The Added Value of Geospatial Information in Disaster and Risk Management

Dissertation

BSc. Tessa Anne Belinfante

Submitted in partial fulfilment of the requirements of the degree

Master of Science in Earth Sciences and Economics

Faculty of Earth and Life Sciences

Vrije Universiteit Amsterdam

Vrije Universiteit Amsterdam
Master Thesis Earth Science, Earth Science and Economics
T.A. Belinfante
Binnenkant 48
1011 BR Amsterdam
tessa.belinfante@gmail.com

First Supervisor VU:
Prof. Dr. H. Scholten
h.j.scholten@vu.nl

Second Supervisor VU:
Dr. N. van Manen
n.van.manen@vu.nl

Faculty of Economics and Business Administration
Department of Spatial Economics
De Boelelaan 1105
1081 HV Amsterdam
the Netherlands

Dr. M. Bokhorst
m.p.bokhorst@vu.nl
Institute for Environmental Studies (IVM)
Vrije Universiteit
De Boelelaan 1087
1081 HV Amsterdam
The Netherlands

Supervisor internship UN:
Robert Backhaus
Robert.backhaus@unoosa.org
Senior Expert, Knowledge Management
United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER)
Hermann-Ehlers-Str. 10
53113 Bonn
Germany

Abstract

Recent studies have proven the variety of ways in which geospatial information contributes to disaster and risk management (DRM) practices. Geospatial information and associated technologies also play a central part in new methods for assessing costs of DRM itself and disaster related damages and losses. However, determining the *economic value* of geospatial information in DRM remains an understudied topic. This thesis proposes an innovative method for determining this value. A systematic analysis of a questionnaire designed for this purpose provides a template to chart the economic value of one geospatial information product, by applying a 'Cost Avoidance Approach'. A case study, the Namibia flooding disaster of 2009, is selected to illustrate the application of this valuation method. Here one specific geo-information product, an early warning system, is analysed. Furthermore, as a co-product of testing the questionnaire, case study specific features were assessed such as the geo-information products used at the time of the flood in 2009, what caused the relatively low level of response to the early warning system in 2009, what improvements have taken place since 2009 regarding the early warning system and what future developments the participants would like to see.

The findings illustrate the steps needed for valuation assessment, which has high potential for future research on the added value of geospatial information products in DRM. Although there was no statistical significance obtained, this study provides a template for future research on this topic and has formulated recommendations for further improvements of this approach. In a later stage of this line of research, the experimental design of this questionnaire can be altered accordingly to other geospatial information products that assist in minimizing losses and damages of other disaster types and during other stages of the DRM cycle.

Table of contents

Abstract ... 4

Table of contents ... 5

List of Figures ... 7

List of Tables ... 8

Acknowledgements ... 9

Preface ... 10

Abbreviations ... 11

1. Introduction ... 12

  1.1. Problem statement ... 13

  1.2. Research objectives and questions ... 13

  1.4 Purpose of study ... 14

  1.5 Statistical Significance ... 14

  1.6 Outline ... 14

2. Background ... 16

  2.1 Framework geo-information & disaster and risk management ... 16

    2.1.1 Geo-information ... 16

    2.1.2 Disaster and risk management ... 18

    2.1.3 Early warning systems ... 21

  2.2 Value of (geo-) information ... 23

    2.2.1 Decision making & benefits of geo-information ... 23

    2.2.2 Approaches to assess the value of information ... 24

    2.2.3 Approaches to value Early Warning Systems ... 25

  2.3 Case study ... 25

    2.3.1 Summary of impacts ... 25

    2.3.2 Motivational reasons ... 27

  2.4 Summary ... 29

3. Methodology and Data Collection ... 30

  3.1 Research Methods ... 30

    3.1.1 PDNA ... 32

    3.1.2 Questionnaires ... 32

3.2 Data Collection and Analysis 33
3.2.1 PDNA 33
3.2.2 Questionnaires 33
3.3 Summary 41
4. Results and Analysis 42
4.1 PDNA 42
4.1.1 Strengthening Risk Assessment 42
4.1.2 GIS mapping 43
4.2 Questionnaires 47
4.2.1 Assessment of 2009: Geo-information products used & EWS 47
4.2.2 Improvements of geo-information value & identifying needs 49
4.2.3 Experimental 'Cost Avoidance Approach' 52
4.3 Summary 55
5. Discussion, Conclusions and Recommendations 58
5.1. Discussion 58
5.2. Conclusions 61
5.3. Recommendations 63
6. References 65
Appendix 1: The Questionnaire 69

List of Figures

Figure 1: Number of Natural Disaster Events and Overall and Insured Losses, 1980-2011, source Munich Re, NatCatSERVICE (Worldwatch-Institute, 2012b) 12
Figure 2: Outline of the research 15
Figure 3: The role of a geo-portal in an SDI. Maguire and Longley (2005) 18
Figure 4: Disaster cycle 20
Figure 5: Components effective early warning system (after (UN/ISDR, 2004)) 22
Figure 6: Flow chart valuation process of information due to altered decision making, adjusted after (Fritz et al., 2008) 23
Figure 7: Overview impacted area Namibian flood 2009 (Source: PDNA/ The Government of the Republic of Namibia, 2009) 26
Figure 8: Flooding Namibia 2009 (source: PPT Guido Van Langenhove) 29
Figure 9: Flowchart Research Structure 31
Figure 10: Example of flood bulletin, 1 March 2010, Source: PPT Guido Van Langenhove (2010) 34
Figure 11: Background of respondents 35
Figure 12: Flood related activities of respondents 36
Figure 13: Part 2 of the questionnaire: What geo-information products were used, what was the supported action and how is the impact evaluated. 37
Figure 14: Data analysis in qualitative research, adjusted after Creswell (2009) 38
Figure 15: Question 3.1, assessing crucial elements of early warning system 38
Figure 16: The scenario presented to the participants 40
Figure 17: The scenario presented to the participants 40
Figure 18: Example of satellite imagery flood extent map (source: http://www.disasterscharter.org/image/journal/article.jpg?img_id=32215&t=1273833015248) 46
Figure 19: Cause of low effective response after early warning in 2009 49
Figure 20: Day - curve: Percentage reduction in damage to be acquired in relation to the warning time (hr) (Carsell et al., 2004) 59
Figure 21: Impact of flood warning lead time on flood damages (Ch. 3: Penning-Roswell et al, 2003) 59

List of Tables

Table 1: Summary of damage and losses (source: PDNA, 2009) 27
Table 2: Summary of damage and losses, estimation by the PDNA team (PDNA, 2009) 41
Table 3: Satellite sensor details 45
Table 4: Geo-information products used and evaluation of impact and supported actions 48
Table 5: Evaluation of different early warning system elements 51
Table 6: Avoidable damage & losses in percentages per economic sector. The thick blue bars indicate the average, where the thin black lines indicate the average *range* given in answers. 53
Table 7: Avoidable damage & losses in 2009 $US Million 54

Acknowledgements

This master thesis study was partly conducted at the UN-SPIDER Bonn office. I'd like to thank all "SPIDERS" that have motivated and inspired me during that time. My special thanks go to my UN supervisor Robert Backhaus for guidance and advice. Also I would like to thank the other members of the VALID project, in particular Sisi Zlatanova.
I offer much gratitude towards my first supervisor of the VU, Henk Scholten, for introducing me to the VALID project, expressing faith in my research abilities. Henk provided guidance when needed and left room where possible for me to draw my own conclusions and making the right choices along the way. Furthermore I owe much gratitude to my second VU supervisor, Niels van Manen. Thank you for your time and advices.
My special thanks go out to the contact person in Namibia, Guido van Langenhove, for distributing the questionnaires and for sticking to the project. Without this valuable contact, this research would not have been possible.
Last, but certainly not least, thanks to my family and friends. Marleen, thank you for reading my thesis every once in a while and providing me motivation and inspiration when needed.

Preface

Part of this research was conducted during an internship period of three months, April-June 2012, at the UN-SPIDER Bonn office. This study is contributing to the VALID project, executed by the Joint Board of Geospatial Information Societies (JBGIS) and UNOOSA/UN-SPIDER. The acronym stands for: "The Value of Geo-information for Disaster and Risk Management" which has as an ultimate purpose to:

1.) Raise awareness in the political and programmatic environment
2.) Set priorities in research and development

The VALID project consists of a stakeholder assessment and an economic assessment; the latter will be the core of this master thesis. The VALID project is a follow up on the publication 'Geo-information for Disaster and Risk Management – Examples and Best Practices' (2010), which is a collection of case studies that illustrate what can be done with the use of geo-information in disaster and risk management, showing methods, systems, applications and experiences.

The UN-SPIDER programme, or *United Nations Platform for Space-based information for Disaster Management and Emergency Response*, is a programme of the *United Nations Office for Outer Space Affairs* (UNOOSA) department. UN-SPIDER got established on 14 December 2006 by the United Nations General Assembly, with the following missions statement: "Ensure that all countries and international and regional organizations have access to and develop the capacity to use all types of space-based information to support the full disaster management cycle". The main tasks are being a gateway to space information for disaster management support, serving as a bridge to connect disaster management and space community and being a facilitator of capacity building and institutional strengthening.

This Master thesis is written in partially fulfilment of the Master Earth Sciences at the VU University Amsterdam, specialization Earth Sciences and Economics.

Abbreviations

DEM	Digital Elevation Model
DFO	Dartmouth Flood Observatory
DLR	German Aerospace Centre
DMS	Department of Surveying and Mapping
DRM	Disaster and Risk Management
EM-DAT	Emergency Events Database
ESA	European Space Agency
EWS	Early Warning System
GDP	Gross Domestic Product
GFDRR	Global Fund for Disaster Reduction and Recovery
GMES	Global Monitoring for Environmental Security programme
GPS	Global Positioning System
GIS	Geospatial Information Systems
JAXA	Japan Aerospace Exploration Agency
JRC-EC	Joint Research Centre - European Commission
NASA	National Aeronautics and Space Administration
NSPA	National Space Program Office
PDNA	Post Disaster Needs Assessment
SAR	Synthetic Aperture Radar
SDI	Spatial Data Infrastructures
SDSS	Spatial Decision Support Systems
TRMM	Tropical Rainfall Measuring Mission
UNISDR	United Nations Office for Disaster Risk Reduction
UNOOSA	United Nations Office for Outer Space Affairs
UNOSAT	United Nations Operational Satellite Applications Programme
UN-SPIDER	United Nations Platform for Space-based Information for Disaster Management and Emergency Response
VALID	The Value of Geo-information for Disaster and Risk Management
VNIR	Visible and Near Infra-Red

1. Introduction

This master thesis aims for assessing the added value of geospatial information in disaster and risk management. This chapter will present an introduction on the topics of research, present the research objective and formulated four research questions. Furthermore the purpose of study and statistical significance of the results will be discussed. Finally, the outline of this thesis is provided.

Worldwide natural disaster related mortalities are lowered, while economic damages are increasing (UN/ ISDR, 2011)(Worldwatch-Institute, 2012a). During 2011, according to the data of Munich Reinsurance Company and analyses of the Worldwatch Institute's *Vital Signs* series, natural disasters were responsible for 27,000 deaths and 2011 $380 billion in economic losses. This record in economic losses is exceeding the former record of $220 billion. The three major events contributing to this new record set in 2011 are the earthquake and tsunami in Japan ($210 billion), the floods in Thailand ($40 billion) and the earthquake in New Zealand ($16 billion) (Worldwatch-Institute, 2012a). These numbers illustrate the order of magnitude in economic terms that are associated with natural disasters and the need for improved disaster and risk management in order to restrain this trend of increasing damages and losses (See Figure 1). Reasons for this continuing expansion could be greater exposure to natural hazards, better reporting of damages and losses, or both (World Bank/ United Nations, 2010). Projections on future disaster risk, being a product of vulnerability, exposure and hazard, ascribe rapidly growing cities (affecting the vulnerability and exposure) and climate change (affecting the characteristics of the hazard) as huge challenges for future disaster and risk management (World Bank/ United Nations, 2010).

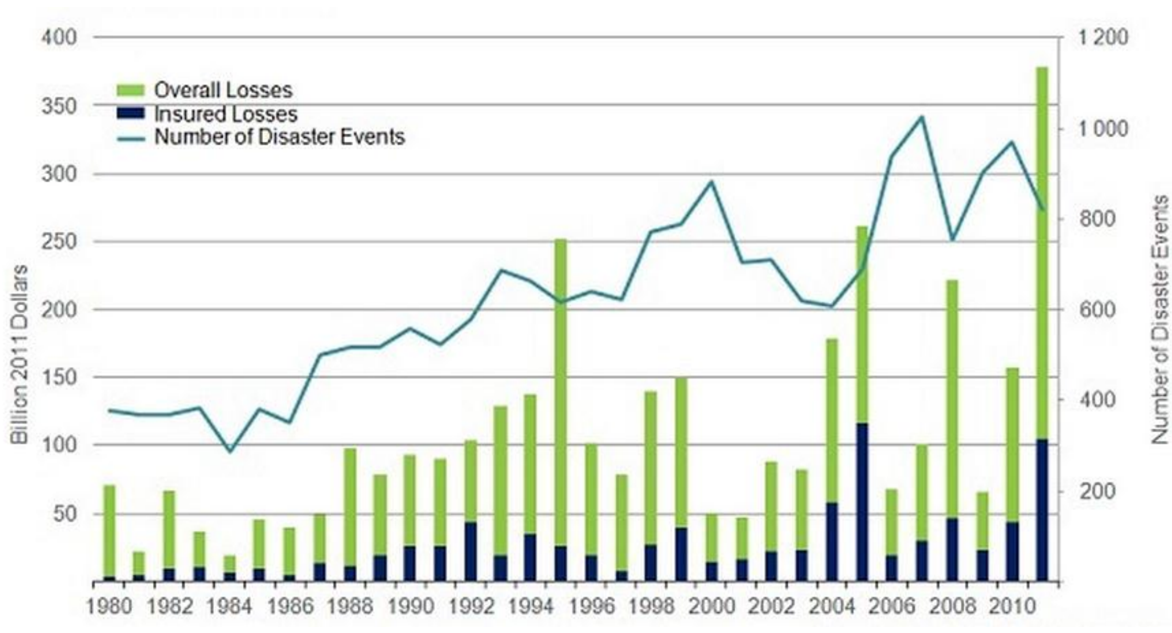

Figure 1: Number of Natural Disaster Events and Overall and Insured Losses, 1980-2011, source Munich Re, NatCatSERVICE (Worldwatch-Institute, 2012b)

The National Research Council (2007) has identified five major characteristics that make disasters hard to overcome and therefore to manage. First, disasters are large rapid-onset incidents relative to the size and resources of an affected jurisdiction. Second, disasters are uncertain with respect to both their occurrences and their outcomes. Third, risks and benefits are difficult to assess and compare. Fourth, disasters are dynamic events. Fifth, disasters are relatively rare. Since basically every emergency preparedness and response challenge has important geospatial aspects (NRC, 2007), the use of geospatial data and tools is vital in disaster and risk management. Recent studies have illustrated the variety of ways in which geospatial information may contribute to risk and disaster management (Altan, Backhaus, Boccardo, & Zlatanova, 2010; Oosterom, Zlatanova, & Fendel, 2005).

1.1.Problem statement

The potential value of geo-information in Disaster and Risk Management (DRM) is high because it can improve the quality and speed of decision making in DRM, which may result in lower associated damages and losses. If we are able to quantify the value of specific geo-information products for different aspects of DRM, it is possible to focus and justify investments on those geo-information products that have the greatest potential to reduce the costs of DRM and to minimize the damages and losses in case a disaster strikes. An explicit value of the benefits can contribute to a more rational basis for policy makers to make these decisions. The aim of this study is to propose and illustrate an innovative method for assessing the added value of geospatial information in DRM.

1.2.Research objectives and questions

The main objective of this study is to assess the added value of geo-information in disaster and risk management, by proposing an innovative valuation methodology. In order to meet this research objective, this thesis has adopted four research questions that all together contribute to inquiring the added value of geo-information in Disaster and Risk Management.

- How are geo-information and Disaster and Risk Management connected?
- How does geo-information aids to Disaster and Risk Management practises?
- How can the added value of geo-information in Disaster and Risk Management be measured?
- How can the value of geo-information in Disaster and Risk Management be improved?

The first two questions will be addressed by a comprehensive literature review that provides context on the topic of valuing geo-information and forms the background needed for the innovative methodology proposed in this study to value geo-information. The third research question forms the core of this research and illustrates by means of an experimental case study how the added value of geo-information can be economically measured. A questionnaire has been developed in order to assess the added value of one geo-information product; an early warning system (EWS), which relies on the input of geospatial information. The case study selected for this study is the Namibian flooding event from 2009. As a co-product of testing and illustrating the valuation method for geospatial information, the so-called 'Cost Avoidance Approach', the questionnaire has included a section encompassing qualitative questions. The latter section enables a case specific analysis on the Namibian flooding disaster addressing the following issues; (1) how geospatial information was used at the time of the flooding, (2) what improvements have been made concerning the Early Warning System (EWS) since the disaster and (3) what further developments the participants would like to see regarding the EWS. This qualitative case specific part is strengthened by an analysis of a Post-Disaster Needs Assessment (PDNA) report written shortly after the flooding 2009 by the World Bank in cooperation with the Government of Namibia. The fourth research question is dealing with the case study specific results on how the value of geospatial information can be improved.

1.4 Purpose of study

The aim of this study is to develop and illustrate an innovative approach for valuing geospatial information in disaster and risk management; namely a 'Cost Avoidance Approach'. In a later stage of this line of research, the experimental design of this questionnaire can be altered accordingly to other geospatial information products that assist in minimizing losses and damages of other disaster types and at other stages of the DRM cycle.

1.5 Statistical Significance

The response rate of the questionnaire was too low for statistical analysis. This might be due to the distance or the involvement of an intermediary person for distributing a large part of the questionnaire. Nevertheless, the 14 questionnaires received back provided useful case specific qualitative information, insight on the feasibility of this 'Cost Avoidance Approach' and what should be undertaken for future development of this method. Consequently, the main purpose of this research is to illustrate the steps needed for evaluation and offer building blocks for future research on this topic.

1.6 Outline

The overview of the outline of this research is presented in Figure 2. First, Chapter 2 provides the foundation of this master thesis, providing the background information needed for context and putting information in perspective concerning the assessment of the value of geo-information in disaster and risk management. The concepts regarding geo-information, disaster and risk management, and how the two are connected are being treated. Furthermore the valuation of geospatial information is discussed, followed by a description of the case study that has served this research. Chapter 3 elaborates on the methodology used in this research and the data collection processes, followed by Chapter 4 discussing the results. Finally, Chapter 5 presents the discussion, conclusions and recommendations for future research on this topic.

