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COASTAL FLOOD RISK: INTEGRATION OF INTANGIBLE LOSSES IN FLOOD RISK ANALYSIS

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ABSTRACT: Flood risk is generally defined as the product of the flooding probability and the possible losses associated with the flood event. Flood losses are categorized as tangible and intangible depending on whether or not the losses can be assessed in monetary values. Up to date, intangible loses are not or only partially incorporated in flood risk analysis due to the lack of appropriate methodologies for their evaluation and integration with tangible losses in the overall risk analysis. Therefore, within this research study, methodologies for the evaluation of intangible losses due to flooding and their integration with tangible economic losses in risk analysis were developed .This paper focuses on the integration methodology which was developed within the framework of a GIS based multi-criteria analysis, including the results of a spatial analysis which was exemplarily performed for the different flood losses and integrated losses for a selected pilot site in Hamburg, Germany.

Keywords: Coastal flood risk, risk analysis, intangible losses.

INTRODUCTION

Coastal floods are among the most devastating natural disasters which occurred in the recent past. They are expected to further increase due to the effects of sea level rise and storm surges associated with climate change (IPCC 2007). Further, human settlements are more concentrated in the coastal zones due to the economic benefits arise from ocean navigation, coastal fisheries, tourism and recreation. It is found that nearly 40% of the world's population lives within 100 km of the coast which may lead to increase the damage due to coastal flooding (Stål et al. 2008). Oumeraci (2004) mentions that the coastal, river and flash floods result in more than 50% of the fatalities and about 30% of the economic losses caused by all natural disasters. Furthermore, as population density and economic activities in the coastal zone increase, pressures on coastal ecosystems also increase. Since the value of the coastal ecosystems represents almost 40% of the value of all marine and terrestrial ecosystems of our planet (Oumeraci, 2000), protection of coastal ecosystems is as vital as minimization of the social and economic losses arise from coastal floods. Therefore, the development of methodologies for the estimation of coastal flood risk has become an urgent need for the identification and implementation of proper coastal protection measures.

The North Sea coast of Germany has suffered substantial damages due to extreme storm surges in the past. For example, the storm surge which occurred in 1962 caused 315 fatalities and considerable economic damage in Hamburg. The joint research project "XtremRisK" (Extreme storm surges at open coasts and estuarine areas: risk assessment and mitigation under climate change aspects) was initiated in October 2008, with the main objective of enhancing the knowledge with respect to the uncertainties of extreme storm surge predictions as well as quantifying the overall flood risks (Oumeraci et al. 2009). Within this project, risk analysis is exemplarily carried out for two pilot sites in Germany: Hamburg and Sylt. Hamburg is a typical example for an urban estuarine area while the island of Sylt at the North Sea represents a typical example for an open coast.

Flood risk is generally defined as the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activities (De Bruijn and Klijn 2009). Flood losses are divided in two categories, namely tangible and intangible depending on whether or not the losses can be assessed in monetary values. Tangible losses, as emphasized by its name, are evaluated in monetary values and hence are commonly incorporated in the flood risk analysis. Generally, intangible losses are recorded by non-monetary measures like number of lives lost or injured and square meters of ecosystems affected (Messner and Meyer 2005). Up to date, intangible loses are not or only partially incorporated in flood risk analysis due to the lack of appropriate evaluation and integration

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methodologies. Therefore, within this research study, methodologies for the evaluation of intangible losses due to flooding and their integration with tangible economic losses in risk analysis were developed. The methodology for the integration of intangible losses in flood risk analysis is developed within the framework of GIS based multi-criteria analysis (MCA). This paper will first describe the background knowledge related to the GIS based MCA. Then the methodology developed for the integration of intangible and tangible losses in flood risk analysis related to one pilot site (Hamburg-Wilhelmsburg) is presented.

GIS-BASED MULTICRITERIA ANALYSIS

Multicriteria analysis (MCA) "provides a valuable collection of diverse techniques and procedures for structuring decision problems, and designing, evaluating and prioritizing alternative decisions" (Malczewski 2006). A wide-range of studies on MCA are available providing a step-wise procedure of the analysis (e.g. Figueira et al. 2005, Meyer 2007, RPA 2004). In the context of flood risk analysis, MCA is an appropriate method of incorporating all relevant types of flood consequences without measuring them on one monetary scale (Meyer 2007).

