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Vulnerability of human environment to risk: Case of groundwater contamination risk

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ABSTRACT

Based on a theoretical revision of the social vulnerability concept, this article proposes a scheme of vulnerability indicators within the human environment focused on different aetiology risks. An adaptation of this generic scheme of vulnerability factors is set for the specific field of aquifer contamination risk, as well as a methodology for its analysis. Finally, model application examples are given for the Sierra de Líbar and Sierra de Mijas carbonate aquifers and the Vélez River detrital aquifer, all of which are located in the south of Spain. Obtained cartography results show a range of utilities for risk mitigation and permit appropriate spatial discrimination for its performance over different scales. The exposure and vulnerability of the groundwater contamination risk concept is evaluated in specific maps, taking into account the resident population as well as their assets.

1. Introduction and objectives

Social vulnerability to risk has been defined by considering two principal viewpoints. Authors such as Alexander (1993), D'Ercole (1994) and Bechler-Carmaux et al. (2000) identified vulnerability as the fact of being physically exposed to a hazard. From a different perspective, Susman et al. (1983), Blaikie et al. (1994), Bohle et al. (1994), Cutter (1996), Cutter et al. (2003) and Hewitt (1997) describe social vulnerability as a more complex notion, considering it as the capacity of the society to address hazard and damage.

Social vulnerability has been considered as a subsidiary aspect for the evaluation of risk provoked by different causes. From an applied perspective, the difficulty in quantifying a complex, and at times, qualitative concept such as social vulnerability, makes it powerless as an indicator compared to, for example, hazard (Cutter, 2006), or reduces its value to a simple concept of exposure. The evaluation of social vulnerability disregards two aspects (Comfort et al., 1999; Cutter, 2001, 2003; Eaking and Luers, 2006; UNDP-BCPR, 2004) the dispersion of methodological strategies and the lack of proposals on creating indicators to allow the transition from the theoretical to the applied regime. The most recent works carried out at the United Nations University regarding this issue (Birkmann and Wisner, 2006; Warner, 2007) provide a guideline for generating systematic and integrated approaches, clarifying terminology and definitions, and approaching vulnerability analysis to specific risk.

The present work focuses on reviewing the current state of the vulnerability of society and its environment to risk, as well as creating a conceptual scheme of those aspects that make up the notion of vulnerability of the human environment. Considering this scheme, a list of vulnerability indicators which are useful in a wide range of risks from different sources has been made. In the second part of the work, a proposal of vulnerability estimators of human media to a given risk, such as the risk of aquifer contamination, is shown, and the indicators are tested by applying the approach to three pilot aquifers located in the south of Spain.

2. Background

The contributions of hazard-risk models, economic and ecological policies, and the latest ecological resilience trends have enriched the concept of social vulnerability, although they do not resolve the dilemma of progressing in an applied context. The general vulnerability indexes proposed to date deal with entire groups of potential risks and are applied at a national scale or involve large territories. Typical vulnerability parameters such as the economic conditions of a population, their cultural traits or health coverage are considered. For instance, the European ARMONIA project (Delmonaco et al., 2005) for harmonisation of multi-hazard mapping proposes the use of four interrelated dimensions for vulnerability: physical, human (social and functional), economic and identity related issues. Nevertheless, the dispersion of indicators and integration of the methodology are problems that remain to be solved.

Examples of general indexes include the Human Development Index (UN, 1999) and the World Bank methodology for global multi-risk analysis (The World Bank, 2005), as well as other more recent proposals made by the Research and Assessment Systems for

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Sustainability Science Program (SUST Framework) or the United Nations Development Programme Adaptation Policy Framework (Downing et al., 2004), regarding vulnerability in a context of climate change. Similar procedures are involved for Europe as a whole in the ESPON Hazards project proposal, cited by Kumpulainen (2006), and in other European initiatives such as the TEMRAP (European Multi-hazard Risk Assessment Project) or the JRC Multi-Risk Approach (Barredo et al., 2005). Other authors such as Moss et al. (2001) and Brooks et al. (2005), who work at a national scale, have also proposed general indicators for vulnerability. These proposals constitute a positive contribution as they permit spatial comparison. However, these indices use only a few indicators that are compatible with a full range of models, and thus they are general indicators, sometimes overlapping with global development parameters. Amongst the most recent ambitious proposals for applied vulnerability indices is the SoVI (Social Vulnerability Index), proposed by Cutter et al. (2003), in which unresolved problems are identified. The basic concept of vulnerability as a potential loss provokes a misleading interpretation for some variables that define the economic level (for example status, industrial or commercial development and housing character), as, paradoxically, a strong economic position can be indicative of a high resistance to hazard, and at the same time contribute to, and increase the total value of losses. To sum up, aspects such as local scale adaptation, common indicators selection, the weighting of the mentioned indicators and the unification algorithm are basic questions that have still to be agreed upon (Eaking and Luers, 2006; Birkmann and Wisner, 2006).