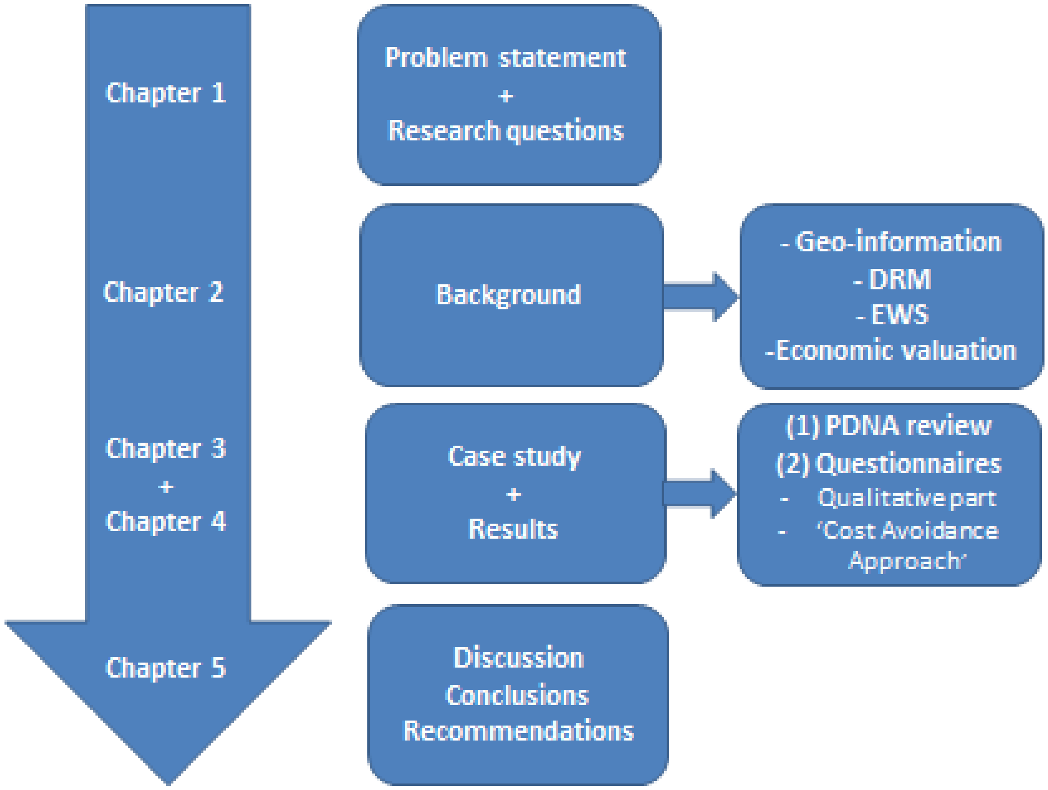

Figure 2: Outline of the research

2. Background

This chapter will provide an overview of related research on the topic of valuing geospatial information in disaster and risk management. The first section will provide a theoretical framework of geo-information, disaster and risk management and how the two are interlinked. This will be followed by a section discussing the topic of valuing geo-information. Furthermore, information concerning the case study selected for this research will be provided. Finally, a summary will be presented on the main findings of this chapter. The first two research questions will be addressed, namely:

- How are geo-information and Disaster and Risk Management connected?
- How does geo-information aids to Disaster and Risk Management practises?

2.1 Framework geo-information & disaster and risk management

First, the concept of geo-information will be explained, treating different geospatial data types, the distinction between data and information, and important aspects that should be taken into account considering geo-information. This will be followed by a section elaborating on the topic of disaster and risk management. The concepts of risk, hazards, vulnerability, exposure and the disaster cycle will be discussed. Next, a section on early warning systems will provide an illustrative case of how geo-information and disaster and risk management are connected. This as well will shape the theoretical background needed for the case study, that focusses on the effective application of an early warning system.

2.1.1 Geo-information

The terms geo-information and geospatial information are used interchangeably in this thesis. Both refer to interdependent data sources (i.e. imagery, maps, data sets, tools and procedures) that link every event, feature or entity to a location (NRC, 2007). The value of geospatial data arises when a location is linked to the properties, or *attributes,* such as events, features or entities (NRC, 2007). The location of attributes can be expressed by specific standards or other readily understood forms, such as GPS coordinates. Adding a geospatial component to a dataset allows for many applications and insights, such as displaying the data on maps or combining several geospatial components or layers in modelling processes.

Geospatial data types

In this study, the choice has been made to adopt the categorisation of the publication of the National Resource Council (2007) "Successful response starts with a map", that focusses on the use of geospatial data in disaster events. The report distinguishes between framework data, foundation data and event related data. *Framework data* covers the geographical basis that offers a set of markers to which the other data can be tied. These data is typically regularly collected (regardless if a disaster takes place or not) and used by most organisations for daily geospatial activities. The *foundation data* complements the framework data as this is created to support operations of the private and/or public sector. Foundation data is more organisational specific for certain purposes such as underground gas pipelines or the location of storages of chemical materials. This data is highly valuable for disaster management as it represents the state of an area before a disaster event and highlights important attributes that need specific attention when a disaster actually occurs. The last category *event-related data* is referring to all data collected after the onset of a disaster in order to respond and recover from the event. In the case of a flood one can think of maps showing the inundated areas. Combined with the framework and foundation data, emergency responders are enabled in their relief activities (NRC, 2007).

Data vs. information

When raw data is converted into something meaningful it's called *information* (Alberts, Garstka, Hayes, & Signori, 2001). Geospatial information is typically what is created when geospatial tools and procedures are applied to geospatial data (NRC, 2007). Examples of tools and procedures are: software and hardware systems that allow for specific operations on geospatial data (NRC, 2007). The applications can range from relatively simple to highly complex modelling systems. One of the most important and widely used tools for converting geospatial data into geospatial information is Geospatial Information Systems (GIS), allowing for capturing, storing, managing, analysing and displaying data tied to a certain location (NRC, 2007). Another important tool, especially in disaster management, are Spatial Decision Support Systems (SDSS) that provide the vital information needed when decisions involve a spatial component. Often multiple alternatives are weighted in order to find the best outcome for specific circumstances (NRC, 2007).
As this study focuses on the value of geospatial information, the choice has been made to adopt the definition *geo-information product* after Krek & Frank (1999) referring to geospatial data that is used to make decisions, which ultimately determines the value the information contains. An example in a flooding event could be a satellite inundation map, used to determine where and when to evacuate people vulnerable to the flood.

Effective usage

The title of this section indicates that the right information should reach the right people in the smallest amount of time. All are considered equally important in disaster and emergency situations. Firstly, the context in which data and information are used is highly important. Often this is referred to as the *geospatial infrastructure*, defined as the set of institutions, people and skills, standards, educational programs, and other arrangements surrounding the geospatial data and information (NRC, 2007).
A helpful feature in understanding this context of data or information is the so called *meta-data* . This term represents "data about the data" describing the characteristics such as the quality, standards, content description and coordinate set (NRC, 2007). Meta-data enables correct interpretation, allows for better processing and analysing and furthermore tracks the source of the data or information.
Furthermore the *Interoperability* determines the usefulness as this refers to the exchangeability of various geospatial tools and data. Often this is related to the software systems used to capture, store, process, analyse and display data sets (NRC, 2007). Difficulties arise when systems and data sets have been created by many different developers, using their own different standards, classifications systems and terminology. Noted by NRC (2007), comprehensive interoperability does not limit itself to the data and tools, but should also include the computer hardware and networks. One can even take it one step further by also including the processes, policies and personnel of organisations and institutions into the framework of interoperability.

In order to streamline interoperability and exchange so called Spatial Data infrastructures (SDI) have emerged. The Global Spatial Data Infrastructure (GSDI) association defines SDI as a "coordinated series of agreements on technology standards, institutional arrangements on technology standards, institutional arrangements and policies that enable the discovery and facilitate the availability of and access to spatial data". Geo-portals, websites offering access to spatial data, are a key element of SDI being gateways to geographical content and capabilities (Maguire & Longley, 2005). Figure 3 illustrates the position of such a geo-portal in a simplified spatial data infrastructure. SDI's and geo-portals have made a major contribution to simplifying access to geospatial information (Maguire & Longley, 2005), and are therefore important for effective usage.

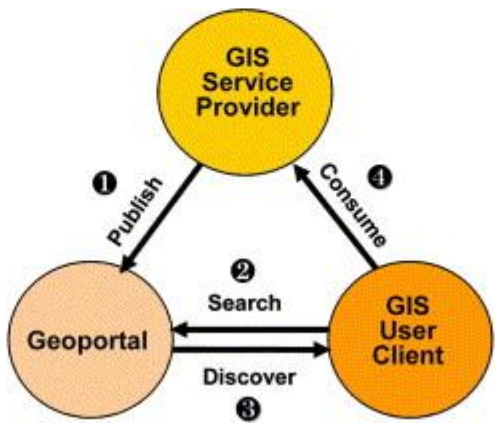

Figure 3: The role of a geo-portal in an SDI. Maguire and Longley (2005)

2.1.2 Disaster and risk management

Definitions and concepts

This section will elaborate on the different definitions and concepts regularly used in disaster and risk management. A disaster is defined as "a serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources" (UN/ISDR, 2004). The NRC (2007) has identified five major characteristics that make disasters hard to overcome and furthermore illustrates the difficulties in managing them. First, disasters are large rapid-onset incidents relative to the size and resources of an affected jurisdiction. Second, disasters are uncertain with respect to both their occurrences and their outcomes. Third, risks and benefits are difficult to assess and compare. Fourth, disasters are dynamic events and fifth, disasters are relatively rare.

The main goal of disaster (and risk) management is to reduce as much as possible the degree to which a community is affected by a disaster relative to its pre-disaster state (NRC, 2007). These may include both pre-and post-disaster activities to reduce the potential impacts. As the occurrence of disasters is related to the associated risk, this concept is taken as a starting point for this section.

Risk is defined as "the probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between natural or human-induced hazards and vulnerable conditions" (UN/ISDR, 2004). The two elements that constitute the risk experienced by a community are:

Risk = Hazard * Vulnerability

A hazard can be described as "a potentially damaging physical event, phenomena or human activity, which may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation" (UN/ISDR, 2004). Natural hazards can be classified by their geological, hydro-meteorological or biological origin, where technological hazards and environmental degradation are both induced by human activities. In practice often combinations and interactions take place between different types of hazards, for example the tsunami in Japan March 2011. A geological hazard was followed by a tsunami, inducing a nuclear technological hazard, which in turn caused, among other impacts, environmental damage.
Vulnerability is the degree of susceptibility of the elements exposed to the disaster (UN/ISDR, 2004). For example the locations of hospitals. Factors determining vulnerability can be social, economic, physical, environmental or a combination. Often a third component is added to the equation, namely exposure, which refers to the people and property that are subject to the hazard (UN/ ISDR, 2011).
The risk components are dynamic as the patterns of hazards as well as the vulnerability and exposure are changing over time. The UN/ ISDR (2011) identified three major drivers of risk; (1) badly planned and managed urban development can increase vulnerability. Also (2) ecosystem decline may contribute to for example coastal ecosystem, as mangroves and wetlands, play a key role in mitigating impacts of storms and floods. Last, also poverty (3), tends to increase disaster risk. How societies and communities perceive and act on risks is influenced by many factors.

Disaster cycle

In contemporary disaster management, four phases are being distinguished: preparedness, response, recovery and mitigation (FEMA, 1998) (NRC, 2007). The phases follow, in theory, one another and can be presented in a continuous cycle (Figure 4). Note that the cycle is a highly simplified overview; a disaster can hit at any time and phases may overlap.

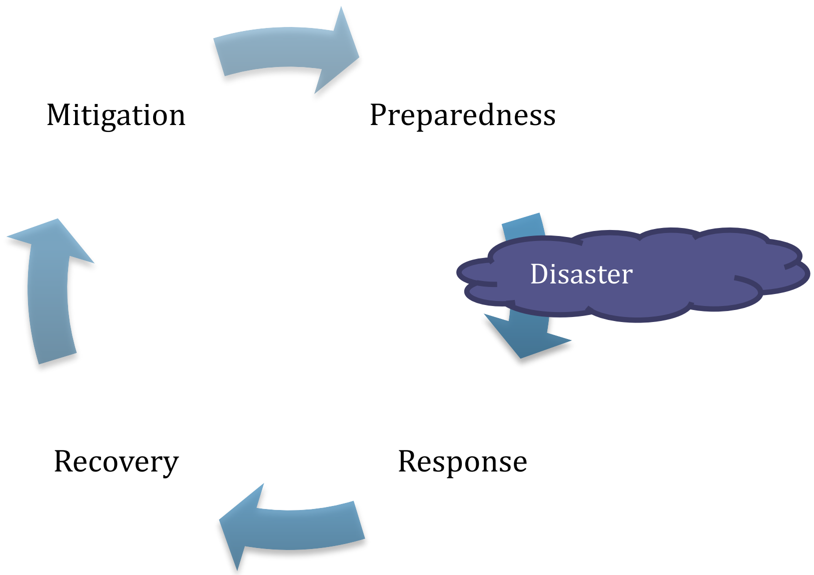

Figure 4: Disaster cycle

The preparedness phase takes place during the short term before the disaster strikes and encompasses activities that improve the readiness of organizations and communities, such as an early warning system. Actions taken during this phase may reduce the time required to respond when a disaster strikes and may even speed up the recovery process. Potential hazards can be identified and subsequent plans can be developed that identify the needs for response and recovery. (NRC, 2007) notes that plans are more effective when developed collectively by all agencies, so coordination can take place and relationships can be established among responders. Other activities in this phase one can think of are the training of people and exercises that prepare organizations and communities to respond the best they can (NRC, 2007).

The response phase starts with the onset of a disaster. It is important to note here that not all disaster types strike without a warning and the distinction between the preparation and response phases can in practice be a grey area. The flooding of a rain fed river can be forecasted hours or even many days in advance, while an earthquake may hit without a warning. The nature of the hazard therefore determines whether the boundary between preparedness and recovery is sharp or rather vague.

Activities in the response phase revolve around immediate actions that can be undertaken to reduce the (possibly life threatening) impacts. This can be in the form of life-sustaining aid or stopping additional economic damages following from the event. The difficulty here lies in the fact that many urgent actions need to be undertaken at the same time, often in stressful situations (NRC, 2007).

The recovery phase refers to the short- and long term activities used to return the community and built environment to the pre-disaster state (NRC, 2007). An example of a short-term activity can be the provisions of temporary housing, while a long-term activity refers to the rebuilding and reconstruction of houses which were lost during the disaster.

During the mitigation phase, activities are carried out to prevent emergencies and reduce impacts that may result from future disasters (NRC, 2007). Actions one can think of are the assessment of risk and reducing vulnerability, disseminating potential losses and/or implementing policy changes. The latter can refer to new building codes that will lower the earthquake vulnerability or prevent new development projects in flood prone areas.

2.1.3 Early warning systems

This section elaborates on the intersection of the two distinct communities of geospatial information and disaster and risk management, and therefore focuses on answering the first research question; how are geospatial information and disaster and risk management connected? As the previous sections have illustrated, geospatial data and tools form vital input for disaster and risk management at all stages, and serve endless applications. Numerous examples could be highlighted, all with their own pros and cons. Due to limitations of the scope of this research, this study focuses on one specific application: early warning systems. Adopting the definition of the (UN/ISDR, 2004), an *early warning* is "the provision of timely and effective information, through identified institutions, that allows individuals exposed to hazard to take action to avoid or reduce their risk and prepare for effective response". An *early warning system* covers furthermore a chain of concerns, namely the understanding and mapping of a hazard, monitoring and forecasting events, processing and disseminating understandable warnings to population and public authorities and undertaking timely and appropriate actions as a response (UN/ISDR, 2004). The applicability of an early warning system depends on the type of hazard, and whether this can be forecasted or not.

As this research aims at addressing the added value of geospatial information, an early warning system would be a suited exemplary case to investigate, as there are great potential benefits since early warnings save lives and property (Hallegatte, 2012; Rogers & Tsirkunov, 2010). The value of geospatial information is in this case substantial as the detection and identification of hazards, especially hydro-meteorological hazards, is highly enabled by geospatial information.

Increased preparedness

An early warning provides people time to flee from the approaching disaster, enables authorities to evacuate or shelter their communities prior to a disaster, provides information on the occurrence, and enables faster and more accurate response. When a warning provides sufficient lead time this may also enable people to protect property and infrastructure (Rogers & Tsirkunov, 2010). Assets may be moved to the second floor of building or outside the flood zone.

Preparedness for natural disasters is a key factor in reducing their impacts (Alfieri, Salamon, Pappenberger, Wetterhall, & Thielen, 2012). The importance of increasing preparedness of a society is indicated by the extensive publication of the World Bank *Natural Hazards, UnNatural Disasters* (2010). The report identifies three specific spending items desirable for disaster prevention, namely: critical infrastructure, environmental buffers and early warning systems. Although there have been many technology improvements made during the last decade(s) on identifying risks and detecting hazards (for example in weather predictions), many countries haven't taken the fullest advantage of this and a modest increase in spending would already benefit countries (World Bank/ United Nations, 2010), indicating the potentials of early warning systems. Early warning systems are an attractive prevention option for reducing the impacts of natural disasters since the benefits can significantly exceed the costs associated with the development and

maintenance of such early warning systems(Rogers & Tsirkunov, 2010; Teisberg & Weiher, 2009). Especially hydro-meteorological hazards which can be detected with a sufficient lead time for adequate action can save lives, property and even provide additional benefits by optimizing economic production in weather sensitive sectors (Hallegatte, 2012).
Note, however, that care must be taken to not overestimate the impact of an early warning system, as not all property is suitable for protection and removal. On the other land the potential of saving lives is present (Teisberg & Weiher, 2009).

Effective application

The UN/ISDR (2004) identifies four distinct components of an effective early warning system, namely (1) risk knowledge; (2) monitoring and warning service; (3) dissemination and communication; and (4) response capability (Figure 5). The elements follow in a logical sequence and interaction takes place in two ways. The importance of communication at all times, levels and across all scales is increasingly being acknowledged (Chang Seng, 2010). Other elements vital to the performance of a warning are the accuracy, timeliness and reliability (UN/ISDR, 2004). Not only the accuracy of the early warning itself is important but also the *communication* of this accuracy is critical, otherwise there is a high risk that the warning will be ignored or misused. This may in turn may lead to significant societal and economic costs (Sarewitz, Pielke, & Byerly, 2000). The timeliness, or lead time, depends on the type of disaster. Overall, the more lead time, the greater the amount of people, property and infrastructure that can be protected. However, a longer lead time also increases the risk for false alarms and accompanying costs (Rogers & Tsirkunov, 2010). Therefore a trade-off exists between timeliness, warning reliability, the costs of a false alert and the damages avoided as a function of this lead time (Rogers & Tsirkunov, 2010).

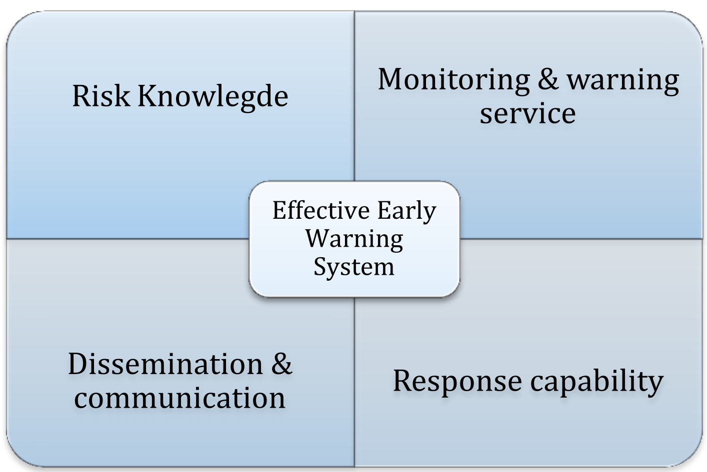

Figure 5: Components effective early warning system (after (UN/ISDR, 2004))

In order to build an effective early warning system the UN/ISDR (2004) identified three prerequisites; (1) the political responsibility to promote integrated early warning strategies; (2) the human dimensions of an early warning; and (3) international and regional support regarding the early warning system. An early warning system should typically be a measure developed by the government and/or international organizations (World Bank/ United Nations, 2010).

