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Correlation between Land Transformation and Climate Change with Flooding Vulnerability: Nature Based Solutions (NBS) Applied in a Mediterranean Case Study †

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Abstract: The combination formed by the intense transformation of the territory and climate change in the Spanish Mediterranean basins has configured an explosive cocktail from the point of view of the risk of flooding in these areas. Climate change is making new intense type cold drop rains called DANA a more frequent phenomenon in Mediterranean basins. The vulnerability of the coastal territory in these areas because of the DANA phenomenon now requires the authorities to implement new strategies and policies that reduce the significant economic damage and loss of human life suffered in recent years. However, correlating these two phenomena with the increased risk of flooding is a difficult problem to diagnose, and even more difficult to solve. For this reason, a structured GIS methodology is proposed based on a geostatistical indicators analysis that correlates the transformation of the territory with the increase in vulnerability due to floods. This methodology has been evaluated and put into practice in a case study of the basin area of a coastal lagoon in Spain. The impacts originated during the last three cold drop phenomena developed in recent years have been evaluated. The analysis carried out allows us to observe how the phenomenon of diffuse territorial anthropization in the territory has increased the damage caused by floods due to the loss of the natural hydrographic structure of the basin. Based on the results obtained in this analysis, risk mitigation actions will be proposed through the improvement of land management by using of nature-based solutions.

Keywords: flooding risk; GIS; DANA; Mar Menor; land transformation; Nature Based Solutions

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1. Introduction

There are numerous effects that the scientific community has managed to associate with climate change, being those related to the problem of floods some of the most dangerous. One of the areas of the planet where these changes are forcing administrations to rethink the methodologies to address this problem are the Spanish Mediterranean regions. There, the appearance of new cold drop phenomena called DANA (Spanish acronym for upper-level isolated atmospheric depression) has replaced the traditional flash floods associated with historical fall storm events.

In these regions, a great process of territorial anthropization has developed in recent decades. The Mediterranean area is undoubtedly the region in which tourism, agriculture, infrastructure expansion, etc. has experienced the greatest degree of growth in recent decades. However, it is not easy to assess how this new phenomenon of anthropization directly affects the growing problem of flooding in a territory. phenomena of a diffuse nature and with a rather indirect impact, such as the sealing effect of the soil due to urbanization processes of the land, orographic alterations produced by changes in land use and dam micro effects that linear communication infrastructures can generate currently do not

have specific methodological approaches in the traditional scientific literature. Several approaches for specific case studies can be found, but comprehensive large-scale evaluation methods from a territorial point of view are still lacking.

This study raises an innovative methodological approach based on the assessment of GIS indicators using geostatistics and Nature Based Solutions as a mitigation strategy. This new method assesses the spatial correlation between the territorial transformation derived from anthropic procedures with the growing risk of a territory to floods. To evaluate this new framework, the proposal is applied to the Campo de Cartagena area from south-eastern Spain, experiencing devastating floods in the last decade.

2. Area of Study and Methodology

2.1. Area of Study

The area of study is located in the Region of Murcia, a semi-arid area in south-eastern Spain (Figure 1). This region is distinguished by limited rainfall (<300 mm/year) which mainly occurs during storm events in autumn and winter. This watershed has been extensively transformed from relatively traditional dryland agricultural area to one of intense human activity in the last 50 years despite having significant environmental values [1].

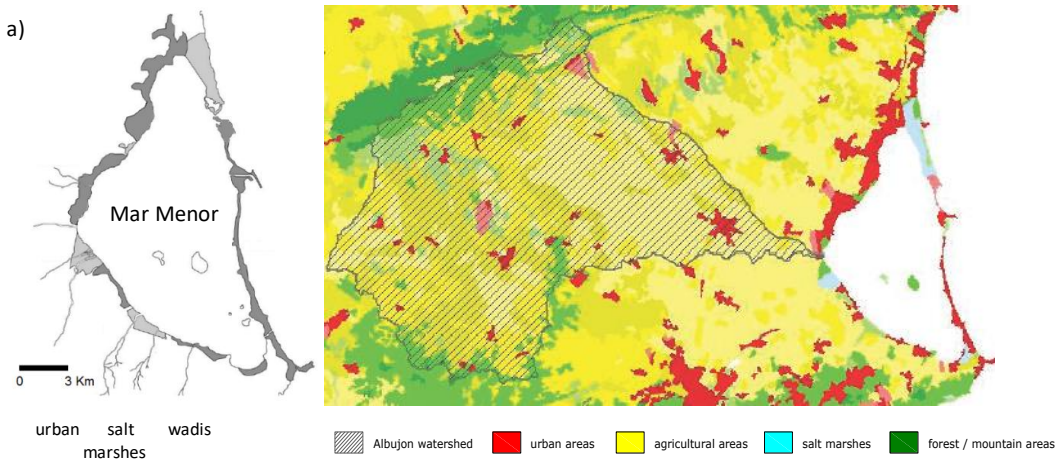

Figure 1. (**a**) Wadis going to the Mar Menor lagoon (**b**) Watershed nourishing Albujon wadi.