Regarding the specific field of groundwater contamination risk, few contributions have been made seeking to define evaluation parameters for contamination and its consequences on a resident population and their assets, in spite of the importance that several authors give to this fact (Daly et al., 2002; Darmendrail, 2001, Ducci, 1999). Models that evaluate the social consequences of a contaminated aquifer give priority to parameters indicating the magnitude of the exposed elements (the volume of assets liable to suffer damage). Less frequent are models that include vulnerability references of such exposed elements. Some contributions, for example Civita (1995), Civita and De Maio (1997) and Corniello and Ducci (1997), considered the aquifer's magnitude as a risk-increasing factor, establishing a relationship between the magnitude of the resource exposed and the severity of the potential consequences. Ducci (1999) proposed as an estimator, besides the volume of population involved, the number of employees linked to activities that depend on the water resource, approaching a financial estimation of the potential consequences related to the contamination. Shechter (1987) introduced the concept of the impact on health and its cost for the community as a vulnerability indicator. Raucher (1983) classified those populations depending on aquifers with greater costs for an alternative supply for hydrologic resources and recuperation of water quality as being more vulnerable. These variables not only quantify the volume of population and assets involved, but their resistance to being affected and their capacity to recover.

From a more general point of view, contributions such as those by Cutter (1996) or Smith (2001) elaborated the meaning of vulnerability. These authors not only considered the physical resistance of the population (impact on health and life) and their economic activities (economic impact), but also the vulnerability of social assets of a non-productive nature, such as the cultural and ecological heritage. Under this approach, Darmendrail (2001) carried out a methodological proposal for risk evaluation (Simplified Risk Assessment) with specific indications for groundwater contamination risk. In this proposal, location factors which are considered crucial to the vulnerability of exposed elements are identified. This is the case for variables such as the distance between the useful land that could be affected and the contaminated resource, or the location of water extraction points with respect to the contaminated resource. In the same way, within the total population framework it is possible to identify certain groups with a higher potential to be affected by the contaminated water resource. Other variables take into consideration social aspects (information and security) such as protection coverage against a contamination event. Finally, the model proposed variables that measure vulnerability by using the concept of aquifer tolerance, for instance, by considering the level of previous contamination, which would result in a decrease in the capacity of an aquifer to resist the accumulation of contaminants.

3. Theoretical proposal to estimate the vulnerability of the human environment to risk

Authors such as Liverman (1990), Dow and Downing (1995), Smith (1992), Cutter (1996) or Cutter et al. (2000) support combining the vulnerability aspects defined, on the one hand, by the position (location of the population and related assets) and, on the other, by those determined by the social media (those which are the most vulnerable, according to their social circumstances). The theoretical proposals developed in this work consider that the consequences for an affected territory will depend on the size of the resident population and on the volume of assets liable to suffer damage (the exposed elements). Additionally, the consequences will vary depending on the characteristics of these exposed elements which condition their capability to resist damage, whether of biophysical or social origin. In the present work, the expression “vulnerability of the human environment” is utilised rather than “social vulnerability”, as it is understood that the former concept summarises the interaction between the population and its assets and activities where these are located. On the contrary, the expression “social vulnerability” is more restrictive, meaning that the social environment constitutes an abstract dimension that does not consider the structural and spatial characteristics of the territorial elements, such as size, distance, position, distribution and topologic sequence.

The theoretical proposal described in this article, as well as the general indicators of human environment vulnerability, given in Table 1, is taken from our review of some typical standards used in evaluating social vulnerability. It is common to use potential losses as a vulnerability indicator, but this results in a lack of precision. If potential loss is measured in absolute terms, the territories with a higher exposure in financial terms will suffer greater losses, but this does not necessarily imply that they are more vulnerable to risk or loss. It is also convenient to evaluate vulnerability against risk and against loss separately. The first aspect is of interest for the provision of preventive measures, while the second focuses on mitigation measures. Besides this, the indicator guidelines proposed in this work consider separately the factors that are responsible for biophysical resistance against risk or loss, and resistance factors in a social context. Being more accurate, vulnerability factors can be classified according to indicators measuring weakness, tolerance or capability of the exposed elements to recover against risk or loss (Pelling, 2001; Holling et al., 1998). Weakness factors are directly related to vulnerability. Recovery capability is equivalent to the resilience concept, defined by Holling et al. (1998) as the capability of a situation to recover its original state once altered. Finally, the concept of tolerance reflects the impact of previous catastrophic episodes, and is related to the past experience of an element to when analyzing risk or loss.

The parameters shown in Table 1, summarising human environment vulnerability indicators, represent variables related to exposure, which fundamentally means the size of population and the value of assets exposed to risk.

The vulnerability of elements exposed to risk depends on their weakness, their tolerance and their recovery capability. Amongst the weakness factors, variables of spatial location have been included, as well as others that address the presence of population groups or assets that are especially fragile, for reasons such as their age or their