Geospatial input
As all hazards have a spatial component (NRC, 2007), geospatial data and tools form vital input for detecting a hazard, if possible. Central to providing an early warning is to integrate the hazard characteristics with vulnerability information in order to determine which individuals and infrastructure components are at risk so warning messages can be generated in order to minimize loss of live and property damage (Asante, Verdin, Crane, & Tokar, 2006). To analyse what levels of vulnerability are experienced by a region, one needs both *foundation* and *framework* data. During preparedness planning, historical geospatial data can be used to develop baseline hazard and vulnerability profiles. To track the (upcoming) hazard one needs *event-related* data. The specific geospatial information and tools required depends on the type of hazard. Concerning flooding, a hydro-meteorological hazard, extensive use is being made of meteorological input data for detection, monitoring and modelling (Alfieri et al., 2012).

2.2 Value of (geo-) information

The value of information is highly dependent on who receives it and what subsequent actions are taken. Consequently, the economic value of information should be determined by estimating the impact of an altered decision making process resulting from the information to be valued (Fritz, Scholes, Obersteiner, Bouma, & Reyers, 2008; Krek & Frank, 1999) (Figure 6). When the impact of altered decision making due to the inclusion of geo-information can be economically assessed, the value of geospatial information rises.

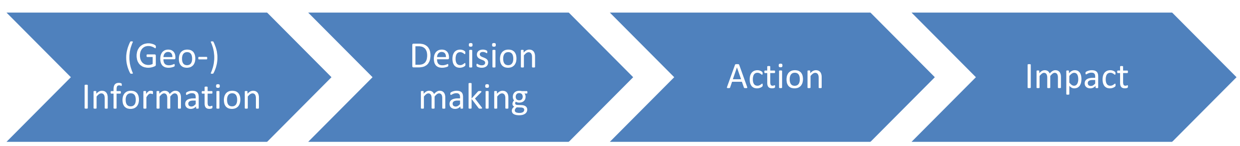

Figure 6: Flow chart valuation process of information due to altered decision making, adjusted after (Fritz et al., 2008)

Opening this chapter, it is important to emphasize that decision making in emergency situations differs greatly from daily situations. This is followed by a section discussing how geo-information aids to the decision making process in these emergency situations. Furthermore challenges are identified and the issue of how to economically value an early warning system is briefly touched upon. Finally, a summary will present the main findings of this chapter.

2.2.1 Decision making & benefits of geo-information

The decision making process differs in emergency situations greatly from daily situations, as denoted by (Borkulo, Scholten, Zlatanova, & Brink, 2005), specifically aiming at the response phase. Characteristics of crisis response are identified by this paper:

- Decisions are taken under stress and time pressure
- Decision makers are dealing with uncertainty which asks for ad hoc decisions which are based on intuition and prior experiences rather than information

- Decision makers often experience external pressure, from for example the media, which affects their decisions
- Crisis response deals with many different actors and decisions that all must be coordinated
- Afterwards, an evaluation of the quality of the decision making process is made

Firstly, geospatial information may serve decision making processes in DRM situations as it reduces *uncertainty* surrounding a disaster event such as the onset, the extent and severity. Reducing this uncertainty of the risk to life and property disasters impose would allow authorities and individuals to prepare ahead, and thereby reduce the both economic and societal impact (Williamson, Hertzfeld, Cordes, & Logsdon, 2002). For example, in the case of hydro-meteorological disaster, better weather forecasts may lead to higher accuracy of the extent and a longer warning time or improved understanding of weather and climate phenomena that will reduce uncertainty around a hazard event. The reduced uncertainty of disaster risks may ultimately lead to better *understanding* of the disaster itself, regarding causes and consequences, and enables improved decision making, making people act faster and more efficient. Especially in the early warning and response phase, speed is required in delivering warning messages and adequate response activities. This improved decision making can then result in reduced economic losses and human suffering and be translated into direct economic value (Williamson et al., 2002).

2.2.2 Approaches to assess the value of information

Studies that analyse the value of *information* fall broadly into three types of models; First, (1) the econometric estimation of output or productivity gains due to information. Second, (2) hedonic pricing studies, assuming the value of information is captured in the prices of goods or services, and third (3) contingent valuation surveys, that is rely on the 'willingness to pay' principle (Macauley, 2005). Most of the studies on the value *of geo-information* focus the impact of weather forecasting, which is in nature geospatial, on agricultural output (Macauley, 2005). This approach falls into the first category described above. Typically in these studies the farm profits under average but uncertain weather patterns are compared with farm profits if rain could be accurately forecasted. A compilation of exemplary studies of (Johnson & Holt, 1986) include the optimization of production levels according projected temperatures or precipitation rates. Besides agriculture, also other weather related sectors can optimize their output or productivity levels accordingly to weather forecasts, such as the energy sector (Roulston, Kaplan, Hardenberg, & Smith, 2003) or aviation safety (Macauley, 2005). Furthermore, disaster and risk management can significantly benefit from weather predictions when a hydro-meteorological natural can be accurately forecasted (Williamson et al., 2002).

There are some difficulties that arise when determining the value of these resulting actions and their impact, as often there is no market value available. The absence of a market value may exist due to (1) the nature of the attribute that is impacted by information, that makes it difficult to put a monetary figure on, for example a nature park. Also it could be that the (2) impact of information is difficult to trace back and therefor is difficult to capture. Once information is disseminated, this is relatively easy transmitted and copied, hereby diminishing the actual market value of information. Unless the originator has developed a method of retaining control on the information it is difficult to track down all the applications, and resulting impacts and benefits, the data is used for (Williamson et al., 2002).

2.2.3 Approaches to value Early Warning Systems

Studies that value the type of geo-information product considered in this paper, early warning systems, generally make use of either the 'cost avoidance method' or the 'contingent valuation method'(Klafft & Meissen, 2011). A 'contingent valuation method' makes use of the concept 'willingness to pay' (WTP). The amount people are willing to pay for a certain product or service is then translated to the value of this product or service. By applying a 'Cost Avoidance Method', the damages and losses that could have been avoided (had the product been in place) determine the (potential) impact of the product. The avoided damages are then interpreted as the benefits of this product. An important assumption made here, is that geospatial information forms a vital input for the early warning system. Finally, these benefits should be compared with the costs of the product to provide a complete overview of the economic *added* value. There are some problems regarding the 'contingent valuation method' as this method has the tendency to produce biased results (Klafft & Meissen, 2011). Problems encountered are that due to strategic reasons respondents may misrepresent their WTP. This may result in both over-as understated answers to their WTP. Also, respondents may fail to consider their budget constraints in hypothetical settings, described by (Diamond & Hausman, 1994). Altogether, the 'Cost Avoidance Approach' should be preferred as valuation method wherever possible (Klafft & Meissen, 2011).

2.3 Case study

This study aims for developing a research approach for eliciting an explicit economic value for the value of geospatial information. To illustrate this, the choice was to adopt a case study, as the added value of geospatial information is highly site and case dependent. The natural disaster selected for this study to research the added value of geospatial information are the flooding events of Namibia, which occurred in spring 2009. The flooding disaster will be explored into detail on how geospatial information was used at that time and what it may offer for future developments in early warning applications, together with the innovative, experimental cost avoidance approach on how to measure the added value of geospatial information.

2.3.1 Summary of impacts

In March 2009 six out of the thirteen regions in Namibia, including Caprivi, Kavango, Ohangwena, Omusati, Oshanan and Oshikoto (see PDNA/ The Government of the Republic of Namibia, 2009), located in the north-central and north-eastern part of the country, were affected by severe flooding. These parts experienced heavy flooding in the 1960s and 1970s, but the last several decades prior to the flooding in 2009 the frequency and magnitude of floods had noticeably reduced. Therefore the flood came as a complete surprise (De Groeve, 2010). Extreme rainfall events in Angola, Namibia and Zambia resulted in high water levels in the catchments of the Cuvelai, Kavango, Kwando and Zambezi rivers, leading to the worst flooding events in more than 40 years or longer(De Groeve, 2010). Historically high waters were recorded in the affected areas. The Zambezi rose to 7.85 m, the highest levels recorded since 1963, the water levels of the Okavango River were 8.67 m in 2009, close to their highest record of 8.91 m in 1969 (PDNA/ The Government of the Republic of Namibia, 2009).

The four central regions are all located in the Cuvelai River Basin which originates in southern Angola (PDNA/ The Government of the Republic of Namibia, 2009). This dense network of ephemeral rivers only carries water in the rain season. The north-eastern part of the country is frequently flooded during the rainy season which seems to be the result of major rivers; whereas the north-central part is not normally subject to flooding and the inundation patterns of the latter region seem to be mostly because of heavy rains. The flood of spring 2009 as a whole can be described as a once every 40 years event (PDNA/ The Government of the Republic of Namibia, 2009).

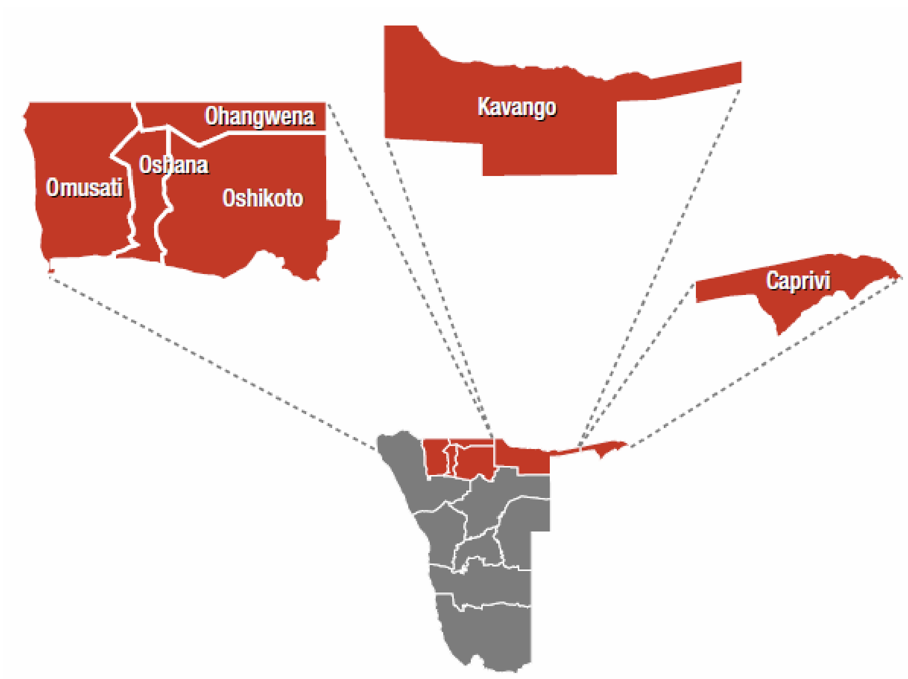

Figure 7: Overview impacted area Namibian flood 2009 (Source: PDNA/ The Government of the Republic of Namibia, 2009)

As a consequence of the flooding commercial and industrial activities were disrupted, local access to health facilities and schools was obstructed. Furthermore, the urban sewage system overflowed which caused great concerns for human health as there had been a cholera outbreak a year before. Also electricity was comprised. The entire economy in the area was disrupted for almost three months, and recovery is still ongoing (at the time of writing the PDNA, August 2009).

The human toll of the 2009 flood was high; according to figures from the local authorities, close to 700,000 people were affected (33% of the total population), around 50,000 people were displaced and 102 lost their lives (PDNA/ The Government of the Republic of Namibia, 2009). The Caprivi area was most affected in terms of flood levels, however in terms of population; the Ohangwena, Omusati, Oshana and Oshikote were most affected.

A vulnerable part of the population was impacted as one third of Namibia's poor live in the affected areas. Most of the population here lives in the rural parts where their income in highly dependent on farming practices. Furthermore the annual harvest and much livestock were lost in the flood, which stressed the income and food sources of the affected. Finally, many houses were washed away.

The damages and losses are categorized per economic sector, as defined by the PDNA team. Damages represent "the replacement value of totally or partially destroyed physical assets that must be included into the reconstruction programme", where losses are defined as "the flows of the economy that arise from the temporary absence of the damages assets". The major sectors infrastructures, productive and social- are responsible for 86% of the total damages. The losses, in contrast, are more concentrated in the subsectors of the productive sectors: agriculture, industry and commerce represent approximately 90% of the losses. The overall economic impact of the floods is estimated by the PDNA team to be about 1% of the 2009 GDP or 0.6% of the 2009 GDP growth (forecasted before the flooding event).

Sector/ Sub-sector	Damage (N$ million)	Losses (N$ million)	Damage (US$ million)	Losses (US$ million)
Infrastructure	**279.7**	**32.2**	**34.3**	**4.9**
Water Supply Sanitation	47.9	28	5.9	3.4
Transport	223.2	2.9	27.4	0.4
Energy	8.6	1.3	1.1	0.2
Productive	**405.1**	**584.4**	**49.7**	**71.7**
Agriculture	38.6	120.9	4.7	14.8
Industry	143.5	162	17.6	19.9
Commerce	209.7	289.7	25.7	35.5
Tourism	13.3	11.8	1.6	1.4
Social	**416.5**	**19.5**	**51.1**	**2.4**
Housing	385.7	13.8	47.3	1.7
Health	0.7	5.7	0.1	0.7
Education	30.1	0	3.7	0.0
Cross-sectoral	**10**	**0.9**	**1.2**	**0.1**
Environment	10	0.9	1.2	0.1
Total	**1,111.30**	**637.1**	**136.4**	**78.2**

Table 1: Summary of damage and losses (source: PDNA, 2009)

2.3.2 Motivational reasons

When selecting a suitable case study for this research, several reasons led to the choice of the Namibia flooding event in 2009. Among the reasons for choosing Namibia is firstly, the *geographical location* which makes Namibia vulnerable for *recurrent* climate hazards, both droughts and floods. Secondly, Namibia is considered as one of the most vulnerable countries for climate change in sub-Saharan Africa (PDNA/ The Government of the Republic of Namibia, 2009). Projections show greater anomalies in rainfall, increasing chances for high intensity rainfalls and subsequent flooding. Therefore, determining the added value of geo-information may set priorities in investments and research that have the potential to lower future impacts resulting from a flooding event. Thirdly, there is *high potential* for the application of geospatial information as input for an early warning system. This is due to the nature of (part of) the flooding events, as the headwaters of the main rivers originate far upstream. Except for the occurrence of flash floods, the ability to predict river floods in this area is substantial, at some places in the catchment even with a lead time up to 30 days (De Groeve, 2010). Since an early warning system is driven by geographical information (systems) this is highly applicable to this research. Especially satellite data is very suitable because the flood in 2009 covered a large area, and timing and dynamic behaviour was variable among regions (PDNA/ The Government of the Republic of Namibia, 2009). Namely, satellite imagery provide an overview of the situation by mapping areas that are remote and/or difficult to reach (PDNA/ The Government of the Republic of Namibia, 2009). Summarising, geo-information has, in theory, a lot to offer to this country and this specific type of natural hazard, with the potential of lowering resulting damages and losses.

In addition, not only the potentials for geospatial information should be high, also the circumstances should be present that enable *executing* the research itself. First, there is already a history of contact established between UN-SPIDER and the Namibia Hydrology Department, which is vital for this study to provide context, additional information and the distribution of the questionnaires. Secondly, a very extensive 'Post Disaster Needs Assessment' was written after the flood of 2009. The National Planning Commission of the Government of Namibia requested the World Bank, through the Global Fund for Disaster Reduction and Recovery (GFDRR), for this assessment. In collaboration with the United Nations and the European Commission, the report was published in 2009. An extensive description of the damages and losses are presented, as well as the needs for early and midterm recovery, and a long-term risk management and reduction strategy. This report provides a holistic view on the flooding event and the additional information needed to perform the research.

Figure 8: Flooding Namibia 2009 (source: PPT Guido Van Langenhove)

2.4 Summary

This chapter presents the background information of this thesis research. The concepts of geospatial information and disaster risk management were discussed and the paramount of geospatial information and tools needed in the entire disaster cycle were emphasized. The applications of geospatial data and tools in disaster and risk management are endless and therefore this study focusses on one particular geo-information product: an early warning system. This forms a suitable exemplary case of how the geospatial information and disaster and risk management are connected, as spatial information and tools are assumed to form vital input for the detection of a hazard and thereby providing an early warning message. Furthermore, the potentials for reducing the impact of disasters are high, increasing its value when applied effectively.

Geospatial information aids to decision making in DRM in multiple ways including: the reduction of uncertainty and the gathering of knowledge. Both have the potential make more informed, better decisions in a shorter time period. Furthermore the valuation of geospatial information has been introduced and two general approaches on how to value an early warning system have been discusses: 'Willingness To Pay' versus a 'Cost Avoidance Approach', the latter will be applied in the case study of this research: the Namibian flooding event from 2009. The impacts have been described and the motivational reasons for choosing this case have been discussed.

3. Methodology and Data Collection

This chapter will discuss the methodology and data collection, including the methods of analysis applied in order to answer the last two research questions proposed in this study:

- How can the added value of geo-info in Disaster and Risk Management be measured?
- How can the value of geo-info in Disaster and Risk Management be improved?

The emphasis of this research will be put on answering the first research question, as this forms the focal point of this study and this is where an innovative approach is discussed on how to value geospatial information in disaster and risk management. First the research methods applied will be discussed, which will encompass a Namibian case study, in which the flooding event of 2009 will be studied. The Namibian case study consists of two lines of research; (1) a review of the Post Damage Needs Assessment report, published by the World Bank in August 2009 and (2) a questionnaire which encompasses an innovative approach on how to measure the added value of one geospatial information product: early warning systems. Both will be used in order to provide a comprehensive picture of the flooding disaster, how geospatial information was used, how the early warning system is evaluated and an innovative experimental cost avoidance approach will be applied in order to illustrate how the added value of geospatial information can be measured. The questionnaire forms an important product of this research approach, as this forms the core of the valuation method. This approach has high scientific potential, as the design serves as a template for future research regarding the economic valuation of geospatial information. Ending this section, the data collection and methods of data analysis will be elaborated on.

3.1 Research Methods

The research approach chosen is overall qualitative in nature and with regards to a case study. Qualitative research is in general exploratory and might be needed when a topic is un(der)studied (Morse, 1991), which is considered to be case when studying the economic value of geospatial information in disaster and risk management. A combination of resources will be used for examining the research questions; namely interview data from questionnaires (data type 1) and documentation regarding the Namibian case study (data type 2). Both research types are used to complement each other and to give an encompassing view of the use of geospatial information in this context. The framework of the methodology will be explained in more detail in this section and is illustrated in the flow chart in Figure 9.

