Using multicriteria method of decision support in a GIS as an instrument of urban vulnerability management related to flooding: a case study in the Greater Lyon (France)

L'intérêt d'une méthode d'aide à la décision associée à un SIG pour la gestion de la vulnérabilité urbaine lors d'inondations : application au Grand Lyon (France)

F. Renard and P.-M. Chapon

UMR 5600 CNRS Environnement Ville Société - 18, rue Chevreul, 69007 Lyon - France (frenard@grandlyon.org)

ABSTRACT

Risk management, long time focused on the control of hazards, is moving towards an attempt to reduce vulnerability. This requires as a first step to acquire accurate knowledge of it. This work is applicable to any territory, and proposes a methodology for vulnerability assessment on the basis of the urban community of Lyon (France), for hydrologic hazards as flooding from heavy precipitations. This study is based on a method of decision support in order to prioritize the issues in order to deduce vulnerability functions using expert judgments. Three kinds of stakes are taken into account in this work: the human issues, the environmental issues and the material issues. In this article, the vulnerability is seen as the relation between the importance of these stakes and their sensitivity facing an inundation. This work finds its application with overlapping layers of hazards through a GIS for a specific risk vision, and is thus a useful method of decision support for policy makers and local elected officials of the greater Lyon (France).

RÉSUMÉ

La gestion du risque, longtemps portée sur le contrôle des aléas, s'oriente de plus en plus vers une tentative de réduction de la vulnérabilité. Cela nécessite dans un premier temps d'en acquérir une connaissance précise. Ce travail, applicable à n'importe quel territoire, propose ainsi une méthode d'évaluation de la vulnérabilité, adaptée ici à l'agglomération urbaine lyonnaise et à l'aléa inondation. Cette étude repose sur une méthode d'aide à la décision, fondée sur le jugement d'experts, afin d'en déduire des fonctions de vulnérabilité. Trois types d'enjeux sont recensés dans cette étude : les enjeux humains, les enjeux environnementaux et les enjeux matériels. Tous ces enjeux ne possèdent ni la même significativité et la même importance pour le Grand Lyon, ni la même sensibilité face à l'aléa pluviométrique. Dans cette étude, la vulnérabilité est donc perçue comme la relation entre la significativité des enjeux d'une part, et leur sensibilité respective face à l'aléa inondation. Ce travail trouve son application concrète avec la superposition de couches d'aléas à l'aide d'un SIG pour une vision précise du risque associé. Il en ressort un outil d'aide à la décision efficace et utile pour les ingénieurs du Grand Lyon.

KEYWORDS

Flooding, GIS, multicriteria method of decision, urban area, vulnerability

1 INTRODUCTION

The urban community of Lyon, situated in France in the north of the Rhône valley, comprises 1.2 million inhabitants within 515 km ². With such a concentration of issues, policy makers and local elected officials therefore attach great importance to the management of hydrological risks, particularly due to the inherent characteristics of the territory. Indeed, with the presence of two major rivers, many torrential character streams, a terrain with steep slopes conducive to the accumulation of water in the bottom, some waterproofed sectors of the agglomeration promoting heavy runoff and often very intense rains during the summer, flood risks are numerous (Fig. 1).

