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A new approach for computing a flood vulnerability index using cluster analysis

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ABSTRACT

A Flood Vulnerability Index (FloodVI) was developed using Principal Component Analysis (PCA) and a new aggregation method based on Cluster Analysis (CA). PCA simplifies a large number of variables into a few uncorrelated factors representing the social, economic, physical and environmental dimensions of vulnerability. CA groups areas that have the same characteristics in terms of vulnerability into vulnerability classes. The grouping of the areas determines their classification contrary to other aggregation methods in which the areas' classification determines their grouping. While other aggregation methods distribute the areas into classes, in an artificial manner, by imposing a certain probability for an area to belong to a certain class, as determined by the assumption that the aggregation measure used is normally distributed, CA does not constrain the distribution of the areas by the classes.

FloodVI was designed at the neighbourhood level and was applied to the Portuguese municipality of Vila Nova de Gaia where several flood events have taken place in the recent past. The FloodVI sensitivity was assessed using three different aggregation methods: the sum of component scores, the first component score and the weighted sum of component scores.

The results highlight the sensitivity of the FloodVI to different aggregation methods. Both sum of component scores and weighted sum of component scores have shown similar results. The first component score aggregation method classifies almost all areas as having medium vulnerability and finally the results obtained using the CA show a distinct differentiation of the vulnerability where hot spots can be clearly identified.

The information provided by records of previous flood events corroborate the results obtained with CA, because the inundated areas with greater damages are those that are identified as high and very high vulnerability areas by CA. This supports the fact that CA provides a reliable FloodVI.

1. Introduction

From 2001 to 2010, hydrological disasters in Europe (flood and mass movements) represented the largest share of total disaster victims (55.1%) and millions of Euros worth of damages (Guha-Sapir et al., 2012). Flood risk assessment entails understanding vulnerability, which is an important issue at present, because climate models project an increase in rainfall intensity in warmer climates (Emori and Brown, 2005; Groisman et al., 2005; Santos et al., 2015; Trigo and Palutikof, 2001) which will lead to an increase in the frequency of flood events (Balica, 2012). Therefore, vulnerability assessment is of paramount importance as a tool for population safety and property protection.

In 2007, the Floods Directive (FD) created a Pan-European framework to support the Member States in evaluating flood risk. The FD is linked to the Water Framework Directive (WFD) and should produce flood risk maps to help decision makers and authorities take appropriate measures aimed at reducing flood risk in an effective and sustainable manner (Mostert and Junier, 2009).

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Furthermore, the development of techniques and assessment methodologies as well as measures regarding the increase of knowledge about flood vulnerability or flood risk can be of great value for decision makers and can help reduce damage and fatalities.

Risk may be defined as the probability that a particular level of loss can be sustained by a given series of elements as a result of a given level of hazard impact (Alexander, 2000). The exposed elements in flood risk are population, communities, buildings and infrastructures as well as economic activities and the natural environment, that are under threat in a given area.

Vulnerability is embedded into the concept of risk, as Risk = Hazard × Vulnerability (Wisner et al., 2004) and is understood as “The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard” (UNISDR, 2009). The existing literature establishes several definitions and conceptual frameworks of vulnerability were established, according to the researchers' views. These can be summarized in three classes (Adger, 2006; Fekete, 2009b; Tate, 2011): i) exposure to a natural event, risk stressor or shock; ii) sensitivity, also described as susceptibility or resistance; and iii) adaptative capacity, also expressed as recovery potential or resilience.

There are usually four dimensions that need to be considered in vulnerability assessment: i) the physical dimension that represents the potential of physical impact on the built environment; ii) the economic dimension that accounts for the potential impacts of hazards on economic assets; iii) the social dimension that is related to the presence of human beings, individuals or communities, and their capacity to cope, resist and recover from hazard impacts; and iv) the environmental dimension that refers to potential impacts on the natural environment and the ability of ecosystems to cope and recover from hazard impacts.

The complex structure of a vulnerability assessment framework is described as a hierarchical model, a deductive model, or an inductive model (Tate, 2012) and aggregate vulnerability indices are computed using the mathematics of index construction (Schmidtlein et al., 2008). Inductive methods were popularized by the Social Vulnerability Index (Cutter et al., 2003) and are used by the majority of the more recent vulnerability indices (Fekete, 2009b; Schmidtlein et al., 2011; Tate, 2012).