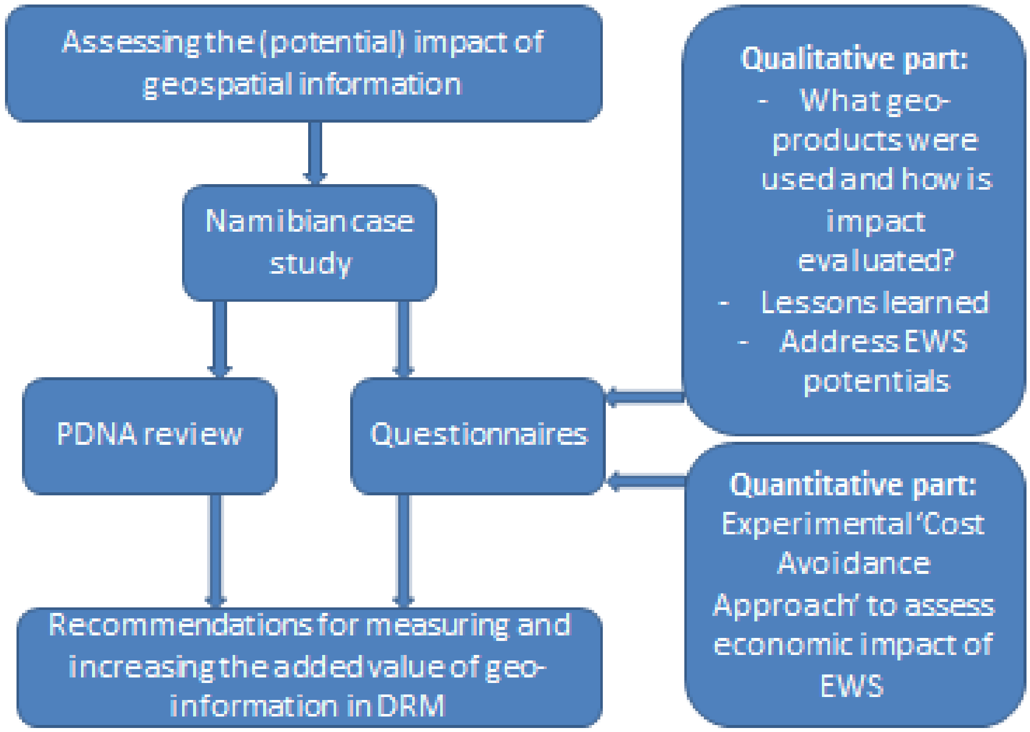

Figure 9: Flowchart Research Structure

This study aims for developing a research approach for eliciting an explicit economic value for the value of geospatial information. To illustrate this, the choice was to adopt a case study, as the added value of geospatial information is highly site and case dependent. The natural disaster selected for this study to research the added value of geospatial information is the flooding event of Namibia, which occurred in spring 2009. The flooding disaster will be explored into detail on how geospatial information was used at that time and what it may offer for future developments in early warning applications, together with the innovative, experimental approach on how to measure the added value of geospatial information.

Both research methods applied in this case study, the questionnaires and the PDNA review, complement each other. Where the PDNA is more describing on what damages and losses have occurred, the PDNA does not provide a detailed description of the causes of the failure of the early warning message. Namely the report indicates that there was "Even though national authorities transmitted hydrological warnings, they did not result in appropriate action at the community level". Therefore the questionnaire focusses on what this study identifies as the *gaps* of the PDNA, what caused the low level of effective response? By identifying the causes into detail, a founded recommendation will be provided. Also, the PDNA has identified the needs shortly after the flooding disaster, as it was published in August 2009. Several options are discussed in the report to provide the Government of Namibia to work towards "longer term, sustainable disaster risk reduction". The questionnaire also targets what has taken place in the context of disaster and risk management, in between the PDNA publishing date and the current situation. Roughly three years later it might be useful to examine the progress made and the current needs identified by the participants anno 2012.

Summarising, the PDNA and the questionnaire complement each other in at least two different ways, which ultimately leads to a more comprehensive analysis. The next sections will elaborate in more detail on how the PDNA will be analysed, how the questionnaires have been set up and what they target.

3.1.1 PDNA

The National Planning Commission of the Government of the Republic of Namibia requested immediately following the relief efforts the World Bank, through the Global Fund for Disaster Risk Reduction and Recovery, to undertake a Post Damage Needs Assessment. This was undertaken in coordination with the United Nations and the European Commission to assist the Government. The PDNA forms major input for the design of the Namibian case study, as the report provides detailed information on the flooding disaster. Concerning the focus of this study, the report will be scanned on the use of geospatial information at the time of the flooding event and what needs are identified by PDNA team that include the application of geo-information products in the context of disaster and risk management.

3.1.2 Questionnaires

The Namibian case study encompasses a qualitative questionnaire, with an experimental quantitative 'Cost Avoidance Approach' applied to study the potentials of an early warning system driven by geospatial information, in order to measure the added value of geospatial information in disaster and risk management.

Using questionnaires as one of the research methods for studying Namibia seemed most appropriate for a number of reason. Firstly, this method is valuable as it is designed to gather data for analysis and interpretation (Babbie, 2007), which could not be detected otherwise. Also, this method can be applied without physical presence, as the distribution and collection can go through email. Another advantage is that the participants can provide historical information needed to understand the situation at that time and how they experienced topics of research such as what geospatial information products were available at that time and how they are evaluated by the users (Creswell, 2009). Therefore a questionnaire allows for a structured approach of interviewing (Creswell, 2009).

One major disadvantage that can be identified when using questionnaires is the possible presence of biases. First, there is the risk of biased responses; the ones who respond to the questionnaire have generally more interest or even more to gain than those who did not respond. Also, the information received is indirect, filtered through the views of interviewees, which can be subjective (Creswell, 2009). Thereby are not all interviewees are equally well articulated (Creswell, 2009). The potentially present biases are taken into account when drawing conclusions from the results. The questionnaire consists of the following three major topics:

- Assessment of 2009: Geo-information products used & Early Warning System

- Improvements of geo-information value & identifying needs
- Experimental ‘Cost Avoidance Approach’

These topics will be elaborated on into more detail in the next section: Data collection and analysis. The complete questionnaire can be found in Appendix 1.

3.2 Data Collection and Analysis

This section will discuss the data collection and the data analysis applied to the returned questionnaires.

3.2.1 PDNA

The PDNA report of 2009 will be scanned on how geospatial information and tools were used and what recommendations can be found to improve the application(s). furthermore the report provides an extensive review on the flooding disaster in 2009, including accompanying damages and losses and provides insightful information on the needs that were identified shortly after the flood in August 2009. The latter can be compared with the questionnaire results in section 4.2; have the needs been met in the period 2009-2012?

3.2.2 Questionnaires

The target group of the questionnaires are people who were involved in flooding related activities concerning the Namibia flooding in 2009 and preferable familiar with geospatial information. Two groups are selected based on these criteria:

1. The Hydrology Department in Namibia, part of the Ministry of Agriculture, Water and Forestry. The contact person, head of the Hydrology Department Guido Van Langenhove, distributed the questionnaire both internally within the Department (5 persons) as well as externally outside the Department to the members of the flood bulletin (around 200 persons), which are people in the field from the government, non-governmental organisations, such as lodge owners, or private homes, receiving regular updates on water levels by e-mail from the Hydrology Department (see an example of the bulletin in Figure 10). Furthermore the questionnaire was distributed to the Directorate of Disaster Risk Management of Namibia (3 persons).
2. Members of the scientific community of the Namibian Early Flood Warning SensorWeb, a pilot project started after the flooding events in 2009, via an international partnership between NASA, UN-SPIDER, Namibia Department of Hydrology, Canadian Space Agency, Ukraine Space Research Institute, DLR (Germany) and others (10 persons). The main aim of this community is a scientifically sound, operational trans-boundary flood management support system for the Southern African region to provide helpful flood and waterborne disease forecasting tools for local decision makers (Mandl, 2010).

Namibia daily flood bulletin 01 March 2010:

The Zambezi River maintains its steady rise in Katima Mulilo. Friday afternoon, ZRA forwarded the upstream readings, confirming ***the arrival of a high flood in the Zambezi River at Chavuma near the Angola border****. Friday's reading was 8.81 m (on 26 Feb, up from 7.71 m on 23 Feb). See attached graphs. It is possible to make the following comparison:*

2007:	*maximum at Chavuma:*	*9.04 m*
	maximum at Lukulu:	*6.56 m*
	maximum at Katima Mulilo:	*7.23 m*
2008:	*maximum at Chavuma:*	*7.53 m*
	maximum at Lukulu:	*5.82 m*
	maximum at Katima Mulilo:	*5.88 m*
2009:	*maximum at Chavuma:*	*9.71 m*
	maximum at Lukulu:	*6.89 m*
	maximum at Katima Mulilo:	*7.85 m*
2010:	*Friday at Chavuma:*	*8.81 m*
	Thursday at Lukulu:	*6.00 m*
	today at Katima Mulilo:	*4.92 m*

The flow time of floods from Chavuma to Lukulu is a few days and then +/- two more weeks to Katima Mulilo. It depends on rains and flow conditions in the intermediate areas what magnitude of flood will ultimately reach Katima Mulilo, and it is also not known how much further the flood will still rise in Chavuma. For the time being, the heavy rains have moved out of the area and no new heavy rains are predicted by various models, but on Friday ZMD indicated the ITCZ still being over southern Zambia.

A prudent forecast is that ***Zambezi waterlevels may reach and pass the 7 m mark in Katima Mulilo by mid-March. This forecast will be updated and improved in the weeks to come.***

Figure 10: Example of flood bulletin, 1 March 2010, Source: PPT Guido Van Langenhove (2010)

The questionnaires were attached as a Word document to an e-mail send out mid June 2012. The last responses were received in September 2012. The scientific community was contacted directly, whereas the head of the Hydrology department, distributed the questionnaire attached to the flood bulletin and motivated internally in the department. Before sending, the questionnaire was tested internally at the UN-SPIDER Bonn office, as well as being reviewed by supervisors from the VU University Amsterdam, in order to prevent the possibilities of misunderstanding questions or how they should be answered (Babbie, 2007). A combination was used of open- and closed-end questions. Open ended questions need to be coded, from text to categories, before they can be analysed (Babbie, 2007). This offers the possibility for misunderstanding and research bias, where on the other hand closed ended questions are more easily structured for analysis but may overlook some possible answer categories (Babbie, 2007). Both have their pros and their cons, and therefore a combination of the two types of questioning was chosen. In the case of open-ended questions, there was no limit set for the amount of words that could be used when elaboration on a topic was asked. The questionnaire included an introduction letter which explained the purpose of research, why participation was important for this research and how much time was needed to complete the questionnaire. Furthermore, the respondents were assured their answers would be treated confidentially and that the main findings would be communicated afterwards. Much effort was put in keeping the questionnaire as short as possible, to avoid the issue of respondents finding it too much trouble to complete the questions.

The questionnaire response rate was relatively low, 14 questionnaires were returned (out of circa 200 send out), even though multiple friendly reminders were send to the scientific community and the Hydrology Department in Namibia. Not all were filled in completely, therefore per section being analysed, additional information is provided on how much respondents answered a particular type of question. The low respondent rate can be due to the distance, as e-mail surveys have proven to be less effective than in-person interviews or interviews by phone (Babbie, 2007) or the fact that there was, for a large part, an intermediate person involved. Both factors may have weakened the motivation for selected persons to participate. A better option would have been a site visit and personal contacting the selected participants, so that the studied topic and why their participation is important could have been explained in more detail. Most importantly, more emphasis can then be laid on why it is in their benefit to participate. However, due to limiting factors, a site visit was unfortunately not feasible. Nevertheless, it was found that even though the low response rate, nevertheless valuable information was provided by the respondents for analysis of the proposed topics of this study and enough feedback was received to illustrate the potentials of the research method to value geospatial information in disaster and risk management.

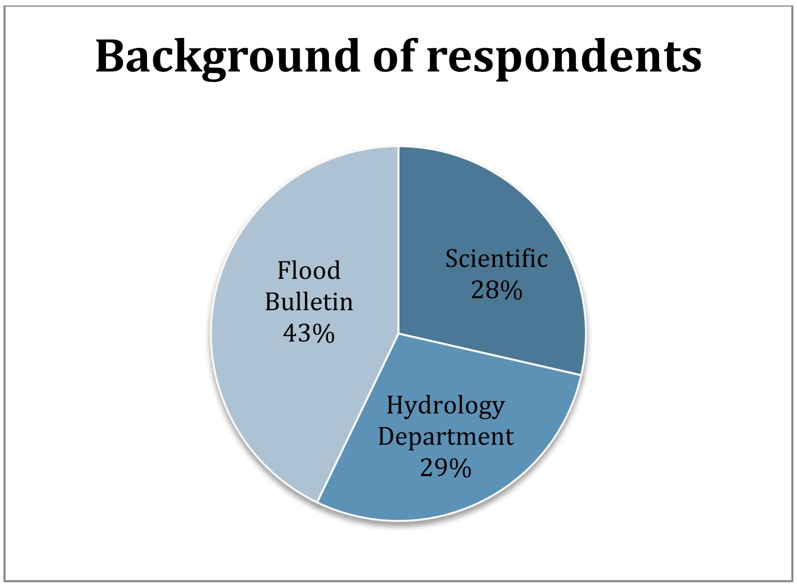

Figure 11: Background of respondents

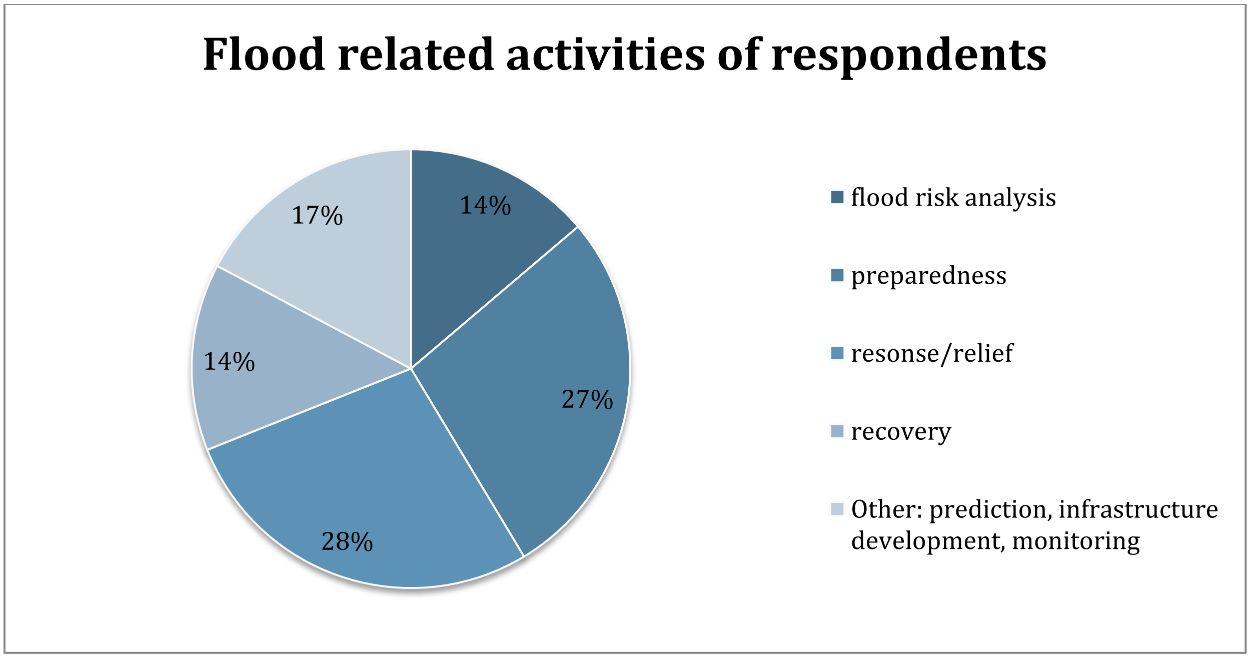

Figure 12: Flood related activities of respondents

As discussed before, the questionnaires addressed three topics (1) An assessment of the flooding situation in 2009; what geo-information products were used and how did the early warning system function at that time, (2) Evaluation of how the EWS has improved (if any) since 2009 and further needs and recommendations identified by the respondents, and the innovative research method of valuing geospatial information; (3) an experimental 'Cost Avoidance Approach' of how much damages and losses could have been avoided, if an effective early warning system had been in place. The main aim of the latter is to sketch the (potential) value of geospatial information in DRM in a *quantitative* manner. The first two topics are analysed in a *qualitative* way.

Assessment of 2009: Geo-information products used & EWS

Respondents were asked what geo-information products were available and used at the time of the flooding event in 2009, what main purpose this product served and how they would evaluate the impact (see Appendix 1: The Questionnaire, section 2, or see Figure 13). The latter is here defined as how much the product has improved decision making compared to a situation where this product is unavailable.

	Geo-information product:	Supported action:	Impact (1-5)*:
Example:	*Satellite based flood inundation map*	*Evacuation of people*	*4*
1			
2			
…			

**(1=low, 5=high, 0=none, X=don't know)*

Figure 13: Part 2 of the questionnaire: What geo-information products were used, what was the supported action and how is the impact evaluated.

This case study focusses on the geo-information product early warning systems. The cause of the low level of response to the early warning in 2009 provided by the Hydrology department was asked. The answers possible (monitoring and warning capacity, communication of warning, awareness of communities and response capacity on a local level) refer to the elements needed for the application of an effective early warning system (see Chapter 2, section 2.1.3). Respondents had room to deviate from choosing one of the predefined answers or provide a different answer in the category 'other', in which respondents could elaborate on this without a word limit.
When dealing with the questionnaires, one should consider that the core of qualitative research is the interpretation of data (Flick, 2002). The process of data interpretation is represented in Figure 14 below, adjusted after and inspired by (Creswell, 2009). The raw data should first be organised and prepared for analysis. The coding of data is the process of organising the data material, dividing it in pieces or segments of text, prior to brining meaning to information (Rossmand & Wilson, 1998). This process involves defining and labelling categories. As soon as the categories are defined, the answers can be grouped which allows for a better view of the overall response. This is followed by interpretation and representation of the answers.

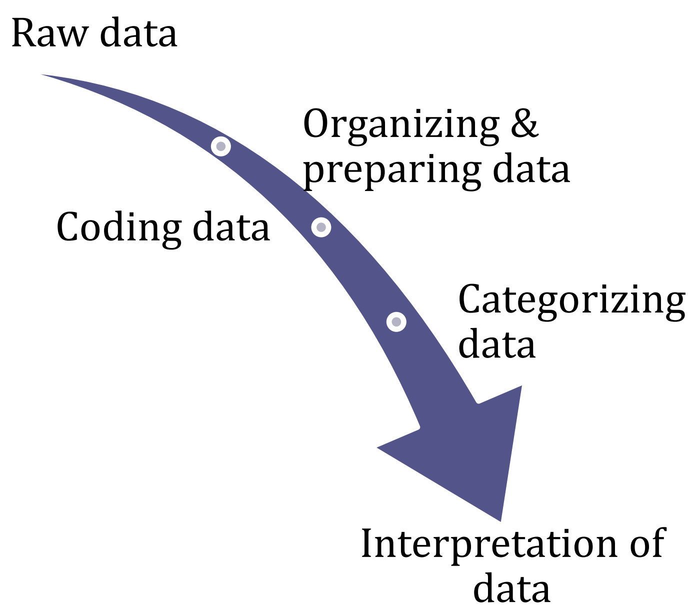

Figure 14: Data analysis in qualitative research, adjusted after Creswell (2009)

Improvements of geo-information value & identifying needs

This part of the questionnaire addresses the improvements that have been made, if any, concerning the early warning system since the flooding event in 2009. Furthermore, the respondents were asked to identify their needs and recommendations regarding the early warning system. The crucial elements of the early warning system (see Chapter 2) are discussed, see Figure 15. Except for the latter, all questions in this section are open-ended. The data analysis of these open-ended questions in this section also makes use of the framework described in Figure 14. For more detailed information on the questions, see Appendix 1: the Questionnaire, section 3.

How do you assess the following;

Questions:	*Pre-2009 flood Scale (1-5)**	*At present Scale (1-5)**
The awareness of communities to flood risk?		
The response capacity on a local level?		
The monitoring and warning capacity?		
The dissemination and communication of the warning?		

**(1=low, 5=high, 0=none, X=don't know)*

Figure 15: Question 3.1, assessing crucial elements of early warning system

Experimental 'Cost Avoidance Approach'

This part of the questionnaire concerns the experimental, innovative approach to measure the added value of geospatial information in disaster management. Opening this section, it is important to emphasize the assumption made in this study that *geospatial information forms crucial input for the effective application of an early warning system.* As discussed earlier, geospatial information is needed for the detection of a flood, and therefore assumed to be indispensable for providing an early warning message to whomever it may concern. This assumption is necessary to translate geospatial information into a tangible geo-information product, which is an essential step before being able to measure the added value of geo-information itself.

