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Development and Application of Flood Vulnerability Indices for Various Spatial Scales

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Master of Science Thesis
by

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To my grandmothers ...

Abstract

Human population world wide is vulnerable to natural disasters, which are increasing due to the consequences of socio-economical and land-use developments and due to climate change. In recent years the impacts of floods have gained importance because of the increasing amount of people who are affected by its adverse effects.

In this study a methodology to compute a *flood vulnerability index*, based on indicators, is developed, aiming at assessing the conditions which favour flood damages at various levels: river basin, sub-catchment and urban area. This methodology can be used as a tool for decision making to direct investments at the most needed sectors. Its implementation could guide policy makers to analyse actions towards better dealing with floods.

The methodology involves two concepts. First, vulnerability, which covers three related concepts called factors of vulnerability: *exposure, susceptibility* and *resilience*. The other concept concerns the actual flooding; understanding which elements of a system is suffering from this natural disaster. Four main components of a system are recognized which are affected by flooding: *social, economical, environmental and physical components.* The interaction between the vulnerability factors and the components serves as the base of the proposed methodology.

The developed methodology distinguishes different spatial scales of flood vulnerability: river basin, sub-catchment and urban area. This allows a more in-depth interpretation of local indicators and pinpoints actions to diminish focal spots of flood vulnerability. The larger scales in international committees to identify and develop necessary plans actions to deal with floods and flooding. The smaller scales aim to improve the (local) decision making process by selecting action plans to reduce vulnerability at local and regional levels.

The methodology has been applied in various case studies spatial scales, which resulted in interesting observations on how vulnerability can be reflected by quantifiable indicators. The testing results indicate that the FVI of a river basin as a whole can be better reflected by the average FVI of its sub-catchments, thereby improving decision-making processes at regional levels. However, the average FVI of urban areas does not reflect the FVI of the sub-catchment or river basin in which they are located.

To fully understand the capacity of the FVI methodology, it is recommended to continue with additional case studies to carry on with the search for more useful indicators, refinement of the equations and enhancement of the concepts. In addition, an international network of knowledge institutes could contribute to the further development of flood vulnerability at different spatial scales.

Keywords: vulnerability indices, flood exposure, flood susceptibility, flood resilience, flood risk management

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BCPR – Bureau for Crisis Prevention and Recovery
CRED – Centre for Research on the Epidemiology of Disasters
CVI – Climate Vulnerability Index
CVI_{SIS} - The Composite Vulnerability Index for Small Island States
DEWA - Division of Early Warning and Assessment
DFO – Dartmouth Flood Observatory
DHI – Water, Environment & Health
DRI – Disaster Risks Index
EPI – Environmental Performance Index
EVI – Environmental Vulnerability Index
FAO – Food and Agriculture Organization
FVI – Flood Vulnerability Index
GDP – Gross Domestic Product
GRAVITY - Global Risk and Vulnerability Index Trends per Year
HDI - Human Development Index, UNDP
HIV/AIDS – Human Immunodeficiency Virus Acquired Immune Deficiency Syndrome
ICPDR – International Commission for the Protection of the Danube River
ICPR - International Commission for the Protection of the Rhine
INTUTE - Science, Engineering and Technology Site
IPCC – International Panel of Climate Change
MRC – Mekong River Commission
PD – population density
PELCOM - Pan-European Land Use and Land Cover Monitoring
PREVIEW - Project for Risk Evaluation, Vulnerability, Information and Early Warning
SAR –Second Assessment Report
SIDS - Small Island Developing States
SUST -The Research and Assessment Systems for Sustainability Program
SVCC - Social Vulnerability to Climate Change for Africa
SVI – Social Vulnerability Index
TAR- Third Assessment Report
UN – United Nations
UNCTAD - United Nations Conference on Trade and Development
UNDP – United Nations Development Programme
ILO - International Labour Organization
UNEP - United Nations Environment Programme
UNESCO- United Nations Educational, Scientific and Cultural Organization
UNH/GRDC – United Nations Hydrology / Global Runoff Data Centre
UNICEF - The United Nations Children's Fund
UNU - United Nations University
UNU-EHS - Institute for Environment and Human Security, UNU
WB – World Bank
WFP - World Food Programme
WHO – World Health Organization
WPI –Water Poverty Index
WRI – World Resource Institute

Chapter 1 Introduction

1.1 Motivation and Background

Human population world wide is vulnerable to natural disasters. In recent years the impacts of floods have gained importance because of the increasing amount of people who are exposed to its adverse effects.

Floods are natural and recurring events in a river or stream. Floods are usually described in terms of their statistical frequency. A "100-year flood" or "100-year floodplain" describes an event or an area subject to a 1% probability of a certain flood occurring in any given year.

The frequency of flood depends on the climate, the material that makes up the banks of the stream, and the channel slope. Where substantial rainfall occurs in a particular season each year, or where the annual flood is derived principally from snowmelt, the floodplain may be inundated nearly every year, even along large streams with very small channel slopes. In regions without extended periods of below-freezing temperatures, floods usually occur in the season of highest precipitation (United States Agency, 1991). In some areas floods occur because of exposure to the cyclones, hurricanes, big tidal waves or tsunamis.

Floods and flooding are two terms which are frequently mixed up, when topics concerning high water stage or peak discharge are discussed. Above are defining the terms as:

A *flood* is “defined as a temporary condition of surface water (river, lake, sea), in which the water level and/or discharge exceeds a certain value, thereby escaping from its normal confines;” this does not necessarily results in flooding (Douben, 2006a).

Flooding is defined as the spilling over or failing of the normal limits for example river, lake, sea, stream or accumulation of water as a result of heavy precipitation through lack or exceeding of the discharge capacity of drains, or snow melt, dams or dikes break affecting areas which are normally not submerged (Douben and Ratnayake, 2005).

Types of floods

A distinction can be made between five different types of floods: coastal floods, river floods, flash floods, urban floods and lake floods (MunichRe, 2007)

Coastal floods

They can occur on the coast and along the banks of large lakes (MunichRe, 2007). Floods usually occur when storms coincide with high tides and can include overtopping or breaching of beaches Coastal flooding can also be produced by sea waves called tsunamis, unusually giant tidal waves that are created by volcanoes or earthquakes in the ocean. Hurricanes and tropical storms can produce heavy rains, or drive ocean water into land. They have extreme loss potential and may cause hundreds of thousands of fatalities.

Figure 1.1 Coastal Floods (Winthrop Maine) [Live Science]

The accelerating rise in sea levels that is certainly to be expected as a result of climate change and variability will aggravate the risk of storm surges and coastal erosion all around the globe — and this will be one of the most detrimental effects of global warming.

Coastal flooding levels (NYC Hazards, 2007) — categorized as minor, moderate or major — are calculated based on the amount of water that rises above the normal tide in a particular area. Flooding of this type can be very destructive (Natural Environmental, 2007).

River floods

Figure 1.2 River Flood (Cambridge shire, UK)

Floods along rivers are a natural event. Some floods occur seasonally when winter snows melt and combine with spring rains. Water fills river basins too quickly, and the river will overflow its banks. River floods are also the result of copious rainfall usually continuing for a period of days over a large area. The ground becomes saturated and cannot cope with any more water so that the rain flows directly into the rivers (Hoyt, 1955).

River floods do not occur abruptly but build up gradually – although sometimes in a short time. As a rule, they last from a few days to a few weeks. The affected area may be very extensive if the river valley is flat and broad and the river carries a large volume of water.

River related flooding also brings indirect threats arising from food and drinking water shortage and the spreading of diseases (Douben, 2006b).

Flash floods

Figure 1.3 Flash floods (Buchanan Missouri) [VAEmergency]

Flash floods are short-term inundations of small areas such as a town or parts of a city. They are caused by what are usually short periods of intense rain often occurring over a very small area and typically in conjunction with thunderstorms. The soil is not usually saturated; but as the rainfall intensity exceeds the infiltration rate, the water runs off on the surface and soon gathers in the receiving waters.

Flash floods can occur almost anywhere, so that nearly everybody is threatened. Sometimes they mark the beginning of a major river flood, but usually they are separate, individual events of only local significance, scattered randomly in space and time.

Dams and levees are built for flood protection. They usually are engineered to withstand a flood with a computed risk of occurrence. For example, a dam or levee may be designed to contain a flood at a location on a stream that has a certain probability of occurring in any year. If a larger flood occurs, then that structure will theoretically be overtopped. If during the overtopping the dam or levee fails or is washed out, the water behind it is released to become a flash flood (Perry, 2000).

Flash floods are the most deadly and damaging kind of floods. This is because they happen without warning and deliver massive amounts of fast-moving water. Sadly, they are also the most common kind of flood. Flash floods are also much shorter in duration than river floods. Most of the water has disappeared again after a few hours.

Urban Floods

Urban floods are usually caused extreme local rainfall, combined with blocked drainage systems. This type of flooding depends on soil and topographical conditions and the quality of the drainage system (Douben, 2006b).

Figure 1.4 Urban Floods (Spences Lane)

These increasingly common floods are the result of urban/suburban sprawl, where developed land areas lose their ability to absorb rainfall. Development may increase runoff up to six times over what would occur naturally in its absence.
In the developed world, most exposed populations are protected from flooding by various structural measures (e.g., UK, the Netherlands and Japan). In the developing world, flood defences are less developed and the exposed populations are more often subject to flooding, resulting in loss of life, disruption, economic loss, etc. People in developing countries, have less capacity to adapt to change and are more vulnerable to environmental threats, floods and global change, just as they are more vulnerable to other stresses (UNEP, 2002).

Floods are the most common occurring natural disasters that affect humans and their surrounding environment (Hewitt, 1997). The world experienced between 1700 - 2500 (major) flood events between 1985 and 2003; more then 50% of the floods occurred in emerging countries (US$ 2,976-9,205 GNI/ capita), approximately 45% in Asia and about 25% in the Americas (Douben, 2006a).

Table 1-1 shows the number of flood events on continental scale, between 1985 and 2003, as recorded by the Dartmouth Flood Observatory (DFO) and The Centre for Research on the Epidemiology of Disasters (CRED). The discrepancies observed can be credited to lack of information in the areas of study.

Table 1-1 Number of flood events 1985 - 2003 (Douben, 2006a)

Continents **Data Source**	**Africa**	**Americas**	**Asia**	**Europe**	**Oceania**
DFO	320	649	1186	251	87
CRED	339	443	668	229	55

In Africa, early February 2000, exceptionally heavy rains with a return period of 200 years occurred over Mozambique, north-eastern parts of South Africa, Zimbabwe, Botswana, Zambia and Madagascar and caused severe flooding (Smithers et al., 2001; Dyson and van Heerden, 2001).
The floods in 2000 left a trail of devastation in Mozambique. The affected sectors were agriculture, infrastructure, including roads, railways, bridges and water control embankments,

water intake and treatment plants and supply systems. Floods left over 700 people dead and half a million homeless (Mirza, 2003). The UN World Food Programme reported that Mozambique lost at least one third of its staple food maize and 80% of its cattle. In 2001, floods destroyed thousands of homes and 27,000 ha of crops. It also affected 400,000 people, 40 people were killed and 77,000 left homeless (WSWS, 2001).

Also in 2000 in Zimbabwe, more than 100 people have died, and an estimated 250,000 have been left homeless, exacerbating the country's worst economic crisis in 20 years. In Madagascar floods caused by two cyclones have forced 600,000 people from their homes, according to the United Nations, at least 130 had died.

In 2003, during the flood events in Ethiopia the floods killed at least 117 people and more then 100,000 have been left homeless; another 40 people have died in Kenya. In western Kenya some 60,000 have fled rising waters, according to Kenya Red Cross Society, and in Somalia 21 out of 33 nearby villages were abandoned because of the floods and people were suffered from lack of food, shelter and medicine (BBC, 2003).

Throughout the history, the United States of America faced many floods, as in 1993 along the Midwest/ Mississippi area which was the worst flooding in recorded history, 38,000 homes damaged or destroyed and 20 million acres of farmland under water (Floods, 2005).

In 2005 in Central America Hurricane Stan triggered heavy rainstorms causing floods that have killed more than 2,000 people in Mexico, Costa Rica, El Salvador, Guatemala, Honduras and Nicaragua. As many as 3.5 million people have been forced to evacuate their homes.

In Latin America in 2005, twenty-eight people have died and over 220,000 have been evacuated from their homes in the worst flooding in Paraguay, Argentina and southern Brazil since 1983. In 2002 a torrential rainstorm hit La Paz, Bolivia, killing 60, injuring 100 and leaving over 500 homeless. In north of Colombia in 2004, the heavy rains claimed the lives of 19 people and left over 200,000 homeless.

Asia and the Pacific regions are also vulnerable and floods affect the social and economic stability of various regions and countries. The worst flood in China in 1998 affected 223 million people, 3,004 people were reported dead, 15 million were homeless and the economic loss was over US$ 23 billion for that year. Due to heavy flooding in Cambodia and Vietnam in 2000, 428 people were reported dead and the estimated economic loss amounted over US$250 million. In 1991, 140,000 people across the world were reported dead and in 1998, it affected 25 million lives (UN, 2003). For the last 10 years due to frequent occurrence of floods, thousands of people have been affected due to flooding in India, Pakistan, Korea, China, and Bangladesh destroying their agricultural fields, residential areas; i.e. livelihood and food.

Chaotic rainfall events in the 20^{th} century in Western Europe have increased the occurrence of flooding. Floods in the UN European Macro Region caused 252 disasters during 1985-2004 (Hoyois and Guha-Sapir, 2005). The worst flood events occurred in The Czech Republic (2002), France (1977 and 2003), Germany (1993 and 2002), Italy (1970, 1994 and 2000), Netherlands, Belgium, Poland (1997), Spain (1982), Sweden (1977, 1985 and 1994) and UK (2000 and 2004) and have affected many human lives and the environment.

Additionally in 2005 high and medium floods in India, China, Serbia, Romania, Germany, Russia and Bangladesh caused enormous economic losses and high fatalities. Worldwide, water-related disasters claim about 25,000 lives and affect over 500 million others annually. The annual costs of flood-related losses are more than $60 billion; by contrast, in 1950 these losses were about $10 billion. Floods often occur frequently, which means that reducing vulnerability and improving coping capacities is an evident need for people living along rivers (UNU – EHS, 2006a).

Floods are regarded as the most dangerous and harmful natural disaster, as seen in Figure 1.5 and Figure 1.6. The number of affected people and lives lost due to floods exceeds any other natural disasters in the past four years. This trend is not new since the damages of floods are historical in many places.

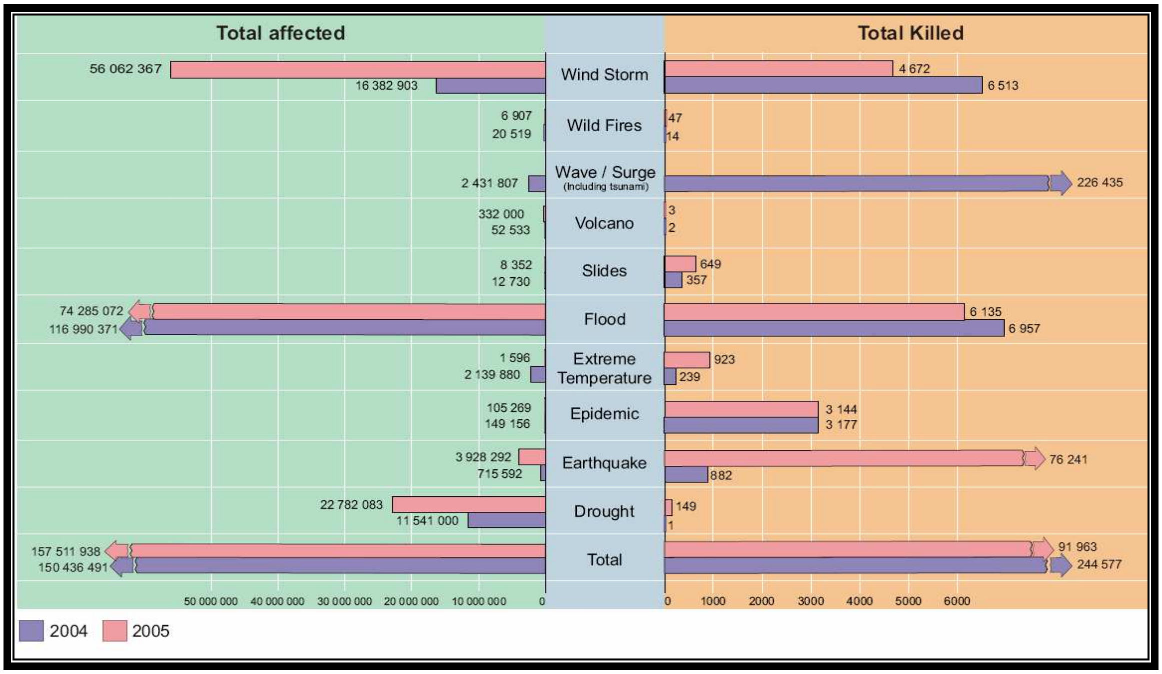

Figure 1.5 Human impact by disaster types: comparison 2004-2005 (CRED)

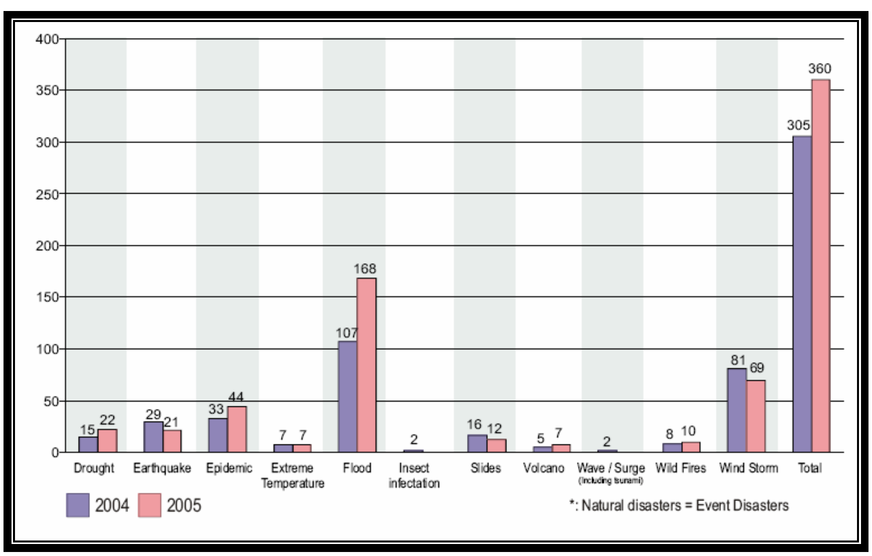

Figure 1.6 Natural disaster occurrence by disaster type: comparison 2004-2005* (CRED)

Researchers and policy-markers are looking for possible solutions to mitigate the damages of floods. There are proposals to add a new Millennium Development Goal: to halve the proportion of human losses due to water-related disasters by 2015.

Many studies describe the possible causes and effects of floods in terms of loss of human lives and costly damages and possible counter measures that can be adopted to minimize its consequences (Hall et al., 2004; Sayers et al., 2002; Connor & Hiroki, 2005; Naess et al., 2005, Nicholls, 2004; Plate, 2002; Montz & Gruntfest, 2002; Mustafa, 2003). Roughly, the approaches for flood mitigation and defence can be divided into two: structural and non-structural measures.

The structural measures consist of infrastructure development that modifies the river flow, like dams, barrages, dikes, levees, channelling, etc. that reduce floods from causing damages to the population or infrastructure in the flood prone area (Douben, 2006b). The basic principles consist of storing, diverting and/or confinement of floods. They usually consist of large investments for large engineering structures, which sometimes are inevitable to preserve the safety and development of a region. Some examples are: the Storm Surge Barrier in The Netherlands, Three Gorges Dam in China, dyke construction in several rivers.

The non-structural measures consist of several mitigation measures not modifying the river flow; such as preparedness, response, legislature, flood forecasting and warning systems, flood proofing, flood fighting, post-flood rehabilitation financing, reconstruction and rehabilitation planning (Andjelkovic, 2001). The aim is to reduce loss of life and damage to property. It may also include educating, training, regulating, reporting, forecasting, warning and informing, insuring, assessing, financing, relieving and rehabilitating. Some examples are the Flood Forecasting Program in Mozambique, Evaluation of Flood Vulnerability in Philippines, etc.

The evolution of non-structural measures is also linked with the need to improve the decision-making process for flood protection, so that investments can be allocated in a more optimal way. For this purpose the introduction of indices for flood protection or other related issues can be helpful.

Indices provide a good help in the decision-making process regarding flood defence, policies, measures and activities. An Index Number is a measure of a quantity related to a specific period and/or area (Sullivan, 2002) providing a method to relate different measures over time generally based on high amounts of data. Its applicability includes a wide range of areas of study from socio-economic sciences to engineering. Some examples of applicable indices are: Water Poverty Index (Sullivan, 2002), Eco-Environmental Vulnerability Index (Li et al. 2006), Environmental Vulnerability Index (UNEP, 2004), and the Economic Vulnerability Index (Adrianto & Matsuda, 2002).

Vulnerability can be reflected through indicators. The indicators allow us to recognize and set goals and provide guidance for strategies to reduce vulnerability. The vulnerability indicators allow us to set more precise and quantitative targets for vulnerability reduction.

Indicators are used to illustrate the present state and/or progress of a country, river basin, sub-catchment or urban area in achieving a range of economic, social, physical and environmental goals. The indicators represent data that have been collected by a variety of agencies using different methodologies.

Indicators are quantifiable variables that provide information either on matters of wider significance than that which is actually measured or on a process or trend that otherwise might not be apparent (Hammond et al; 1995). Essentially they are a means to summarize a complex reality in a single construct. Gross domestic product (GDP), for example, is created by summing the dollar output of final goods and services in an economy over a given time period (usually a year), and is a general proxy measure for the vitality of an economy (Vincent, 2004). A change in GDP, for example, indicates if a country is getting richer or poorer, at least in money terms. The indicators can quantify the economy, industry, poverty, environment, vulnerability, etc.

The Flood Vulnerability Index (FVI) (Connor & Hiroki, 2005) is a method to assess flood vulnerability on a river basin scale by identifying different components that influence the susceptibility to floods of the people who live in these areas. The current FVI identifies four main components; climate, hydro-geological, socio-economic and existing counter measures, which are specified by eleven indicators.

The FVI methodology uses a multiple linear regression analysis to evaluate the different weights of each indicator, comparing it with the loss of life and damages. Several case studies of floods in different rivers basins have been carried out to verify the applicability of the FVI methodology. Its methodology includes two main indices, the human and economic impacts of floods which are calculated separately and afterwards combined to generate the overall FVI.

The human index (FVI_H) takes into account the loss of lives, and the economic index (FVI_M) considers the material losses caused by flooding events. Each index has its own set of indicators which are included in different equations. This dual approach allows decision-makers to select indices (human or economic) depending on the orientation of their policy question (Connor & Hiroki, 2005).

1.2 Problem Definition

There is a need to further develop the methodology used for calculating the FVI. One of the problems encountered refers to the homogeneity of large areas, which can lead to unrealistic results, involving relatively high investments for monitoring and evaluating the necessary data. Another problem reflects the avoidance of some indicators which may reflect a higher or lower vulnerability to floods. This is for instance the case for tidal wave influence in coastal zones.

An evaluation of the FVI assessment, involving 18 catchments in the Philippines, shows that the errors in the equations used are relatively large (Connor & Hiroki, 2005).

The purpose of this research is to evaluate the current method of calculating the flood vulnerability index in order to make it applicable to sub-catchments and urban scale, so that the main indicators for different scales are used in accordance with their significance.

The different scales have different factors which makes them vulnerable to floods. The current FVI focuses on the river basin scale, neglecting some of the factors which make sub-catchments and urban areas vulnerable to floods. The aim of this study is to develop an improved methodology for FVI which identifies the most important factors for each scale.

To analyze the accuracy of the methodology two scenarios will be examined; one city and three sub-catchments in the same river basin and one city and one sub-catchment in two different river basins, which will also be analyzed.

For the first case the cities of Timisoara and the sub-catchments of Bega, Timis and Tisza in the Danube River Basin. For the second case the cities of Mannheim and Phnom Penh and the sub-catchments of Neckar and Mun, from the Rhine, and Mekong River Basins will be selected.

1.3 Objectives

General objective: To evaluate the applicability of Flood Vulnerability Index for different scales: river basins, sub-catchments and urban areas.

Specific objectives:

- To develop a methodology for FVI which is applicable on all scales; urban, sub-catchments and river basin areas;
- To develop additional flood vulnerability indices based on the recognized significant components that form the system;
- To identify new indicators and analyze their influences on the assessment capacity of flood vulnerability for different scales;
- To compare the developed FVI methodology with the existing FVI methodology at the river basin scale;
- Using methodologies of different vulnerability indices for developing an improved FVI;

1.4 Methodology

The first task of the study is to review the different literature about risk based indices, with the purpose of identifying and defining the different terminologies which have been used so far for different risks (floods, droughts, earthquakes, avalanches) and indices (climate vulnerability, environmental vulnerability, water poverty, risk disasters).

After that the different sources of vulnerability within the system must be recognized. In the original FVI methodology for river basin scale four main components of the system are recognized: climate, hydro-geological, socio-economical and countermeasures. A revision of these components must be done on a system analysis approach, taking into account a holistic view and considering the different scales.

The next task was to identify the main factors which cause vulnerability to floods, regardless the geographic position, climate and scale. Identifying these factors will facilitate the recognition of different indicators to facilitate the development of equations for the FVI. The indicators must be categorized among the factors identified.

The FVI must have different indicators for different scales. The next step is to cluster the indicators from the different factors into the three scales. The indicators can be featured in one or all of the scales, depending on the necessity.

The indicators can have a direct, indirect or both impacts on vulnerability of the area of study.

They can also be experienced on a short or long term basis. Their influence is not always the same which means they can have different weights or different radicals. It is possible that some indicators chosen will have a weight of zero, which will leave them out of the equation. However, an initial weight value for each indicator must be assumed at this point.

Knowing the indicators needed to compute the FVI at the three different scales, an analysis of the FVI for diverse areas must be done to compare the results with the existing FVI methodology, at the river basin scale, and other methodologies and indices which can be compared at all the scales. The other indices selected are Environmental Vulnerability Index, Water Poverty Index, Disasters Risk Index and Climate Vulnerability Index. The chosen areas are presented in Table 1-2.

By comparing and revising the results of the computed FVI, using the developed, the existing and the chosen methodologies, the method will be further developed and improved, taking into consideration some steps that the other methodologies have applied to increase its efficiency as indices.

Table 1-2 Selected areas for studies

<table>
<tr><th>River Basins</th><th>Sub-catchments</th><th>Urban Areas</th></tr>
<tr><td>Rhine</td><td>Neckar</td><td>Mannheim</td></tr>
<tr><td>Mekong</td><td>Mun</td><td>Phnom Penh</td></tr>
<tr><td rowspan="3">Danube</td><td>Tisza</td><td rowspan="2"></td></tr>
<tr><td>Timis</td></tr>
<tr><td>Bega</td><td>Timisoara</td></tr>
</table>

This part of the research involves trial and error to show how the methodology is representing reality. Changes in the weights of the indicators, the number of indicators and possibly changes in the methodology itself will provide a better relationship among all the FVI methodologies. The results will be presented using GIS.

Chapter 2 Conceptualizing vulnerability

2.1 Who and what is vulnerability?

Defining vulnerability can help us understand the best ways to reduce it. The main objective to assess vulnerability is to inform decision-makers or specific stakeholders about options for adapting to the impact of flooding hazards (Douben, 2006b). The aim of vulnerability studies is to recognize correct actions that can be taken to reduce vulnerability before the possible harm is realized. The need for vulnerability analysis is noted in scientific literature, and the concept includes natural vulnerability, social vulnerability and economic vulnerability.

The notion to vulnerability has changed over the last 20 years. There have been several attempts to define and capture what is meant by vulnerability, the use of the term varies among disciplines and research areas. There are many different schemes which classify the components and the factors of vulnerability; the concept still has many different meanings for different people, among different disciplines of study.

In socio-economic sciences Ramade (1989) includes in his approach of vulnerability, human and socio-economic terms; involving the predisposition of goods, people, buildings, infrastructures and activities to be damaged, offering low resistance, as it was introduced in the 1980s in some geographical studies. These latter studies interpreted the vulnerability of a geographical or territorial system as the result of different behaviour and coping capacities in socially, economically and technologically heterogeneous contexts (Menoni, 1997).

Watts and Bohle (1993) look to the social context of hazards and relate (social) vulnerability to coping responses of communities, including societal resistance and resilience to hazards. They were trying to find an easier way to understand and reduce the concept through a better understanding of the social background.

Vulnerability in described by the International Strategy for Disaster Reduction (ISDR) (2004) as the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards. The concept tries to understand which of the factors is more relevant to community vulnerability.

In 2005, Veen & Logtmeijer broaden the concept of vulnerability to explain flood vulnerability from an economic point of view. Here the vulnerability is characterized as a function of dependence, redundancy and susceptibility. Susceptibility is the probability and extent of flooding. Dependency is the degree to which an activity relates to other economic activities in the rest of the country. Redundancy is the ability of an economic activity to respond to a disaster by deferring, using substitutes or relocating. Redundancy is measured as the degree of centrality of an economic activity in a network. The more central an activity is, the less it encounters possibilities to transfer production and the more vulnerable it is for flooding.

Gheorghe (2005) explains vulnerability as a function of susceptibility, resilience, and state of knowledge.

Social science's approach to vulnerability focuses on the human's capacity to respond to hazards and to promptly recover from damages and losses. They require little knowledge of the physical system, since their aim is to explain society's behavior.

Natural sciences take another point of view to explain vulnerability; they mainly focus on the physical system to defined vulnerability, leaving out socio-economic characteristics of the system.

Chambers (1989), described vulnerability as a potential for loss, with two sides: an external side of shocks and perturbations to which a system is exposed, and an internal side which represents the ability or lack of ability to adequately respond to and recover from external stresses.

Jones and Boer (2003) explain as the amount of *potential damage* caused to a system by a particular event or hazard. Sarewitz et al. (2003) take into account inherent characteristics of a system that create the *potential for harm* but are independent of the probability of any particular hazard or extreme event. Green (2004) expresses as *the potential for a receptor* to be harmed. These three (quite similar) definitions are contemporaneous and express vulnerability as potential damage or harm.

Included in the physical aspects which natural sciences look to explain are the hazards of climate change. The International Panel of Climate Change (IPCC) has evolved its definitions of vulnerability through the years. In 1992 they defined vulnerability as the degree of incapability to cope with the consequences of climate change and sea-level rise.

In 1996, SAR defined vulnerability as the extent to which climate change may damage or harm a system; it depends not only on a system's sensitivity, but also on its ability to adapt to new climatic conditions. It is seen as the residual impacts of climate change after adaptation measures have been implemented (Downing, 2005). This definition includes the exposure, susceptibility, and the capability of a system to recover, to resist hazards as a result of climate change.

IPCC TAR (2001) explains the concept of vulnerability as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, including its sensitivity and its adaptive capacity. Briefly summarized as:

Vulnerability = Risk (predicted adverse climate impacts) – Adaptation

The definitions described above have evolved, in the SAR and TAR, to include social components to explain vulnerability. During the 1980s and especially the 1990s the relationship between human actions and the effects of disasters, the socio-economic dimension of vulnerability, has increased. Improved definitions on vulnerability describe a holistic view of society, involving the natural and socio-economic aspects of the system.

Early in the 1990s, Heyman et al. (1991) and Alexander (1993) focused their definitions on exposure to biophysical hazards, including the analysis of distribution of hazardous conditions, human occupancy of hazardous zones, degree of loss due to hazardous events and the analysis of characteristics and impacts of hazardous events. Both definitions use the concept of vulnerability to measure the capacity to resist impacts of hazards.

Blaikie et al. (1994) describe vulnerability as a measure of a person or a group's exposure to the effects of a natural hazard, including the degree to which they can recover from the impact of that event. This explanation of vulnerability includes the term susceptibility as perceived by Penning-Rowsell & Chatterton in 1977.

Cutter (1996) defines vulnerability as a hazard of place which encompasses biophysical risks as well as social response and action. This definition is increasingly gaining in significance in the scientific community in recent years.

Klein and Nicholls (1999) express vulnerability for the natural environment as a function of three main components: resistance, the ability to withstand change due to a hazard, resilience, the ability to return to the original state following a hazardous event and susceptibility, the current physical state, without taking into account temporal changes. Their definition is specifically relevant to society.

Pelling (2003) denotes vulnerability as exposure to risk and the inability to avoid or absorb potential harm.

The vulnerability of human settlements is intrinsically tied to different social processes. It is related to the fragility, the susceptibility and lack of resilience of the exposed elements (Cardona, 2003). The author calls the exposure, physical fragility. He tries to holistically integrate the contributions of physical and social sciences to define a vision of indicators which create vulnerability.

Vulnerability is the degree of fragility of a (natural or socio-economic) community or a (natural or socio-economic) system toward natural hazards (EPSON, 2006).

$$\text{Vulnerability} = \text{Damage potential} + \text{Coping capacity}$$

Klein (2004) developed a scheme to explain the interaction between the components of vulnerability, as presented in Figure 2.1 and Figure 2.2

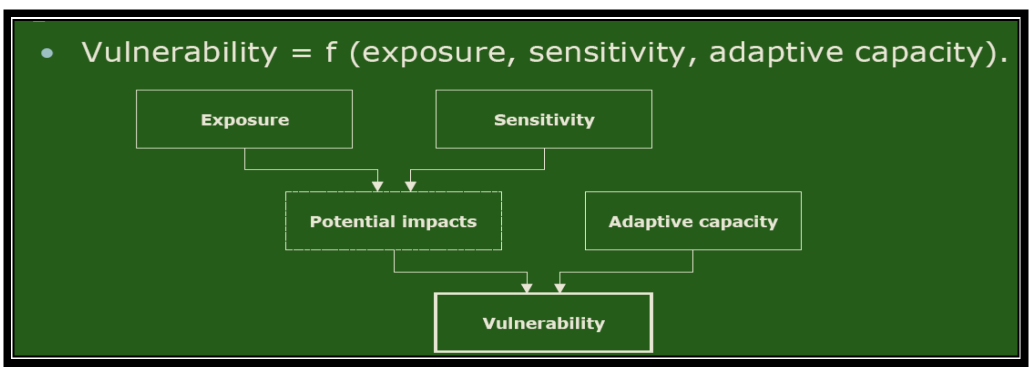

Figure 2.1 Interaction between the components of vulnerability Klein, (2004)

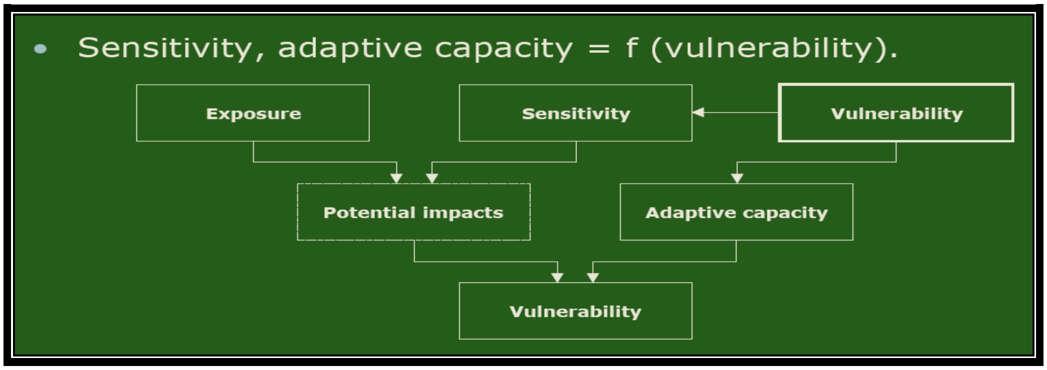

Figure 2.2 Interaction between the components of vulnerability Klein, (2004)

This revision demonstrates that vulnerability is registered not by exposure to hazards (perturbations and stresses) alone but also resides in the sensitivity and resilience of the system experiencing such hazards.

Based on these definitions, vulnerability is considered in this study as *the extent of harm, which can be expected under certain conditions of exposure, susceptibility and resilience.*

Combing all the definitions above, we decide that the following vulnerability equation is:

Vulnerability = Exposure + Susceptibility – Resilience

2.2 Vulnerability to floods

In the above mentioned vulnerability definitions, the hazards exposed on societies differ from definition to definition. Some of them give a definition of vulnerability to certain hazards like climate change (IPCC, 1992, 1996 and 2001) or environmental hazards (Blaikie et al., 1994); (Klein and Nicholls, 1999), (ISDR, 2004), but more important for this research is the definition of flood vulnerability (Veen & Logtmeijer 2005).

In the past United Nations (1982) have defined flood vulnerability as the degree of loss to a given element, or a set of such elements, at risk resulting from a flood of given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage). This definition falls short on this research focus, since it only considers some aspects of importance in the study of flood vulnerability.

Since the quantification of vulnerability can help in decision making processes, parameters and indicators (indices) should be designed to produce information for specific target areas and they should provide information to counter attack different hazards which societies face, like floods. In recent years the impacts of floods have gained importance because of the increasing amount of people, economic activities and ecosystems that are impacted by its adverse effects.

Societies have developed close to water access, forcing its people to search for innovative ways to control and prosper with the more limited resources as the population grows, adding pressure on the water resources. A distinction can be made over the most and least creative sorting them as developed and developing countries.

Societies in the developed countries are well organized, their innovations have turned their back to the river system; most of them are heavily engineered, confined and leveed, safety standards are basically sufficient to prevent floods (Douben, 2006). This society's vulnerability to floods is mainly reflected by possible economic losses as development grows; the cities grow into flood prone areas, leading to increases in economic assets and increasing its vulnerability to floods.

The damages will be extremely high when a flood defence structure fails, especially in urbanized areas, where the most important industries are located. For example; an interruption of electricity will cause all the system to suffer, and the economic damages will be enormous. In the developed countries the losses will be reflected in the economy, there will be little losses of lives.

Developing countries are characterized by high population density, widespread poverty, high rates of unemployment, illiteracy, enormous pressure on rural land, and an economy traditionally dominated by agriculture and dependant on developed countries.

The societies of developing countries are vulnerable to floods because of: *first*, socio-economic conditions in terms of poverty and lack of development; *second* most of the dams in developing countries are not multipurpose (Page, 2000); *third* during floods, planning, design and implementation of the measures are inadequate and ineffective (Vaz, 2000); *fourth* rural areas depend heavily on agriculture and are generally more affected than urban areas; *fifth*, lack of education; *sixth* lack of non-structural measures; and *lastly* there is a lack of adequate human and material resources to tackle the massive disaster-like floods that occurred in the past (Mirza, 2003).

Because of their vulnerability often millions of peoples become homeless and hundreds of thousands are in need for food and medicines. Houses, industries, infrastructure and agriculture will be completely destroyed. In these countries the losses of floods are mainly cultural, people, agriculture and cattle; the reconstruction costs are huge, these societies depend on the international aid (Davidson, 2004).

All societies are vulnerable to floods, under different cases and situations, which make them somewhat unique; understanding the distinctions amongst them, may help to plan ahead and provide policy ideas to improve the quality of life of the people living in them.

A practice in defining vulnerability comes from natural hazards, such as floods: *The extent to which a system is susceptible to floods due to exposure, a perturbation, in conjunction with its ability (or inability) to cope, recover, or basically adapt.*

2.3 Systems Approach

The systems approach aims to identify the interactions of different actors or components within certain defined boundaries. It is considered to be a holistic and reductionist approach of understanding complex processes. Their bases are to understand the processes within the boundaries which transform all inputs into outputs.

2.3.1 The water resource system

Management of water resource systems poses risks to the economic, social and environmental well being of communities, regions, nations and ultimately the world. It is of national and international interest to identify and evaluate economically viable, socially acceptable and environmentally conscious water management strategies to sustain river basins in general, as well as other world water and agricultural resources (GROWE, 2005).

Figure 2.3 illustrates the interrelationships, complexity and reach of management decisions related to water issues, at a family level, community level, regional level and ultimately global level.

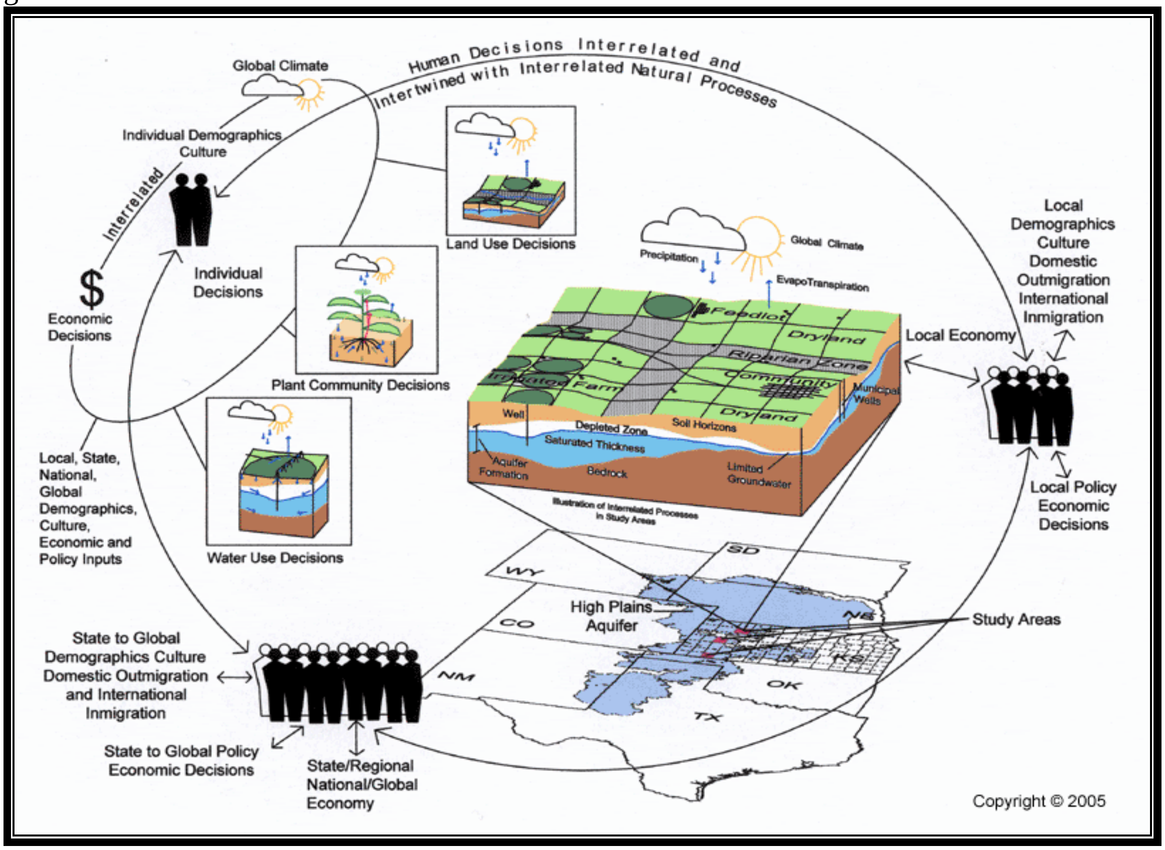

Figure 2.3 Water Resource systems (GROWE, 2005)

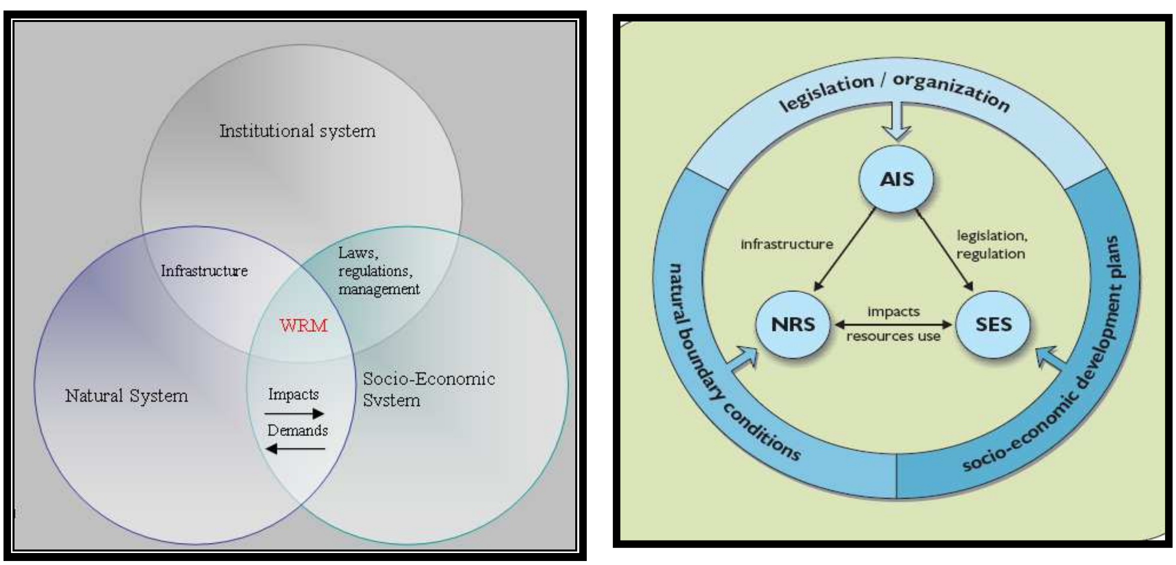

Figure 2.4 a) and b) Water resource system's sub-systems and its interactions (van Beek, 2006)

Van Beek (2005) identifies three interdependent subsystems in the water resources system, Figure 2.4 a) and b) illustrates their interaction, consisting of:

- The natural river subsystem NRS, in which the physical, chemical and biological processes take place
- The socio-economic subsystem SES, which includes the societal (human) activities related to the use of the natural river system
- The administrative and institutional subsystem, AIS of administration, legislation and regulation, where the decision and planning and management processes take place.

