detailed information about the different data is listed in Table 10 (Appendices).

Also the IFVI matrix in Table 4, section 4.4.3 is useful as a guideline for data collection and later processing, because it offers an overview of all inputs and it is a reminder of the different aspects to look into. The computed result will be subject to a more descriptive than analytical study. The components and indicators derived and developed from earlier studies supported the methodological approach calculating risk and vulnerability more concrete. The list was thus helpful to specify indicators of the characteristics/components identified. The IFVI matrix is structured in such a way that it is comprehensive and covers the important variables for all social, economic, ecologic and physical components. It gives equal consideration but differential importance to different aspects depending on its degree of vulnerability. This approach is clearly advantageous in terms of ensuring that all relevant data is collected, indicators identified and importance and weights assigned to compute vulnerability.

All component data sets are profiled and aggregated. Users of the IFVI tool, according to the outcome wanted can always update the data according to their own needs. Therefore, the type, accuracy, and amount of information collected and applied is subject to accuracy of the analysis. A lot of subjective judgment was given in completing the IFVI data. Those applying the method must understand what data or information is required to use the tool accordingly for the specific purpose of study. The following chapters deal with the detailed guidelines, showing how the IFVI is constructed and applied. The approach conducted aimed to be comprehensible, so it can be applied in practice.

The practical utilization of the completed IFVI will help to gain better insights to a problem investigated and thus be supportive in capacity building by all users at all levels. The next section continues to give brief descriptions about the data collected and the different components of the analysis.

4.3. Data collection and preparation

All data used is publicly available and was obtained from the following sources mentioned in Table 3 and Table10 (see appendices). Except for the vector data for the Natura 2000 sites and protected areas - none of the layers were ready for use right away. Most of the vector and raster layers were pre-processed in ArcGIS to make the vector or raster layers data sets usable. For instance, ready to use vector data had to be reprojected, clipped and rasterized. In comparison, the final used project layer had to be generated from scratch. The layer for the city of Ingolstadt had to be digitized from analogous maps, georeferenced, clipped and later on rasterized. The final project layer for the prospective study area was later on used to aggregate all data feed into the IFVI analysis. Thus, for each indicator one layer was made, vectorized (polylines and polygons) and rasterized for later means of processing (i.e. calculating risk and vulnerability maps). Hence, the maps and data obtained was arranged, digitised, georeferenced, and aggregated for the specific purpose to derive the maps produced and included in this thesis.

There two important issues which need consideration before describing the index components. First, the social vulnerability always concerns the various types of functions of the element at risk as they can be affected by the flood to a certain degree. In comparison, housing and other infrastructural set up in the specific study area are always affected differently as people. Furthermore, timescale is also an important factor since there can be long or short term damages caused by the occurring flood. Barroca (2006) indicates that short term effects “may cause human casualties or direct costs to economic activities, whereas on longer timescales costs for maintenance will be considered more important.” Secondly, Barroca (2006) also emphasizes in his indicator study that it must be considered that “vulnerability is connected to the intelligence of element at risk and relations between the object at risk.” The reason therefore is that people are in general aware of the risk, hence, they possess the ability to act (i.e. better infrastructural planning, introducing better flood prevention measures etc). This is especially important when considering the strength or weakness of individuals (e.g. male, females, young or old people) and their actual vulnerability to a flood hazard.

4.3.1. Social Components

The social vulnerability components are designed and arranged in a similar way how society is organized across the spatial extent of the city’s area. The data used was organized into the city’s subdistrict areas. Like mentioned above, people are most vulnerable to flood hazards and literature on vulnerability identifies (Rygel, 2006) children, females, elderly and the poor, disabled or unemployed people suffer the most in consequence of a flood. Also social and physical isolation, play an enormous role to be considered (see Buckle 1998). Those people usually have limited financial means and/or thus limited access to resources in the aftermath of a flood. In the IFVI approach the following indicator variables were chosen and used to cover all the above-mentioned criteria of vulnerability:

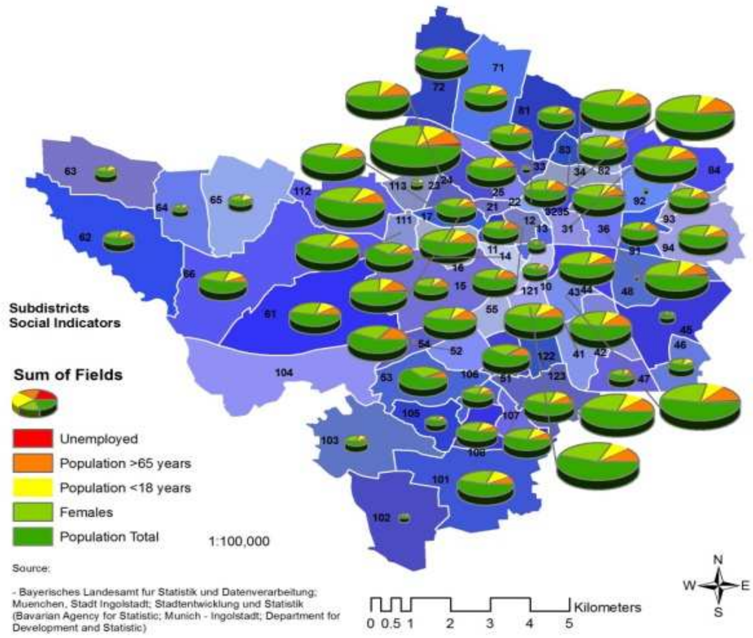


Figure 4-2: Shows the study area of Ingolstadt with the social parameters aggregated for each sub-district

The social component for the IFVI is made up of the following indicators: Population Total (0-18years; 18-65years; >65years)(2008); Female (2008); Population density; and Population growth (2008); and the unemployed (2008). The data mentioned and used was available for the subdistrict level only. However, due to the limited time-frame of this thesis, but also for means of simplification, only a few the five variables were chosen to be analyzed.

For clarification, social vulnerability is always rooted in the actions and multiple attributes of human actors. Social vulnerability is a complex phenomenon and not a single measure; it covers a whole spectrum of variables and indicators for the manifestation of what vulnerability is. For instance, gender plays an important role as women can be more vulnerable because of a more difficult time during recovery than men. This is often due to means of their specific employment, lower wages, and family care responsibilities (Blaikie et al. (1994), Enarson and Morrow (1998), Enarson and Scanlon (1999), Morrow and Phillips (1999), Fothergill (1996), Peacock, Morrow, and Gladwin (1997, 2000), Hewitt (1997), and Cutter (1996) in Cutter, 2003) and are thus more vulnerable to a hazard. A large set of measurable variables is usually necessary to obtain accurate measurements. For the IFVI, a limited set of variables and indicators is chosen to yet obtain a similar outcome with an equally high accuracy.

Socioeconomic processes are either directly or indirectly linked to social behavior and hence to the degree of vulnerability. The socioeconomic indicates the ability to absorb losses and enhance the ability to cope with hazard impacts (Cutter, Mitchell, and Scott (2000), Burton, Kates, and White (1993), Blaikie et al. (1994), Peacock, Morrow, and Gladwin (1997, 2000), Hewitt(1997), Puente (1999), and Platt(1999) in Cutter, 2003). Race and ethnicity do also play an important role to investigate how lingual barriers affect access to services or funding in the aftermath of a hazard (Pulido (2000), Peacock, Morrow, and Gladwin (1997, 2000), Bolin with Stanford (1998), and Bolin (1993) in Cutter, 2003). However, race and ethnicity were included only indirectly. The total number of females includes foreigners. for the IFVI study. Another important factor is age as the age spectrum is affected by the way the hazard impacts certain parties. Parents must invest time and money for racing their children in case schools or kindergartens' or other public facilities are struck to some extent. Also elderly are constraint by limited mobility and become thus a burden to their relatives or public services (Mitchell, and Scott (2000), O'Brien and Mileti (1992), Hewitt (1997), and Ngo (2001) in Cutter 2003). Mileti (1999) also indicates the importance of unemployed people and their difficulty to recover from potential loss. Many other indicators for more detail could be included like peoples occupation, family structure, education, and so on. Population growth, which is included in the IFVI remains rather important as a population, which experiences rapid growth may lack of available shelter or the social services network may withstand or be adjusted to the increased population number (Heinz Center for Science, Economics, and the Environment (2000), Mitchell, and Scott (2000), Morrow (1999), and Puente (1999), in Cutter 2003, and Birkmann 2006). All indicators were chosen according to the criteria mentioned above.

Additionally, analysts should always consider the interlinkages of all socioeconomic processes in place. This is especially important for policy and management to know, that by using the natural environment for their means, the ongoing processes of socioeconomic modes are certainly hindered or diminished once the ecological system becomes affected to some degree (IPCC, 2001).

4.3.2. Economic Components

The economic component (Figure 4.3) is defined to all residential, industrial and commercial property or dwellings. Residences are comprised of house unit, flats (apartments) and other dwellings. Vehicle registrations were included in the analysis which helps to derive just another estimate of economic vulnerability in case of vehicles likely to be damaged. The vulnerability regarding vehicle damage could also be part of the social component (i.e.socioeconomic) as it indicates to be a measure of social status and wealth. In general, the monetary value, quality, and density of commercial and industrial units offers insight into the actual state of economic health of a place, its community, and the losses experienced in the long term to recovery from a destructive event such as a flood (Heinz Center for Science, Economics,and the Environment (2000) and Webb, Tierney, and Dahlhamer (2000), in Cutter 2003, and Birkmann, 2006). Residentail property was identified by several authors as vulnerability factor because the loss or repair of homes is costly and causes other financial expenses for affected parties to deal with (Heinz Center for Science, Economics, and the Environment (2000), Mitchell, and Scott (2000), and Bolin and Stanford (1991) in Cutter 2003). The list of economic losses could easily be extended to, for instance infrastructural loss and damages, as well as, details information regarding rented places and the like. However, for the IFVI study the following cited indicators are used.