Previous studies valuing early warning systems generally make use of the 'Cost Avoidance Approach' or the Contingent Valuation method, discussed in chapter 2. The 'Cost Avoidance Approach' uses cost estimations to determine the amount of damage that can be avoided if an early warning system is in place and compares these benefits with the costs that are associated with such a system (Klafft & Meissen, 2011). This can be seen as an interpretation of how information leads to output or productivity gains, described in the flow chart of Figure 6.

The objective of this study is to develop an alternative application of the 'Cost Avoidance Approach'. By assessing what damages could have been avoided if an effective early warning system had been in place, providing a certain amount of time prior to a disaster, an estimation is made of the impact of an early warning system. The avoided damages are then interpreted as the benefits of an early warning system. The next step, translating the benefits of an early warning system into the value of geospatial information, is what makes this approach new and innovative. Ultimately, these benefits should be compared with the costs of an early warning system to provide a complete overview to determine the added value of geospatial information. It is important to note that this study aims at illustrating the possibility of measuring the added value of geospatial information in disaster and risk management by applying a 'Cost Avoidance Approach' in the particular manner explained in this thesis. However, the *entire execution* of this analysis, which would involve additional detailed assumptions and mathematical calculations, is beyond the scope of this research and not the purpose of this study.

Based on a literature review, it was found that it is in the Namibian case study on average possible to foresee a flooding event, driven by high rainfall events in the higher catchment, with a minimum period of ten 10 days prior to the upcoming flood wave (De Groeve, 2010; Mandl, 2010). An early warning system has the potential to prevent damages and losses, and this particular interpretation of the 'Cost Avoidance Approach' studies what damages and losses could have been avoided had there been an early warning message of 10 days in advance, due to the application of geospatial information. Note that the choice has been made to add up both the damages and the losses, as they are both likely to be affected by the effective application of an early warning system.

In order to make a valuation of a flood early warning system, it is important to assess of what damages could have been avoided resulting from the 2009 flood. Therefore, please consider in this section the following scenario:

- *Imagine there is a flood information system in place that provides you the following information:*
  - *A spatial component showing the up-to-date flood extent.*
  - *A temporal component proving an early warning approximately 10 days in advance that a flooding event is expected.*
- *Assume you have* ***all the capacities*** *needed to respond (materials and human resources).*

Concerning the following sectors; what percentage of the damages and losses in 2009 could have been avoided if there was such a flood information system in place assuming:

- *Effective communication*
- *Adequate follow-on actions*

Please provide the upper and lower boundary of your estimate: for example: 20-35%

0	10	20	30	40	50	60	70	80	90	100%

Figure 17: The scenario presented to the participants

Participants of the questionnaire were asked to answer on a scale ranging from 0-100% to indicate what damages and losses could have been avoided in their opinion, had there been an early warning 10 days in advance. Some other assumptions were incorporated in formulating the scenario of this question, in order to correct for the risk of bias that other factors than geospatial information influenced the outcome of the estimates. One is the assumption of *no limitations on the capacities* needed to respond, as this appeared to be, in some cases, one of the limiting factors to adequate response in 2009. Furthermore *effective communication* and *adequate follow-on actions*, which translates to appropriate decision making and response action, have to be assumed in order to focus on the impact of geospatial information. The scenario the respondents were presented with can be found in Figure 16. The participants were asked to answer for four different sectors (infrastructure, productive, social and cross-sectoral) which correspond with the economic sectors of the PDNA. Additionally, participants were asked what percentage of lives could have been saved, had there been such an early warning system.

Finally, the percentage received will be coupled to the sum of the actually occurred damage and losses figures from the PDNA report of 2009 (see Table 2). This provides a monetary term for the costs that could have been avoided due to the effective application of an early warning system, based on geospatial information and according to the assumptions made. The monetary values are in $US millions, currency of August 2009. The chance of a flood occurring the size of what was experienced in 2009 has been characterised as a 1 every 40 years event (PDNA/ The Government of the Republic of Namibia, 2009). The benefits and costs should therefore be corrected for this order of magnitude flood.

Sector/ Sub-sector	Damage (N$ million)	Losses (N$ million)	Damage (US$ million)	Losses (US$ million)
Infrastructure	**279.7**	**32.2**	**34.3**	**4.9**
Water Supply Sanitation	47.9	28	5.9	3.4
Transport	223.2	2.9	27.4	0.4
Energy	8.6	1.3	1.1	0.2
Productive	**405.1**	**584.4**	**49.7**	**71.7**
Agriculture	38.6	120.9	4.7	14.8
Industry	143.5	162	17.6	19.9
Commerce	209.7	289.7	25.7	35.5
Tourism	13.3	11.8	1.6	1.4
Social	**416.5**	**19.5**	**51.1**	**2.4**
Housing	385.7	13.8	47.3	1.7
Health	0.7	5.7	0.1	0.7
Education	30.1	0	3.7	0.0
Cross-sectoral	**10**	**0.9**	**1.2**	**0.1**
Environment	10	0.9	1.2	0.1
Total	**1,111.30**	**637.1**	**136.4**	**78.2**

Table 2: Summary of damage and losses, estimation by the PDNA team (PDNA, 2009)

Due to the limited number of responders, no statistical significance can be obtained from the results concerning the damages that could have been avoided had there been an effective early warning system in place. Nevertheless, the findings of this study still offer case-specific information and should be seen as potential building blocks for future research. The innovative value of this research lies within the design of the 'Cost Avoidance Application' to measure the added value of geospatial information in disaster and risk management. The questionnaire design, therefore, serves as a *template* for future quantitative assessment to be obtained *with* statistical significance.

3.3 Summary

This chapter has presented the methodology and data collection procedures. The Namibian case study that is selected will be researched on a qualitative manner by means of a PDNA review and a questionnaire. This questionnaire consists of two parts; (1) a qualitative part; assessing the flooding of 2009: what Geo-information products were used and what caused the relatively low level of response to the early Warning System in 2009. Furthermore the participants are asked about the elements of an effective early warning system and what improvements of the early warning system they would like to see. The (2) second part comprises an experimental 'Cost Avoidance Approach' in order to illustrate how the economic value of geospatial information may be assessed.

4. Results and Analysis

This section will elaborate on in what way the Post Damage Needs Assessment report from 2009 addresses the (potential) use of geospatial information in the context of the flooding disaster in 2009. Next, the results of the questionnaire will be analysed, followed by a summary on the Namibian case study as a whole, combining the results of the PDNA and the questionnaire, for an extensive overview on the use, potentials and measurement of geospatial information in this particular flooding context.

4.1 PDNA

The PNDA report was scanned for evaluations on the use of geospatial information. Recommendations formulated by the PDNA team regarding the use of geospatial information in this case can be distilled, mostly related to flood risk reduction. The report identifies four main priorities to reduce disaster risk: (1) An enabling legislation and strengthening of institutions for disaster risk reduction. This point refers to the institutional part of risk reduction, addressing the need for a national act and protocols to make clear who is in command during emergencies and the need for stronger disaster risk management institutions. (2) The strengthening of risk assessment, (3) the improvement of community awareness for disaster risks and (4) a strengthened disaster preparedness and response capacity, referring to planning and simulation training.

All points direct or indirectly relate to application opportunities for geospatial information. However as the second point has most evidently geospatial information related recommendations integrated into the needs to strengthen risk assessment, this will be discussed in more detail in section 4.1.1. Here the needs regarding the early warning system will also be discussed. Additionally, the PDNA has a special annex section regarding the (potential) use of GIS for the actual execution of a Post Damage Needs Assessment, which is discussed in section 4.1.2.

4.1.1 Strengthening Risk Assessment

Four recommendations are suggested by the PDNA of how geospatial information can be used to strengthen risk management. The recommendations for improved application of geospatial information are as follows:

Climate variability and hazard mapping

A national study on climate change in Namibia was carried out in 1998, which analysed past climate trends and incorporated an economic impact study. However, there is a need to further assess future climate variability trends, by means of modelling climate indicators (rainfall intensity, potential evapotranspiration, river discharge, etc.), and also to map projected changes in national key hazards resulting from climate change, such as floods, droughts and wildfires. The modelling could be carried out in global or regional centres, where it is important to ensure that Namibian experts are trained in the process.

Participatory flood risk mapping

This application includes the simulation of disaster impacts of different flood return periods, which provides input for participatory decision making. Consensus should be reached on which levels of risk are acceptable and which not. Furthermore, independent stakeholder consultation provides input to reach zoning regulations and what flood proof measures should follow. The spatial modelling scale of this mapping should depend on the density of people and matter in a particular area. Coarser resolution maps are lower cost options for less dense populated areas.

Linking data for hazard monitoring and response

Here, the interoperability of the system is analysed, which is an institutional issue. Several different agencies collect different geospatial datasets. Consequently, if this information is not linked, the flow of information is delayed, slowing down decisions to be made regarding flood response activities. The Department of Water Affairs issues most flood warnings and has substantial access and analysing capabilities to information databases. However, the Directorate of Disaster Risk Management is limited in collecting and analysing relevant geospatial data. Therefore, a 'harmonized disaster risk management information database and operations room' should be made available to inform the public and policy makers in real time basis. UN-SPIDER has recommended four types of interventions that are desirable for such a system, in a Technical Advisory Mission early 2009 (before the flooding event) as an answer to the flooding event a year earlier in 2008. These include (1) awareness raising for end users, (2) training for usage of spatial data (think of hazard mapping, risk identification, GIS/GPS), (3) interpretation of remote sensing images, and (4); the integration of data and information.

Stronger early warning system and response

As the flood warning in 2009 did not result in subsequent adequate actions, a strengthened early warning system is needed and the PDNA identified three recommendations that could lead to this end;

1. Improving the trans-boundary collaboration with the Zambezi River authority and the Okavango River Basin Commission, to ensure communication across borders. The Zambezi River Authority experienced good collaboration for the transmission of early warning in the past, but due to financial limitations this was disrupted at the time of the flood in 2009. The collaboration with Angola in Kavango has historically been weak.
2. The instalment of 17 new gauging stations and 20 new rain gauges in the Cuvelai basin. This should increase the monitoring and thereby warning capacity.
3. The development of warning systems that match local conditions; such as the use of flags, megaphones or other means of communication. Community volunteer groups could play an important role here.

Further issues that are important in the strengthening of an early warning system are that the messages should be received by end users and most importantly be taken seriously. Especially the second point refers to geospatial information, as the monitoring of the river flow is information tied to the location.

4.1.2 GIS mapping

The annex on GIS mapping in the PDNA provides useful information on which geospatial information is perceived as important for disaster response and damage assessment to support the PDNA team activities in this particular case. No attention is paid to future possibilities for applying geospatial data to early flood detection and thereby early warning systems.

The importance of geospatial information is acknowledged in three significant stages of the PDNA; (1) to organise reference data and to plan and prioritize of field missions; (2) to subscribe damage and losses in the flood impacted area to relevant administrative units; (3) to extrapolate field observations on damage and losses accordingly to the level of the administrative unit.

Several issues are discussed which should be in place for effective flood response actions. The availability of relevant data sets of geospatial information should be in order, preferably in an early stage before the onset of the flooding. Furthermore, the relevant base data should be of sufficient quality, implying the spatial detail, the actuality and the correctness of this data should be adequate to serve efficient execution of PDNA response activities.

Furthermore, the arrangements at the time of the flooding around available geospatial data sets in Namibia are treated and which institutions are in charge of this. The Ministry of Lands and Resettlements is operating the Department of Surveying and Mapping (DMS), which offers both paper and digital maps at different scales (1.000.000, 1:250.000 and 1.50.000) derived from ortho-photography produced in 1996. New full colour (incl. near-infrared) 1 m. resolution of ortho-photography images for Northern-Namibia were produced in 2006-2007, in the context of a land reform programme, financed by the European Commission. These photos were taken during the dry season, which implies that they provide good possible reference data for flood assessment. Unfortunately, this coverage was not yet processed at the time of the flooding. Only tiles of 10 x 10 km^2 were digitally available. The PDNA field teams were provided by the DMS with copies of paper maps at a 1:250.000 and 1:50.000 scale. Especially where the latter is useful for "detailed field verification planning and comparison to satellite image based results" (PDNA/ The Government of the Republic of Namibia, 2009). Unfortunately, digital map data at 1:50.000 and ortho-photography tiles for the affected towns were not available.

At the time of the flood, the Statistical Office of the National Planning Commission was collecting updated GIS data sets and relevant, thematic -layers, such as agriculture, administrative boundaries and population, were made exclusively available to the PDNA team for sector specific analysis. Particularly in the north, these updated layers were useful as many changes have taken place since the 1996 ortho-photography. The latest update of the road network was made in 2008 and 2009 by means of GPS surveys. Altogether these data sets were used to plan field visits for damage and losses assessment in the education and health sector.

Moreover, the significance of satellite imagery is emphasized. For impact assessment, pre- and post-disaster imagery is useful to perform a comparative analysis. The shape, size and visual appearance of imagery depends on several variables; the sensor on board of the satellite and how the data was processed after reception. The report describes two types of satellite sensors which provided data during the flooding disaster in 2009; Visible and Near Infra-Red (VNIR), the most commonly used satellite sensor for situation assessment, and Synthetic Aperture Radar (SAR) data (see Table 3 for details). The availability of satellite imagery of the impacted area and required mapping scales in turn depend on the orbital characteristics of the satellite and the sensor that it is hosting. Relevant satellite data was attained at the time of the flooding disaster by the Government, triggering the International Charter “Space and Major Disasters”. A number of different sources were used for the creation of flood extent maps and were provided to the PDNA team. An example of such a flood extent map is shown in Figure 18. Several organisations were involved in the mediation process between agencies, provision of data and mapping procedures, such as UN-SPIDER, UNOSAT, NASA, the German Aerospace Centre (ZKI-DLR), and the JRC-EC.

Type of sensor:	Characteristic Details:
VNIR – Visible and Near Infra-Red	Electro-optical sensors, i.e. digital devices that register the reflected visual and near infrared part of the electromagnetic spectrum. For example QuickBird data.
SAR- Synthetic Aperture Radar	These sensors use microwave radiation to illuminate the scene and register the backscattered proportion that returns to the sensors antenna.

Table 3: Satellite sensor details

In summary, the PDNA team made extensive use of geospatial data sets and applications to support its activities. The importance of geospatial information, both foundation- as well as disaster related data, is widely acknowledged. There is awareness about some crucial issues identified for efficient and effective application: the availability and the quality of data sets. The latter refers to spatial detail, actuality and correctness. Also thematic maps were found to be highly useful for sector specific damage and losses assessment. Unfortunately, difficulties were encountered concerning the (digitally) availability of updated maps. In particular, satellite imagery was found highly useful for impact assessment, as pre- and post-disaster imagery is useful to perform a comparative analysis.

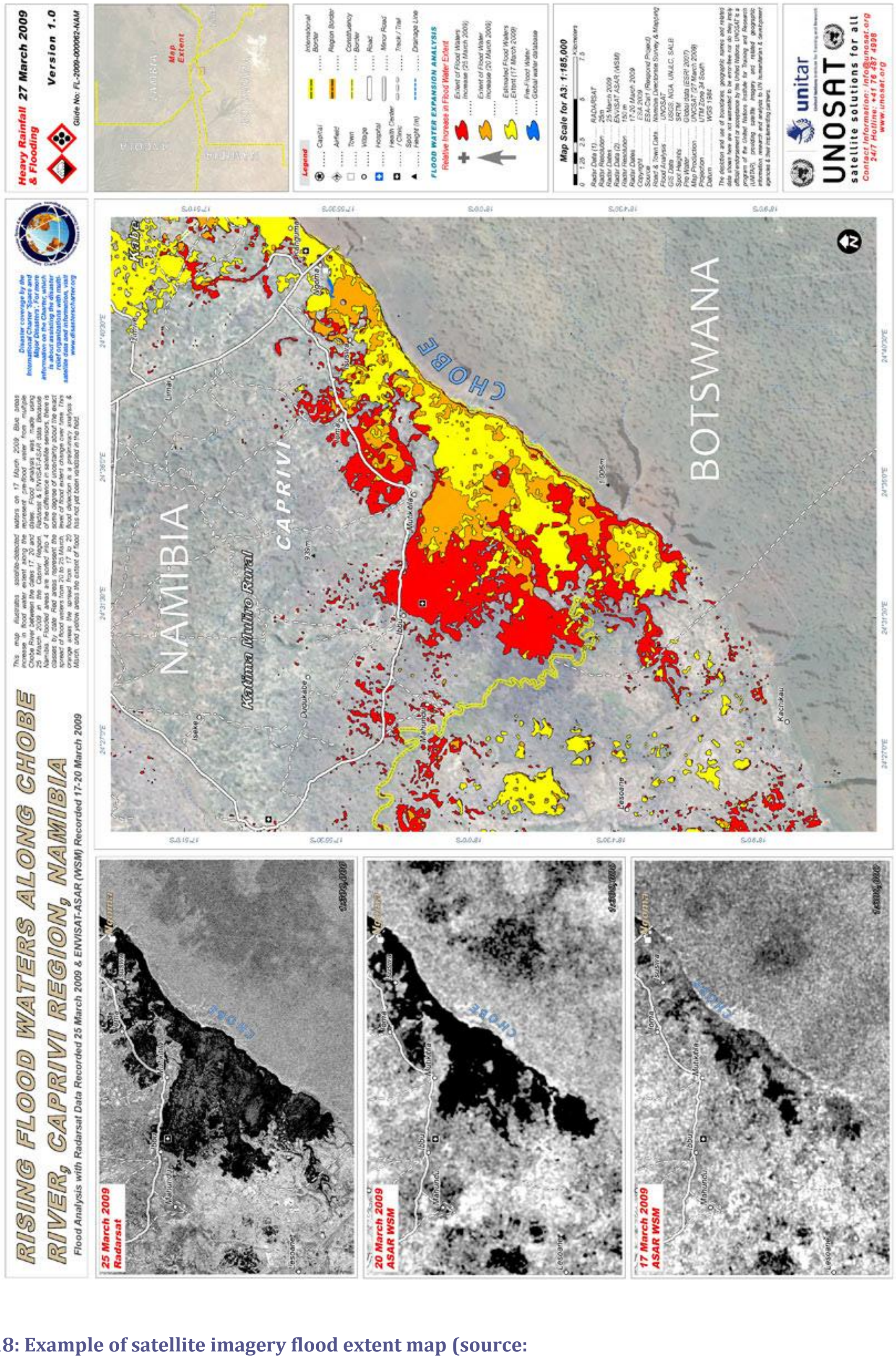

Figure 18: Example of satellite imagery flood extent map (source: http://www.disasterscharter.org/image/journal/article.jpg?img_id=32215&t=1273833015248)

4.2 Questionnaires

4.2.1 Assessment of 2009: Geo-information products used & EWS

Out of 14 received questionnaires, 6 indicate they had made actively use of geo-information products or had been involved with the creation of these products during the flooding event of 2009. The identified geo-information products used fall broadly into 5 categories: (1) satellite based flood maps, indicating the flood extent, (2) satellite based rainfall estimates and monitoring, (3) DEM, representing the terrains surface area, (4) base data such as administrative boundaries and normal water bodies, and (5) (hydrological) ground data (summarised in Table 4 see below). As this research aims for identifying the added value of the geospatial information, the impact (defined as how much the product improved decision making and resulting actions, compared to NOT having this type of product) per geo-information product was asked to assess. The respondents could answer on a scale ranging from 1 (low) to 5 (high). The options 0 (no impact) and X (I don't know) were also possible. Note that the number of respondents is small and that outliers are present in a small number.

