Urban policies as a factor of vulnerability to flooding in Mediterranean urban areas: retrospective spatial analysis of the case study of the Region of Murcia

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Abstract: The Region of Murcia, on the south-eastern Mediterranean coast of Spain, has suffered from flooding throughout history. These floods have for centuries been the natural disasters with the greatest socio-economic impact in the region. Despite this, the great increase of urban expansion during the last quarter of the 20th century, mainly on the coastline due to the sun and beach tourism boom, failed to take into account the disadvantages and challenges of building in flood-prone zones. When studying the current urban planning models of three municipalities, analyses using GIS indicators show that the urban flooding vulnerability level is too high.

Keywords: flooding vulnerability; Murcia Region; urban planning

1. Introduction

The increasing effect of climate change on the phenomena associated with torrential rains is forcing a rethink in those methodologies and approaches. One of the locations where this change has been particularly virulent is in Spanish Mediterranean basins. There, the appearance of the DANA phenomenon has replaced the traditional flash floods associated with cold fall phenomena.

2. Area of study

The Region of Murcia, on the south-eastern Mediterranean coast of Spain (Figure 1), characterized by a scarce annual mean precipitation of around 300 mm -most of which falls during storm events in autumn- has suffered from pluvial flooding throughout history. These floods, as they occur on a global scale, have for centuries been the natural disasters with the greatest socio-economic impact in the region.

Figure 1. Study area. Region of Murcia, on the South-eastern Mediterranean coast of Spain.

Figure 2. Case study. Location of the cities: Murcia, Águilas and Los Alcázares.

Despite this, the great increase of urban expansion during the last quarter of the 20th century, mainly on the coastline due to the sun and beach tourism boom, failed to take into

Citation: Franco, A.; García-Ayllón, S., 2022, Urban policies as a factor of vulnerability to flooding in Mediterranean coastal areas: retrospective spatial analysis of the case study of the Region of Murcia. *SUPTM 2022 conference proceedings sciforum* 054503.

<https://doi.org/10.31428/10317/10609>

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account the disadvantages and challenges of building in flood-prone zones [1]. In the last decade, in the Region of Murcia some municipal planning models have incorporated a number of flood risk mitigation measures based on guidelines of regulations and plans at both national and regional scale. However, such measures may be insufficient and of short temporal scope; which is supported by reports of the Intergovernmental Panel on Climate Change [2,3] predicting an increase in the frequency and severity of extreme rainfall events in the Mediterranean area. In fact, in the last five years, this area has suffered three catastrophic floods derived from the DANA phenomenon with effects are much more devastating [4].

3. Methodology

This study proposes a spatial retrospective analysis correlating how the urban policies of three municipalities of Murcia Region (Murcia, Águilas and Los Alcázares, Figure 2) have influenced the current vulnerability of the territory to floods. The process of analyzing the impact of diffuse territorial anthropization in increasing vulnerability of a territory of floods is carried out in applied stages in the following framework.

A series of GIS indicators of anthropic phenomena and damages derived from floods are elaborated. The first indicators must spatially represent the different levels of damage caused. The latter must be able to model, in a significant way, the spatiotemporal evolution of the anthropic phenomena estimated as more related to the problem of flooding in the chosen study area. With these indicators, a geostatistical analysis is carried out to assess the spatial correlation of the evolution of the selected indicators of territorial transformation to the generation of damages derived from floods. Two georeferenced databases are implemented to model spatial values of the damage that occurred in the last three DANAs and spatiotemporal distribution of the most relevant land transformation.

3.1 Spatial Damage Values Database

To analyze the spatial distribution of damage caused by DANA we have created an index called the flood damage severity index (I_{FDS}). From the information provided by the emergency services from various local and regional administrations which are in charge of processing the damage files of those affected by the flooding events, we generate a spatial qualitative punctual database of damage (Figure 3). These data are obtained on aggregate units such as tourist resorts, residential buildings, industrial estates, shopping centers, etc. to make georeferenced treatment possible whilst preserving the legal requirements of anonymity. To obtain a uniform sequence of discrete values, the alphanumeric data is classified into three categories based on the level of significance of the damage: minor, relevant, and catastrophic damage, following criteria from Table 1.

