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Urban flood vulnerability index based on differences in infrastructure, socioeconomic, and population factors.

Indice de vulnérabilité aux inondations urbaines basé sur les différences entre les infrastructures, les facteurs socio-économiques et la population.

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RÉSUMÉ

L'évaluation de la vulnérabilité des villes aux inondations est essentielle pour cibler les plans d'action visant à atténuer leur impact dans les zones les plus touchées. Le niveau de vulnérabilité des quartiers des villes varie en raison des inégalités créées par la morphologie, ce qui entraîne des caractéristiques structurelles et sociales variables. Pour identifier ces zones, il existe des indices qui évaluent la vulnérabilité en fonction des facteurs à l'origine de ces inégalités. Dans ce but, nous avons développé une méthodologie pour collecter, classer et sélectionner les variables clés des indices de vulnérabilité établis. Nous avons évalué ces facteurs en fonction de leur variabilité spatiale dans les districts de recensement de Santander (Espagne) et les avons appliqués comme élément de pondération pour la cartographie de notre indice de vulnérabilité. En combinant différentes classes de vulnérabilité et en utilisant des outils statistiques pour réduire la complexité, notre approche peut aider les urbanistes à contrer efficacement les menaces posées par les inondations.

ABSTRACT

Assessing the vulnerability in cities to flooding is crucial for targeting action plans to mitigate their impact in the most affected areas. City districts vary in their level of vulnerability due to inequalities created by morphology, leading to variable structural and social characteristics. To identify these areas, there are indices that assess vulnerability according to factors that cause such inequalities. With this aim, we developed a methodology to collect, classify and select key variables from established vulnerability indices. We evaluated these factors according to their spatial variability across census districts of Santander (Spain) and apply them as a weighting element for mapping of our vulnerability index. By combining different classes of vulnerabilities and using statistical tools to reduce complexity, our approach can help city planners to effectively counter threats posed by flooding.

KEYWORDS

Geographic information system (GIS); Principal component analysis (PCA); Flooding; Urban planning; Vulnerability

1 INTRODUCTION

Flood risk mitigation in cities is a complex issue with multiple dimensions involved. The vulnerability of different urban areas is one of the key inputs that must be accounted for by decision-makers in flood management (Defossez et al., 2017; Nasiri et al., 2019). Geographic Information Systems (GIS) are supporting tools that use efficiency resources in locating and reducing potential damages caused by floods (Rehman et al., 2019).

For this purpose, several indices for identifying vulnerable areas to environmental hazards at different scales and representing different types of vulnerability have been developed (Chang et al., 2021; Moreira et al., 2021; Salazar-Briones et al., 2020). There is, however, a need to better integrate these indices such that inequalities in demographic, social, economic circumstances and urban critical infrastructure can be assessed together to provide a holistic view. Therefore, this research aims to create an index that enables the assessment of spatial variability of vulnerability.

2 METHODOLOGY

This study proposes a classification of the factors reported by the regional government and the Spanish National Statistics Institute (INE) (Gobierno de Cantabria, 2021; INE, 2015, 2011), based on three categories or classes; demographic, socioeconomic, and infrastructure vulnerability. After censal sections from different years were homogenised, we analysed the spatial variability of the factors in each class, using principal component analysis (PCA) to assess and identify the most important causes of inequality. Finally, their combination into a flood vulnerability map allowed easier comprehension of all the data and supported the identification of most vulnerable locations. We tested our proposed methodology on the city of Santander (northern Spain) which increasingly experiences floods in several areas of the city (Manchado et al., 2021).

Figure 1 presents an overview of our methodology's. Based on data availability and existing literature across the three classes aforementioned, we screened and organised 159 different factors based on these three key topic areas. Factors were then reduced to a manageable and significant number based on statistical cross-correlations and a PCA. We selected those factors with the highest geographical heterogeneity and weighted them according to their variance. Having identified this subset of critical factors, we then mapped an overall vulnerability for each of the three major vulnerability classes by aggregating spatial data based on individual class weightings. Finally, we performed a sensitivity test that relates all created maps of the three classes by subjecting them to an asymmetric combination modifying the weights to give more importance among them.

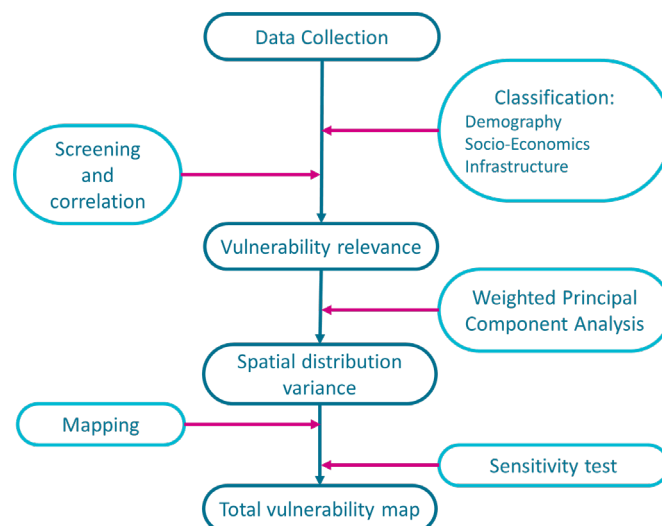


Figure 1. Diagram summarising the flow of concepts employed in this research.

3 RESULTS AND DISCUSSION

The implementation of this methodology in the city of Santander yielded the following results:

- We reduced the demographic class from 57 to 10 factors. We combined certain factors based on their correlation.