The category most mentioned was the *satellite based flood maps*. The average impact is estimated to be 3.6 based on 9 valuations. This value is above average, therefore can be assumed that the satellite based flood maps contributed clearly to the decision making processes and resulting actions. Satellite based flood maps can be derived from high resolution optical, radar or thermal infrared satellite instruments. Also raw passive microwave remote sensing data lends itself for this purpose. The supported actions resulting from the flood maps are in the first place flood detection and mapping of the size and the extent of the flooding event. These maps can be used to raise awareness among the population of the size of the flood and support the first response efforts, such as evacuation of the population and assessments of basic needs in the affected areas. Furthermore, preliminary damage assessments can be made. Also, these flood maps can form reference points and/or boundaries for future flooding events and future mitigation measures can be based on these maps.

Based on the grouping of answers, the next category of geo-information products used is defined as *Satellite based rainfall estimates*. One of the applications mentioned by the participants is The Tropical Rainfall Measuring Mission (TRMM), which is a joint mission between NASA and the Japan Aerospace Exploration Agency (JAXA), that is designed to monitor and study tropical rainfall (website NASA, accessed at 21-09-2012). These rainfall monitoring's provide important input for hydrological models that may form early flood warning messages. The rainfall estimates are judged to have an impact of 4, based on 5 valuations. As the range goes from 1 – 5, this can be translated into a relatively high impact of the geo-information product on decision making, compared to NOT having this product available. The added value of this product may therefore be perceived to be relatively high.

There was one evaluation of using a DEM, which translates itself to Digital Elevation Model, indicating an impact of 2. The supported action related to this geo-information product is that it assists modelling of potential flooded areas. Furthermore it could be used for identification of low located high-risk zones.

In the category of base geospatial data are administrative boundary maps and a baseline water map to show differences, which is the flooded area. This category was valued 2 times, leading to an

average impact of 4. This is a relatively high impact of the geospatial information product, meaning the product is highly helpful during the decision making process and subsequent actions.
The category is here named ground data. These are measurements made on the ground in order to validate and calibrate other geo-information products, both models and satellite imagery. The average impact was valued to be 4.3, based on 3 respondents.

Geo-information product:	Average impact: *(1=low, 5=high)*	Supported action(s):
Satellite based flood maps (9)*	3.6	Flood detection, measurement of flood size/extent, support response efforts (including evacuation and basic needs supply), evaluate damages, reference for future events, raise public awareness and mitigation measures
Satellite based rainfall estimates (5)	4	Early warning purposes, preparation for disaster managers for upcoming event, Estimates of which areas are flooded.
DEM (1)	2	Assist modeling of potential flood-affected areas
Baseline: Administrative boundaries or pre-flood water bodies extent (2)	4	Important for production of accurate maps, estimate affected population
(Hydrological) ground data (3)	4.3	Calibration and validation of modeled estimates of water levels and verification of satellite imagery

Table 4: Geo-information products used and evaluation of impact and supported actions

Concerning the evaluation of the early warning system in 2009, at the time of the flood, 13 out of the 14 respondents indicated what in their opinion caused the ineffective response after the early warning provided in 2009. In the category "other" respondents indicated factors such as:

- "Local communities not taking warnings and calls of authorities seriously, referring back to historical likeliness of disasters happening."
- "Due to low interpretation ability by those responsible to act."
- "Understanding of warning, response plans not adequate or not activated."
- The absence of reliable data in the upper catchments of Kunene / Cuvelai - Etosha and Kavango was a major cause of retarded response.
- "Timely decision-making" and although there were warning and monitoring messages coming from the Department of Hydrology both through emails and sms at national level, "At a local level, it seems this information is usually not circulated."

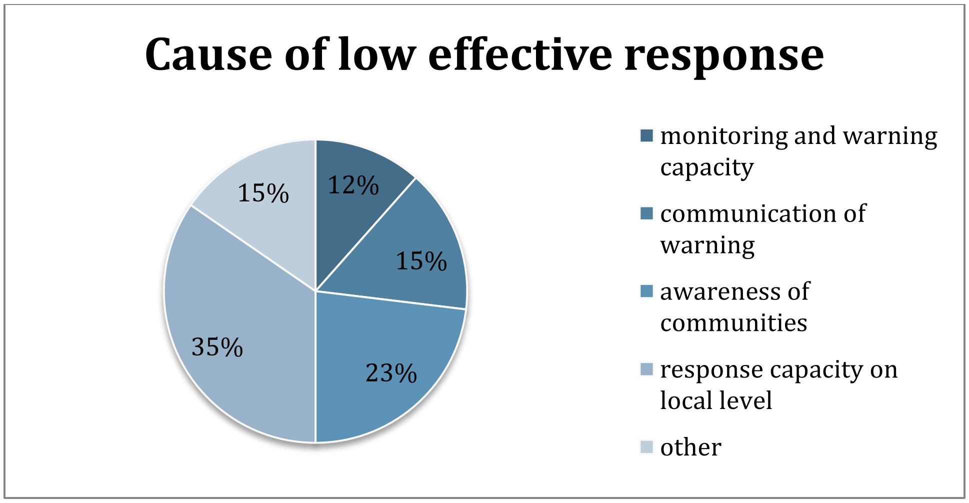

Figure 19: Cause of low effective response after early warning in 2009

4.2.2 Improvements of geo-information value & identifying needs

This section discusses the findings on how participants indicated the early warning system had improved, if at all, since the flooding in 2009. Furthermore, the needs and recommendations of the participants regarding the early warning system are discussed.

Firstly, the participants were asked to discuss in their own words if, and if so in what way, the early warning system has improved since the flooding event of 2009. Of the 13 respondents who answered this section, all replied unanimously that the early warning system has improved. The sources of improvement can be categorised into the following groups:

1.) Communication

The biggest source of improvement can be found regarding the communication of the warning, according to 8 of the respondents. Due to the efforts of the Department of Hydrology, a daily flood bulletin is delivered to approximately 200 people, with updates on the water levels of the major and crucial rivers at different sites. Early warning messages are thereby better communicated. Furthermore it was indicated that the telemetry network has improved and that the local radio is used to announce flood information.

2.) Awareness, understanding & reliance

In line with the communication of the warning, respondents also indicate that the awareness of the population regarding flooding events has improved and that there is increased understanding of the early warning messages. Furthermore, one of the respondents articulated that "stakeholders are now using satellite images maps for their planning purposes compared to previously". This implies that flood risk is increasingly taken into consideration. Also, there is more reliance in the early warning system, which ultimately increases the effectiveness of an early warning.

3.) International cooperation

Following from the flooding events in 2009, international actors (space agencies) were involved to support Namibia, after UN-SPIDER got involved in 2008. The World Bank, JRC-EC, Dartmouth Flood Observatory (DFO), NASA, ESA, NSPO etc. were able to provide their (space based) resources for supporting early warning and mapping efforts. This resulted in a higher availability of more accurate geo-information products for early warning and flood response coordination. This better contact with space agencies leads to better knowledge of what products and services are available.

4.) Monitoring & forecasting

Due to increased international cooperation, better monitoring and forecasting is possible based on satellite imagery. This may serve as input for flood modelling. Furthermore the satellites images “helped identifying upstream events in Angola since Angola doesn’t have any river gauges or rain gauges for monitoring upstream levels”. Additionally, more monitoring stations are present in the field.

5.) Internal capacity

The internal capacity for flood mapping of the Hydrological department has improved.

Two of the respondents identified challenges with the material available, as one of the respondents mentions that the monitoring stations are vandalised.

Additionally, participants were asked to indicate on a scale from 1 to 5 how they assessed the following four aspects needed for the effective application of an early warning system. This with as main purpose to study in more detail *what aspects* has improved of the early warning system and furthermore to validate the answers of the former question.
1.) The awareness of the communities to flood risk?
2.) The response capacity on a local level?
3.) The monitoring and warning capacity?
4.) The dissemination and communication of the warning?
Of the 14 responders, 9 provided numbers for all the categories, pre flood and at present. 3 delivered a partial fill in due to the fact that they felt they could not judge the local situation from a distance or because they felt only the current situation could be judged from their perspective. From the graph below it can be seen that all four aspects have increased and therefore it can be assumed that the early warning system also has increased.

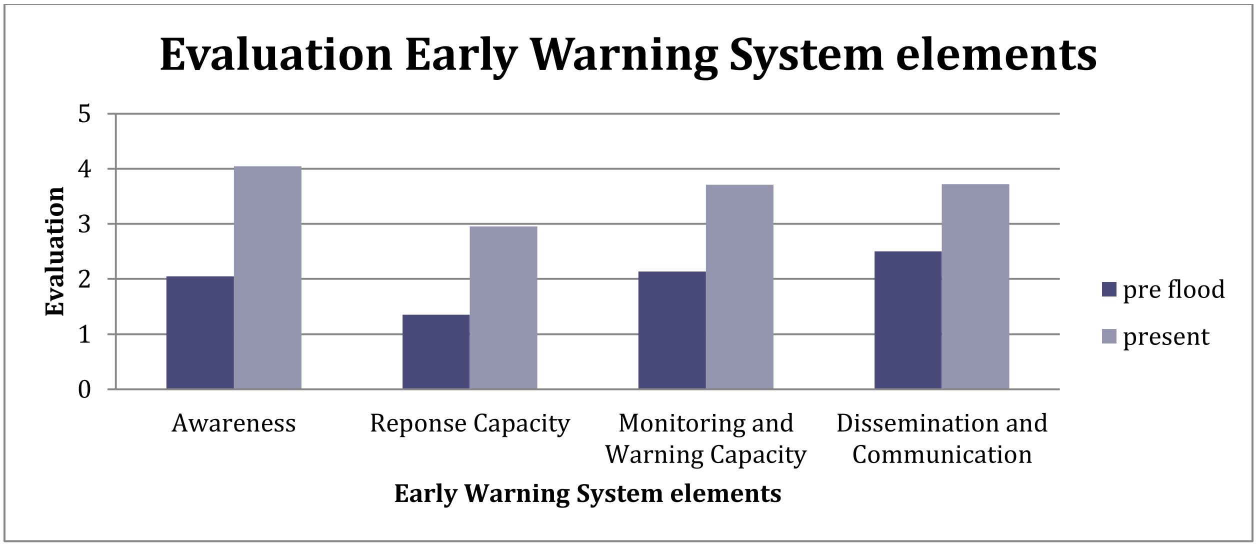

Table 5: Evaluation of different early warning system elements

Concerning the future developments the respondents wanted to see, 11 out of 14 respondents provided their input. Again, categories were assigned to streamline the received data resulting in the following groups:

1.) Communication

Two respondents indicated that it would be helpful to develop coloured maps for certain "zones" indicating flood risk and/or danger. This would clearly indicate the areas for the communities and thereby enhance early warning communication.

Furthermore two of the respondents mentioned that the access to and the dissemination of information can still be improved. One proposed the media could help with informing the people. Another respondent indicated the needs for crowdsourcing by local experts, to correct water extent maps for both normal water levels as well as during various flood stages. Crowd sourcing already proved promising in other disaster relief situations, such as the mapping efforts subsequent of the Haiti earthquake (Zook, Graham, Shelton, & Gorman, 2010).

2.) Resources

In this category the needs for resources such as materials and data are discussed. The requirements of the respondents in terms of material are rain gauges, river gauges, monitoring stations or human resources for disaster management. Not only new, but also an update for the current existing materials was indicated.
In terms of (geospatial) data resources, two respondents indicated the need for a high resolution DEM. This could be applied for flood modelling. This would make the models more accurate. Due to a higher accuracy, the communities have greater reason to trust them and will be more willing to act on them. In general "accurate and high-resolution, freely-available datasets are crucial". Also more detailed population data is desirable as this allows for better evacuation plans, damage

assessment and disaster management in general. As data forms input for several modelling purposes, this naturally leads to the next group concerning modelling needs.

3.) Modelling

As 3 respondents indicated, there is a need for further development of models. They should be "more accurately predicting the timing of the arrival of the flood wave, in addition to the magnitude of the flooding". Also, there is a need for a flood forecasting model that is based on TRMM rainfall. Another respondent mentioned the need for "improved modelling applications tailored to the specific conditions in Namibia".

4.2.3 Experimental 'Cost Avoidance Approach'

Out of the 14 respondents, 8 were able to fill in the economic valuation part. Five gave a range as was asked for, where 3 gave their average estimate. In order to combine and analyse all 8, the choice has been made to work with the average estimates and provide the average range per category, of the 5, with it. The averages are displayed as the blue bars (see Table 6), where the average range per category is displayed as the thin black lines on either side of the maximum point of the blue bars. Again, note that the number of respondents is small and that outliers are present in a small number. This experimental approach serves as an illustration of how this type of study can be performed and aims to provide building blocks for future research. The choice has been made to round up the percentages at whole numbers, as these numbers form estimates that give an indication of the order of magnitude instead of a precise final number. This being said, the results indicate the following.

In total 102 persons lost their lives due to the flood. The percentage that could have been saved, had there been an effective early warning system was estimated to be 57%, with an average range of 33%. This was the largest range to be discovered among the different categories. The cross-sectoral category, covering the environment, was estimated on 55%, with an average range of 17%. The social sector had most to gain from an effective early warning system, namely 58%, with an average range of 25%. The productive sector was estimated on 41% of the damages and losses that could have been avoided, with an average range of 18%. The sector infrastructure was estimated to have the lowest gains, namely 35%, with an average range of 33%. Summarising, the respondents indicate they feel that most gains of the effective application of an early warning system are to be expected in the social sector, closely followed by the number of human lives lost in the flood. The range provided by participants was largest in the category number of lives lost, indicating there is much uncertainty in providing an estimate.

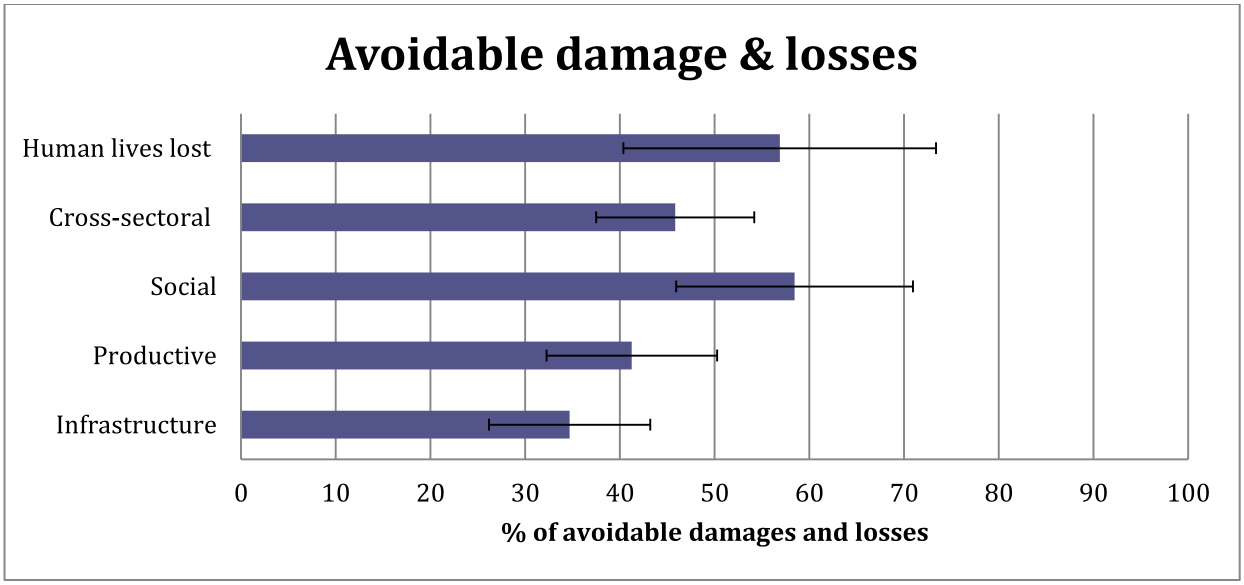

Table 6: Avoidable damage & losses in percentages per economic sector. The thick blue bars indicate the average, where the thin black lines indicate the average *range* given in answers.

When coupling the average percentage numbers to the actual occurred damage and losses monetary figures, this leads to data as presented in Table 7. The choice has been made to adopt the same amount of decimals after the comma as the PDNA report uses, namely one. Note that the US$ currency rate is from the year 2009. The highest amount of money to be saved, according this approach, can be found in the productive sector ($US 50,1), followed by the social sector ($US 31,3). Damages and losses that could have been avoided in the infrastructure sector are estimate to be $US 13,6. The cross-sectoral is said to be at $US 0,6. In total the four sectors add up to a sum of $US 95,54, that could have been avoided had there been an effective early warning system.

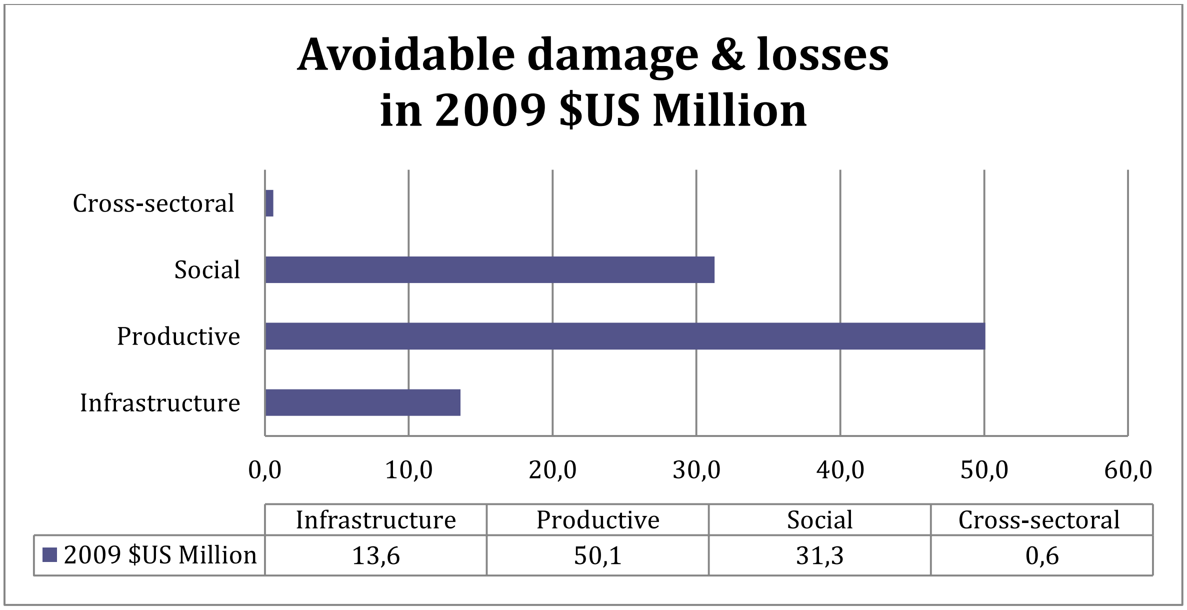

Table 7: Avoidable damage & losses in 2009 $US Million

The economic valuation of a human life is a sensitive topic. Many studies discuss the issue that some perceive a human life to be *invaluable* (World Bank/ United Nations, 2010; Zweifel, Breyer, & Kifmann, 2009). Nevertheless, not taking the economic value of a human life into account leads to a lower (economic) damage, which in turn leads to an incomplete analysis when considering all costs and benefits of a disaster (Jonkman, Van Gelder, & Vrijling, 2003; World Bank/ United Nations, 2010; Zweifel et al., 2009). The value of a human life is unsurprisingly a 'hot topic', with several different approaches and subsequent estimates that are widespread. Lives lost are generally expressed in economic terms that represent the lost productivity that is typically foregone when a life is ended (PWC, 2006). There are many factors influencing the value of a human life such that it may vary across countries (Miller, 2000) or according to the age of the diseased (Aldy & Viscusi, 2008). A meta-analysis of Mrozek & Taylor (2002), based on a quantitative analysis of the available literature on the value of a statistical life, estimated that the value ranges substantially from less than $100.000 up to more than $25 million per life (currency anno 1995). Evidently, the value chosen will affect the estimates *greatly*. An extensive analysis of what would be an appropriate value in this particular case is beyond the scope of this research. If one would like to include an economic value for a human life, this study recommends to adopt the approach applied in the analysis of the PWC (2006) Global Monitoring for Environmental Security (GMES) programme Benefits and Impacts Report, as this value is used with the- same purpose as this study aims for: "relating a statistical value of life of €200.000 (Fankhauser, 1995)[1] to the mortalities projected to be avoided through the application of GMES". This value needs to be corrected for currency and

[1] Fankhauser, S. (1995). *Valuing climate change, the economics of the greenhouse.* Earthscan Publications Limited, London, suggests a value of life of €200,000 (1995 prices). Inflated to 2005 prices using the prevailing rate of inflation throughout Europe during the period 1995 through 2005 (an average of 2.56% per annum) this equates to €251,200. Assuming average life expectancy of 48.0 years throughout Africa (source: World Bank, BBC News (2002), 'Life Expectancy in Africa Still Falling', 11 February') this equates to €5,230 per DALY

year, before it is multiplied by the number of mortalities to be expected according to the respondents of the questionnaire.