On the other hand, geographic information systems (GIS) represent an appropriate tool for processing spatial data and analyzing spatial decision problems. Cowen (1988) defined GIS "as a decision support system involving the integration of spatially referenced data in a problem solving environment". Integrated GIS-MCA studies have been reported since late 1980s. Wallenius et al. (2008) say that MCA "offers useful tools and concepts that incorporate preferences into GIS-based decision making". A comprehensive GIS-MCA methodology is provided in the textbook by Malczewski (1999). Malczewski (2006) has carried out a survey on GIS-MCA literature and has found 319 publications within the period 1990-2004. The results showed that a substantial growth of implementing this technique in research studies within this period. Further, more than 150 publications have reported that they have used raster-based GIS-MCA approaches.

The application of spatial MCA in flood risk analysis and management is becoming increasingly popular (e.g. Meyer 2007, Tkach and Simonovic 1997). Meyer (2007) provides a comprehensive report on the methodology for the GIS-based MCA as a decision support in flood risk analysis, which will build the primary basis for the current research study. Spatial MCA of floodplain management alternatives in a raster GIS environment for the red river valley region was carried out by Tkach and Simonovic (1997). Further, Raaijmakers (2006) has also developed a GIS based MCA methodology for the development of sustainable flood risk management in the Ebro delta in Spain. Fernández and Lutz (2010) developed a GIS-aided urban flood hazard zoning methodology of the two cities, yerba Buena and Tucuman in Argentina, applying multicriteria decision analysis. Moreover, a recent study has been successfully carried out on the spatial multicriteria decision analysis of flood risk due to the aging of the existing dams in china, especially in densely populated areas, incorporating economic, social and environmental dimensions in decision making (Yang et al., 2011).

DEVELOPMENT OF THE INTEGRATION METHODOLOGY

Steps of GIS based MCA Approach

The procedure of MCA may consist of several steps as in Fig. 1 (based on Malczewski 1999, Meyer 2007).

Fig. 1 Steps of Multicriteria analysis (MCA)

Problem definition

First, the problem should be identified and clearly defined as in every other decision making process. The decision problem may be defined as "a perceived difference between the desired and existing states of a system" (Malczewski 1999). For instance, floods may cause significant damage, including not only tangible (economic) damages, but also intangible (social and environmental) losses. Therefore, the decision problem of the MCA in this study is to determine the spatial distribution of flood losses, including both tangible and intangible losses.

Identification of criteria

The second step of MCA is the identification of a set of evaluation criteria. In the context of MCA in flood risk assessment studies, a wide range of criteria have been taken into account. However, most of the studies have selected economic, social and environmental criteria as the main evaluation criteria in MCA for flood risk assessment studies (Dassanayake and Oumeraci 2012).

For the multicriteria loss assessment in Hamburg-Wilhelmsburg area, the following loss criteria are selected:

- Economic losses (EL)
  - Estimated economic damage in monetary value
- Social losses
  - Estimated loss of life in number (LL)
  - Estimated number of people with injuries (PI)
  - Level of cultural losses (in a score) (CL)

In this analysis, the environmental losses in Hamburg-Wilhelmsburg are omitted, since within the category of intangible losses, social losses represent the governing intangible losses in this specific pilot area.

Definition of alternatives

The third step of MCA is to define the different options to be compared. The process of generating alternatives should be based on the value structure and be related to the set of evaluation criteria (Malczewski 1999). There are two distinct MCA approaches regarding the selection of alternatives: multi-objective decision analysis (MODA) and multi-attribute decision analysis (MADA).

A MADA approach solves a problem by choosing the best alternative among a set of pre-selected alternatives. These alternatives are compared regarding their attributes and each attribute is used to measure performance in relation to an objective. On the other hand, in MODA approaches the number of alternatives is not explicitly defined. Therefore, within the decision space MODA will search for optimal alternatives regarding the objective function (Meyer 2007).

However, in this flood loss assessment study, the alternatives to be compared are the different spatial units (grid cells of 100mx100m and 50mx50m, in this case). In this case, flood losses will be assessed for each grid cell and later, the grid cells will be compared for the determination of areas with high flood losses.

Criteria evaluation/ Decision Matrices

Once the evaluation criteria and the alternatives are defined, the performance of each alternative in each criterion has to be evaluated (Meyer 2007). Generally, in non-spatial MCA approaches, decision matrices are used to summarize the results of the criteria evaluation.

