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Balica, SF, Popescu, I, Wright, NG et al. (1 more author) (2013) Parametric and physically based modelling techniques for flood risk and vulnerability assessment: A comparison. Environmental Modelling and Software, 41. 84 - 92 . ISSN 1364-8152

https://doi.org/10.1016/j.envsoft.2012.11.002

Parametric and physically based modelling techniques for flood risk and vulnerability assessment: a comparison

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Abstract

Floods are one of the most common and widely distributed natural risks to life and property. There is a need to identify the risk in flood-prone areas to support decisions for risk management, from high-level planning proposals to detailed design. There are many methods available to undertake such studies. The most accepted, and therefore commonly used, of which is computer-based inundation mapping. By contrast the parametric approach of vulnerability assessment is increasingly accepted. Each of these approaches has advantages and disadvantages for decision makers and this paper focuses on how the two approaches compare in use. It is concluded that the parametric approach, here the FVI, is the only one which evaluates vulnerability to floods; whilst although the deterministic approach has limited evaluation of vulnerability, it has a better science base.

Keywords: floods, vulnerability, risk, physically-based models, flood vulnerability index

1. Introduction

Floods are one of the most common and widely distributed natural risks to life and property. Damage caused by floods on a global scale has been significant in recent decades (Jonkman and Vrijling, 2008). In 2011, floods were reported to be the third most common disaster, after earthquake and tsunami, with 5202 deaths, and affecting millions of people (CRED, 2012). River, coastal and flash floods can claim human lives, destroy properties, damage economies, make fertile land unusable and damage the environment. The development of techniques, measures and assessment methodologies to increase understanding of flood risk or vulnerability can assist decision makers greatly in reducing damage and fatalities. Different methods to assess risk and vulnerability of areas to flooding have been developed over the last few decades. This paper aims to investigate two of the more widely used methods:

traditional physically-based modelling approaches to risk assessment and parametric approaches for assessing flood vulnerability. The paper aims to present and discuss the benefits of each to decision makers.

Flood risk as a concept

The term "risk" in relation to flood hazards was introduced by Knight in 1921, and is used in diverse different contexts and topics showing how adaptive any definition can be (Sayers et al., 2002). In the area of natural hazard studies, many definitions can be found. It is clear that the many definitions related to risk (Alexander, 1993; IPCC, 2001; Plate, E., 2002; Barredo et al., 2007) are interrelated and interchangeable and each of them has certain advantages in different applications (e.g. Sayers et al., 2002; Merz et al., 2007).

This study will consider risk as the product of two components, i.e. probability and consequence (Smith, 2004):

$$\text{Risk} = \text{Probability X Consequence} \qquad (1)$$

This concept of flood risk is strictly related to the probability that a high flow event of a given magnitude occurs, which results in consequences which span environmental, economic and social losses caused by that event. The EU Flood Directive 2007/60/EC (EC, 2007) and UNEP, (2004) uses this definition of risk where "flood risk" means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event

Hazard and Flood Hazard as a concept

"The probability of the occurrence of potentially damaging flood events is called flood hazard" (Schanze, 2006). Potentially damaging means that there are elements exposed to floods which may be harmed. Flood hazards include events with diverse characteristics, e.g. a structure located in the floodplain can be endangered by a 20-year flood and a water level of 0.5m and by 50-year flood and a water level of 1.2m. Heavy rainfall, coastal or fluvial waves, or storm surges represent the source of flood hazard. Generally these elements are characterised by the probability of flood event with a certain magnitude and other characteristics.

Vulnerability and Flood vulnerability as a concept

While the notion of vulnerability is frequently used within catastrophe research, researchers' notion of vulnerability has changed several times lately and consequently there have been several attempts to define and capture the meaning of the term. It is now commonly understood that "vulnerability is the root cause of disasters" (Lewis, 1999) and "vulnerability is the risk context" (Gabor and Griffith, 1980). Many authors discuss, define and add detail to this general definition. Some of them give a definition of vulnerability to certain hazards like climate change (IPCC, 2001), environmental hazards (Blaikie et al., 1994); (Klein and Nicholls, 1999), (ISDR, 2004), or the definition of vulnerability to floods (Veen & Logtmeijer 2005, Connor & Hiroki, 2005, UNDRO, 1982, McCarthy et al., 2001).

This study will use the following definition of vulnerability specifically related to flooding:

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. The practice of flood risk and vulnerability assessment

Different methods to assess or determine hazard, risk and vulnerability to flooding have evolved through ongoing research and practice in recent decades (Junqiang Xia et al., 2011; Hartanto et al., 2012; Gichamo et al., 2012). Two distinct method types can be distinguished and are considered in this paper:

- Deterministic modelling approaches which use physically based modelling approaches to estimate flood hazard/probability of particular event, coupled with damage assessment models which estimate economic consequence to provide an assessment of flood risk in an area.
- Parametric approaches which aim to use readily available data of information to build a picture of the vulnerability of an area.

Each method has developed from different schools of thought; the first approach mentioned is the traditional method which is routinely used in practice and academia alike. The second approach has evolved from several concerns such us: the internal characteristics of the system, global climate change and the political and institutional characteristics of the system. However, it takes a long time to develop the structural and non-structural measures required to prepare for flooding. In order to help guide such policy decisions, the development of a practical method for assessing flood vulnerability was needed. Among this need, this parametric approach points on vulnerability assessments to minimize the impacts of flooding and also to increase the resilience of the affected system.

The physically based modelling approach

Floods are primarily the result of extreme weather events. The magnitude of such an extreme event has an inverse relationship with the frequency of its occurrence i.e. floods with high magnitude occur less frequently than more moderate events. The relationship between the frequencies of occurrence and the magnitude of the extreme event is traditionally established by performing a frequency analysis of historical hydrological data using different probability distributions.

Once the frequency, magnitude and shape of the hydrograph are established, computer models which discretise the topographical river and land form are used to estimate flood depth, flood elevation and velocity (Hansson et al., 2008). Calculation of flood inundation depth and inundation extent is done using computational models based on solutions of the full or approximate forms of the shallow water equations. These types of models are one (1D) or two-dimensional (2D). 1D modelling is the common approach for simulating flow in a river channel, where water flow in the river is assumed to flow in one dominant direction which is aligned with the centre line of the main river channel. A 1D model can solve flood flows in open channels, if the shallow water assumptions that vertical acceleration is not significant and that water level in the channel cross-section is approximately horizontal are valid. However problems arise when the channel is embanked and water levels are different in the floodplain than in the channel and 2D models are needed in this situation. The hydraulic results from a computer model, such as inundation depth, velocity and extent can be used for loss estimation due to a particular design flood event. These parameters can then be linked to estimates of economic damage and loss in the affected area. Different models of damage and loss are available and are based on established economic relationships (ref).

