1 Introduction

Disasters are of major global concern and reducing disaster risk is an urgent priority for the humanitarian / development community worldwide. Between 1994 and 2003 natural disasters caused, on average, 58,000 deaths per year and affected the lives of 224 million people (GUHA-SAPIR et al. 2004). In the last decades the number of natural hazards with disastrous impact has increased, whilst the number of fatalities has decreased (GARATWA & BOLLIN 2001; IFRC 2002; GUHA-SAPIR et al. 2004). Even though loss of life as a result of disasters has more than halved since 1970, those affected - that is injured, made homeless or hungry – has tripled to 2 billion during the past decade. Meanwhile, direct economic loss due to natural hazards has multiplied fivefold over the same period (IFRC 2002) and even 14-fold when compared with the 1950s (GUHA-SAPIR et al. 2004).

Nearly every country in the world is affected by natural hazards but natural disasters cause most damage and fatalities in developing countries: Between 1971 and 1995 circa 97 per cent of deaths and 99 per cent of people affected by disasters were in developing countries (TWIGG / HRC 2004). Despite many efforts at mitigation it is expected that the number of disastrous hazards, their long-term impact and the number of people killed will increase. "Rapid population growth, urbanisation, environmental degradation, and global climate change are all contributing to an increase in the frequency and magnitude of disasters. And their most deadly impact is on the lives and living environment of the poor" (WOLFENSOHN & CHERPITEL 2002, p 1).

TWIGG, WOLFENSOHN & CHERPITEL'S statements are based on the key fact that natural disasters happen when two sets of causes coincide. Firstly the natural hazard itself, be it earthquake, storm, tsunami etc, secondly the vulnerability of the element at risk, which is the human population in the scope of this work. Only those people who are vulnerable to a particular event are likely to be negatively affected or harmed by it and the higher the number of the population in an affected area the higher the level of negative human impact.

The reduction of disaster impact, that is disaster mitigation, cannot be limited to short-term preparedness and post-disaster assistance. Without denying the importance given to post-hazard quick response and humanitarian aid, it is now widely accepted that long-term economic and social development is crucial in order to significantly reduce the risk of loss of life in all disaster-related incidents. "Humanitarian actions do not address the development processes that are shaping disaster risk in the first place" and therefore "[…] much remains to be done if disaster loss is not to jeopardise the achievement of the Millennium Development Goals" (UNDP 2004b, p I).

In order to achieve these goals or at least in heading towards fulfilling them, decisions have to be made regarding the prioritisation of money and aid flow as well as concerning the type of activities for the best use of donor resources. These decisions require relevant and timely information available at an adequate scale and with an appropriate degree of accuracy. The level of precision and spatial resolution needed varies with the different tasks and mandates of the respective institutions. International organisations, such as the United Nations or a multi-governmental institution such as the European Commission, often require information allowing approximations or estimations for global overviews. In contrast, the information needs expressed by national governments and locally acting NGOs

focus on high accuracy covering smaller areas. Despite this difference in spatial resolution and demand for accuracy the set of questions most frequently asked by decision makers involved in disaster mitigation maybe summarised as:

WHERE and HOW MANY people are living at risk of one or several natural disasters and to WHICH disaster(s) are they most vulnerable?

This work is a contribution to the development of scientific tools that can be used for answering these questions in a more timely and reliable manner.

1.1 The aims of the study

The ultimate objective of this work is to contribute to the development of tools and methodologies for the generation of information relevant for decision making in crisis management. The focus of the study is set on the assessment of people's risk and vulnerability in respect to natural hazards. It proposes tools for the implementation of these assessments at national and sub-national scale, thus targeting potential users acting at global, regional or country level. One of the specific goals is to emphasise the potential of modern technologies such as Geo Information Systems (GIS) and Earth Observation (EO) platforms as one of the sources for information in a crisis situation in order to better achieve:

- independence from local conditions,
- timeliness of product generation,
- ability to repeat assessments,
- a complete spatial coverage, including areas difficult to access.