	Minor damage	Relevant damage	Catastrophic damage
Impact on communications	Temporary pathblocks	Temporary roadblocks	Block on highways or critical road infrastructure
Damage to buildings and material goods	Flooding of garages in buildings	Flood inside homes and main areas of buildings	Structural destruction or complete loss of the value of material goods
Agriculture and Livestock	Partial crop damage	Complete loss of the crop	Tree uprooting or drowning of animals
Operation of public services	Malfunction of non-essential services (e.g. streetlamps)	Temporary outages of essential supply services (water, electricity)	Permanent or prolonged outages of essential supply services (water, electricity)
Environmental damage	Damage to unprotected areas with no environmental, historical or cultural value.	Recoverable damage to protected areas (e.g. loss of the beach line)	Irreversible damage in protected areas

Table 1. I_{FDS} criteria for the level of significance of the damage.

Figure 3. Detail of spatial distribution of the GIS database generated for damage in Los Alcazares.

3.2 GIS Indicators of land transformation

The phenomenon of land transformation or anthropization is spatially evaluated using GIS indicators of territorial transformation. By using historic GIS cartography, the evolution of various dimensionless indicators associated with these sub-phenomena is evaluated numerically over time. The indicators selected to evaluate the patterns of territorial transformation in the study area are detailed below:

- Linear infrastructure density index (LID): linear communication infrastructures are largely associated with the generation of "dam effects" during episodes of torrential rain that generate floods. This dimensionless index evaluates the spatial presence of these infrastructures in each analysis spatial cell, considering the size and relevance of the linear infrastructure.

$$LID = \frac{\sum h_i L_i^2}{S_{tr}}$$

L_i = length of existing linear infrastructures (m)
 h_i = weighting coefficient (highway=1, normal road=0.75, country road=0.5)
 S_{tr} = territorial surface in reference (m²)

- Index of soil artificialization (SA): The urbanization of the territory is, together with erosion, the main cause of the "sealing effect" of the soil. This phenomenon notably reduces the soil's ability to absorb rainwater. To analyze this phenomenon, the artificial transformation process of the territory is evaluated over the last decades.

$$SA = \frac{\sum h_i A_i}{S_{tr}}$$

A_i = Artificial surface area (m²)
 h_i = weighting coefficient (highly waterproof artificial surface = 1, medium waterproof artificial surface = 0.75, low waterproof artificial surface = 0.5)

- Index of alteration of the terrain orography (ATO): In this section, aggressive transformations such as the replacement of trees or herbaceous crops by fruit and vegetable crops are differentiated from intermediate actions such as relevant pending changes or elimination of the terraced structures of the crops, and minor ones such as simple changes in the crop direction or land use without three-dimensional alteration of its orography.

$$ATO = \frac{\sum h_i A_i}{S_{tr}}$$

A_i = orographically altered surface (m²)
 h_i = weighting coefficient (relevant orographic alterations = 1, intermediate alterations = 0.75, simple land use change = 0.5)

4. Results and Discussion

When studying the current urban planning models of the three municipalities, analyses using GIS-based indicators of the National System of Cartography of Floodable Areas show that the urban flooding vulnerability level is too high (Figures 4, 5 and 6). As described by other authors [5], the results show how some errors in urban planning have systematically contributed to the increase in the risk of flooding in urban areas in which it is currently very difficult to solve the problems created.

These analyses can also highlight whether it is necessary to implement measures for the mitigation of flood risk and damages within these models to enable sustainable and resilient urban planning from the perspective of the new European Union Adaptation Strategy [5], that sets out how the EU can adapt to the unavoidable impacts of climate change and become climate resilient by 2050. This strategy recognizes territorial management and urban planning regulations as the most appropriate framework in which climate resilience must be inscribed.

Figure 4. Evolution of urban development of Murcia between 1956 and 2019: (a) 1956; (b) 1981; (c) 2019; (d) Urban flood-prone areas for a theoretical simulation for a return period $T = 500$ years. Data source: National System of Cartography of Floodable Areas [3].

Figure 5. Evolution of urban development of Águilas between 1956 and 2019: (a) 1956; (b) 1981; (c) 2019; (d) Urban flood-prone areas for a theoretical simulation for a return period $T = 500$ years. Data source: National System of Cartography of Floodable Areas [3].

Figure 6. Evolution of urban development of Los Alcázares between 1956 and 2019: (a) 1956; (b) 1981; (c) 2019; (d) Urban flood-prone areas for a theoretical simulation for a return period $T=500$ years. Data source: National System of Cartography of Floodable Areas [3].

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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