Nevertheless, such a matrix is not applicable for spatial MCA. In spatial MCA, as previously mentioned, the alternatives are the spatial units. In this case, each alternative (e.g. grid cell) is evaluated regarding each criterion and the results for different criteria are represented in different map layers in GIS.

Under economic losses, the monetary damage to residential and non-residential buildings, industries, vehicles etc. are assessed and total monetary value per each grid cell is calculated. The loss of life and injuries are calculated for each cell in number of people. The level of cultural losses are assessed in a score of 0 - 5 ("not affected" to "very high loss" as described in Dassanayake and Oumeraci 2011).

In this paper, the criterion maps of 50m grid for Hamburg-Wilhelmsburg for the storm surge scenario HH_XR2010A, one of four storm surge scenarios used in the project, are selected as illustrated below.

Criterion map for economic losses (EL)

Fig. 2 illustrates the criterion map for the economic losses in Hamburg-Wilhelmsburg. The maximum estimated economic loss per 50m grid cell is 76 million Euro for this storm surge scenario. No economic losses occur in 31% of the area. 52% of the area has economic losses less than 100,000 Euro. 15% of the area has economic losses between 100,000 to 1 million Euro. Only 2% of the grid cells has losses more than 1 million Euro. More economic losses are visible in the residential areas of Wilhelmsburg.

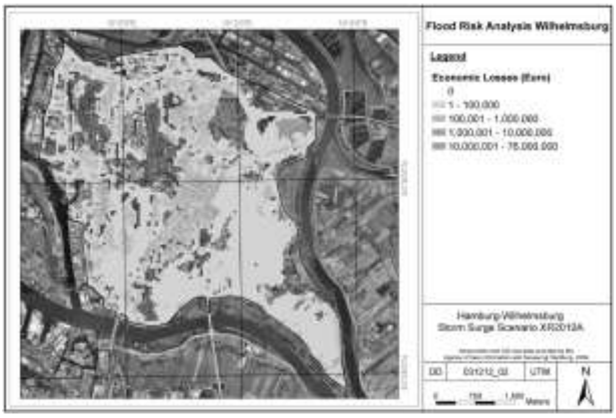


Fig. 2 Criterion map for economic losses in Hamburg-Wilhelmsburg

Criterion map for loss of life (LL) and physical injuries (PI)

For the storm surge scenario HH_XR2010A, possible number of fatalities and physical injuries are calculated as illustrated in Fig. 3 (Burzel et al. 2012). For this scenario, two fatalities are estimated in the north-west part of Wilhelmsburg. The maximum number of injuries per cell is estimated as 11. However, most of the grid cells which contain physical injuries (c.a. 88%) have 1 to 2 injuries. 10% of the grid cells contains 3-5 physical injuries while only 10 grid cells have more than 6 injuries.

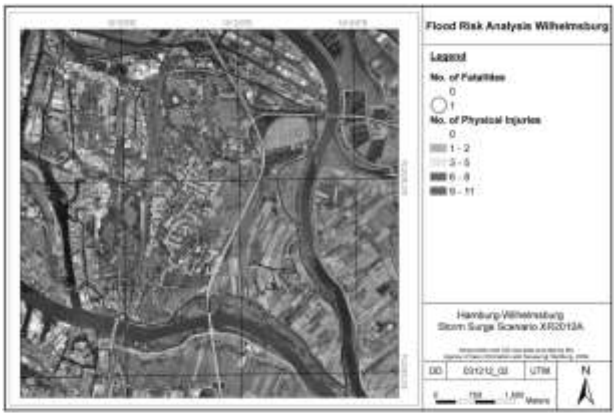


Fig. 3 Criterion map for loss of life and physical injuries in Hamburg-Wilhelmsburg

Criterion map for cultural losses

Cultural losses are presented in a five-point scale: 1-very low, 2-low, 3-medium, 4-high and 5-very high (as illustrated in Fig. 4). The scenario HH_XR2010A results mainly a loss level ‘medium’, which is 54% of the total grid cells containing cultural assets. The highest loss level resulted from scenario HH_XR2010A is ‘high’ with 18% damaged cells. Further, nearly one fourth of the total cells containing cultural assets are not affected by this scenario.