Each of the three subsystems is surrounded within its own environment. The NRS is delimited by climate and (geo) physical conditions, the SES is formed by the demographic, social and economic conditions of the surrounding economies and the AIS is formed and bounded by the constitutional, legal and political system.

The NRS insists of the: *natural subsystem* of rivers, lakes and their embankments and subsurface soils and the groundwater aquifer; the *infrastructure subsystem,* like canals, reservoirs, dams, weirs, sluice, wells, pumping plants and waste water treatment plants; the *water* itself, regulated by physical, chemical and biological processes which is influenced, by human factors (www.essp.org). The boundaries of the NRS can be defined clearly.

The SES, the water use and water related human activities. However the economic system generally does not have a physical boundary like the natural system. The factors that determine the socio-economic activities in the study area are now and in the future usually analyzed in the context of the problem being analyzed (van Beek, 2005). The SES can be specified for any scale ranging from the local community and its surrounding environment to the global system (Gallopin et al. 2001).

To characterize the AIS, the responsible institutes at the national, regional and local level have to be identified. At the country level the following aspects can be distinguished: the central government, a coordinating body, regional bodies (provinces, districts, cities, villages) and water supplying and user organizations.

2.3.2 Floods and the water resource system

Floods can be considered as a disruption in a normal functioning of a water resource system. There are three main systems that are affected by floods, with boundaries depending on the scale: the river basin system, the sub-catchment system and the urban system (Figure 2.5).

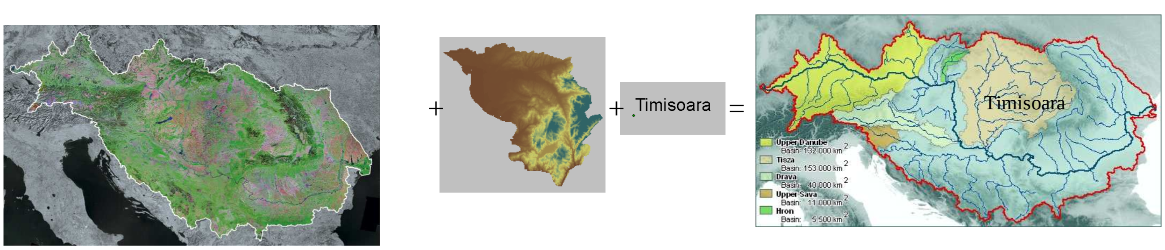

Figure 2.5 Boundaries of a Water Resources System

Floods distress four components of the water resources system, each of them belong to one of the subsystems described before, and their interactions affect the possible short term and long term damages. The components can be assessed by different indicators to understand the vulnerability of the system to floods. The components are: social, economical, environmental and physical.

The social component is part of the SES; the flooding affects the day to day lives of the population that belongs to the system. The socio component relates to the presence of human beings and encompasses issues related to e.g. deficiencies in mobility of human beings associated with gender, age, or disabilities; Floods can produce destruction of houses, disruption in communication ways, or even kill people. Included in this component are the administrative arrangements of the society, consisting of institutions, organizations and authorities at their respective level.

The economic component belongs to the same subsystem as the social component. The economic components are related to income or issues which are inherent to economics that are predisposed to be affected. There are many economic activities which can be affected by flooding events, among them are adversely agriculture, fisheries, navigation, power production, industries, etc. The breakdown of these activities can influence the economic prosperity of a community, region or a country.

The environmental and physical components encompass the NRS. In recent years floods have intensified due to e.g., lack of environmental awareness, creating even more damages to the ecosystems; if the flood water is polluted or if large sedimentation processes occur, ecological systems can be disrupted significantly (Haase, 2003). The environmental component continues to relate to the interrelation between the sector and the environment and the vulnerability associated with this interaction (Villagran, 2006). Activities such as afforestation, deforestation, urbanization and industrialization have enhanced environmental degradation, creating effects like climate variability and sea level rise, increasing the potential occurrence of floods.

The physical component is the other part of the NRS. It comprises geo-morphological and climatic characteristics of the system, and different infrastructures, like channels, reservoirs, dams, weirs, levees which have shaped its physical conditions. The physical component relates to the predisposition of infrastructure to be damaged by a flooding event. More than being affected by floods, this component may reduce its adverse consequences.

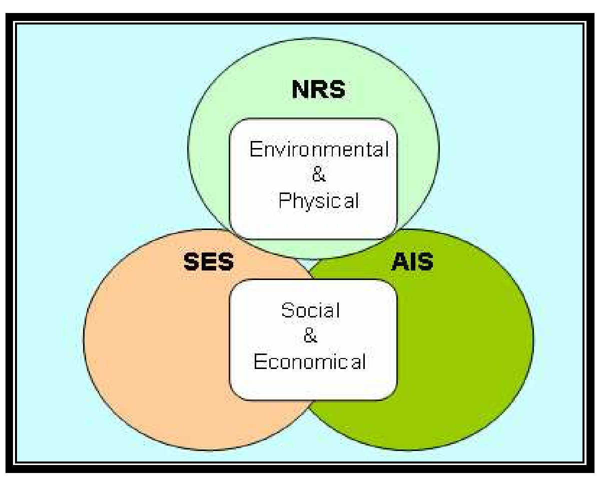

Figure 2.6 Link between subsystems and components

The relationship between the components affected by floods and the subsystems of the WRS are shown in the Figure 2.6. The social and economical components comprise the socio-economic and the administrative and institutional subsystem.

2.4 Flood Vulnerability Factors

Water resource systems are vulnerable to floods due to three main factors; exposure, susceptibility and resilience. The vulnerability of any system (at any scale) is reflective of (or a function of) the exposure and susceptibility of that system to hazardous conditions and the ability, capacity or resilience of the system to cope, adapt and/or recover from the effects of those conditions (Smit & Wandel, 2006).

Understanding each concept and considering certain indicators may help to characterize the vulnerability of different systems, by which certain actions can be identified to decrease it.

2.4.1 Exposure

Exposure can be understood as the values that are present at the location where floods can occur. These values can be goods, infrastructure, cultural heritage, agricultural fields or mostly people. Exposure is the extent to which property is located in flood risk areas, determining also the extent that occupants are exposed to (UNDP/BCPR, 2003). Exposure is generally described as patterns and processes which estimate its intensity and duration.

The indicators for this component can be separated in two categories; the first one covers the exposure of different elements at risk and the second one give details on the general characteristics of the flood.

The first category of indicators supplies information about the location, elevation, population density, land-use, their proximity to the river, their closeness to inundation areas. The second category provides information about return periods (frequency of occurrence) of different types of floods in the floodplain and similar to. These indicators tell us of the frequency of floods in floodplains, their duration and magnitude.

The return periods refer to the probability of a certain extreme event to occur. However, some regions experience floods without being an extreme event, generally depending on the type of flood. Five different types of floods can be identified: Stagnant and urban floods, flash floods (which requires a different approach of thinking to reduce vulnerability), river floods, coastal floods and lake floods, which influence the second category of indicators.

Urban floods occur mostly as a result of the impermeability of buildings and roads. In time of heavy precipitation, the large amount of rain water cannot be absorbed into the ground and leads to urban runoff. These types of floods depend on the topography and soil conditions (Douben, 2006). Flash floods are caused by short periods of intense rain, often occurring over a very small area and typically in conjunction with thunderstorms. They can also occur by the sudden failure of a dam or dikes. River floods are the result of abundant rainfall, usually continuing for a period of days or weeks over a large area. The ground becomes saturated and cannot cope with any more water so that the rain flows directly into the rivers. Coastal floods can occur along coastal zones. Coastal and estuarine floods occur when the sea level rises beyond its normal fluctuations or/and in conjunction with high river flows. Land subsidence and progressive sea level rise are also factors that increase the height of the sea level beyond its normal fluctuations. Low-lying island states and coastal areas are vulnerable to this type of flooding. Lake floods occur when exceptional periods of precipitation or long lasting inflow from streams increase the water level of lakes. These types of flood, with different flow regimes and interventions strategies can create different kinds of vulnerability in river basins, depending on the local situation.

The second category includes indicators like duration, flow velocity, extent of flooding, sedimentation load and inundation depth. They indicate the severity of inundation as well as its distribution in space and time.

Exposure indicators provide specific facts about hazardous threats to the diverse elements at risk (Messner & Meyer, 2005).

Exposure is defined as the predisposition of a system to be disrupted by a flooding event due to its location in the same area of influence.

The disruptions in the systems can be interpreted as damages and losses. They are categorized as direct, resulting from the physical contact of flood water with damageable property, or indirect, resulting from the interruption or disruption of social and economic activities. Damages and losses from floods can also be classified as tangible, for which a monetary value can be easily assigned, or intangible, for which a monetary value cannot be easily assigned.

Examples of damage in these four categories are (Hekal, 2000):

- Direct, tangible: loss of food and appliances, infrastructure collapse;
- Direct, intangible: loss of photographs and negatives, heirlooms, loss of life;
- Indirect, tangible: days absent from work and changed spending patterns;
- Indirect, intangible: quality of life lessened due to stress, delays in formal education.

2.4.2 Susceptibility

The concept of susceptibility, or sensitivity, has developed through the years. For example Penning-Rowsell and Chatterton defined susceptibility in 1977 as the relative damageability of property and materials during floods or other hazardous events. The IPCC (2001) argued susceptibility as the degree to which a system is affected, either adversely or beneficially, by climate related stimuli. At this moment the definition is still argued and is creating confusions between social and natural scientists (Gallopin, 2006).

For Di Mauro (2006), susceptibility combines the likelihood of a hazardous event, the differential exposure and the potential sensitivity of a target. I.e. the degree to which a target could be potentially damaged or affected by a given hazard and the existing capacity of this target that could potentially reduce this level of damages (e.g. existing measures of prevention, mitigation, etc.).

Susceptibility relates to system characteristics, including the social context of flood damage formation. Especially the awareness and preparedness of affected people regarding the risk they live with (before the flood), the institutions that are involved in mitigating and reducing the effects of the hazards and the existence of possible measures, like evacuation routes to be used during the floods.

In this study susceptibility will be defined as *the elements exposed within the system, which* *influence the probabilities of being harmed at times of hazardous floods.*

Susceptibility indicators evaluate the sensitivity of an element at risk during a flood event. Three categories of indicators can be distinguished; social, infrastructure and institutional. Figure 2.7 shows some examples of susceptibility indicators, according to their category.

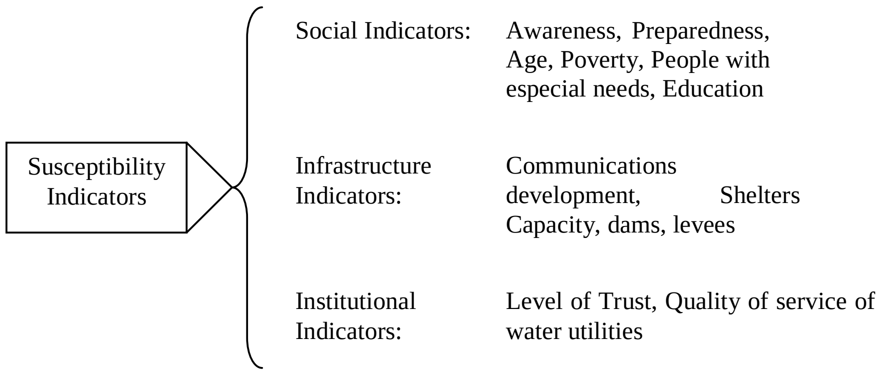

Figure 2.7 Susceptibility Indicators by category

Awareness and preparedness indicators for individuals and communities reflect the attentiveness of threatened people and communities for dealing with hazardous events. This includes, for example the number of households protected against physical flood impacts by means of technical measures, like dikes or dams, the number of people with insurance against flood damages, etc. These measures can only be taken before flood events occur. Other indicators, like the number of persons ready for action in disaster management, as well as the quality of flood protection measures and disaster management organizations or institutions, can be measured only during flood events, refer to Figure 2.8 (Messner & Meyer, 2005).

The ability of individuals and social systems to handle the impact of floods is often correlated to general socio-economic indicators. These indicators embrace general information on age, poverty, gender, race, education, social relations, institutional development, and population with special needs (children, elderly or disabled) (e.g., Blaikie et al. 1994, Watts/Bohle 1993, and Smith 2001). The location and condition of evacuation routes can serve as an important indicator of the susceptibility to floods of a certain area.

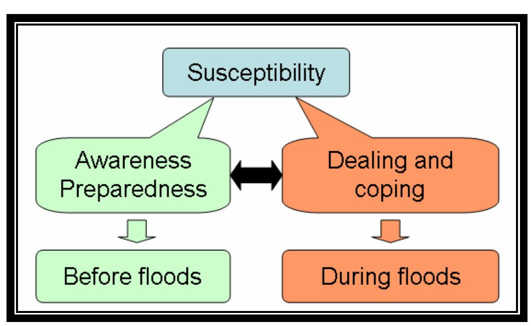

Figure 2.8 Susceptibility framework

After having identified and quantified the most important indicators for exposure and susceptibility in a narrow and a broader sense, it is the task of vulnerability analysis to identify the most important relationships between expected flood damages and the exposure and susceptibility characteristics of the affected social, economical, environmental and physical components, within the system. The system can be defined as a river basin, a sub-catchment or an urban area (Messner & Meyer, 2005). Each of these systems is more or less exposed to flood events and more or less susceptible to them.

Vulnerability can be described by the physical, social, economical and environmental characteristics of a system that explain its potential to be harmed in cases of floods. It can be expressed in terms of functional relationships between expected damages regarding all systems and the susceptibility and exposure characteristics of the affected system, referring to all the different types of possible flood hazards.

2.4.3 Resilience

During the 1990s, the results of studies on complex systems influenced the concept of vulnerability, stressing the relation between vulnerability and resilience of a system and providing new conceptual tools for vulnerability studies (Galderisi et al. 2006).

Originally, resilience was defined by Holling in 1973 as "a measure of persistence of systems and their ability to absorb change and disturbance and still maintain the same relationships between populations and state variables". A definition more in tone with social science, but still remarkable useful for this study. Walker (2004) argued that resilience is "the capacity of a system to absorb disturbance and being reorganized while undergoing change, so as to still retain essentially the same function, structure, identity and feedbacks".

Resilience is the capacity of a system, community or society, potentially exposed to hazards to adapt to any change, by resisting or modifying itself, in order to maintain or to achieve an acceptable level of functioning and structure (Galderisi et al, 2006). Pelling (2003) defines resilience as the capacity to adapt, to adjust to threats and mitigate or avoid harm.

Resilience to flood damages can be considered only in places with past events, since the main focus is on the experiences encountered during and after the floods. Floods are a physical disruption which threats social, economical and/or environmental systems. Flood resilience can be expressed as the ability of a system or community to defy or alter itself so that the harm of floods is mitigated or minimized.

The actual amount of flood damage of a specific flood event depends on the vulnerability of the affected socio-economic and ecological system; more broadly defined, on their potential to be harmed by a hazardous event (Cutter 1996).

Resilience indicators are composed by coping capacities (existing means to deal with the state of emergency and to balance short-term impacts, like organization capacities, emergency resources, etc.) and by recovery capacities (existing means to return to the equilibrium of the system and to balance long-term impacts, once the state of emergency is over). Resilience is therefore analyzed through a political, administrative, and social organizational evaluation (Di Mauro, 2006).

During floods, coping capacity indicators must include technical systems, because the social impact of floods significantly relates to the susceptibility of basic infrastructure and lifelines which support the population's supply of basic needs, like water, energy or food. Technical indicators specify flood-specific weaknesses and the ability of socio-technical systems to withstand the consequences of flood events like drinking water supply, waste water treatment, communication systems and energy supply, see figure 2.9 and 2.10 (Gasser and Snitofsky, 1990; Platt, 1990).

After the flooding event, recovery capacity indicators refer to the impact of floods on economic, social, environmental and physical components.

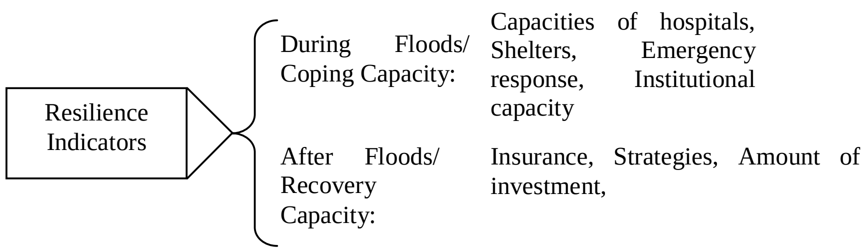

Figure 2.9 Resilience Indicators

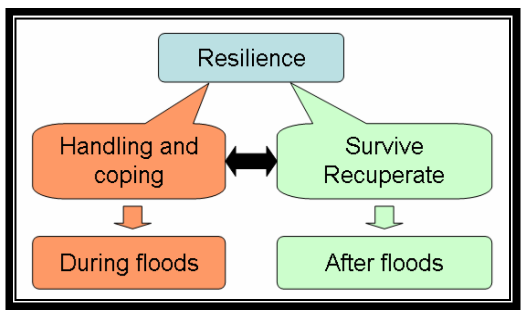

Figure 2.10 Resilience framework

In this study *resilience is defined as the capacity of a system to endure any perturbation, like floods, maintaining significant levels of efficiency in its social, economical, environmental and physical components.*

2.5 Summary

Vulnerability is a term with many meanings, depending on the specific topic emphasized social vulnerability, biophysical vulnerability, economic vulnerability and environmental vulnerability.

Every vulnerability factor (exposure, susceptibility and resilience) represents a set of indicators, which can help to better understand the weaknesses of a region to floods.

This framework figures 2.11 and 2.12 aims to make vulnerability analysis consistent; provides the broad classes of factors and linkages that comprise a coupled system's vulnerability to hazards (Turner II et al. 2003).

The framework emphasizes that place-based vulnerability analysis needs to consider multiple scales (i.e., processes and hazards at local, regional, and global scales), and that it needs to analyze the coupled human-environment system in an integrated rather than reductionist manner (Füssel & Klein, 2004). The same framework can be applied for all the sub-systems as social, economical, physical and environmental interaction with the factors of vulnerability.

Figure 2.12 presents a more detailed picture of the factors of vulnerability and shows the relationship between the three factors, giving an indication of the changes needed to reduce vulnerability. It is seen that changes in the resilience can affect the susceptibility of a system. For example the susceptibility will affect the response capability, forcing adjustments in the resilience for future flood events which in itself modifies the susceptibility of the system.

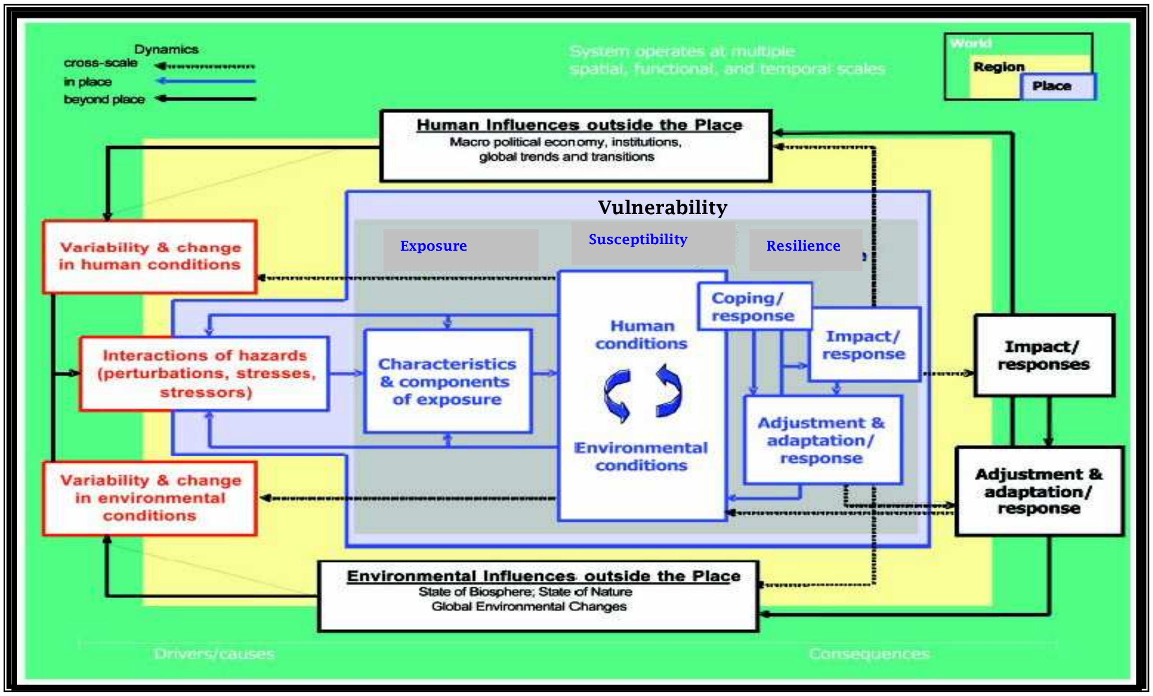

Figure 2.11 SUST vulnerability framework. Full framework (Turner II et al. 2003)

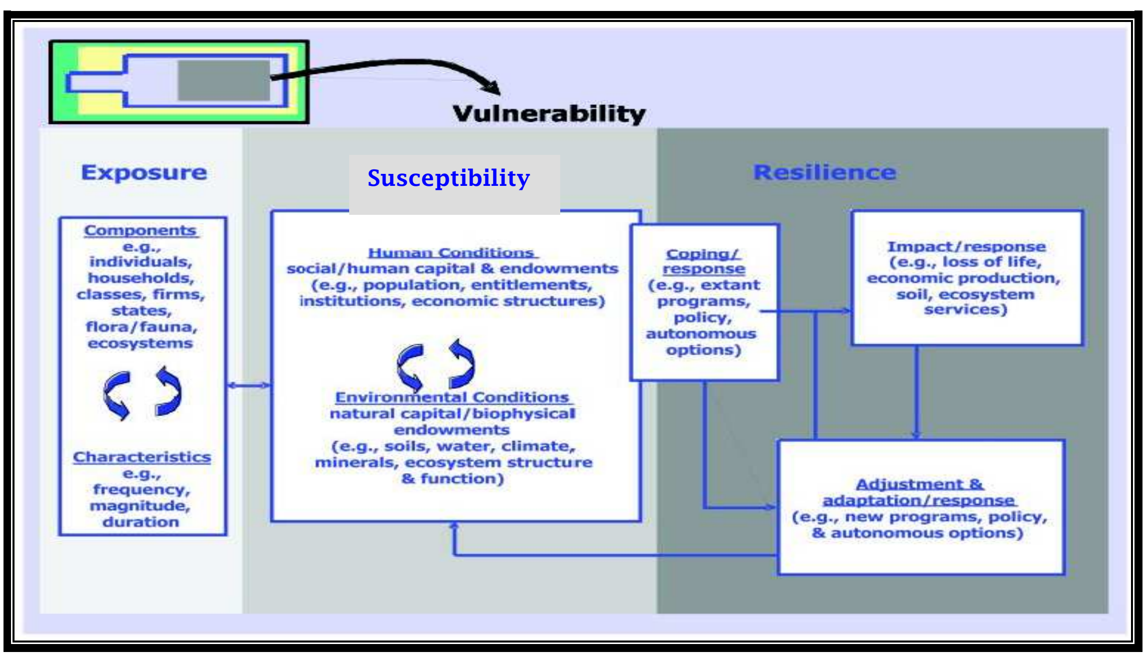

Figure 2.12: SUST vulnerability framework detailed framework (Turner II et al. 2003)

This framework shows human conditions only in the susceptibility. However, it has also important determinants of the resilience of human-environment systems, as is reflected in the concepts of coping capacity.

Therefore, any flood vulnerability analysis requires information regarding these factors, which can be specified in terms of exposure indicators, susceptibility indicators and resilience indicators.

Finally, the vulnerability of a system to flood events can be expressed with the following general equation, also found in Figure 2.13

$$Vulnerability = Exposure + Susceptibility - Resilience$$

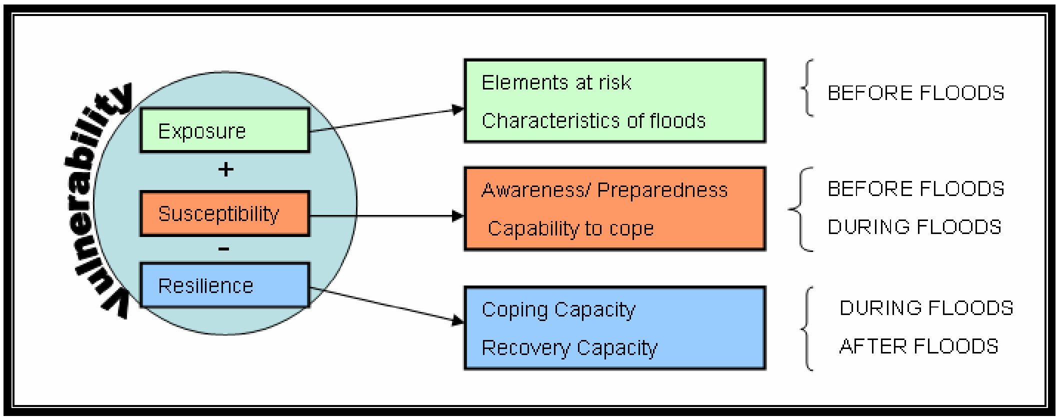

Figure 2.13 Factors of Vulnerability

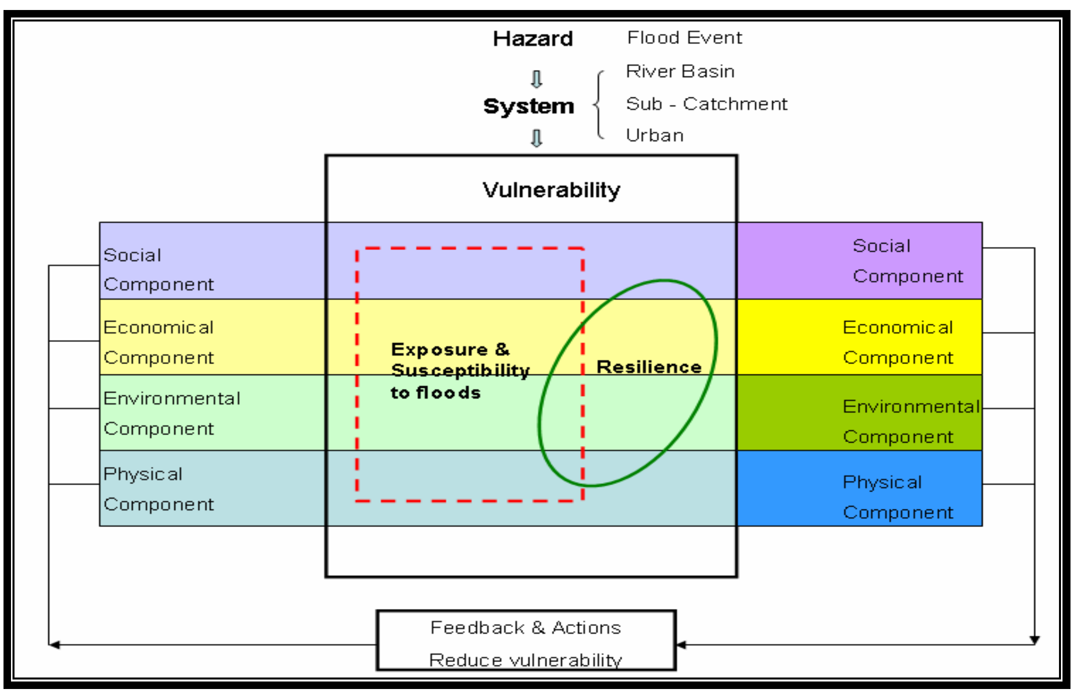

Figure 2.14 System vulnerability

All systems are in hazard, but their vulnerability reflects the possible damages which can be expected in the case of an event. All the components can be affected by floods, after the events, new components must arise and give feedback to reduce the vulnerability towards future flood events, see Figure 2.14.

Vulnerability is a relative concept; it depends on the differential access of the people, buildings and infrastructure to the social, economic, environmental and institutional sub-systems. Vulnerability is different for each hazard, is different for each location, different for every person or family.

A system at risk is more vulnerable; when it is more exposed to a hazard and the more it is susceptible to its forces and impacts. However, it will be less vulnerable the more resilient it is.

From the vulnerability equation, high exposure and high susceptibility lead to increases in vulnerability. On the other hand, high resilience levels decreases vulnerability.

Chapter 3 Vulnerability Indicators

An indicator, or set of indicators, can be defined as an inherent characteristic which quantitatively estimates the condition of a system; they usually focus on small, manageable, tangible and telling piece of a system that can give people a sense of the bigger picture.

While indicators play an increasingly important policy role, they capture only synoptic aspects of a system at the scale at which they are applied.

Vulnerability indicators are commonly used in vulnerability assessment. The first step in an indicator-based vulnerability assessment is to select indicators. The standard practice is to assemble a list of indicators using criteria such as: suitability, following a conceptual framework or definitions, availability of data, and sensitivity to formats.

Vulnerability needs to be reflected through indicators. The indicators should allow decision and policy makers to recognize and set goals and provide guidance for strategies to reduce vulnerability. The vulnerability indicators should provide additional information to set more precise and quantitative targets for vulnerability reduction. System indicators facilitate the analysis of the relative state of the overall system and they should reflect the socio-economic, environmental and physical condition of the geographic region.

Procedures for indicator selection follow two general approaches, one based on a theoretical understanding of relationships and one based on statistical relationships. Conceptual understanding does, however, play a role in both. The first approach represents a deductive research approach and the second an inductive research approach.

The deductive approach to selecting indicators involves proposing relationships derived from theory or conceptual framework and selecting indicators on the basis of these relationships. In the deductive research approach, verification involves assessment of the goodness of fit between theoretical predictions and empirical evidence (Adger et al., 2004).

Identifying the shortfalls and potential for improving the indicator selection and such assessments is crucial. The outcome of the test may identify weaknesses or scope for improvement in any one of the steps in indicator selection, including definitions of vulnerability, theoretical approaches and assumptions made, conceptualization, weighting, and data collection and analysis.

There are two aspects to dynamism critical to indicator studies: first, that local capacity and command over resources, and thus vulnerability, are shaped by processes and thus vary in time and space; and second, that individuals, households, social groups and communities may be faced by multiple pressures at the same time, such as economic change or political conflict (de Waal 1989).

Inductive research often uses empirical generalizations, filled with empirical content and statements of empirical regularities. Theory consists of generalizations derived by induction from data: in other words, the finding of patterns in data that can be generalized.

A large variety of indicators are widely used today (Adriaanse, 1993; DFO, till 2006, CRED, till 2006, World Bank (WB), 1994, 1997), for example the detailed World Bank Africa Database 2005, consisting of almost 1200 indicators (WB, 2005). Many studies about vulnerability indexes stress on the issue of indicators; below is a description of the indicators used for different vulnerability indices.

3.1 Environmental Vulnerability Indicators

The *Environmental Vulnerability Index (EVI)* was developed by the South Pacific Applied Geosciences Commission (SOPAC); the purpose of the EVI is to represent the vulnerability of small island developing states (SIDS) to a range of natural and anthropogenic hazards, based on 50 indicators of vulnerability; these indicators represent risk, resilience and environmental integrity or degradation.

The *EVI* is defining its indicators as "smart indicators"; the authors (Pratt et al., 2004) use 50 indicators "which aim to capture a large number of elements in a complex interactive system while simultaneously showing how the value obtained relates to some ideal condition" (UNEP, 2004). The indicators selected for use in the EVI are based on the best scientific understanding currently available and have been developed in consultation with international experts, country experts, other agencies and interest groups. The indicators are classified into 5 categories (Kaly et al., 1999):

- M = Meteorological;
- G = Geological;
- B = Biological;
- C = Country Characteristics; and
- A = Anthropogenic.

The 50 indicators selected to measure environmental vulnerability are classified into a range of sub-indices including: hazards, resistance, damage, climate change, biodiversity, water, agriculture and fisheries, human health aspects, desertification, and exposure to natural disasters. These indicators can be grouped into three sub-indices namely:

- REI = Exposure to natural or human risks / hazards
- EDI= Environmental Degradation Index. This index measures the present status of the 'health' of the environment. It is based on the assumption that past impacts affect the ability of the environment to tolerate new impacts.
- IRI = Intrinsic Resilience Index

Environmental indicators are of a heterogeneous nature, that is they include variables for which the responses are numerical, qualitative and on different scales (linear, non-linear, or with different ranges). Several different indicators are used resulting in a wide variety of different unit measurements.

The indicators are chosen based on expert judgment; they are heterogeneous and their resulting values are rated on a scale of 1 to 7, with 7 representing high vulnerability, an overall average of all is calculated to generate a country's EVI. The index has been applied to a limited number of SIDS to date.

3.2 Social Vulnerability Indicators

The indicators for *Social Vulnerability to Climate Change for Africa (SVCC)* were chosen as a determinant of vulnerability. The indicators or proxy indicators have been chosen within the constraints of data availability. The majority of indicators used in the index are derived from the World Bank which compiles approximately 800 World Development Indicators from data derived, either directly or indirectly, from official statistical systems organized and financed by national governments.

The process of developing indicators involves uncertainty at several levels. Adger & Vincent (2005) present a *social vulnerability index (SVI)* to illustrate the issues of uncertainty in adaptive capacity. Table 3-1 shows the summary of variables, indicators and data sources used in the SVI (Vincent, 2004).

The SVI is an aggregate index of human vulnerability to climate change-induced changes in water availability that is based on the weighted average of five composite sub-indices, as shown in Figure 3.1:

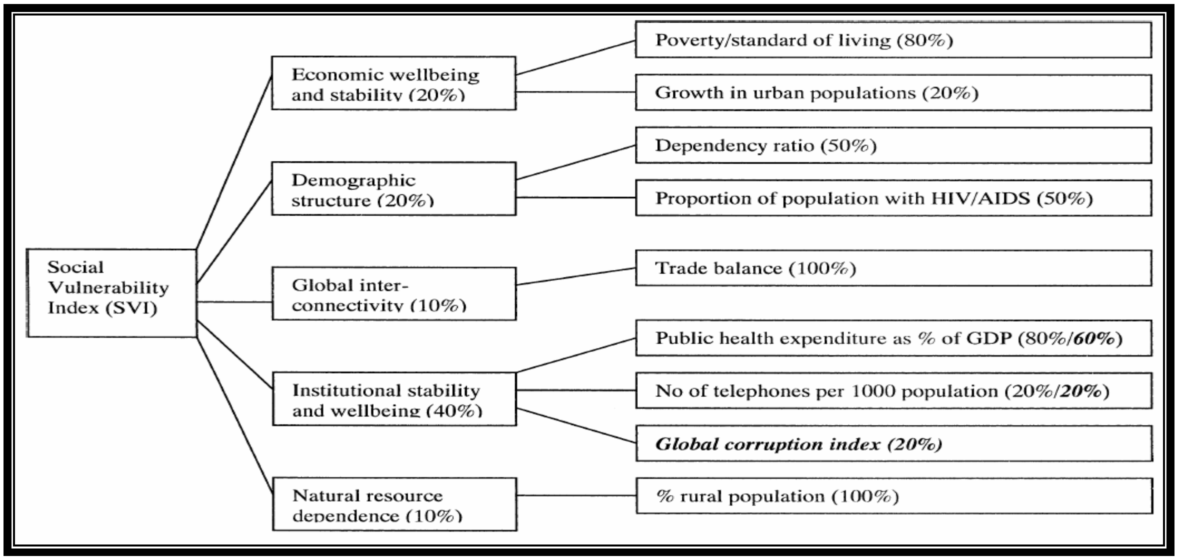

Figure 3.1 Structure of the aggregate Social Vulnerability Index, composite sub-indices, and components indicators (Adger & Vincent, 2005)

Table 3-1 Summary of variables, indicators and data sources used in the SVCC (Vincent, 2004)

Determinant of vulnerability/sub-index	Component indicators	What each indicator represents:	Hypothesised functional relationship between indicator and vulnerability	Data source
Economic well-being and stability	Standard of living/poverty	population below income poverty line, 2000. The % of the population living below the specified poverty line.	The greater the population below the income poverty line, the greater the vulnerability.	World Bank (2002)
	Change in % urban population	change in % urban population between 1975 and 2000, based on midyear population of areas defined as urban in a country.	The greater the change in urban population the greater the vulnerability.	UN (2002)
Demographic structure	Dependent population	population under 15 and over 65 as % of total, refers to de facto population, i.e. all people actually present in a given area at a given time.	The higher the dependent population, the greater the vulnerability.	UN (2001)
	Proportion of the working population with HIV/AIDS	Adults aged 15-49 living with HIV/AIDS as a percentage of the population aged between 15-49 in 2001.	The higher the proportion of working population with HIV/AIDS, the higher the vulnerability.	UNAIDS and WHO (2002)
Institutional stability and strength of public infrastructure	Health expenditure as a proportion of GDP	public health expenditure as % of GDP in 1998: recurrent and capital spending from central and local government budgets (including donations from international agencies and NGOs) and social (or compulsory) health insurance funds.	The higher the health expenditure as a proportion of GDP, the lower the vulnerability (inverse).	World Bank (2002)
	Telephones	number of mainland telephone lines per thousand population in 2000.	The higher the number of telephones, the lower the vulnerability (inverse).	ITU (2002)
	Corruption	composite index using data from 15 sources from 9 institutions and perceptions of well informed people with regard to corruption, in 2002.	The lower the score (i.e. the higher the corruption), the higher the vulnerability (inverse).	Transparency International (Hodess, 2003)
Global inter-connectivity	Trade balance	Net trade in goods and services (BoP, current US$, 1999). Derived by offsetting imports of goods and services against exports of goods and services. Exports and imports of goods and services comprise all transactions involving a change of ownership of goods and services between residents of one country and the rest of the world.	The more negative the trade balance, the higher the degree of vulnerability (inverse).	World Bank (2001)
Natural resource dependence	Rural population	% of rural population, defined as the difference between the total population and urban population in 1999.	The higher the rural population, the greater the vulnerability.	World Bank (2002)

The SVI is calculated through a simple equation (Villagran, 2006):

$$SVI = 0.2\ Iewb + 0.2\ Ids + 0.4\ Iis + 0.1\ Igi + 0.1\ Inrd$$

In this equation:

Iewb is the indicator associated to economic well being;
Ids is the indicator related to demographic structure;

Iis is the indicator associated to institutional stability;
Igi is the indicator related to global interconnectivity;
Inrd is the indicator associated to natural resource dependence.

The weights have been assigned to each indicator via suggestions emanating from an expert group. Most of the data has been acquired from international sources such as the World Bank, UN agencies, ITU, and Transparency International. Results for 50 countries in Africa are presented in Figure 3.2:

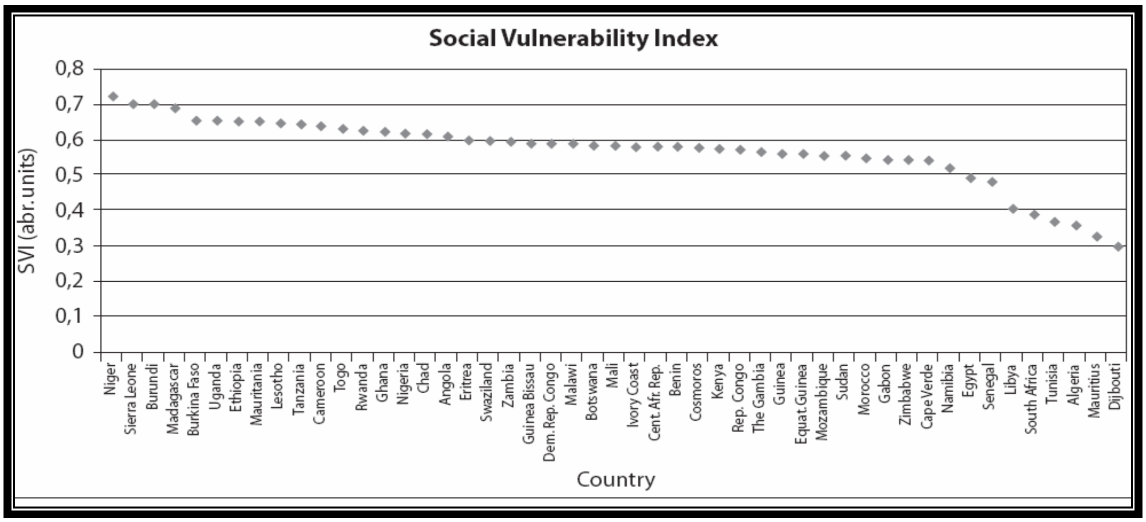

Figure 3.2 Social Vulnerability Index for Africa as proposed by Vincent (2004)

The SVI essentially comprises predictive indicators of vulnerability based on existing insights.

3.3 The Composite Vulnerability Index for Small Island States (CVI_{SIS})

A group headed by Dr. Briguglio (2003; 2004) has been developing a composite vulnerability index in relation to the small island developing states. The aim of the index is to point out the intrinsic vulnerability of such states in comparison to large countries which possess several advantages associated with their large scale.

This index is composed of four indicators:

➢ A two-level indicator which expresses whether the country is considered a small or large state, with numerical values 1 or 0 respectively;
➢ The vulnerability or susceptibility of the country in relation to natural disasters;
➢ The economic exposure of the country, which has been assessed via the export dependence, which in turn is assessed in terms of the average exports of goods and non-factor services as a percentage of the GDP; and
➢ The lack of diversification, which has been characterized in terms of the UNCTAD diversification index.

Through the use of weighted least squares routines, the index is represented mathematically through the following equation:

$$CVI_{SIS} = 1.4142 + 0.0096\ Vul \times D + 0.0322\ Ex\text{-}Dep + 3.3442\ Div$$

In this equation:

Vul represents the susceptibility of the country to natural disasters;
D is a two level indicator for the respective country regarding its status as a small state;
Ex-Dep represents the economic exposure of the country;
Div stands for the lack of diversification in a particular country.

The selection of weights has been carried out using regression techniques and eliminating extreme values that might shift the index in undesired directions. Of the 111 countries (both small and large) over which the index has been assessed, 11 have been eliminated on this issue of extremes values.

The results from this method are presented in Figure 3.3 which displays the CVI_{SIS} as a function of the countries labeled on the horizontal scale.

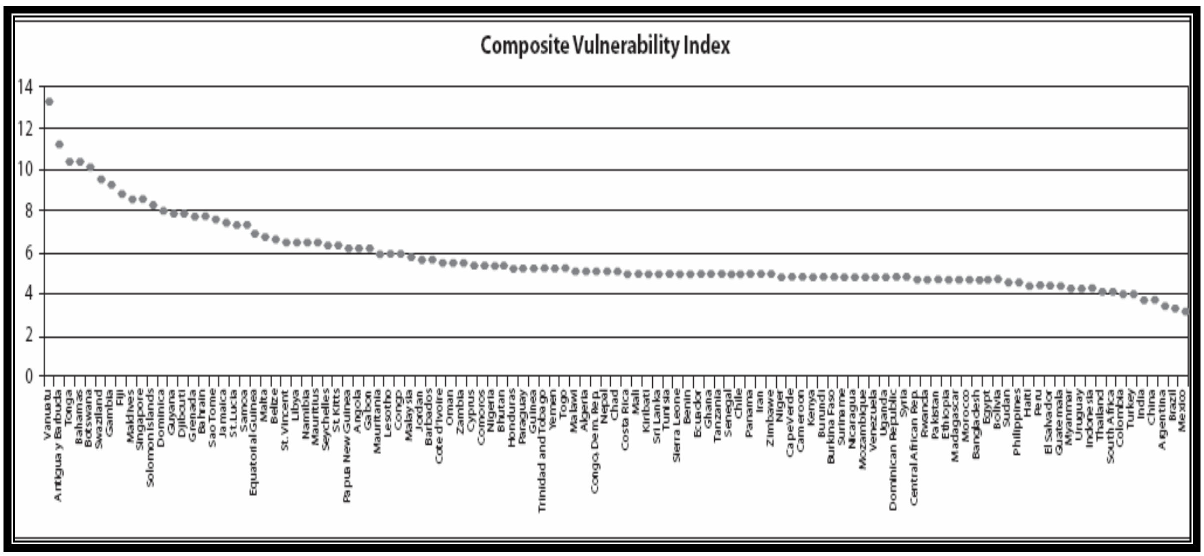

Figure 3.3 Composite Vulnerability Index for countries of the world according to the model developed island developing states (Villagran, 2006)

The results can be summarized as follows:

➢ The proposed method does display that small states are in general more vulnerable than large states, but this could be a direct outcome of the proposed method.