This method relies on a significant amount of detailed topographic, hydrographic and economic information in the area studied. If the information is available, fairly accurate estimates of the potential risk to an area, as a result of economic losses, can be calculated. This type of flood hazard and associated economic loss information is reasonably easily communicated to the public. With the case of economic loss the public is used to hearing information provided in this manner. However, if the information for the model construction is not available, the method is likely to incur significant anomalies, which can call into question the validity of the assessment. These types of knowledge gaps and uncertainties are difficult to communicate effectively and can confuse decision makers and the public alike.

The scientific community therefore has researched methods that will overcome these problems. In this context it becomes important to evaluate the hazard, risk and vulnerability to flooding also from a different perspective: the parametric approach.

The parametric approach

The parametric approach, introduced in 80's by Little and Robin, (1983), starts from the perspective of limited data, and has developed further since. The parametric approach aims to estimate the complete vulnerability value of a system by using only a few readily available parameters relating to that system, though the implementation of the approach is not simple.

Four types of parametric approaches have been developed by the scientific communities: i) estimating the complete vulnerability value of a system by using only few parameters relating to that system, ii) estimation of "the imputation of non-observable values" (Glynn et al., 1993), in which the observed parameters are used to model the non-observed ones. (This assumption can be wrong), iii) the "parametric modelisation via maximum likelihood" (Little and Rubin, 1987), which is not a direct approach and is based on large number of assumptions; and iv) the "semi-parametric approach" (Newey, 1990) which allows modelling only of what is strictly necessary.

This study considers the first type of parametric approach, where the indicators and results rely on assumptions that cannot be validated from the observed data. This parametric approach tries to design a methodology that would allow the experts to assess the vulnerability results depend on the system characteristics and also to show the drawbacks, the practical and the philosophical in the specifications of the likelihood function (Serrat and Gomez, 2001).

In a general context, vulnerability is constructed like an instrumental value or taxonomy, measuring and classifying social, economic and environmental systems, from low vulnerability to high vulnerability. The vulnerability notion has come from different disciplines, from economics and anthropology to psychology and engineering (Adger, 2006); the notion has been evolving giving strong justifications for differences in the extent of damage occurred from natural hazards.

Whatever the exact measure of vulnerability one chooses to work with, the starting point is to estimate the right parameters of the process under the specification of the datasets. Vulnerability assessments have to be explicitly forward-looking. No matter how rich the data, the vulnerability of various systems is never directly obvious.

At spatial and temporal scales, several methodologies such as parametric-based approaches are applied to a vast diversity of systems: Environmental Vulnerability Index (EVI), Pratt et al, 2004; The Composite Vulnerability Index for Small Island States (CVISIS), Briguglio, 2003; Global Risk and Vulnerability Index (GRVI), Peduzzi et al., 2001; Climate Vulnerability Index (CVI), Sullivan and Meigh, 2003, etc..

This study uses a parametric approach proposed by Balica et al., (2009) to determine and index flood vulnerability for four system components (social, economic environmental and physical).
The parametric approach has some drawbacks, such as: an inevitable level of assumptions, the need for a sensitivity analyses, reliable sources and the subjective manner of interpreting the results.

Comparison of approaches

Physically based modelling and parametric approaches offer two different techniques for assessing flood risk and vulnerability. In light of these two distinct approaches, a clear question arises: what are the different advantages and disadvantages for decision makers using these techniques and "how do the two approaches compare in use?"

In order to answer this research question it is important to assess what decision makers require from these techniques in order to reach decisions. For the purposes of this study the following key components are identified:

- Information on the mechanism and cause of flooding (flood hazard) in the area studied.
- Information on the health and safety implications for the affected population of the flood hazard posed in the area, and the relative areas or population who are particularly vulnerable (and why).
- Information on the economic damage and losses expected in the area given a particular event.

In addition to these key components a fourth criteria was identified:

- How easily is this information communicated, both
    - From the expert undertaking the study to the decision-maker and
    - From the decision-maker to the public

This study will use the above identified criteria to compare the application of the two techniques (physically based modelling and the parametric approach) to a case study area in Budalangi, on the Nzioa River in Western Kenya. The paper aims to investigate the benefits and drawbacks of each approach, with the purpose of informing decision makers of the use.

3. Methodology

The scope of the present paper is to compare a parametric approach (Flood Vulnerability Index (FVI)) with traditional physically-based hydraulic modelling for flood risk analysis in order to determine what are the advantages of using one or the other in design and decision-making when flood hazard is involved. The general framework for the methodology is set out in Figure 1.

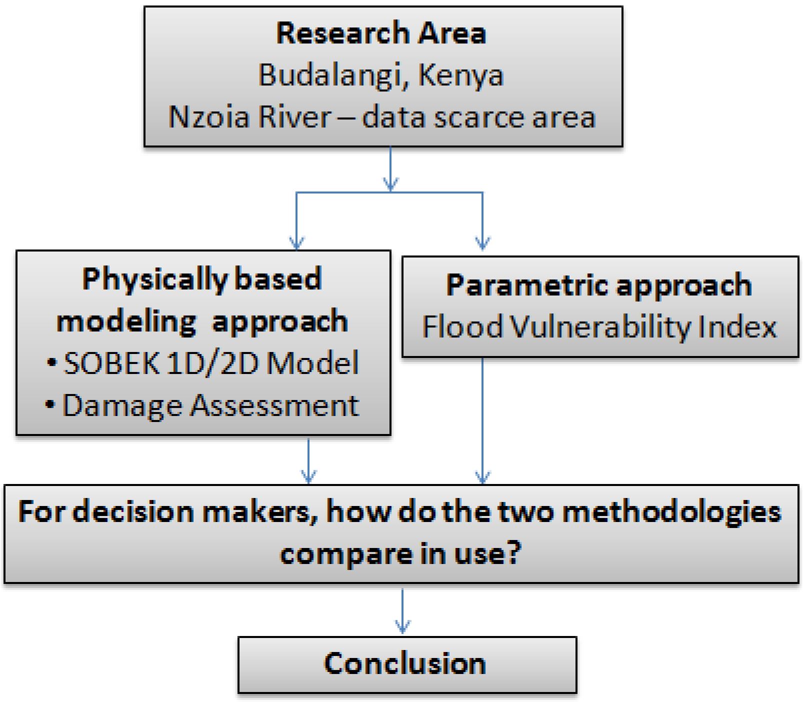

Figure 1. Proposed methodology

3.1 Case Study Area

The Nzoia river originates in the South Eastern part of Mt. Elgon and the Western slopes of Cherangani Hills at an elevation of about 2300 m.a.s.l and it is one of the major rivers flowing into Lake Victoria. Nzoia river basin covers an area of 12709 km^2 in Western Kenya (Figure 2). The Nzioa River discharges into Lake Victoria in Budalangi, Busia district. The river is of international importance, as it is one of the major rivers in Nile basin contributing to the shared water of Lake Victoria (NRBMI, (nd)).