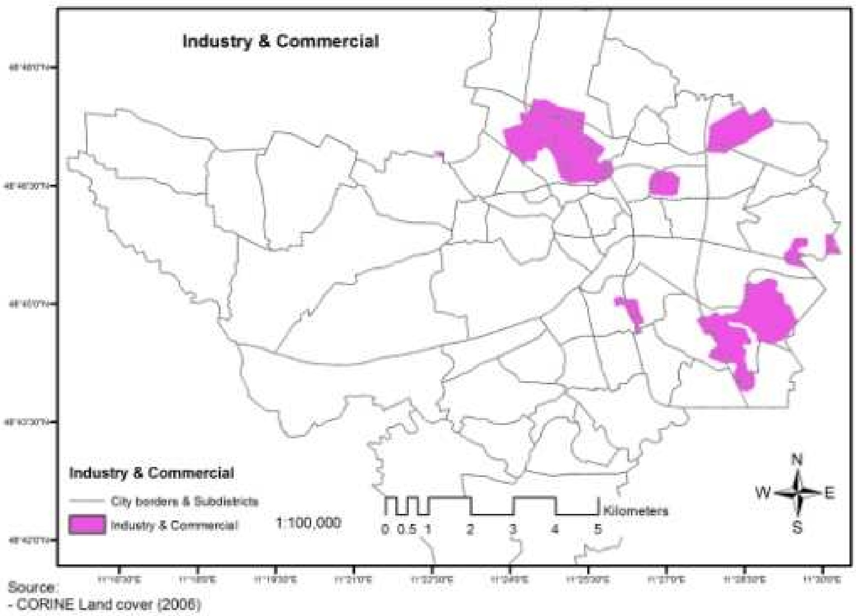


Figure 4-3: Economic components

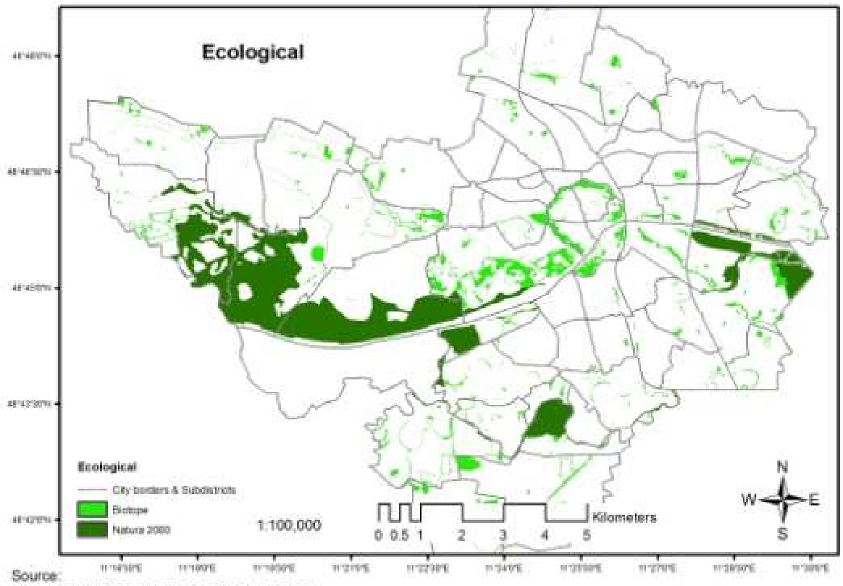
The economic component for the IFVI is made up of the following indicators: Development housing stock (2008); Dwellings and other residential units (2008); Vehicle registrations (2008); and Industrial and commercial (2008) units.

4.3.3. Ecological Components

The ecological components in Figure 4.4 and Figure 4.5 are comprised of variables of vulnerabilities that are hazard specific. A vulnerability index for the natural environment has been developed by the South Pacific Applied Geoscience Commission (SOPAC), the United Nations Environment Programme (UNEP).[22] This index is designed to provide insights into the processes that can negatively influence the sustainable development of a system.[23] The final report argues that a hazardous event can ultimately lead to "loss of diversity, extent, quality and function of ecosystems." (Kaly, 2005). However, indicators identified and selected for the ecological component is comprised of Natura 2000, as well as the natural preserved areas in the study are. The maps below (Figure 4.4 and 4.5) show the Natura 2000 sites including a bird protection zone, biotope areas, and other protected areas. Hence, the ecological component for the IFVI is made up of the following indicators: Biological reserve; Protected Area; and Natura 2000. A detailed list of species of the ecological environment displayed in Figure 4.4 and 4.5 can be found in appendices (German only). (Kaly, 2005)

[22] Source: http://www.vulnerabilityindex.net/ [accessed 12.09.2009]

[23] Source: EVI Final report, available from http://www.vulnerabilityindex.net/Files/EVI%20Final%20Report%202005.pdf [accessed 12.09.2009]



Source:
- Bavarian Environmental Agency (Lfu Bayern)

Figure 4-4: Ecological component

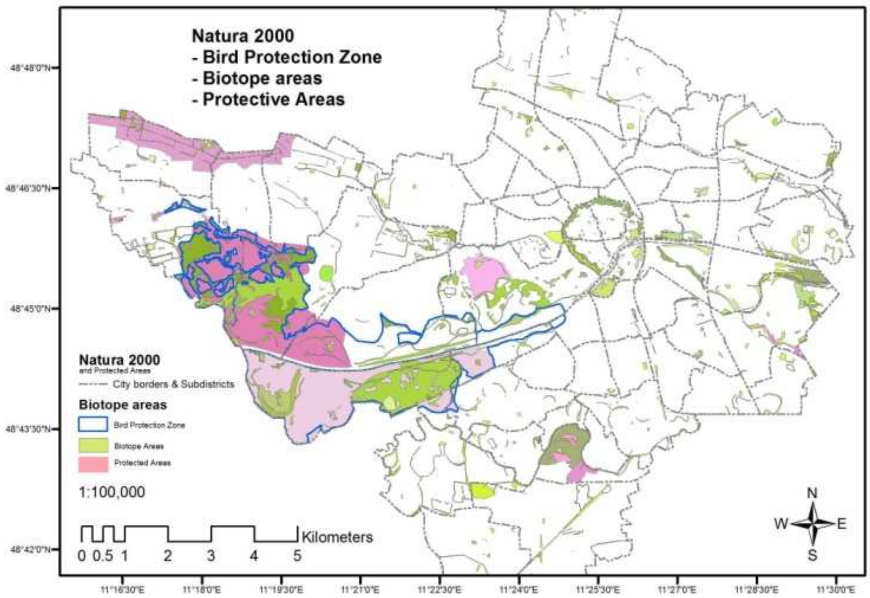


Figure 4-5: Natura2000 areas - a detailed legend can be found in appendices, Figure 11

4.3.4. Physical Components

The physical vulnerability components in this thesis are basically the most visible area of the flood risk as it includes also the social, economic and ecologic components at the same time. The physical vulnerability is concerned with the hazard itself. The flood hazard is a complex cannot be described in a simple way due to its various occurrences (e.g. flash flood or slow flood). Scale is therefore becomes important as it depends largely on the intensity, and thus scale of a flood. Again, scale always depends as such to the amount or intensity of damage discovered before or after the impact of a flood. Moreover, to understand physical vulnerabilities, one has to ask what made the elements at risk (van Westen et al)[24] affected by the flood and thus vulnerable. Is it the economic activities (e.g. agriculturalists cannot work their fields because of floods), their geographic location (e.g. houses and homes built in flood-prone areas) or they lack of resources? However, the physical component in the study is described as the multiplying factor to calculate risk and vulnerability.

Two types of flood scenarios were applied for the vulnerability assessment. Reason therefore was to show a past event in comparison to a worst case scenario. This helps to further elaborate on known and “what if” situations in the case of a flood in occurring in the future. However, first, the “Flood Extent 1999” layer in Figure 4.6 shows the worst-case scenario across the entire city. For means of analysis, but also to stick to a lower scale, the analysis carried out utilized a flood layer expanding across a limited area within the city centre of the city of Ingolstadt. Second, a “Worst-Case–Flood-Scenario” layer in Figure 4.6 was prepared and analyzed. The flood layer shown depicts different heights of inundation (0.00->4m). The layer was created with a simultaneous occurrence of intense winter conditions and annual rainfall combined. The probability for realistic return periods, adverse hydraulic pressures as smaller floods of the Danube and a 100-years flood including other water bodies in the area (i.e. Sandrach, Mailinger creek) with a simultaneous occurrence of high winter and annual rainfall combined were thus calculated. The aim of the Worst Case Scenario (>4m) was to create a map, which offers a high level of security to urban development planning. The second aim was to include likely impacts of climate change to help produced maps to derive better precautionary measurements. Finally, from all these factors, the likely flood risk and associated vulnerability has been calculated. According to Apel et al (2009), “many river floodplains and their assets are protected by dikes. In case of extreme flood events, dikes may breach and flood water may spill over into the dike hinterland. Depending on the specific situation, e.g. time and location of breach, and the capacity of the

[24] Source: Cees van Westen, Nanette Kingma & Lorena Montoya: Guide book Session 4: Elements at Risk

hinterland to contain the flood water, dike breaches may lead to significant reductions of flood peaks downstream of breach locations.