➢ The degree of vulnerability is independent of the GDP per capita. Many countries with high GDP per capita are indexed with a higher vulnerability than countries with a low GDP per capita.

3.4 Global Risk and Vulnerability Indicators

The United Nations Environment Programme (UNEP) Division of Early Warning and Assessment (DEWA) and GRID-Geneva are developing a Disasters Risk Index under their Global Risk and Vulnerability Trends per Year (GRAVITY) project. This index will be used for systematic inter-country comparisons, and builds on GRID-Geneva's Project for Risk

Evaluation, Vulnerability, Information and Early Warning (PREVIEW).

The GRAVITY project examines the major hazard types:

- cyclones,
- droughts,
- floods,
- windstorms,
- volcanoes and
- earthquakes.

A major element of the project is to develop indices of human exposure to these hazards, using grid data. The conceptual framework used by UNEP is represented by the following formula:

Risk = frequency x population x vulnerability

Where:

Risk = number of expected human losses per exposed population per time period;
Frequency = expected (or average) number of events per time period;
Population = number of people exposed to hazard;
Vulnerability = expected percentage of population loss due to socio-political-economic context.

Global Risk and Vulnerability Index Trends per Year (GRAVITY), describe the concepts, data and methods applied to achieve the Disaster Risk Index (DRI). Categories of potential vulnerability indicators were defined as (Peduzzi et al., 2002):

- Economy;
- Dependency and quality of the environment;
- Demography;
- Health and sanitation;
- Politic;
- Infrastructure;
- Early warning and capacity of response;
- Education;
- Development.

The socio-economical parameters were chosen to reflect the level of quality of different constituents of a civil society such as illustrated in Table 3-2.

Vulnerability indicator data used in GRAVITY are (Peduzzi et al., 2001):

- An urbanization indicator was selected in order to include the fact that urban populations may be more or less exposed to a hazard than other populations, depending on the hazard. Urbanization is considered an indicator of affectable population.
- An indicator of corruption was included in the selection, for it might contain information about presence of dangerous situations, e.g. houses built in hazardous areas. Hence, corruption is an indicator of vulnerability.
- The Human Development Index was selected because it seems rather natural to assume that there is a strong correlation between a country's development level and its mitigation capacities. Note that nor life expectancy neither literacy

rate were selected in the set of vulnerability factors. The reason is that life expectancy and literacy rate were strongly correlated, and that HDI provides even more information by itself.

- Population density is an indicator of affectable population. Exposure is important for a given hazard if population is concentrated. This variable is calculated as follows:

$$P_D = \frac{Total\_population}{Surface}$$

Where: P_D – population density [#];
Total_population – the number of the total population;
Surface – the area [km^2].
$P_D = [\#/km^2]$

- It is assumed that GDP/capita is an indicator of mitigation capacities. This variable is obtained through the following formula:

$$GDP/Cap = \frac{GDP_T}{Totalpopulation}$$

Where: GDP/Cap - Gross Domestic Product per Capita;
GDP_T – Total Gross Domestic Product [$];
Total Population - # of total population which is living in the area [#];
GDP/Cap = $[\$/\#]$

- Urban growth over last 3 years. The assumption is made that fast urban growth may result in poor quality housing, thus making people more vulnerable. However, this assumption may very well be only valid in particular regions. Yearly urban growth was not used because of its high variability. Considering growth over a longer time span is certainly more likely to represent a risky housing situation. In that context, *urbang3* is considered as an indicator of vulnerability. This variable was calculated as follows:

$$urbang3 = \frac{urban_t - urban_{t-3}}{urban_{t-3}}$$

Where: urbang3 – % of urban growth over the last 3 years;
$urban_t$ – current urban area [ha];
$urban_{t-3}$ – urban area 3 years ago[ha];
urbang3 = [-]

- Population growth over last 3 years (*popg3*). The assumption is made that fast population growth may create pressure on housing capacities, and result in risky situations increasing vulnerability.

$$popg3 = \frac{pop_t - pop_{t-3}}{pop_{t-3}}$$

Where: popg3 – population growth over last 3 years;
pop_t – current population [#];
pop_{t-3} – population 3 years ago [#];
popg3 = [-].

Note that this process suppresses 3 years of observations. Since *urban* is observable for years 1960-2000, *urbang3,* and *popg3* is only observable for years 1963-2000.

This section presents the statistical approach of vulnerability modelling as methodology. A regression model is defined for each disaster type. For every disaster type, n observations are available.

Considering a given disaster type: let Y the vector of n observed damages, each element of vector Y corresponds to a different disaster that happened in a particular country c at a particular time t

$$Y = [victimsict]i=1,...,n$$

and let X the matrix of vulnerability factors corresponding to the country and time (when possible) of yict,

$$X=[x1i ; x2i ; ... ; x7i]i=1,...,n$$

Where:

x1=popdct
x2=corupc2000
x3=hdic1998
x4=gdpcapct
x5=urbanct
x6=urbang3ct
x7=popg3ct

The following linear regression model is proposed:

$$Y=\beta\cdot X +\varepsilon$$

Where β is the vector of parameters:

$$\beta'=[\beta1 ; \beta2; ... ; \beta7]$$

and ε is a random perturbation satisfying the usual hypothesis of classical linear regression models.

Table 3-2 Vulnerability Indicators for GRAVITY (UNDP/BCPR, 2003)

Categories of vulnerability	Indicators	Drought	Flood Earthqu. Cyclones	Source[3]
Economic	Gross Domestic Product per inhabitant at purchasing power parity	X	X	WB
	Human Poverty Index (HPI)	X		UNDP
	Total dept service (% of the exports of goods and services),		X	WB
	Inflation, food prices (annual %),		X	WB
	Unemployment, total (% of total labour force)		X	ILO
Type of economical activities	%age of arable land		X	FAO
	%age of urban population		X	UNPOP
	%age of agriculture's dependency for GDP	X		WB
	%age of labour force in agricultural sector	X		FAO
Dependency and quality of the environment.	Forests and woodland (in %age of land area),		X	FAO
	%age of irrigated land		X	FAO
	Human Induced Soil Degradation (GLASOD)	X		UNEP
Demography	Population growth,		X	UNPOP
	Urban growth,		X	GRID[4]
	Population density,		X	GRID[5]
	Age dependency ratio,		X	WB
Health and sanitation	Average calorie supply per capita,		X	FAO
	%age of people with access to adequate sanitation,		X	WHO / UNICEF
	%age of people with access to safe water (total, urban, rural)	X	X	WHO / UNICEF
	Number of physicians (per 1000 inh.),		X	WB
	Number Hospital Beds		X	WB
	Life Expectancy at birth for both Sexes		X	UNPOP
	Under five years old mortality rate	X		UNPOP
Politic	Transparency's CPI (index of corruption)		X	TI
Early warning capacity	Number of Radios (per 1000 inh.)		X	WB
Education	Illiteracy Rate,		X	WB
	School enrolment,		X	UNESCO
	Secondary (% gross),		X	UNESCO
	Labour force with primary, secondary or tertiary education		X	WB
Development	Human Development Index (HDI)	X	X	UNDP

3.5 Climate Vulnerability Indicators

Climate Vulnerability Index (CVI) Climate change indicators help us to determine whether our climate is changing or not. These indicators are based on features of climate, like temperature and precipitation. Others indicate whether or not a changing climate is affecting the environment and people's lives.

The Climate Vulnerability Index is based on a framework which incorporates a wide range of issues. It is a holistic methodology for water resources evaluation in keeping with the sustainable livelihoods approach used by many donor organizations to evaluate development progress. The scores of the index range on a scale of 0 to 100, with the total being generated as a weighted average of six major components. Each of the components is also scored from 0 to 100. The six major categories or components are shown in Table 3-3:

Table 3-3 Major Components of the CVI (Sullivan & Meigh, 2003)

CVI component	Sub-components / variables
Resource (R)	• assessment of surface water and groundwater availability • evaluation of water storage capacity, and reliability of resources • assessment of water quality, and dependence on imported/desalinated water
Access (A)	• access to clean water and sanitation • access to irrigation coverage adjusted by climate characteristics
Capacity (C)	• expenditure on consumer durables, or income • GDP as a proportion of GNP, and water investment as a % of total fixed capital investment • educational level of the population, and the under-five mortality rate • existence of disaster warning systems, and strength of municipal institutions • percentage of people living in informal housing • access to a place of safety in the event of flooding or other disasters
Use (U)	• domestic water consumption rate related to national or other standards • agricultural and industrial water use related to their respective contributions to GDP
Environment (E)	• livestock and human population density • loss of habitats • flood frequency
Geospatial (G)	• extent of land at risk from sea level rise, tidal waves, or land slips • degree of isolation from other water resources and/or food sources • deforestation, desertification and/or soil erosion rates • degree of land conversion from natural vegetation • deglaciation and risk of glacial lake outbursts

In order to assess the CVI in practice, geographical types were identified; each of these has particular aspects which make it vulnerable to climate variability and change. Some of the possible geographical types and examples of the issues and locations where they may be relevant are Table 3-4 (Sullivan & Meigh, 2003):

Table 3-4 Geographical types (Sullivan & Meigh, 2003)

Geographical type	Example locations	Some relevant issues
Small islands	Pacific atolls, Maldives, Caribbean islands	Sea-level rise, salt water intrusion, isolation
Developing cities	Delhi, Cairo, Lagos, especially mega-cities	Inadequate infrastructure, social exclusion, squatter communities
Mountainous regions	Nepal, Bolivia, Ethiopia	Glacier loss, land slides, soil degradation, loss of forest cover
Semi-arid regions	Sahel, North-east Brazil	High rainfall variability, desertification
Low-lying coastal zones	Indus, Ganges and Nile deltas	Reduced river flows from upstream, sea-level rise, salt water intrusion

The methodology used for CVI is based on the methodology of Water Poverty Index developed by Sullivan, 2002:

$$\mathrm{CVI} = \frac{w_r R + w_a A + w_c C + w_u U + w_e E + w_g G}{w_r + w_a + w_c + w_u + w_e + w_g},$$

Where: R – Resources;

A- access;
U – Use;
C – Capacity;
E – Environment;
G – Geospatial, and
w_r, w_a, w_u, w_c, w_e, w_g – the weights of indicators.

Every component is made up of sub-components; the components are joint using a composite index structure.

There are different vulnerabilities to climate change, some of the studied are vulnerability to climate related mortality, social vulnerability to climate change, even some countries have defined their vulnerability to climate change using different indicators; for example: Canada, Peru, USA, etc.

Mortality from climate-related disasters can be measured using emergency events database data set, statistical relationships between mortality and a shortlist of potential proxies for vulnerability are used to identify key vulnerability indicators. Brooks et al (2005) identified 11 indicators;

- population with access to sanitation;
- literacy rate;
- 15-25 year olds;
- maternal mortality;
- literacy rate, over 15 years;
- calorific intake;
- voice and accountability;
- civil liberties & political rights;
- government effectiveness
- literacy ratio (female or male);
- life expectancy at birth.

The indicators can be divided in three categories:

- Health status;
- Governance;
- Education.

Almost 100 possible indicators were examined for climate change report in Canada (Canada Council of Ministers of the Environment, 2003). The 12 indicators which remained (Table 3-5) were grouped into two sections. The first one includes those whose impacts are more directly on nature; the second, those whose impacts are more directly on people (IPCC, 2001).

Table 3-5 Chosen indicators for climate change report in Canada, 2003

Nature	People
sea level rise	traditional ways of life
sea ice	drought
river and lake ice	great lakes–St.Lawrence water levels
glaciers	frost and the frost-free season
polar bears	heating and cooling
plant development	extreme weather

Adger (1999) describes another type of vulnerability; social vulnerability to climate change is the exposure of groups or individuals to stress as a result of social and environmental changes. The author proposes a set of indicators to examine the relative vulnerability of any given set of individuals or social situation. Among the indicators are:

- Poverty: income is taken as an economic indicator of poverty;
- Resource dependency at the individual level;
- Inequality: as an indicator of collective social vulnerability, which affects directly the vulnerability through constraining the options of households and indirect through its links to poverty and others factors;
- Institutional adaptation at the collective level.

The CVI provides a powerful technique to systematically express the vulnerability of human communities in relation to water resources. It is a holistic approach which integrates the physical, social, economic and environmental issues. The results are simple to understand –a single number can represent the index for a particular location –but at the same time, the underlying data can be examined, and the whole process is open and transparent (Sullivan & Meigh, 2003). The CVI is suitable for examining vulnerability to present levels of climate variability, and it can also be used to examine the impacts of climate change, combining climate scenarios with expected changes in social, economic, environmental and physical conditions.

3.6 Flood Vulnerability Indicators

During the last few decades, scientific evidence has pointed to a marked increase in frequency, intensity and economic effects of meteorological-related events such as floods. The objective to develop indicators is to provide decision makers with tools to asses and analyze flood events.

3.6.1 Existing Flood Vulnerability Index

Connor & Hiroki, 2005, presented a methodology to calculate a Flood Vulnerability Index (FVI) for river basins, using eleven indicators divided in four components. The index uses two sub-indices for its computation; the human index, which corresponds to the social effects of floods; and the material which covers the economic effects of floods. The purpose of the FVI is to serve as a tool for assessing flood risk due to climate change in relation to underlying socio-economic conditions and management policies.

The selection of the indicators, shown in Table 3-6, required the application of a cause and effect diagram which identified over 40 possible indicators to be used. The factors were acknowledged by a group of over 50 participants during an event at the Asian Development Bank Water Week, 2004 (Manila).

3.6.1.1 Flood Vulnerability Index applied for the major river basins in the world

The methodology was tested on river basins in Japan, where there is a lot of accessible information. Relatively easily available indicators were selected to facilitate the application of the method to other basins in the world; the results are shown in Figure 3.4.

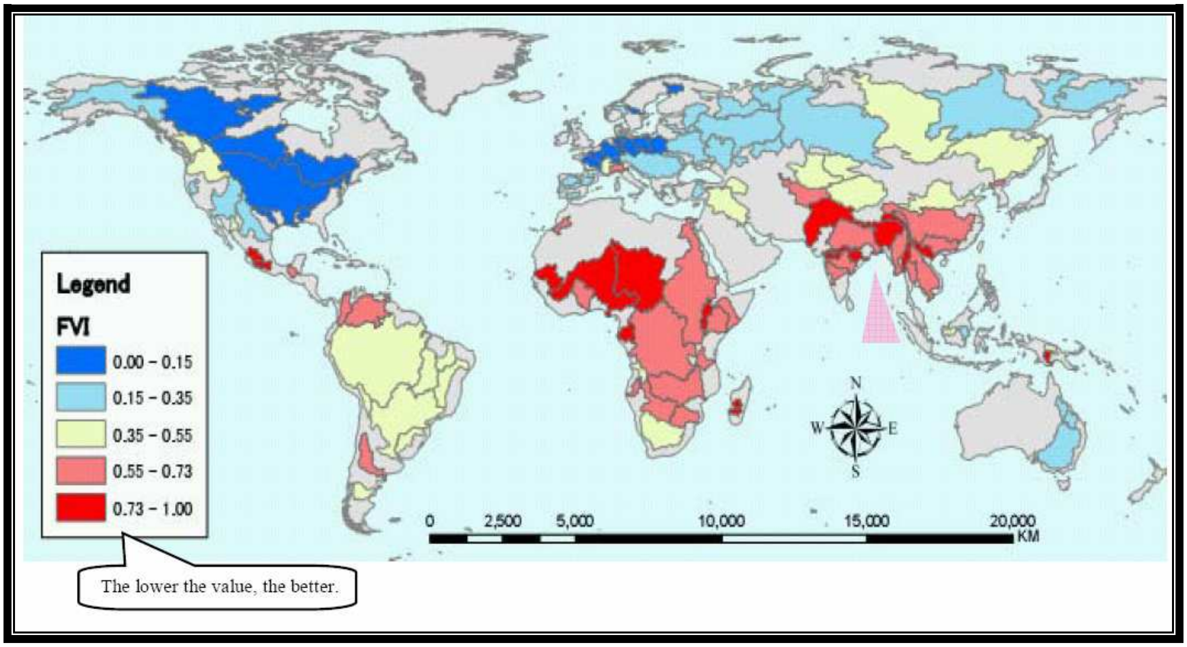

Figure 3.4 Results of FVI computation for major river basins (114) in the world, using Connor & Hiroki (2005) methodology.

Using the Japan data, the researchers used multi-linear regression analysis to calculate the weights of each indicator to the human and material FVI, based of number of casualties and material losses of past flood events the indicators reflected the actual vulnerability to floods of each river basin. The weights of the indicators were presented with the following equation:

$$FVI = C + H + S - M$$
$$FVI = (3*I_1) + (3*I_2 + I_3) + (-I_4 - I_5 + I_6 - I_7 + I_8 + I_9) - (I_{10} + I_{11}),$$

Table 3-6 Indicators and components used for existing FVI

Component	Indicator	Abb.
Climate	Frequency of heavy rainfall	I_1
Hydro-geological	Average slope	I_2
	Urbanized area ratio	I_3
Socio-Economic	TV Penetration rate	I_4
	Literacy Rate	I_5
	Population Rate under poverty	I_6
	Years Sustaining Healthy Life	I_7
	Population in Flood Area	I_8
	Infant mortality Rate	I_9
Countermeasure	Investment Amount for structural	I_{10}
	Investment Amount for non-structural	I_{11}

As seen in Figure 3.4 the values of FVI using this methodology oscillate between 0 and 1, where 1 means the highest flood vulnerability and 0 represent the lowest vulnerability to floods.

3.6.1.2 Flood Vulnerability Index applied for river basins in Philippines

The methodology was also tested in 18 river basins in the Philippines (Figure 3.5), where some indicators were added or changed because of lack of information.

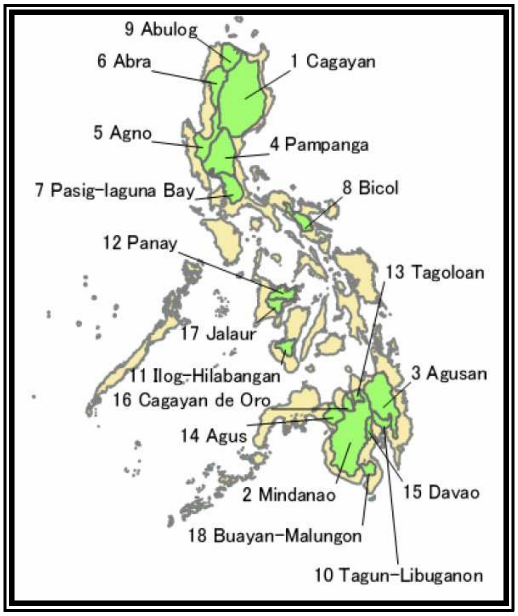

Figure 3.5 River Basins in The Philippines

The equation used for The Philippines:

$$FVI = \frac{w_c C + w_h H + w_s S}{w_m M},$$

Where:
C – Climate Component;
H – Hydro-geological Component;
S – Socio-Economic Component;
M – Counter measures Component.

$$FVI = \frac{3 * I_1 + 2 * \frac{\sum_{l=2}^{3} I_l}{2} + \frac{\sum_{m=4}^{9} I_m}{6}}{\frac{\sum_{n=10}^{11} I_n}{2}};$$

Average slope of the basin

Highly urban and capital city area ratio in basin

Tropical cyclone passage 5 years average frequency

Infant mortality rate

Literacy rate

TV penetration rate

Years sustaining healthy life

Population under poverty

Population density in basin

State of structural countermeasures

State of non-structural countermeasures

The methodology included a step of converting the indicators into non-dimensional units, by interpolating the maximum and minimum of the series of data obtained, using the formula shown below:

$$Value = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$

Using this methodology allows for comparison of a series of river basins, but comparisons between two different series, for example river basins from different countries, can be misleading since part of the comparison involves the interpolation of data, and not the value of the indicator itself.

3.7 Summary

Indicators can be a guide to understanding in a holistic way the current state of a system, also indicating the possible strategies to improve the functioning of the system.

Vulnerability indicators are not something new; they have been used for different risk based assessment for different fields of study, like socials, economic, environmental or engineering. Having an understanding of all these areas of study can complement even more the understanding of the correct functioning of a water system.

For the development of these indices, the authors stressed the need to identify indicators which represent in a clear and objective way the reality. Apart of the EVI and GRAVITY, all the indices have different weights for each indicator used, evaluating this individual weight must be done in a way that the end result improves the perception of reality given by the index.

Chapter 4 Development of Flood Vulnerability Indices for various spatial scales

4.1 Introduction

The flood vulnerability index (FVI), aims to identify hotspots related to flood events in different regions of the world, so that it can be seen as a tool to assist planners and policy makers in prioritizing their areas of intervention and also as a tool to provide useful information for awareness rising.

The main idea consists in identifying the different characteristics of a system, which will make it vulnerable to floods on different levels. These are considered the social, economic, environmental and physical aspects of a system (see section 2.3.2) which can be affected by floods.

4.2 Identifying key indicators of developed FVI

Since the development of the FVI involves the understanding of different relational situations and characteristics of a system with flood events, a deductive approach to identify the best possible indicators has been used, based on existing principles and the conceptual framework (Chapter 2). Understanding the causes of floods and their main effects on the different components of a system led to the recognition of the optimal indicators (Figure 4.1).

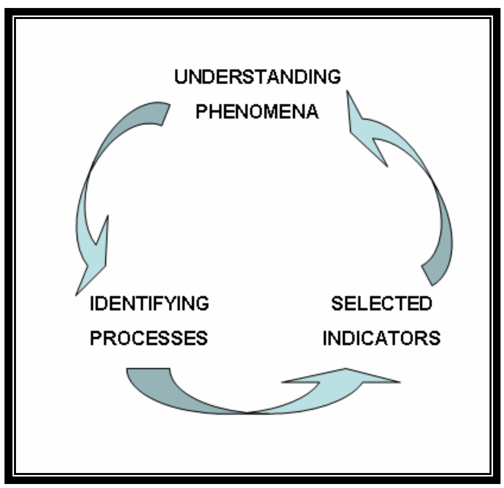

Figure 4.1 Deductive approach processes

Almost 80 possible indicators were examined for upgrading the "new" FVI, taking into account the following geographical scales: river basin, sub-catchment and urban. 40 indicators were included in the FVI computation; the rest were taken out of the equations due to redundancy of definitions, low relevance in flood vulnerability or difficulty in obtaining the required data.

The main reasons to divide the FVI into three different scales are:

- Vulnerability is geographically and socially differentiated. Any assessment at the national level must take account of regional patterns of vulnerability within

the country and the distribution of vulnerability within the national community (Adger et al., 2004);
- It is increasingly recognized that vulnerability is a dynamic characteristic, a function of the constant evolution of a complex of interactive processes (Leichenko et al., 2002);
- Spatial heterogeneity results in more accurate description of reality;
- Differences in vulnerability components, as described further below;
- Differences in vulnerability factors also described ahead;
- Political and administrative division can facilitate or impede the availability of data, according to certain scales. Data from river basins stretching out over more then one country will be more difficult to estimate; data from urban areas may vary from country data;
- The results can be more applicable and understandable through accumulation of knowledge of how vulnerability is distributed and how it is developing throughout the world.

For each geographical scale indicators have been selected and divided in four main vulnerability components (sub-indices):

- Social Component;
- Economical Component;
- Environmental Component;
- Physical Components.

The *social component* includes indicators which are measures and/or variables to describe the context, capacity, skills, knowledge, values, beliefs, and behaviours of individuals, households, organizations, and communities at various geographic scales. Social indicators are typically used to assess current conditions or achievements of social goals related to human health, housing, education levels, recreational opportunities, and social equity issues.

The *economical component* illustrates the well-being of the region of study. These indicators must provide knowledge on the capacity to produce and distribute goods and services which may be vulnerable to floods. For example, developing countries are characterized by low income per capita, human resources deficiencies, lack of investment and finance and weak internal interlink- ages. On the other hand, developed countries can be distinguished by large amounts of investment in mitigation and counter measures, high life expectancy, flood insurances, urban planning, etc. If the economic development increases, the potential flooding damages may also increase.

The *environmental component* includes indicators which refer to damages to the environment caused by flood events or man made interferences which could increase the vulnerability of certain areas. Activities like industrialization, agriculture, urbanization, afforestation, deforestation, among others have been proven to create higher vulnerability to floods, which may also create even more environmental damages. Some of the indicators taken into consideration are groundwater level, land use for economic activities or for natural reserves, degraded area, percentage of urbanized area, forest change rate, etc.

The first point of view focuses on the susceptibility and fragility of the environmental component itself.

The *physical component* tries to explain how the physical condition, either natural or man-made, can influence the vulnerability of a certain region to floods. Some indicators found are topography, heavy rainfall, evaporation rate, flood return periods, proximity to river, river discharge, flood water depth, flow velocity, sedimentation load, length of coast line, etc.

These components have been linked with the three factors of vulnerability, as shown in Table 4-1. This relationship should increase the robustness of FVI:

- Exposure: considers the indicators which explain how social entities such as individuals, households, organizations, communities, or economic activities like industries, agriculture, etc., are exposed to flood events;
- Susceptibility: considers the indicators which evaluate the sensitivity of an element at risk before and during a flood event. They can be evaluated through levels of preparedness, education, income, communication penetration rate, trust in institutions, forest change rate, etc.
- Resilience: under resilience are the indicators which clarify the ability of a system to persist if exposed to a perturbation by recovering during and after the flood event. The indicators used are warning system, evacuation routes, institutional capacity, emergency service, dams and dikes, etc.

This criterion for selecting the indicators was used to develop dimensionless results. This is different from the original FVI methodology since the dimensionless process does not involve interpolation between data series.

Table 4-1 Relationship between components and factors

Overall Indicators Relationship between components and factors						
Flood Vulnerability =	**Exposure +**		**Susceptibility -**		**Resilience**	
		Geographic Scale		Geographic Scale		Geographic Scale
Social Component	Population density	R,S,U	Past experience	R,S,U	Warning system	R,S,U
	Population in flood area	R,S,U	Education (Literacy rate)	R,S,U	Evacuation routes	R,S,U
	Closeness to inundation area	R,S,U	Preparedness	R,S,U	Institutional capacity	R,S,U
	Population close to coast line	R,S,U	Awareness	R,S,U	Emergency service	R,S,U
	Population under poverty	R,S,U	Trust in institutions	R,S,U	Shelters	R,S,U
	% of urbanized area	R,S	Communication penetration rate	R,S,U		
	Rural population	R,S	Hospitals	R,S,U		
	Cadastre survey	S,U	Population with access to sanitation	R,S,U		
	Cultural heritage	S,U	Rural population w/o access to WS	R,S		
	% of young & elder	S,U	Quality of Water Supply	S,U		
	Slums	U	Quality of Energy Supply	S,U		
			Population growth	S,U		
			Human health	S,U		
			Urban planning	U		
Economic Component	Land use	R,S,U	Unemployment	R,S,U	Investment in counter measures	R,S,U
	Proximity to river	R,S,U	Income	R,S,U	Infrastructure Management	R,S,U
	Closeness to inundation areas	R,S,U	Inequality	R,S,U	Dams & Storage capacity	R,S,U
	% of urbanized area	R,S	Quality of infrastructure	R,S,U	Flood insurance	R,S,U
	Cadastre survey	S,U	Years of sustaining health life	R,S,U	Recovery Time	R,S,U
			Urban growth	S,U	Past experience	S,U
			Child mortality	S,U	Dikes/ Levees	S,U
			Regional GDP/ capita	S		
			Urban planning	U		
Environmental Component	Ground WL	R,S,U	Natural reservations	R,S,U	Recovery time to floods	R,S,U
	Land use	R,S,U	Years of sustaining health life	R,S,U	Environmental concern	R,S,U
	Over used area	R,S,U	Quality of infrastructure	R,S,U		
	Degraded area	R,S,U	Human health	S,U		
	Unpopulated land area	R,S	Urban growth	S,U		
	Types of vegetation	R,S	Child mortality	S,U		
	% of urbanized area	R,S				
	Forest change rate	R				
Physical Component	Topography (slope)	R,S,U	Buildings Codes	U	Dams & Storage capacity	R,S,U
	Geography	R,S,U			Roads	R,S,U
	Geology	R,S,U			Dikes / Levees	S,U
	Heavy rainfall	R,S,U				
	Flood duration	R,S,U				
	Return periods	R,S,U				
	Proximity to river	R,S,U				
	Soil moisture	R,S,U				
	Evaporation rate	R,S,U				
	Temperature (yearly average)	R,S,U				
	River discharge	R,S,U				
	Frequency of occurrence	R,S,U				
	Flow velocity	S,U				
	Storm surge	S,U				
	Tidal	S,U				
	Flood water depth	S,U				
	Sedimentation load	S,U				
	Coast line	S,U				
	Coastal bathymetry	S,U				

Where: R represents River Basin Scale;
S represents Sub-catchment Scale;
U represents Urban Scale.

With the format of Table 4.1 format four types of vulnerability components per scale are defined, which can be further determined using each of the indicators. The availability of data, the importance of certain indicators and the condition that all FVI's computed must be dimensionless for purposes of comparison, led to the formulation of the equations for each scale and for each vulnerability component.

4.3 River Basin Scale

A River basin is the portion of land drained by a river and its tributaries. It encompasses the entire land surface dissected and drained by many streams and creeks that flow downhill into one another, and eventually into one river. The final destination is a lake, an estuary or an ocean (Figure 4.2).

In general river basins require information from more than one country, therefore sub-catchments and urban areas have to be considered and represented as a system in their own.

The data of each country must be interpolated to reflect the reality of the area of study and not of the entire country.

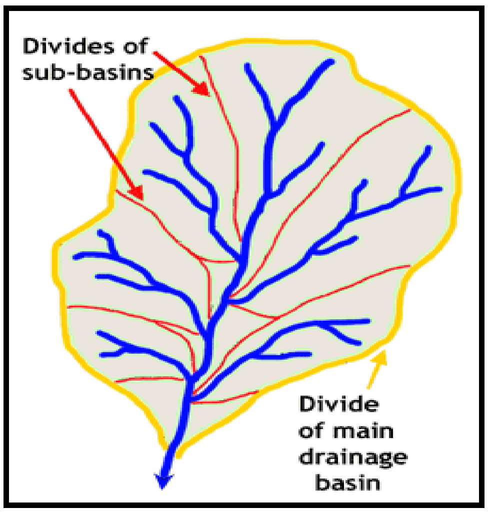

Figure 4.2 River basin

The river basin is the largest scale studied for this research. It may include river basins as big as the Amazon River, the largest in the world with more than 7,000,000 km^2, or as small as Rhine River, 185,000 km^2, or Tagus River 81,600 km^2.

4.3.1 Components and Key Indicators

In total 58 indicators have been taken into consideration for this geographical scale, as presented in Table 4.2. However 26 indicators were used to develop the equations for the river basin FVI's, for each flood vulnerability factor and component, as presented Table 4-2. The remaining indicators were not applied because of difficulties in developing a dimensionless FVI, redundancy of definitions or complexity of obtaining the data. Figure 4.3 shows the number of indicators per component and factors of the FVI equations, taking into account the original number of indicators considered.

Table 4-2 River Basin Scale Indicators

River Basin Scale Indicators						
Relationship between components and factors						
Flood Vulnerability =	**Exposure +**		**Susceptibility -**		**Resilience**	
		ABB.		ABB.		ABB.
Social Component	Closeness to inundation area	Cia	Population with access to sanitation	Pwas	Emergency service	Es
	Population density	Pd	Past experience	Pe	Warning system	Ws
	Population in flood area	Pfa	Trust in institutions	Ti	Evacuation routes	Er
	% of urbanized area	Ua	Communication penetration rate	Cpr	Institutional capacity	Ic
	Population close to coast line	Pccl	Hospitals	H		
	Rural population	Rp	Quality of Water Supply	Qws		
			Rural population w/o access to WS	Rpwaws		
			Education	E		
			Preparedness	P		
			Awareness	A		
			Quality of Energy Supply	Qes		
Economical Component	Land use	Lu	Unemployment	Um	Amount of investment of counter measures	AmInv
	% of urbanized area	Ua	Income	I	Dams & Storage capacities	D_Sc
	Proximity to river	Pr	Inequality	Ineq	Infrastructure Managemen	Im
	Closeness to inundation area	Cia	Quality of infrastructure	Qi	Economic Recovery	Er
			Human Development Index	HDI	Storage capacity	Sc
Environmental Component	Over used area	Oua	Natural reservations	Nr		
	Types of vegetation	Tv	Forest change rate	FCR		
	Land use	Lu	Human health	HH		
	Degraded area	Da				
	Unpopulated land area	Unpop				
Physical Component	Coast Line	Cl			Roads	R
	Topography	T			Dams & Storage capacity	D_Sc
	Geography	G			Dikes / Levees	D_L
	Geology	Gl				
	Heavy rainfall	Hr				
	Flood duration	Fd				
	Evaporation rate	Ev				
	Temperature	Tc				
	Frequency of occurrence	Fo				
	Proximity to river	Pr				
	River discharge	Q				
	Soil moisture	Sm				

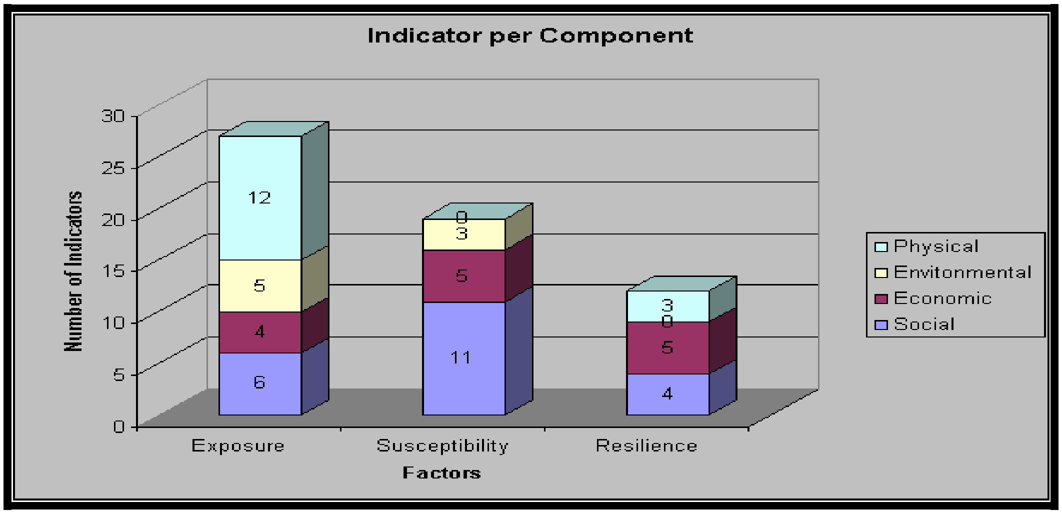

Figure 4.3 The Number of Indicators per Component for River Basin Scale

4.3.2 Equations

The equations presented for vulnerability components at the river basin scale, show the indicators as a ratio, favouring the omission of units. Each FVI component has its own range of values, depending on the numerical values of the indicators, reflecting the need to evaluate each component on its own.

On a global perspective the results will be presented in values between 0 and 1; 1 being the highest vulnerability found in the samples studied and 0 the lowest vulnerability. This procedure will be used for all geographical scales, taking care that comparisons will be done only on merits of higher relative vulnerability within the sample.

Flood Vulnerability Index for Social Component

$$FVI_S = \left[\frac{P_{FA}, C_M, U_m}{P_E, AP, C_{PR}, HDI, W_S, E_R} \right] \qquad 4.1$$

$$FVI_S = \frac{[People][\%][\%]}{[People][-][\%][-][-][\%]} \text{ dimensionless;}$$

Flood Vulnerability Index for Economical Component

$$FVI_{Ec} = \left[\frac{L_U, U_M, I_{neq}, HDI}{AmInv, E_R, Sc/yeardischarge} \right] \qquad 4.2$$

$$FVI_{Ec} = \frac{[\%][\%][-][\%]}{[-][-][m^3/m^3]} \text{ dimensionless;}$$

Flood vulnerability Index for Environmental Component

$$\text{FVI}_{\text{En}} = \left[\frac{R_{a\inf\, all}, D_A}{N_R, E_V, U_{npop}, L_U} \right] \qquad 4.3$$

$$\text{FVI}_{\text{En}} = \frac{[m/year][\%]}{[\%][m/year][\%][\%]} \text{ dimensionless;}$$

Flood Vulnerability Index for Physical Component

$$\text{FVI}_{\text{Ph}} = \left[\frac{T, D_{HR}, R_D, F_o}{E_V \big/ R_{a\inf\, all}, D\_S_C} \right] \qquad 4.4$$

$$\text{FVI}_{\text{Ph}} = \frac{[-][\#][m^3/s][year]}{\dfrac{[mm/year]}{[mm/year]}[m^3]} * 86400 * 365 \text{ - dimensionless;}$$

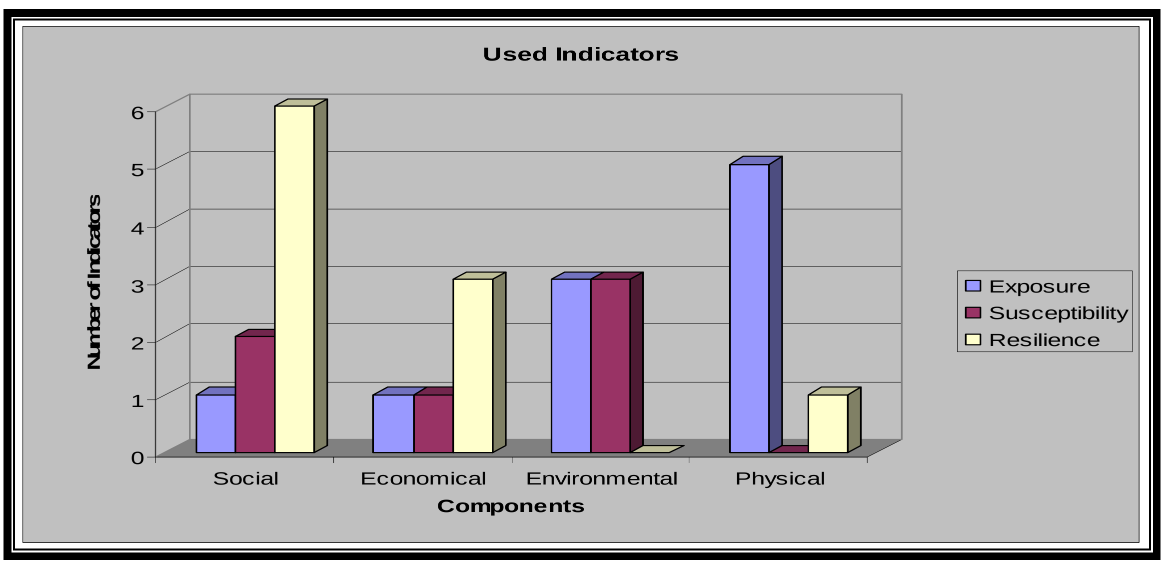

Figure 4.4 Indicators used for River Basin Scale

Figure 4.4 illustrates the number of indicators used per component and factor. Each set of columns represents an equation which together describes the FVI of a river basin.

Table 4-3 shows the list of indicators proposed for the river basin scale for the various vulnerability components. Each indicator must be a factor of exposure, susceptibility or resilience.

Table 4-3 Indicator information for river basin scale

River Basin Scale							
No	**Abb.**	**Name**	**Sub-index**	**FV Fact**	**Units**	**Definition of indicator**	**Functional relationship with vulnerability**
1	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability
2	HDI	Human Development Index	$FVI_{S,Ec}$	S	-	$^*HDI = \frac{1}{3}(LEI)+\frac{1}{3}(EI)+\frac{1}{3}(GI)$	The higher value, lower vulnerability
3	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren higher vulnerability
4	P_E	Past Experience	FVI_S	R	people	# of people affected in last 10 years because floods;	The higher value, lower vulnerability
5	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability
6	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability
7	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability
8	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods
9	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	The higher %, the high vulnerability
10	U_H	Unemployment	$FVI_{S,..}$	S	%	$U_H = \frac{\#of\_people\_Unempl}{Total\_Pop\_Apt\,To\,Work}*100$	The higher %, the high vulnerability
11	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability
12	$A_oI_{..}$	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability
13	Er	Economic Recovery	FVI_{Ec}	R	-	How affected is the economy of a region at a large time scale, because of	Higher the recovery lower vulnerability
14	$R_{rainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB $R_{rainfall} = \frac{mm}{1000 * year} = \frac{m}{year}$	Higher rainfall, higher vulnerability
15	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	Bigger D_A, higher vulnerability
16	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total RB $N_R = \frac{A_{NR}}{Total\_Area\_of\_River\_Basin}*100$	Higher %, Lower vulnerability
17	Ev	Evaporation Rate	$FVI_{Ec,Ph}$	E	m/year	yearly evaporation rate	higher GWL, higher vulnerability
18	U_{pop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Higher Unpop area. Lower vulnerability
19	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	The higher %, the low vulnerability
20	T	Topography	FVI_{Ph}	E	-	average slope of river basin	The steeper slope, higher vulnerability
21	D_{HR}	# of days with heavy rainfall	FVI_{Ph}	E	#	number of days with heavy rainfall, more than 100mm/day	higher # of days, higher vulnerability
22	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	higher RD, higher vulnerability
23	Fo	Frequency of occurance	FVI_{Ph}	E	years	years between floods	bigger # of years, high vulnerability
24	$E_V/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability
25	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m^3	The total volume of water, which can be stored by dams, polders, etc.	higher m3, higher vulnerability
26	Sc/D	Storage capacity over yearly discharge	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	higher Sc means lower vulnerability

*HDI – The Human Development Index (HDI) represent the average of the following tree indices:

- Life Expectancy Index LEI $= \frac{LE - 25}{85 - 25}$
- Education Index EI= $\frac{2}{3}ALI + \frac{1}{3}GEI$

  Adult Literacy Index: $ALI = \frac{ALR}{100}$

  Gross Enrolment Index: $GEI = \frac{CGEI}{100}$
- GDP Index (GI) = $\frac{\log(GDPpc) - \log)(100)}{\log(40000) - \log(100)}$

$$\text{HDI} = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI),$$

Where:

LE (life expectancy),
ALR (Adult Literacy Rate),
CGEI (Combined gross enrolment index),
GDPpc (GDP per capita at PPP in $);

The use of HDI integrates other indicators like life expectancy, education, or the effect of the GDP.

4.4 Sub-catchment Scale

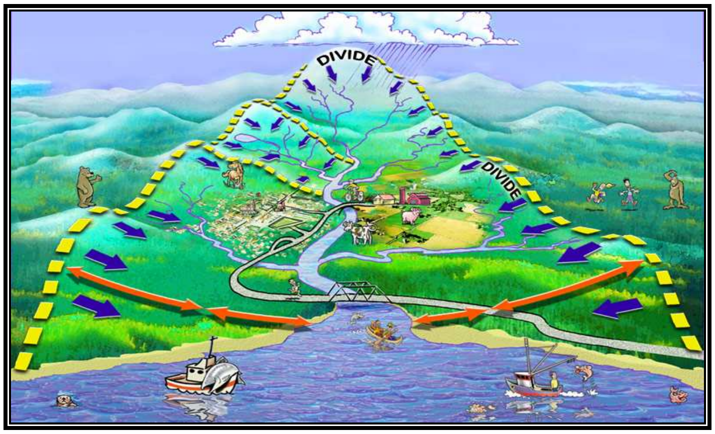

Figure 4.5 Sub-catchment

The term sub-catchment describes an area of land that drains part of a river basin down slope to the lowest point (Figure 4.5). The water moves through a network of drainage pathways, both underground and on the surface. Generally, these pathways converge into streams and rivers, which become progressively larger as the water moves on downstream, eventually reaching an estuary and the ocean. Other terms used interchangeably with watershed include drainage basin or catchment basin.

4.4.1 Components and Key Indicators

For this scale a total of 71 indicators have been considered, presented in Table 4-4. 35 of these indicators have been selected for the sub-catchment FVI equations. Figure 4.6 shows the number of indicators considered for each component and each factor.