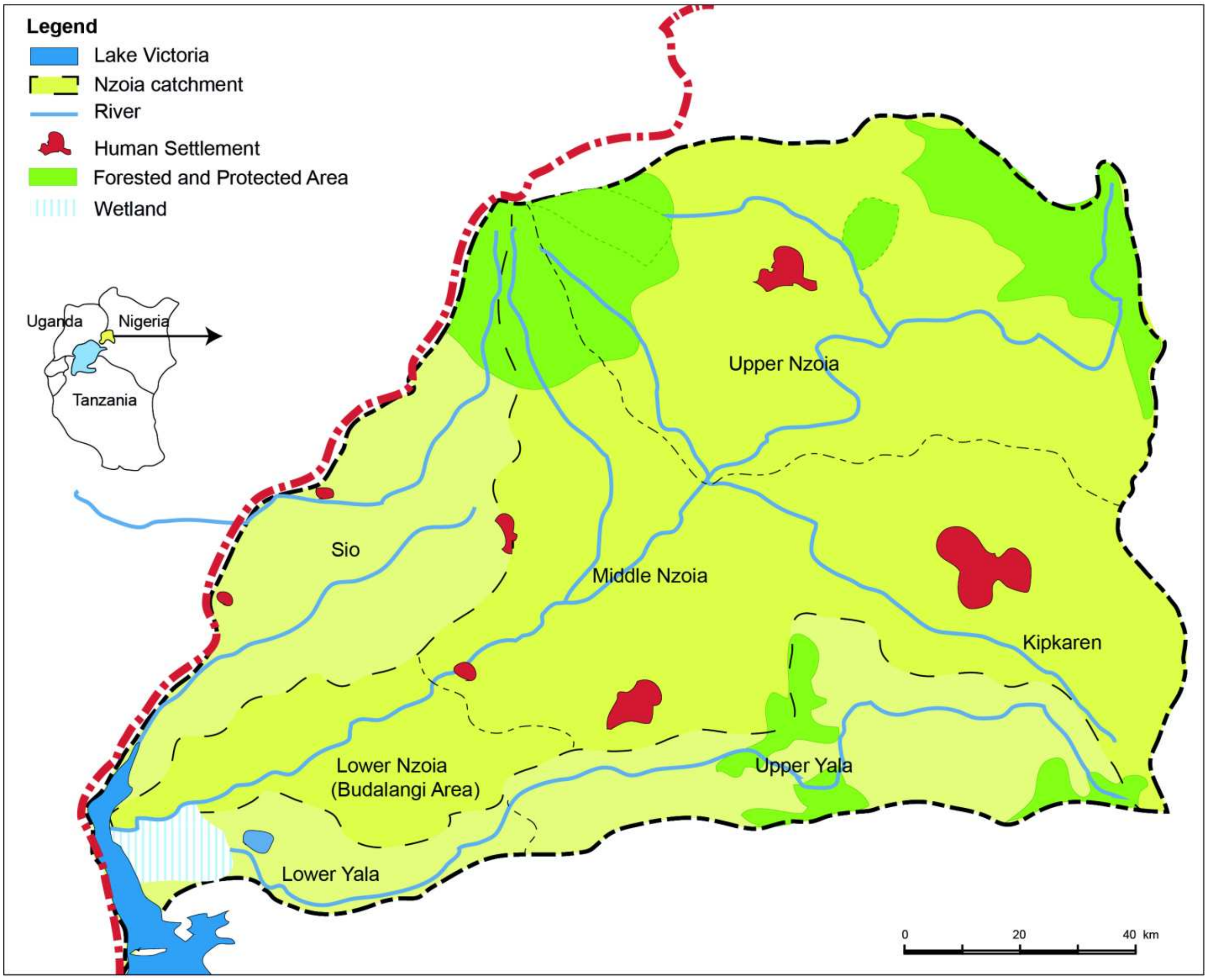

Figure 2. Nzoia River Basin

The Nzoia river basin is divided into three sub-catchments: the Lower Nzoia, characterised as flat and swampy; the Middle Nzoia and the Upper Nzoia, characterised with hills and steep slopes. The major tributaries of the Nzoia River are: Koitogos (Sabwani), Moiben, Little Nzoia, Ewaso Rongai, Kibisi, Kipkaren and Kuywa. The climate is tropical-humid and the area experiences four distinct seasons. Nzoia catchment has two rainy periods per year, one from March to May, with long rains and a second one from October to December, with short rains associated with ITCZ (the Inter Tropical Convergence Zone). The mean annual rainfall varies from a minimum of 1076 mm in the lowland to a maximum of 2235mm in the highlands. Average annual volume of precipitation of the catchment is about $1740 x 10^6 m^3$. The average temperature of the area varies from 16ºC in the upper catchment (highlands) to 28º C in the lower catchment (lower semi-arid areas).

The dominant land use in the river basin is agriculture and the main agriculture production of the area are corn, sorghum, millet, bananas, groundnuts, beans, potatoes, and cassava and cash crops are coffee, sugar cane, tea, wheat, rice, sunflower and horticultural crops (Githui et al, 2008). The river basin plays a large role in economic development at local and also at national level. Major problems and challenges in the basin are soil erosion and sedimentation, deforestation, flooding, and wetland degradation. The area located at the most downstream end of the catchment is, as previously mentioned the Budalangi area, which is the focus of the present study. Floods are frequent in the Budalangi area (WMO/MWRMD/APFM, 2004) and their impact is felt through loss of life, damage to property and agricultural/crop destruction.

This case study is data scarce area. The lower the accuracy in the data, the lesser the accuracy in the predictions, therefore in data scarce areas this can result in bad or poor vulnerability predictions. Consequently, the results of the two approaches chosen may prove which one is a more appropriate approach to be used by the decision makers in such cases.

3.2. Assessing the flood risk of Budalangi region using physically based modelling

There are many simulation models available for solving problems of unsteady or steady flow. In this present study, an unsteady flow analysis was carried out using the SOBEK 1D/2D tool, developed by Deltares. SOBEK 1D/2D couples one-dimensional (1D) hydraulic modelling of the river channel to a two-dimensional (2D) representation of the floodplains. The hydrodynamic 1D/2D simulation engine is based upon the optimum combination of a minimum connection search direct solver and the conjugate gradient method. It also uses a selector for the time step, which limits the computational time wherever this is feasible. Detailed numerical implementation of the solution of the Saint Venant flow equations in SOBEK 1D/2D is given in the technical user manual of Verwey, (2006).

Generally the damages by flooding are classified as damages which can be quantified as monetary losses (tangible) and the damages which cannot be evaluated quantitatively in economic terms (intangible). These damages may be direct or indirect depending upon the contact to the flooding.

Flood damage estimation methodologies are applied worldwide (Dutta et al., 2003). For example, in the United Kingdom a standard approach to flood damage assessment is used (developed in the mid 1970s). Since then continually refined, this approach is mandatory for local authorities and agencies wanting central government assistance with flood mitigation measures. In United States, U.S. Army Corps of Engineers (USACE) has developed its own guidelines for urban flood damage measurement, (USACE, 1988). The method is based on the US Water Resources Council's 1983 publication on 'Principles and Guidelines for Water and Related Land Resources Implementation Studies'. The approach adopted in the method is very comprehensive for estimation of damage to urban buildings and to agriculture. In Australia, authorities considered that is no standard approach and it is a little attempt to achieve standard approach. Flood damage estimation methodologies are applied as well in many countries in Europe (Forster et al., 2008). These approaches are useful in conducting cost-benefit analyses of the economic feasibility of flood control measures.