Freshwater inputs into Mar Menor come mainly from six main ephemeral watercourses called 'wadis'. These wadis can reach lengths of over 50 km. The watershed area that nourishes some of them, such as the Albujon, even exceeds that of the Mar Menor Lagoon itself. These wide and shallow channels are not usually active but are able to hold huge amounts of water and sediment during the usual flood periods of autumn and winter in the Mediterranean. The torrential nature of the water supply is now worsened by the impermeable soils and scarce vegetation cover of the watershed areas, going directly to the coastal lagoon. During the last decades there has been a great transformation of the territory that has coincided with a sharp increase in the damage caused by the rains, being especially relevant those produced in the years 2016, 2018 and 2019 ([2]).

2.2. Methodology

The framework used to analyze the impact of the phenomenon of diffuse territorial anthropization and its relationship with the increase in damage caused by floods is detailed below. A geostatistical assessment is developed to analyze the spatial correlation of the evolution of the selected indicators of territorial anthropization and the increasing of damages derived from floods. this spatial statistical analysis has been developed using the Local Indicators of Spatial Association (LISA). These statistical indicators have evaluated the level of correlation between the behavior patterns of each of the spatial indicators of

transformation of the territory generated and the distribution of the levels of damage detected in the last three DANA. Once the numerical analysis has been carried out, the level of two-dimensional correlation will be analyzed from the graphic point of view through the Getis-Ord Gi* statistic indicator. We next detail the methodological process of these stages [3].

Two georeferenced databases are implemented in this model to generate the indicators that serve as evaluation elements in the geostatistical analysis:

- Spatial values of the damage that occurred in the last three DANAs
- Spatiotemporal distribution of the most relevant GIS transformation indicators found in the bibliography

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 oversee processing the damage files of those affected by the flooding events, we generate a spatial qualitative punctual database of damage (Figure 2). 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 (technical details of the database configuration can be find in Appendix A). 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.

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

	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 environ- mental, historical or cultural value.	Recoverable damage to protected areas (e.g., loss of the beach line)	Irreversible damage in protected areas

Figure 2. Detail of spatial distribution of the georeferenced database generated for damage. Source: own elaboration from several emergency services.

By the other hand, the phenomenon of anthropization is spatially evaluated using GIS indicators of territorial transformation. This spatial transformation generates sub-phenomena such as the "dam effect" and "soil sealing" or alterations in the orography of the land that, according to the bibliography consulted, may have important implications on the risk of flooding of a territory. 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): weighted indicator of the level of territorial density of the linear communication infrastructures (these elements usually generate "dam micro effects").

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

L_i = length of existing linear infrastructures (m)/h_i = weighting coefficient (high capacity motorway = 1, traditional road = 0.75, country path = 0.5)/S_{tr} = sector of the area of study (m²)

Index of soil artificialization (SA): weighted indicator of the level of artificial soil transformation associated with urbanization phenomena by applying the Corine Land Cover criteria (these processes usually generate "soil sealing" effects) [4].

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

A_i = Urbanized surface area (m²)/h_i = weighting coefficient (highly artificial surface = 1, medium artificial surface = 0.75, low waterproof artificial surface = 0.5)/S_{tr} = sector of the area of study (m²)

Index of alteration of the terrain orography (ATO): weighted indicator associated with orographic transformations or land use changes in the territory [5].

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

A_i = land use altered surface (m²)/h_i = weighting coefficient (relevant orographic alterations = 1, medium alterations = 0.75, similar or partial land use change = 0.5)/S_{tr} = sector of the area of study (m²)

3. Results

Based on the framework proposed in the methodology section, the following results have been achieved. First, the existence of geostatistical significance in the distribution of the behavior patterns of the different indicators analyzed has been verified. Subsequently, the levels of statistical correlation between each of the indicators of anthropic transformation and the spatial distribution of the damage detected in the last DANA were studied numerically. This evaluation is carried out considering an evolutionary approach in the 1956–2020 period to analyze the incidence of each of the indicators of territorial transformation in the global land transformation process. Then, the level of statistical correlation of each of those anthropic sub-phenomena with the intensity of damage caused by floods is assessed. to implement this analysis, the hot and cold spots indicators from LISA two-dimensional statistics have been used.