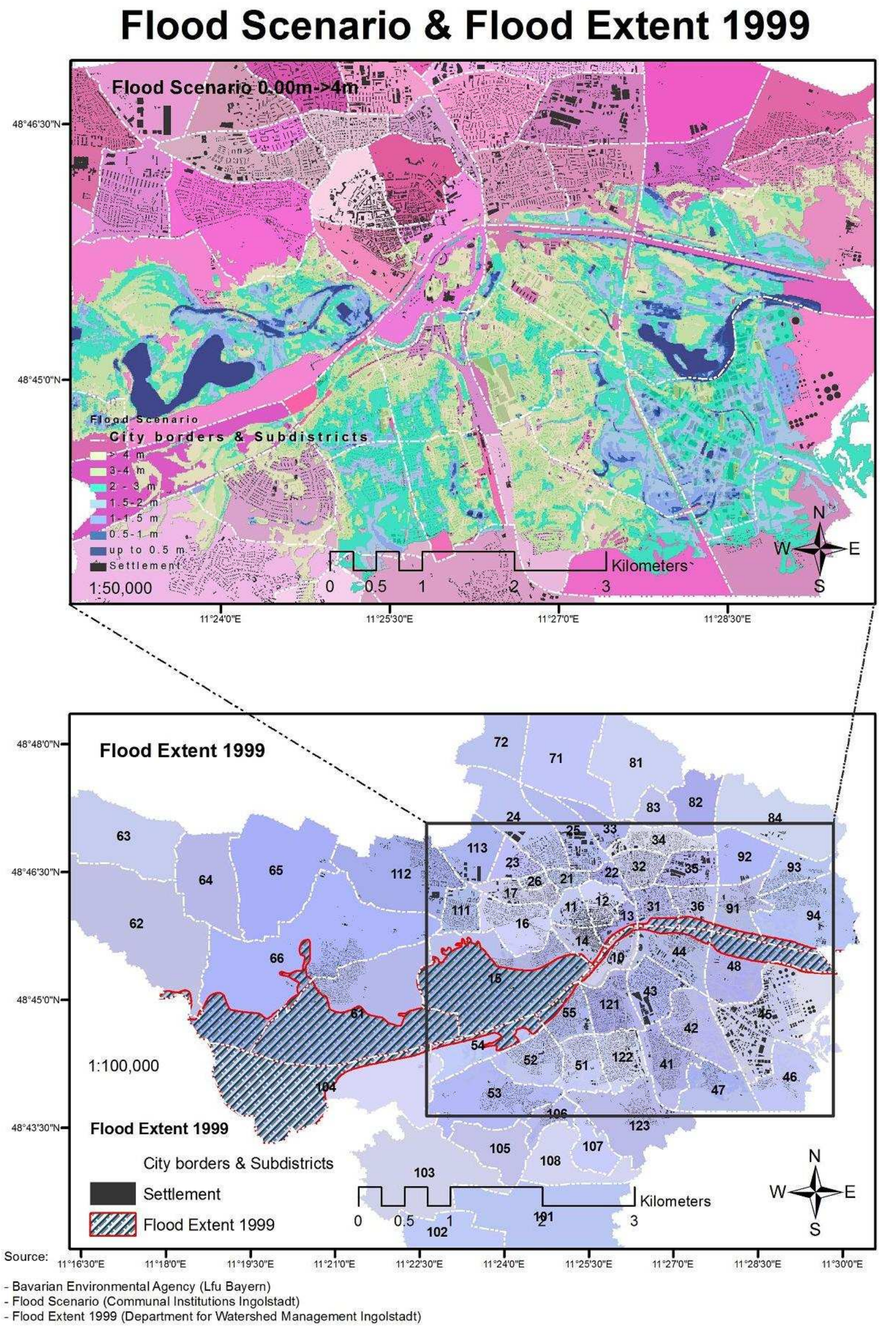


Figure 4-6: Physical component

4.4. IFVI Assessment Method

In general, all analogue and digital spatial data were prepared as shown and decribed in the prior subsections in Chapter 4, and there are theoretically no scale limitations. For more detailed scales below subdistrict level (i.e. residential area or single housing units) the accuracy for the display as well as the analysis will increase. However, the subdistrict layer had to be generated in order to incorporate and aggregate specifically all social data.

The very first step of the assessment includes the selection of the components for the land use of the particular study area and these are presented as maps. The following step includes the criteria definition and how the land use is measured in the form of economic or ecological means. This helps to get a better picture about how the components can be arrange and display different indicators on a spatial scale and translated into a non spatial multi criteria analysis by aggregating the data. Once these steps have been conducted, the most common method applied is to take the averages of all values, weighted or not, for further data and map aggregation. The last step includes the ranking according to the alternatives previously chosen for the analysis.

4.4.1. Software used

As mentioned in the sections above, only the most necessary and basic Software was used in combination for the processing and analysis of the data.

Microsoft Word
Microsoft Excel
ArcGIS 9.3

4.4.2. Vulnerability criteria

The objective of the vulnerability mapping is to compare different areas regarding their social, economic, and ecological vulnerability (i.e. the four alternatives, including the physical are then compared despite different spatial units.) The spatial basis for the vulnerability analysis is raster files with 10 x 10 meter resolution. All vector files are prepared to match the same input requirements. The vulnerability is calculated for each of these grid cells, so that the actual vulnerability map for each event mentioned before is produced. By using the vulnerability formula described in section 4.7, the average vulnerability per grid cell is then computed.

4.4.1. Vulnerability weights

The weights assigned for each indicator is to express the importance of each indicator relative to the others included in the analysis. The more important indicator for within each component of the index received a higher weight in the overall evaluation. In addition, the ranking method and pairwise comparison method were used and the results compared with the Boolean overlay approach. This approach was chosen because decision makers would also assign different weights for each indicator according to their knowledge, wants and preferences. Hence, that makes the IFVI rather simple to grasp for decision makers by selecting the criteria they want and then comparing it in the matrix of the calculator (Figure 9.4). The specific weight of each indicator is thus calculated in calculator interface.

4.4.2. Indicator selection and design

The presented indicators in the prior section 4.3 were selected according to the established framework applying the criteria of suitable indicators discussed. One of the main objectives by working on this thesis was to develop, test, and implement indicators to identify and assess vulnerability. This is essential in the light of a flood to plan and set up proper preventive measures, and thus reduce likely risk and vulnerability. It is particularly important for the science community and all managerial as well as governance instances to derive a universal set of indicators instead of having each study come up with a new and different set of indicators.

For instance, the The CARBRI-Volga Report[25] also outlines that “there is a requirement to increase the understanding of vulnerability and also to develop methodologies and tools to measure and assess vulnerability and risk.” In this context the final declaration of the World Conference on Disaster Reduction (WCDR) in Kobe, Japan in 2005, underlined precisely the necessity to develop vulnerability indicators in order to enable decision-makers to assess the impact of disasters (Hyogo Framework for Action 2005-2015, UN 2005)[26].

However, according to Birkman (2006), a “vulnerability indicator can be defined as an operational representation of a characteristic or quality of a system able to provide information ... of an element at risk to an impact of an albeit ill defined event (flood, landslide, drought) linked with a hazard of natural origin” (Birkmann 2006).

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[25] Source: CARBRI-Volga Report D3 http://www.cabri-volga.org/publications.html [accessed 11.10.2009]

[26] Source: http://www.unisdr.org/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf [accessed 30.12.2009]

On the basis of this statement, the indicators introduced in section 4.3 were chosen and included for the study. Initially, the available data was put into five classes to derive a fast way of classifying more or less vulnerable areas within the study area. Advantage of this approach is that the aggregated data put in to its administrative units can quickly be applied to run calculation in the GIS software. Continuous value maps were later on generated in the analysis, which basically eliminated the rather limited uncertainty caused by grouping the data values in the first place. Alternatively, it might even be better to use continuous values by utilizing GIS tools like ILWIS, the SMCE module of ILWIS-GIS software package. The SMCE application assists and even guides users when performing multi-criteria evaluation in a spatial manner (ITC 2001). However, the grouping of the data is just another way to process the data in GIS and was attempted for this study. The data was aggregated into just a few classes for the computing analysis. The outcomes were reclassified to retrieve continuous data display and thus get rid of the class structure. Like mentioned before, this may cause some uncertainty, but on the other hand, it can be advantageous to make these classes for the data values (1-5 classes for all values were applied), which results then in “Low-to-High risk” classes (1-5) for immediate analysis.

Defining the method for quantifying vulnerability is certainly challenging. Because the analysis may not be completely comprehensive, the different component definitions for it are given for a better understanding. However, the many different definitions of risk and vulnerability found in the literature still indicates that aspects of vulnerability depend on the subjective and qualitative input of the user of such a tool like the IFVI, which in turn affects the meaning of the risk calculation and outcomes generated.

Having derived the three sub-index values, the same method was a similar range of methodological concerns need to be addressed when deciding how to aggregate these into the final composite index of social vulnerability.

4.4.3. Vulnerability Matrix

Table 2 contains all component indicators and information about the spatial unit and scale. The vulnerability matrix presents the indicator system grouped according to the main components, and names of indicators

Vulnerability Components	Evaluation Criteria	Elements at risk	Damage unit (.../year)
Economic	Aggregated economic vulnerability	Development housing stock (since census 1987) 2008	Number of housing
		Dwellings and other residential units (since the 1987 census) 2008	Number of units
		Vehicle Registrations (2008)	Number of vehicles
		Industrial and commercial	binary
Social	Aggregated social vulnerability	Total Population	Number of people
		Female (31 Dec 2008)	Number of females
		Population density 2008 (Residents/km2)	binary
		Population growth -trend since 1998	binary
		Unemployed (Dec 2008)	Number of unemployed
Ecological	Aggregated ecological vulnerability	Biological reserve/Protective Area Lfu (Schutzgebiete, Landschaftsschutzgebiete)	binary
		NATURA 2000 (Bird protection zone & protected areas)	binary

Table 4: Displays the IFVI vulnerability matrix

The vulnerability matrix provides a system for predicting the consequences for all vulnerability indicators, which are subjected to social; economic, or ecological vulnerability equation combinations.

The following steps describes now deal with the necessary step to apply the defined vulnerability indicators, the equation and the IFVI calculator that involves summing up all component parameter values and those of the respective flood parameter over all elements at risk.

4.4.4. Rating the Components

The method, addapted by Meyer et al (2007) deployed the point allocation approach and the ratio estimation procedure. Both methods, according to Meyer et al are "more precise than ranking methods as they allow the decision maker to specify the relative importance of criteria on an interval scale and not only on an ordinal scale." Another advantage of the point allocation approach is its simplicity and easy to grasp approach makes it attractive to users like decision makers. The user (e.g. managers) has to allocate 100 points among the selected component variables. This may be related to a very similar procedure in real life. In order to surely distribute only 100 points throughout the process the IFVI calculator has a function crosschecking the range of values allocated and thus ensure the consitent dissemination of the 100 points allocated. (Figure 9.4)

For instance, to allocate financial support or aid of a given aid budget available to managers; polititions; to the prospective vulnerable zones or areas, the approach is therefore good because of it comes pretty close to real life situation and is familiar to many decision makers. However, Meyer and colleagues emphpasized that according to Malczewski (1999) the risk remains that "the components are weighted without knowing their specific unit and range. In this case the weights would be meaningless."(FLOODsite, 2009). Still, the purpose of this thesis is to evaluate the relative vulnerability by using the IFVI tool. Using continuous values instead of cut-off-points (i.e. grouping the parameter values), in order to know the specific range is just another appoach and could also be integrated in the study.

Point allocation for each component

IFVI Weights Criterion	Economic	Social	Ecological	Total
Economic	1	2	0	3
Social	0	1	0	1
Ecological	2	2	1	5
SUM	3	5	1	9
Calculated weight for each component category	33	56	11	100

Table 5: Point allocation for each IFVI component

The points allocated for each component are assigned amongs all indicators in the IFVI calculator (see appendices Figure 9.4) and weighted according to their importance. Assigning the value "1" to a category implies a greater importance, while the value “0” equals to so not important. In this case, 33 Points were distributed for the economic component and its indicators. In comparison, the social indicator received 56 points. That is becasue people are much more vulnerable to the flood hazards compared to their economic assets or processe in place they rely on. For instance, buildings can be replaced or rebuild, while human lifes cannot be restored, hence the greater importance and thus more points are asigned to the social component. The ecological components received only 11 points due to the limited importance and vulnerabili to a flood. The natural environment may be vulnerable to a limited extent, but will certainly recover quickly in the aftermath of a flood. The points distributed amongst the three major components are then again assigned to each indicator and their relative importance. Section 4.3 describes in more detail why and which type of indicator should be given a higher or lower weight to derive the final weights used to calculate the vulnerability maps.