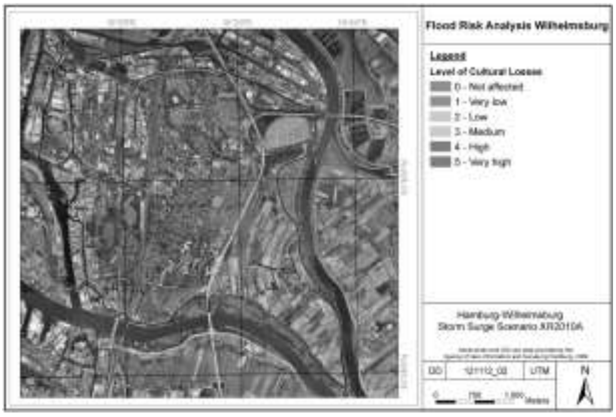


Fig. 4 Criterion map for cultural losses in Hamburg-Wilhelmsburg

Criteria weights

The purpose of estimating criterion weights is to express the importance of each criterion relative to the other criteria (Malczewski 1999). According to Meyer (2007) “the weight assigned to a criterion determines the degree of influence of that criterion in the overall evaluation”. Hence, weighting is generally considered as the most crucial and sensitive as well as the most time-consuming and controversial part of MCA.

There are several methods available for the determination of criterion weights such as ranking, rating, pairwise comparison and trade-off analysis method. In all methods weights are usually normalized to a sum of 1 ($\Sigma w_j = 1$, where w_j is the weight of j^{th} criterion) (Meyer 2007). A detailed description of available methods is provided in Dassanayake and Oumeraci (2012).

For the estimation of criterion weights, the pairwise comparison method (Saaty 1977) is adopted in this study. The pairwise comparison method, which was developed in the context of the analytical hierarchy process (AHP), is more complex than the ranking and rating methods. Each criterion is compared to all the others regarding their relative importance and allocated an importance scale of 1-9 (Table 1).

Table 1 Importance scale of pairwise comparison

Importance scale	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very strong to extremely strong importance
9	Extreme importance

The pairwise comparison matrix for the flood losses is shown in Table 2 (LL=Loss of life, PI= Physical injuries, CL=Cultural losses and EL=Economic losses). When relative importance values are allocated for the more important criteria against less important criteria, the reciprocal values are allocated for the less important criteria against more important criteria. Here the relative importance values are allocated merely based on the authors’ estimation for this exemplary study. From Table 2 the criterion weights are calculated as indicated in Table 3.

Table 2 Pairwise comparison matrix for loss criteria

Criterion	LL	PI	CL	EL
LL	1	2	5	3
PI	1/2	1	3	2
CL	1/5	1/3	1	1/2
EL	1/3	1/2	2	1

Table 3 Criterion weights for the flood losses

Criterion	Weight
Loss of life	0.48
Injuries	0.27
Cultural losses	0.09
Economic losses	0.16

Decision rules

Among the several decision rules such as Multi Attribute Utility (Value) Theory (MAUT), Analytic Hierarchy Process (AHP), Compromise Programming (CP), and Outranking/Concordance approaches, the MAUT approach is selected for this study. The general model of multi-attribute utility theory is:

$$U_i = \sum_j w_j u_{ij} \quad (1)$$

where U_i is the overall value or utility of alternative i, u_{ij} is the value or utility of the alternative i regarding criterion j and w_j is the weight for criterion j.

The basic steps for spatial MAUT approach are as follows (Malczewski 1999):

1. Standardize each criterion map scores to values (or utilities).
2. Construct the weighted standardized map layers by multiplying the standardized values of each alternative (in this case, raster cell) with the weight assigned to each criterion.
3. Calculate the overall value (or utility) for each raster cell by summing the weighted values (utilities) of each criterion map.
4. Rank the alternatives according to their aggregate value (or utility).

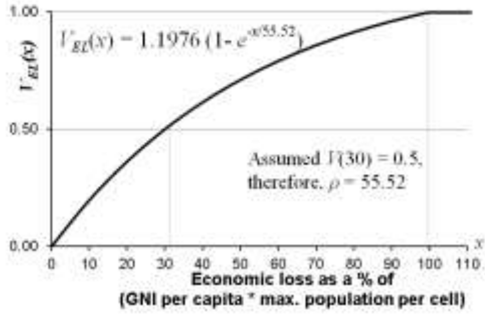
Two methods are available in MAUT: simple additive weighting method and utility/value functions approach. The basic difference between the two approaches lies in the standardization process. Simple additive weighting method assumes that there is a linear relationship between the original criteria value and the utility, which is called linear scale transformation. Value/utility function approach considers further functional relationships which are not necessarily based on the linearity assumption between the criterion score and the value/utility in the standardization process. For this study, the value function approach is selected for the standardization.