Table 4-4 Sub-Catchment Scale Indicators

Sub-Catchment Scale Indicators

Relationship between components and factors

Flood Vulnerability =	Exposure +	ABB.	Susceptibility -	ABB.	Resilience	ABB.
Social Component	Population density	Pd	Population with access to sanitation	Pwas	Emergecy service	Es
	Population in flood area	Pfa	Past experience	Pe	Warning system	Ws
	% of urbanized area	Ua	Human Development Index	HDI	Evacuation routes	Er
	Cadastre survey	Cs	Preparedness	P	Institutional capacity	Ic
	Closeness to inundation	Cia	Awareness	A		
	Cultural heritage	Ch	Communication penetration rate	Cpr		
	Rural population	Rp	Trust in institutions	Ti		
	Population close to coast line	Pccl	Hospitals	H		
			Urban planning	Up		
			Quality of Water Supply	Qws		
			Quality of Energy Supply	Qes		
			Population growth	Pg		
			% of young & elder	%ye		
			Rural population w/o access to WS	Rpwaws		
Economical Component	Closeness to inundation	Cia	Gross Domestic Product	GDP	Amount of investment of counter measures	AmInv
	Land use	Lu	Child mortality	Cm	Past experience	Pe
	% of urbanized area	Ua	Income	I	Infrastructure Management	Im
	Proximity to river	Pr	Unemployment	Um	Economic Recovery	Ecr
	Cadastre survey	Cs	Urban growth	Ug	Storage capacity	Sc
			Inequality	Ineq		
			Quality of infrastructure	Qi		
Environmental Component	Unpopulated land area	Unpop	Natural reservations	Nr	Environmental Recovery	EnR
	Types of vegetation	Tv	Human health	HH		
	Land use	Lu	Forest change rate	Fcr		
	% of urbanized area	Ua	Ground WL	Gwl		
	Degraded area	Da				
	Over used area	Oua				
Physical Component	Coast line	Cl			Dams & Storage capacity	D_Sc
	Topography	T			Dikes / Levees	D_L
	Geography	G				
	Geology	Gl				
	Heavy rainfall	Hr				
	Flood duration	Fd				
	Evaporation rate	Ev				
	Temperature	Tc				
	Return periods	R				
	Contact with river	Cr				
	River discharge	Q				
	Average River Discharge	AvD				
	Flood water depth	Fwd				
	Flow velocity	Fv				
	Sedimentation load	Sl				
	Coastal bathymetry	Cb				
	Storm surge,	Ss				
	Flood occurrence	Fo				
	Yearly Discharge	Vyear				

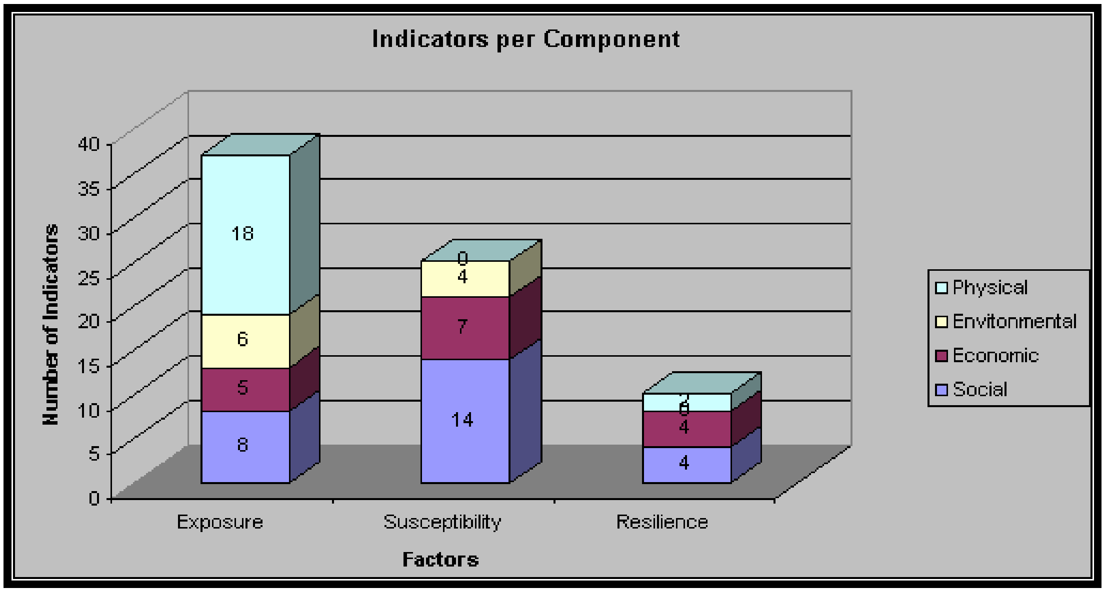

Figure 4.6 Numbers of Indicators per Component for Sub-catchment Scale

4.4.2 Equations

The equations presented in this section aim to reflect the vulnerability of a determined geographical area, limited by watershed divisions and not by administrative boundaries, adding difficulty to the collection of data.

Some of the indicators which were not included in the equation of FVI_S (social-component) are: C_{IA}, Q_{WS}, Q_{WE}, C_S, P_{CCL}, $R_{PW/AWS}$, P_G, H_H, C_H, S_{lums}, P_{WaccS}, U_P , H and I_C (see Table 4.4). Some of them have been excluded for the same reason like in the river basin scale, other ones, for example Qws and Qwe, are very difficult to quantify. Cs, Ch, PWaccS and Ic would be difficult to obtain data; Pccl, for a sub-catchment scale is hard to obtain data; Slums have very little information on people are living there, making it difficult to quantify.

For FVI_{Ec} (economic component) the following indicators have been excluded C_{IA}, C_S, Q_I, U_G, C_M, GDP, I, I_M, U_P, P_E, where GDP/cap and I would not differentiate between sub-catchments and country.

The excluded indicators for FVI_{En} (environment component) are presented further O_{ua}, Q_I, U_A, L_{EI}, T_V, C_M. The indicator Oua does not help reflects reality; Tv is one of the indicators which is hard to define and quantify and the Cm indicator will not really affect the environment.

The next indicators were eliminated from FVI_{Ph} (physical component) T, F_D, S_M, G, G_l, R, P_R, C_B, F_V, S_S, F_{WD}, G, G_l, $P_{R,}$ R. Most of them were excluded because their relationship with the physical system may not have an effect on flood vulnerability of the sub-catchment.

Flood Vulnerability Index for Social Component

$$\mathrm{FVI_S} = \left[\frac{P_{FA}, R_{Pop}, \%_{disable}, C_m}{P_E, A/P, C_{PR}, W_S, E_R, HDI} \right] \qquad 4.5$$

$$\mathrm{FVI_S} = \frac{[persons]\%[\%][-]}{[persons][-][\%][-][\%][-]} \text{ - dimensionless;}$$

Flood Vulnerability Index for Economical Component

$$\mathrm{FVI_{Ec}} = \left[\frac{L_U,, U_M, I_{neq}, U_A}{L_{EI}, F_I, AmInv, {S_C}/{Vyear}, E_{CR}} \right] \qquad 4.6$$

$$\mathrm{FVI_{Ec}} = \frac{[\%][\%][-][\%]}{[-][-][euro/euro][m^3/m^3][-]} \text{ dimensionless;}$$

Flood Vulnerability Index for Environmental Component

$$\mathrm{FVI_{En}} = \left[\frac{R_{a\inf all}, D_A, U_G}{L_U, E_V, N_R, U_{npop}} \right] \qquad 4.7$$

$$\mathrm{FVI_{En}} = \frac{\%[\%](m/year)}{\%(m/year)\%[\%]} \text{ dimensionless;}$$

Flood Vulnerability Index for Physical Component

$$\mathrm{FVI_{Ph}} = \left[\frac{T}{{E_V}/{R_{a\inf all}}, {S_C}/{Vyear}, D\_L} \right] \qquad 4.8$$

$$\mathrm{FVI_{Ph}} = \frac{[-]}{{[mm/year]}/{[mm/year]}\left[{m^3}/{m^3}\right]\left[{Km}/{Km}\right]} \text{ dimensionless;}$$

Table 4-5 shows the list of indicators proposed for the sub-catchment scale for various vulnerability components. Each indicator must be a factor of exposure, susceptibility or resilience.

Table 4-5 Indicator information for sub-catchment scale

No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with vulnerability
Sub-catchment Scale							
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is	Higher # of people, higher vulnerability
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability
3	U_A	Urbanized Area	$FVI_{S,Ec}$	E	%	% of total area which is urbanized	higher %,higher vulnerability
4	R_{pop}	Rural population	FVI_S	E	%	% of population living outside of urbanized area	higher %,higher vulnerability
5	% of disable	Disable People	FVI_S	E	%	% of population with any kind of disabilities, also people less 12 and more than 65	higher %,higher vulnerability
6	HDI	Human Development	FVI_S	S	-	"HDI $=\frac{1}{3}(LEI)+\frac{1}{3}(EI)+\frac{1}{3}(GI)$	The higher value, lower vulnerability
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events;	The higher value, lower vulnerability
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability
11	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability
12	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads improves the evacuation during floods
13	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	The higher %, the high vulnerability
14	U_H	Unemployment	FVI_{Ec}	S	%	$=\frac{\#of\_people\_Unempl}{Total\_Pop\_AptToWork}*100$	The higher %, the high vulnerability
15	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability
16	L_{EI}	Life expectancy Index	FVI_{Ec}	S	-	LEI= $\frac{LE - 25}{85 - 25}$	Higher LEI, Lower vulnerability
17	Er	Economic Recovery	FVI_{Ec}	R	#		The higher #, the high vulnerability
18	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances, if 0 than take 1	higher # of FI, lower vulnerability
19	A_{Inv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability
20	D_L	Dikes_ Levees	FVI_{Ec}	R	km/km	Km of dikes/levees over total length of river	Longer D_L, lower vulnerability
21	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m	amount of storage capacity over area of sub-catchment	higher capacity, lower vulnerability
22	$R_{ainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB $=\frac{mm}{1000 * year}=\frac{m}{year}$	Higher rainfall, higher vulnerability
23	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	Bigger D_A, higher vulnerability
24	U_G	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 10 years;	fast urban growth may result in poor quality housing and thus make people more vulnerable
25	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	The higher %, the low vulnerability
26	Ev	Evaporation rate	FVI_{Ec}	S	m/year	yearly evaporation rate	higher Ev, higher vulnerability
27	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total SC $=\frac{A_{NR}}{Total\_Area\_of\_River\_Basin\ area}*100$	Higher %, Lower vulnerability

Sub-catchment Scale							
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with
28	U_{unpop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Higher Unpop area. Lower vulnerability
29	T	Topography	FVI_{Ph}	E	-	average slope of sub-catcment	The steeper slope, higher vulnerability
30	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	higher RD, higher vulnerability
31	Fo	Frequency of occurrence	FVI_{Ph}	E	years	years between floods	bigger 3 of years, high vulnerability
32	$E_V/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability
33	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m	amount of storage capacity over area of sub-catchment	higher m, higher vulnerability
34	AvRd	Average River Discharge	FVI_{Ph}	E	m3/s	average river discharge at the mouth	
35	Sc/Vyear	Storage capacity over yearly discharge	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	higher Sc means lower vulnerability

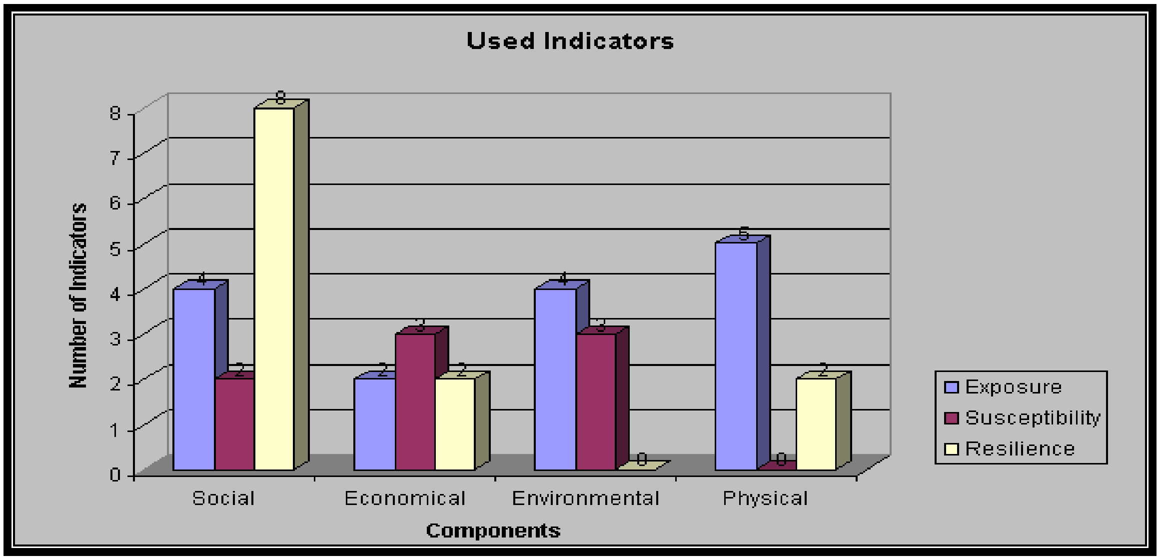

Figure 4.7 Indicators used for Sub-Catchment Scale

Figure 4.7 illustrates the number of indicators, by component and factor, used to develop the equations to compute flood vulnerability at the sub-catchment scale.

4.5 Urban Scale

The traditional concept of a town or city would be a free-standing built-up area with a service core with a sufficient number and variety of shops and services, including a market (Figure 4.8). It would have administrative, commercial, educational, entertainment and other social and civic functions and, evidence of being historically well established. A local network of roads and other means of transport would focus on the area, and it would be a place drawing people for services and employment from surrounding areas (Statistics UK, 2001).

The urbanisation process itself is one of the causes of flood disasters. The loss of natural retention areas, previously provided by marsh paddy and other agricultural areas, due to urban expansion has allowed floodwater to travel more quickly to receiving streams, swelling them beyond their capacity (UNU, 2005). The phenomenon is exacerbated by the paved urban landscape and the continuing urbanisation. Adding that the urban areas are highly dense populated make them especially vulnerable to flood effects.

Figure 4.8 Example of Urban Scale

In general, the cities or urban areas, followed early settlers who located along river banks for water supplies and transportation. In some cases, the city is surrounded by many rivers that regularly overflow such as Dhaka which is surrounded by five rivers; here the floods are a normal occurrence and usually not an outstanding event (Kastrup, UNU-EHS, 2006).

The Chinese city of Wuhan is cut through by the Yangtze River - the third biggest river in the world - and lies at the estuary of its longest tributary (Hanjiag River). Another example is the Mississippi River, which has more than 50 cities along its trial ending in the Mexico Gulf near the city of New Orleans.

4.5.1 Components and Key Indicators

Table 4-6 shows 63 indicators which have been considered for this geographical scale. The distribution of indicators over the vulnerability components and factors is shown in Figure 4.9.

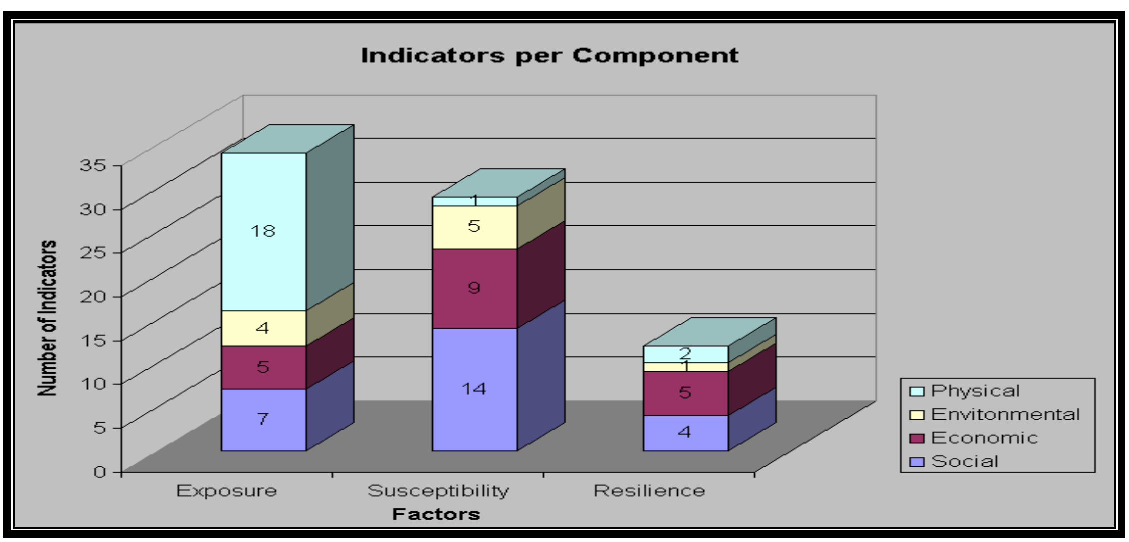

Figure 4.9 Numbers of Indicators per Component for Urban Area Scale

Table 4-6 Urban Scale Indicators

Urban Area Scale Indicators						
Relationship between components and factors						
Flood Vulnerability =	**Exposure +**		**Susceptibility -**		**Resilience**	
		ABB.		ABB.		ABB
Social Component	Closeness to inundation areas	Cia	Population with access to sanitation	Pwas	Emergency service	Es
	Population density	Pd	Past experience	Pe	Warning system	Ws
	Population in flood area	Pfa	Human Development Index	HDI	Evacuation routes	Er
	Cadastre survey	Cs	Preparedness	P	Institutional capacity	Ic
	Cultural heritage	Ch	Awareness	A		
	Population close to coast line	Pccl	Trust in institutions	Ti		
	Slums	Sl	Communication penetration	Cpr		
			Shelters	S		
			Quality of Water Supply	Qws		
			Quality of Energy Supply	Qes		
			Urban planning	Up		
			Human health	HH		
			Population growth	Pg		
			% of young & elder	%ye		
Economical Component	Industries	Ind	Unemployment	Um	Amount of investment of counter measures	AmInv
	Proximity to river	Pr	Income	I	Infrastructure Management	Im
	Cadastre survey	Cs	Flood insurance	Fi	Past experience	Pe
	Closeness to inundation areas	Cia	Child mortality	Cm	Drainage	D
	Contact to river	Cr	Urban growth	Ug	Recovery time	Rt
			urban planning	Up		
			Human Development Index	HDI		
			Inequality	Ineq		
			Quality of infrastructure	Qi		
Environmental Component	Land use	Lu	Natural reservations	Nr	Environmental Recovery	EnR
	Degraded area	Da	Human health	HH		
	Over used area	Oua	Sea Level Rise	SLR		
	Coast Line	Cl	Urban planning	Up		
			Ground WL	Gwl		
Physical Component	Coast line	Cl	Building codes	Bc	Dikes / Levees	D_L
	Topography	T			Dams & Storage capacity	D_Sc
	Geography	G				
	Geology	Gl				
	Heavy rainfall	Hr				
	Flood duration	Fd				
	Evaporation rate	Ev				
	Temperature	Tc				
	Frequency of occurrence	Fo				
	River discharge	Q				
	Average River Discharge	AvD				
	Flood water depth	Fwd				
	Flow velocity	Fv				
	Sedimentation load	Sl				
	Yearly Discharge	Vyear				
	Storm surge	Ss				
	Yearly runoff	Vyear				
	Proximity to river	Pr				

4.5.2 Equations

Urban vulnerability to floods is mainly driven by the changes forced by humans on nature on a restricted area. Characteristics like high density of population, high levels of pollution, infrastructure development, among other characteristics of urban areas, increase the vulnerability to floods.

The following equations aim to gain an understanding of what characteristics of cities makes them more vulnerable to every component of floods.

Flood Vulnerability Index for Social Component

$$\text{FVI}_\text{S} = \left[\frac{P_D, P_{FA}, C_H, P_G, \%_{disables}, HDI, C_M}{P_E, A/P, C_{PR}, S, W_S, E_R, E_S}\right] \qquad 4.9$$

$$\text{FVI}_\text{S} = \frac{\frac{people}{km^2}[people][-][\%][\%][HDI][-]}{people[-][\%]\frac{1}{km^2}[\%][people][-]} \text{ - dimensionless}$$

Flood Vulnerability Index for Economical Component

$$\text{FVI}_\text{Ec} = \left[\frac{I_{ND}, C_R, U_M, I_{neq}, U_G, HDI, R_D, R_T}{F_I, AmInv, D\_S_C, D}\right] \qquad 4.10$$

$$\text{FVI}_\text{Ec} = \frac{\#[km][\%][-][\%][-][m^3/s][days]}{[-][\%][m^3][km]} * 86400 \text{ - dimensionless;}$$

Flood Vulnerability Index for Environmental Component

$$\text{FVI}_\text{En} = \left[\frac{U_G, R_{a\inf all}}{E_V, L_U}\right] \qquad 4.11$$

$$\text{FVI}_\text{En} = \frac{[\%](m/year)}{(m/year)[\%]} \text{ - dimensionless;}$$

Flood Vulnerability Index for Physical Component

$$\text{FVI}_\text{Ph} = \left[\frac{T, C_R}{E_V / R_{a\inf all}, S_C / Vyear, D - L}\right] \qquad 4.12$$

$$\text{FVI}_\text{Ph} = \frac{[-][km]}{[mm/year]/[mm/year][m^3/m^3][km]} \text{ - dimensionless;}$$

Figure 4.10 shows the classification of indicators among components and factors, used for the equations which describe the flood vulnerability of urban areas.

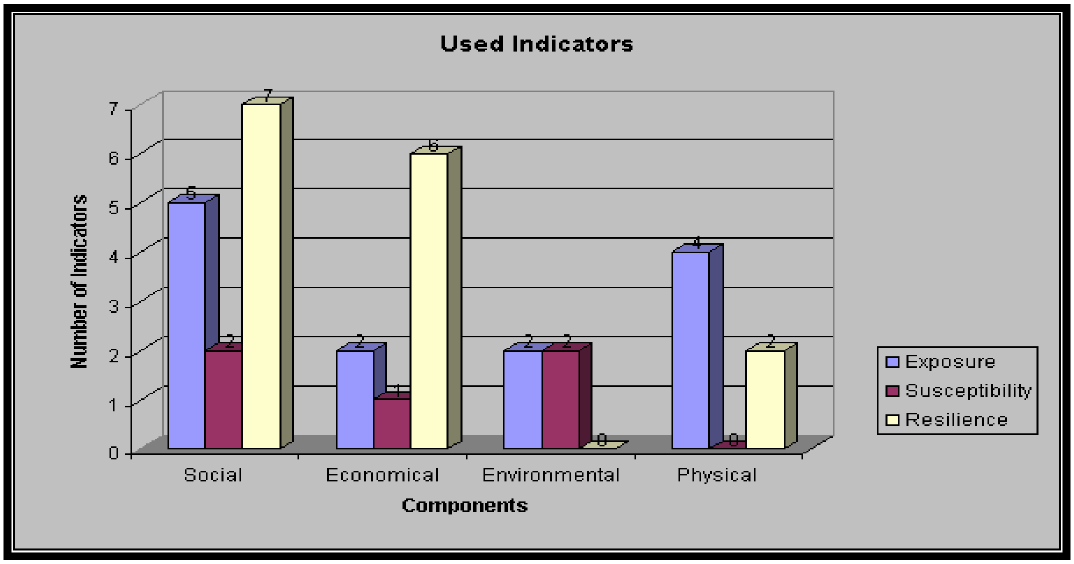

Figure 4.10 Used indicators for Urban Area Scale

Table 4-7 Indicator information for urban scale

Urban Scale							
No	**Abb.**	**Name**	**Sub-index**	**FV Factor**	**Units**	**Definition of indicator**	**Functional relationship with vulnerability**
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is concentrated	Higher # of people, higher vulnerability
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability
3	C_H	Cultural Heritage	FVI_S	E	-	number of historical buildings, museums, etc., in danger when flood occurs, if none take 1	high # of CH, higher the vulnerability
4	P_G	Population growth	FVI_S	E	%	% of growth of population in urban areas in the last 10 years	fast PG, higher vulnerability, hypothesis is made that fast population growth may create pressing on housing capacities
5	% of disable	Disable People	FVI_S	E	%	% of population with any kind of disabilities, also people less 12 and more than 65	higher %,higher vulnerability
6	HDI	Human Development Index	$FVI_{S,E}$	S	-	HDI $=\frac{1}{3}(LEI)+\frac{1}{3}(EI)+\frac{1}{3}(GI)$	The higher value, lower vulnerability
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because	The higher value, lower vulnerability
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability
11	S	Shelters	FVI_S	R	$\#/km^2$	number of shelters per km^2, including hospitals	bigger # of S, lower vulnerability
12	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability
13	E_S	Emergency Service	FVI_S	R	#	number of people working in this service	bigger # of people, less vulnerable they are
14	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during
15	Ind	Industries	FVI_{Ec}	E	#	# of industries or any types of economic activities in urban area	The higher %, the high vulnerability
16	Cr	Contact with River	FVI_{Ec}	E	km	Distance of city along the river	more distance, more vulnerability
17	U_H	Unemployment	FVI_{Ec}	S	%	$U_R=\frac{\#of\_people\_Unempl}{Total\_Pop\_AptToWork}*100$	The higher %, the high vulnerability
18	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability
19	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances, if 0 than take 1	higher # of FI, lower vulnerability
20	A_oI_{nv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability
21	D_L	Dikes_ Levees	FVI_{Ec}	R	km	Km of dikes/levees	Longer D_L, lower vulnerability
22	D_Sc	Dams_Storage capacity	FVI_{Ec}	R	m^3	Storage capacity in m3 of dams, polders, etc., upsteam of the city	higher m3, higher vulnerability
23	RT	Recovery time	FVI_{Ec}	R	days	Amount of time needed by the city to recover to a functional operation after flood events	the higher amount of time, the higher vulnerability
24	$R_{rainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year	Higher rainfall, higher vulnerability
25	L_U	Land Use	FVI_{Ec}	E	%	area destined for green areas inside the urban area	The higher %, the low vulnerability
26	UG	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 10 years	fast urban growth may result in poor quality housing and thus make people more vulnerable
27	EV	Evaporation	FVI_{Ec}	S	m/year		higher ev, lower vulnerability
28	T	Topography	FVI_{Ph}	E	-	average slope of the city	The steeper slope, higher vulnerability
29	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum river discharge in recor of the last 10 years, m^3/s	higher RD, higher vulnerability

Urban Scale							
No	Abb.	Name	Sub-index	FV Facto	Units	Definition of indicator	Functional relationship with vulnerability
30	E_v/R_{ain}	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability
31	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m^3	amount of storage capacity	higher m3, higher vulnerability
32	D	Drainage system	FVIec	R	Km	Km of canalization in the city	higher km, low vulnerability
33	AvD	Average Discharge	FVI_{Ph}	E	m^3/s		
34	Sc/Vyear	Storage over yearly runoff	FVI_{Ph}	R	m^3/m^3	Amount of storage capacity over the yearly average runoff	Larger storage capacity means lower vulnerability

Table 4-7 shows the list of indicators proposed for the urban scale, for various vulnerability components. Each indicator must be a factor of exposure, susceptibility or resilience.

4.6 Summary

Dividing the FVI into different components, such as social, economical, environmental and physical and linking them with the factors of vulnerability, as exposure, susceptibility and resilience can help identify the weak points of a flood defence system (in any scale), and in that way also assist to propose strategies for improvement of the overall system.

The proposed equations in this chapter link the values of all indicators to flood vulnerability components and factors, without balancing or interpolating from a series of data. These equations allow comparisons between different geographical scales, since the outcome of the computation is dimensionless. Relating all the FVI's must be done on a similar basis, that's why comparisons should be done on dimensionless results, for the same components and same scales for different study cases.

Chapter 5 Testing of Flood Vulnerability Indices Methodology at various spatial scales

5.1 Introduction

This chapter describes the case studies selected for application of the Flood Vulnerability Indices and the process of data collection for each spatial scale. Firstly, a general overview and description of each case follows. After that a description of the sources of data and assumptions follows and lastly the results of each case are described and discussed.

The cases are presented starting with larger scales, meaning river basins, and finishing with the smallest scale, the urban areas.

5.2 Case study: Description of the three case studies on River Basin Scale

A river basin is the land area drained by a river and its tributaries. It includes the entire land surface divided and drained by many streams that flow downhill into one another, and eventually into one river. The final destination is an estuary, a central river and/or the sea or an ocean (see section 4.3).

The three river basin case studies were selected because of different reasons. The Danube River Basin covers 18 countries, of which 5 are developed with strong flood resilience; the other 12 are developing countries susceptible to floods and with little resilience. The Rhine River Basin is formed by 9 developed countries, with a large resilience to floods, and lastly the Mekong River Basin includes 6 countries of which some countries experience a large exposure to floods because of their physical characteristics and low resilience.

5.2.1 Danube River Basin

The Danube River Basin is covered by 18 countries; Austria (10 %), Albania (<0.1 %), Bulgaria (5.9 %), Bosnia (4.6 %), Czech Republic (2.9 %), Croatia (4,4 %), Germany (7 %), Hungary (11.6 %), Italy (< 0.1 %), Macedonia(< 0.1 %) , Moldova (1.6 %), Poland (< 0.1 %), Romania (29 %), Slovenia (2 %), Slovakia (5.9 %), Switzerland (0.2 %), Serbia (11.1 %) and Ukraine (3.8 %), as shown in Figure 5.1 (ICPDR, 2004).

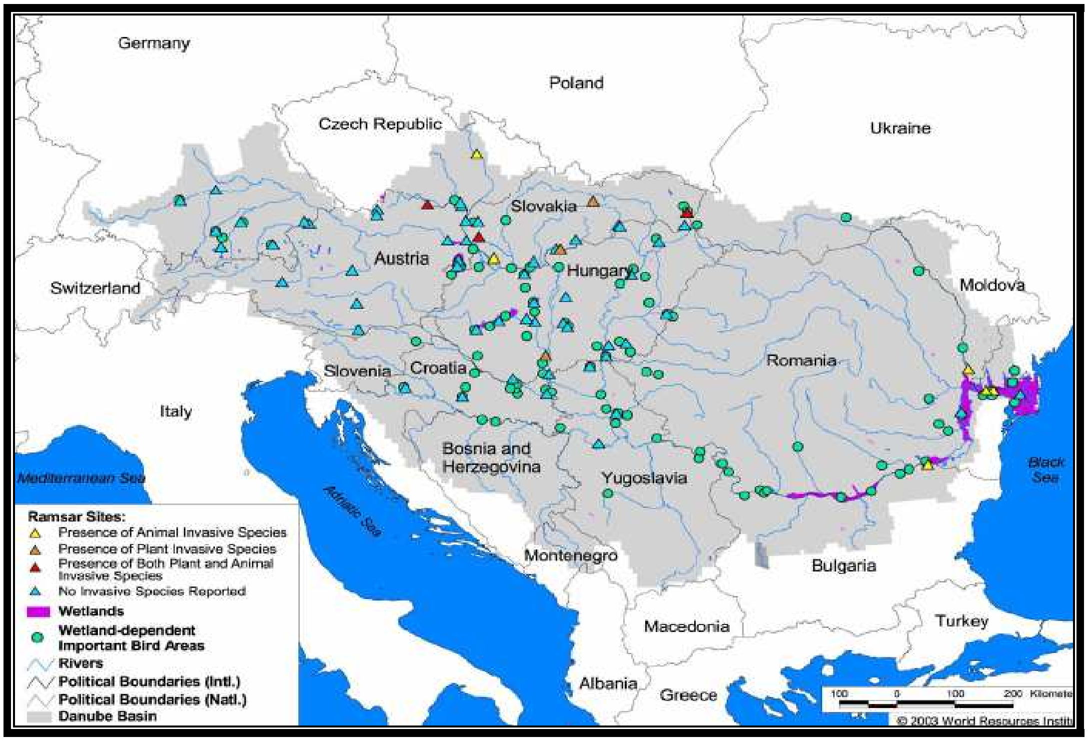

Figure 5.1 Danube River Basin (Water Resources eAtlas)

The Danube is the second longest river in Europe. It is approximately 2,900 km long and drains an area of about 817,000 km², with a population of 80,000,000 people and a mean annual discharge of 6,500 m^3/s. It originates in the Black Forest Mountains of Germany and drains into the Black Sea in Romania (UNEP, 2007).

The Danube river distributes its length in three sections by function of its elevation: the Upper Danube (Germany, Austria, Czech Republic) the Middle Danube (Slovak Republic, Hungary, Serbia, Croatia) and the Lower Danube (Romania, Bulgaria, Moldova, Ukraine) including Danube Delta in Romania and Ukraine (ICPDR, 2004).

The Danube's tributary rivers reach into ten different countries. Some Danubian tributaries are important rivers by their own. Ordered from source to mouth, the main tributaries are; Iller, Lech, Regen, Isar, Inn, Enns, Leitha, Vah, Hron, Ipel, Sio, Drava, Vuka, Tisza (Danube longest tributary 966 km), Sava, Timis, Velika Morava, Caras, Jiu, Iskar, Olt, Vedea, Arges, Ialomita, Siret and Prut.

The Danube River Basin has a higher resilience in the upper part. The annual amount of investment on flood protection is larger here, because of its most developed countries. The river basin is more exposed and susceptible in the lower part because of its larger river discharge and lower slopes.

During the last century, characteristic maximum flood levels occurred in 1902, 1924, 1926, 1940, 1941, 1942, 1944, 1954, 1965, 1970, 1974, 1991, 2002, 2005 and 2006 (ICPDR, 2006).

In August 2002 heavy rains in Central and Eastern Europe have led to some of the worst flooding the region has witnessed over a century. The floods have killed more than 100 people in Germany, Russia, Austria, Hungary and the Czech Republic and have led to as much as $20 billion in damage (NASA, 2002).

In April 2006, heavy rainfalls coinciding with snow melt, instigated flood events in the lower Danube, in Romania and Bulgaria. 4,000 people from the village of Rast in south-western Romania have been evacuated to schools, hospitals or the houses of relatives in higher areas, due to a emanate dike collapse (BBC, 2006).

Flooding in the Balkans in 2005 killed dozens of people and destroyed huge swathes of farmland. Economic losses from 2006 floods are not thought to be as high as they were in 2005 or in 2002.

The Danube basin contains a diverse system of natural habitats. Among these are the German Black Forest, the Alps and Carpathian Mountains, the Hungarian Puszta plains, the Bulgarian islands and the giant reed beds and marshes of the Danube Delta.

Floodplain forests, marshlands, deltas, floodplain corridors, lakeshores and other wetlands form the basis of the rich biodiversity in the Danube River Basin. In fact, the Danube River Basin extends into five of the eight bio-geographical regions of Europe, each with its own particular characteristics. However, in those regions, industrialization, population growth and agriculture have had a negative impact on the size and biodiversity of wetlands.

5.2.2 Rhine River Basin

The countries which are included in this river basin are: France, Switzerland and The Netherlands (20,000 to 30,000 km² each), Austria and Luxemburg (about 2,500 km² each), Belgium, Italy, Liechtenstein (very small share each) and Germany. The Rhine is Western Europe’s largest river basin, with a length of 1,320 km and a catchment area of 185,000 km² and mean annual discharge of 2,200 m^3/s. Approximately 50,000,000 inhabitants live in the basin (UNEP, 2007).

The river basin has six characteristic river sections: the Alp Rhine from the confluence of the source rivers at Reichenau (Switzerland) to Lake Constance, the High Rhine from the outlet of Lake Untersee to Basel, the Upper Rhine from Basel till Bingen, the Middle Rhine from Bingen to Cologne, the Lower Rhine from Cologne to Lobith and the Rhine Delta from Lobith to North Sea.

In the Rhine River floods occurred in the last centuries during the years: 1819, 1847, 1883, 1918, 1926, 1949, 1983, 1998, 1999, 2000 and 2005 (ICPR, 2006)

The Rhine River Basin has a very high resilience to floods, mainly due to the high amount of (annual) investments of 419 millions euro (IRMA, 2004), which is invested to protect its banks and its people. Many cities and major industrial areas have occupied its banks for centuries. The major cities are situated along the Rhine or its larger tributaries. Its important tributaries are the Ill in France, Aare, Neckar, Main, Lippe, Mosselle, and Ruhr rivers in Germany.

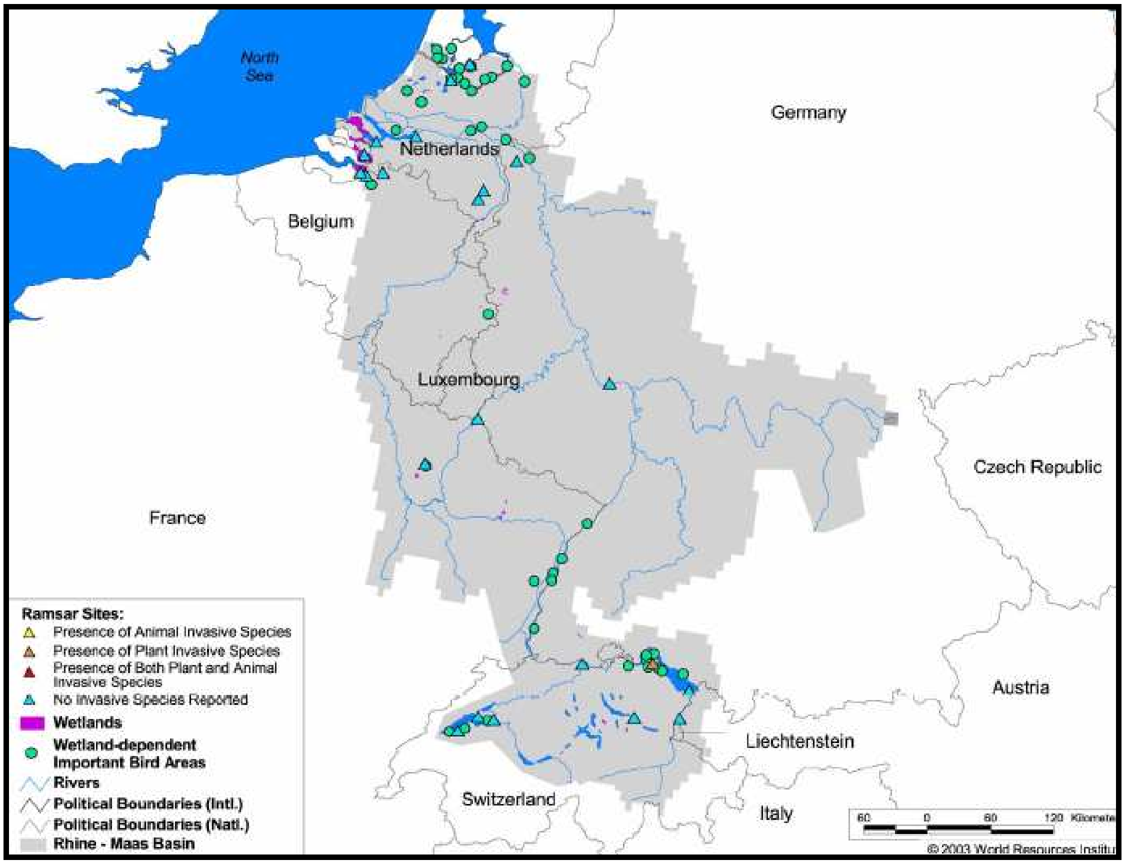

Figure 5.2 Rhine River Basin (Water Resources eAtlas)

The Rhine has been subjected to enormous amounts of pollutants over a long period of time. In particular high loads of organic waste (sewage) resulted in oxygen levels too low for many fish species. The Rhine became a dead river, loosing its function as provider for drinking water and depositing large amounts of polluted sediments in the river's tidal areas and on its floodplains (Klein et al., 2004).

The countries along the Rhine River have contributed to restore the river's health, after an ecological disaster upstream (a fire at a chemical manufacturing plant at Schweizerhalle (near Basel) in November 1986 and the subsequent release of toxic agrochemicals into the Rhine (Guttinger, 1990)). The return of fish is a clear sign that the water quality has improved, however, several environmental problems remain. A major issue is the Rhine delta basin in the Netherlands, where toxin-filled mud dredged from the port of Rotterdam has been dumped since the 1970s. Contamination levels are falling now, but several old toxins in the river's sediment are only very slowly being removed.

5.2.3 Mekong River Basin

The Mekong is one of the world's major rivers. It is the 13th-longest in the world, and the 10th-largest by volume (discharging 475 km^3 of water annually). Its estimated length is 4,620 km (Akira, 2007). It drains an area of 795,000 km^2, of which some 606,000 km^2 is occupied by the Lower Mekong basin that starts near Chiang Saen (Thailand) at the junction of the borders of Thailand, Laos and Myanmar. About 90,000,000 people rely on the river, from which 55,000,000 are living in the lower Mekong (MRC, 2005).

The Mekong River Basin crosses though 6 countries; in the Upper Mekong (18%) through China (16%) and Myanmar (2%), in the Lower Mekong (82%) through Cambodia (18%), Laos (35%) Thailand (18%), and Viet Nam (11%) (MRC, 2005).

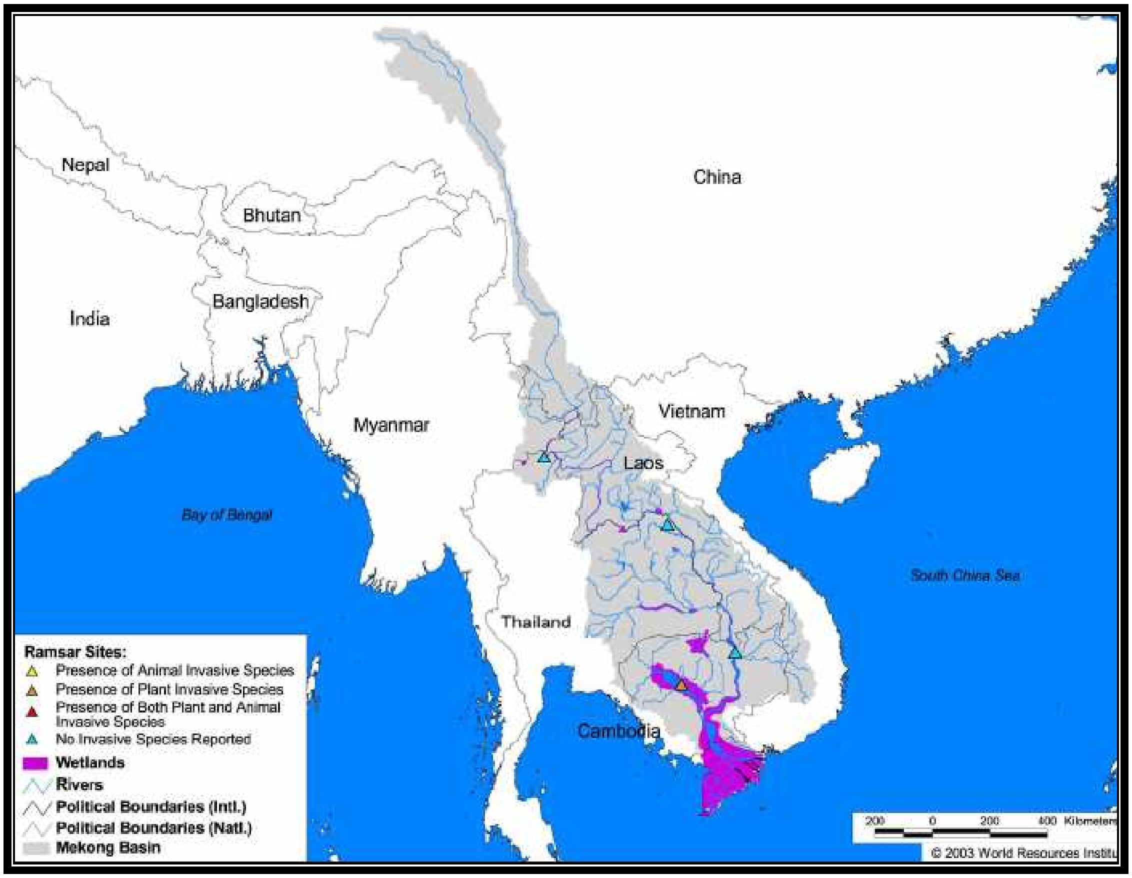

Figure 5.3 Mekong River Basin (Water Resources eAtlas)

The lower Mekong Basin consists of a large delta, starting in Cambodia and finishing in Viet Nam. The Mekong Delta begins in the city of Phnom Penh, where the river divides into its two main distributaries, the Mekong and the Bassac. The Mekong then divides into six main channels and the Bassac into three to form the "Nine Dragons" of the outer delta in Viet Nam. The main delta is made up of a vast triangular plain which is lower than five meters above sea level, large areas of which are flooded every year.

The main cities and a big number of villages are situated on the banks of this river. Also the agriculture depends very strongly on this river, in some of the countries this is the only river which crosses the country.

The largest tributaries of the Mekong are the Mun River and Chi River (Thailand), the Khan river joins the Mekong at Luang Prabang (Cambodia).

The Mekong River Basin is exposed to floods due to its location in Southern Asia. The most exposed are the population of Cambodia and Viet Nam, whose flood resilience is quite small.

The amount of flood mitigation investment hardly surpasses 6,000,000 dollars per year, even though the population is well prepared and aware, due to their experience, with floods.

During the last 40 years (1966 to 2005), 30 notable floods have occurred with an average frequency of once in 1.4 years. Of these historic floods, only four were large, covering all the riparian countries (1966, 1971, 1978 and 1995), giving an average frequency of once in every 7.5 years (FAO, 1999). The 1966 flood is recalled as one of the most disastrous and probably the longest. It caused unprecedented water levels in the Mekong, inundation of large areas and extensive damage. Agriculture and agricultural infrastructure suffered the worst damage. The Laotian flood pattern is also distinct from that of Thailand or Cambodia since floods in Laos tend to be more 'flashy' and frequent than in Thailand, due to relatively high rainfall in the Laos mountains and the lack of land use regulations along its tributaries.