The main criticisms regarding indices construction methods are the subjective process of both variable selection and weighting, unavailability of certain variables, problems related to aggregation at different scales, and difficulties in validating the results (Barnett et al., 2008; Fekete, 2012; Jones and Andrey, 2007). Furthermore, different combinations of the variables may produce diverse vulnerability assessments (Chakraborty et al., 2005; Koks et al., 2015). Nevertheless, the usefulness of indicators aimed at reducing complexity, measuring progress, and establishing priorities makes them an important tool for decision makers.

Jones and Andrey (2007) have argued that Principal Component Analysis (PCA) offers an alternative to the otherwise subjective variable selection by objectively simplifying a large number of variables into a few uncorrelated factors that capture the variability in the underlying data (Abdi and Williams, 2010). The PCA approach increases flexibility regarding the choice and number of variables, thereby allowing for a more robust and consistent set of variables (Cutter et al., 2003) and provides several potential advantages with regard to aggregation of spatially explicit and potentially incommensurable variables (Abson et al., 2012).

PCA is labelled as an inductive method and has been used by the majority of the more recent vulnerability indices studies (Borden et al., 2007; Cutter et al., 2003; Fekete, 2009a; Finch et al., 2010; Rygel et al., 2006; Schmidtlein et al., 2011; Tate et al., 2010). The vulnerability index is built as a function of principal components (PC) and their subsequent aggregation. Aggregation of PC refers to the procedure used to combine transformed, normalized, and weighted indicators into a simpler measure, reducing the amount and complexity of information that must be used during the process of classifying the areas into vulnerability classes (Nguyen et al., 2016). It should be emphasized that the existing aggregation methods do not guarantee that those areas have similar characteristics in terms of the variables of interest's values and thus of vulnerability. Furthermore, and as stated before, the choice of the aggregation method conditions the results, making the aggregation of the PC a subjective decision in the index construction process (Böhringer and Jochem, 2007).

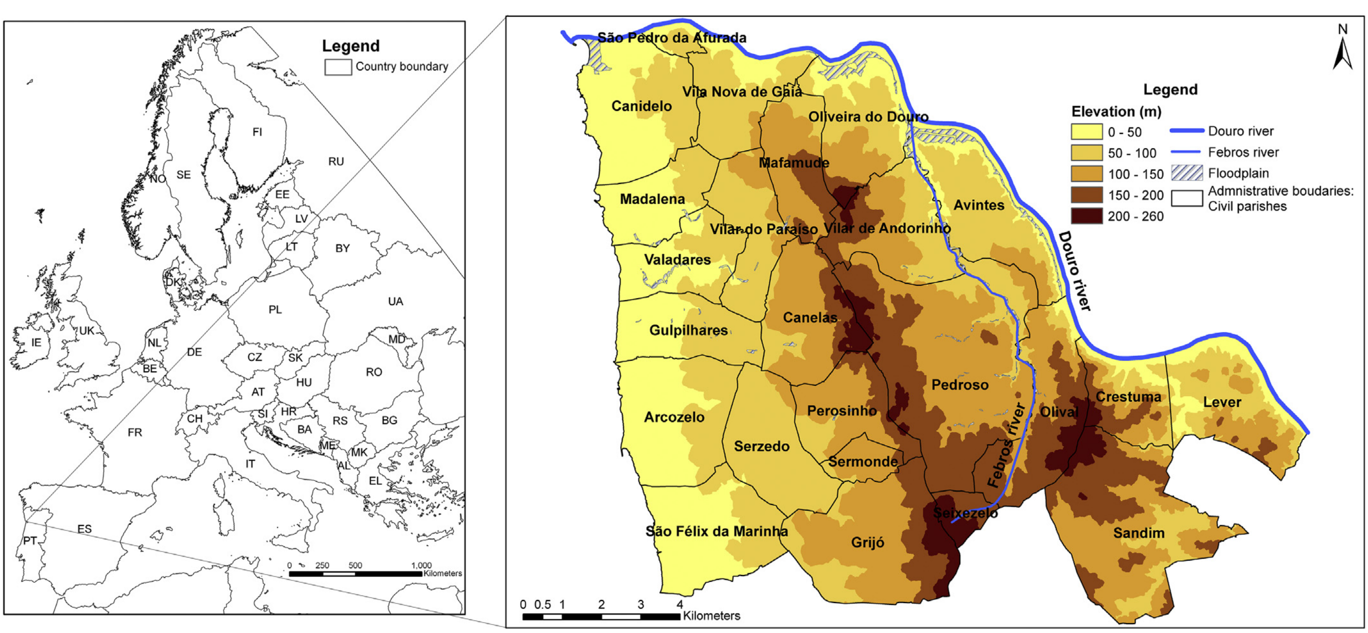

Fig. 1. Study area location.