Value function for economic losses (EL) – $V_{EL}(x)$

A monotonically increasing value function is considered, which aligns with the shape of the value function introduced by Kahneman and Tversky (1979) for losses. Therefore, an exponential function is selected. For the derivation of the exponential function, it is necessary to define a minimum value for the attribute x (x_{min}) and a maximum (x_{max}). As flood prone areas can be flooded without any economic losses, the minimum value x_{min} is therefore taken as zero. Generally, in the standardization process of MCA, the maximum attribute value of the considered dataset is allocated the maximum utility/value, 1 (in this case, it can be the value of the cell with the maximum economic loss). However, this method is not suitable for this study, as the maximum economic losses for different flooding scenarios are different. Therefore, it is proposed to have a general maximum value for all scenarios, which is independent of the estimated values of economic losses, but based on the worth of the total economic assets in the area. However, the worth of the economic assets is assumed to be dependant of the income of the people and the population of the area. Therefore, x_{max} is calculated by the product of gross national income (GNI) per capita and the maximum population per grid cell. Based on the method proposed by Garvey (2009), an exponential value function is developed as (Fig. 5):

$$V_{EL}(x) = \begin{cases} 1.1976\,(1 - e^{-x/55.52}) & \text{for } x \le 100\% \\ 1 & \text{for } x > 100\% \end{cases} \quad (2)$$

Fig. 5 Value function for economic losses



Value function for loss of life (LL) – $V_{LL}(x)$

For the value function for loss of life, it is proposed to have a Boolean-type function. The main assumption underline this function is that, people are more concerned about whether there is any threat to life but not how many will die. That means even a single loss of life due to flooding is not accepted by the community. Therefore, the value $V_{LL}(x)$ becomes 1 when the loss life is 1 or more (Fig. 6). Then the value function for loss life can be written as,

$$V_{LL}(x) = \begin{cases} 0 & (x = 0) \\ 1 & (x \ge 1) \end{cases} \quad where\, x = 0, 1, 2, \ldots n \quad (3)$$

Fig. 6 Value function for loss of life

Value function for physical injuries (PI) – $V_{PI}(x)$

A linear relationship is proposed in Fig. 7 for the value function of physical injuries. It is assumed that all the injured people are valued equally, whether young or old, employed or unemployed and the severity level of the injuries is not considered. Therefore, the value function for physical injuries can be written as,

$$V_{PI}(x) = \begin{cases} \frac{1}{x_{\max}} x & (x \le x_{\max}) \\ 1 & (x > x_{\max}) \end{cases} \tag{4}$$

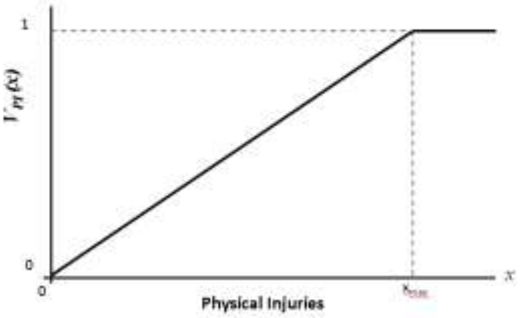


Fig. 7 Value function for physical injuries

Value function for cultural losses (CL) – $V_{CL}(x)$

A piecewise linear single dimensional value function is adopted in this analysis for the derivation of values for the cultural losses, since the cultural losses are assessed in a score of 0 to 5 as described in Dassanayake and Oumeraci (2011). Values are determined by a value increment approach (see Fig. 8). The smallest value increment is taken as 1/15 (say Δ) and the subsequent value increments are 2/15, 3/15, 4/15 and 5/15 respectively, which can be given by multiples of the smallest value increment Δ. The sum of the all value increments amounts to 1.