This number should be added to the sum of the four sectors to get the complete benefits. Based on the assumptions made, this number represents the benefits of geospatial information in disaster and risk management for this particular case study. The number and associated costs of injuries that could have been avoided is beyond the scope of this case study and not included in the analysis.

Note: This study aims at illustrating the possibility of measuring the added value of geospatial information in disaster and risk management by applying a 'Cost Avoidance Approach' in the particular manner explained in this thesis. However, a *comprehensive execution* of this analysis, which would involve more detailed assumptions and mathematical steps, is beyond the scope of this research and not the purpose of this study. Therefore, this section only provides an illustration of the necessary steps to be taken for the measurement process, and not a conclusive monetary figure for the added value of geospatial information in this Namibian case study.

4.3 Summary

The latter two sections have contributed to an overview of the use and valuation of geospatial information in the context of the Namibia flooding disaster in 2009, by including a PDNA report as well as a questionnaire designed for this specific case study. This analytical framework, with appropriate amendments to the questionnaire in order to suit the specific case study, can be applied to other cases in future research aiming for the economic measurement of geospatial information in a disaster. The ultimate goal of including these two research approaches is to provide an extensive review of the case where both information sources complement each other in shaping our understanding of the flooding disaster and the associated use and valuation of geospatial information. This section provides a summary of the main findings of the PDNA review and the questionnaire findings.

The review of the PDNA disclosed the use and potentials of geospatial information in twofold, namely: (i) the PDNA team *applied* geospatial information for its activities to gather information and to write the report; (ii) the PDNA team *formulates* needs and recommendations referring to the potentials geospatial information for this flooding type of disaster, especially regarding its applications for the strengthening of risk assessment.

First, overall the PDNA showed that:

- There is awareness of the opportunities geospatial information offers for the relief activities of the PDNA team to assess damage and losses and identify needs for early-, medium- and long-term recovery
- The importance of both foundation as well as disaster related datasets, is widely acknowledged
- Some crucial issues are identified for efficient and effective application: the availability of data sets and the quality, referring to spatial detail, actuality and correctness.
- Satellite imagery was found highly useful for impact assessment, as pre- and post-disaster

imagery is useful to perform a comparative analysis
- Unfortunately, one major difficulty of the PDNA team was the (digital) availability of updated maps

Secondly, the recommendations regarding the strengthening of risk assessment, applications of geospatial information are clearly formulated. Four options are discussed that require geospatial input:

- Climate variability and hazard mapping
- Participatory flood risk mapping
- Linking data for hazard monitoring and response
- A stronger early warning system and response

Summarising the questionnaire results, the following main findings can be distilled:

(i) The experimental 'Cost Avoidance Approach' illustrated a systematic manner for the measurement of the added value of geospatial information in the flooding of the Namibian case study. The illustration of this method can be seen as the most important finding of the Namibian case study. This approach has great potential for future research aiming at the measurement of the added value of a geospatial information product in disaster and risk management. One can alter the framework of this approach accordingly to a different kind of geo-information product one would like to value. Theoretically, when the potentials of a geo-information product promises to be high, damage and losses figures are present, and stakeholders are available for questioning, one can apply this framework to other disaster cases and support future research on the valuation of geospatial information in disaster and risk management.

(ii) The geo-information products identified by the respondents that were used at the time of the Namibia flooding in 2009 were grouped into five categories, of which all, accept for the DEM, were estimated to have a higher than average impact on decision making processes related to the flooding, compared to NOT having this geo-information product available.

(iii) The low level of response to the early warning message in 2009 can be subscribed to the low response capacity at a local level (35% of respondents) followed by the awareness of communities (23%). Other options were communication of warning (15%), other (15%) and monitoring and warning capacity (12%).

(iv) Sources of improvement of the early warning system since 2009 have been the improved communication, especially the flood bulletin correspondence on water level updates is highly appreciated. Furthermore, the awareness, understanding and reliance of communities regarding the system have improved. Also international cooperation, monitoring and forecasting and increased internal capacity have been identified as sources of improvement.

(v) All elements of an effective early warning system (awareness, response capacity, monitoring and warning capacity and dissemination and communication) are said to have improved since the 2009 flooding disaster compared to the current situation anno 2012.

(vi) Finally, respondents also indicated what future developments they would like to see for the early warning system, which boils down to: further improved communication, more resources and exploration of improved modelling capabilities.

As noted before, the PDNA review and the questionnaire findings, both reinforce as well as complement each other. One major point of replenishment of the two information sources is that the questionnaire addressed thoroughly the value of the early warning system. First, the causes of the low level of response following the early warning message delivered in 2009 are identified, including; response capacity, followed by community awareness. By understanding the errors that occurred, future developments for improved response can be better targeted and suitable recommendations can be made. Also, the questionnaire goes into more detail of the different aspects that, in combination, are required for an effective early warning system and how these are evaluated. The analysis showed that all four aspects are valued higher in the current situation than at the time of the flooding. Therefore, it can be assumed that also the early warning system as a whole has developed positively since the flooding in 2009. Furthermore, the PDNA delivers substantial input on damage and losses figures required for the experimental 'Cost Avoidance Approach'. These figures are crucial for the development of the 'Cost Avoidance Approach' on how to measure the added value of geospatial information. Another point of enrichment by combing both sources is that the PDNA was written closely three months after the flooding disaster. The questionnaire was proposed three *years* later which offered more time for reflection as well as insight on what developments have taken place since the disaster in 2009. Improvements of the early warning system have been identified that were denoted by the PDNA such as the intensification of available resources for river monitoring purposes. Nevertheless, the questionnaire also highlighted early warning system issues that still need attention such as; further improvements of communication of the warning message in several ways (e.g. including coloured maps with risk zones) and further exploration and implementation of modelling capabilities for flood forecasting.

5. Discussion, Conclusions and Recommendations

This research has studied the value of geospatial information in disaster and risk management. In this chapter, first the issues that that arose during the execution of this research will be discussed. Then the main findings regarding the four research questions will be summarised. Finally recommendations for future research will be made in light of the experiences and lessons of this study.

5.1.Discussion

Two main problems were encountered when implementing the questionnaire for this study; (1) a relatively low response rate and (2) participants indicated they experienced difficulties answering the assessment questions concerning the 'Cost Avoidance Approach'. Regarding the low respondent rate, reasons could be the long distance and thereby the digital distribution of the questionnaires by email or the fact that there was an intermediary person involved in part of the distribution. In retrospect, this could not have been done differently. Unfortunately, at the time there were no resources available to perform the research in situ, which would have been the most preferable option. Furthermore, concerning the low response rate, the head of the Namibian Hydrology Department indicated that it should have been made more clearly to the participants at a local level why their cooperation was needed and what they personally had to gain by participating. This was not the first study on the flooding events in Namibia and locals pointed out to be 'fatigues' regarding flood studies. Especially considering that another major flooding event occurred in 2011, that exceeded the impact of the flood in 2009 in terms of deaths, number of affected people and economic damage costs (EM-DAT, 2012). This may have resulted in the flood of 2009 being less prevalent on the respondents mind, potentially making them less eager to respond to the questionnaire.

Regarding the second problem of participants experiencing difficulty in answering the 'Cost Avoidance Approach' questions, reasons provided were that participants did not find themselves to be qualified or informed enough to provide answers. In addition, the scenario of a 10 days in advance warning and the research approach were criticized as unrealistic. Concerning the 10 days in advance warning, one should note that this is only the case when flooding situations occur due to high intensity rainfall events far upstream, which were responsible for a considerable part of the flooding in 2009. Flash floods are not accounted for by this methodology.

This 10 days in advance notice scenario may be further criticized, in retrospect, as 10 days is a very long time to prepare for a flooding event. In terms of saving lives, one may wonder whether 10 days is likely to save more lives than 1-3 days (depending on the speed of the warning, accessibility of the location and other factors). In retrospect hindsight, this warning time could have been reduced. This would both have lowered the scepticism of the participants towards the representativeness of the scenario as well as increasing the reliability of the warning using more up to date data, lowering the possibility of false alarms which may lead to lower response to future early warnings. There is also another reason for the suggestions of lowering the number of days before the onset of the flooding, as there is only a maximum amount of damage that can be prevented. This has been shown by Day, (1970), who describes what is now known as the Day-curve for flood damages

(Figure 20). As is shown, the image depicts the relationship between the warning time and the percentage damage reduction that can be acquired. Note that this only refers to the *tangible* benefits of the warning system. The Day curve suggests that there is a maximum possible reduction of 35%, no matter how great the warning time (Carsell, Pingel, Asce, & Ford, 2004). The smoothening of the curve towards a maximum is furthermore confirmed by Penning-Rowsell et al. (2003) showing the same trend for different inundations depths (see Figure 21). Thereafter this master thesis recommends to set a maximum amount of percentage the participants feel that can be saved, in order to eliminate outliers above the percentage that is actually found to be feasible. This maximum amount should however be determined according to local conditions and this study does not recommend a static value of this maximum percentage.

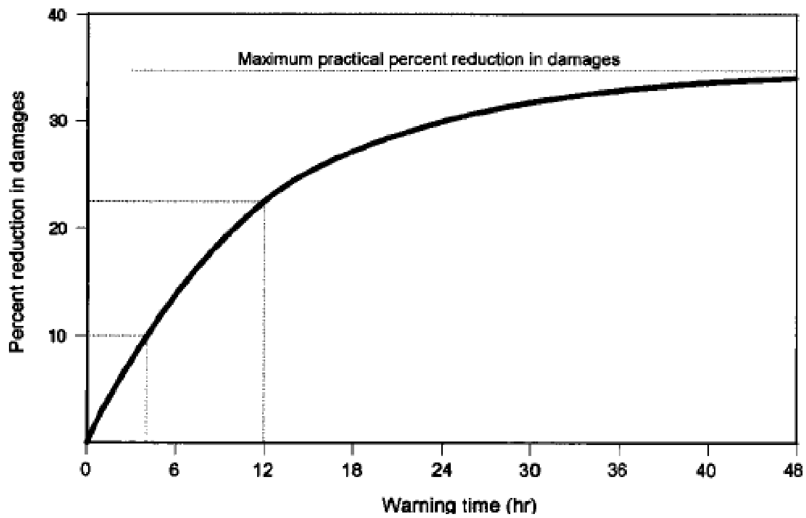

Figure 20: Day - curve: Percentage reduction in damage to be acquired in relation to the warning time (hr) (Carsell et al., 2004)

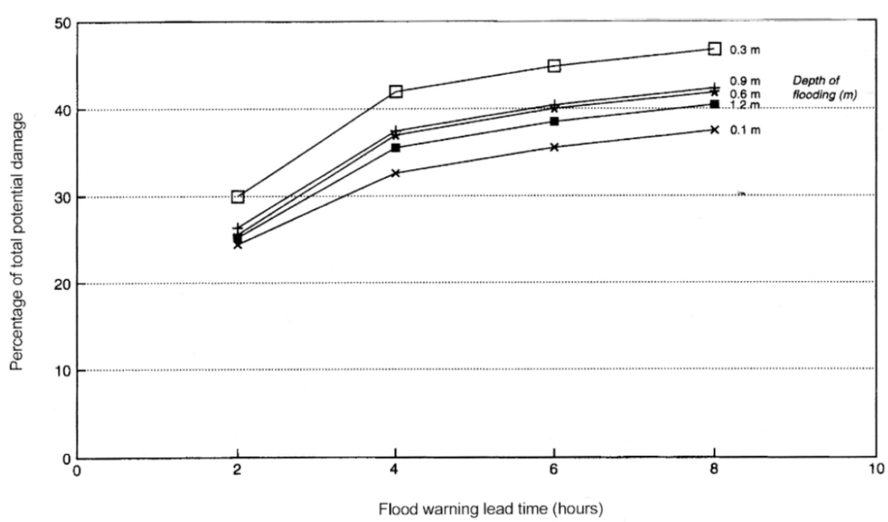

Figure 21: Impact of flood warning lead time on flood damages (Ch. 3: Penning-Roswell et al, 2003)

Also, the 'Cost Avoidance Approach' proposed only includes the *tangible* damages and losses that an effective early warning system could have avoided had it been in place. There is no inclusion of intangible damages that a flooding event may incur, such as stress, family destruction or health effects on those that have survived (Carsell et al., 2004). Translating these intangible effects to an economic value and adding them to the tangible damage and losses would likely further increase the value of the EWS considered.

Following the low response encountered during the execution of the questionnaire one may argue that the monetary findings of the value of the EWS based on this 'Cost Avoidance Approach' are not scientifically grounded. Due to this low number that completed the 'Cost Avoidance Approach', the results are sensitive to outliers which could distort the true average values. The larger the number of responses, the more stable and significant the answers become. Therefore, this study does not claim to have found a 'final' or 'concluding' monetary figure of the value of geospatial information. This study aims to provide insight on the methodology proposed and illustrate the steps that need to be taken if one would like to execute this research for another case study.

Another important aspect that influences the outcome of this final figure is the value one choses a life is worth in economic terms. Estimate ranges are large and the number chosen is likely to have a great impact, or even determinative effect, upon the end monetary value of the geospatial product evaluated. This study chooses not to adopt one particular value, but illustrates how large the estimates range is, showing that the inclusion of this 'value of life' would affect the outcome greatly.

Notwithstanding the low level of responses, the results of the *qualitative part* has added much scientific value to this research. Together with testing the 'Cost Avoidance Approach', this research took the opportunity of digging deeper into the causes and specific circumstances of the Namibian flooding event. Additionally, opportunities for further improvement of the early warning system and geospatial information were studied. Because part of the questions were open-ended and participants had much room to elaborate on the topics studied, the word "questionnaire" may in this case not totally cover the load of the actual obtained results. A better choice of words would be in this case "interviews".

Another line of improvement of the results would be to translate this 'questionnaire' template further into an actual 'interview' template. By asking and discussing the questions face to face with the participants, one can extract much more information on the topic. Information may get lost along the way when the questionnaire is distributed per email. This issue will be further discussed in the section 'recommendations' for further research.

Finally, the largest benefit of the 'Cost Avoidance Approach' applied in this study is that it is relatively easy to apply. Basically, the only thing a researcher needs for analysis are the damage and losses figures and a group of participants found feasible for questioning. The downside, however, remains that the results from the 'Cost Avoidance Approach' are still estimates that are assessed based on a expert-based feeling rather than a calculation of facts. Future research on this approach should therefore aim at making the monetary figure on the benefits more precise and empirical evidence based. Obtaining statistical significance would be the first step towards that goal. The

‘Willingness To Pay’ approach, which is the other main valuation method for Early Warning Systems, deals with the same difficulties regarding the errors in estimations. Nevertheless, with the ‘Cost Avoidance Approach it is possible to provide a *percentage*, instead of an exact monetary figure. Therefore the participants potentially experience less stress as they only have to provide an order of magnitude instead of an exact amount of money, which is even more difficult to assess. Furthermore, this ‘Cost Avoidance Approach’ offers a great opportunity for *relative comparison* between the benefits of several different geo-information products. When there is a certain amount of money available and a decision maker wants to invest in the geo-information with highest benefits for DRM, then this ‘Cost Avoidance Approach can be applied to compare the benefits of different geo-information products for the same case study. The geo-information product that has the highest benefits can then be selected. In this case, the benefits of a certain geo-information product have a relative meaning instead of representing the absolute final economic figure on the benefits.

5.2.Conclusions

The aim of this research is to assess the value of geospatial information in disaster and risk management. The choice has been made to adopt a geospatial information product, early warning systems (EWS), to make the concept more tangible. Additionally, a flooding disaster case study was selected to test and illustrate a ‘Cost Avoidance Approach’ as a tool for valuing a geo-information product. The Namibian flooding event from 2009 were found to be a suitable case as there is large potential for an EWS to be successful in reducing damages and losses. As a co-product of testing this ‘Cost Avoidance Approach’, also qualitative case study topics were studied. The causes of the relatively low level of response of the communities to the early warning in 2009 was studied, together with the geo-information products used during the 2009 flood, the improvements made since 2009 and what future developments the participants would like to see in the EWS.

The research questions of this research were as follows and will be answered briefly below.

- **How are geo-information and Disaster and Risk Management connected?**

Geo-information is information that is tied to a location and serves DRM in many ways. Disasters are dynamic and geospatially dependent in nature, which makes geospatial information a vital tool for managing them. Early warning systems are chosen as the geo-information *product* evaluated by this study, as this is seen as a potential source of damage reduction. Geo-information is assumed to form vital input for the application of an effective early warning system as geo-information plays a significant role in risk knowledge and the detection of a hazard.

- **How does geo-information aids to Disaster and Risk Management practises?**

Geospatial information adds knowledge and understanding of the disaster to DRM practices. Geospatial information generates value by influencing or altering the decision making process in a positive manner compared to a situation of not having this geo-information. It creates value as it may increase both the quality of a decision as well as the speed of the decision making process. When a better decision is made, regarding for example the evacuation of people, this may lead to lower or even (most preferable) no mortalities. When the impact resulting from improved decisions due to the application of geospatial information can be economically assessed, compared to a situation *without* this particular information, the benefits of geospatial information arise.

- **How can the added value of geo-information in Disaster and Risk Management be measured?**

To answer this research question, a case study was adopted and thereby theory was pragmatically studied. The choice was made to adopt a geo-information product to make the concept of geospatial information tangible. The Namibian flooding event from 2009 was found suitable for many reasons to study the added value of an early warning system. A questionnaire was designed and distributed, containing a quantitative part: aiming to assess the economical contribution an early warning system would have; and a qualitative part studying case specific elements of the flood with the aim of answering the fourth research question. A 'Cost Avoidance Approach' was chosen and developed matching local circumstances, to capture the economic benefits of one particular geo-information product; an early warning system. Participants were asked to assess what percentage damage and losses could have been avoided in their opinion had there been an effective early warning system providing a 10 days warning time. This question was asked for four different sectors (infrastructure, productive, social and cross-sectoral) which coincided with available *actually occurred* damages and losses figures from the flood in 2009. Also, this question was asked for the percentage of lives that could have been saved. Despite the fact that there was not enough response for the results to be statistically significant, the results of the questionnaire illustrate this method is feasible and promising for future research on the valuation of geospatial information. Note that if one would like to assess the added value, one should also include the *costs* of this early warning system. The 'Cost Avoidance Approach' proposed in this study assesses the *benefits*.