4.4.5. Weighting Components & Pairwise Comparison

Pairwise comparison method from the AHP approach from Thomas Saaty (see e.g. Zimmermann & Gutsche (1991); Malczewski (1999) in Meyer et al (2009) was applied. Again, each of the component variables is compared to all the others, depending on their importance. As a measure for this relative importance a pair wise comparison was made and the assigned points for each components were futehr distributed witha value of 0 or 1 according to their importance. 0 indicates less or no importance while the value 1 indicates higher importance, thus comparing a pair of indicators according to their importance. The resulting parameter values are then calculated in the IFVI as they indicator weights and finally feed into ArcGIS9.3 to calculate risk and vulnerability on the preprocessed raster layers for each component and its indicators. Note that each indicator can always be changed according to the interest of the user. The following section discusses the calculation process in more detail. Once again, for example, there is little vulnerability of the ecological environment towards flood risk in the area, the weights assigned in the weighting scheme were rather low to indicate low vulnerability compared to the high vulnerability of the social component.

4.4.6. Combining and aggregating all data layers

Having calculated all index values in the above section 4.5, the next step is to aggregate the layers these into the final index calculations to derive vulnerability estimations. Table 6 shows the resulting IFVI vulnerability parameter values for the vulnerability calcualtions to be used in ArcGIS 9.3.

ComponentVariable	Social					Economic				Ecological		Total
Factor	Total Population - Ages	Female	Population density (Residents/ km2)	Population growth %	Unemployed	Housing stock	Dwellings and other residential units	Vehicle Registrations	Industrial and commercial	Biological reserve/Protected Area Lfu	NATURA 2000	Consistenc check!
Weights	15.38	19.23	3.85	7.69	3.85	10.00	13.33	3.33	6.67	11.11	5.56	100.00

Table 6: shows all calculated IFVI values

All variables of each component (i.e. social, economic, ecological, and physical) were dissolved and thus aggregated to generate the final IFVI Project Layer (Figure 4.1), which contains the entire range of chosen parameter values in order to produce risk and vulnerability maps.

In this thesis a composite approaches to build the index was used. It was done by using an explicit scalar function (1 to 5) within the conceptual framework to create a single aggregate overall score for all vulnerability maps. In addition, the approach was chosen to ensure transparency concerning the component configuration of that score. As a result, the overall IFVI is generated from these IFVI scores (weights) for each indicator variable. The aggregated maps, according to each scenario calculated were standardized for a value between 1 and 0 after reclassification of the resulting vulnerability layer, with 1 representing the highest level of risk to vulnerability, and 0 non.

4.4.7. Calculating Vulnerability

The vulnerability equation, as defined for all social parameters is applied:

$$\mathrm{Vul} = \sum_{i=0}^{n} (v_i * w_i)$$

where:

Vul	=	Social Vulnerability
v_i	=	vulnerability factor i
n	=	number of indicators
w_i	=	weight of v_i value
$\sum w_i$	=	$w_{(indicator)}$
$W_{(indicator)}$	=	total weight of specific indicator

This definition of vulnerability is adopted for this thesis in principle.
Bilinear interpolation for outcome values is applied for map display.

4.5. Vulnerability Measures used for "Aid-Distribution Maps"

Example values are used to describe the final process to derive the vulnerability maps. The vector project layer generated contains all indicator values for social, economic, and ecologic. Hence, all generated vulnerability data in the prospective vulnerability layer is scaled to the subdistrict level. Each of the components indicator is was rasterized into a grid format using ArcGIS9.3 with a spatial resolution of 10m (10x10) containing the assigned data. The risk/damage of the physical component (i.e. flood extent layer) was classified into flooded or not flooded area. In addition, Figure 9.5 shows an area closer to the river was multiplied and thus calculated with a higher likelyhood value (e.g.7) of risk as the areas further away from the river (e.g.1), which received a lower multiplying value.

The particular vulnerability index value is derived after prior "point allocation-approach" (section 4.4.5) to assign different weights criterion to each indicator variable. That was done by distributing 100 points to all indicators. That is, all indicators equal 100%. Because all the indicator values (i.e. data processed) are grouped and stored in 5 groups from 1- [value]., these 5 groups become automatically 100% of the total data input. In addition, it can be argued that each class for itself can be perceived having also got 100% of its containing data/values. That means: adding up 100% x 5 = 500% or "500"Consequently, "500" = 100% Vulnerability = "500"

The total value calculated for an individual component scenario, or all aggregated component (see maps below) and each indicator parameter is now contained in the respective raster cells. That means that there are no classes left and the raster layer is basically made up of "continuous data/values". Therefore, by obtaining the value 277 from 500 comprises the final risk to vulnerability values standardized between 0 and 1. The layer is now ready for display and further calculations of vulnerability. That can be in the form of deriving the respective level of vulnerability in percent for each subdistrict.

Sum up all risk components
(Example values are used to describe the next step.)

First, all calculated index components are aggregated to one vulnerability layer:

Vuln = [Social] + [Economic] + [Ecologic]

The calculated raster file now contains all aggregated values from all components.

Exampe: the raster values are 0- 227. So 227 is the vulnerable percentace value out of 500 (=100% vulnerability), and 500 is the total vulnerability.

Standardize layer values from actual cell value to 0-1 display

The raster values are finally standardized by dividing the obtained net raster value e.g.227 (total vulnerability value calculated) by 500 (= total vulnerability; 100%).

Calculating relative affected area (percentage) for the aid-distribution map in percentage:

(raster value of 0-227) / 500 (500 (= total vulnerability; 100%) =
0.002266 (= 0% out of 100%)

The total calculated area at risk is used to calculate the vulnerability as percent value for each components on every subditrict level.

First, the potentially vulnerable area [gridcode] is selected and exported to vector shapefile format and intersected with the IFVI project layer. The second step is to dissolve the new project layer into a new vector file with the following features: [gridcode], [subdistrict] and [SUMarea]. The total of the vulnerable area is then derived using the SUM function to derive the total subdistrict area in km$^{2.}$ The final step is to reclassify the resulting layer into a 11 classes, indicating class 1 as zero percent and classes 1- 11 as 0% - 100%.. The continuous data for area affected [percent] is then used to create a vulnerability map and display the calculated relative risk (percentage) as the net vulnerability measure for each subdistrict.

The aim of the vulnerability maps calculated was to create vulnerability maps by using the IFVI tool and offer an insight to likely risk to flood in the study area. This can help to ensure a greater level of planning security and support the necessary precautionary measures to be taken for the area.

5. Results

Based on the components, criteria and indicators identified in the literature review earlier in this thesis and further described in section 4.3, the spatial multi-criteria analysis was carried out in Chapter 4 and vulnerability maps were generated. The final results, in the form of vulnerability and aid map are shown below in Figure 5.1 to Figure 5.7

The calculation results are generally in the form of a classified statistics for the flood risk data in the different administrative subdistricts. The final "Integrated Vulnerability Map" was created by overlaying the flood extent with the total inundated area for every indicator. Further evaluation can be done by relating the results to other social, economic, or ecological flood risk or data. The results of the vulnerability evaluation and flooded area are visually displayed below. However, to create the final vulnerability maps, all data had to be aggregated into one IFVI Project Layer. Hence, the IFVI study integrated all four components to determine how much area is vulnerable to the flood in the city of Ingolstadt.

For instance, there was zero ecological vulnerability detected when the "Flood Extent 1999" was applied to calculate risk the risk to ecological vulnerability.
For clarification, in the light of social vulnerability, for instance, flood risk and vulnerability is always rooted and closely related to the actions and multiple attributes of human actors in place. Because social vulnerability is a complex phenomenon and no single measure can cover the whole spectrum of variables.

The variations of the IFVI vulnerability calculations are apparent on each vulnerability map. The vulnerability maps for each component are presented in the following pages with bigger images in the next sections below.