This paper uses the Forster et al., 2008, approach where the expected damage (ED) on agriculture was calculated using the following equation, which is modified from Forster et al., (2008).

$ED = MV * Y * A * DI$, where ED – estimation damage; MV – market value; Y – yield per unit area; A- area of cultivation; DI – damage impact factor.

The number of houses in the inundated area was calculated using the information on population density and average number of family member per household.

$NH = \frac{IA * PD}{FM}$; where NH – number of houses in inundated area; IA – inundated area; PD – population density; FM – average number of family per household.

In order to estimate the flood damage, the estimation of some flood parameters are needed: flow velocity, depth and duration at any given point, proper classification of damage categories considering nature of damage, establishment of relationship between flood parameters and damage for different damage categories.

Flood Inundation Modelling

In order to build the 1D/2D hydrodynamic model of the Budalangi river, in SOBEK, available topographical information from the Shuttle Radar Topography Mission (SRTM) at a resolution of 90m by 90m and sparse cross-section data were used. Hydrograph variations at the upstream boundaries of the model were provided by a calibrated hydrological SWAT model of the Nzoia catchment. Recorded water levels for Lake Victoria were used as downstream boundary conditions. The SWAT model used to provide the upstream boundary condition was the one originally built and described by Githui et al. (2008) and recalibrated by van Hoey (2008). The 1:200 years design flood determined by SWAT was routed downstream by the hydrodynamic SOBEK model and inundation extents were drawn. A 1 in 200 year return flood was recorded on Nzoia river on November 2008, and therefore the inundation extent produced by the model was compared with available aerial information captured by to the Advanced Land Imager (ALI) on NASA's earth observing-1 satellite on the 13th November 2008.
The results of the model, at the moment of the largest flood extent, for the 1:200 return flood period are represented in Figure 3.

Flood Damage Evaluation

Many flood damage assessment methods have been developed since 1945 (White, 1945).
However, quantifying the expected flood damage is very difficult because the impact of a flood is a function of many physical and behavioural factors. For the purposes of this paper, flood damage was assumed to be related only to the flood depth.

The Budalangi region is a poorly developed rural area whose main industry is agriculture. Consequently the main expected damages were anticipated to be on the agricultural sector and were calculated based on a formula developed by Forster et al., (2008). The main cash crops in the area are known to be sugarcane, maize and rice. These crops were used, with readily available yield and expected local market values, to calculate the potential losses due to floods as a result of the 200 year return period event. In addition, loss of property and the affected population were included in the damage estimation, however it is recognised that in excluding the calculation of damage in relation to velocity this estimation is significantly simplified.

3.3. Assessing flood vulnerability of Budalangi using a parametric method

As mentioned above the parametric method used in this study is the one developed by Balica et al, 2009, which consists in determining a flood vulnerability index (FVI), based on four components of flood vulnerability: social, economic, environmental and physical and their interactions, which can affect the possible short term and long term damages.

The four components of the flood vulnerability have been linked with the factors of vulnerability: exposure, susceptibility and resilience (Bosher et al., 2007, Penning-Rowsell and Chatterton, 1977).

The conceptual FVI equation is:

$$\text{FVI} = (E * S)/R, \qquad (2)$$

where E-exposure, S-susceptibility and R-resilience.

The indicators belonging to exposure and susceptibility increase the flood vulnerability index therefore they are placed in the nominator; however the indicators belonging to resilience decrease the FVI, this is why they are placed in the denominator (Quang et al, 2012).

The application of this formula for each component leads to four distinct FVI indices; $\text{FVI}_{\text{Social,}}$ $\text{FVI}_{\text{Economic}}$, $\text{FVI}_{\text{Environmental}}$ and $\text{FVI}_{\text{physical.}}$, which aggregates into:

$$\text{Total FVI} = \frac{\left(\frac{E*S}{R}\right)_{Social} + \left(\frac{E*S}{R}\right)_{Economic} + \left(\frac{E*S}{R}\right)_{Environmental} + \left(\frac{E*S}{R}\right)_{Physical}}{4} \qquad (3)$$

The exposure can be understood as the intangible and material goods that are present at the location where floods can occur, such as: loss of photographs and negatives, loss of life, delays in formal education (Penning-Rowsell et al., 2005). The susceptibility relates to system characteristics, including the social context of flood damage formation (Begum et al., 2007) and can be i.e. poverty, people with special needs, education, level of trust. Susceptibility is defined as the extent to which elements at risk (Messner & Meyer, 2006) within the system are exposed, which influences the chance of being harmed at times of hazardous floods. 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 floods (Cutter, 1996, Cutter et al., 2003, Pelling, 2003, Walker et al., 2004, Turner II et al., 2003). Resilience describes the ability of a system to preserve its basic roles and structures in a time of distress and disturbance. Indicators showing resilience are flood insurance, amount of investment, dikes and levees, storage capacities, etc.

There are in total 29 indicators identified to contribute to Eq (3), each with their own unit of measure. Some indicators are not always used while evaluating the FVI of a region. They are evaluated in each case and the most representative are used for the FVI. A comprehensive description of such indicators in case of floods in the Mekong delta can be found in Quang et al (2012).
After identifying the indicators, in order to use them in Eq (3) they need to be normalised using a predefined minimum and maximum. In general classical proportional normalization is used, which keeps the relative ratios in the normalized values of the indicators as they were before normalization. The indicators become dimensionless, but still keep their proportion.

The FVI of each of the social, economic, environmental and physical component is computed using Eq. 1. The results of each FVI component (social, economic, environmental and physical) are summed up in Eq. 3.

The FVI methodology does not require researchers to judge the relative importance of different components, i.e. they do not need to develop arbitrary weights for the indicators.
The Equation 1 links the values of all indicators to flood vulnerability components and factors (exposure, susceptibility and resilience), without weighting, as suggested by Cendrero and Fisher in 1997. This is done because of different number of rating judgments which "lie behind combined weights", or interpolating. The same approach of assigning no weights was used by Peduzzi et al., 2001, the Global Risk and Vulnerability Index –Trends per Year, GRAVITY, by Briguglio, 2003 in the Economic Vulnerability Index and Rygel et al., 2006.

The main issue while computing the FVI is actually to determine these indicators. There are different sources for determining the values of the indicators, and these are in general statistical data stored by environmental agencies, water boards, UN overviews and annual data from city halls.

4. Results obtained when applying the two approaches

4.1. Physically based modelling approach

The SOBEK simulation of the 1:200 year event results were water depths and inundation extents, as can be seen in figure 3. The model is able to produce velocities of flow during an inundation event as well; however these velocities were not considered in the estimation of the damages and therefore not reported herein.

The maximum inundation extent was checked with an available satellite image on 13 November 2008. The obtained maximum inundation extent from the model was of 12.61km^2, which represents 97% of the inundation extent of the satellite image. Due to lack of data in the area, it is considered that this is good for the calibration of the model.