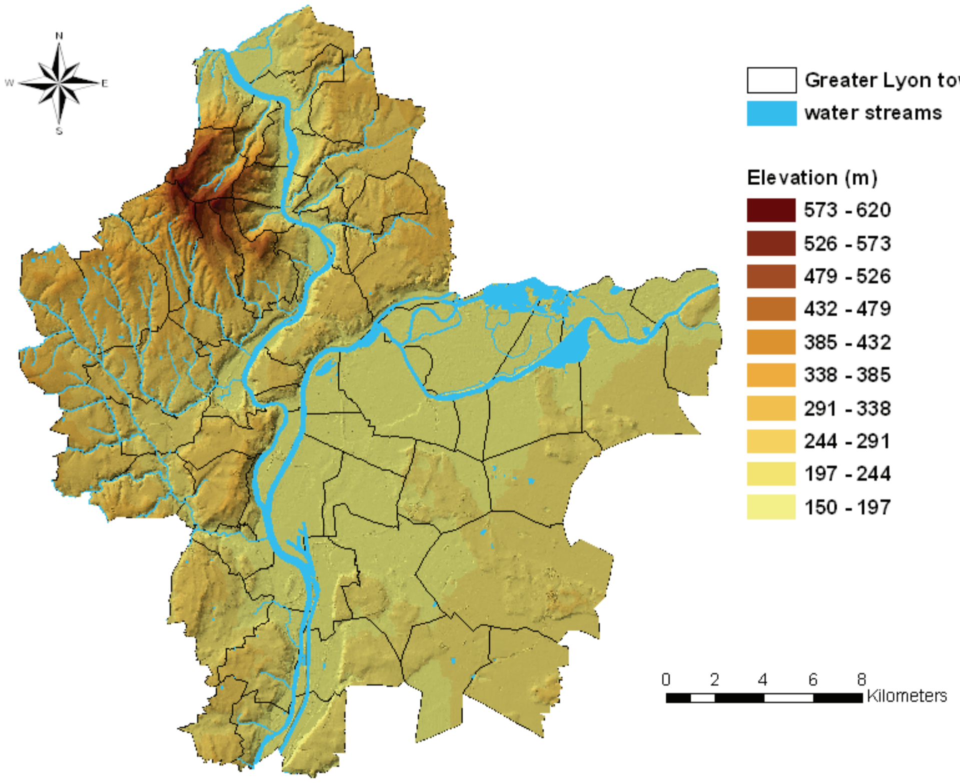

Figure 1 – Topography and water streams of the Greater Lyon (France)

If the hazards associated with these risks in the territory of Lyon have been the subject of numerous analyses, studies on the vulnerability of greater Lyon are rare and have common shortcomings that impair their validity. This is regrettable because the knowledge of the vulnerability of urban systems is as important as the knowledge of the hazard for the control of risks associated with heavy rainfalls. We recall that the risk is seen as the classic relationship between the probability of occurrence of hazards and vulnerability. In this article, this vulnerability will be composed of two parts. The first one is the sensitivity of the stakes facing hydrological hazards as urban runoff, that is to say, their propensity to suffer damage during a flood (Gleize and Reghezza, 2007). The second factor is their relative importance in the functioning of the community. Indeed, not all the stakes could provide the same role and contribution to the Greater Lyon. For example, damage to the urban furniture such as bus shelter seems less harmful to the activities of the urban area than that of transport infrastructure (Renard and Chapon, 2010).

This communication proposes to assess the vulnerability of Lyon urban area facing to hydrological hazards. This territory is composed of human, environmental and material stakes. The first part of this work is to identify all these issues so as to completeness. Then, is it required to build a “vulnerability hierarchical tree” (Barczak and Grivault, 2007), or a “vulnerability index” (Tixier *et al*, 2006). Thus, it is necessary to use methods of multicriteria decision aid to evaluate the two components of vulnerability: the sensitivity and the contribution to the functioning of the community. Finally, the results of the overall vulnerability are presented, and then coupled to various hazards related to water such as runoff associated with heavy rains, to locate areas of risk in the urban area.

2 HIERARCHICAL STRUCTURE OF THE SYSTEM AND EVALUATION OF THE IMPORTANCE AND SENSITIVITY OF THE STAKES

2.1 Creation of a hierarchical structure of the stakes of Greater Lyon

The hierarchical structure, made in collaboration with engineers from Greater Lyon, is based on a typology combining the three main classes of issues (human, environmental and materials, themselves subdivided in vulnerable targets), impacts and vulnerability factors, as detailed in Figure 2 (Griot, 2007). The method is applicable to any territory, but this tree is specific to the field of study.