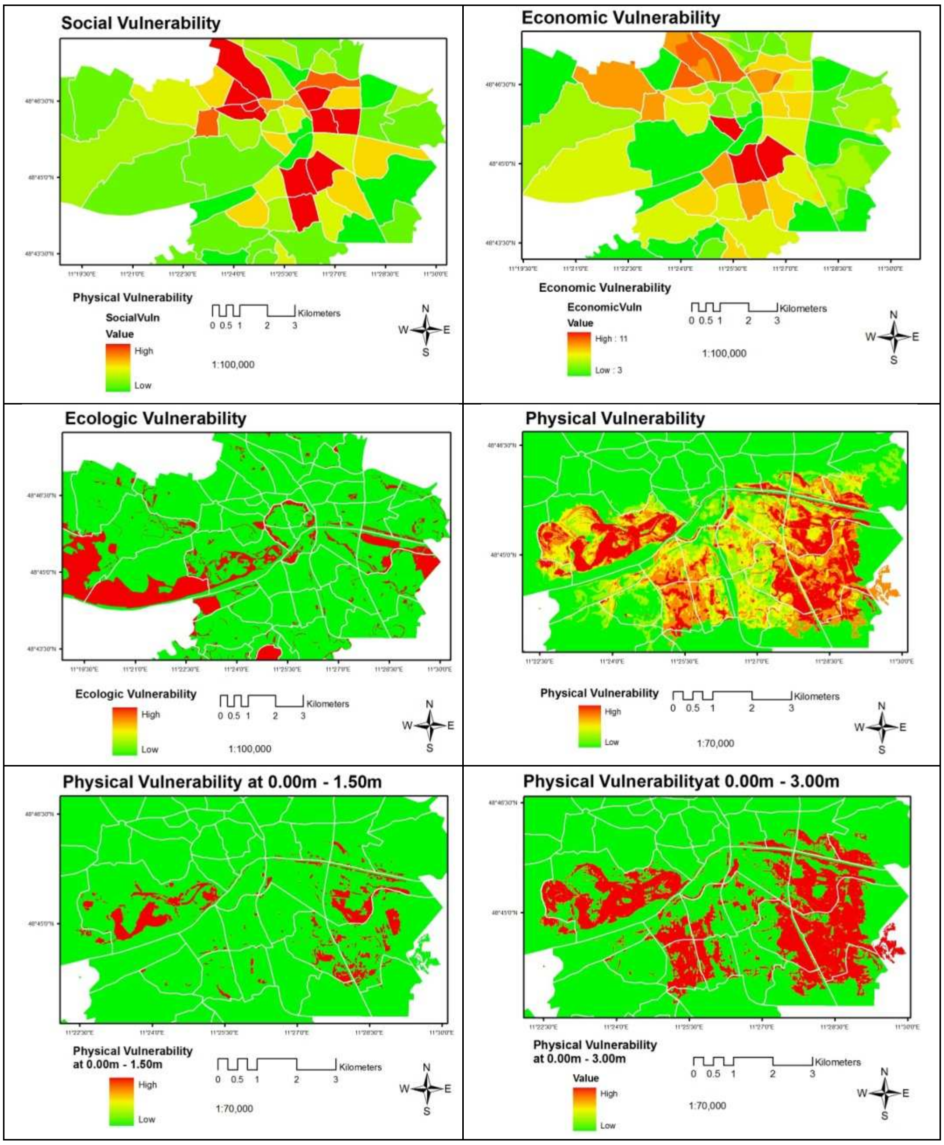

Figure 5-1: Vulnerability maps

Figure 5.1 displays the social, economic, ecologic and physical vulnerability maps displayed next to each other for better visual comparison. The physical vulnerability map is included to display the entire extent of the likely physical vulnerability in case of a flood with an inundation depth of more than 4 meters. The two maps in the bottom of the table (i.e.0.00-1.50 meters and 0.00-3.00 meters are included for means of visual comparison to the physical vulnerability map with >4m meter, which is displayed in the middle of the table to the right.

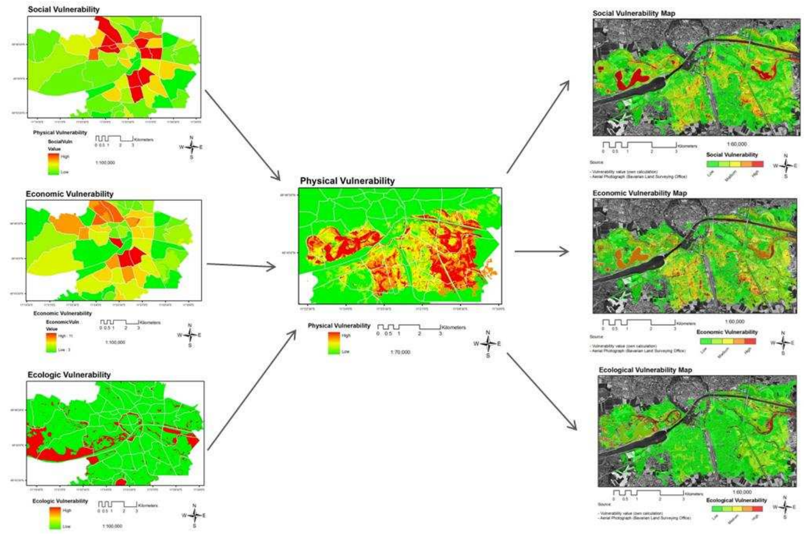

Figure 5-2: Aggregating social, economic and ecological vulnerability maps for final IFVI map

Figure 5.2 shows how the individual vulnerability components (i.e. social, economic and ecological) aggregated with the physical vulnerability (i.e. the flood extent and other surrounding) to derive the detailed vulnerability maps at an inundation of >4 meters .

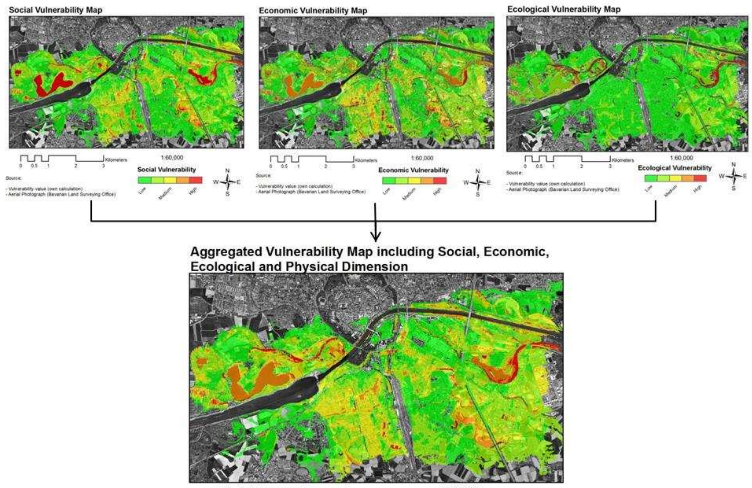

Figure 5-3: Aggregating total vulnerability map for the study area at an inundation greater than 4 meter

Figure 5.3 displays the three component maps before and after aggregation to derive the final vulnerability map for the study area.

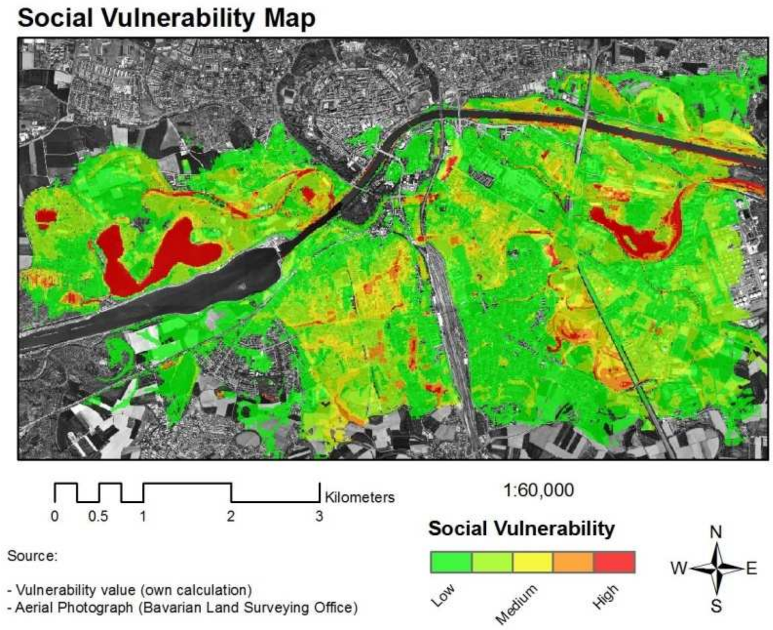

Figure 5-4: Social vulnerability

The social vulnerability map (Figure 5.4) displays very limited vulnerability in some areas where the inundation appears to be greater. However, because the region topographic setting is rather flat, the water may only reach up to 0.5 meters according to expert knowledge. Thus there is no real threat, but only some buildings and their cellars would be flooded and get wet. The vulnerability to people is thus rather low.

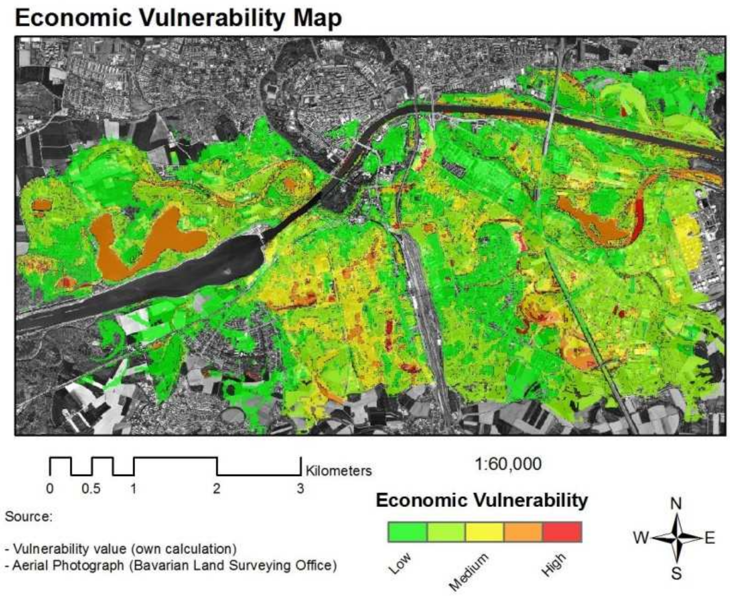

Figure 5-5: Economic vulnerability

In comparison, the economic vulnerability map (Figure 5.5) looks rather similar to the social. The reason for this may also be the flat area and thus limited height of the flood water it can reach. Hence, the economic vulnerability display appears to be slightly higher compared to the social. However, both maps show a similar and yet different calculated outcome.

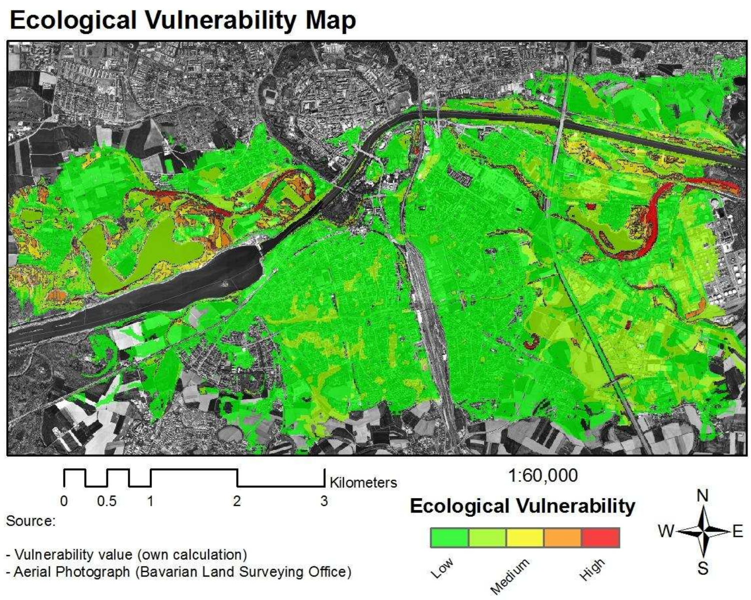

Figure 5-6: Ecological vulnerability

Figure 5.6 displays nearly or no vulnerability in the study area. Only the areas closer to the river or other bodies of water may experience some erosion.