With the development of a composite indicator the work contributes to the development of "[…] systems of indicators of disaster risk and vulnerability at national and sub-national scales that will enable decision-makers to assess the impact of disasters […]", which was identified as a priority for action in the UN's Hyogo Framework for Action 2005 – 2015 (UN 2005, p 7).

The outcomes of this study are not only aimed at supporting the prioritisation and choice of actions within the immediate disaster relief phase. They may also be used for long-term disaster mitigation planning and the implementation of development programmes.

1.2 Structure of the work

The work starts with a review of the most commonly used terms in the realm of crisis management. Following this, an equation to determine risk is presented and the concept of vulnerability is discussed in its complexity. The introduction of the temporal aspects of vulnerability and its characteristics at various social scales lays the foundation for the vulnerability assessment carried out in the succeeding section. The 'Theoretical Background' concludes with a list of parameters and potential indicators for an approach to quantify vulnerability. This list is divided into a hazard dependent and a hazard independent component and a special focus is placed on the potential value of EO data input.

In the following section of the work a worldwide assessment of people's risk of natural hazards is carried out for the case of earthquakes. This assessment is based on three main input layers; the Global Seismic Hazard Assessment Program (GSHAP) dataset as a determinant for seismic risk, the Landscan dataset for the allocation of population numbers, and a composite indicator describing the people's (hazard independent) vulnerability. The former two datasets allow the generation of raster input data layers at various resolutions, the latter is restricted in its spatial resolution to national level. The statistical analysis resulting in the composite indicator for the vulnerability component is described in detail. Finally, the combination of the three input data layers is visualised in a worldwide map representing the risk of loss of lives due to earthquakes at sub-national scale.

Since the estimation of populations' risk strongly relies on population data, the last part of the work introduces a methodology for the estimation of population densities at sub-national level. This method models the distribution of inhabitants within the administrative units of a case study in central Zimbabwe. Zimbabwe is a country with increasing economic difficulties and growing political and social tensions. Recent 'land reforms' and land distribution activities led to significant movements of populations, which are not registered by any census. Up-to-date satellite images and ancillary spatial data about topography, infrastructure and traffic were available, complemented by field knowledge provided by the author and a local expert.

In the last section of the work the results are summarised, conclusions are drawn and potential future activities for further research on relevant topics are pointed out.

1.3 Research Context

The significance of scrutinising people's risk and vulnerability to external impacts when talking about disasters, rather than dealing solely with hazardous events and their damaging effects on objects (such as buildings and infrastructure lines) was recognised in the early 80s (DILLEY & BOUDREAU 2001, see chapter 2.1.4). The cornerstone for the wide acceptance of the necessity of integrating socio-economic parameters in order to predict and explain the extent of disasters was laid out by the UN initiated 'International Decade for Natural Disaster Reduction' (IDNDR 1990-2000). Since then, numerous researchers have attempted to conceptualise the complex issues of risk, and in particular these of vulnerability. To name but a few: BOHLE's double structure of vulnerability (BOHLE 2001), CARDONA's holistic approach to disaster risk assessments and management (CARDONA 1999 and 2001) and its modified versions (CARDONA & BARBAT 2000; CARREÑO et al. 2004), TURNER et al.'s vulnerability concept emphasising the influence of environmental parameters (TURNER et al. 2003) and the 'Pressure and Release Model' of BLAIKIE et al. (1994) and WISNER et al. (2004). The general tendency in the scientific community dealing with the topic of disaster risk is to widen the conceptual framework. The understanding of vulnerability has evolved from an internal risk factor to a multi-dimensional and dynamic feature (BIRKMANN 2006b). An extensive overview of the existing frameworks and definitions is given by BIRKMANN (2006b) and various relevant research contributions to the topic are referenced in section 2 of this work.