The livelihoods and quality of life of several million people who inhabit this area depends on the resources of the Mekong River. The lives of the people in the riparian countries depend on the rich natural resources available as global commons, like rice, and other agricultural products such as fisheries. The imminent revival of economic growth in the region, likely to accelerate with increased trade liberalization and investments, will have significant impacts on the livelihoods of communities, on their cultures and ways of life, and on the ecological balance of this biodiversity rich region (MERI, 2007).

5.2.4 Data collection river basin case studies

The river basin scale FVI equations require 26 different indicators, as mentioned in section 4.3.2. In the search for the values of the flood vulnerability indicators for the three case studies, 15 different sources were consulted. Nine web-sites were sufficient to gather indicators for all three case studies; CRED, UNDP/BCPR, UNDP, EPI, INTUTE, WRI, World FactBook, Water Resources eAtlas and FVI.

CRED EM-DAT is the Centre for Research on the Epidemiology of Disasters from the Catholique University of Louvain in Belgium. *UNDP* is the United Nations Development Programme; they finance the *BCPR*, which is the Bureau for Crisis Prevention and Recovery. *EPI* is the Environmental Performance Index, an index developed by the Yale Centre for Environmental Law and Policy to serve as a research tool on data-driven policymaking, environmental indicators, and quantitative evaluation of sustainable development. *INTUTE* is a free online service providing access to resources for education and research of social sciences, developed by a network of UK universities and partners. *WRI* is the World Resources Institute, a United States based environmentalist NGO. *World FactBook* is a database developed by the CIA with basic information on all the countries in the world. The *Water Resources eAtlas* is an electronic Atlas developed by IUCN, IWMI, Ramsar and WRI with information on the watersheds of the world; and lastly the existing *FVI* (Connor & Hiroki, 2005), which contained data on major river basins in the world.

The indicators collected in these sources were: HDI, Child mortality, Evacuation routes, and unemployment, Gini, GDP/cap, Communication penetration Rate, Population in Flood Prone Area, Natural Reservations, Unpopulated areas and Land use (see Appendices I).

Six sources were used for indicators on case specific river basins, *Mekong River Commission* (MRC), *International Commission for the Protection of Danube River* (ICPDR), the *EU-IRMA Project*, *World Bank*, *UNH/GRDC* and *Ekstrom et al., 2006*.

The MRC is an organization which includes all the Mekong member states, except China and Myanmar, aiming for joint management of their shared water resources and development of the economic potential of the Mekong. The ICPDR is an organization which comprises 13 Contracting Parties who have committed themselves to implement the Danube River Protection Convention. The European Union IRMA Project, which stands for INTERREG Rhine-Meuse Activities, is a project for the whole Rhine Basin aiming to reduce the effects of floods. The World Bank (WB) has relevant data on water resources of developing countries; UNH/GRDC is the University of New Hampshire Global Runoff Data Centre and in Ekstrom et al., 2006 data for climate change assessment is analyzed.

For the Mekong River Basin the MRC provided data on past experiences annual amounts of flood mitigation investments, rainfall and evaporation and the WB presented data on storage capacity. For the Danube River Basin, the ICPDR provided data on the river discharge and Ekstrom et al., 2006 on rainfall and evaporation. For the Rhine River Basin the IRMA Project provided data on the annual amount of investments, and Ekstrom et al., 2006 on rainfall and evaporation. The sources of data collected are shown in Annex I.

Some indicators were not quantifiable based on data from different sources, because of their subjective nature. Indicators like *awareness & preparedness* are presented on a scale from 1 to 10 to assess the level of each basin, based on the institutional capacity, experience and people’s understandings of flood risks (see Table 5-1), and the Economic Recovery Indicator was scaled from 10 to 100, based on the size and duration of damaged economic activities from previous flood events, see Table 5-2.

Table 5-1 Scale for Awareness & Preparedness Indicator

Scale	*Urban and sub-catchment*	*River Basin*
Score	**Indicating**	
1	The population has no concern with floods	Floods do not represent a problem to the population
2	The population has not experienced floods in recent times	The population has not experienced floods in recent times
3	The population has little experience with floods;they have not created institutions for flood mitigation. Population does not realize the effects of their actions towards flood protection	The population has little experience with floods;they have not created river basin organizations for flood mitigation. Population does not realize the effects of their actions towards flood protection
4	The population has little experience with floods; institutions have neglected their responsabilities. Population does not realize the effects of their actions towards flood protection and are not prepared for emergency situations	The population has little experience with floods; river basin organizations have neglected their responsabilities. Population does not realize the effects of their actions towards flood protection and are not prepared for emergency situations
5	The population has experienced floods a long time ago, so that institutions still exists, popualtion is not aware of these institutions; budget is enough, there is no flood insurance	The population has experienced floods a long time ago, so that river basin organizations still exists, popualtion is not aware of these institutions; budget is enough, population is not prepared
6	The population has experienced floods; they have recently created institutions to mitigate the harms of floods, budget is scarce, awareness and preparedness is in process of being raised	The population has experienced floods; they have recently created river basin organizations to mitigate the harms of floods, budget is scarce, awareness and preparedness is in process of being raised
7	The population has experienced floods for a long time; they have created and have little trust in institutions to mitigate the harms of floods, populations has limited concern over their actions towards flood protection and are not quite prepared for emergency situations	The population has experienced floods for a long time; they have created and have little trust in river basin organizations to mitigate the harms of floods, populations has limited concern over their actions towards flood protection and are not quite prepared for emergency situations
8	The population has experienced floods for a long time; they have created and have some trust in institutions to mitigate the harms of floods, there is no flood insurance, population understand the consequences and restrictions of their actions, they are prepared for certain emergency situations	The population has experienced floods for a long time; they have created and have some trust in river basin organizations to mitigate the harms of floods, population understand the consequences and restrictions of their actions, they are prepared for certain emergency situations
9	The population has experienced floods for a long time; they have created and trust in institutions to mitigate the harms of floods, limited flood insurance, population understands the consequences and restrictions of their actions, they are prepared for emergency situations	The population has experienced floods for a long time; they have created and trust in river basin organizations to mitigate the harms of floods, population understands the consequences and restrictions of their actions, they are prepared for emergency situations
10	The population has experienced floods for a long time (know the potential for floods in the area); they have created and have high trust the institutions to mitigate the harms of floods, they have flood insurances, they understand the consequences and restrictions of their actions towards flood protection, they are prepared for emergency situations	The population has experienced floods for a long time (know the potential for floods in the area); they have created and have high trust in river basin organizations to mitigate the harms of floods, the population understands the consequences and restrictions of their actions towards flood protection, they are prepared for emergency situations

Table 5-2 Economic Recovery Scale

Scale	River Basin & Sub-catchment
Score	**Indicating**
10	All economic activities are strongly damaged, and they may not recover for years
20	The most representative economic activity is strongly damaged, but will recover after a long period of time (years)
30	The most representative economic activity is damaged, but will recover after some time (months)
40	The most representative economic activity is slightly damaged, but will recover after a short period of time (weeks)
50	Some economic activities are strongly damaged., they will recover after a large period of time (years)
60	Some economic activities are damaged., they will recover after some time (months)
70	Some economic activities are slightly damaged., they will recover after a short period (weeks)
80	Some small non-representative economic activities are very damaged, because of this they may recover only after a long time
90	The economy is damaged slightly in some non-representative economic activities, which will recover in little time
100	The economic activities of the region; agriculture, industry, commerce, etc., are almost not affected by floods, neither on the short term or on the long term

For most of the indicators collected on this spatial scale, the allotment method was used to determine an average value from data of different countries, that way giving weight to each country based on the proportional area represented in the entire area of the river basin (Figure 5.4).

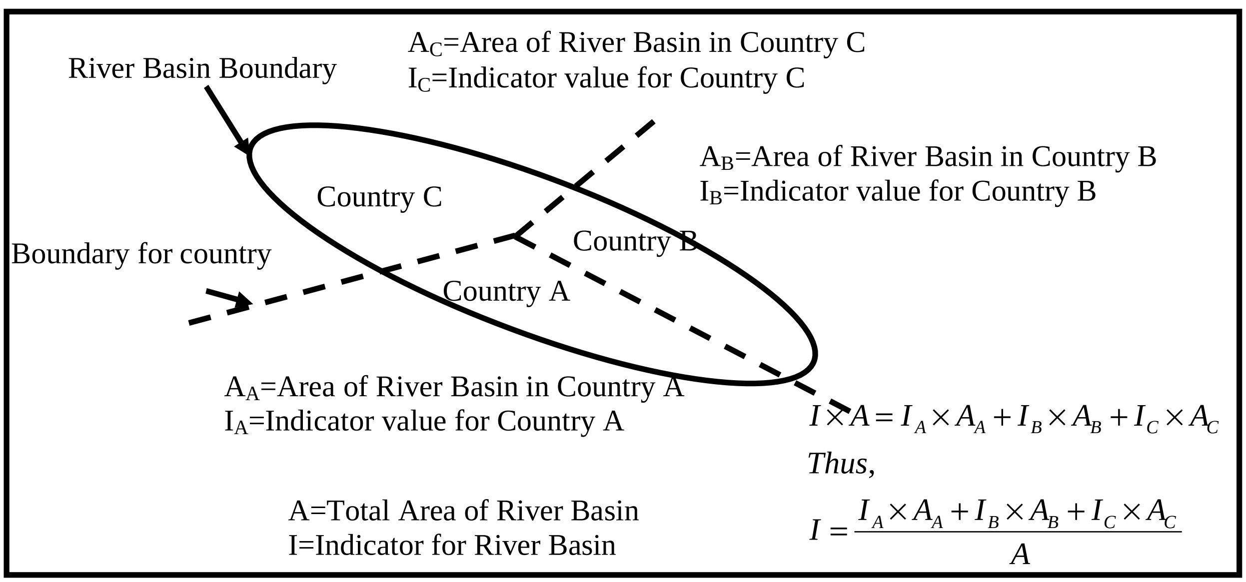

Figure 5.4 Explanation of allotment method (Connor & Hiroki, 2005)

5.3 Results and discussions on the River Basin Scale

After data collection only one indicator remained to be identified. The total storage capacity of the Danube River Basin is still unknown. Therefore a sensitivity analysis was carried out to evaluate the real weight this indicator has on the FVI value. This indicator influences two of the FVI components; economical and physical (see section 5.3.2 and 5.3.4).

The remaining river basins studied have data from the sources mentioned in the previous section 5.2.4. Alongside the FVI values for each component, standardized results are presented for further comparison between components and the current FVI and also serve the purpose of easier interpretation. The formula used to standardize FVI values between 1 and 0 is presented as:

$$sFVI = \frac{FVI_{basin}}{FVI_{\max}} \qquad 5.1$$

5.3.1 Social Component

The values of the indicators were used in equation 4.1, described in section 4.3.2. The FVIs results are shown in Figure 5.5.

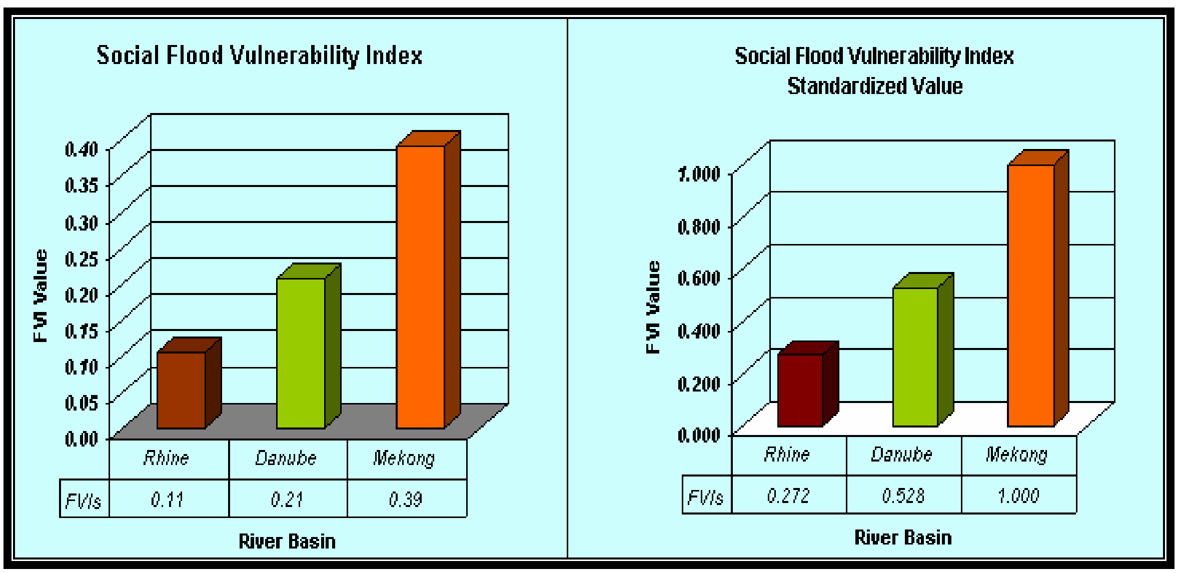

Figure 5.5 Normal and Standardized Values for FVIs at river basin scale

Nine indicators are used to determine the FVIs values, divided in vulnerability factors as: two represent exposure, three for susceptibility and the remaining four for resilience.

The river basin most socially vulnerable to floods is the Mekong, followed by the Danube, and the Rhine as the least vulnerable. Considering the vulnerability factors, the Mekong is the most exposed, most susceptible and the least resilient, even though in some factors the difference is not large, as is the case with the susceptibility of all river basins.

The high resilience of the Rhine River Basin is mainly due to the communication penetration rate and evacuation roads, which is sometimes more than double the values presented for the other river basins. The Danube River Basin presents itself as caught between two extreme cases.

Some justification can be found in these results by looking at the amount of people affected by floods in the last ten years in the three river basins. The Mekong has experienced five times more distress than in the Danube and over 30 times more than the Rhine.

5.3.2 Economical Component

Seven indicators are used to determine the FVIec values, see section 4.3.2. As mentioned before, a sensitivity analysis had to be carried out for the Danube River Basin with the values of storage capacity. The results of this analysis are presented in Figure 5.6:

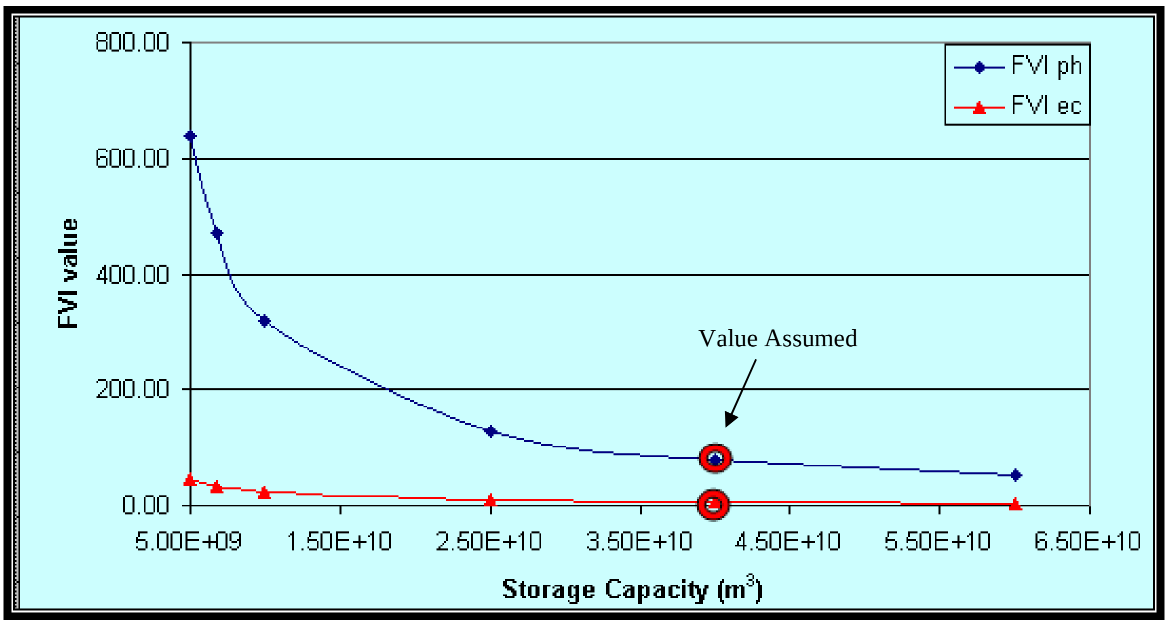

Figure 5.6 Sensitivity Analysis of the Danube River Basin for Dams and Storage Capacities

Figure 5.6 shows the rate of change of the economical FVI in the Danube River Basin, based on a ranging in storage capacity. The economical FVI is not largely affected by the value of storage capacity, however a value of 40 billion m^3 was used because of the large catchment area and the storage volume of some of its dams, for example Iron Gate I and II, whom together store more than 5 billion m^3.

The results of the economical FVI component, using equation 4.2 of section 4.3.2, are presented in Figure 5.7.

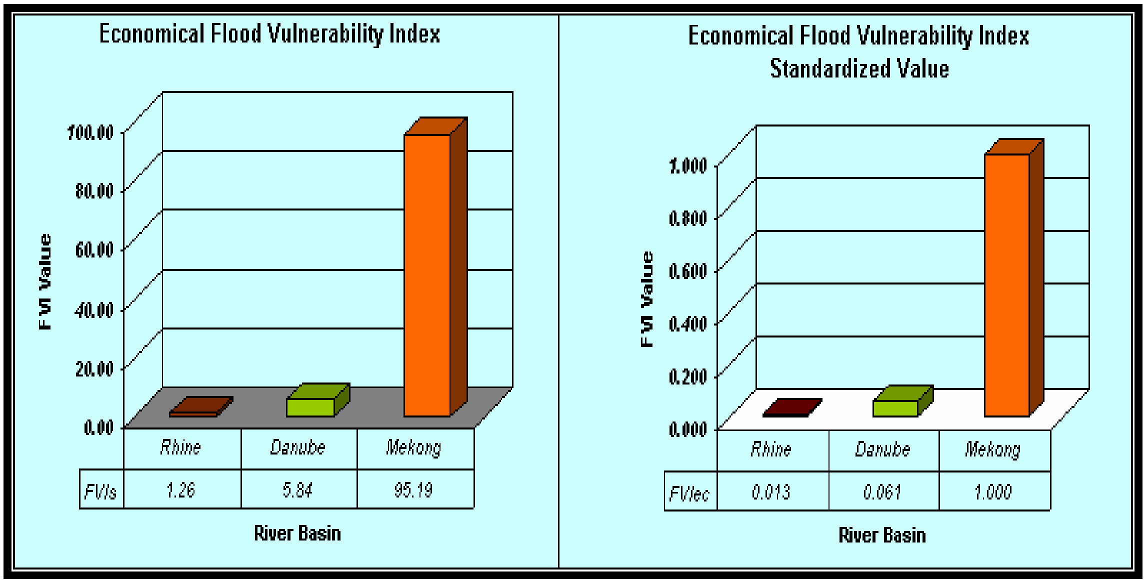

Figure 5.7 Normal and Standardized Values for FVIec at river basin scale

As seen in Figure 5.7, the values of the Rhine and the Danube are very low compared with the values of the Mekong, which is over 50 times higher than the Rhine and 10 times more than the Danube.

The indicators selected to analyse the economical FVI favours those basins with a large storage capacity, such as the Rhine and the Danube, as a measure of economic wellbeing and resilience. The Mekong has a higher economical vulnerability due to relative low investments in flood protection and low storage capacities to protect the economic activities of the region.

The other factors of vulnerability, exposure and susceptibility, have little influence, especially exposure which is represented in the equation by only one indicator.

The low value for the Rhine River Basin can be misinterpreted as not being economically vulnerable to floods. However this is not the case since all systems can be damaged under certain conditions. This low value must be interpreted as that the conditions for which the system is vulnerable are unlikely to happen. A down scale study may present more detailed results for further interpretation, for example a study has been done for the Neckar River (see section 5.5.2)

5.3.3 Environmental Component

Six indicators are used to identify the environmental FVI, with the particularity that none of them represent resilience to environmental factors, and 5 of them are a factor of exposure, leaving only 1 for susceptibility. The results are presented in Figure 5.8.

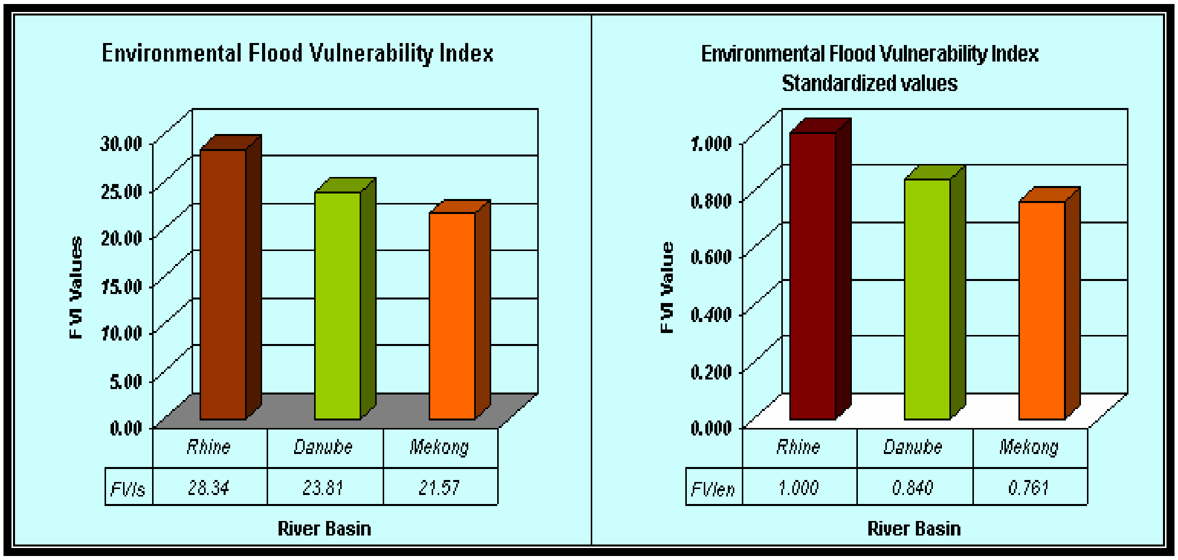

Figure 5.8 Normal and Standardized Results for Environmental FVI

The results shown indicate that the Rhine River Basin is more vulnerable to Environmental impacts as a result of flooding. However, with very little difference with the other two case studies, the Mekong River Basin is the least environmentally vulnerable. The FVI values are so close to each other, that a more detailed study is needed for any reasonable comparison.

The environmental exposure of the Rhine is almost 5 times higher than the Mekong; this can be explained by the large industrialization process which the Rhine River has sustained for decades, leading to an environmental degradation of the river. However, this value is restored by the percentage of natural reservations which exist in the Rhine after the environmental concerns of the last 20 to 30 years, leading to the concept of *room for the rivers*, which is not (yet) know in the Mekong.

In this case the results may be misleading because of the definitions of the indicators. The susceptibility indicator of Natural Reservations can be interpreted in different ways, comparing the western and developing world. For further analysis, downscaling may lead to a more detailed interpretation.

5.3.4 Physical Component

Like for the Economical component, a sensitivity analysis had to be carried out to analyse the influence of the storage capacity for in Danube River Basin on the physical FVI, the results are shown in Figure 5.6, where it can be seen that the rate of change for the physical FVI is much higher than for the economical component. A change in the assumption of this value may considerably change the value of the physical FVI. Therefore a more downscaled analysis is needed for this component.

For the assumed value for Storage Capacity of 40 billion m^3, as mentioned in section 5.3.2, the physical FVI results are presented in Figure 5.9.

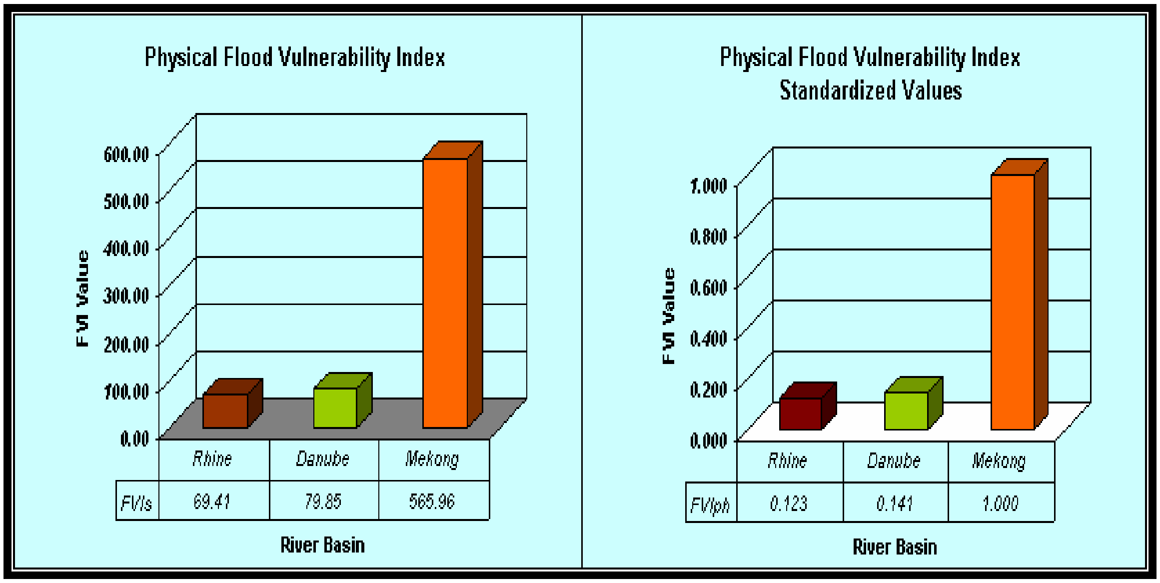

Figure 5.9 Normal and Standardized Results for Physical FVI

The results show a large difference between the Rhine and the Danube, who are very close to each other, and the Mekong, which is more than seven times higher. This FVI component is largely related to the storage capacity of the basin, as could well be explained by the sensitivity analysis made in the Danube River. In this case, the storage capacity of the Mekong is very low compared with the Rhine, considering the uncertainty in the Danube River Basin.

Six indicators are selected to represent the physical vulnerability to floods, with the particularity that five of them are exposure indicators and the remaining one for resilience. The most exposed river basin is the Mekong, but not by a large ratio of difference. The main difference lies in the resilience indicator of each river basin, represented by the basin's storage capacity.

The Mekong presents a storage capacity which is five times lower than the Rhine, and six times lower than the assumed storage capacity of the Danube.

5.3.5 Summary of Results

The different FVI components have been summed to calculate a total FVI, the results are shown in Figure 5.10. For the river basin scale the FVI results were compared with the existing FVI methodology (Connor and Hiroki, 2005), which are presented in Figure 5.11. Figure 5.12 shows these values in graphical form.

The results for the total FVI show that the Mekong River is the most vulnerable as it was in three of the four components explained previously. The high difference is encountered in the economical and physical components, where it can be more than respectively ten and five times as compared to the Rhine and Danube River Basin.

There is much difference between the cases studied. The Mekong represents the most vulnerable of all. The factors which influence this result can be contributed to exposure and resilience. Susceptibility may be the most equal of the factors studied, even though the Mekong is the most susceptible of all.

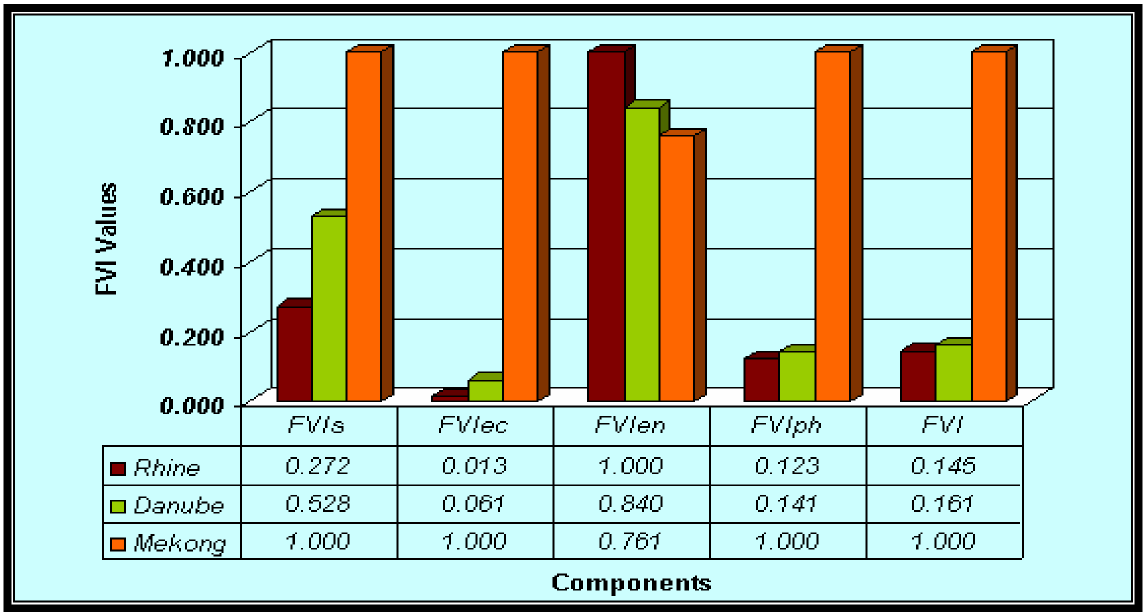

Figure 5.10 Overall Standardized Results for FVI at River Basin Scale

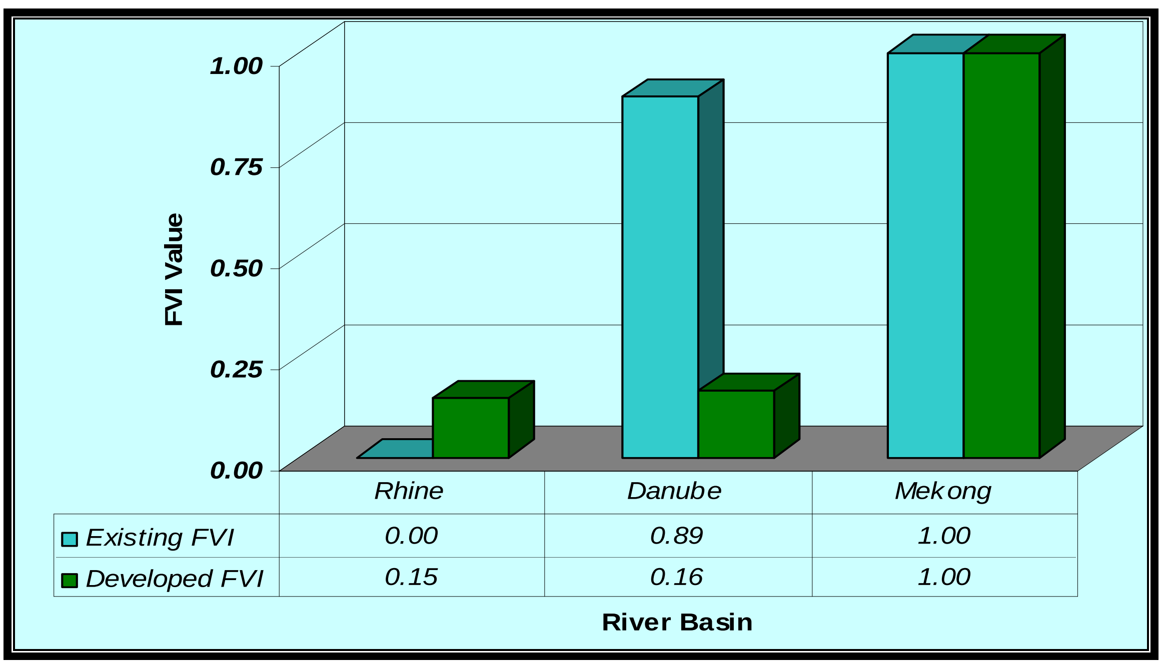

Figure 5.11 Comparison between Methodologies

Policies to improve these factors in the Mekong river basin may reduce the vulnerability to floods in all components. Additional care should be taken in increasing the resilience at all levels, especially with regard to economic and physical components.

The existing FVI methodology (Hiroki & Connor, 2005) uses the following equation to standardize (FVI between 1 and 0) the values obtained:

$$sFVI = \frac{FVI_{basin} - FVI_{\min}}{FVI_{\max} - FVI_{\min}} \tag{5.2}$$

The overall FVI's, illustrated in Figure 5.11 show the same trend, with the Mekong being the most vulnerable, and the Rhine the least, and the Danube in between. However, for the existing FVI, the Danube is closer to the Mekong.

The FVI value obtained for the Rhine equals zero for the existing methodology. This value can be misleading, since it can be misinterpreted as the Rhine having no flood vulnerability. In the newly developed methodology, there is still a minimal room for vulnerability, even though in the case of the Rhine this result is very low.

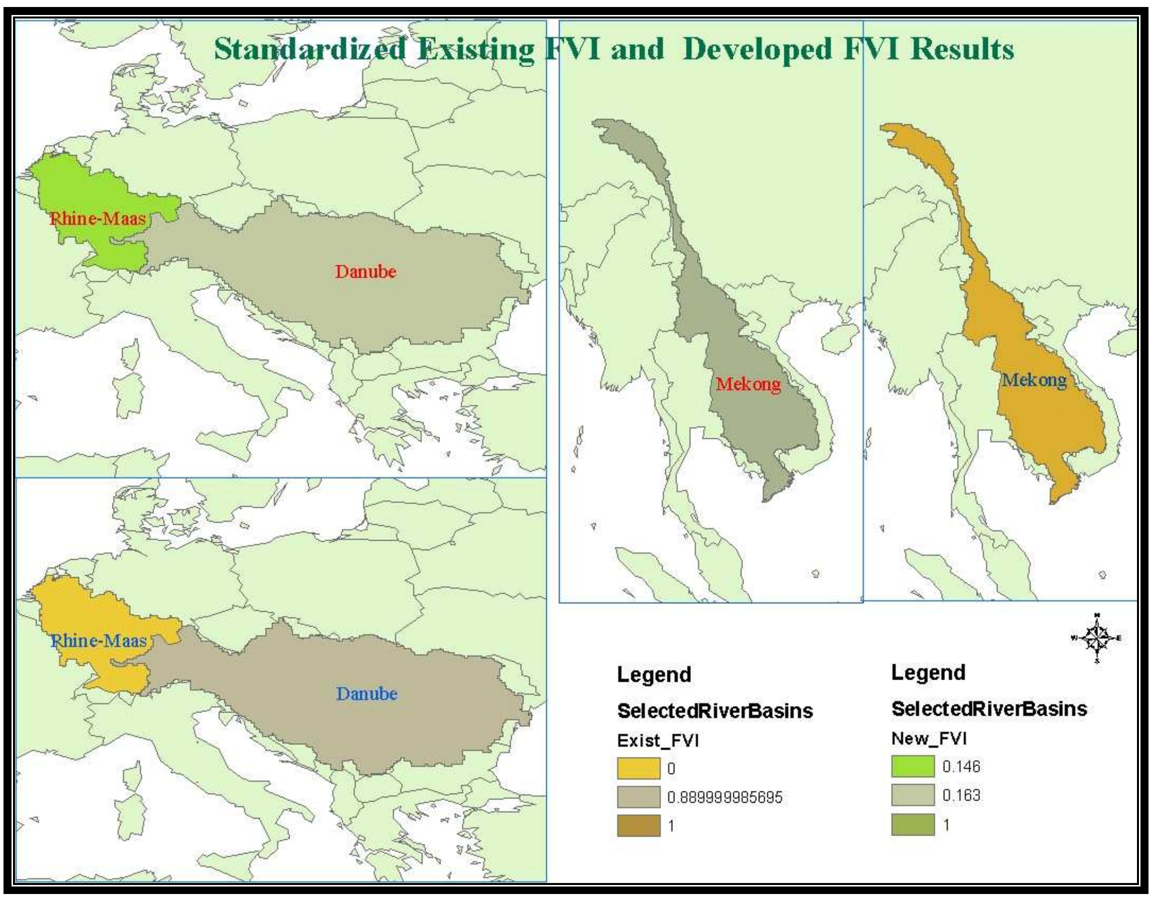

Figure 5.12 Maps of River Basins, for comparisons of FVI methodologies

5.4 Case study: Description of the case studies on Sub-catchment Scale

As expressed in section 4.4 the term sub-catchment describes an area of land that drains part of a river basin down slope to its lowest point.

For this study five sub-catchments were selected; three in the Danube River Basin: Tisza, Timis and Bega Rivers, one in the Rhine Basin: Neckar River and one in the Mekong Basin: Mun River.

A comparative analysis of the results from river basins and sub-catchments (downscaling) will be carried out to assess the robustness of the FVI methodology. These sub-catchments were also selected because it allows comparisons between river basins and sub-catchments, besides comparing some sub-catchments in the same river basin. The selected sub-catchments have different social, economical, environmental and physical conditions.

5.4.1 Tisza Sub-catchment

The Tisza is the longest tributary of the Danube (966 km in Hungary) and drains an area of 157,186 km² in five countries (Slovakia, Ukraine, Hungary, Romania, Serbia and Montenegro) with a population of 14,200,000 inhabitants. The length of the river is 1,358 km and has a maximum river discharge of 4,000m^3/s, see Figure 5.13. Its large size it a River Basin inside the Danube (Jolankai, 2004, ICPDR, 2004).

The Tisza can be divided into three main sections: the Upper Tisza in Ukraine, the Middle Tisza in Hungry, Slovakia and Romania and the Lower Tisza in Serbia-Montenegro and Romania. Its main tributaries are: the Bodrog, Slava, Somes, Mures, Crisul and Bega.

Large scale floods in the Tisza River occurred in 1895, 1913, 1932, 1940-42, 1947-48, 1964, 1970, 1974, 1979, 1985 (ice-jams), 1993, 1998, 1999, 2000 and 2001 (Szlávik, 2003).

Between 1998 and 2001, four extraordinary floods occurred in the Tisza River Basin. Considering the magnitude of the endangered areas, the populations threatened, and the goods damaged, these floods broke every record in the upper and middle Tisza areas (ICPDR, 2004).

Figure 5.13 Tisza Sub-catchment (UNEP)

The Tisza got into the global spotlight in January 2000, when two industrial accidents occurred along a tributary in north-western Romania; a tailing of an explosion close to Baia Mare (Romania). Almost 100,000 m^3 of waste water, containing 120 tones of cyanide and heavy metals was released into the river. The second accident was in March 2000 when another tail dam burst occurred in Baia Bocsa, the material was retained within the dam complex (ICPDR, 2004).

5.4.2 Timis Sub-catchment

The Timis is a 359 km long river originating in the Semenic Mountains, southern Carpathian Mountains, Caras-Severin County, Romania (Figure 5.14). It flows through the Banat region into the Danube near Pancevo, in northern Serbia. The drainage area covers 13,085 km^2 (in Romania 8,085 km^2, in Serbia 5,000 km^2) with a population of around 800,000 inhabitants. The maximum river discharge measured was 1,290 m^3/s at Graniceri in 2005.

Figure 5.14 The Timis River (DFO) and b) Floods on the Timis River in spring 2005

The Timis River main tributaries are: the Raul Rece, Slatina, Valea Mare, Rugiu, Armenis, Sebes, Poganis, Timisul Mort and Barzava.

Flooding with 'large damage' occurred in 1912 (Q= 1,500 m^3/s), 1966 (Q= 1,200 m^3/s), 2000 (Q= 1,100 m^3/s), 2005 (Q= 1,200 m^3/s), 2006 (Stanescu and Drobot, 2005).

5.4.3 Bega Sub-catchment

The Bega River is a 254 km long river in Romania (178 km) and Serbia (76 km). It originates in the Poiana Rusca mountains in Romania, part of the Carpathian Mountains, and it flows into the Tisza river near Titel, Vojvodina, Serbia. The drainage area covers 2,878 km^2 with a population of around 500,000. The Bega River is a part of the Tisza sub-catchment.

In the middle part of the river a diversion scheme was built to transfer water from the Bega River to the Timis River, regulating a maximum of 83 m^3/s of discharge through the Bega River, as stipulated in the convention with Serbia. The scheme of both rives and the diversion structure is shown in Figure 5.15.

This diversion scheme works as a flood protection device for the lower part of the sub-catchment, including important cities in Romania and Serbia like Timisoara and Zrenjanin.

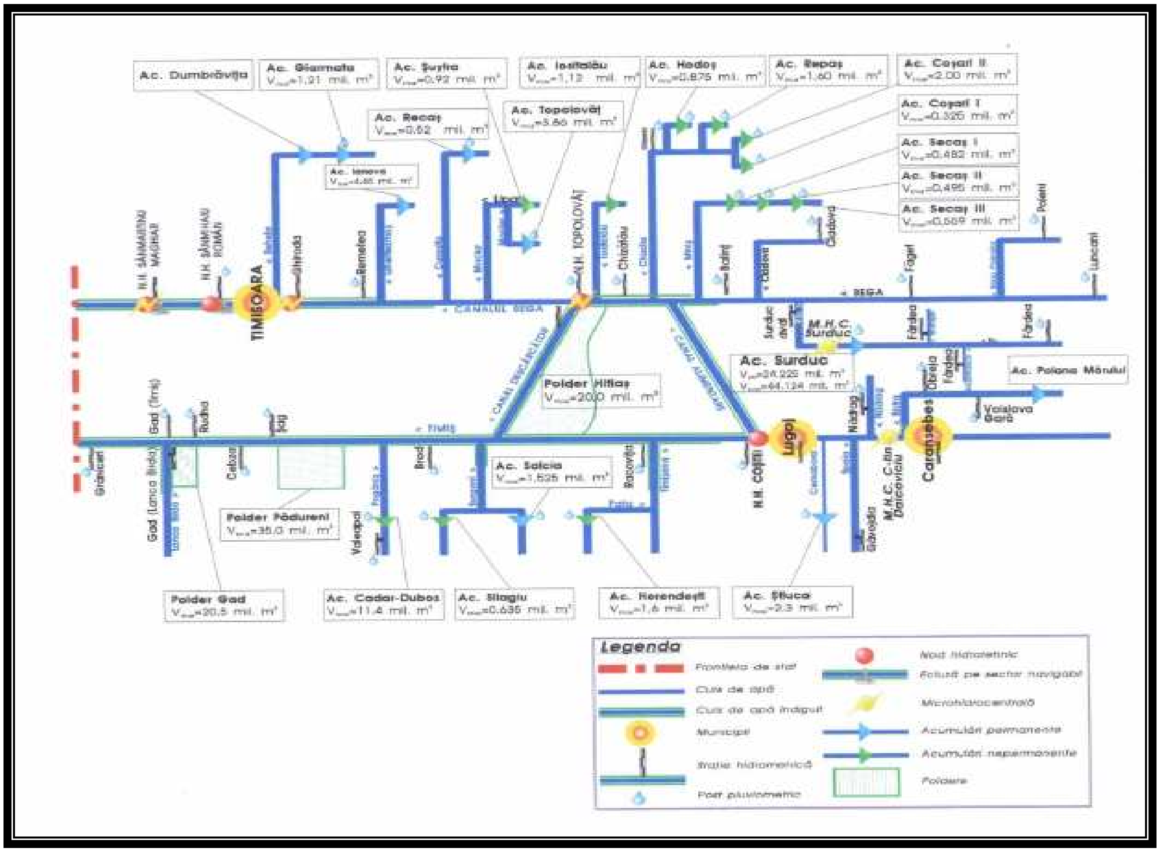

Figure 5.15 Bega-Timis Interconnection (Banat Water Directorate, Romania)

5.4.4 Neckar Sub-catchment

The Neckar River in Germany is 367 km long and it is a major tributary of River Rhine which confluences near the city of Mannheim. It originates in the Black Forest (like the Danube).

The drainage area covers around 14,000 km² and the river has an average discharge of 2,557 m^3/s. The population of the sub-catchment is around 2,500,000 inhabitants.Flooding with large damage occurred in 1529, 1651, 1663, 1744, 1784, 1789, 1817, 1824, 1844, 1882, 1970, 1978, 1990, 1993, 1994 and 2002 (IKONE, 2006)

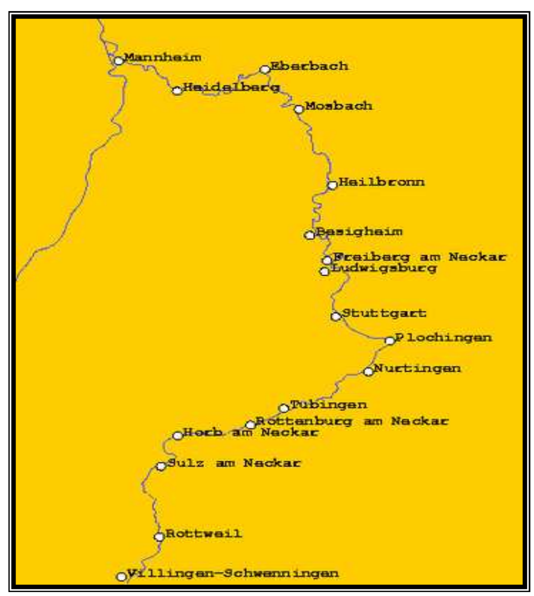

Figure 5.16 Neckar River

5.4.5 Mun Sub-catchment

The Mun River is a tributary of the Mekong River. It originates in the Khao Yai National Park in the Isan area of Thailand. Its length is 673 km, until it joins the Mekong at Khong Chiam in Cambodia. The main tributary of the Mun River is the Chi River (Wikipedia, 2006). The livelihoods of 10 million people living in the river basin (drainage area of 70,961 km²) depend on the richness of riverine ecosystems and natural resources. The average discharge is 760 m^3/s.