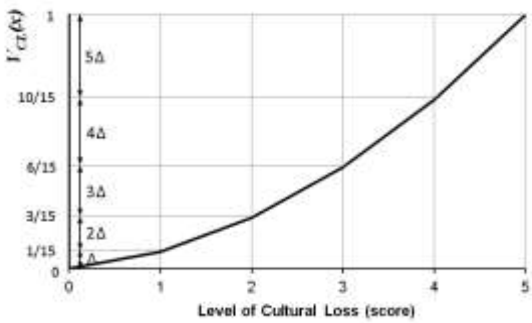


Fig. 8 Value function for cultural losses

Ranking/ scoring of alternatives

This study focuses on the determination of areas with high flood losses. Ranking of grid cells in the final step of MCA is not necessary in this case. Instead, a scoring method is adopted to define the level of flood losses in grid cells. Here, a score is allocated for each grid cell based on their aggregated value as shown in Table 4. Further, the final values for the integrated losses in each cell can be multiplied by the flooding probability in order to determine the flood risk in each spatial unit.

Table 4 Allocation of a score for the aggregated value

Aggregated value	Score
0	0 - no loss
0.01 – 0.20	1 - very low
0.21 – 0.40	2 - low
0.41 – 0.60	3 - medium
0.61 – 0.80	4 - high
0.81 – 1.00	5 - very high

INTEGRATION OF FLOOD LOSSES IN THE XTREMRISK PROJECT

In the XtremRisK project, mainly four storm surge scenarios; XR2010A, XR2010A Dike Breach (DB), XR 2010B and XR2010C are developed based on storm surge events on 03.01.1976 and 27./28.02.1990 (Oumeraci et al. 2012). Based on the estimated flood depths and velocities, the criterion maps are produced for each storm surge scenario as before. Then the integrated flood loss maps are elaborated for storm surge scenarios. Figures 9-12 represent such maps for integrated flood losses in Hamburg-Wilhelmsburg for aforementioned four flooding scenarios.

XR2010A scenario resulted a zero or 'very low' level of integrated loss in almost entire area except for 0.02% of area which has 'medium' level of integrated loss. On the other hand, XR2010A dike breach scenario comprises a significant integrated loss in west part of Hamburg-Wilhelmsburg, including 2.77% of area of 'medium', 'high' and 'very high' levels of integrated loss.

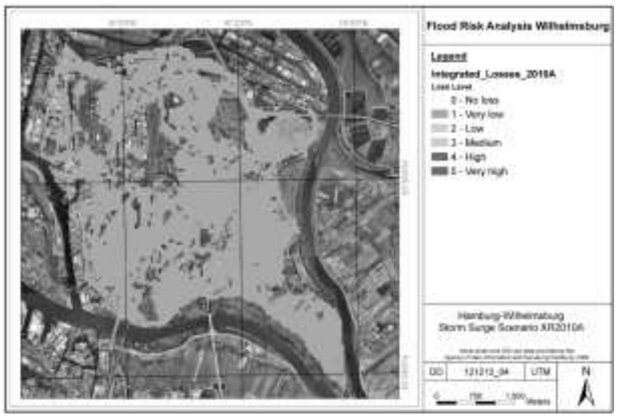


Fig. 9 Integrated flood loss map for storm surge scenario HH_XR2010A

XR2010B scenario resulted only a 'very low' level of integrated loss in 11.4% of the area. XR2010C is the severest storm surge scenario considered within the project, which comprises 'medium', 'high' and 'very high' levels of integrated loss for more than 18% of the area, mainly in the residential areas in middle and west parts of Hamburg-Wilhelmsburg.