Compared with the significant developments in theoretically conceptualising vulnerability, the progress in assessing the vulnerability of people has remained minute in practice. In

order to enable the measurement of vulnerability it is necessary to deconstruct the underlying concept (VILLAGRAN 2006a). Some authors propose separating typical dimensions of vulnerability such as economy, environment and administration (for example CARDONA & BARBAT 2000 and VILLAGRAN 2006a) in order to ease the quantification of vulnerability. However, guidelines as well as generally accepted rules and standards for assessing and comparing vulnerability are yet to be agreed. Therefore the Hyogo Framework of Action calls for the development of indicators that enable decision makers to assess disaster impacts (UN 2005). As one response to this call the United Nations University's Institute for Environment and Human Security compiled the book 'Measuring Vulnerabilities to Natural Hazards' which reflects state-of-the-art research regarding vulnerability assessments (BIRKMANN 2006a). This book discusses the main issues arising when working on the development of vulnerability–specific indicators or proxies. These are, beside the general rules that need to be taken into account when creating indicators; (1) the difficulty to simplify the multidimensional and often fuzzily defined concept of vulnerability and to transfer it into a universal methodology or equation allowing for measurements, (2) the problem of basing indicators on adequate and accurate source data, and last but not least (3) the question of spatial scale and aggregation (BIRKMANN 2006a).

Numerous vulnerability concepts considering people at risk that have been put into practice are of local character. Hence, they are focusing on a limited spatial area and often on a specific population group or community (for example GRANGER 2003, BOLLIN 2003 or VILLAGRAN 2006b), though they might consider global potentially hazardous processes (for example DOWNING & LÜDEKE 2002). They can differ significantly in their conceptual approach and the methods applied. GIS and Remote sensing technologies are increasingly used in order to support bottom-up participatory approaches (VAN WESTEN et al.; 2002, WISNER 2006). However, all these research activities address the same group of end-users: People involved, in one way or another in disaster management at local or sub-national scale.

The number of studies focusing on risk and vulnerability at a wider scale, or attempting to provide a global overview is limited. Outstanding is the work of the UNDP / BCPR office in Geneva on a Global Risk and Vulnerability Index (PEDUZZI et al. 2002) and the research carried out by the Global Natural Disaster Risk Hotspots project under the umbrella of the ProVention Consortium (DILLEY et al. 2005). Both studies investigate people's risk concerning a number of natural disasters, the former by comparing countries and the latter by working at raster based worldwide data layers[1]. The results of both groups' work are of great importance for the disaster management community and they have helped to increase awareness on the importance of populations' vulnerability in crisis situation. At the same time they both use solely post-event mortality data for the determination of vulnerability which is problematic from a conceptual point of view; firstly due to the reduced spectrum of vulnerability considered and secondly because of the limited temporal aspect included. Moreover, both approaches suffer from the lack of appropriate available datasets. A major source of criticism regarding the liability of the scientific output of their work is the dependence on data provided by the Emergency Events Database (EM-DAT), of which the accuracy is debatable and the time span covered is very limited, in particular when considering geological natural disasters (see also chapter 3.4.).

In recent years a number of studies have attempted to provide a global overview on risk and vulnerability, focusing exclusively on global climate change or on certain types of

[1] The Global Natural Disaster Risk Hotspots project additionally looks at economic losses due to natural hazards.

states, which are particular vulnerable to potential impacts of global warming (SOPAC 2003; BROOKS et al. 2005; ESTY et al. 2005). Though they might exclude certain aspects required for a more general approach to natural disaster research, they contribute valuably to the development of methodologies for global vulnerability estimations.

Research on the estimation of population distribution at very fine scale and its modelling for the creation of raster data layers is strongly correlated to the progress of GIS and Remote Sensing technologies. An overview of the pioneering and extensive developments in the 80's and the early 90's is summarized in DEICHMANN (1996). Latest research contributions include 'population surface modelling' based on high resolution satellite images (CHEN 2002; MENNIS 2003; LO 2003; LIU 2004) and are referred to in detail in chapter 4.2.