In order to determine the impact of flood and to evaluate the damages water depths obtained from the model were analysed. The obtained water depths were overall less than 2m (95% of the inundated area), and only 5% bigger than 2m in the upstream of the river. The main water depth is less than 0.5 m for 30% of the inundated area; 0.5m for 20% of the inundated area, between 1m and 1.5m for 35% of the inundated area; and 1.5 -2m for 10% of the inundated area.

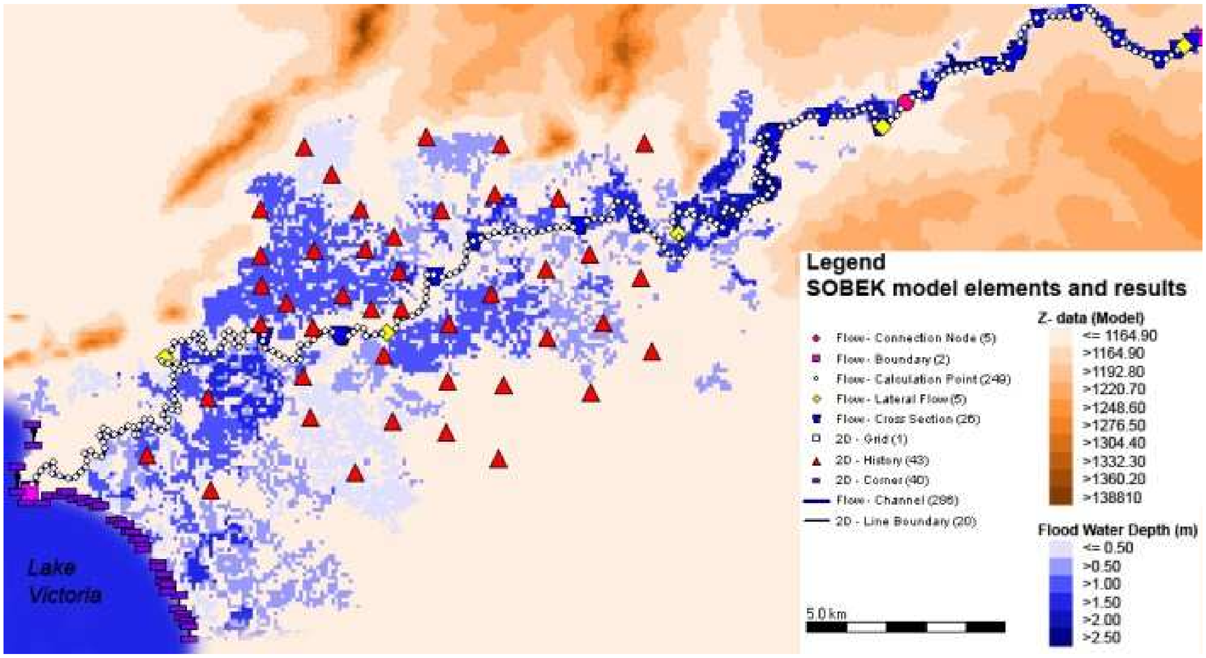

Figure 3. Lower Nzioa Flood Inundation Extent 1:200 year prediction

Based on the results from the hydrodynamic model, damage in the Budalangi area was computed using Forster et al, (2008) method and damage functions (Duggal & Soni, 2005).

In the Budalangi area the expected potential damages of 1.54M Euros (+/-80000 Euros was calculated for the event of 1:200 year return.

4.2. Parametric approach

The FVI methodology was applied to Budalangi Settlement, the results can be seen in Table 2. Budalangi vulnerability in the social and economic components is higher than the environmental and physical component, (1.00 means the highest vulnerability, see Table 1 for flood vulnerability index designations).

The incorporation of flood vulnerability designations is probably the most difficult of all variables to include in the vulnerability index. There are problems involved in deciding how to rank vulnerability zones; but since the purpose of the FVI is to assess vulnerability in relation to flood vulnerability components and indicators, it was decided to rank the designation zones on the basis of standardised vulnerability indices results, between 0 and 1.

Flood vulnerability designations are assigned based on vulnerability potential in the event of flooding. A very high vulnerability designation is assigned if there is very high potential for loss of life and/or extreme economic loss based on vulnerability indicators, i.e. low amount of investment in counter measures or very slow recovery. A high vulnerability designation is assigned if there is a high potential for loss of life but still high economic loss. A medium vulnerability designation is assigned if there is a medium potential for loss of life but an appreciable economic loss, the area can recover in months and the amount of investment in counter measures is enough to maintain the existing structural measures. A low flood vulnerability designation is assigned if there is a small but still existing potential for loss of life and the economic loss is minor. Lastly, a very low flood vulnerability designation is assigned if there is a vanishingly small potential for loss of life and the economic loss can be minor or even if flood insurances apply.

The data for the Budalangi area consulted to gather the indicators are: UNDP: United Nations Development Programme (HDI, child mortality, inequality); INTUTE: a web-site which provides social data for education and science research, (population density, unemployment, disabled people); the World Fact-Book, a database developed by the CIA with basic information on all the countries in the world (communication penetration rate, past experience); UNEDRA: University Network for Disaster Risk Reduction in Africa; Nzoia River Basin Management Initiative a public private partnership between Water Management Resource Authority and Mumia Sugar, Pan Paper and Nzoia Sugar Company (land use, flood insurance, shelters, closeness to river); DEFRA - Department for Environment, Food and Rural Affairs economic and statistical database at no cost charge (urban growth, population growth, amount of investment, dikes-levees, storage capacity); WKCDD & FMP, Western Kenya Community Driven Development & Flood Mitigation Project (river discharge, rainfall, evaporation); Western Water Board, Kenya (drainage, topography, industries, evacuation roads).

Table 1. Flood Vulnerability Designations

Designation	**Index Value**	**Description**
Very small vulnerability to floods	<0.01	Very small Vulnerability to floods, the area recover fast, flood insurances exist, Amount of investment in the area is high
Small vulnerability to floods	0.01 to 0.25	Social, economic, environmental and physical the area can once in a while experience floods, the area is vulnerable to floods and the recovery process is fast due to the high resilience measures, high budget, on the other hand if the area is less developed economic, even if a flood occurs the damages are not high, so small vulnerability to floods
Vulnerable to floods	0.25 to 0.50	Social, economic, environmental and physical the area is vulnerable to floods, the area can recover in months average resilience process, amount of investments is enough
High Vulnerability to floods	0.50 to 0.75	Social, economic, environmental and physical the area is vulnerable to floods, recovery process is very slow, low resilience, no institutional organizations
Very high vulnerability to floods	0.75 to 1	Social, economic, environmental and physical the area is very vulnerable to floods, the recovery process very slow. The area would recover in years. Budget is scarce.