If we parameterize the values reached to the numerical level in a bivariate Getis-Ord Gi* statistic of hot and cold spots from a spatial perspective, we can see clearly differentiated areas in the watershed, as displayed in Figure 3.

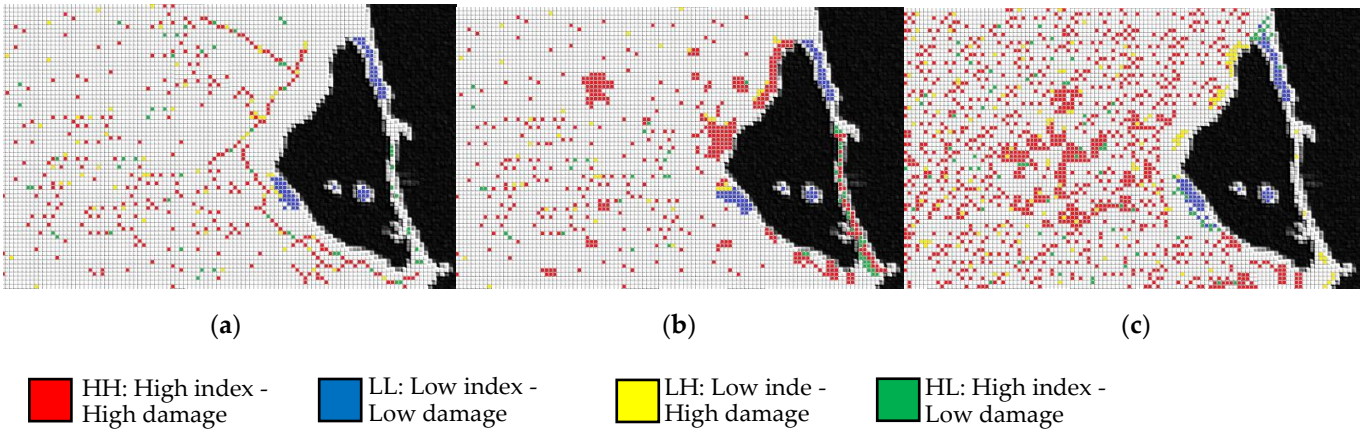

Figure 3. Hot and cold spot Getis-Ord Gi* statistic analysis for spatial statistical correlation between damage and anthropization indices: (**a**) $LID - I_{FDS}$ (**b**) $SA - I_{FDS}$ and (**c**) $ATO - I_{FDS}$.

As it can be verified, diffuse territorial anthropization is a phenomenon whose effects are not easy to appreciate since they gradually accumulate over the decades. However, once the impacts corresponding to this phenomenon surface, the consequences, as seen in the latest DANA in the area, can become catastrophic. In this sense, it is interesting to propose large-scale solutions that do not imply the development of aggressive infrastructures with nature to mitigate the effects of these phenomena.

The so-called nature-based solutions (NBS) are alternatives that are friendlier to the territory and whose ability to integrate into the natural environment makes them ideal alternatives to solve large-scale problems of this nature. They are tools traditionally used on an urban scale, such as the so-called sustainable urban drainage systems (SUDS). However, its combined approach by aggregating various actions on a large supra-municipal scale could be an innovative solution in this case from the point of view of integrated land management. In this context, it has been proposed as a conceptual approach the assignment of different alternative solutions based on nature as mitigation elements at a subregional scale of the effects of this problem in the Mar Menor drainage basin. The LISA analysis of hot and cold spots carried out shows how the least anthropized areas with the highest surface runoff retention and absorption capacity have been those that respond with the best capacity to extreme weather events.

Consequently, a strategic planning is proposed at a subregional level, assigning the most appropriate alternatives to the local problems that have been observed based on the spatial statistical analysis carried out. Based on the levels of damage and the anthropic problems detected as their cause, the following SBNs have been proposed based on the results obtained for the three previously studied GIS indicators: vegetated roofs, permeable pavements and rain gardens in urban areas; infiltration ditches, vegetated ditches and floodable bioretention beds near linear infrastructures, and, finally, green filters, detention tanks and retention ponds in large peri-urban areas. An initial allocation of proposals as a first approximation to this action can be seen in greater detail at a supra-municipal scale in Figure 4.