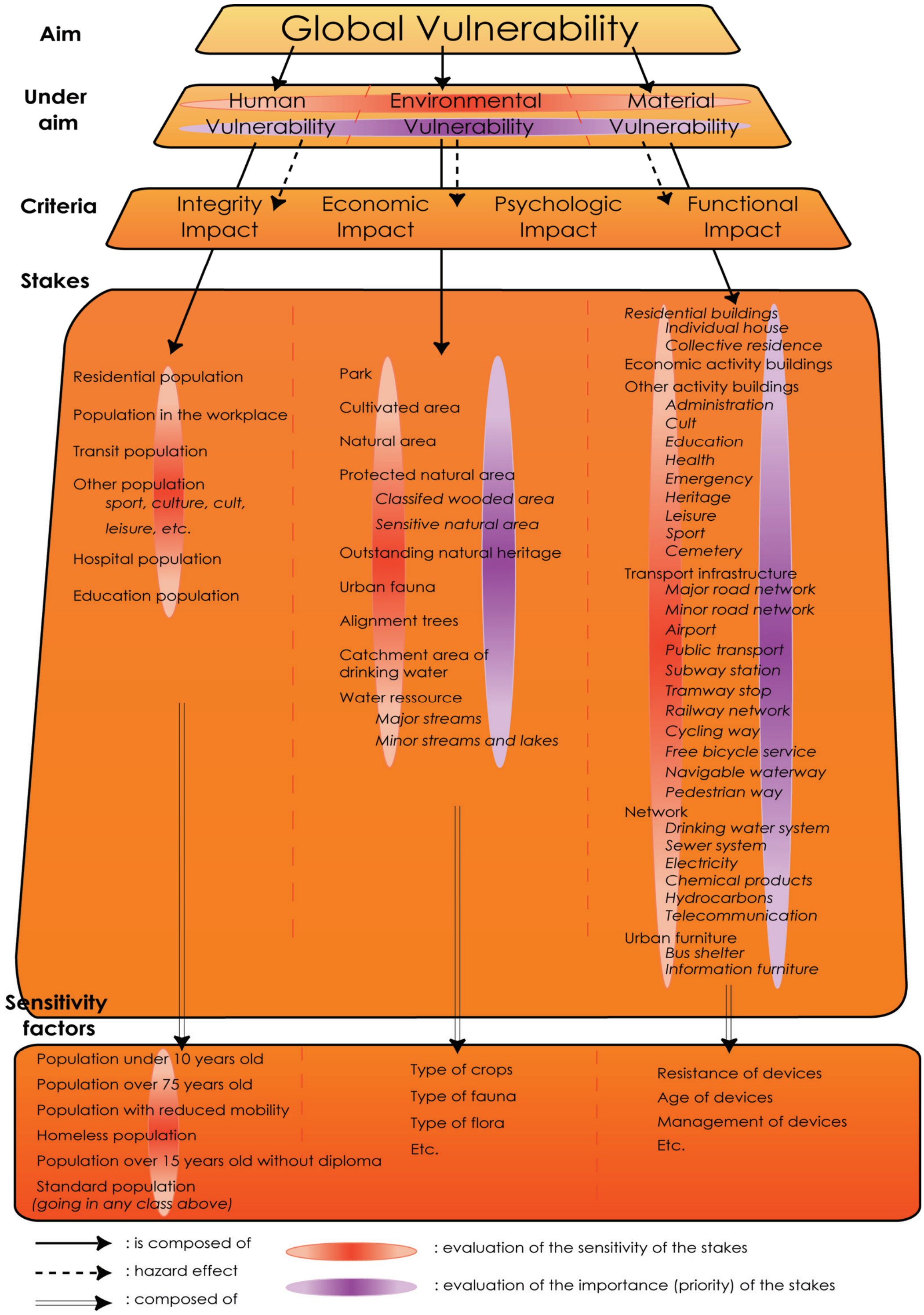

Figure 2 – General hierarchical structure of the spatial system of Greater Lyon vulnerability

The targets that share the same rank of this hierarchical structure (Fig. 2) do not possess the same importance, or the same sensitivity to the flood hazard. Therefore, the second part of this work is to define the priorities and sensitivities of different targets based on the judgments of experts.