Table 2. Budalangi FVI results

Budalangi Flood Vulnerability Index		
FVI Components	**FVI Values**	**FVI designation**
FVI Social	0.768	Very high vulnerability to floods
FVI Economic	0.521	High vulnerability to floods
FVI Environmental	0.314	Vulnerable to floods
FVI Physical	0.341	Vulnerable to floods
FVI Total	0.490	Vulnerable to High vulnerability to floods

Socially, the Budalangi area has very high vulnerability to floods, since has high population density, high child mortality rate, and a large affected population due to floods. The study also shows that the region has few shelters (0.6/km^2), no warning systems, no evacuation roads (no asphalted road), and only limited emergency services.

Economically the region is high vulnerable to floods since the area has low exposure to floods as the main economic activity is agriculture. The Human Development Index is low, and the area is not covered by flood insurance. Budalangi has few industries, the investment levels and a recovery process take long to recover after a flood event.

Environmentally, the Budalangi settlement is vulnerable to floods. The environmental component includes indicators which refer to damage to the environment caused by flood events or manmade interferences which could increase the vulnerability of certain areas. But activities like industrialisation, agriculture, urbanisation, deforestation, can increase the flood vulnerability, which may also create even more environmental damages.

When examining the physical vulnerability, the Budalangi area has very low slope and the settlement area is in contact with the river all along the length of the river so the exposure of Budalangi is high and has low resilience with little or no installed storage capacity.

Overall, the area following the designations of FVI is high vulnerable to floods, the recovery process is slow, the area has low resilience and no institutional organizations.

5. Discussion (Comparison – analysis and discussion of the approaches)

5.1 The physically based modelling approach

Physically based models have the advantage that they calculate the solution of a complicated and coupled set of equations that describe the phenomena of river flow and flooding. These models are dependent on physical knowledge that they incorporate into the equations and associated parameters. A key element for a good physically based model is the minimum of historical data that they need to determine the values for the parameters included in the physically based equations. Often, historical data is not available, in particular in areas of weak infrastructure, and this would make physically based models unusable in certain areas.

The advantage in using physically based models is their high capability for prognosis and forecasting, and their disadvantage is the high input data demand. In the past computational demand was a big disadvantage, but nowadays with the development of cloud and cluster computing capabilities over the internet, this disadvantage is reduced. However this is only true in case of larger, better-funded organisations that have good computer power to create cluster of computers, and not yet true for small consultancy companies or water boards who cannot dedicate cluster of computers for a specific modelling task. Due to the high computation resources demands, in case of 2D and 3D models, the calibration of physically or semi-physically based models can still be a tremendous effort.

In the present study the data on flooding was scarce, however the 2D physically based model was able to predict well the extent of flood, which shows that even in an ungauged catchment if the model is properly build, confidence in the construction of such a model does not require calibration (Cunge et al, 1980) and the results are good for design. A model based on the physics of the phenomena can be used to produce synthetic data to be used with a simple forecasting model (Van Steenbergen et al., 2012).
One of the important tasks of the decision makers in flood situations is not only to take management decision but also to properly disseminate knowledge to involved stakeholders, including the general public. The objectives of knowledge dissemination is to offer simple and clear information, which can prepare the public for the future and also can actively involve the stakeholders in flood management planning. The information should be delivered in relevant spatial and temporal scales. A physically based model has the advantage that can offer all types of information on a very fine spatial resolution, at a level of a street, or a house, in a familiar and easily recognisable user interface. It is very important that the decision makers use thoroughly verified results, rather than results characterised by uncertainties, because the stakeholders and the public are taking often quick evacuation measures based on such information.

5.2 The parametric approach

The FVI approach regarding the *information on the mechanism and cause of flooding* has some limitations, what is given from this approach are the indicators values for river discharge, topography, closeness to the river, the amount of rainfall, dikes and levees. Considering these indicators the FVI approach can only evaluate the flood vulnerability, cannot tell the extent of flooding nor the expected inundation area through the physical and environmental component. The application of this approach takes less preparation time than physically-based model construction, calibration and simulation.

The FVI approach regarding the *information on the health and safety implications to the affected population* is well designed; the approach shows through the social vulnerability indicators the exact population exposed to floods, the ones which are susceptible (youngest and eldest), if these people are aware and prepare, if they have and know how to interpret a warning system, which of the roads can act as an evacuation road. The social flood vulnerability index expresses whether the population of that specific area has experienced floods, the number of people working in the emergency service and the number and locations of shelters in the area. The social FVI provides a greater understanding of how people might be affected, which can feed into emergency services and evacuation strategy development.

The FVI approach regarding the *information on the economic damages and losses to the affected areas* gives basic damage estimation. The economic component is related to income or issues which are inherent to economics that are predisposed to be affected (Gallopin 2006).

Many economic activities can be affected by flooding events, among them are agriculture, fisheries, navigation, power production, industries, etc. The loss of these activities can influence the economic prosperity of a community, region or a country. The FVI can assess the economic vulnerability using a single number, though this number cannot evaluate the exact damage and losses but instead the index shows the number of industries in the area and their closeness to the river and also the amount of investment in counter measures and the number of flood insurances in that specific area.

How easily the information of the FVI approach is communicated?

From experts undertaking the study to the decision makers it can be said that the use of the FVI approach improves the decision-making process by identifying the vulnerability of flood prone areas. The FVI approach will direct decision-makers to a simplified usage and simpler understanding of the vulnerability; the FVI approach can be seen as a tool for decision making to direct investments to the most appropriate sectors and also to help in the decision-making process relating to flood defence, policies, measures and activities. The FVI approach allows, irrespective of uncertainties, relative comparisons to be made between case studies. While a level of uncertainty is inherent in FVI, the use of it in operational flood management is highly relevant for policy and decision makers in terms of starting adaptation plans. It offers a more transparent means of establishing such priorities, which inevitably are considered as highly political decisions. It may also be considered as a means to steer flood management policy in a more sustainable direction. However, as individual information is lost in the aggregation process, it needs to be retrieved by a more in-depth analysis of each process in order to design policies and their implementation.

From decision maker to the public:

Hence it is useful to have an *easy-to-apply* and *communicating* instrument that can help give an overview of the main points by having one single and comparable number, the FVI. The FVI is necessary, but not sufficient, for decision making and therefore should be used in combination with other decision-making tools. This should specifically include participatory methods with the population of areas identified as vulnerable and should also include a team of multidisciplinary thematic specialists and knowledgeable societal representatives and those with expert judgments.

6. Conclusions

The two approaches, modelling and parametric, have been applied to a data-scarce area - the Budalangi settlement. Examining the **approaches** in the context of this study leads to the following conclusions:

1. FVI does not assess flood risk directly, but does contribute to assessing flood risk. Vulnerability takes a step further and covers other aspects, such as: social aspects, environmental damage and infrastructure resilience.
2. The deterministic approach has a better science base, but limited evaluation of vulnerability;
3. FVI gives a wider evaluation, but is less rigorous. Therefore FVI is useful in a larger-scale vulnerability assessment, but a deterministic approach is better for more focused studies. In fact FVI could be used to decide where a deterministic model is necessary.