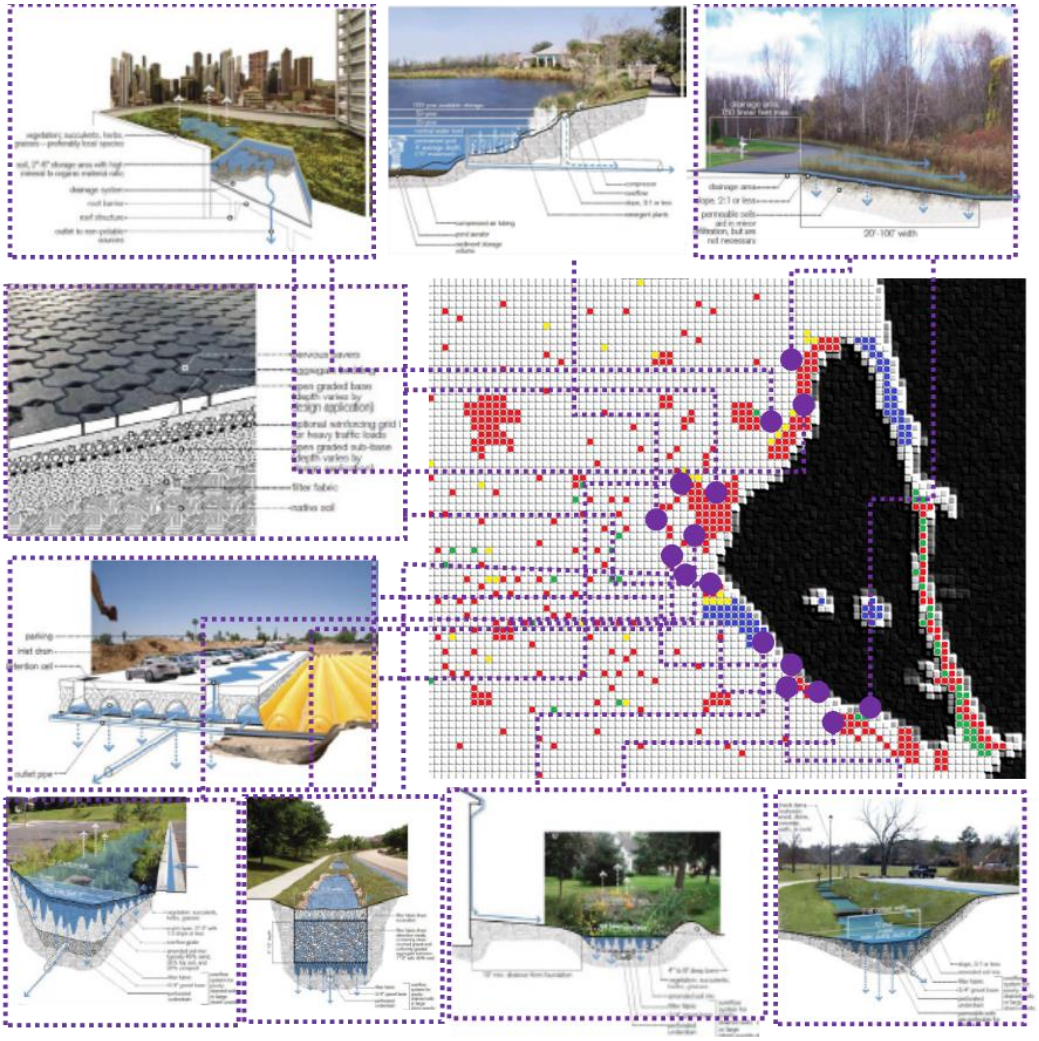

Figure 4. Different alternative solutions based on nature proposed in the context of the Mar Menor watershed as a solution to mitigate the effects of damage caused by floods.

4. Discussion and Conclusions

The results show, at a general level, a new methodological option which may constitute an interesting alternative in the study of the risk of flooding. The analysis of the relationship between the anthropization of the territory and the increase in vulnerability to flooding is an unusual approach in the study of flood risk, which frequently tends to focus its evaluation mainly on hydrological variables rather than territorial ones.

At the specific level, it has been possible to verify how the use of land management as a nature-based solution can be a very useful tool for mitigating this phenomenon. We have the atmospheric phenomenon of DANAs in coastal Mediterranean regions which, as highlighted by several studies [6], are increasing in frequency and intensity because of climate change. This issue, although belonging to another scientific disciplines, forces us to pay more attention to this problem from the point of view of territorial planning, since its effects on the territory will also be growing.

Considering the findings achieved through the geostatistical analysis, the anthropization of the territory in the area during the last decades has had a substantial impact on increasing the vulnerability of the Mar Menor watershed to floods. The loss of the natural hydrographic network of the basin has clearly boosted the vulnerability to flooding with a distinct impact in the damage caused to populations, crops, and natural areas. Nevertheless, as in other parts of the Mediterranean façade [7], this correlation of cause-effect does not seem to be homogeneous.

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