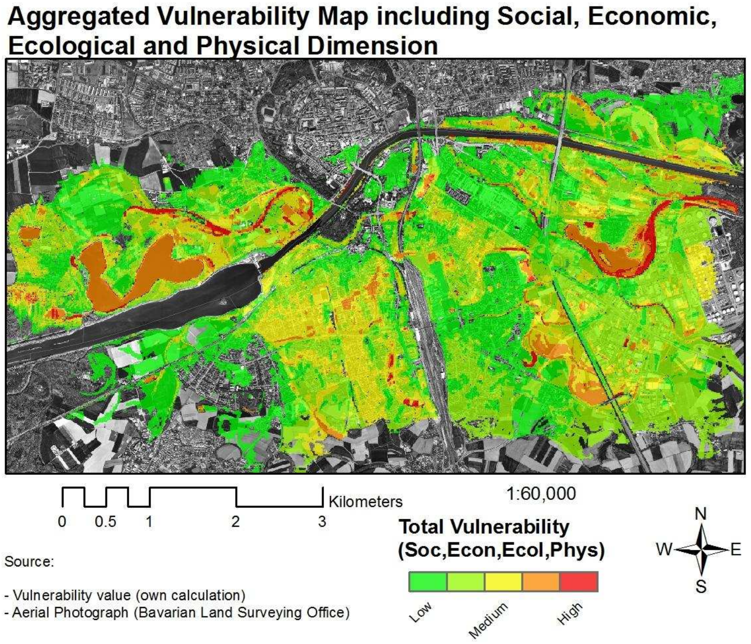

Figure 5-7: Integrated vulnerability map (IFVI map)

Figure 5.7 shows the total vulnerability calculated for the study area. Yet again, the actual vulnerability for the prospective study area is rather low. The aim of the "Vulnerability Scenarios" calculated was to create vulnerability maps by using the IFVI tool and offer an insight to likely risk to flood in the study area. This can help to ensure a greater level of planning security and support the necessary precautionary measures to be taken for the area. Now that the risk map was calculated, the total area affected (Figure 5.7) by the flood was derived to calculate the percentage of vulnerability for each district. The maps are displayed in Chapter 6. This can be done with all derived risk maps and their respective outcomes. As for the purpose of this was to show whether or not the IFVI can be used, the thesis includes only three maps with all aggregated components to display the total risk and vulnerability.

6. Discussion

6.1. Validity and validation

Disregarding of the quality of the data, the results of the IFVI study depend mainly upon how well the indicators capture the identified components at risk and thus their likely vulnerability to a flood hazard. Another important point is to consider of how well are the assumptions made about the functional relationship between the indicators rating vulnerability. It would certainly be of advantage and important to collect ground-truth and validate the precise role of various indicators. However, this has been done in the form of interviews with local experts. The IFVI comprises therefore predictive indicators of risk and vulnerability based on existing theory. One of the disadvantages is the difficulty to validate the effectiveness and accuracy since the main goal of the indicators is to capture obscured processes. Consequently, information obtained may likely be used for means of distribution or to reduce vulnerability.

The data used serves for a better understanding of the occurrence of flood vulnerability (or damage) and the assessment of the effectiveness of prevention measures.

Water flow data has been analyzed for Danube water flow and discharge, describing peak and baseflow pattern to statistically calculate and determine whether water discharge is a contributes to increased vulnerability due to expected but random "bad-luck" events within the last decade. Stronger trends in the data could have indicated the likelihood of more future and potential flood impacts in the near future. However, the analysed stream flow data does not provide insight into the situation.

The flood extent was perceived as part of the physical the component in the IFVI study. In comparison, the temporally specific data (i.e. social/census data) might at least act as a means of validation for the structure of the index in explaining social vulnerability.

6.2. Limitations of capturing vulnerability

A critical evaluation needs to take account of the limitations of indices in general when assessing vulnerability. Because vulnerability is comprised multi-dimensional factors, it is also subject to time and space features of the components which are scale specific.

This indicates that the IFVI displays vulnerability only in a short window in time-space. Because some of the displayed data cannot be the latest, including newly evolved and interrelated processes that makes it hard to map, for instance, climate change processes", as "they interact in different ways according to the temporal and spatial scales of analysis" (Wilbanks and Kates, 1999; Dow, 1992 in Fekete 2009). It is definitely worth noting that the latest data available and applied, actively helps to capturing local and temporal elements.

The aggregated social and economic data together with obtained spatial data for the ecologic and physical components results is the IFVI with current measures of vulnerability. Nevertheless, it is necessary to imply that these conditions
are not constant as climate changes are projected to occur.

Fekete (2009) argues in his SVI (Social Vulnberability Index) evaluation validation study that:

> *"although some indices have embraced the use of socio-economic scenarios (e.g. Moss et al, 2001 in Fekete 2009), ... using current vulnerability and being unable to capture temporal shifts and assess their potential effect on the overall social vulnerability must be borne in mind when using the results." (Fekete A., 2009) …*

… of the derived outcomes of such a study like the IFVI assessment.

The likely and yet unknown increasing frequency of extreme weather events calls for new technical solutions. Hence, the IFVI study emphasized on its importance to not only promote a possible solution towards the identification and assessment of the various vulnerabilities of societies, their economy and environment, but to also bring out an easy to use tool which can be applied and used by the non scientific community. Thus probable causes and problems can be tackled on a local scale where the most changes in flood impacts are felt.

7. Conclusion

Measuring and predicting flood vulnerability into the future is difficult because of accumulating uncertainty on how geo-hydrological pattern and societal development will change in the future. Nevertheless, four components were analyzed and applied in this thesis, that is the (1) the social component, (2) the economic component, (3) the ecological component, and (4) the physical component to derive the objectives and products mentioned in Chapter 2. Emphasis is given to the social and the economic components as they are the most important and most vulnerable features for the people living in the place.

However, the results of the IFVI study show that better knowledge of all elements at risk (i.e. social, economic and ecologic) can help to develop a better criteria grouping to calculate and eveluate past or probable future flood events. In this way, the IFVI helps to identify the exact areas of potential vulnerability for the particular elemt or elements at risk disregarding of the intensity of the flood, which may occur.

The IFVI approach attempted to accomplish to take in social science knowledge to define the index indicators indicidually and thus calculate their vulnerability. However, a great amount of detail to include good social science knowledge can be added to an assessment like the IFVI and thus enhance accuracy and validity of such an assessment. For instance, each subdistrict could be evaluated on a house to house basis to derive greater accuracy before calculating aid distribution maps as it has be done for Figure 7-1 to 7-3. This can be done by including individual household inhabitants, building structures, socioeconomic situation of the individuals, and financial situations of groups as such. All these criteria were not included in the IFVI study to such a detailed level, but this can be done to bring such a project to the next level and impove vulnerability studies such as the IFVI assessment.

7.1. Aid-Distribution Map for Flood "Pfingsthochwasser" 1999

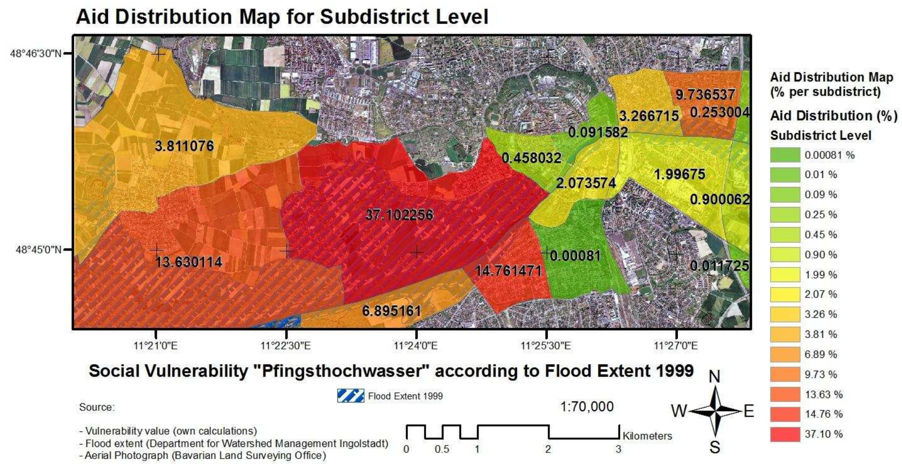

Figure 7-1: Aid distribution map (Pfingsthochwasser 1999) according to degree of vulnerability on a subdistrict level

Figure 7.1 shows the calculated Aid Distribution map according to the recent flood back in 1999. Damage caused by the flood could have been evaluated and easily planned by closer investigating the aid map, which was calculated according to the inundated area on a subdistrict – administrative level.

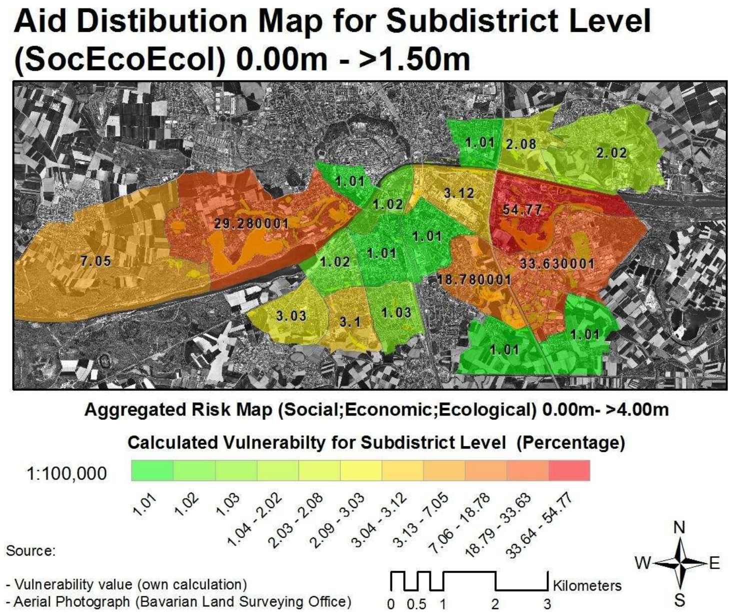

Figure 7-2: Aid distribution map (Worst Case Scenario 0.00m- 1.50m) according to degree of vulnerability on a subdistrict level

In comparison, Figure 7.2 and Figure 7.3 display the calculated Aid Distribution Map according to the worst case scenario calculation. Figure 7.2 shows little damage occurring and the affected areas are to the East and West part of the city. Figure 7.3 in comparison shows clearly that the more vulnerable areas with greater damage are to the East once the water rises above 4 meters. Probable damage can be calculated and evaluated with the help of these the aid distribution maps and administrative planning and action for help better organized.