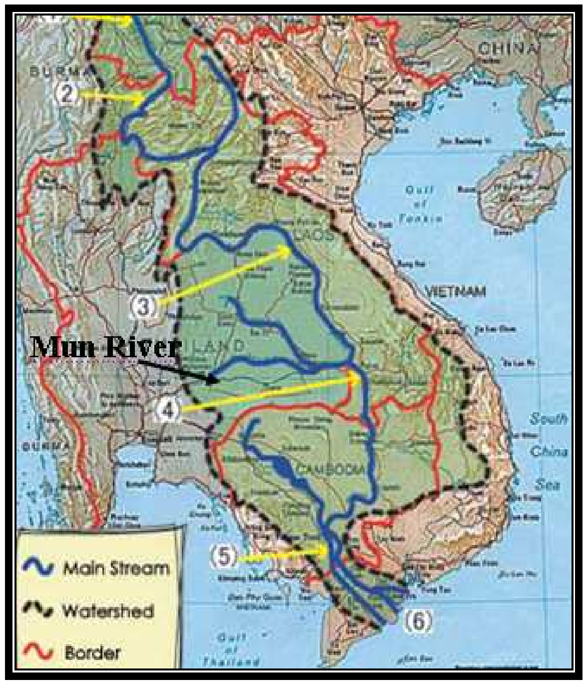

Figure 5.17 Mun River (MRC, 2005)

In the last 45 years between 1962 and 2007, 14 flood events occurred in the sub-catchment of the Mun River, the large floods where in 1962, 1966, 1969, 1972, 1976, 1982, 1983, 1991, 2000 and 2001 (Thai National Mekong Committee, 2005).

Though South East Asia faces monsoon flooding every year, 2006 brought unusually heavy and widespread flooding; 39 people have died in Thailand since August 2006 because of monsoon flooding, and at least 138,000 others have suffered from waterborne illnesses (EO, 2006).

5.4.6 Data collection sub-catchment case studies

The sub-catchment scale FVI equations require 35 out of 71 different indicators, as mentioned in section 4.4.2**.** The values of flood vulnerability indicators for the sub-catchment scales were found on the internet. More than 20 web-sites were consulted for all five sub-catchments; ten of these were used for the river basins: UNDP/BCPR, INTUTE, EPI, CRED/EM-DAT, UN, Ekstrom et al., 2006, World FactBook, WRI, Water Resources eAtlas and MRC.

Other sources were used for the European sub-catchments: PELCOM, Pan-European Land

Use and Land Cover Monitoring, data from urbanized area have been collected; Wikipedia, which also provided data for the Mun Sub-catchment on topography, and Google Earth which was used to determine the average distance of populated areas to the river.

Other sources used are: The World Commission on Dams, the Romanian Water Authority, the Romanian Environmental Ministry, Tisza River Basin Economic Development Programme, Tisza Flood action plan, IKONE project, Aktionsplan Hochwasser Neckar, UNEP and an article by Weesakul (2005). For case specific data more information is shown in Appendices II (a, b, c, d and e).

5.5 Results and discussions on the Sub-catchment Scale

After data collection five out of thirty-five indicators remain to be identified. The total storage capacity of the Tisza River is still unknown, the amount of annual flood protection investments of the Tisza and the Mun rivers are unidentified and also the kilometres of dikes and levees of the Neckar and the Mun rivers must be deduced. Therefore a sensitivity analysis has been carried out to evaluate the real weight these indicators have on the FVI value.

The storage capacity indicator influences two of the FVI components; economical and physical. The amount of annual investment influences only the economical component of the Tisza and the Mun sub-catchments, the dikes and levees influences the physical component of the Neckar and Mun rivers.

Alongside the FVI values for each component, standardized results are presented, using the same approach as illustrated in section 5.3.

5.5.1 Social component

The values of the social component indicators were used in equation 4.5, described in section 4.4.2. The results of the social FVI are shown in Figure 5.18.

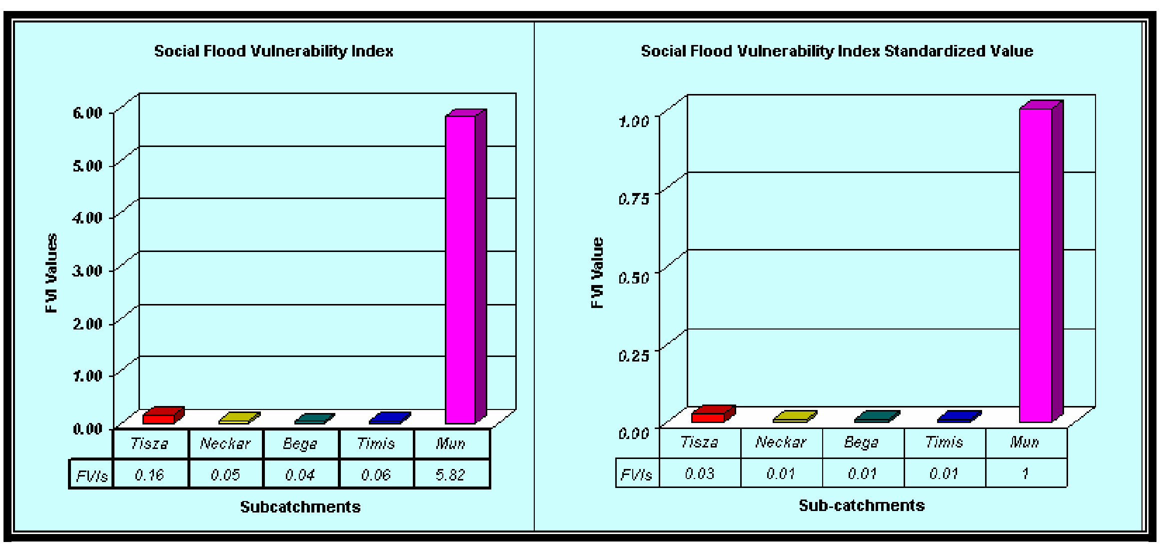

Figure 5.18 Normal and Standardized Values for FVIs at sub-catchment scale

Ten indicators are used to determine the social FVI values. The indicators are divided in the following vulnerability factors: three for exposure, two for susceptibility and the remaining five for resilience.

The Mun River is socially the most vulnerable to floods, due to the large amount of people living there. In addition this sub-catchment is also the most exposed and resilient of all.

Tisza river is the second most socially resilient, because of this, its high social exposure to floods is counteracted.

The Bega, Timis and Neckar Rivers have a very low social vulnerability to floods, due to high resilience; all of them show different values of social exposure. The least socially exposed to floods is the Bega River, a value which can be confirmed by the diversion works upstream of the river, which leaves only the sparse upstream population vulnerable to floods. The Neckar River experienced floods in the middle part of the 20^{th} century, which made its population more aware and direct their investments in flood protection actions, such as increasing Communication or Evacuation roads.

One indicator that confirms these values is the high amount of affected people of the Mun River over the last ten years. Close to 10% of the total population in the sub-catchments has been affected by floods, a number far exceeding the other sub-catchments.

5.5.2 Economical Component

Nine indicators are used to determine the economic FVI values. As mentioned before sensitivity analysis had to be carried out with the indicator values of storage capacity for the Tisza sub-catchment and amount of annual investments for the Tisza sub-catchment and for the Mun sub-catchment. The results of these analyses are presented in Figure 5.19, Figure 5.20 and Figure 5.21 respectively.

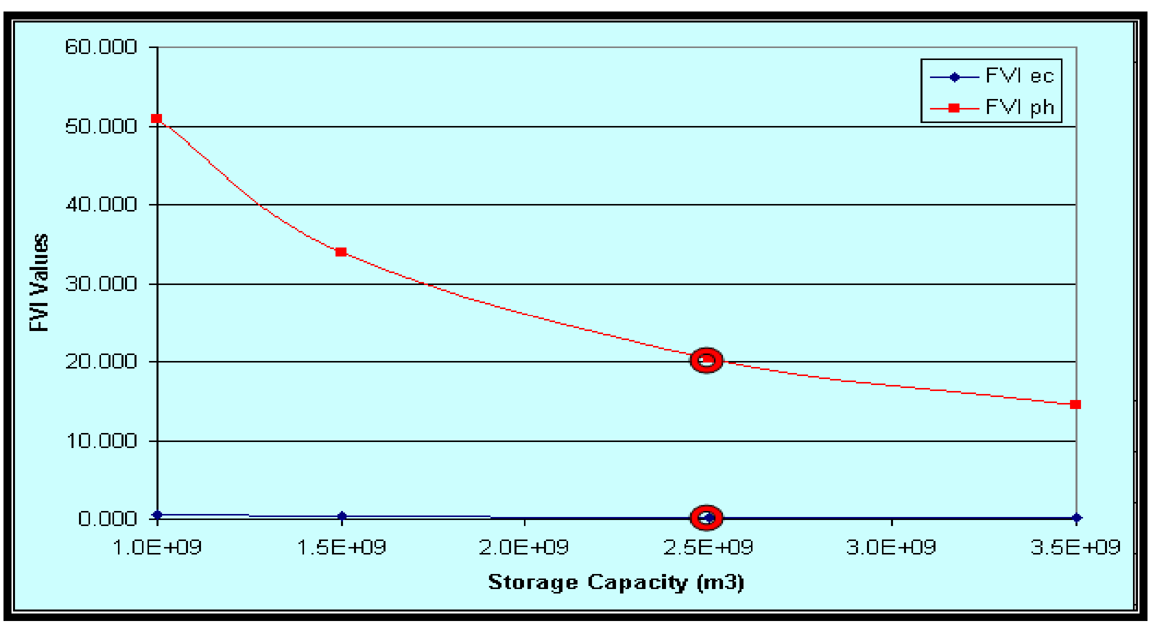

Figure 5.19 Sensitivity analysis of Storage Capacity for Tisza Sub-catchment

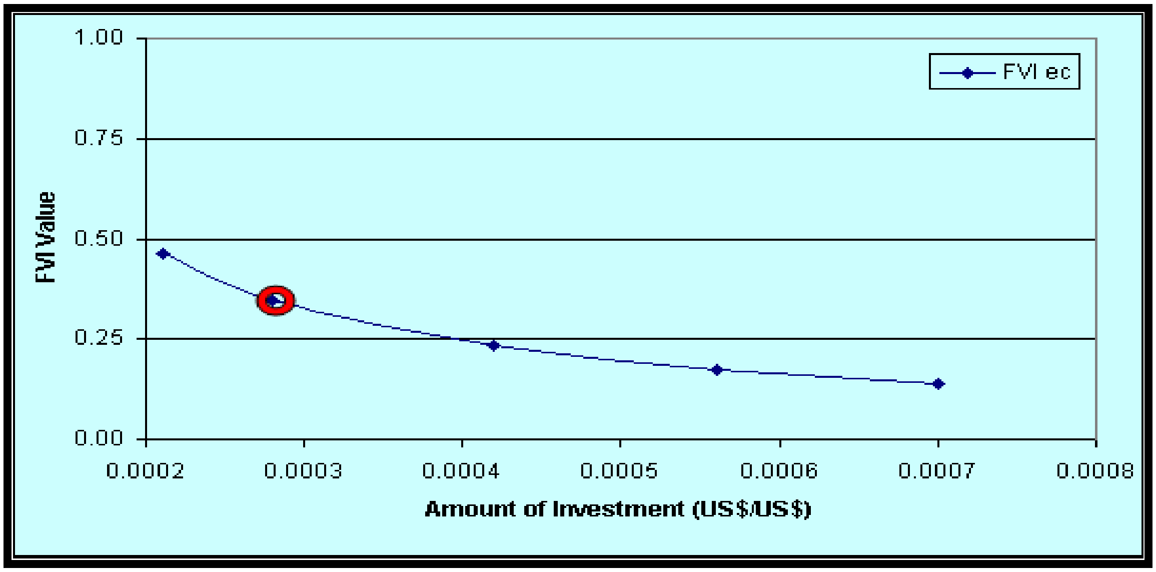

Figure 5.20 Sensitivity analysis of Amount of Investment for the Tisza Sub-catchment

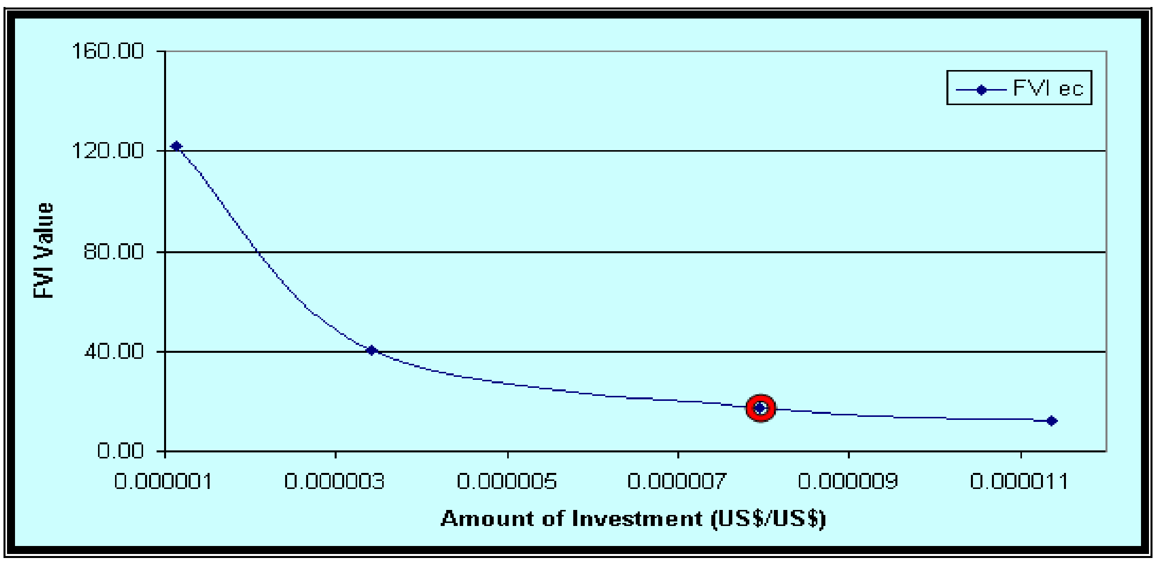

Figure 5.21 Sensitivity Analysis of Amount of Investment for the Mun Sub-catchment

As seen in Figure 5.19 the storage capacity does not have a large influence on the economic FVI component, since the rate of change of the economical FVI is relatively low when the storage changes, especially for larger storage volumes. A similar trend occurs for the values of amount of investment, where a change in this value only slightly changes the economical FVI, as seen in Figure 5.20 for the Tisza sub-catchment. For the Mun River (Figure 5.21), the curve presents two different trends; the one on the left presents a high rate of change, and the one on the right, a lower one. This may raise a sensitivity question, since the assumed values, presented by a red spot, appears on the right (less steep) side of the curve.

For the Tisza River a storage capacity of 2.5 billion m^3 was assumed because of the large storage capacity in Hungary, where a large part of the catchment is situated; close to 30% of the sub-catchment belongs to this country. The largest part of the sub-catchment is situated in

Romania, but the storage capacity in this area is relatively small. The storage capacity of the whole sub-catchment is mainly situated in Hungary.

The amount of annual flood protection investments for Tisza was considered to be € 40 million (US$ 52 million), knowing that the total investment on flood protection for the Danube is € 220 million (US$ 288 million), and the countries belonging to the Tisza sub-catchment are not developed countries, the percentage of this amount was considered to be smaller.

The graph in Figure 5.21 shows an annual investment of US$ 700,000 in the Mun sub-catchment, a value which was assumed because of its position in a developing country, and low amount of investments in the entire Mekong River Basin (US$ 6 millions), which focuses more on flood protection in the Mekong Delta.

To evaluate the economical component nine indicators are used, divided in two indicators for exposure, three for susceptibility and four for resilience.

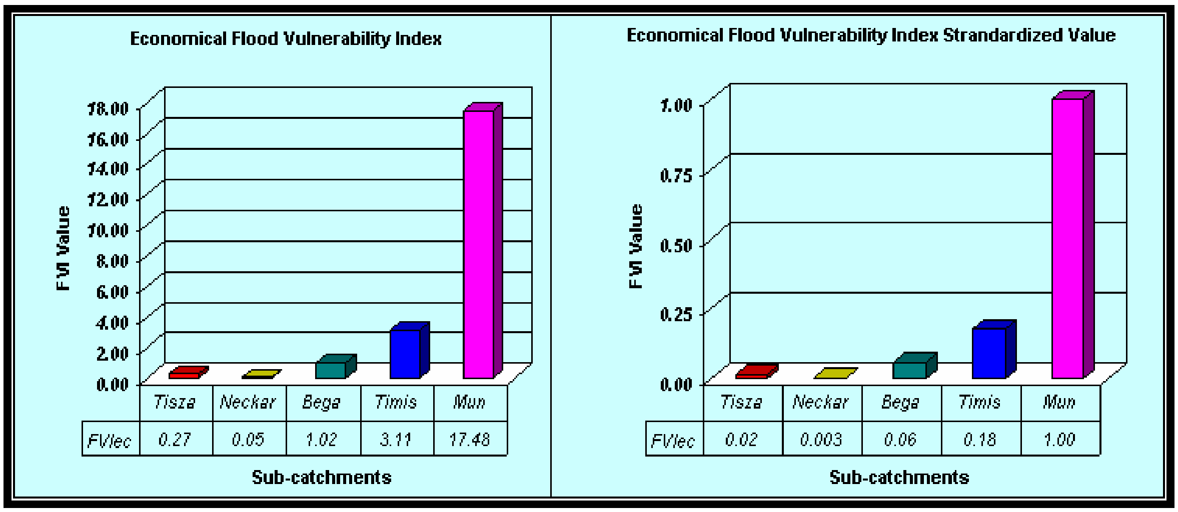

Figure 5.22 Normal and Standardized Values for FVIec at sub-catchment scale

Figure 5.22 shows the values for the economic vulnerability to floods, as computed using equation 4.6, in section 4.4.2. The value for the Mun River is the highest, meaning that this sub-catchment is the most economically vulnerable to floods. This is underpinned because of the agricultural nature of the sub-catchment, which needs a relative long time in case of floods to recover from the damages in this economic sector.

In Europe, the Bega and Timis Rivers are the most economically vulnerable rivers, following the Mun. These rivers are connected to each other by a diversion structure, which transfers the water from the Bega to the Timis River. Therefore only the upstream part of the Bega River is vulnerable to floods. Its economic FVI value can be explained by the sparse rural population, of which its main economic activity is agriculture with relative low flood resilience. The Timis River is more economically vulnerable due to this diversion, leaving the economically active downstream zones more exposed and less resilient.

The Tisza River is the second most susceptible sub-catchment studied, but is also the second most resilient. It is not a highly exposed river, but its economic FVI reflects that it's not highly economically vulnerable to floods. However, these data must be verified, since two indicators were assumed after a sensitivity analysis.

The Neckar River appears to be the less vulnerable to floods regarding economic activities. Industrial facilities are well protected from flooding events, and the vulnerability is reduced by the existence of flood insurance, which measures the economic wellbeing of the region and reduces its recovery time. These factors make the Neckar River the least economically vulnerable sub-catchment of the five studied, which can be verified by also being the most resilient sub-catchment, despite being also the most susceptible.

5.5.3 Environmental Component

A total of seven indicators are used to determine the environmental FVI, three of them are for exposure and the remaining four for susceptibility. In the equation 4.7 (section 4.4.2) no indicator represents resilience to environmental FVI. The results for the five case studies are presented in Figure 5.23.

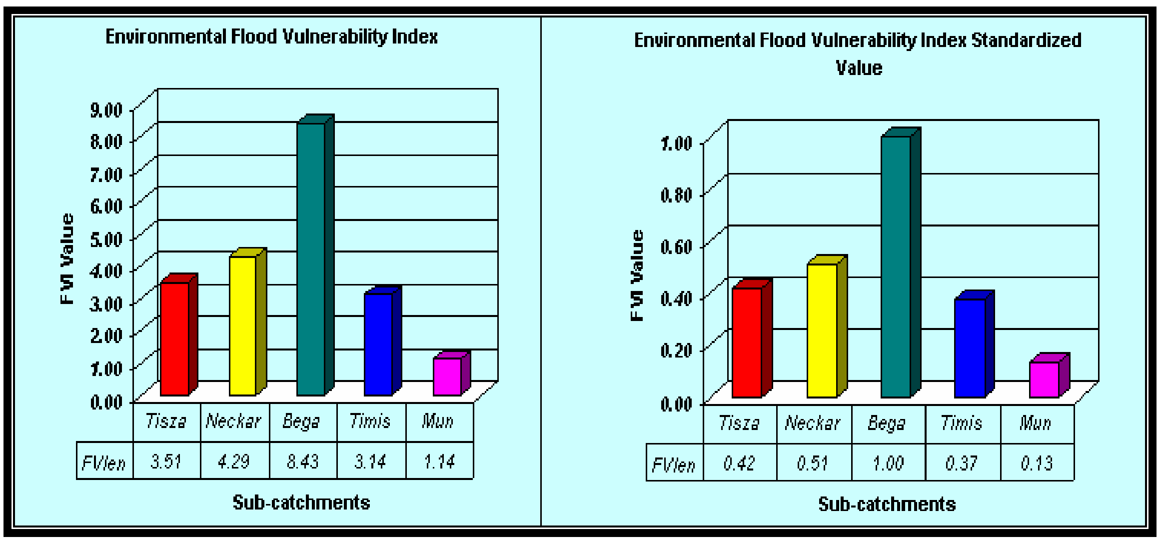

Figure 5.23 Normal and Standardized Values for FVIen at sub-catchment scale

As seen in Figure 5.23, the most environmentally vulnerable sub-catchment is the Bega River, almost double the value of its closest rival, the Neckar River. For the Bega River, environmental concerns relate to the non-natural flow that the river experiences downstream of the diversion scheme, creating damages to the ecology of the river, evidenced by poor fish growth, algae and eutrophication in some parts of the river.

The Neckar River has experienced environmental problems as well, due to large industries and lack of concern for many years. This way of thinking has changed in the last 20 years to a more environmentally friendly approach of river management; these improvements have contributed to the reduction of floods damages.

The Tisza and the Timis Rivers have very similar values, but their values correspond to very different factors; the Tisza being more susceptible and the Timis more exposed. Knowing these values may help in the analysis to define strategies for the reduction of this FVI. For the Timis a strategy focusing on reducing exposure will be more efficient, contrary to the Tisza, where a strategy should focus on reducing susceptibility.

Contrary to the previous discussed components the Mun River is the least vulnerable to environmental flood damages. This value can be explained by the low anthropogenic influence over the sub-catchment, which makes it the most exposed, but also the least susceptible.

5.5.4 Physical Component

Four indicators are used to determine these values, two of the indicators are a factor of exposure and the other two of resilience.

As mentioned before sensitivity analysis had to be carried out with the values of storage capacity for the Tisza sub-catchment and Dikes and Levees for the Neckar sub-catchment and for the Mun sub-catchment. The results are presented in Figure 5.19 (section 5.5.2), Figure 5.24 and Figure 5.25 respectively.

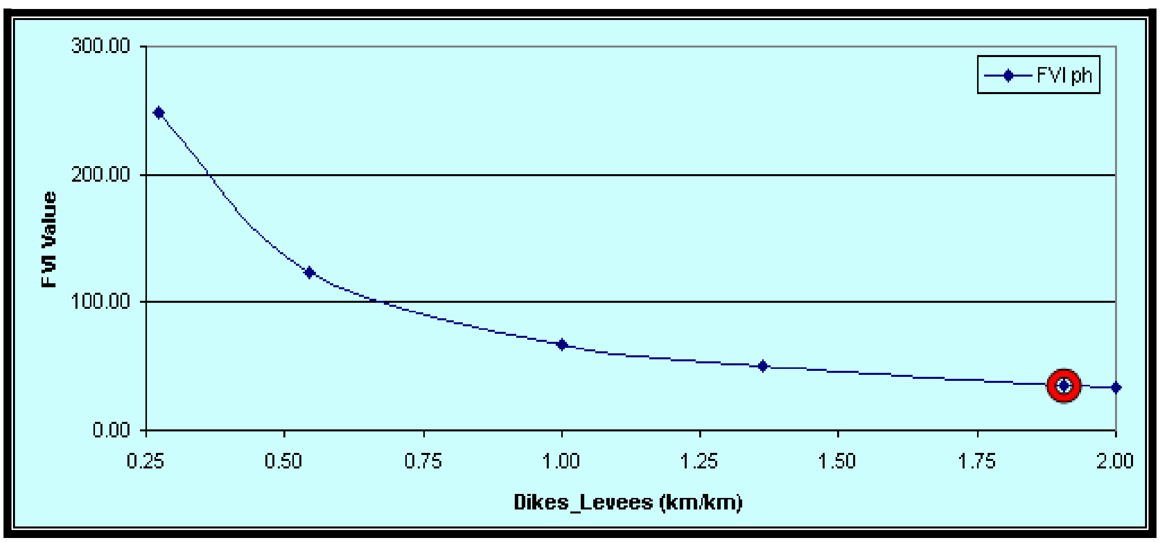

Figure 5.24 Sensitivity Analysis of Neckar Sub-catchment for Dikes Levees Indicator

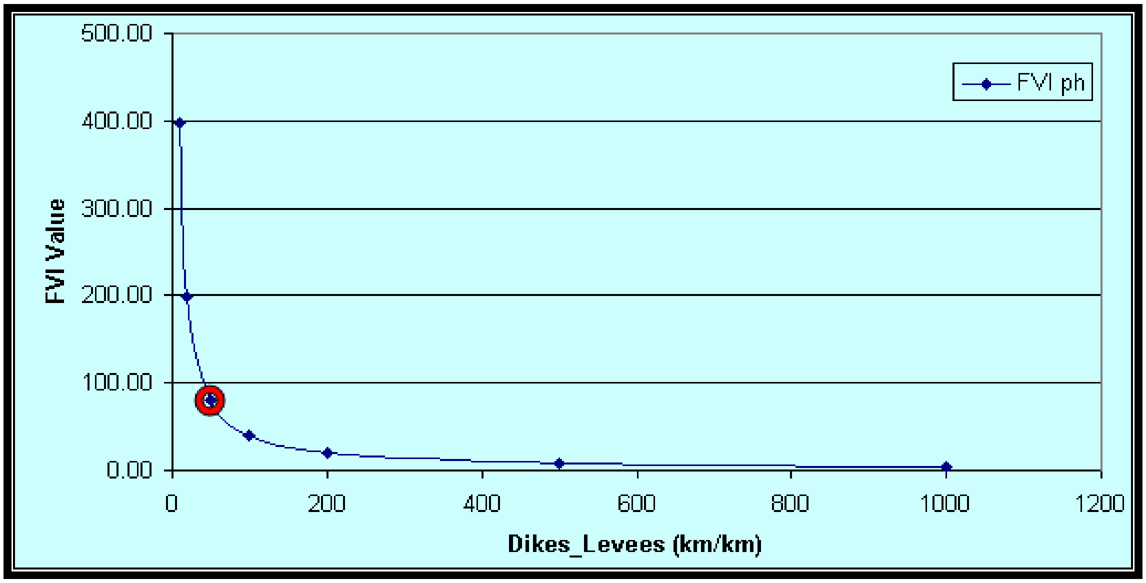

Figure 5.25 Sensitivity Analysis of Mun Sub-catchment for Dikes Levees Indicator

Figure 5.19 shows the sensitivity analysis of storage capacity in the Tisza River, it illustrates curves for the physical and economical component. Even though the curve for the physical component shows a larger sensitivity than the curve for the economical component, it shows that values within a certain range close to the selected value of 2.5 billion m^3 will not vary considerably.

The sensitivity analysis of the Neckar Sub-catchment for the Dikes and Levees indicator is shown in Figure 5.24. The curve shows that for a selected value of 700 km of dikes (the indicator is defined as km of dikes over the total length of the river) the steepness of the curve is small, any values along this range are considered more accurate for this sub-catchment based on the economic development and the lack of environmental concern experienced until recently in the region.

The sensitivity analysis of the Mun Sub-catchment for the Dikes and Levees indicator is shown in Figure 5.25. In this case the value selected is a highly sensitive part of the curve, where any change in the value may modify the result of the physical FVI to a large extend. In this case it is recommended to continue the research of the Mun sub-catchment until reliable sources for this indicator are found. The assumed value of 50 km of dikes was taken from visualization of Google Earth digital images, a source which can be considered as unreliable.

Figure 5.26 shows the values found for the physical vulnerability to floods, as computed using equation 4.8, in section 4.4.2. Taking the assumed value as mentioned before, the Mun river is the most physically vulnerable to floods. This can be certified by its severely low resilience, even though it also has the lowest exposure value.

The Neckar River follows in physical vulnerability, with a value close to half of the Mun. The main physical problem is its high exposure, due to high average river discharge and low storage capacity. The same problem experienced in the Tisza river, however, a higher resilience is decreasing its physical vulnerability.

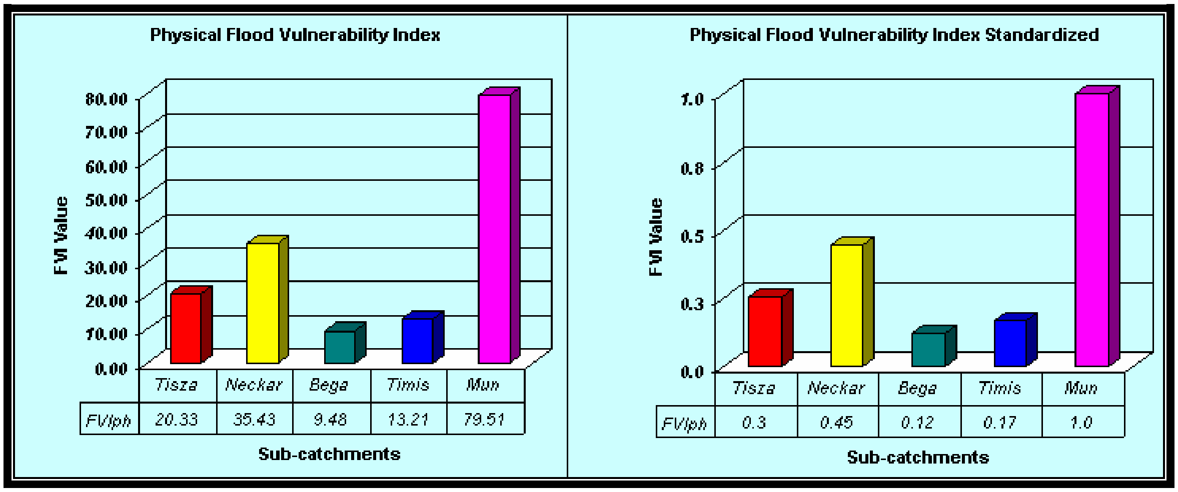

Figure 5.26 Normal and Standardized Values for FVIph at sub-catchment scale

The Bega and Timis Rivers are close in results for their physical vulnerability to floods, with hardly any difference in exposure or resilience. Their main difference relies on the average discharge, which is bigger in the Timis River. They have the lowest FVIph results of the sub-catchments studied.

5.5.5 Summary of results

The results for the FVI in all components and the total FVI, are summarized up in Figure 5.27. It clearly shows that the Mun is the most vulnerable sub-catchment to floods of the five studied, followed by the Neckar River. The other three; the Tisza, Timis and Bega Rivers have similar values.

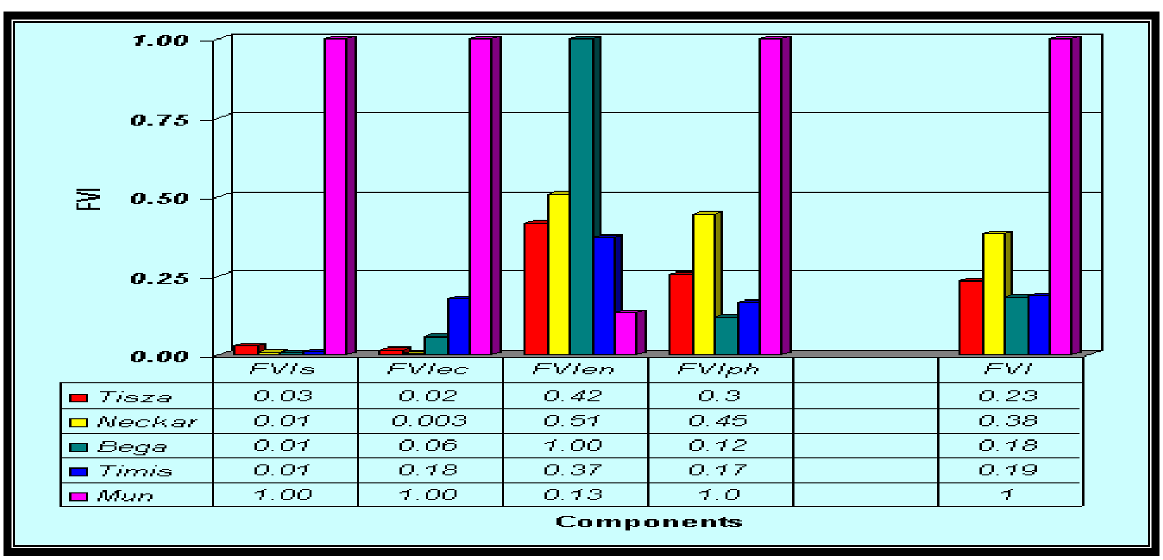

Figure 5.27 Comparison between sub-catchments standardized values

In all components the Mun River is the most vulnerable, with the exception of the environmental component. Especially social and economically, the Mun River experiences a high vulnerability to floods. Developing plans to reduce these two components may reduce the total FVI of the Mun River.

5.5.6 Downscale Analysis of Results

Since the study of river basins covers large areas, interpreting the FVI can be limited or misleading. Therefore the study of smaller spatial scales can lead to a more accurate evaluation of the FVI of a region. Interpreting the values of all sub-catchments in one river basin can provide a sharper image of the situation of the basin.

Three sub-catchments in the Danube River basin were selected to downscale and analyse the FVI results; Tisza, Bega and Timis Rivers. These rivers are close to each other, the Bega River is a tributary of the Tisza River, and the Timis river drains in the Danube just close to 10 km after the Tisza river confluences. Some of their physical characteristics are very similar, for example rainfall and evaporation.

These similarities result in more or less equal values of FVI, even though there are some differences in the results of the FVI components. A comparative graph of the results from the Danube River Basin and its studied sub-catchments is shown in Figure 5.28. The highest FVI values always occur in the river basin scale, over any of its sub-catchments.

As mentioned before, all three studied sub-catchments have almost the same value of FVI, values which are smaller compared with the whole river basin. This might indicate that the sub-catchments studied have smaller flood vulnerability with respect to the river basin. Other sub-catchments in the river basin should have higher flood vulnerability to balance the results for the river basin. Locating and reducing the flood vulnerability of these sub-catchments would also reduce the flood vulnerability at the river basin scale.

This aspect of the FVI methodology can be used as a policy tool for directing investments at most vulnerable areas at a local and regional level, reducing the vulnerability at a large-scale level.

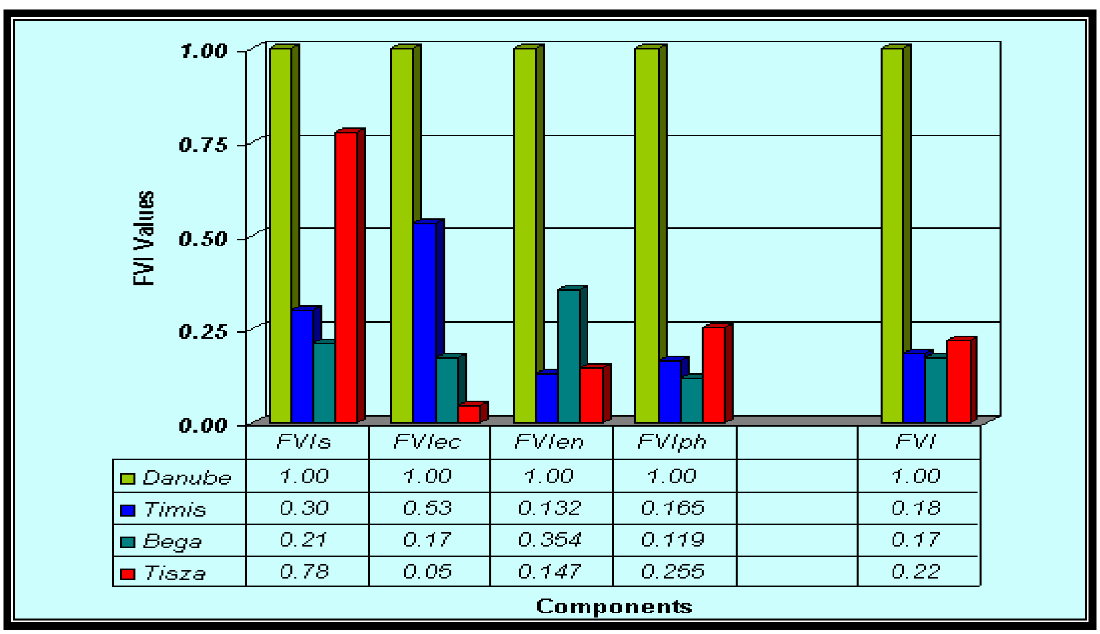

Figure 5.28 FVI comparison between Danube River Basin and its Sub-catchments

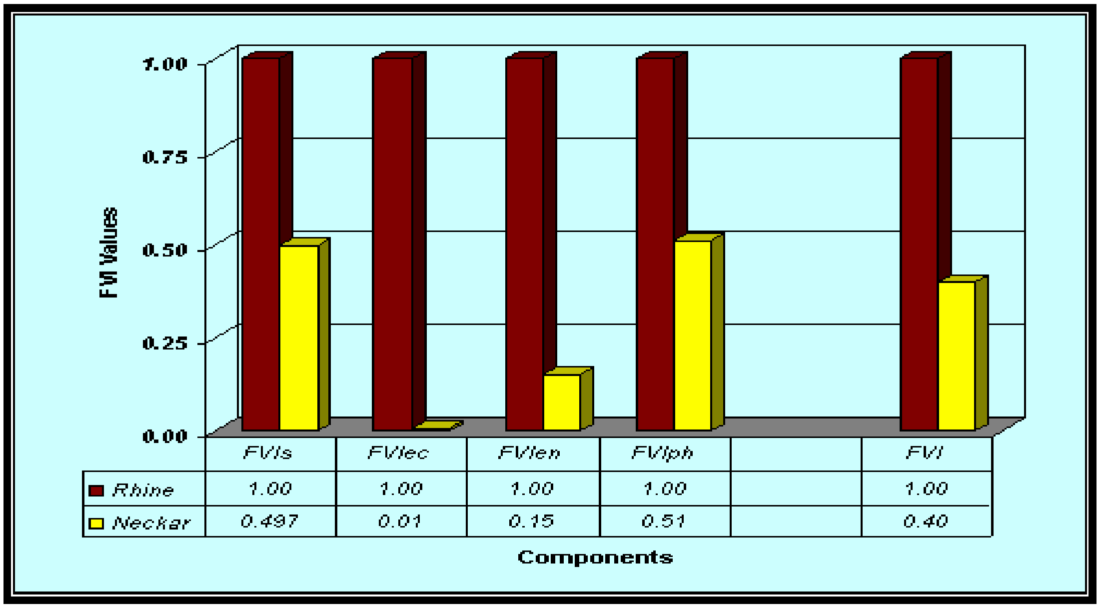

Figure 5.29 FVI comparison between Rhine River Basin and Neckar Sub-catchment

Figure 5.29 shows the comparison between the Rhine River Basin and its sub-catchment Neckar, just like in the Danube and its sub-catchments. The FVI values for the river basin scale are always higher than the sub-catchment scale.

These values are as expected, since the Neckar River is a very important economical part of the Rhine River, and many efforts have been done to promote flood protection by different ways, including; renaturation, awareness rising and implementing a real time warning system. Other sub-catchments in the Rhine River basin are more vulnerable to floods and further studies are needed to identify them to reduce the FVI at river basin scale.

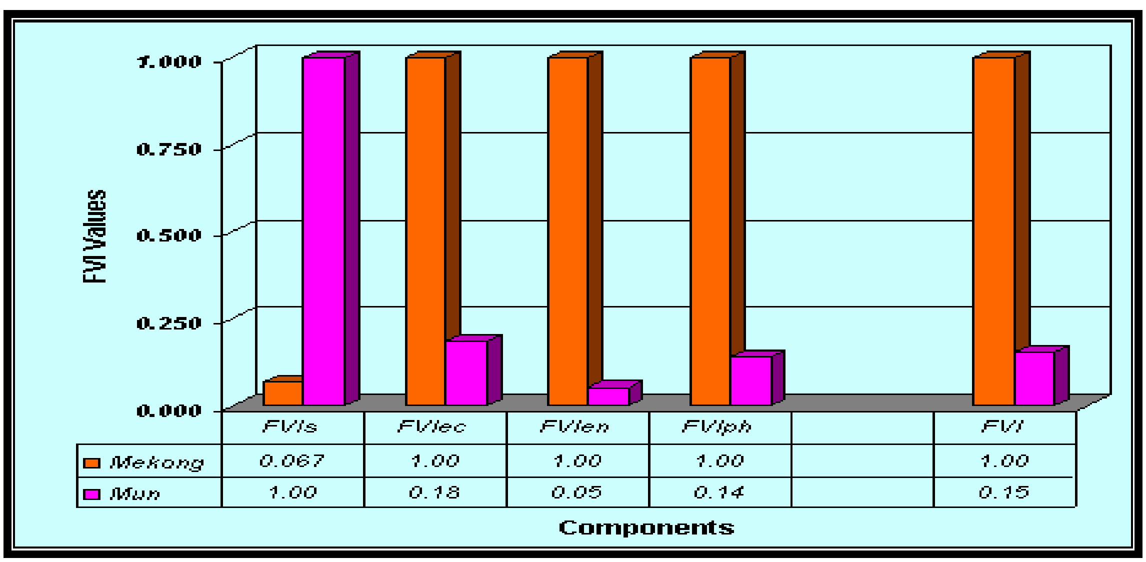

Figure 5.30 FVI comparison between the Mekong River Basin and the Mun Sub-catchment

Figure 5.30 describes the comparison between the Mekong River Basin and its sub-catchment Mun. As the other case studies, the Mekong river basin is more vulnerable than its sub-catchment, with the exception of the social component, where the Mun sub-catchment is more vulnerable than the Mekong River Basin. This can be certified by the fact that the Mun River is 30 times more susceptible than the Mekong and that the Mekong River Basin is socially five times most resilient to floods than the Mun River.

A further analysis of these downscaling results would have to include a more detailed quantification of the impacts of the sensitivity analysis on certain indicators for the sub-catchment scale, which was needed for three of the five sub-catchments studied. With the exception of one indicator, the dykes and levees indicator in the Mun sub-catchment, the values assumed do no represent a large range of change in FVI results. The FVI values for sub-catchments always remain below the values of river basin, for the cases studied.

The sub-catchment study is more detailed than the river basin study, something which can be certified by the higher amount of indicators needed to calculate the FVI at sub-catchment level. Some indicators which were not considered at river basin level were considered at sub-catchment, because they could be easier to find at smaller scales, or they would not be representative at larger scales. This condition should make a study of all sub-catchments in a river basin more representative than the study of a whole river basin, a study which is recommended to do in future researches.

5.6 Case study: Description of the case studies on Urban Scale

The three case studies for urban areas were selected because of their different flood history, their location within a sub-catchment and River Basin or their social and economic background. Timisoara, in Romania, was selected due to its location, along the Bega River in the sub-basin of the Tisza and in the Danube River Basin; a developing city, with a large resilience to floods. Mannheim city was chosen due to its location in a developed country; Germany, and also because of its position at the confluence of two big rivers, the Rhine and Neckar and lastly Phnom Penh city, which is in a least developed country; Cambodia, with a large exposure to floods.

5.6.1 Timisoara City, Romania

Timisoara is a city in the Banat region of western Romania. With a population of 336,089 inhabitants in 2006, it is the capital City of Timis County. The area of the city is 130.5 km^2.

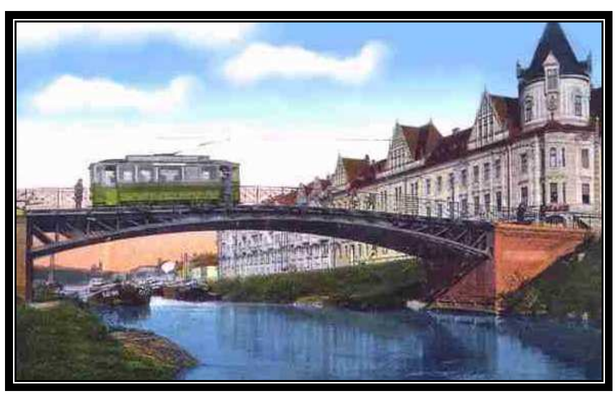

Figure 5.31 Timisoara City

Timisoara is one of the largest cities in Romania, it is a large economic as well as cultural centre in Banat in the country.