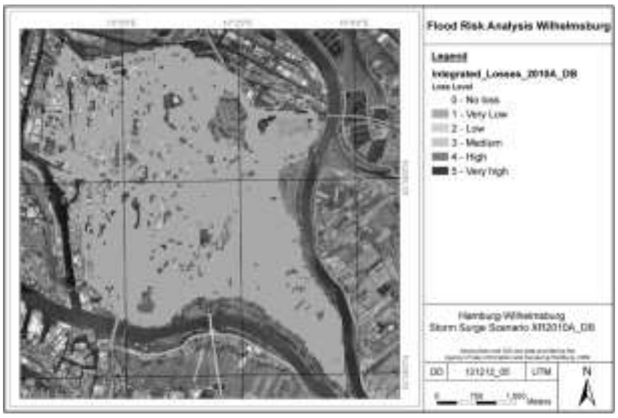


Fig. 10 Integrated flood loss map for storm surge scenario HH_XR2010A _DB

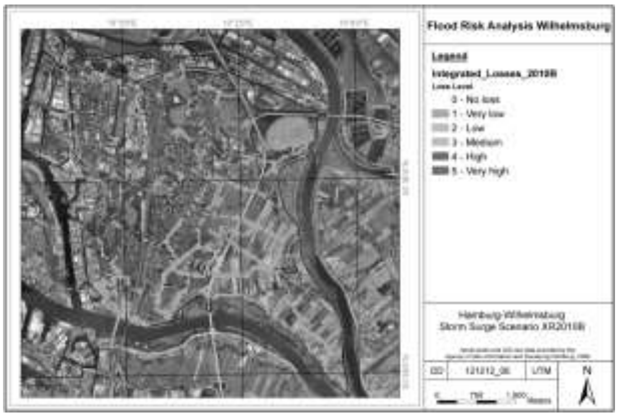


Fig. 11 Integrated flood loss map for storm surge scenario HH_XR2010B

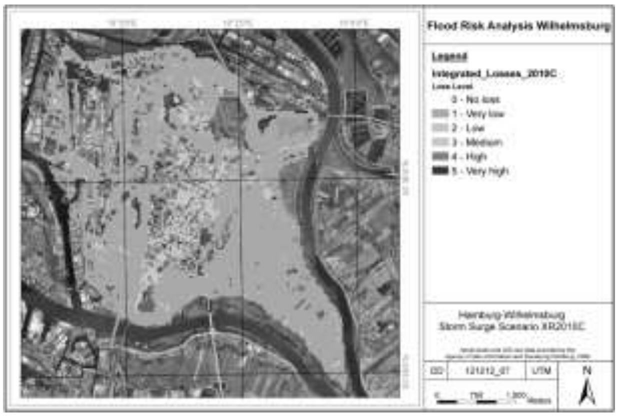


Fig. 12 Integrated flood loss map for storm surge scenario HH_XR2010C

CONCLUDING REMARKS

This report focused on developing a methodology for the integration of tangible and intangible flood losses, in order to properly include the intangible losses in flood risk analysis. To achieve this objective, the following tasks were carried out within this study:

- A basic methodology was developed based on the multicriteria analysis: multi-attribute utility theory referring to literature.
- A spatial analysis was exemplarily performed for the different flood losses and integrated losses for a selected pilot site in Hamburg

One of the major challenges encountered in the process of the implementation of this integration methodology is the determination of criterion weights. In this exemplary study, he criterion weights mainly depend on the decision-maker's preferences on the criteria. In real practice, the definition of relative importance of criteria should be carried out by a group of appropriately selected persons, which may include experts from different research fields, individuals who might actually be affected by the decisions (as in Proctor and Drechsler 2006) etc.. As a result, a reasonable set of criterion weights, which incorporates a collective effort, can then be defined.

The other main challenge is to define the maximum attribute values, x_{max}, in value functions for $V_X = 1$. In this study, a number of assumptions had to be made basically for the simplicity of the methodology. Future studies may focus on adopting more comprehensive methods to define these values. For example, the x_{max} for economic losses was calculated based on the assumption that the worth of the total economic assets in the area depends on the income of the people and the population of the area. A future study may consider calculating the actual worth of the economic assets in the area.

This study integrated the tangible and intangible losses in a MCA as the different criteria have different measuring units. However, further research will be carried out in order to calculate the intangible losses in monetary terms. This will enable the integration of losses in a cost-benefit analysis (CBA) framework. Extending this integration to incorporate environmental losses is also a main consideration of future research.

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REFERENCES

Burzel, A., Dassanayake, D.R. and Oumeraci, H. (2012). Development of a spatial loss-of-life-model for Hamburg-Wilhelmsburg, XtremRisK Progress Report. Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Technische Univ. Braunschweig, Germany.

Cowen, D. J. (1988). GIS versus CAD versus DBMS: What are the differences? Photogramm. Eng. Remote sens., 54(11):1551–1555.

Dassanayake, D.R. and Oumeraci, H. (2011). Evaluation of cultural losses due to coastal floods, Progress Report. Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Technische Univ. Braunschweig, Germany.

Dassanayake, D.R. and Oumeraci, H. (2012). Integration of Tangible and Intangible Flood Losses: A GIS Based Multicriteria Analysis (MCA) Approach, Progress Report. Leichtweiß-Institute for Hydraulic Engineering and Water Resources, Technische Univ. Braunschweig, Germany.

De Bruijn, K.M. and Klijn, F. (2009). Risky places in the Netherlands: a first approximation for floods, J. Flood Risk Management, 2: 58–67.