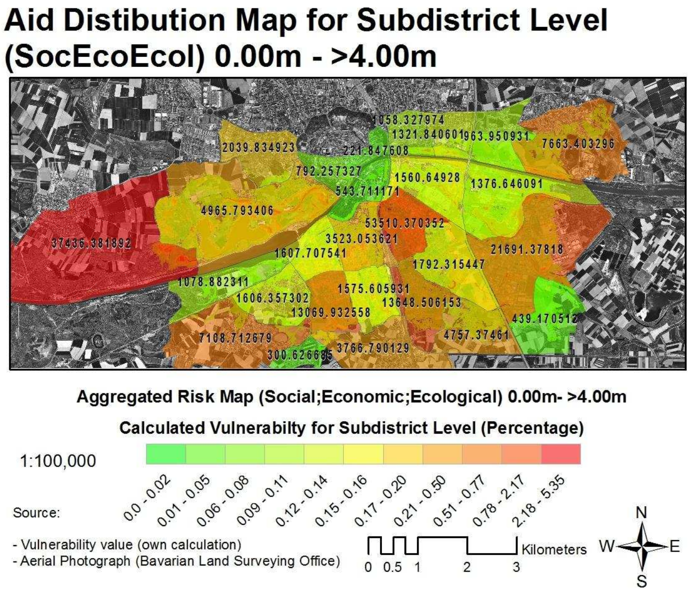

Figure 7-3: Aid distribution map (Worst Case Scenario 0.00m- >4.00m) according to degree of vulnerability on a subdistrict level

The proposed indicator system provides an efficient method and tool to evaluate vulnerability on a local level for the administrative levels of a city. It helps to generate information, which is then to be applied by decision-makers to better manage likely impacts of natural hazards like a flood. The IFVI can also be seen as an instrument providing the capacity of communities and local governments to measure key elements (at risk). The approach uses a comprehensive IFVI system concept adapted specifically for the purpose of this study, which can be applied elsewhere.

Literature available indicated that there is quite a lot of work conducted in this research field. However, using and applying the IFVI indicator system creates risk and vulnerability awareness for the user in particular. The results provide insight into the causes and links of the flood vulnerability. Furthermore, it is a very cost efficient way of assessing risk and vulnerability, which can help and guide complementary studies or provide managers with better knowledge about likely risk and the associated vulnerability of probable exposure to hazards. Repetitive application of the IFVI tool will certainly allow more precise monitoring of the changes in the face of flood hazard risk mitigation and reduction, thus the tool can be applied fast and with little cost due to its simplicity. That is one of the main reasons for its usefulness. New measures can be derived and financial aid or city development budgets can then be targeted accordingly.

As a reminder, the limitation of existing work shows that most collected data is rather descriptive than analytical. That is because most data is gathered and stored in a different ways and formats as this in turn can make comparisons difficult. According to literature, much work has been done on either the micro-scale with focus on local detail, or on regional scale where data is so aggregated and generalized that the underlying processes are difficult to discern (see Vogel 1997 in Birkman 2005). This calls for better concepts and approaches in data storage to derive more accurate and detailed information. As a consequence, data processing and preparation for such assessments helps to derive higher accuracy.

To conclude, the IFVI Assessment demonstrated that the IFVI tool can be applied in a wide variety of contexts (including conditions of the applied index components and variables), and that it can generate valuable insights into vulnerabilities and capacities for use in planning and implementing projects. The IFVI was designed to help prior planning processes and respond to a flood hazard/disaster by understanding what impact interventions will have on vulnerabilities in place. The IFVI study intended to provide concepts, tools and guidance on decisions and choices in project design and implementation throughout the project cycle. It is seen as a simplified framework for mapping complex situations by identifying critical factors and the relationships between them.

The produced vulnerability maps can give planners and managers a valuable tool for assessing flood vulnerability. Therefore the IFVI tool has been applied for post-flood evaluation to identify areas of risk and the associated probable vulnerability. The outcomes generated in the form of maps can help approaches to rehabilitation and mitigation. However, pre-flood mapping is also possible along with other diagnostic tools like a GIS. Thus, scenarios calculated (Chapter 5) show different flood situations mapped in the area. By applying the IFVI and using classification mapping and a Spatial Multi Criteria Analysis (SMCA) (Floodsite, 2009), an vulnerability assessment has been carried out and past like probable flood impacts were modeled to explore how vulnerability can be mapped and used with the IFVI to improve flood mitigation and risk prevention. Hence, the IFVI study provides insights to which degree the natural and social domain are susceptible to flood risk and its degree of vulnerability for the four dimensions of the social, economic, ecological and physical for the city of Ingolstadt. The results of the IFVI study could be further analyzed and used for stakeholder utilization like urban and rural planning like the planning of new or better protected settlement in the area.

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9. Appendices

Physical Indicators	Flood properties	Danube Streamflow		Topographical Data:	Administrative Boundaries	Digital Orthographic Photographs (DOP)
Data Source	Communal Institution and Planning Department, Ingolstadt; Department for Watershed Management, Ingolstadt	Bavarian Environmental Agency (Land Surveying Department)			ESRI (ArcGIS9.3)and The GIS Data Depot, own generated vector layers	Bavarian Environmental Agency (Land Surveying Department)
Social Indicators	**Population Total (Age) Subdistrict (31 Dec 2008)**	**Female (all Ages) Subdistrict (31 Dec 2008)**	**Population above 0-18; 18-65; >65 Years**	**Population density 2008 (Residents/km2)**	**Population growth - trend since 1998**	**Unemployed Total Dec 2008 Total**
Data Source	Stadt Ingolstadt; Stadtentwicklung und Statistik	Stadt Ingolstadt; Stadtentwicklung und Statistik	Stadt Ingolstadt; Stadtentwicklung und Statistik	Stadt Ingolstadt; Stadtentwicklung und Statistik	Stadt Ingolstadt; Stadtentwicklung und Statistik	Stadt Ingolstadt; Stadtentwicklung und Statistik
Economic Indicators	**Development housing stock (since census 1987) 2008**	**Dwellings and other residential units (since 1987 census) 2008**	**Industrial and Commercial**	**Vehicle Registrations Total 2008**		
Data Source	Stadt Ingolstadt; Stadtentwicklung und Statistik	Stadt Ingolstadt; Stadtentwicklung und Statistik	CORINE Land cover	Stadt Ingolstadt; Stadtentwicklung und Statistik		
Ecological	**Biological reserve and Protected Areas (Lfu (Schutzgebiete, Landschaftsschutzgebiete)**	**Bird Protection Area (Vogelschutz) NATURA 2000 delineation**	**Biotope Areas and NATURA 2000**			
Data Source	Bavarian Environmental Agency (Land Surveying Department)	Bavarian Environmental Agency (Land Surveying Department)	Bavarian Environmental Agency (Land Surveying Department)			

Table 7: IFVI Data obtained and used for the IFVI study

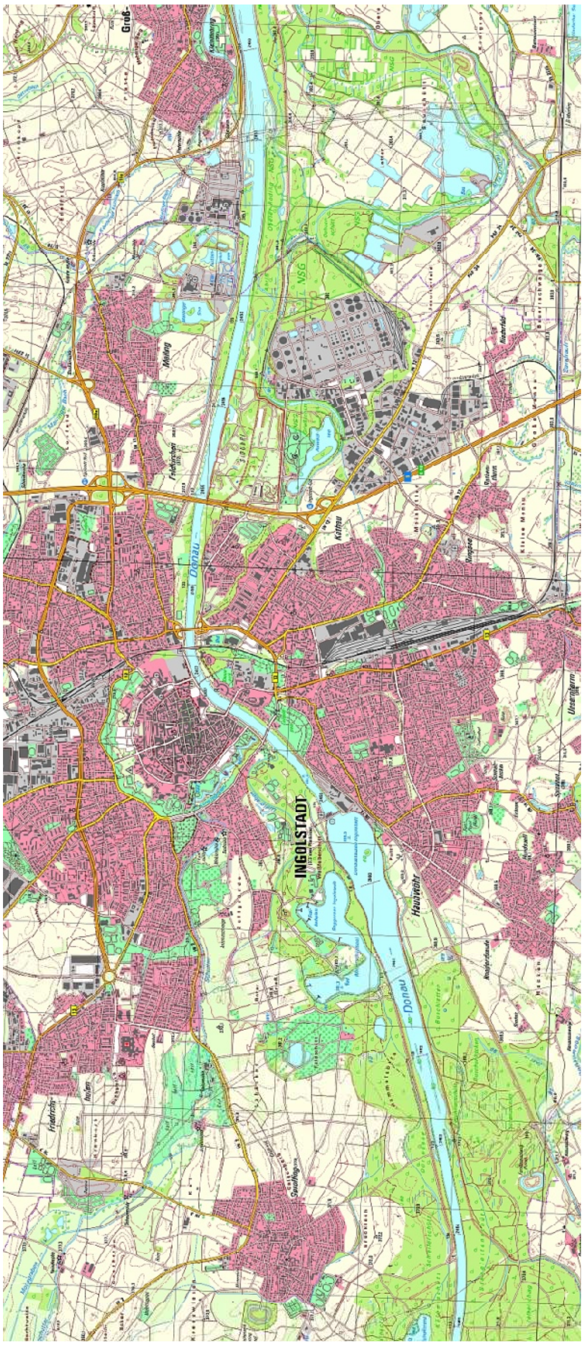

Figure 9-1: 1:25 000 Topographical map of Ingolstadt (Courtesy of Bavarian Environmental Agency; Chief Directorate: Surveys and GeoMapping)

Figure 9-2: Flood extent 1999 and Worst Case Scenario[27]

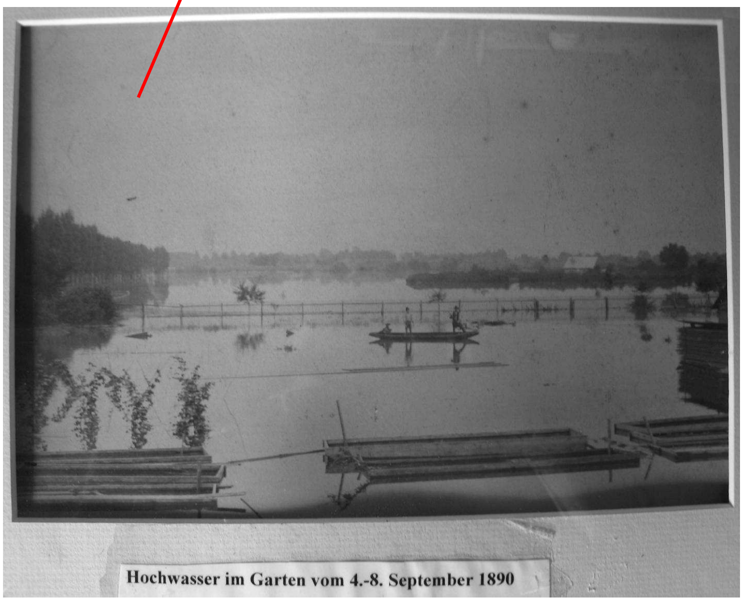

Figure 9-3: High-Water in September 1890, Curtsey Gaertnerei Troegl (Nursery)