The Bega River is crossing Timisoara with an annual discharge of 83 m^3/s. The city after the construction of the diversion upstream (see Figure 5.15) has never experienced flood events.

5.6.2 Mannheim City, Germany

Mannheim is a city in the west of Germany, situated near the confluence of the Rhine and Neckar River. The city has a population of 307,640 inhabitants living in an area of 145 km^2. Mannheim is one of the richest cities of Baden-Wurttemberg Region. The city is highly developed, with more than 10 large industries, which are close to its banks.

Figure 5.32 Mannheim City

The Neckar River which crosses the city of Mannheim before entering the Rhine River, has an annual river discharge of 145 m^3/s.

5.6.3 Phnom Penh City, Cambodia

Phnom Penh is located in the south-central region of Cambodia, at the confluence of the Tonle Sap Lake and Mekong rivers. Being the capital of Cambodia, Phnom Penh is its largest and most populous city; it is also the commercial, political and cultural centre of Cambodia. Phnom Penh is home to 2,009,263 inhabitants of the country's total population of almost 15,000,000. The city covers an area 367 km^2.

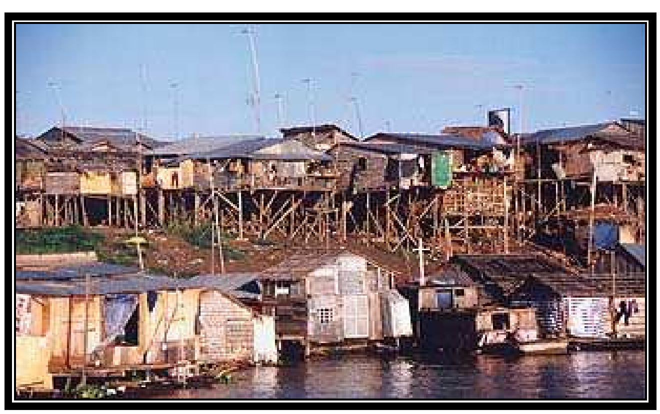

Figure 5.33 Phnom Penh City

The city is very exposed to floods because of its location. These flood events occur during heavy rainfall with very large discharges, a situation which is becoming more frequent

5.6.4 Data collection urban scale case studies

The urban scale FVI equations require 35 out of the 63 originally considered indicators, as mentioned in section 4.5.1**.** The values of flood vulnerability indicators for the urban scales were found on the Internet, through the Water Authority of Banat Region for Timisoara and the Standtentwasserung for Mannheim. Web-sites were consulted for all three urban areas; some of these were also used for the river basins and sub-catchments: UNDP/BCPR, INTUTE, UN, Ekstrom et al. (2006), World FactBook, WRI, ADB.

Other sources used for the urban areas are; Wikipedia, which provided data for Timisoara, Mannheim and Phnom Penh on topography and population density, and Google Earth which was used to determine the kilometres of dikes or levees and distance of contact with the river.

Additional sources used are: the Romanian Water Authority, the Romanian Environmental Ministry, Aquatim Timisoara and IKONE project, Aktionsplan Hochwasser Neckar. For specific data more information is shown in Appendices III (a, b and c).

5.7 Results and discussions on the Urban Scale

After data collection three of the 35 indicators remain to be identified. The total storage capacity of the Phnom Penh and Mannheim cities are unknown, the amount of annual flood protection investments of Mannheim city is unidentified, and the last is the Land use for green areas for the city of Mannheim. Therefore a sensitivity analysis was carried out to evaluate the influence these indicators have on the FVI value.

The storage capacity indicator influences two of the FVI components; economical and physical. The amount of annual investment influences only the economical component of Mannheim city, and Land Use was considered in the Environmental component equation.

Alongside the FVI values for each component, standardized results are presented, using the same approach as illustrated in section 5.3.

5.7.1 Social Component

The values of the social component indicators were used in equation 4.9, described in section 4.5.2; the results of the social FVI are shown in Figure 5.34.

Fourteen indicators are used to determine the social FVI values. The indicators are divided in the following vulnerability factors: five for exposure, two for susceptibility and the remaining seven for resilience.

Phnom Penh City is socially the most vulnerable to floods, due to the large amount of people living there. In addition this urban area is also the most exposed, susceptible, but also the most resilient of all (taking Tonle Sap Lake into account).

Mannheim is the second most socially resilient, the least social exposed and the least susceptible. Mannheim has a very low social vulnerability to floods.

Timisoara is second regarding the social component of vulnerability to floods, being also the second most exposed.

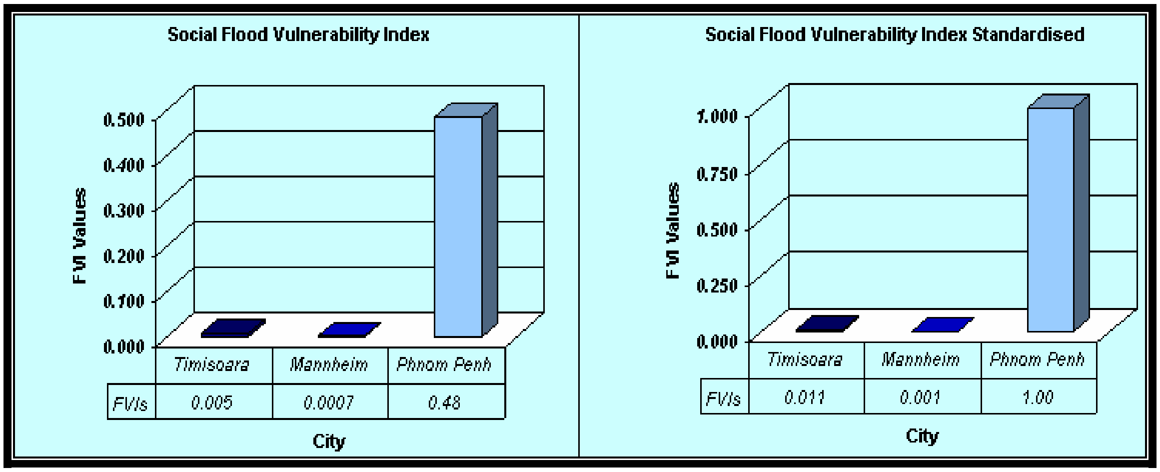

Figure 5.34 Normal and Standardized Values for FVIs at urban scale

5.7.2 Economical Component

Three of the indicators evaluated by a sensitivity analysis have an influence on the economic component of the FVI for urban areas. Figure 5.35, Figure 5.36 and Figure 5.37 show the values assumed for Storage capacity for Phnom Penh and Mannheim, and the amount of investment for the city of Mannheim.

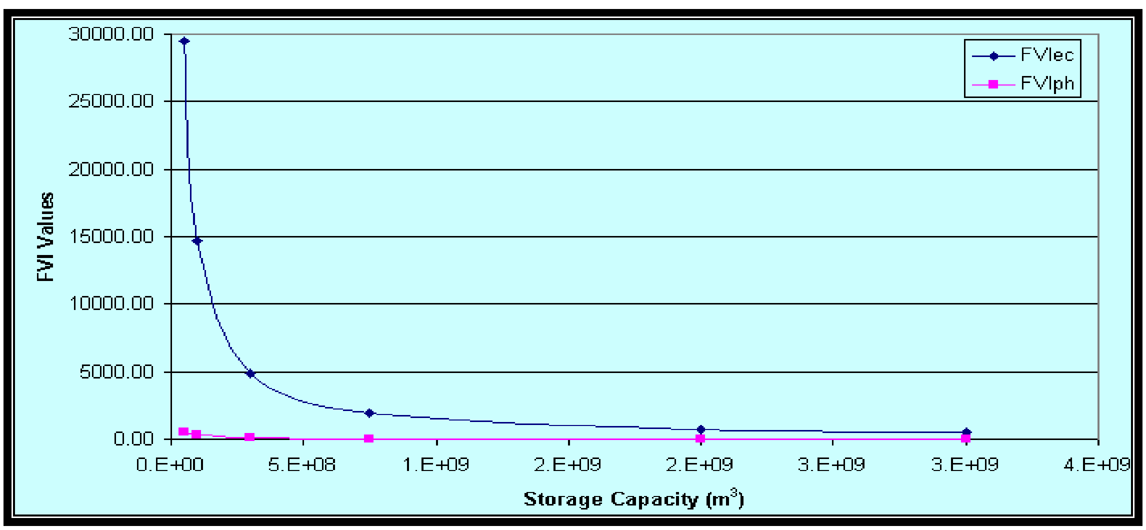

Figure 5.35 Sensitivity Analysis of Storage Capacity for Phnom Penh City

Figure 5.35 illustrates that the value for FVIec is largely sensitive to the value of storage capacity of the area; for the physical component the sensitivity is much less. The city has the particularity that the city is Tonle Sap lake is situated north of the city, which does limit the discharge of Mekong River, flowing to the east of the city, but protects it from heavy rainfall season. In the Mekong River, no relevant storage capacity structures were found, other than natural wetlands and floodplains.

Two extreme cases, considering and not considering the volume of storage capacity of Tonle Sap Lake were analyzed, as shown in Figure 5.38.

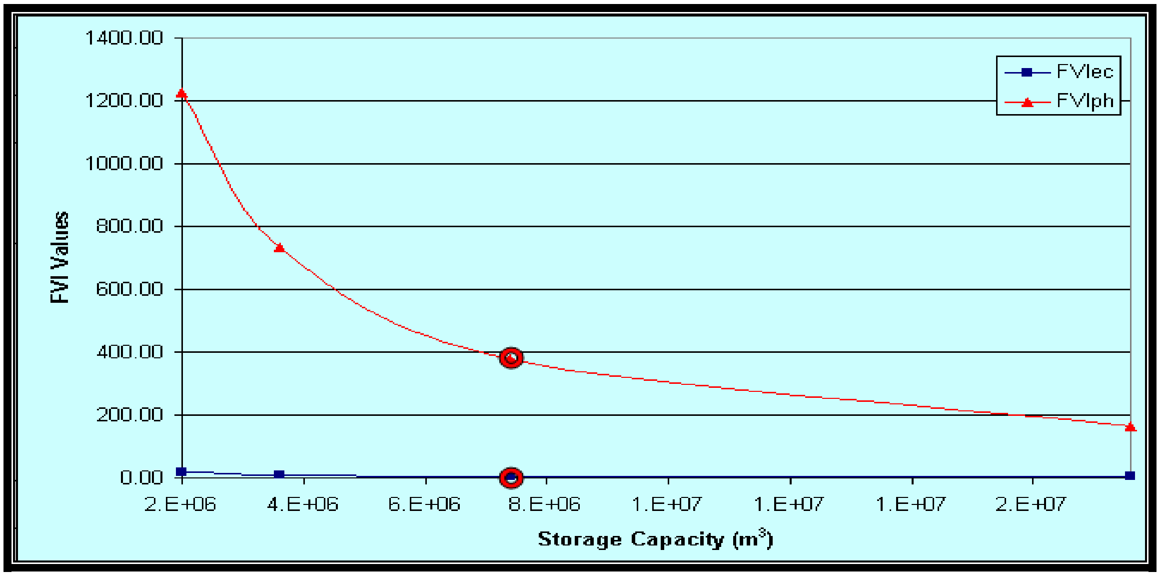

Figure 5.36 Sensitivity Analysis of Storage Capacity for Mannheim City

Figure 5.36 shows the small influence that assumed values of Storage capacity have on the results obtained for the economic component. The value chosen is the storage capacity of the Neckar River, considering that the river is 673 km long, this retention capacity improves the resilience of the cities downstream, including Mannheim.

In Figure 5.37, the curve for the amount of investment in the city of Mannheim shows some degree of sensitivity to the economic component of FVI. The assumed value remains in a less steep part of the curve, indicating that ranges similar to the selected value will provoke little changes in the result. In the flood action plan for the Neckar sub-catchment, the annual amount of investment is close to US$ 20 million; an important city like Mannheim would represent a large part of this investment, however, US$ 3 million a year was considered for this research.

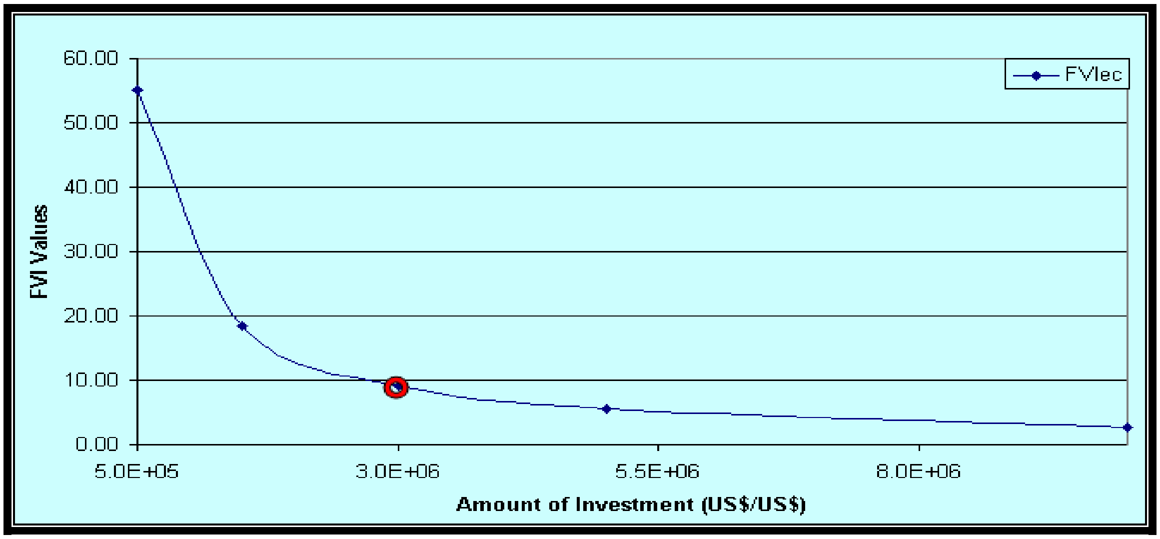

Figure 5.37 Sensitivity Analysis of Amount of Investment for Mannheim City

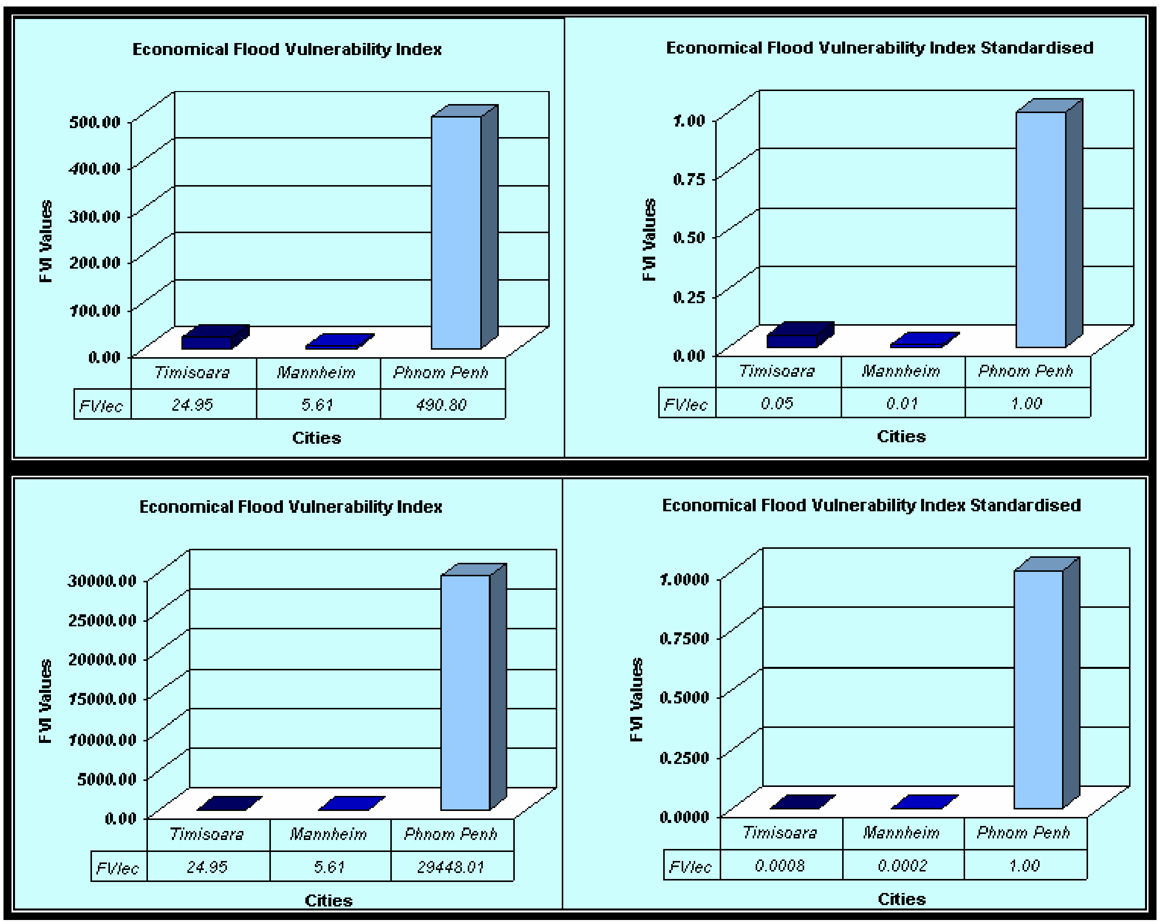

Figure 5.38 a) and b) Values for FVIec for urban scales, with extreme values of Storage capacity in Phnom Penh

Twelve indicators were selected to compute the economic FVI component, as shown in equation 4.10, section 4.5.2; three for exposure, four for susceptibility and five for resilience.

The final results, taking into account the assumed values mentioned before, are shown in Figure 5.38 a) and b). The first chart shows the values for economical vulnerability to floods considering the storage capacity of the Tonle Sap Lake, the values show that e Phnom Penh is economically very vulnerable compared with the other two cities.

Not taking into account the storage capacity of Tonle Sap Lake makes Phnom Penh extremely vulnerable to floods, as shown in Figure 5.38 b), were the values of economical vulnerability to floods for the city goes as high as 29,448.

As for the other two case studies, the case of Timisoara city shows some peculiarities, presenting very low values of exposure and also low value for resilience. Contrary to this, Mannheim city presents large values of exposure, but even larger values for resilience.

5.7.3 Environmental Component

Concerning the environmental component, one sensitivity analysis was carried out for the indicator Land Use for green areas in the city of Mannheim. As shown in Figure 5.39, a large sensitivity occurs of the environmental component, the value assumed for land use is situated in the middle part of the curve, which means that the physical FVI for Mannheim City can oscillate between a value very close to 0 and almost 8, which will make significant a difference in the value of the environmental FVI.

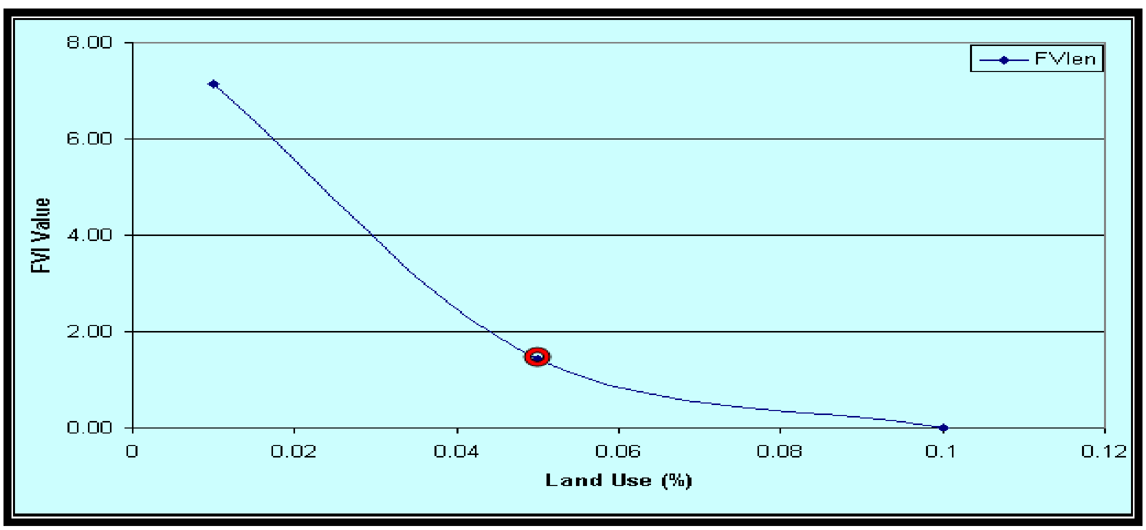

Figure 5.39 Sensitivity Analysis of Land Use for Mannheim City

Four indicators have been chosen to compute the values of the economic FVI component with equation 4.11, in section 4.5.2; two for exposure and the other two for susceptibility. The results for his component are shown in Figure 5.40, which illustrates that Phnom Penh City has a higher environmental vulnerability to floods due to large rainfall amounts, evaporation and the low percentage of green areas. Timisoara and Mannheim have almost the same environmental FVI, the ratio between rainfall and evaporation, the urban growth and the land use (taking into account the assumed value) are very alike, vis-à-vis of the accuracy of data.

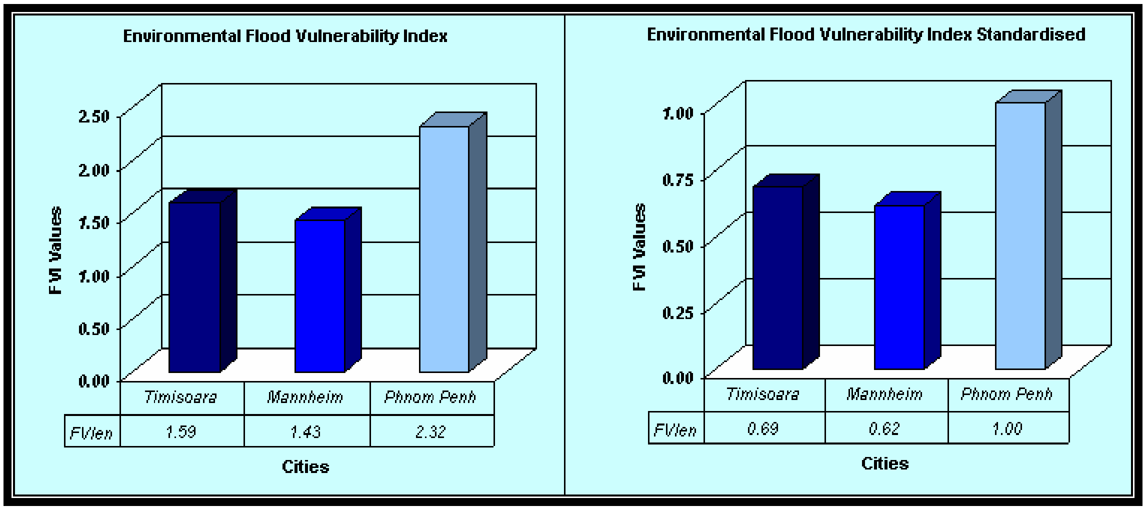

Figure 5.40 Normal and Standardized Values for FVIen at urban scale

5.7.4 Physical Component

Two sensitivity analyses, concerning the physical component of flood vulnerability, were evaluated in section 5.7.2. Figure 5.35 and Figure 5.36 show the results of the analysis for Storage capacity for Phnom Penh and Mannheim.

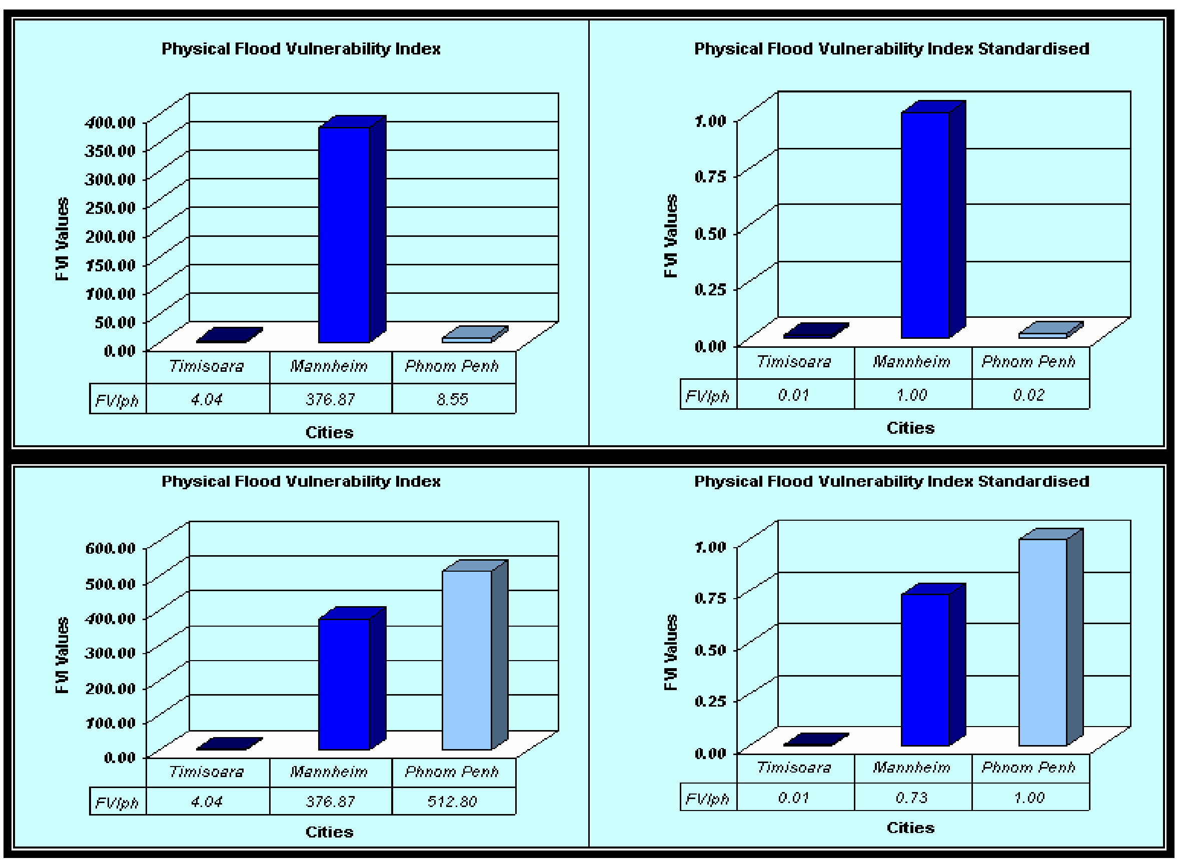

Figure 5.41 a) and b) Values obtained for FVIph, regarding Phnom Penh storage capacity values

Figure 5.35 shows the range of values which can be obtained from considering Tonle Sap Lake as a storage capacity protecting the city from floods. The results for the FVIph are shown for all three case studies in Figure 5.41 a) and b).

In Figure 5.41 a), includes considers the Tonle Sap Lake for storage, the results show that Mannheim is the most physically vulnerable to floods, due to its low physical resilience (the storage capacity of Mannheim is very low, 7,8 millions m^3) and it has a very large value of the physical exposure; Timisoara and Phnom Penh have similar values because of very large ratio between storage capacity over the average discharge.

The results in Figure 5.41 b) considers that Tonle Sap Lake does not protect Phnom Penh from floods, in that case Phnom Penh will be the most physically vulnerable, over Mannheim and Timisoara, whose values does not change from Figure to Figure.

5.7.5 Summary of Results

All the components together show the overall vulnerability to floods of an urban area. The results shown previously, however, have certain elements which still need consideration; for example taking the Tonle Sap Lake into account as a flood protection element of Phnom Penh city.

There is still lack of criteria for the economical and physical components regarding the storage capacity, which protects an urban area from floods. This will need to be revised in the future.
Because of this, two sets of results are given as a summary, as shown in Figure 5.42 a) and b). The first one a) shows that three components have a higher value in Phnom Penh city, and that the overall value gives its second place to Mannheim city.

The city of Timisoara has positive results on all components, with the arguably exception of environmental vulnerability. This is a result which was expected, since it’s a city which has not suffered from floods in the last three decades.

The results shown in Figure 5.42 b) change with regard to the economical and physical component were the difference between Phnom Penh city and Mannheim and Timisoara becomes extremely large, especially for the economical component of flood vulnerability. For the physical component there is an increasing vulnerability of Phnom Penh, to a value higher than Mannheim, making it also the most vulnerable urban area in all components.

Of all components studied the environmental vulnerability to floods ended up being the most equal in values; since the lowest value is only 60% of the highest.

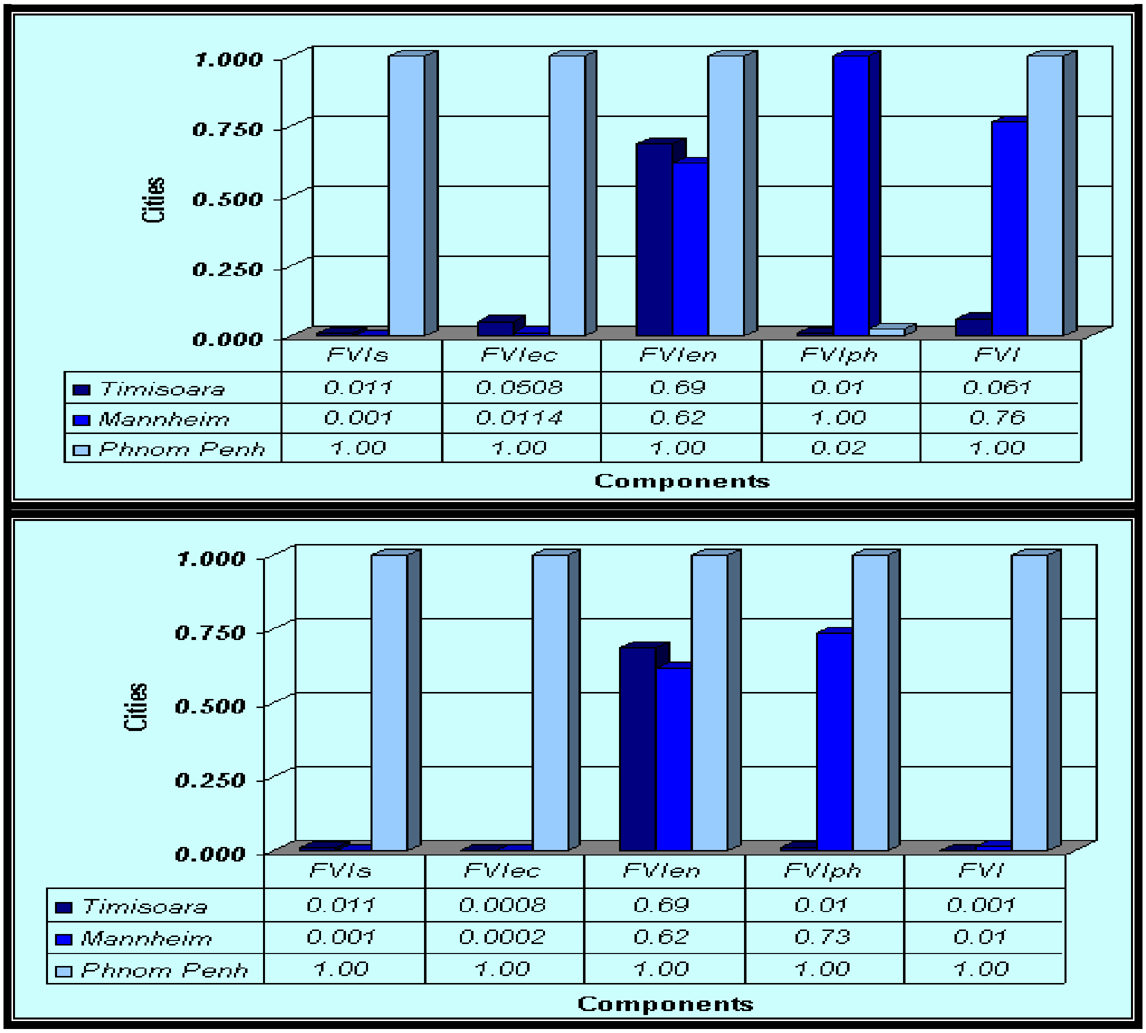

Figure 5.42 a) and b) Summary of results, considering and not considering Tonle Sap Lake, respectively

The results illustrated in Figure 5.42 a) and b) show a clear difference between developing and developed cities for vulnerability to urban floods. Phnom Penh city needs a flood protection plan according to all vulnerability components analyzed social, economical, environmental and physical.

5.7.6 Downscale Analysis of Results

A downscale analysis was carried out for all three spatial scales studied; river basin, sub-catchment and urban areas. In this section the results are shown from all three cities studied starting with Timisoara, continuing with Mannheim and finishing with Phnom Penh.

This analysis was carried out to examine the differences of flood vulnerability between geographical scales at all components. The FVI is different from component to component and from scale to scale, as shown in Figure 5.43 to Figure 5.45.

From the Danube River Basin to Timisoara

Figure 5.43 illustrates the relation of the Danube River Basin with the smaller spatial scales in the system studied in this research. It can be observed that the Danube River Basin is overall most vulnerable than the sub-catchments and the city of Timisoara. The Tisza and Bega Rivers and Timisoara are very close in the overall results.

Considering each component the Danube River Basin is not the most economically vulnerable to floods. This is, however, the case for Timisoara City, due to its low annually amount of investment, no existing flood insurances and the large number of industries which can be affected in the case of floods. For the remaining components, Timisoara is the least vulnerable to floods, mainly due to the river diversion scheme which protects the city from floods, as seen in section 5.6.1, Figure 5.15.

Bega river is overall the least vulnerable spatial scale in the chart; this is not surprising considering the river diversion scheme mentioned before, which protects all downstream areas from flooding, therefore reducing the vulnerability of all components.

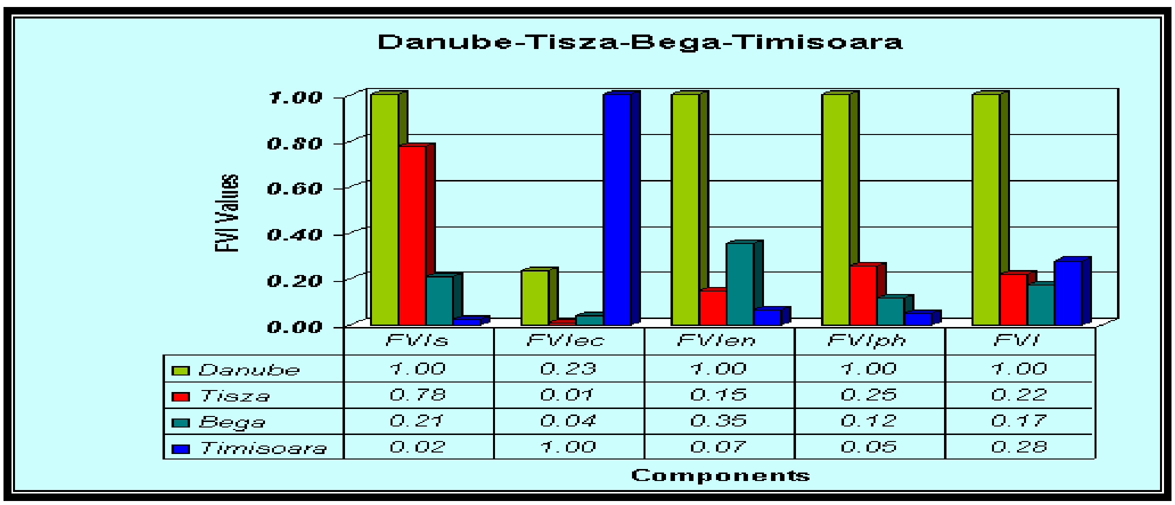

Figure 5.43 Comparison between *river basin-subbasin-subcatchment-city* standardized values

From the Rhine River Basin to Mannheim

The chart shown in Figure 5.44 for the Rhine River Basin, the Neckar Sub-catchment and Mannheim City follows the same line of results for the social, economical and environmental components as the Danube River Basin and its smaller scales, with the exception that the Neckar sub-catchment is the most physically vulnerable to floods.

The city of Mannheim is the most vulnerable scale both economically and physically in this region. With respect of the economical component this result is as expected, considering the large number of industries in the area, which in case of floods would leave a permanent damage to the economy of the region. Regarding the physical component, some indicators increase the vulnerability of the city to floods in a large extend, such as: contact with river, upstream storage capacity and slope of the city.

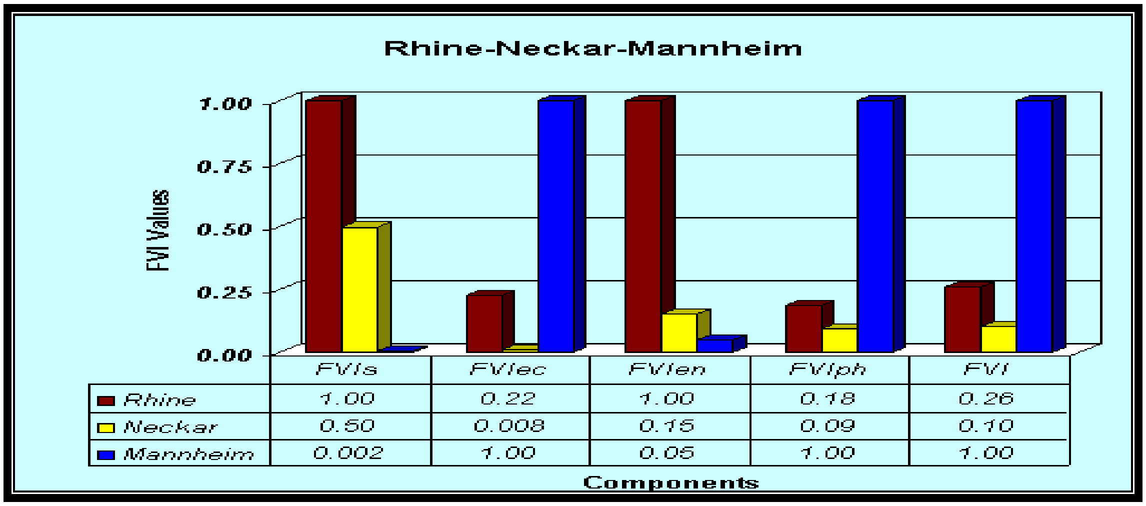

Figure 5.44 Comparison between *river basin-subcatchment-city* standardized values

In the overall values, the Neckar River does not show large amounts of vulnerability in any of its components, resulting in the lowest value of vulnerability among the three scales studied in the Rhine River Basin.

From the Mekong River Basin to Phnom Penh

For the case of the Mekong River Basin, the city of study (Phnom Penh) is not situated in the sub-catchment studied; the Mun River, making the analysis more direct, considering only two elements instead of three.

Another point of consideration is the fact that there is still a decision to be made about the storage capacity which protects the river from upstream flooding, in other words whether to include the storage capacity of the Tonle Sap Lake as explained beforehand. Figure 5.45 a) describes the results taking into account the storage capacity of the lake, however, Figure 5.45 b) shows the results without the storage capacity.

As seen, the results are highly sensitive to the decision of including the storage volume, since the first case shows the Mekong River Basin with an overall flood vulnerability higher than the urban area, and the second case creates a much larger difference in the overall results.

In the second case, Phnom Penh City is overall the most vulnerable spatial scale due to being the most vulnerable for the social and economical components. Not considering the storage volume increases the influence of the economical component in the overall results.

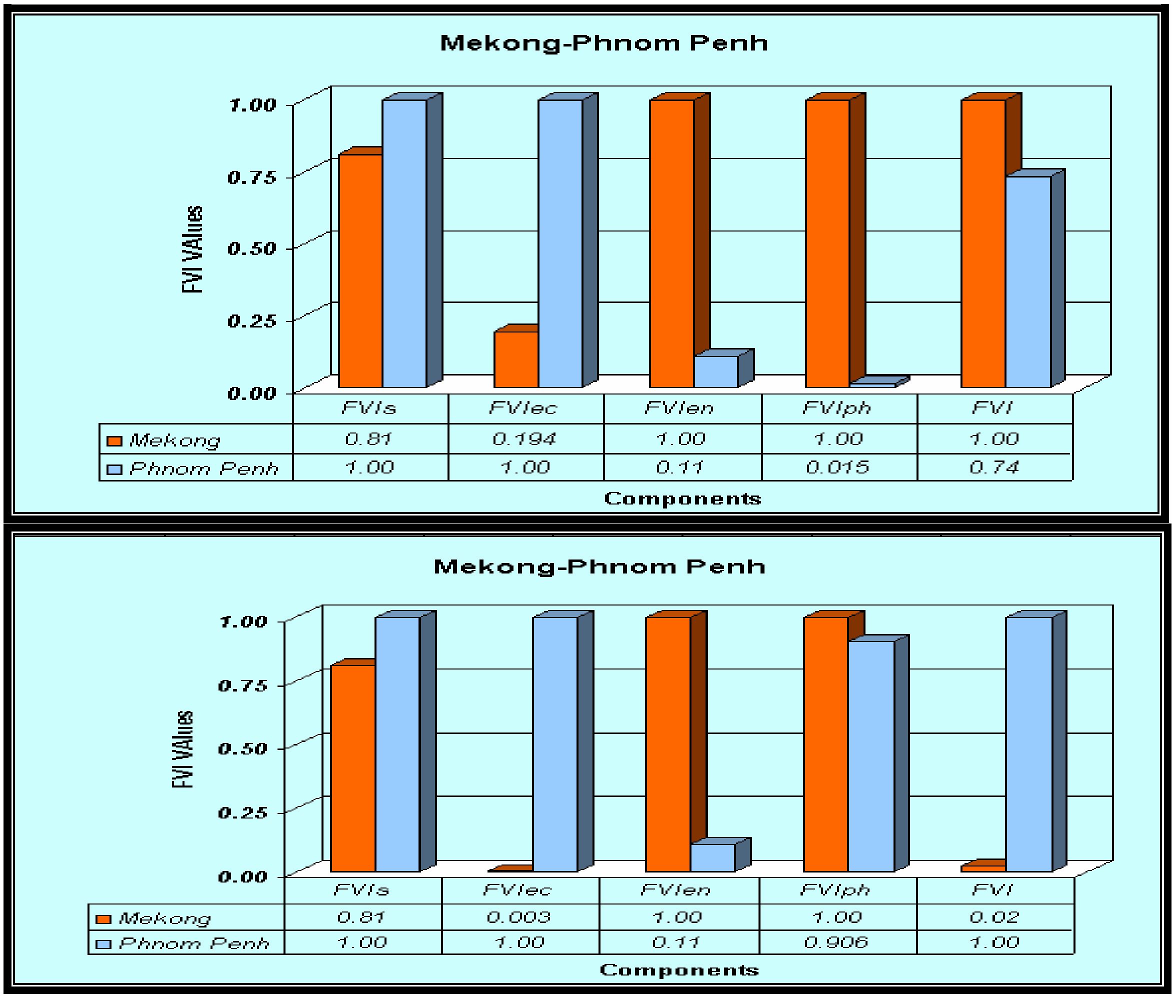

Figure 5.45 a) and b) Comparison between *river basin-city* standardized values

Downscaling is a powerful tool in order to assist decision makers in improving their investments strategies for the reduction of flood damages. Recognising which spatial scale is more vulnerable to floods and in which places this vulnerability can be reduced more easily, may show decision makers to prioritize certain projects in flood protection in local and regional areas.

Certain indicator values which could not be assumed due to uncertainties in the sensitivity analysis could twist these results. This is the case of one indicator: storage capacity for Mannheim and Phnom Penh cities. Other values than the assumed ones could lead to different results in this analysis.

Smaller spatial scales are more detailed and specific in this study. There are more indicators to evaluate the FVI for sub-catchments and urban areas than for River Basins, even though many indicators are different than each other. The equations developed for each component brings more detailed information on smaller scales. However, some of these values would have no influence on larger scales.

For these downscaling results, it can be concluded that urban areas are entities in their own, the results from their study would only be representative for that specific area of land. FVI values of all cities in a sub-catchment or a river basin can not be linked to the FVI values obtained on larger scales. However, reducing the vulnerability to floods of a city may also reduce the vulnerability of a larger area.

Chapter 6 Discussions

This chapter discusses general problems with regard to the development of flood vulnerability indices and analyzing flood vulnerability in various case studies. The discussion focuses on issues such as: indicators which were not taken into account, the accuracy of data and possible weaknesses identified while testing the methodology.

Most of the literature studied in chapter 2 defines vulnerability as a predisposition of something to be affected. Another aspect to consider regarding flood vulnerability is related to how it is perceived by those affected, and by decision and policy makers who should do something to counter attack it.

The methodology, in principle, is based on sets of indicators for different factors and different geographical scales, focusing on fluvial and urban floods. Various indicators were taken into account to quantify flood vulnerability. Some of the indicators originally proposed were not considered in the final equations, due to the difficulty of quantifying them, finding data, possible redundancy with other indicators or with the purpose of creating a dimensionless result for each equation.