The Flood Vulnerability Index as analysed in the research provides a quick, reliable evaluation of flood vulnerability and in fact is the only method for assessing the vulnerability to flooding of a particular geographical area. The fact that indicators are used, allows for comparison of flood vulnerability in different areas as well as the identification of which indicators can determine the relative level of flood vulnerability. FVI can measure trends in the changing natural and human environments, helping identify and monitor priorities for action. These features, alongside the ability to identify the root causes of increased vulnerability, provide key information at a strategic level for flood risk planning and management. However the results would provide neither sufficient information nor the required level of detail for input into engineering designs or project level decisions.

FVI can provide an insight into the most vulnerable locations. It can analyse the complex interrelation among a number of varied indicators and their combined effect in reducing or increasing flood vulnerability in a specified location. It is very useful when there is a large level of uncertainty and decision makers are faced with a wide array of possible actions that could be taken in different scenarios, in this case the FVI can present readily understood and readily communicated results that can decision-makers in identifying the most effective measures to be taken. In this way the proposed measures can be prioritised for areas that are at greatest risk. Uncertainty is not removed, but is integrated into the assessment. On the other hand this complexity is also a negative point, since it takes a long time and good knowledge of the area and the system behind the FVI to be able to implement it.

As all with models, this FVI model is a simplification of reality and its application should be compensated for with thorough knowledge and expert-based analysis. The difficulties that the quantification of social indicators poses to the calculation may constitute a considerable weakness of the model. The FVI is a useful tool to identify the most vulnerable elements of the water resource system and safety chain components (Pro-action, prevention, preparation, response and recovery).

Obviously such a parametric model is limited by the accuracy and availability of good datasets. A number of the indicators are very hard to quantify especially when it comes to the social indicators. On the other hand, such a model can give a simplified way of characterising what in reality is a very complex system. Such results will help to give an indication of whether a system is resilient, susceptible or exposed to flooding risks and help identify which measures would reap the best return on investment under a changing climate and population and development expansion. The important point is that such a model is used as one tool among others within the whole process of deciding on a roadmap for flood assessment.

References

Adger, W.N., 2006. “Vulnerability”, *Global Environmental Change*, **16,** 268-281.

Alexander, D., 1993. Natural disasters, New York, Chapman & Hall

Balica, S.F., Douben, N., Wright, N.G., 2009. Flood Vulnerability Indices at Varying Spatial Scales, *Water Science and Technology Journal*, **60** (10), 2571-2580

Balica, S.F., Wright N.G., 2010. Reducing the complexity of Flood Vulnerability Index, Environmental Hazard Journal, **9** (4), 321 - 339.

Barredo, J.I., de Roo, A., Lavalle, C., 2007. Flood risk mapping at European scale. *Water Science and Technology*, **56** (4), 11-17

Begum, S., Stive, M. J. F. and Hall, J.W., 2007. Flood Risk Management in Europe: Innovation in *Policy and Practice*. Springer, London, 237.

Blaikie P., Cannon T., Davis I., and Wisner B., 1994. At risk – natural hazards, people´s vulnerability and disasters. London: Routledge

Bosher, L., Dainty, A., Carrillo, P. and Glass, J., 2007. Built-in resilience to disasters: a pre-emptive approach, *Engineering, Construction and Architectural Management*, **14** (5), 434-46.

Briguglio, L., 2003. Methodological and Practical Considerations for Constructing Socio Economic Indicators to Evaluate Disaster Risk. Institute of Environmental Studies, University of Colombia, Manizales, Colombia, Programme on Information and Indicators for Risk Management, IADB-ECLAC-IDEA.

Cendrero A., Fischer D.W., 1997. A procedure for assessing the environmental quality of coastal areas for planning and management. J Coast Res 13:732–744

Connor, R. F. and Hiroki, K., 2005. Development of a method for assessing flood vulnerability. *Water Science and Technology*, **51**(5). 61–67.

CRED CRUNCH, 2012. Disaster data. A balanced perspective, issue **27**, February 2012, Centre for Research on the Epidemiology and Disasters, Universite Catholique de Louvain as seen on 8th March 2012 on http://www.cred.be/sites/default/files/CredCrunch27.pdf

Cutter S.L., 1996. Vulnerability to environmental hazards; *Progress in Human Geography* **20**(4) 529-539.

Cutter S.L., Boruff B.J., Shirley W.L., 2003. Social vulnerability to environmental hazards. *Soc Sci Q* **84**(2):242–261

Dinh, Q., Balica, S., Popescu, I., Jonoski, A., 2012. Climate change impact on flood hazard, vulnerability and risk of the Long Xuyen Quadrangle in the Mekong Delta, *International Journal of River Basin Management*, **10**:1, 103-120

Duggal, K.N., Soni, J.P., 2005. Elements of water resources engineering, New age international Publishers, New Delhi, 413

Dutta, D., Srikantha, H., Katumi, M., 2003. A mathematical model for flood loss estimation, J. Hydrol., 277, 24–49.

European Floods Directive, L 288/27, Official Journal of the European Union, Brussels, 2007

Forster, S., Khuhlmann, B., Lindenschmidt, K. E., Bronstert, A., 2008. Assessing flood risk for rural detention area. *Natural Hazards and Earth System Sciences*, **8**, 311-322

Gabor, T., Griffith, T.K., 1980. The assessment of community vulnerability to acute hazardous materials incidents, Journal of Hazardous Materials, **8**, 323-22

Gichamo Z., G., Popescu, I., Jonoski, A., Solomatine D.P., 2012. River Cross Section Extraction from ASTER Global DEM for Flood Modeling, *Journal of Environmental Modelling & Software*, **31**(5), 37-46

Githui F., Gitau W., Mutuab F., Bauwensa W., 2008. Climate change impact on SWAT simulated streamflow in western Kenya. *International Journal of Climatology* **29**, 1823 - 1834

Glynn, P.W., Heidelberger, P., Nicola, V. and Shahabuddin, P., 1993. Efficient Estimation of the Mean Time Between Failures in Non-regenerative Dependability Models Proceedings of the 1993 Winter Simulation Conference, 311-316

Hansson, K., Danielson, M., Ekenberg, L., 2008. A framework for evaluation of flood management strategies, *Journal of Environmental Management* **86**, (3), 465–480

Hartanto, I.M., Beevers, L., Popescu, I., Wright, N.G., 2011. Application of a coastal modelling code in fluvial environments*, J. of Environmental Modelling and Software*, **26** (12),1685-1695

IPCC, 2001. Climate change 2001: The scientific basis. Cambridge, Cambridge University Press

ISDR, 2004. International Strategy for Disaster Reduction. Living with floods: UN guidelines offer decision makers hope to reduce flood losses. Available from: http:// www.unisdr.org/archive/5353 on 5th Apr 2011

Jonkman, S.N., Vrijling, J.K., 2008. Loss of life due to floods. *Journal of Flood Risk Management*, **1**. 43–56

Junqiang Xia, Roger A. Falconer, Binliang Lin, Guangming Tan, 2011. Numerical assessment of flood hazard risk to people and vehicles in flash floods *Environmental Modelling & Software*, **26** (8), 987-998

Klein, R.J.T., R.J. Nicholls, and N. Mimura 1999. Coastal adaptation to climate change: Can the IPCC Technical Guidelines be applied? *Mitigation and Adaptation Strategies for Global Change*, **4**, 51-64.