[27] Source: http://www.wwa-in.bayern.de/projekte_und_programme/riedensheim/index.htm [accesses 04.10.2009]

Natura 2000

City borders & Subdistricts

Biotope areas

Biotope type

- Bird Protection Zone
- Artenreiches Extensivgrünland
- Auwald
- Baumgruppe / Baumreihe / Allee
- Einzelbaum
- Feldgehölz, naturnah
- Feuchte und nasse Hochstaudenflur (planar bis montan)
- Feuchtgebüsch
- Flachmoor, Quellmoor
- Gebüsch / Gehölz, initial
- Gewässer-Begleitgehölz, linear
- Großröhricht
- Großseggenried außerhalb der Verlandungszone
- Großseggenried der Verlandungszone
- Hecke, naturnah
- Initialvegetation, kleinbinsenreich
- Initialvegetation, trocken
- Kiefernwald, basenreich
- Kleinröhricht
- Landröhricht
- Laubwald, mesophil
- Magere(r) Altgrasbestand / Grünlandbrache
- Magerrasen (Trocken-/ Halbtrockenrasen), basenreich
- Mauer-/ Ritzenvegetation
- Mesophiles Gebüsch, naturnah
- Offene, vegetationsarme Fläche / Rohboden
- Park / Hain / Grünanlage mit Baumbestand
- Pfeifengraswiese (Molinion)
- Quelle, Quellflur naturnah
- Seggen- od. binsenreiche Feucht- u. Nasswiesen/Sumpf
- Sonstige Flächenanteile
- Streuobstbestand
- Sumpfwald
- Unterwasser- und Schwimmblattvegetation
- Vegetationsfreie Wasserfläche (in geschützten Gewässern)
- Vegetationsfreie Wasserfläche (in nicht geschützten Gewässern)
- Verlandungsvegetation an nicht geschützten Stillgewässern
- Wald
- Wärmeliebende Ruderalflur
- Wärmeliebender Saum
- Wärmeliebendes Gebüsch

Protected areas

Name/Description; Area qm

- LSG "Auwald südlich der Donau", 6401362.37153
- LSG "Auwaldreste südlich der Wankelstraße", 173751.656628
- LSG "Donauschüttlandschaft im Roten Gries", 668510.269495
- LSG "Gerolfinger Eichenwald", 7683539.51647
- LSG "Rankenkomplex westlich von Irgertsheim", 37187.110235
- LSG "Sandrachaue südwestlich von Unterbrunnenreuth", 188852.427092
- LSG "Zucheringer Wäldchen", 720807.229198
- Schutz der Donauauen östlich der Stadt Neuburg in der Stadt Neuburg und den Gemeinden Weichering und Bergheim, Landkreis Neuburg sowie des Gebietes "Branst" in der Gemeinde Weichering als LSG, 19052122.8656
- Schutzzone im Naturpark "Altmühltal", 1633066597.41

Source:
- Bavarian Environmental Agency (Lfu Bayern)

Table 8: Detailed legend for Natura 2000 and Protected areas (available in German only)

Subdistricts of the city of Ingolstadt

Subdistrict, District, Subdistrict ID

- Altstadt NO, Mitte, 12
- Altstadt NW, Mitte, 11
- Altstadt SO, Mitte, 13
- Altstadt SW, Mitte, 14
- Am Auwaldsee, Suedost, 48
- Am Suedfriedhof, Suedwest, 51
- Am Wasserwerk, Nordost, 34
- Antonviertel, Muenchner Strasse, 121
- Augustinviertel, Suedost, 43
- Auto-Union-Bezirk, Nordwest, 25
- Bahnhofsviertel, Muenchner Strasse, 122
- Brueckenkopf, Mitte, 10
- Buschletten, Suedwest, 54
- Duenzlau, West, 65
- ESSO Gelaende, Oberhaunstadt, 84
- Etting Ost, Etting, 71
- Etting West, Etting, 72
- Feldkirchen, Mailing, 91
- Friedrichshofen, Friedrichshofen Hollerstauden, 112
- Gabelsbergerstrasse, Nordwest, 21
- Gaimersheimer Heide, Friedrichshofen Hollerstauden, 113
- Gerolfing Nord, West, 66
- Gerolfing Sued, West, 61
- Gerolfinger Strasse, Mitte, 16
- Gewerbegebiet NO, Nordost, 33
- Gewerbegebiet SO, Suedost, 45
- Hagau, Sued, 103
- Haunwoehr (Neu Haunwoehr), Suedwest, 52
- Herschelstrasse, Nordwest, 23
- Herz Jesu Viertel (Alt Haunwoehr), Suedwest, 55
- Hollerstauden, Friedrichshofen Hollerstauden, 111
- Hundszell, Suedwest, 53
- Im Freihoefl, Mitte, 17
- Irgertsheim, West, 62
- Josephsviertel, Nordost, 32
- Konradviertel, Nordost, 36
- Kothau, Suedost, 42
- Mailing (Fort Wrede), Mailing, 92
- Mailing Nord, Mailing, 93
- Mailing Sued, Mailing, 94
- Monikaviertel (Peisserstrasse), Suedost, 44
- Muehlhausen, West, 64
- Muellerbadsiedlung, Oberhaunstadt, 83
- Niederfeld, Suedost, 46
- Nordbahnhof, Nordwest, 22
- Oberbrunnenreuth, Sued, 105
- Oberhaunstadt, Oberhaunstadt, 81
- Pettenhofen, West, 63
- Piusviertel, Nordwest, 24
- Probierlweg, Mitte, 15
- Richard Strauss Strasse, Nordwest, 26
- Ringsee, Suedost, 41
- Rothenturm, Suedost, 47
- Schlachthofviertel, Nordost, 31
- Schubert und Salzer Bezirk, Nordost, 35
- Spitalhof, Sued, 106
- Stadt Ingolstadt, , 0
- Stangletten, Sued, 104
- Unsernherrn, Muenchner Strasse, 123
- Unterbrunnenreuth, Sued, 107
- Unterhaunstadt, Oberhaunstadt, 82
- Winden
, Sued, 102
- Zuchering Nord, Sued, 108
- Zuchering Sued, Sued, 101

Table 9: Subdistricts of the city of Ingolstadt

Weighting and pairwise comparison

IFVI Weights Criterion	Economic	Social	Ecological	Total
Economic	1	2	0	3
Social	0	1	0	1
Ecological	2	2	1	5
SUM	3	5	1	9
Calculated weight for each component category	33	56	11	100

Point allocation distribution for each component according to relative importance

Social	Total Population - Ages	Female	Population density (Residents/km2)	Population growth %	Unemployed	Total
Total Population	1	1	0	0	0	6
Female	0	1	0	0	0	1
Population density (Residents/km2)	1	1	1	0	0	3
Population growth %	1	1	0	1	0	3
Unemployed	1	1	0	1	1	3
SUM	4	5	1	2	1	13
56	17.09	21.37	4.27	8.55	4.27	55.56

Economic	Development housing stock	Dwellings and other residential units	Vehicle Registrations	Industrial and commercial	Total
Development housing stock	1	1	0	0	2
Dwellings and other residential units	0	1	0	0	1
Vehicle Registrations	1	1	1	1	4
Industrial and commercial	1	1	0	1	3
SUM	3	4	1	2	10
33	10.00	13.33	3.33	6.67	33.33

Calculated IFVI vulnerability parameter values for GIS input to compute componnt and overall maps

Ecological	Biological reserve/Protective Area Lfu	NATURA 2000	Total
Biological reserve/Protective Area Lfu	1	0	1
Natura 2000	1	1	2
SUM	2	1	3
11	7.41	3.70	11.11

IFVI vulnerability parameters

ComponentVariable	Social					Economic				Ecological		Total
Factor	Total Population - Ages	Female	Population density (Residents/km2)	Population growth %	Unemployed	Housing stock	Dwellings and other residential units	Vehicle Registrations	Industrial and commercial	Biological reserve/Protected Area Lfu	NATURA 2000	Consistency check!
Weights	17.09	21.37	4.27	8.55	4.27	10.00	13.33	3.33	6.67	7.41	3.70	100.00

Figure 9-4: The IFVI Calculator (example: stakeholder approach)

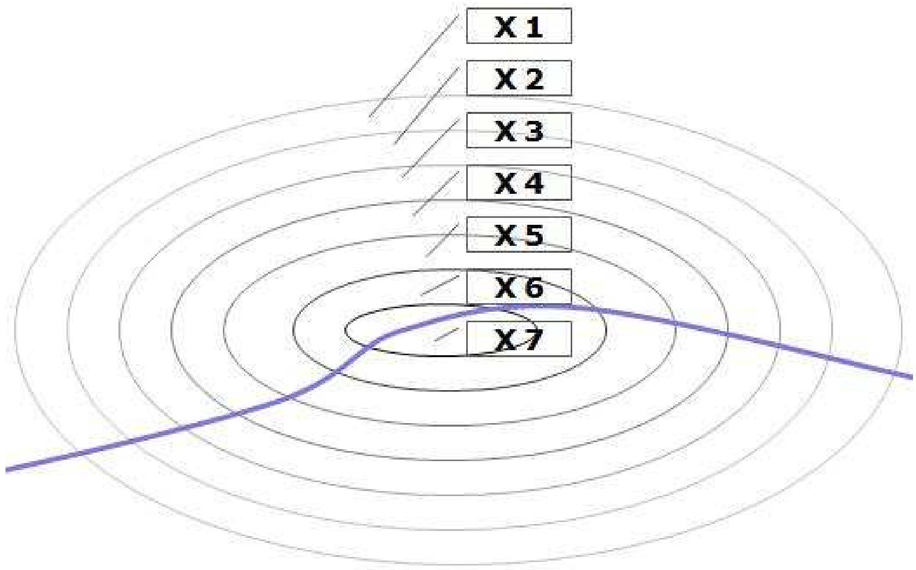

Figure 9-5: Shows risk and vulnerability calculation scheme: the closer the elements at risk in a specific area are to the river, the higher the risk.