- The socio-economic class contains of 20 (out of an initial 84) factors for the study's initial phase. Almost all the income factors were strongly correlated, except for the population's share living below the poverty line (family income that is lower than 60% of the median income).
- Infrastructure class: we selected 11 of the 18 potential factors. The disaggregated uses of residential buildings, and the differences in the number of rooms, were discarded due to high correlation.

PCA showed the first two principal components explained more than 50% of the spatial variability in all classes. Figure 2 shows the maps created from the selected factors and the PCA with these two first principal components. Finally, we combined these three maps to create a final map with the total vulnerability index.

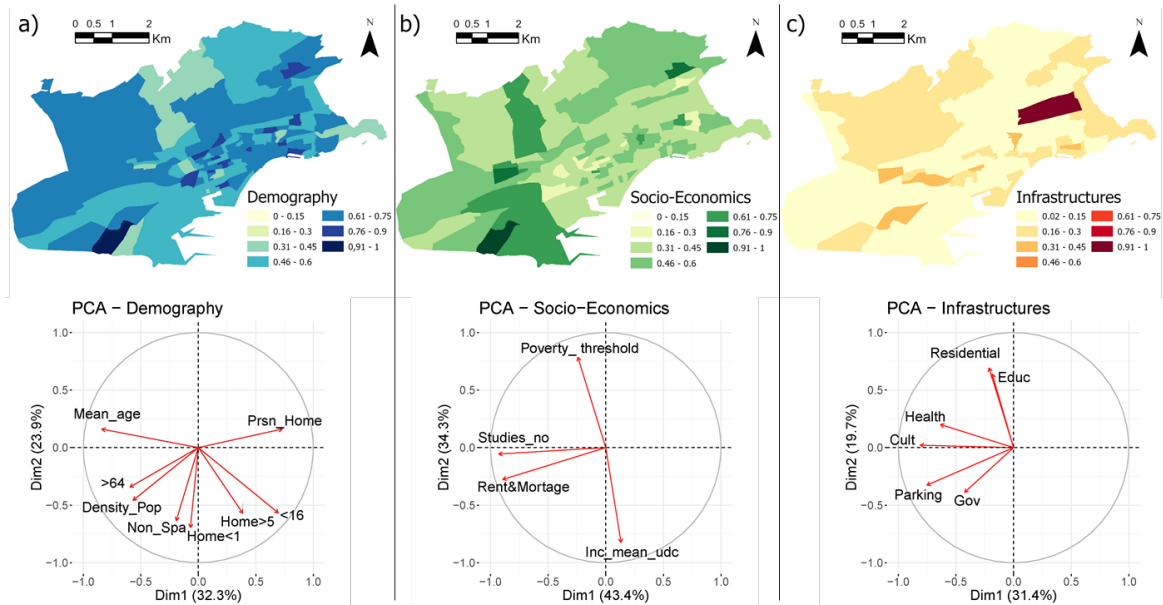


Figure 2. Vulnerability maps for each class (top) and the Principal Component Analysis (PCA) graphs for the first two principal components of each class (bottom). a) Demography; b) Socio-economics; c) Infrastructures

The final vulnerability map showed three main vulnerable census tracts in Santander (Figure 3). Because of the relevance of educational buildings in the infrastructure class, a census tract in the east of the city where the universities are located is the most vulnerable. Several socioeconomic and demographic factors are combined to establish the second most vulnerable census tract in south-west. Finally, the third most vulnerable area stems from a combination of has the most number of significant factors that come from the three classes in a census tract in middle west of the city. Sensitivity analysis did not result in significant changes in the map shown in Figure 3, indicating the stability of the results.

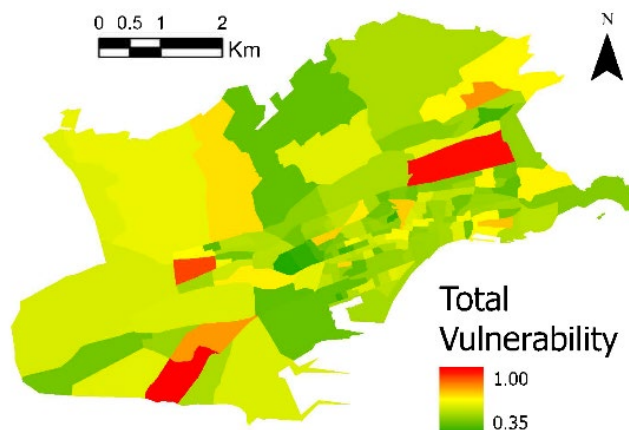


Figure 3. Map representing the total vulnerability index of Santander city.

4 CONCLUSIONS

We identify critically vulnerable locations to form the basis for the development of strategies to mitigate flood vulnerability or risk and also allows identification based on its criticality how these mitigation strategies might have to be designed (i.e., large-scale infrastructure or more decentralised and distributed infrastructure). Urban planners can use our developed methodology to assess urban flood vulnerability and to readily simplify and accelerate the planning of new actions. The method can also support governments in making the best use of available resources to deal with climate change and its potential impact on urban environments.

Our research is a three-dimensional approach by the classification into three classes, which may offer a comprehensive understanding of how flooding affects a certain location. Also, the use of PCA and correlation improves objectivity in management by selecting those factors that have an unequal effect on different parts of the city. This methodology can readily be applied to any city in Spain as it is built upon pre-existing and available national data sets. With minor adjustments, however, its simplicity makes it adaptable to other countries as well. In the future, by automating the methodology, it could be possible to analyse both the spatial and temporal differences between cities as well as the evolution of a single city over time.

5 ACKNOWLEDGEMENTS

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