Fernández, D. S. and Lutz, M. A. (2010). Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. Engineering Geology, 111(1-4):90-98.

Figueira, J., Greco, S., and Ehrgott, M. (2005). Multiple criteria decision analysis: state of the art surveys, Springer.

Garvey, P. (2009). Analytical methods for risk management: A systems engineering perspective, Taylor & Francis.

IPCC (2007). Climate change 2007: WG II: Impacts, Adaptation and Vulnerability, Chater 6. Coastal systems and low lying areas. Intergovernmental Panel on Climate Change (IPCC), Cambridge.

Kahneman, D. and Tversky, A. (1979). Prospect theory: an analysis of decisions under risk, Econometria, 47 (2):263–292.

Malczewski, J. (1999). GIS and Multicriteria Decision Analysis. John Wiley and Sons, New York, USA.

Malczewski, J. (2006). GIS-based multicriteria decision analysis: a survey of the literature, Int. J. Geographical Information Science, 20 (7):703-726.

Messner, F. and Meyer, V. (2005). Flood damage, vulnerability and risk perception-challenges for flood damage research. UFZ Discussion Papers. Department of Economics, Leipzig.

Meyer, V. (2007). GIS-based Multicriteria Analysis as Decision Support in Flood Risk Management FLOODsite Project Report, HR Wallingford, UK.

Oumeraci, H. (2000). The sustainability challenge in coastal engineering. Keynote lecture, Proc. of 4th International Conference on Hydrodynamics, Keynote lecture, Volume I, Yokohama, Japan, 57-84.

Oumeraci, H. (2004). Sustainable coastal flood defences: scientific and modelling challenges towards an integrated risk-based design concept, Keynote lecture. Proc. of. First IMA International Conference on Flood Risk assessment, Univ. Bath, UK: 9-24.

Oumeraci, H., Kortenhaus, A., Burzel, A., Naulin, M., Dassanayake, D.R., Jensen, J., Wahl, T., Mudersbach, C., Gönnert, G., Thumm, S., Daemrich, K.-F., Pasche, E., Ujeyl, G. (2012). Integrated Flood Risk Analysis for Extreme Storm Surges at Open Coasts and in Estuaries: Background, Methodology, Key Results and Lessons Learned . Proc. 2nd European Conference on FLOODrisk Management, Rotterdam, The Netherlands.

Oumeraci, H., Jensen, J., Gönnert, G., Pasche, E., Kortenhaus, A., Naulin, M., Wahl, T., Thumm, S., Ujeyl, G., Gershovich, I. and Burzel, A. (2009). Flood risk analysis for a megacity: The German XtremRisK project, Proc. of Conference on Road Map towards a Flood Resilient Urban Environment, Paris, France.

Proctor W, Drechsler M. (2006). Deliberative multicriteria evaluation. Environment and Planning C-Government and Policy, 24:169–190.

Raaijmakers, R. (2006). A spatial multi-criteria analysis methodology for the development of sustainable flood risk management in the Ebro Delta. Master thesis, Univ of Twente, The Neherland.

RPA. (2004). Evaluating a multi-criteria analysis (MCA) methodology for application to flood management and coastal defence appraisals. Case studies report. Defra, UK.

Saaty, T. L. (1977). A scaling method for priorities in hierarchical structures. J. mathematical psychology, 15:234-281.

Stål, J., Paulsen, S., Pihl, L., Rönnbäck, P., Söderqvist, T. and Wennhage, H. (2008). Coastal habitat support to fish and fisheries in Sweden: Integrating ecosystem functions into fisheries management, Ocean and Coastal Management, 51: 594–600.

Tkach, R. J., and Simonovic, S. P. (1997). A New Approach to Multi-criteria Decision Making in Water Resources. J. Geographic Information and Decision Analysis, 1(1):25-44.

Wallenius, J., Dyer, J. S., Fishburn, P. C., Steuer, R. E., Zionts, S., and Deb, K. (2008). Multiple Criteria Decision Making, Multiattribute Utility Theory: Recent Accomplishments and What Lies Ahead. Management Science, 54:1336-1349.

Yang, M., Qian, X., Zhang, Y., Sheng, J., Shen, D. and Ge, Y. (2011). Spatial Multicriteria Decision Analysis of Flood Risks in Aging-Dam Management in China: A Framework and Case Study. Int. J. Envir. Research and Public Health, 8:1368-1387.