2.2 The need to use a multicriteria method of decision support to evaluate importance and sensitivity of issues

Multicriteria decision methods are used to prioritize elements and are therefore adapted to the modelling of the sensitivity of the issues of greater Lyon (Griot, 2008). The purpose of these methods is the assessment of priorities between the different components of the situation. Thomas Saaty's analytic hierarchy process (1980) is the most frequently used because of its many advantages. It was chosen because it corresponds precisely to the modelling of our situation, is accessible, and has a great flexibility and adaptation (Griot, 2003).

On this basis, the formal calculations of priorities and sensitivities of the elements have been conducted. These calculations are based on the judgments of experts. Indeed, during semi-structured interview, the 38 experts in our sample delivered a verdict on issues that seem relatively more important than others by binary comparison. They carry the same manner to determine sensitivity's stakes to hazard flooding. Finally, the consistency of answers given by experts is validated by calculating a ratio of coherence, and their results are aggregated to provide functions of priority (based on the relative importance of each stakes), and functions of sensitivity (based on the relative sensitivity of each stakes). From these functions of priority and sensitivity is obtained the general function of vulnerability.

3 USING A GIS TO MAP THE RISK ASSOCIATED WITH HYDROLOGIC HAZARD

3.1 Getting vulnerability functions from priority and sensitivity functions to quantify urban vulnerability

The vulnerability functions allow defining the importance of the stakes of Greater Lyon and their sensitivity to hydrological hazards. The global vulnerability function (Equation 1) is obtained from sensitivity (Equation 2) and priority functions (Equation 3) and shows the great importance of human issues (75 %). The vulnerability factor of environmental targets represents 12 % of the global vulnerability function, as much as the materials issues. However, it can be seen from equations 2 and 3 that the environmental and material stakes do not represent the same weight into the priority and sensitivity functions. Indeed, the environmental issues seem more important than the material ones (17 % for the environmental stakes whereas only 5 % for the material stakes in the priority function), but less sensitive to an hydrological hazard (6 % for the environmental issues while 20 % for the material issues in the sensitivity function).

Equation 1:

Global Vulnerability = 0,7535 x *Human Vulnerability* + 0,1185 x *Environment Vulnerability* + 0,128 x *Material vulnerability*

Equation 2:

Global Sensitivity = 0,735 x *Human Sensitivity* + 0,064 x *Environment Sensitivity* + 0,201 x *Material Sensitivity*

Equation 3:

Global Priority = 0,772 x *Human Priority* + 0,173 x *Environment Priority* + 0,055 x *Material Priority*

Similarly, priority functions and sensitivity are established for all stakes at all levels (Fig. 2). The stakes are then converted into a mesh form (500 meters wide). This will standardize the collection framework and the heterogeneous nature of data to allow their comparison. Finally, it is obtained a detailed, consistent and objective vulnerability of the territory of Greater Lyon (Figure 3 and 4). At the end, to get a direct reading of risk, combination of hazard and vulnerability, it is overlaid the two maps. For example, figure 5 shows the risk of runoff associated with heavy rains and the risk of flooding in the Lyon area caused by the two major rivers. If the runoff hazard is present over much of the urban area, the zones affected are not the most vulnerable, contrary to the flood hazard that affects the most critical areas and thus constitutes a major risk for the city.

This methodological proposal for territorial analysis of the vulnerability is trying to overcome the shortcomings of previous studies on this same site, including for the first time the use of the analytic hierarchy process to evaluate the sensibility and the importance of the stakes. However, this type of method and the databases used have some limitations that it is essential to take into account to improve the study retrospectively.