Knight, F. H.,1921. Risk, Uncertainty, and Profit. Boston, MA: Hart, Schaffner & Marx; Hou ghton Mifflin Company, 1921. [Online] available: http://www.econlib.org/library/Kni ght/knRUP1.html, as seen on 14th of December 2011

Lewis, J., 1999. Development in Disaster-prone Places, Intermediate Technology Publications, London.

Little, R. J. A. and Rubin, D. B., 1983. On Jointly Estimating Parameters and Missing Data by Maximizing the Complete-Data Likelihood, The American Statistician, **37**, 3 (Aug., 1983), 218-220, Published by: American Statistical Association

Little, R.J.A. and Rubin, D.B., 1987. Statistical Analysis with Missing Data, J. Wiley & Sons, New York.

McCarthy, M. A., Possingham, H. P., Day, J., & Tyre, A. J. 2001. Testing the accuracy of population viability analysis. *Conservation Biology*, **15**(4), 1030-1038.

Merz, B., Thieken, A.H. and Gocht, M. 2007. Flood risk mapping at the local scale: Concepts and challenges. In: Begum, S., Stive, M.J.F. and Hall, J.W. (Eds.) *Flood risk management in Europe*, **25**. Advances in natural and technological hazards research. Springer Netherlands, 231-251.

Messner, F. &Meyer, V. 2006. Flood damages, vulnerability and risk perception—challenges for flood damage research. In: Schanze, J., Zeman, E., Marsalek, J., (eds) *Flood Risk Management: Hazards, Vulnerability and Mitigation Measures*. Springer. 149–167.

Newey. W.K., 1990. Semiparametric efficiency bounds, *Journal of Applied Econometrics*, **5**, 99-135

NRBMI (nd) Nzoia river basin management initiative, a public private partnership between water resources management authority and Mumimas Sugar Company Limited / Nzoia Sugar Company Limited / PAN PAPER / Civil society, learning institutions and communities. http://www.unep.org/Training/downloads/PDFs/NRBMI_small.pdf. Cited December 2009, van Hoey 2008

Peduzzi, P., Dao, H., Herold, C., Rochette, D. and Sanahuja, H., 2001. Feasibility Study Report – on Global Risk and Vulnerability Index –Trends per Year (GRAVITY). United Nations Development Programme Emergency Response Division UNDP/ERD, Geneva.

Pelling, M., 2003. The vulnerability of cities; Natural disaster and social resilience, Earth scan Publications, UK & USA

Penning-Rowsell E.C., Chatterton J.B., 1977. The benefits of flood alleviations: a manual of assessment techniques (The blue manual) Aldershot, UK Gower Technical Press

Penning-Rowsell, E., Floyd, P., Ramsbottom, D., Surendran, S., 2005. Estimating injury and loss of life in floods: A deterministic framework, *Natural Hazards* **36**, 43-64

Plate Erich J., 2002. Flood risk and flood management, *Journal of Hydrology* **267** 2-11

Pratt, C., Kaly, U. and Mitchell, J., 2004. How to Use the Environmental Vulnerability Index, UNEP/SOPAC South Pacific Applied Geo-science Commission. Technical Report 383. www.vulnerabilityindex.net/Files/ EVI%20Manual.pdf (accessed 17 November 2011).

Rygel, L., O'sullivan, D., Yarnal, B., 2006. A method for constructing a social vulnerability index: an application to hurricane storm surges in a developed country, Mitigation and Adaptation Strategies for Global Change (2006) 11: 741–764

Sayers P., Hall J., Dawson R., Rosu C., Chatterton J., Deakin R., Risk assessment of flood and coastal defenses for strategic planning (rasp) – a high level methodology. Wallingford, as seen on http://www.raspproject.net/RASP_defra2002_Paper_Final.pdf, on 29th of September, 2011

Schanze, J., 2006. Flood risk management – a basic framework, Flood Risk Management: Hazards, Vulnerability and Mitigation Measures *NATO Science Series: IV: Earth and Environmental Sciences*, 2006, **67**, Part 1, 1-20

Scottish Government 2009. Flood Risk Management (Scotland) Act 2009 [online] http://www.legislation.gov.uk/asp/2009/6/pdfs/asp_20090006_en.pdf (Accessed on 04/03/12)

Serrat, C., Gomez, G., 2001. Estimating the stratified survival with missing covariates: I A semiparametric approach. Chapter 4, page 69. DR 2001/12. Departament d'Estadística i Investigació Operativa. UPC

Slovic, P., 1987. Perception of risk. *Science*, **236**: 280–285.

Smith K., 2004. Environmental hazards: assessing risk and reducing disaster. Routledge, London

Sullivan, C.A, Meigh, J., 2003. Using the Climate Vulnerability Index to assess vulnerability to climate variations, Water Policy and Management, CEH Wallingford as seen on: http://www.ceh.ac.uk/sections/ph/ClimateVulnerabilityIndex.html on 12th of December, 2011

Turner BL, Kasperson RE, Matson PA, McCarthy JJ, Corell RW, Christensen L, Eckley N, Kasperson JX, Luers A, Martello ML, Polsky C, Pulsipher A, Schiller A 2003. A framework for vulnerability analysis in sustainability science. *Proc National Acad Sci* USA **100**(14) 8074–8079

UNEP, 2004. Manual: How to Use the Environmental Vulnerability Index (EVI), as see on http://www.vulnerabilityindex.net/EVI_Calculator.htm , on 27th of September 2010

United Nations, 1982. Proceedings of the seminars on flood vulnerability analysis and on the principles of floodplain management for flood loss prevention, September, Bangkok

van der Veen, A. & Logtmeijer, C. 2005. Economic hotspots: visualizing vulnerability to flooding. *Nat. Hazards* **36**(1–2), 65–80.

Van Steenbergen, N., Ronsyn, J., Willems, P., 2012. A non-parametric data-based approach for probabilistic flood forecasting in support of uncertainty communication *Environmental Modelling & Software*, **33**, 92-105

Verwey, A., 2006. Computation Hydraulics, WL Delft Hydraulics, version 2006 – 1, UNESCO-IHE Lecture Notes

Walker, B., C. S. Holling, S. R. Carpenter, and A. Kinzig 2004. Resilience, adaptability and transformability in social–ecological systems. *Ecology and Society* **9**(2): 5. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art5/

White, G.F., 1945. Human Adjustments to Floods: A Geographical Approach to the Flood Problem in the United States Doctoral Dissertation and Research paper no. 29. Department of Geography, University of Chicago.

WMO/MWRMD/APFM, 2004. Strategy for Flood Management for Lake Vitoria Basin, Kenya, Associate programme on flood Management, http://www.apfm.info/pdf/strategy_kenya_e.pdf