For example the indicators such as: *ground water level*, *geology* and *building codes* were very hard to find via the Internet. The indicators like *quality of infrastructure, infrastructure management* and *human health* were difficult to quantify, however, indicators such as *closeness to inundation areas*, *proximity to river* were replaced with *contact with river,* because of the similarities of what they indicate.

For the three geographical scales studied, no indicators were used to analyse the flood vulnerability index for the resilience factor of the environmental component and the susceptibility factor of the physical component. For the River Basin scale no indicators could be identified to describe these two components.

However, the indicator *environmental recovery* for the environmental component was identified for the sub-catchment scale, which was not used because of difficulties with quantification; A scale of environmental recovery time would have to be created, but certain lack of knowledge and time prevented its further development.

The same problem occurred for the urban scale, where an indicator was identified for each component, *environmental recovery* for the environmental component and *building codes* for the physical component. The first one was not used for the same reason as in the sub-catchment scale, the second one was very hard to find via the Internet or via direct contact with municipalities of certain cities.

Some indicators were not considered because of the decision to simplify the results of the FVI into a single non-dimensional value. The most convenient way to get this result is using fractions with indicators as part of numerator or denominator, depending on its effect in the vulnerability, that way eliminating all units. Some of the indicators not considered were: *maximum river discharge, flow velocity, flood duration, ground water level* or *temperature*, whose units could not be eliminated using other indicators.

The possible impacts of using these indicators on vulnerability indices was not tested during this research, but its use may lead to different outcomes, for example: including *maximum river discharge*, *flow velocity* and *flood duration* should increase the values of vulnerability at all geospatial scales; *ground water level* should make a greater impact at smaller scales than at larger scales, meaning that it should increase the vulnerability at urban scales more than at river basin scale, the *temperature* should not influence the values of vulnerabilities at any scale. Still the real influence of these and other non recognized indicators should be studied in future works.

Since the methodology is based on indicators, its main *weakness* is the *accuracy of data* to compute the equations. For the results to be valid, all data must be derived from reliable sources, specified for a precise spatial area at a defined time.

Examples of these problems were found in the case studies. Some information was derived from sources that can be considered as non-reliable, for example the cities distance of contact with a river, which was taken from *Google Earth*, by computing the distance using the *ruler* tool in the software. Some data from spatial scales were collected from different years, for example: child mortality and unemployment were only found for 2005, other data were found for different years as old as 2001, creating an uncertainty for some of the results.

The indicators must be explained and concepts must be clear to all users of the methodology. For example, the amount of investment indicator for flood protection plans could only be found per project, without considering the duration of the project. In the definition of the indicator the value assumes the yearly investment in flood protection. This kind of freedom can be assumed in the using methodology, however, the same approach should be considered for all case studies.

Another example where the data quality is poor is the *amount of investment* indicator, where the sum of investments is divided by the GDP, taken from the *GDP per capita* and *population living in flood prone area*. In the sub-catchment scale the *GDP per capita* selected is the same as each country, sometimes using an allotment method, instead of using regional GDPs, which could not be obtained via the Internet.

Some indicators, such as *cultural heritage*, *shelters* and *emergency service* for urban areas, which were not found, were assumed to be the same for all the studied cases.

Another indicator which may cause confusion is the *storage capacity*, used for the economical and physical components. In the study at hand these two values are assumed the same, but considering their purpose in the methodology it is proposed to be used separately for future case studies. The main difference between them is that the first one tries to explain the capacity of a society to finance large structural measures of protection, meaning dams, barrages, polders, however, for the physical component it should be used to account for all possible means of protection, either natural such as lakes, wetlands, floodplains or man-made as accounted for the economical component. A revision of these concepts is proposed to avoid misleading results.

Improving the weaknesses identified in this chapter may lead to a variation of some of the results. This variation is very difficult to assess without certain mathematical approaches, like a sensitivity analyses, but considering the approach of the methodology and the homogeneity of the concepts, the variations of the results should stay in a close range.

As the methodology is still under development, these weaknesses and other issues which might be identified in due time can be improved leading to further adaptations of concepts or introduction of new concepts, resulting in a better methodology.

Chapter 7 Conclusions and Perspectives

In this chapter the conclusions and main contributions of the Flood Vulnerability Index, which has been developed and studied in this thesis, are summarized. Perspectives for further developments (recommendations) are presented at the end of this Chapter.

7.1 Conclusions

The conclusions concerning the development of FVI methodology and the applicability can be summarized as follows:

- FVI provides a method to systematically express the vulnerability of a river system to disruption factors, such as floods;
- Vulnerability can be reflected by three factors: exposure, susceptibility and resilience;
- The river and urban systems can be damaged regarding four different components: social, economical, environmental and physical. Floods can be a cause of these damages;
- The FVI is applicable in three different spatial scales: river basin, sub-catchment and urban area scales;
- FVI is a powerful tool for policy and decision-makers to prioritize investments and makes the decision making process more transparent. Identifying areas with a high flood vulnerability may guide the decision making process towards a better way of dealing with floods by societies;
- FVI offers easy to understand results, with the use of a single value to characterize high or low vulnerability. This also allows continuous data interpretation for more in-depth analysis and it is suitable to policy-makers;
- From the testing results it appear that the FVI of a river basin as a whole can be reflected by the average of the FVI of its sub-catchments;
- FVI's of urban areas cannot reflect the FVI of the sub-catchment or river basin which they belong to;
- Finally, the proposed methodology to calculate a FVI provides an approach to quantify how much floods are affecting, or can affect, the livelihood of a spatial scale: in all the aspects that make a society function properly.

7.2 Future works and perspectives

Based on this research there are several perspectives for future developments and they concern on the one hand the Flood Vulnerability Methodology for coastal floods and on the other hand, the further development of the proposed methodology.

The future works and its perspectives concerning the FVI methodology and the applicability can be summarized as follows:

- Based on the research of this MSc thesis, about the development of an FVI methodology applicable to river basins, sub-catchments and urban scales, the methodology of continuing research refers to *gathering required information to test the indices*, and to *improve the methodology* with the specific results of the case studies.

- *Additional case studies.* To fully understand the capacity of the FVI methodology, the case studies which were analyzed in this research cannot be considered sufficient, hence it is recommended to continue with additional case studies to carry on with the search for *more useful indicators, refinement of the equations* and *enhancement of the concepts.*

- It is recommended to analyse the real influence of non-used and other non-recognized indicators in this suggested future case studies.

- *Software tool for case studies.* Testing the applicability implies having as much as possible case studies, for each of the studied scales. This requires prompt solutions to large amount of data, giving way to the need of a computer based tool to help organize, monitor, process and compare the data of the different case studies.

- It is highly recommended to create a *network of knowledge* between different institutions and universities in which this methodology may be used. Another point of interest at this stage is to encourage the collaboration between all the members of the network, concerning the need for information management on flood vulnerability, and also promoting further studies on flood risk assessment on all scales.

- Using the developed methodology, *a new set of equations* can be built to quantify the vulnerability of a certain spatial scale to the hazards of extreme events which cause *coastal floods*, such as: storm surges, tidal waves, tsunamis, etc.

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Appendices

Appendix I The Rhine River Basin Data Source

Rhine River Basin Scale							
No	Abb.	Name	Sub-index	Factor of	Units	Definition of indicator	Data Source
1	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	CRED, UNDP/BCPR
2	HDI	Human Development Index	$FVI_{S,Ec}$	S	-	*HDI $= \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	UNDP, 2004
3	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	EPI report 2006
4	P_E	Past Experience	FVI_S	R	people	# of people affected in last 10 years because floods;	EM-DAT
5	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	reffer to table
6	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of mobile phones over the total population	INTUTE
7	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Y/N
8	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	INTUTE
9	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	WRI
10	U_H	Unemployment	FVI_S	S	#	$U_N = \frac{\#of\_people\_Unempl}{Total\_Pop\_Apt\_ToWork} * 100$	The World Factbook
11	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	UN
12	A_{Inv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	IRMA Project - EF
13	Er	Economic Recovery	FVI_{Ec}	R	-	How affected is the economy of a region at a large time scale, because of	Reffer to table
14	$R_{rainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB $R_{rainfall} = \frac{mm}{1000 * year} = \frac{m}{year}$	Ekstrom et al.
15	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	WRI
16	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total RB $N_R = \frac{A_{nr}}{Total\_Area\_of\_River\_Basin\ area} * 100$	World Resources Institute
17	Ev	Evaporation rate	FVI_{Ec}	S	m/year	yearly evaporation rate	Ekstrom et al.
18	U_{unpop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Water Resources Atlas
19	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	World Resources Institute
20	T	Topography	FVI_{Ph}	E	-	average slope of river basin	FVI
21	D_{HR}	# of days with heavy rainfall	FVI_{Ph}	E	#	number of days with heavy rainfall, more than 100mm/day	FVI
22	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	ICPR
23	Fo	Frequency of occurrence	FVI_{Ph}	E	years	years between floods	ICPR
24	$E_V/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Ekstrom et al.
25	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m^3	The total volume of water, which can be stored by dams, polders, etc.	ICPR
26	AvRd	Average River Discharge			m3/s	average river discharge at the mouth	ICPR
27	Sc/Year	Storage capacity over yearly discharge	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	Reffer to 25 & 26

Appendix II The Danube River Basin Data Source

Danube River Basin Scale							
No	**Abb.**	**Name**	**Sub-index**	**Factor**	**Units**	**Definition of indicator**	**Data Source**
1	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	UNDP/BCPR
2	HDI	Human Development Index	$FVI_{S,Ec}$	S	-	$^*HDI = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	UNDP, 2004
3	C_M	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	EPI report 2006
4	P_E	Past Experience	FVI_S	R	people	# of people affected in last 10 years because floods;	ICPDR, EM-DAT
5	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	reffer to table
6	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of mobile phones over the total population	INTUTE
7	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Y/N
8	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	INTUTE
9	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	WRI
10	U_M	Unemployment	FVI_S	S	%	$U_M = \frac{\#of\_people\_Unempl}{Total\_Pop\_Apt\_To\_Work} * 100$	World Factbook 2005
11	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	UN
12	A_{Inv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Index Mundi for GDP
13	Er	Economic Recovery	FVI_{Ec}	R	-	How affected is the economy of a region at a large time scale, because	Reffer to table
14	$R_{rainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole $R_{rainfall} = \frac{mm}{1000 \cdot year} = \frac{m}{year}$ RB	Ekstrom et al.
15	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	WRI
16	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total $N_R = \frac{A_{NR}}{Total\_Area\_of\_River\_Basin} * 100$ RB area	WRI
17	Ev	Evaporation rate	FVI_{Ec}	S	m/year	yearly evaporation rate	Ekstrom et al.
18	U_{pop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Water Resources Atlas
19	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	World resources institute
20	T	Topography	FVI_{Ph}	E	-	average slope of river basin	FVi
21	D_{HR}	# of days with heavy rainfall	FVI_{Ph}	E	#	number of days with heavy rainfall, more than 100mm/day	FVI
22	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	ICPDR
23	Fo	Frequency of occurrence	FVI_{Ph}	E	years	years between floods	ICPDR
24	$Ev/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Ekstrom et al.
25	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m^3	The total volume of water, which can be stored by dams, polders, etc.	Sensitivity analysis
26	AvRd	Average River Discharge			m3/s	average river discharge at the mouth	ICPDR
27	Sc/D	Storage capacity over yearly discharge	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	Reffer to 25 & 26

Appendix III The Mekong River Basin Data Source

Mekong River Basin Scale							
No	Abb.	Name	Sub-inde	Factor	Units	Definition of indicator	Data Source
1	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	CRED, UNDP/BCPR
2	HDI	Human Development Index	$FVI_{S,Ec}$	S	-	$HDI = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	UNDP, 2004
3	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	EPI report 2006
4	P_E	Past Experience	FVI_S	R	people	# of people affected in last 10 years because floods;	Mekong River Commision, 2005
5	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	reffer to table
6	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of mobile phones over the total population	INTUTE
7	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Y/N
8	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	INTUTE
9	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	WRI
10	U_H	Unemployment	FVI_S	S	%	$U_H = \frac{\#of\_peopleUnempl}{Total\_Pop\_AptToWork} * 100$	World Factbook 2005
11	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	UN
12	A_oI_{nv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Mekong River Commision, 2005
13	Er	Economic Recovery	FVI_{Ec}	R	-	How affected is the economy of a region at a large time scale, because of	reffer to table
14	$R_{ainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB $R_{ainfall} = \frac{mm}{1000 * year} = \frac{m}{year}$	Mekong River Commision, 2005
15	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	water resources institute
16	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total RB $N_R = \frac{A_{nr}}{Total\_Area\_of\_a\_River\_Basin} * 100$	water resources institute
17	Ev	Evaporation rate	FVI_{Ec}	S	m/year	yearly evaporation rate	Mekong River Commision, 2005
18	U_{pop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Water Resources Atlas
19	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	water resources institute
20	T	Topography	FVI_{Ph}	E	-	average slope of river basin	FVI
21	D_{HR}	# of days with heavy rainfall	FVI_{Ph}	E	#	number of days with heavy rainfall, more than 100mm/day	FVI
22	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	UNH/GRDC
23	Fo	Frequency of occurrence	FVI_{Ph}	E	years	years between floods	Mekong River Commision, 2005
24	$E_V/R_{ainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Mekong River Commision, 2005
25	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m^3	The total volume of water, which can be stored by dams, polders, etc.	WB
26	AvRd	Average River Discharge			m3/s	average river discharge at the mouth	MRC
27	Sc/D	Storage capacity over yearly discharge	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	Reffer to 25 & 26

Appendix IV The Tisza Sub-catchment Data Source

Tisza Sub-catchment Scale								
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with	Data Source
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is concentrated	Higher # of people, higher vulnerability	Tizsa River Basin Economic Development Programme
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability	Tizsa River Basin Economic Development
3	U_A	Urbanized Area	$FVI_{S,Ec}$	E	%	% of total area which is urbanized	higher %,higher vulnerability	PELCOM
4	R_{pop}	Rural population	FVI_S	E	%	% of population living outside of urbanized area	higher %,higher vulnerability	Platts, UNDP
5	% of disable	Disabled People	FVI_S	E	%	% of population with any kind of disabilities, also people less 15 and more than 65	higher %,higher vulnerability	INTUTE
6	HDI	Human Development Index	FVI_S	S	-	*HDI $= \frac{1}{3}(LEI)+\frac{1}{3}(EI)+\frac{1}{3}(GI)$	The higher value, lower vulnerability	UNDP, 2004
7	C_M	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability	EPI report 2006
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events;	The higher value, lower vulnerability	Selected Global Extreme Information, Reuter News, EM-DAT
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability	Reffer to Table
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability	INTUTE
11	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability	Yes/No
12	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods	INTUTE
13	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	The higher %, the high vulnerability	UNEP
14	U_M	Unemployment	FVI_{Ec}	S	%	$= \frac{\#of\_people\_Unempl}{Total\_Pop\_AptToWork}*100$	The higher %, the high vulnerability	World Factbook 2005
15	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability	UN
16	L_{EI}	Life expectancy Index	FVI_{Ec}	S	-	LEI= $\frac{LE - 25}{85 - 25}$	Higher LEI, Lower vulnerability	UNDP, 2004
17	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances per 100 inhabitants, if 0 than take 1	higher # of FI, lower vulnerability	
18	A_{Inv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability	UNEP, 2004
19	D_L	Dikes_ Levees	FVI_{Ec}	R	km/km	Km of dikes/levees over total length of river	Longer D_L, lower vulnerability	sensitivity analysis
20	D_Sc	Dams_Storage capacity	FVI_{Ec}	R	m	amount of storage capacity over area of sub-catchment	higher capacity, lower vulnerability	sensitivity analysis
21	Ecr	Economic recovery	FVI_{Ec}	R	#	How affected is the economy of a region at a large time scale, because of floods		Reffer to table
22	$R_{ainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB $= \frac{mm}{1000 * year} = \frac{m}{year}$	Higher rainfall, higher vulnerability	Ekstrom et al.
23	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	Bigger D_A, higher vulnerability	WRI
24	U_G	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 10 years;	fast urban growth may result in poor quality housing and thus make	UNDP/BCPR, 2004
25	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	The higher %, the low vulnerability	Tizsa River Basin Economic Development Programme
26	EV	Evaporation rate	FVI_{Ec}	S	m/year	yearly evaporation rate	higher EV, lower vulnerability	Ekstrom et al.
27	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total SC $= \frac{A_{NR}}{Total\ Area\ of\ the\ River\ Basin}*100$	Higher %, Lower vulnerability	UNEP

Tisza Sub-catchment Scale								
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with	Data Source
28	U_{pop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Higher Unpop area. Lower vulnerability	Water Resource Atlas
29	T	Topography	FVI_{Ph}	E	-	average slope of sub-catcment	The steeper slope, higher vulnerability	wikipedia
30	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	higher RD, higher vulnerability	Tizsa Flood action plan
31	Fo	Frequency of occurance	FVI_{Ph}	E	years	years between floods	bigger # of years, high vulnerability	Tizsa Flood action plan
32	$E_V/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability	Ekstrom et al.
33	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m3	amount of storage capacity	higher m3, higher vulnerability	UNEP, rec.hu,
34	AvRd	Average River Discharge	FVI_{Ph}	E	m3/s	average river discharge at the mouth		S. Djordjevic et al
35	Sc/Vyear	Storage capacity over yearly	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	higher Sc means lower vulnerability	Reffer to 35 & 36

Appendix V The Bega and Timis Sub-catchments Data Sources

Bega and Timis Sub-catchment Scale								
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with vulnerability	Data Source
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is	Higher # of people, higher vulnerability	answer.com
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability	UNDP/BCPR
3	U_A	Urbanized Area	$FVI_{S,Ec}$	E	%	% of total area which is urbanized	higher %,higher vulnerability	PELCOM, 2001
4	R_{Pop}	Rural population	FVI_S	E	%	% of population living outside of urbanized area	higher %,higher vulnerability	wikipedia, Platts, UNDP
5	% of disable	Disable People	FVI_S	E	%	% of population with any kind of disabilities, also people less 12 and more than 65	higher %,higher vulnerability	INTUTE
6	HDI	Human Development Index	FVI_S	S	-	$HDI = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	The higher value, lower vulnerability	UNDP, 2004
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability	EPI report 2006
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events;	The higher value, lower vulnerability	Selected Global Extreme Information, Reuter News, EM-DAT
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability	Reffer to table
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of mobile phones over the total population	Higher percentage means lower vulnerability	INTUTE
11	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability	Y/N
12	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods	INTUTE
13	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	The higher %, the high vulnerability	UNEP
14	P_R	Proximity to river	FVI_{Ec}	E	km	average proximity of populated areas to flood prone areas	close to the river, higher vulnerability	Google Earth
15	U_H	Unemployment	FVI_{Ec}	S	%	$= \frac{\#of\_people\_Unempl}{Total\_Pop\_AptToWork} * 100$	The higher %, the high vulnerability	UNDP, 2004, World Factbook,2005
16	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability	UN
17	L_{EI}	Life expectancy Index	FVI_{Ec}	S	-	$LEI = \frac{LE - 25}{85 - 25}$	Higher LEI, Lower vulnerability	UNDP, 2004
18	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances per 100 inhabitants, if 0 than take 1	higher # of FI, lower vulnerability	
19	A_{Inv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability	Environmental Minister of Romania, UNEP

Bega and Timis Sub-catchment Scale								
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with vulnerability	Data Source
20	D_L	Dikes_ Levees	FVI_{Ec}	R	km/km	Km of dikes/levees over total length of river	Longer D_L, lower vulnerability	Authority of Water, Romania
21	D_Sc	Dams_Storage capacity	FVI_{Ec}	R	m	amount of storage capacity over area of sub-catchment	higher capacity, lower vulnerability	Authority of Water, Romania
22	Er	Economic recovery	FVI_{Ec}	R	#	How affected is the economy of a region at a large time scale, because of floods	Higher economic recovery, less vulnerable	Reffer to table
23	$R_{rainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB $= \frac{mm}{1000 * year} = \frac{m}{year}$	Higher rainfall, higher vulnerability	Ekstrom et al.
24	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	Bigger D_A, higher vulnerability	WRI
25	U_G	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 3 years;	fast urban growth may result in poor quality housing and thus make people more vulnerable	UNDP/BCPR, 2004
26	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	The higher %, the low vulnerability	WRI
27	Ev	Evaporation Rate	FVI_{Ec}	S	m/year	yearly evaporation rate	higher EV, lower vulnerability	Ekstrom et al.
28	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total SC $= \frac{A_{nr}}{Total\_Area\_of\_River\_Basi} * 100$ area	Higher %, Lower vulnerability	http://www.iatp.md/arii/TEXT/RO/internationale/arii RO.htm , UNEP
29	U_{pop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km²	Higher Unpop area. Lower vulnerability	Water Resource Atlas
30	T	Topography	FVI_{Ph}	E	-	average slope of sub-catcment	The steeper slope, higher vulnerability	Authority of Water, Romania, Wikipedia
31	R_D	River Discharge	FVI_{Ph}	E	m³/s	maximum discharge in record of the last 10 years, m³/s	higher RD, higher vulnerability	Authority of Water, Romania,
32	Fo	Frequency of occurrence	FVI_{Ph}	E	years	years between floods	bigger # of years, high vulnerability	Authority of Water, Romania,
33	$E_V/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability	Ekstrom et al.
34	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m3	amount of storage capacity	higher m3, higher vulnerability	Authority of Water, Romania
36	AvRd	Average River Discharge	FVI_{Ph}	E	m3/s	average river discharge at the mouth		Authority of Water, Romania
37	Sc/Vyear	Storage capacity over yearly	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	higher Sc means lower vulnerability	Reffer to 35 & 36

Appendix VI The Neckar Sub-catchment Data Sources

Neckar Sub-catchment Scale								
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with vulnerability	Data Source
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is	Higher # of people, higher vulnerability	IKONE project, Aktionsplan Hochwasser
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher	IKONE project, Aktionsplan Hochwasser
3	U_A	Urbanized Area	$FVI_{S,Ec}$	E	%	% of total area which is urbanized	higher %,higher	PELCOM
4	R_{pop}	Rural population	FVI_S	E	%	% of population living outside of urbanized area	higher %,higher vulnerability	Platts, UNDP
5	% of disable	Disabled People	FVI_S	E	%	% of population with any kind of disabilities, also people less 15 and more than 65	higher %,higher vulnerability	INTUTE
6	HDI	Human Development Index	FVI_S	S	-	$^*HDI = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	The higher value, lower vulnerability	UNDP, 2004
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability	EPI report 2006
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events:	The higher value, lower vulnerability	Selected Global Extreme Information, Reuter News, EM-DAT

No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with	Data Source
Neckar Sub-catchment Scale								
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability	Reffer to Table
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability	INTUTE
11	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability	Yes/No
12	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods	INTUTE
13	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	The higher %, the high vulnerability	UNEP
14	P_R	Proximity to river	FVI_{Ec}	E	km	average proximity of populated areas to flood prone areas	close to the river, higher vulnerability	Google Earth
15	U_M	Unemployment	FVI_{Ec}	S	%	$= \frac{No\_of\_people\_Unempl}{Total\_Pop\_AgeToWork} * 100$	The higher %, the high vulnerability	World Factbook 2005
16	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability	UN
17	L_{EI}	Life expectancy Index	FVI_{Ec}	S	-	$LEI = \frac{LE - 25}{85 - 25}$	Higher LEI, Lower vulnerability	UNDP, 2004
18	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances per 100 inhabitants, if 0 than take 1	higher # of FI, lower vulnerability	MunichRE
19	$A_{I..}$	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability	IKONE project, Aktionsplan Hochwasse
20	D_L	Dikes_ Levees	FVI_{Ec}	R	km/km	Km of dikes/levees over total length of river	Longer D_L, lower vulnerability	sensitivity analysis
21	D_Sc	Dams_Storage capacity	FVI_{Ec}	R	m	amount of storage capacity over area of sub-catchment	higher capacity, lower vulnerability	IKONE project, Aktionsplan Hochwasse
22	Er	Economic	FVI_{Ec}	R	#			reffer to table
23	$R_{ainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB $= \frac{mm}{1000 * year} = \frac{m}{year}$	Higher rainfall, higher vulnerability	Ekstrom et al.
24	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	Bigger D_A, higher vulnerability	WRI
25	U_G	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 10 years;	fast urban growth may result in poor quality housing and thus make people more vulnerable	UNDP/BCPR, 2004
26	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	The higher %, the low vulnerability	
27	EV	Evaporation rate	FVI_{Ec}	S	m/year	yearly evaporation rate	higher EV, lower vulnerability	Ekstrom et al.
28	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total SC $= \frac{A_{NR}}{Total\_Area\_of\_River\_Basin\ area} * 100$	Higher %, Lower vulnerability	UNEP
29	U_{pop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Higher Unpop area. Lower vulnerability	Water Resource Atlas
30	T	Topography	FVI_{Ph}	E	-	average slope of sub-catcment	The steeper slope, higher vulnerability	wikipedia
31	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	higher RD, higher vulnerability	21 December 1993 [Wikepedia]
32	Fo	Frequency of occurance	FVI_{Ph}	E	years	years between floods	bigger # of years, high vulnerability	IKONE project, Aktionsplan Hochwasse
33	$E_V/R_{ainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability	Ekstrom et al.
34	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m3	amount of storage capacity	higher m3, higher vulnerability	IKONE project, Aktionsplan Hochwasse
35	AvRd	Average River Discharge			m3/s	average river discharge at the mouth		wikipedia
36	Sc/Vyear	Storage capacity over yearly discharge	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	higher Sc means lower vulnerability	Reffer to 34 & 35

Appendix VII The Mun Sub-catchment Data Sources

Mun Sub-catchment Scale								
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with	Data Source
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is concentrated	Higher # of people, higher vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.pdf
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.pdf
3	U_A	Urbanized Area	$FVI_{S,Ec}$	E	%	% of total area which is urbanized	higher %,higher vulnerability	INTUTE
4	R_{pop}	Rural population	FVI_S	E	%	% of population living outside of urbanized area	higher %,higher vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.pdf
5	% of disable	Disabled People	FVI_S	E	%	% of population with any kind of disabilities, also people less 15 and more than 65	higher %,higher vulnerability	INTUTE
6	HDI	Human Development Index	FVI_S	S	-	$^*HDI = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	The higher value, lower vulnerability	UNDP, 2004
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.pdf
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events;	The higher value, lower vulnerability	http://68.178.233.117/MPcomp/2003/maps/Academicindividual-Caquard.pdf
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability	Reffer to Table
10	C_{PR}	Communication Penetration	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability	INTUTE
11	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability	Yes/No
12	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods	INTUTE
13	L_U	Land Use	FVI_{Ec}	E	%	% area used for industry, agriculture, any types of economic activities	The higher %, the high vulnerability	INTUTE
14	U_H	Unemployment	FVI_{Ec}	S	%	$= \frac{\#of\_people\_Unempl}{Total\_Pop\_AptToWork} * 100$	The higher %, the high vulnerability	World Factbook 2005
15	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability	UN
16	L_{EI}	Life expectancy Index	FVI_{Ec}	S	-	$LEI = \frac{LE - 25}{85 - 25}$	Higher LEI, Lower vulnerability	http://www.dams.org/docs/kbase/studies/drafts/thscope.pdf
17	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances per 100 inhabitants, if 0 than take 1	higher # of FI, lower vulnerability	
18	A_{Inv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability	UNEP, 2004
19	D_L	Dikes_ Levees	FVI_{Ec}	R	km/km	Km of dikes/levees over total length of river	Longer D_L, lower vulnerability	Google earth
20	D_Sc	Dams_Storage capacity	FVI_{Ec}	R	m	amount of storage capacity over area of sub-catchment	higher capacity, lower vulnerability	www.ucowr.siu.edu
21	Er	Economic recovery	FVI_{Ec}	R	#			Reffer to Table
22	$R_{ainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole $= \frac{mm}{1000 * year} = \frac{m}{year}$	Higher rainfall, higher vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.pdf
23	D_A	Degrated Area	FVI_{Ec}	E	%	% of degraded area	Bigger D_A, higher vulnerability	VRI
24	U_G	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 10 years;	fast urban growth may result in poor quality housing and thus make	UNDP/BCPR, 2004
25	L_U	Land Use	FVI_{Ec}	E	%	% of forested area	The higher %, the low vulnerability	http://www.mekongnet.org/images/5/5b/Uruya.pdf
26	EV	Evaporation rate	FVI_{Ec}	S	m/year	yearly evaporation rate	higher Ev, higher vulnerability	Mekong River Commission
27	N_R	Natural Reservation	FVI_{Ec}	S	%	% of natural reservation over total $= \frac{A_{NR}}{Total\_Area\_of\_River\_Basin} * 100$ SC area	Higher %, Lower vulnerability	UNEP

No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with	Data Source
						Mun Sub-catchment Scale		
28	U_{unpop}	Unpopulated Area	FVI_{Ec}	E	%	% of area with density of population less than 10 pers/km^2	Higher Unpop area. Lower vulnerability	Water Resource Atlas
29	T	Topography	FVI_{Ph}	E	-	average slope of sub-catcment	The steeper slope, higher vulnerability	wikipedia, google earth, http://www.hydro.washington.edu
30	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum discharge in record of the last 10 years, m^3/s	higher RD, higher vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.p
31	Fo	Frequency of occurance	FVI_{Ph}	E	years	years between floods	bigger # of years, high vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.p
32	$E_V/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.p
33	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m3	amount of storage capacity	higher m3, higher vulnerability	http://www.dams.org/docs/kbase/studies/csthanx.p
34	AvRd	Average River Discharge	FVI_{Ph}	E	m3/s	average river discharge at the mouth		www.dams.org
35	Sc/Vyear	Storage capacity over yearly discharge	FVI_{Ec}	R	m3/m3	Storage capacity divided by yearly volume runoff	higher Sc means lower vulnerability	Reffer to 35 & 36

Appendix VIII Timisoara Urban Area Data Sources

No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with vulnerability	Data Source
						Timisoara Urban Scale		
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is concentrated	Higher # of people, higher vulnerability	wikipedia
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability	wikipedia
3	C_H	Cultural Heritage	FVI_S	E	-	number of historical buildings, museums, etc., in danger when flood occurs, if none take 1	high # of CH, higher the vulnerability	water authority of Banat, INTUTE
4	P_G	Population growth	FVI_S	E	%	% of growth of population in urban areas in the last 10 years	fast PG, higher vulnerability, hypothesis is made that fast population growth may create pressing on housing capacities	wikipedia, INTUTE
5	% of disable	Disable People	FVI_S	E	%	% of population with any kind of disabilities, also people less 12 and more than 65	higher %,higher vulnerability	wikipedia, INTUTE
6	HDI	Human Development Index	$FVI_{S,E}$	S	-	$HDI = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	The higher value, lower vulnerability	UNDP, 2004
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability	UNDP, 2004
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events;	The higher value, lower vulnerability	water authority of Bana
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability	reffer to table
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability	INTUTE
11	S	Shelters	FVI_S	R	#/km^2	number of shelters per km^2, including hospitals	bigger # of S, lower vulnerability	water authority of Bana
12	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability	water authority of Bana
13	E_S	Emergency Service	FVI_S	R	#	number of people working in this service	bigger # of people, less vulnerable they are	water authority of Bana
14	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods	INTUTE
15	Ind	Industries	FVI_{Ec}	E	#	# of industries or any types of economic activities in urban area	The higher %, the high vulnerability	water authority of Banat, INTUTE
16	Cr	Contact with River	FVI_{Ec}	E	km	Distance of city along the river	more distance, more vulnerability	google earth
17	U_H	Unemployment	FVI_{Ec}	S	%	$U_e = \frac{\#of\_people\_Unempl}{Total\_Pop\_AptToWork} * 100$	The higher %, the high vulnerability	Worldfact Book, 2007
18	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability	UNDP, 2004
19	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances, if 0 than take 1	higher # of FI, lower vulnerability	water authority of Bana

Timisoara Urban Scale								
No	**Abb.**	**Name**	**Sub-index**	**FV Factor**	**Units**	**Definition of indicator**	**Functional relationship with vulnerability**	**Data Source**
20	$A_{I..}$	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability	water authority of Banat
21	D_L	Dikes_ Levees	FVI_{Ec}	R	km	Km of dikes/levees	Longer D_L, lower vulnerability	water authority of Banat
22	D_Sc	Dams_Storage capacity	FVI_{Ec}	R	m^3	Storage capacity in m3 of dams, polders, etc., upsteam of	higher m3, higher vulnerability	water authority of Banat
23	RT	Recovery time	FVI_{Ec}	R	days	Amount of time needed by the city to recover to a functional operation after flood events	the higher amount of time, the higher vulnerability	
24	$R_{ainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB	Higher rainfall, higher vulnerability	Ekstrom et al., http://lcweb2.loc.gov/frd/cs/khtoc.html
25	L_U	Land Use	FVI_{Ec}	E	%	area destined for green areas inside the urban area	The higher %, the low vulnerability	water authority of Banat
26	UG	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 10 years	fast urban growth may result in poor quality housing and thus make people more vulnerable	water authority of Banat
27	EV	Evaporation	FVI_{Ec}	S	m/year		higher ev, lower vulnerability	Ekstrom et al.
28	T	Topography	FVI_{Ph}	E	-	average slope of the city	The steeper slope, higher vulnerability	water authority of Banat, google earth
29	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum river discharge in recor of the last 10 years, m^3/s	higher RD, higher vulnerability	water authority of Banat, http://www.aii.edu.kh/pp/pp.html
30	E_V/R_{ain}	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability	Ekstrom et al., http://lcweb2.loc.gov/frd/cs/khtoc.html
31	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m^3	amount of storage capacity	higher m3, higher vulnerability	water authority of Banat
32	D	Drainage system	FVIec	R	Km	Km of canalization in the city	higher km, low vulnerability	Aquatim Ro
33	AvD	Average Discharge	FVI_{Ph}	E	m^3/s			Water Authority of Banat
34	Sc/Vyear	Storage over yearly runoff	FVI_{Ph}	R	m^3/m^3	Amount of storage capacity over the yearly average runoff	Larger storage capacity means lower vulnerability	Water Authority of Banat

Appendix IX Mannheim Urban Area Data Sources

Mannheim Urban Scale								
No	**Abb.**	**Name**	**Sub-index**	**FV Factor**	**Units**	**Definition of indicator**	**Functional relationship with vulnerability**	**Data Source**
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is concentrated	Higher # of people, higher vulnerability	wikipedia
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability	wikipedia
3	C_H	Cultural Heritage	FVI_S	E	-	number of historical buildings, museums, etc., in danger when flood occurs	high # of CH, higher the vulnerability	identic for all cities
4	P_G	Population growth	FVI_S	E	%	% of growth of population in urban areas in the last 10 years	fast PG, higher vulnerability, hypothesis is made that fast population growth may create pressing on housing capacities	INTUTE
5	% of disable	Disable People	FVI_S	E	%	% of population with any kind of disabilities, also people less 12 and more than 65	higher %,higher vulnerability	INTUTE
6	HDI	Human Development Index	$FVI_{S,E}$	S	-	*$HDI = \frac{1}{3}(LEI)+\frac{1}{3}(EI)+\frac{1}{3}(GI)$	The higher value, lower vulnerability	UNDP, 2004
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability	UNDP, 2004
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events;	The higher value, lower vulnerability	

Mannheim Urban Scale								
No	**Abb.**	**Name**	**Sub-index**	**FV Factor**	**Units**	**Definition of indicator**	**Functional relationship with vulnerability**	**Data Source**
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability	reffer to table
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability	INTUTE
11	S	Shelters	FVI_S	R	#/km²	number of shelters per km², including hospitals	bigger # of S, lower vulnerability	identic for all cities
12	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability	yes
13	E_S	Emergency Service	FVI_S	R	#	number of people working in this service	bigger # of people, less vulnerable they are	identic for all cities
14	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods	INTUTE
15	Ind	Industries	FVI_E	E	#	# of industries or any types of economic activities in urban	The higher %, the high vulnerability	google map, industry
16	Cr	Contact with	FVI_{En}	E	km	Distance of city along the river	more distance, more	google earth
17	U_H	Unemployment	FVI_E	S	%	$U_H = \frac{No\_of\_people\_Unemployed}{Total\_Pop\_AgeToWork} * 100$	The higher %, the high vulnerability	Worldfact Book, 2007
18	I_{neq}	Inequality	FVI_E	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability	UNDP, 2004
19	FI	Flood Insurance	FVI_E	R	-	the number flood insurances per 100 inhabitants, if 0 than	higher # of FI, lower vulnerability	MunichRe
20	A_{Inv}	Amount of Investment	FVI_E	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability	See sensitivity analysis
21	D_L	Dikes_ Levees	FVI_E	R	km	Km of dikes/levees	Longer D_L, lower vulnerability	google earth
22	D_Sc	Dams_Storage capacity	FVI_E	R	m³	Storage capacity in m3 of dams, polders, etc., 100 km upsteam of the city	higher m3, lower vulnerability	IKONE project, Aktionsplan Hochwasser Neckar, 2006
23	RT	Recovery time	FVI_E	R	days	Amount of time needed by the city to recover to a functional operation after flood events	the higher amount of time, the higher vulnerability	
24	$R_{rainfall}$	Rainfall	FVI_{En}	E	m/year	the average rainfall/year of a whole RB	Higher rainfall, higher vulnerability	Ekstrom et al.
25	L_U	Land Use	FVI_{En}	E	%	area destined for green areas inside the urban area	The higher %, the low vulnerability	Sensitivity Analysis
26	UG	Urban Growth	FVI_{En}	S	%	% of increase in urban area in last 10 years	fast urban growth may result in poor quality housing and thus make people more vulnerable	UNDP/BCPR, 2004
27	EV	Evaporation	FVI_{En}	S	m/year	yearly decrease rate in groundwater level	higher GWL, higher vulnerability	Ekstrom et al.
28	T	Topography	FVI_{Ph}	E	-	average slope of sub-catcment	The steeper slope, higher vulnerability	wikipedia
29	R_D	River Discharge	FVI_{Ph}	E	m³/s	maximum river discharge in recor of the last 10 years, m³/s	higher RD, higher vulnerability	21 December 1993 [Wikepedia]
30	$E_V/R_{rainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability	Ekstrom et al.
31	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m³	amount of storage capacity	higher m3, lower vulnerability	IKONE project, Aktionsplan Hochwasser Neckar, 2006
32	Drain	Drainage system	FVIec	R	Km	Km of canalization in the city	higher km less vulnerability	Stadtentwasserung Mannheim
33	AvD	Average	FVI_{Ph}	E	m³/s	Average discharge		wikipedia
34	Sc/Vyear	Storage over yearly runoff	FVI_{Ph}	R	m³/m³	Amount of storage capacity over the yearly average runoff	Larger storage capacity means lower vulnerability	reffer to 34 and 36

Appendix X Phnom Penh Urban Area Data Sources

Phnom Penh Urban Scale								
No	Abb.	Name	Sub-index	FV Factor	Units	Definition of indicator	Functional relationship with vulnerability	Data Source
1	PD	Population density	FVI_S	E	people/km2	There is an important exposure to a given hazard if population is concentrated	Higher # of people, higher vulnerability	wikipedia
2	P_{FA}	Population in flood prone area	FVI_S	E	people	Number of people living in flood prone area	The higher number of people, higher vulnerability	Mekong Organization
3	C_H	Cultural Heritage	FVI_S	E	-	number of historical buildings, museums, etc., in danger when flood occurs, if none take 1	high # of CH, higher the vulnerability	
4	P_G	Population growth	FVI_S	E	%	% of growth of population in urban areas in the last 10 years	fast PG, higher vulnerability, hypothesis is made that fast population growth may create pressing on housing capacities	INTUTE, Worldfact Book, 2007
5	% of disable	Disable People	FVI_S	E	%	% of population with any kind of disabilities, also people less 12 and more than 65	higher %,higher vulnerability	Worldfact Book, 2007
6	HDI	Human Development Index	$FVI_{S,E}$	S	-	$^*HDI = \frac{1}{3}(LEI) + \frac{1}{3}(EI) + \frac{1}{3}(GI)$	The higher value, lower vulnerability	wikipedia
7	C_H	Child Mortality	FVI_S	S	-	Number of children less than 1 year old, died per 1000 births	The higher number of chilren, higher vulnerability	UNDP, 2004
8	P_E	Past Experience	FVI_S	R	people	# of people who have been affected in last 10 years because flood events;	The higher value, lower vulnerability	ADB, 2005
9	A	Awareness&Preparedness	FVI_S	R	-	Range between 1-10	10 means lower vulnerability	reffer to table
10	C_{PR}	Communication Penetration Rate	FVI_S	R	%	% of households with sources of information	Higher percentage means lower vulnerability	INTUTE
11	S	Shelters	FVI_S	R	$\#/km^2$	number of shelters per km^2, including hospitals	bigger # of S, lower vulnerability	identic for all cities
12	W_S	Warning system	FVI_S	R	-	if No W_S than the value is 1, if yes W_S than the value is 10	Having WS reduces the vulnerability	Y/N
13	E_S	Emergency Service	FVI_S	R	#	number of people working in this service	bigger # of people, less vulnerable they are	identic for all cities
14	E_R	Evacuation Roads	FVI_S	R	%	% of asphalted roads.	The better the quality of roads, improves the evacuation during floods	INTUTE
15	Ind	Industries	FVI_E	E	#	# of industries or any types of economic activities in urban	The higher %, the high vulnerability	INTUTE
16	Cr	Contact with River	FVI_{Ec}	E	km	Distance of city along the river	more distance, more	google earth
17	U_H	Unemployment	FVI_{Ec}	S	%	$U_u = \frac{\#of\ people\ Unempl}{Total\ Pop\ AgeToWork} * 100$	The higher %, the high vulnerability	Worldfact Book, 2007
18	I_{neq}	Inequality	FVI_{Ec}	S	-	Gini Coefficient for wealth inequality, between 0 and 1	Where 1 means low vulnerability	UNDP, 2004
19	FI	Flood Insurance	FVI_{Ec}	R	-	the number flood insurances, if 0 than take 1	higher # of FI, lower vulnerability	Mekong Organization
20	A_{Inv}	Amount of Investment	FVI_{Ec}	R	-	Ratio of investment over the total GDP	Higher the investment lower vulnerability	ADB, 2005
21	D_L	Dikes_ Levees	FVI_{Ec}	R	km	Km of dikes/levees	Longer D_L, lower vulnerability	ADB, 2006
22	D_Sc	Dams_Storage capacity	FVI_{Ec}	R	m^3	Storage capacity in m3 of dams, polders, etc., upsteam of the city	higher m3, higher vulnerability	Tonle Sap Lake
23	RT	Recovery time	FVI_{Ec}	R	days	Amount of time needed by the city to recover to a functional operation after flood events	the higher amount of time, the higher vulnerability	
24	$R_{ainfall}$	Rainfall	FVI_{Ec}	E	m/year	the average rainfall/year of a whole RB	Higher rainfall, higher vulnerability	http://lcweb2.loc.gov/frd/cs/khtoc.html
25	L_U	Land Use	FVI_{Ec}	E	%	area destined for green areas inside the urban area	The higher %, the low vulnerability	
26	UG	Urban Growth	FVI_{Ec}	S	%	% of increase in urban area in last 10 years	fast urban growth may result in poor quality housing and thus make people more vulnerable	ADB, 2005
27	EV	Evaporation	FVI_{Ec}	S	m/year	yearly decrease rate in groundwater level	higher GWL, higher vulnerability	http://lcweb2.loc.gov/frd/cs/khtoc.html
28	T	Topography	FVI_{Ph}	E	-	average slope of the city	The steeper slope, higher vulnerability	ADB, 2005
29	R_D	River Discharge	FVI_{Ph}	E	m^3/s	maximum river discharge in recor of the last 10 years, m^3/s	higher RD, higher vulnerability	http://www.aii.edu.kh/pp/pp.html
30	$E_V/R_{ainfall}$	Evaporation rate/Rainfall	FVI_{Ph}	E	-	Yearly Evaporation over yearly rainfall	Higher the Ev, lower vulnerability	http://lcweb2.loc.gov/frd/cs/khtoc.html
31	D_Sc	Dams_Storage capacity	FVI_{Ph}	R	m^3	amount of storage capacity within 100Km upstream of the	higher m, higher vulnerability	Tonle sap lake

Phnom Penh Urban Scale								
No	**Abb.**	**Name**	**Sub-index**	**FV Factor**	**Units**	**Definition of indicator**	**Functional relationship with vulnerability**	**Data Source**
32	Drain	Drainage system	FVIec	R	Km	Km of canalization in the city		ADB, 2005
33	AvD	Average Discharge	FVI_{PL}	E	m^3/s	average discharge		wikipedia
34	Sc/Vyear	Storage over yearly runoff	FVI_{PL}	R	m^3/m^3	Amount of storage capacity over the yearly average runoff	Larger storage capacity means lower vulnerability	reffer to 34 and 36