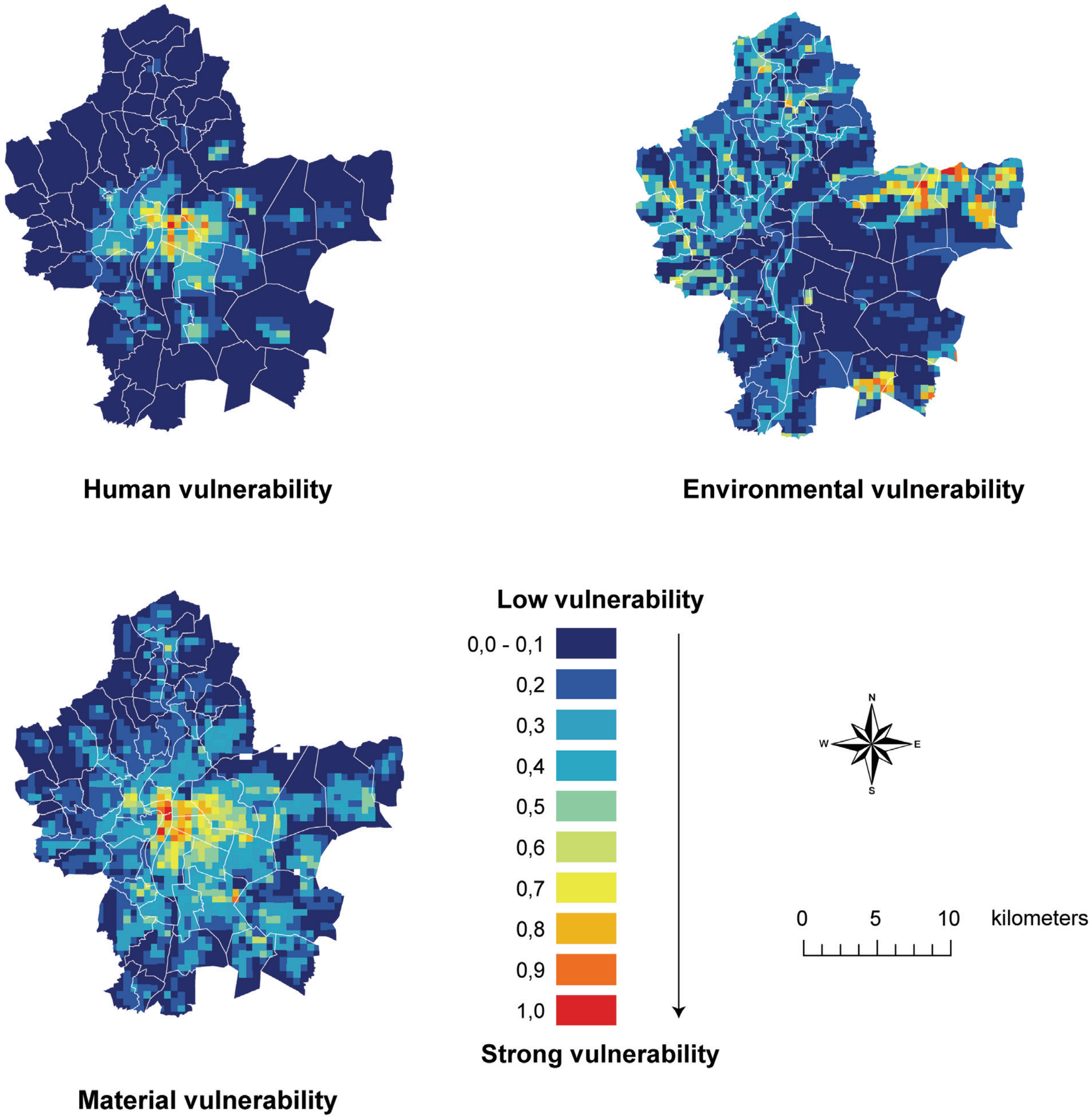

Figure 3 – Mapping of the human, environmental and material vulnerabilities of Greater Lyon