- **How can the value of geo-information in Disaster and Risk Management be improved?**

This research question addresses the options for improvements regarding geo-information in DRM in the Namibian case study, and thereby the added value it may contribute in the future. It is important to note that improvements regarding geo-information are not only referring to introducing or improving the geo-information product itself, but also *how this product is used and applied* in DRM. The Post Damage Needs Assessment (PDNA) report review and the questionnaire results have together provided answers to this end.

In general, the PDNA has revealed four opportunities regarding the usage of geospatial information in this case study namely further improvements of: climate variability and hazard mapping, flood risk mapping, hazard monitoring and response and a stronger EWS and response. The questionnaire developed for this study has focussed on the EWS in particular. As the flood in Namibia occurred in 2009 it is primarily important to study what improvements have taken place since 2009 concerning the EWS, before formulating further options for the improvements of this geo-information product in DRM. The participants indicated that overall the EWS as a whole has improved, based on the evaluation of different elements of an effective EWS. Communications were said to have improved the most, especially the introduction of a 'flood bulletin' mailing list was highly appreciated. Also the awareness, understanding and reliance in the EWS of communities have improved. Other sources of improvements were noted such as international cooperation, monitoring and forecasting, and increased internal capacity. The future developments the participants indicated that would increase the value of the EWS in DRM were: (1) further improved communication. One suggestions regarding the EWS element "risk awareness" formulated by the participants were coloured risk maps. This could contribute to a very clear understanding of differing flood risks in different areas. Also, (2) more resources in terms of monitoring equipment and data that would enable EWS activities, such as a detailed DEM map were discussed. Last, improved modelling capabilities that enable flood forecasting were indicated as a potential source of improvement.

Concluding, this methodology has high potential to serve future research as it provides a systematic manner of identifying the economic value of a specific geospatial information product. This section has formulated recommendations to serve future development of this proposed valuation methodology, in response to the problems encountered during the execution of this research. In a later stage of this line of research, the experimental design of this questionnaire can be altered accordingly to other geospatial information products that assist in minimizing losses and damages of other disaster types and during other stages of the DRM cycle.

5.3.Recommendations

The recommendations provided in this section all relate to the questionnaire as this is seen as the main product of this study. One of the main recommendations to improve future research would be to conduct the questionnaires in situ through in-person interviews. This would have multiple benefits:

- Multiple contact moments can then be initiated (individually or group sessions) with the selected participants. More detailed information can then be provided regarding the purpose of the study and why their contribution is important.
- Generally, this would lead to more information for the research, as some information may get lost when people don't feel like typing their answers to a person they have never met. Also this would reduce misinterpretations, by either the researchers and/or responders, which may occur more easily when the answers are written down.
- There is more time to explain the scenario of the 'Cost Avoidance Approach', lowering the feeling of the participants that they are not "informed enough" to answer the questions.
- There is opportunity to gather more background knowledge on the disaster itself, including subsequent damage and losses.
- Performing the research in situ is also likely to increase the response rate to the questionnaire

Related to the methodology there are two main recommendations that arise. First, on the issue of a non-realistic scenario, more research is needed before proposing the scenario to the participants. When there is more research regarding the feasibilities of techniques serving DRM beforehand, the assumptions will be strengthened and a more grounded scenario can be developed. Especially the warning time should be considered carefully as this may also trigger scepticism towards the rest of the research method. Altogether this will also reduce the feelings some participants experienced not to be “qualified” or “informed” enough.

Ultimately, more research is needed for testing this ‘Cost Avoidance Approach’ in other case studies in order to obtain statistical significance of the results to put an economic value on a specific geo-information product. It would be interesting to study different geo-information products and then ultimately compare the added value, in order to justify investments in the geo-information products that obtain the highest added value to DRM practices.

6. References

Alberts, D. S., Garstka, J. J., Hayes, R. E., & Signori, D. A. (2001). *Understanding Information Age Warfare*. CCRP.

Aldy, J. E., & Viscusi, W. K. (2008). Adjusting the Value of a Statistical Life for Age and Cohort Effects. *The Review of Economics and Statistics*, *90*(3), 573–581.

Alfieri, L., Salamon, P., Pappenberger, F., Wetterhall, F., & Thielen, J. (2012). Operational early warning systems for water-related hazards in Europe. *Environmental Science & Policy*, *21*, 35–49. doi:10.1016/j.envsci.2012.01.008

Altan, O., Backhaus, R., Boccardo, P., & Zlatanova, S. (2010). *Geoinformation for Disaster and Risk Management Examples and Best Practices* (p. 142). Joint Board of Geospatial Information Societies (JB GIS); United Nations Office for Outer Space Affairs (UNOOSA).

Asante, K. O., Verdin, J. P., Crane, M. P., & Tokar, S. A. (2006). The Role of Spatial Data Infrastructure in the Management of Natural Disasters, (December 2004), 6–10.

Babbie, E. (2007). *The Practice of Social Research* (Eleventh E., p. 511). Thomson Wadsworth.

Borkulo, E. Van, Scholten, H. J., Zlatanova, S., & Brink, A. Van Den. (2005). Decision Making in Response and Relief Phases. *Paper for the Geo-information 4 Disaster Management Conference, 21-23March 2005, Delft Technical University.*

Carsell, K. M., Pingel, N. D., Asce, M., & Ford, D. T. (2004). Quantifying the Benefit of a Flood Warning System, (August).

Chang Seng, D. (2010). *Disaster Risk Preparedness - The Role of Risk Governance; Multi-Institutional Arrangements and Polycentric Frameworks for a Resilient Tsunami Early Warning System in Indonesia*.

Creswell, J. W. (2009). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (Third Edit., p. 260). SAGE.

Day, H. J. (1970). *Flood warning benefit evaluation- Susquehanna River Basin (urban residences)* (p. 42). Silver Spring, Md. : Weather Bureau, Office of Hydrology.

De Groeve, T. (2010). Flood monitoring and mapping using passive microwave remote sensing in Namibia. *Geomatics, Natural Hazards and Risk*, *1*(1), 19–35. doi:10.1080/19475701003648085

Diamond, P. A., & Hausman, J. A. (1994). Contingent Valuation : Is Some Number Better than No Number ? *American Economic Association*, *8*(4), 45–64.

EM-DAT. (2012). EM-DAT online database. Retrieved December 11, 2012, from http://www.emdat.be/result-country-profile

FEMA. (1998). Introduction to mitigation, independent study course.

Flick, U. (2002). *An Introduction to Qualitative Research* (Second Edi., p. 310). SAGE.

Fritz, S., Scholes, R. J., Obersteiner, M., Bouma, J., & Reyers, B. (2008). A Conceptual Framework for Assessing the Benefits of a Global Earth Observation System of Systems. *Systems Journal, IEEE*, *2*(3), 338–348.

Hallegatte, S. (2012). A Cost Effective Solution to Reduce Disaster Losses in Developing Countries and Evacuation: Hydro-Meteorological Services, Early Warning, and Evacuation.

Johnson, S. R., & Holt, M. T. (1986). The Value of Climate Information. *Policy Aspects of Climate Forecasting. Proceedings, May 4. Wahsington, DC: Resources for the Future*, 53–78.

Jonkman, S. N., Van Gelder, P. H. a. J. M., & Vrijling, J. K. (2003). An overview of quantitative risk measures for loss of life and economic damage. *Journal of Hazardous Materials*, *99*(1), 1–30. doi:10.1016/S0304-3894(02)00283-2

Klafft, M., & Meissen, U. (2011). Assessing the Economic Value of Early Warning Systems. Proceedings of the 8th International ISCRAM Conference - Lisbon, Portugal, May 2011.

Krek, A., & Frank, A. U. (1999). Optimization of Quality of Geoinformation Products.

Macauley, M. K. (2005). The Value of Information : A Background Paper on Measuring the Contribution of Space-Derived Management The Value of Information : A Background Paper on Measuring the Contribution of Space-Derived Earth Science Data to National Resource Management.

Maguire, D. J., & Longley, P. a. (2005). The emergence of geoportals and their role in spatial data infrastructures. *Computers, Environment and Urban Systems*, *29*(1), 3–14. doi:10.1016/j.compenvurbsys.2004.05.012

Mandl, D. (2010). Namibian Flood Early Warning SensorWeb Pilot. Retrieved May 18, 2012, from http://sensorweb.nasa.gov/Namibia Flood Early Warning SensorWeb Pilot as of Nov 10 2010 v7.pdf

Miller, T. R. (2000). Variations between Countries in Values of Statistical Life. *Journal of Transport Economics and Policy*, *34*(2), p. 169–188.

Morse, J. M. (1991). Approaches to qualtitative-quantitative methodological traingulation. *Nursing Research*, *40*(1), 120–123.

Mrozek, J. R., & Taylor, L. O. (2002). What determines the value of life? a meta-analysis. *Journal of Policy Analysis and Management*, *21*(2), 253–270. doi:10.1002/pam.10026

NRC. (2007). *Succesful response starts with a map: Improving Geospatial Support for Disaster*

Management (p. 184). Washington: National Academies Press.

Oosterom, P. van, Zlatanova, S., & Fendel, E. (2005). *Geo-Information for Disaster Management* (p. 1434). Springer.

PDNA/ The Government of the Republic of Namibia. (2009). *Post-Disaster Needs Assessment - Floods 2009* (p. 136).

Penning-Rowsell, E., Johnson, C., Tunstall, S., Tapsell, S., Morris, J., Chatterton, J., Coker, A., et al. (2003). *The Benefits of flood and coastal defence: techniques and data for 2003.* (p. 322). Flood Hazard Research Centre, Middlesex University.

PWC. (2006). Main Report Socio-Economic Benefits Analysis of GMES October 2006, (18868).

Rogers, D., & Tsirkunov, V. (2010). *Costs and benefits of early warning systems* (p. 16).

Rossmand, G. B., & Wilson, B. L. (1998). *Learning in the field: An introduction to qualitative research*. Thousand Oaks, CA: SAGE.

Roulston, M. S., Kaplan, D. T., Hardenberg, J., & Smith, L. A. (2003). Using medium-range weather forecasts to improve the value of wind energy production. *Renewable Energy*, *28*, 585–602.

Sarewitz, D., Pielke, R. . A. J., & Byerly, R. J. (2000). *Prediction, Science, Decision Making and the Future of Nature*. Island Press.

Teisberg, T. J., & Weiher, R. F. (2009). Background Paper on the Benefits and Costs of Early Warning Systems for Major Natural Hazards 1 Submitted by.

UN/ ISDR. (2011). United Nations Global Assessment Report on Disaster Risk Reduction- Revealing Risk, Redefining Development, (August).

UN/ISDR. (2004). *Living with risk: a global review of disaster reduction initiatives* (Vol. I, p. 429).

Williamson, R. a, Hertzfeld, H. R., Cordes, J., & Logsdon, J. M. (2002). The socioeconomic benefits of Earth science and applications research: reducing the risks and costs of natural disasters in the USA. *Space Policy*, *18*(1), 57–65. doi:10.1016/S0265-9646(01)00057-1

World Bank/ United Nations. (2010). *Natural Hazards, UnNatural Disasters: The Economics of Effective Prevention* (p. 276). World Bank.

Worldwatch-Institute. (2012a). Losses from Natural Disasters Reach New Peak in 2011. Retrieved from http://www.worldwatch.org/losses-natural-disasters-reach-new-peak-2011

Worldwatch-Institute. (2012b). Losses from Natural Disasters Reach New Peak in 2011 (2). Retrieved from http://vitalsigns.worldwatch.org/vs-trend/losses-natural-disasters-reach-new-peak-2011

Zook, M., Graham, M., Shelton, T., & Gorman, S. (2010). Volunteered Geographic Information and

Crowdsourcing Disaster Relief: A Case Study of the Haitian Earthquake. *World Medical & Health Policy*, *2*(2), 6–32. doi:10.2202/1948-4682.1069

Zweifel, P., Breyer, F., & Kifmann, M. (2009). *Health Economics* (Second., p. 594). Springer.

Appendix 1: The Questionnaire

Introduction

Dear Participant,

This questionnaire will address the added value of geo-information during the Namibian flood of spring 2009, by assessing the potentials of an early warning system. As the main rivers in the northern area of Namibia are rain fed and have their headwaters upstream in other countries, an early warning system has high promises. Your experience and knowledge as an expert are very important for this research.

Your answers will be contributing to the VALID project, which is an initiative of the *Joint Board of Geospatial Information Societies* (JBGIS) and the *United Nations Platform for Space-based Information for Disaster Management and Emergency Response* (UN-SPIDER), and my master thesis for the MSc in Earth Science and Economics at the VU University Amsterdam. The VALID project aims to assess the impact and value of geo-information in risk and disaster management and seeks to improve future information systems.

You have been recommended for participation by Guido Van Langenhove, head of the Hydrological Services Namibia, Department of Water Affairs. Your answers will be treated confidentially and the main findings and results will be communicated to you. If there are any further questions, please do not hesitate to contact me by e-mail.

A short example will be provided on how to fill in the questionnaire on the second page, it will take you approximately 10-15 minutes. May I kindly ask you to send your answers by e-mail to: tessa.belinfante@gmail.com **BEFORE 15th of July 2012**.

Thank you for your time and participation,

Tessa Belinfante

MSc. Student VU University Amsterdam

Intern at UN-SPIDER office in Bonn

www.un-spider.org

Instructions

Open questions:

If there is a dotted line, please delete the dots and type your answer. There is no limitation to what and how much you can type.

Multiple choice:

To make a choice you can type an X instead of the bullet.
For example: How would you describe your experience with questionnaires?

- O No experience
- O Little experience
- O Some experience
- X Considerable experience
- O A lot of experience

Scale

If you are asked to give the upper and lower boundary of your estimate, and you believe this to be 15% and 40% you can indicate as follows.

		X					x												

0 10 20 30 40 50 60 70 80 90 100%

You may also be asked to indicate your opinion on a scale ranging from 1-5, where 1=low, 5=high, 0=none, X=don't know.

Structure

The first section you will be asked about your (professional) background, followed by a second section concerning what geo-information products you used in 2009 in general, as it is important to know what was(n't) there. In the third section you are asked about the present state of the early warning system and what future developments you would like to see. The fourth section will address what damages and losses could have been avoided in 2009, in order to assess the potential value of an early warning, for the scenario described in that section.

Important notes:

The following definitions are adopted by this research:

- **Geo-information product**: The end product of spatial information, not the raw data.
- **Damage:** The replacement value of totally or partially destroyed physical assets that must be included in the reconstruction programme.
- **Losses**: The alteration of flows in the economy that arise from the temporary absence of the damaged assets.

Section 1: Personal details and questions

Name:...
Age: ....
Gender: ....
Educational background: ………………………………………………………………………….
Profession/function:...
Organisation: ....

Level of organisation:

- Local
- Regional
- National
- International

Type of organisation:

- Public
- Private
- NGO
- Academic
- Other:…………..

1.1 How long have you been in this function?
- Less than 1 year
- 1-5 years
- 6-10 years
- 11-20 years
- 21-30 years
- 31 years or longer

1.2 How would you describe your main activities related to flooding events? More answers are possible.
- Flood risk analysis
- Preparedness activities
- Response/relief activities
- Recovery after flood
- Other:........

1.3 Have you experienced a similar flooding event before or after 2009?
....
....

1.4 How would describe your experience with the use of geo-information?

- No experience
- Little experience
- Some experience
- Considerable experience
- A lot of experience

Section 2: Use of geo-information in 2009

The following questions will be about the geo-information products that were available during the 2009 flood.

2.1 What geo-information products did you use (column 1) and what concrete actions resulted from this information during the 2009 flood (column 2)?

2.2 How much do you think the product improved decision making and resulting actions during the 2009 flood, compared to NOT having this type of product? Please indicate this estimated impact of the geo-information product in column 3.

	Geo-information product:	**Supported action:**	**Impact (1-5)*:**
Example:	*Satellite based flood inundation map*	*Evacuation of people*	*4*
1			
2			
3			
4			
5			
...			

**(1=low, 5=high, 0=none, X=don't know)*

2.3 What caused the low level of effective response after the early warning given in spring 2009? More answers are possible.

- O Monitoring and warning capacity
- O Communication of warning
- O Awareness of communities
- O Response capacity on local level
- O Other:..............................

Section 3: Present situation

3.1 How do you assess the following;

Questions:	*Pre-2009 flood Scale (1-5)**	*At present Scale (1-5)**
The awareness of communities to flood risk?		
The response capacity on a local level?		
The monitoring and warning capacity?		
The dissemination and communication of the warning?		

**(1=low, 5=high, 0=none, X=don't know)*

3.2 Has the early warning system improved since 2009; if yes *in what aspects*?
(For example in terms of usage of (new) geo-info products, communication, materials available, etc.)

………

………

3.3 What future developments in the use and application of an early warning system you would like to see?

………

………

3.4 Do you have any further comments regarding the evaluation of the early warning system?

………

………

Section 4: Impact of Flood Information System

In order to make a valuation of a flood early warning system, it is important to assess of what damages could have been avoided resulting from the 2009 flood. Therefore, please consider in this section the following scenario:

- Imagine there is a flood information system in place that provides you the following information:
    - A *spatial component* showing the up-to-date flood extent.
    - A *temporal component* proving an early warning approximately 10 days in advance that a flooding event is expected.
- Assume you have ***all the capacities*** needed to respond (materials and human resources).

You are asked to give the upper and lower boundary of your estimate, on a scale ranging from 0 – 100%. Please consider the proposed scenario for the following questions.

4.1 Concerning the following sectors; what percentage of the damages and losses in 2009 could have been avoided if there was such a flood information system in place assuming:

- Effective communication
- Adequate follow-on actions

Please provide the upper and lower boundary of your estimate: for example: 20-35%

Infrastructure (water supply, sanitation, transport, energy)

0 10 20 30 40 50 60 70 80 90 100%

Productive (agriculture, industry, commerce, tourism)

0 10 20 30 40 50 60 70 80 90 100%

Social (housing, health, education)

0 10 20 30 40 50 60 70 80 90 100%

Cross-sectoral (environment)

0 10 20 30 40 50 60 70 80 90 100%

4.2 What percentage of the human lives lost in 2009 could have been avoided if there was such a flood information system in place assuming:

- Effective communication
- Adequate follow-on actions

Please provide the upper and lower boundary of your estimate: for example: 20-35%

0 10 20 30 40 50 60 70 80 90 100%

4.3 How much more effective, in terms of avoiding damages and losses, could the following measures have been in the 2009 flood, had there been such a flood information system in place giving 10 days advance notice? Remember the assumption that you have <u>all capacities</u> needed to respond.

Preventive actions:	*Effectiveness (1-5)*:*
Evacuation of communities	
Evacuation of livestock	
Protection agriculture (remove stocks and (if possible) equipment at flood prone areas)	
Protection commerce & industry (if possible: protection of premises, remove stocks and equipment at flood prone areas)	
Protection of housing/education/health buildings	
Supply of boats and emergency supplies	
...	
...	

(1=little more, 5=much more, 0=no more, X=don't know)

Effectiveness in terms of avoiding damages and losses

Section 5: Wrap up

5.1 Are there any further comments or remarks you would like to make regarding this questionnaire?

………

………

♦

This is the end of the questionnaire. Thank you very much for your participation. May I kindly ask you to send your answers by e-mail to: tessa.belinfante@gmail.com