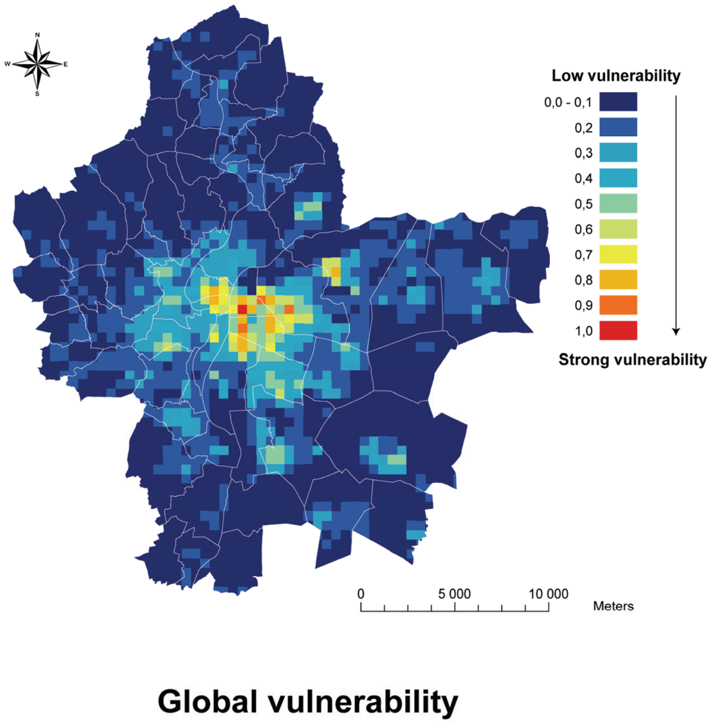

Figure 4 – Mapping of the global vulnerability of Greater Lyon

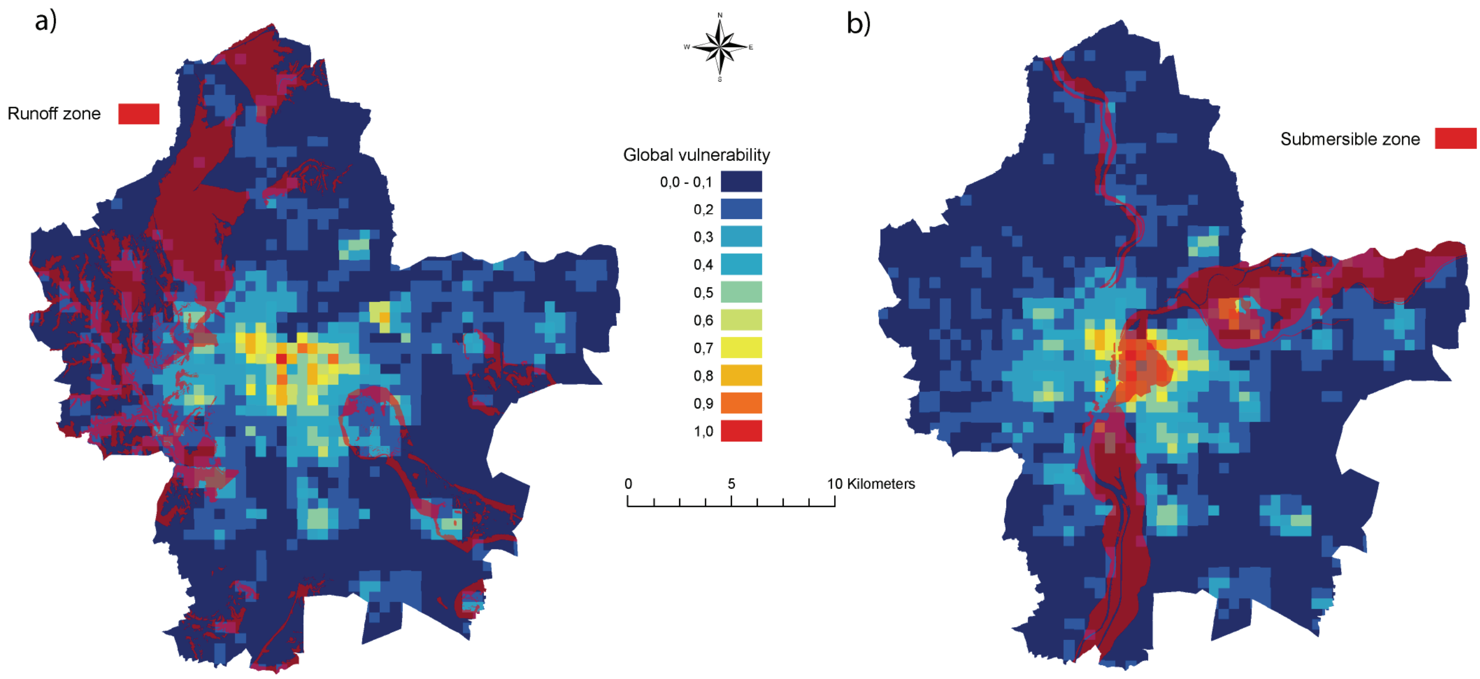

Figure 5 – Spatial representation of urban runoff risk (a) and urban flooding risk (b) in the Greater Lyon

3.2 Limits of the method

The *AHP* has sometimes been questioned, especially by himself Saaty (Saaty and Hu, 1998). Indeed, it has been criticized the validity and legitimacy of storage made from the matrix (Dodd *et al.* 1995; Yue *et al.*, 1998). In addition, pairwise comparisons of elements of one level higher than seven can sometimes be complicated for experts (Dodd and Donegan, 1989). This problem can be solved by making associations of targets located at the same hierarchical level, despite the loss of precision induced (Dodd and Donegan, 1989). Finally, the consistency of judgments of experts was assessed using a ratio of inconsistency. However, this ratio has been questioned because of its lack of rigidity for matrices of low orders (Dodd *et al.*, 1995), which in addition tend to be at high levels of hierarchical decomposition (hence influence greater than the high-order matrices near the base).

Regarding the study area itself, the assessment of human vulnerability is based on data from INSEE census of population that dates from 1999 and based for the moment on residential population only. Then, it would be interesting to weight our results by time of day, or at least to have diurnal and nocturnal human vulnerability map. In addition, the layer representative of *urban wildlife* issue has not been taken into account because there is not, for the moment to our knowledge, quantitative identification of it on the Grand Lyon. Finally, if evaluating the importance of stakes is not so complicated for the chosen experts, they found quiet difficult to evaluate the sensitivity of issues, despite the global consensus obtained at the end.

4 CONCLUSION

The vulnerability assessment of urban land as dense as the Greater Lyon facing hydrological hazard is a delicate operation requiring many resources and techniques. Previous studies on this urban area had deficiencies. It has been tried to remedy these problems by trying to take into account all the stakes, using an analytical hierarchy process and evaluating the sensitivity and the importance of these, and using adapted meshes to our study area. This analysis showed the predominance of human vulnerability (75%) in the overall vulnerability. This leads to a decreasing gradient centred on the urban heart, with however some poles of vulnerability in periphery, particularly influenced by environmental vulnerability. From this perspective, this analysis has shown the need for managers to take into account vulnerability very precisely and locally, due to the strong spatial variability of the latter.

This method, which can be extrapolated to any territory, provides maps of global vulnerability, but also specific vulnerability, and has the advantage of being able to superimpose the hazard maps previously available for a direct reading of hydrological risks. Thus, this view of risk becomes more relevant with the opportunity to show new types of interactions between vulnerability and types of hazards that could remain hidden until then.

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