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CARTOGRAPHY OF TERRITORIAL VULNERABILITY TO FLOODING RISK. ADAPTED PROPOSAL TO THE EUROPEAN FLOODS DIRECTIVE AND DERIVED LEGISLATION

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I. INTRODUCTION AND OBJECTIVES

The main goal of this paper is to present a cartographic proposal for vulnerability assessment of the territory against flooding. The proposed maps are intended to collect the propounded indications in European legislation and to be useful for the effective implementation of the mitigation measures included in the Risk Management Plans and Action Plans in Local Scope.To achieve this main goal, it has been necessary to address, among others, the following partial objectives: 1. Conceptualization of the notion of vulnerability in order to clarify a very scattered panorama; 2. Identification of specific problems related to vulnerability at different stages of flooding (pre-emergency, emergency and normalization).

II. BACKGROUND AND CONCEPTUAL BASIS OF THE CARTOGRAPHIC PROPOSAL

A critical review of the cartographies of vulnerability to flooding has been performed in several contexts. This analysis allowed us to detect some major challenges to be resolved that are specified in the following section.

Vulnerability "to what?". Vulnerability of the territory to flooding is defined by a set of characteristics that enables it to better withstand the impact of the flood. It is critical to distin-

guish whether the exposed element is vulnerable to hazard itself, in other words, against the aggression of the flood, or to loss, that is, once there has been a negative impact, which will mean the resilience of the exposed element will be low. To merge indicators of vulnerability to hazard and to loss in the same map makes it very dificult to be interpreted. That is because those concepts are not necessarily neither proportional nor coherent and also because solutions of different nature are required in the context of risk management

Vulnerability *for what?*. a useful approach is proposed to implement solutions. The structure of the methodology and the resulting maps are based on a scheme of vulnerability issues that have been organized focusing on the type of solution to apply for mitigation. (Mitigation measures in each phase). We have been very careful about not mixing problems whose solutions belong to different management areas. The aim is to provide a mapping tool to support the implementation of specific management mesures.

Vulnerability *whose responsibility?*. Cartography of vulnerability is considered, for this specific proposal methodology, a supporting tool for implement mitigation measures. That being said, efforts have been made to propose measures and documents that clearly distinguish public or individual responsibility in solving every issue.

Vulnerability *where?*. When identifying the exposed elements and its vulnerability, it becomes necessary to make a special effort in order to match the space of risk and the spatial units in which the statistical data subject is expressed (artificial). There are some adaptation strategies to link synthetic statistical units to those other areas resulting of the impact of hazard.

Vulnerability *comparable?* It is highly recommended that vulnerability levels in any territory would be comparable to levels in another distinct area. To address this purpose, statistical procedures of measure of central tendency and dispersion have been used to calculate mean values (and therefore normal) of every variable of exposure or vulnerability in all floods areas of Andalusia. These data have been used as reference when defining thresholds intervals between high, medium and low vulnerability. Hence gravity intervals are not only comparable with one another in different basins, but realistically correspond with the gradation of the severity of the variable in the whole Andalusian territory.

III. METODOLOGY TO DO A CARTOGRAPHIC CATALOGUE

The following sequence of reasoning has been adopted to design the cartographic catalog: What is the problem of vulnerability ?; What mitigation measures could be implemented and are planned in the Risk Management Plans ?; What kind of maps are useful for implementing these mitigation measures? . The following main issues on vulnerability have been identified (after a prospective phase from previous events):Problems related to vulnerability to the hazard: *1. Interruption of basic local services; 2. Isolation of the population; 3. Difficulties of relief and assistance; 4. Risky or unsafe behaviors of the population; 5. Affection of goods or sectors of the territory that are particularly sensitive; 6. Affection of elements of the territory by pollution and other risks associated with flood*.Problems related to vulnerability to loss and resilience: *7. Generation of large losses; 8. Difficulty of the population to recover after impact*.

IV. RESULTS: CATALOG MAPPING OF VULNERABILITY TO FLOOD

IV.1. Block E: Maps concerning exposure

Maps IV.1.1. Concerning exposure of the population (Ep):

- *Map Ep1: Volume of affectable population by flooding (inside and outside the flood area)*
- *Map Ep2: affectable population density by flooding (in the flood area and outside the flood area)*
- *Map Ep3: Points concentration of the exposed population in the flooded area*

Maps IV.1.2. concerning exposure of goods (Eb)

- *Map Eb4: Cultivated area likely to be flooded*
- *Map Eb5: Surface for livestock likely to be flooded*
- *Map EB6: Industrial area likely to be flooded*
- *Map Eb7: Residential or services likely to be flooded area*
- *Map EB8: Infrastructure and equipment surfaces that could be affected*
- *Map EB9: Surface of protected areas and assets susceptible to flooding*

Block V: Maps related to vulnerability

IV.2.1. Mapping oriented to solving problems related to vulnerability to hazard (VPE):

Problem 1: Interruption of basic local services

Map Vp1: basic territorial services interrupted by the flood graded according to the spatial extent of the impact.
Map 1.1 Vp: Relief and assistance services to the affectable population by flooding or isolation scaled according to its territorial scope (local / regional / international)
Map 1.2 Vp Basic facilities affected by flooding or isolation scaled according to its territorial scope (local / regional / international)
Map 1.3 Vp: Transportation infrastructures affectable by flooding or isolation scaled according to its territorial scope (local / regional / international)
Map Vp2: Vehicular traffic interruptions due to flooding graded according to the magnitude of its impact (volume of traffic interrupted and affected population)
Map Vp 2..1: Vehicular traffic interruptions due to flooding graded according to the importance that disrupt traffic (ADT)
Map Vp 2..3: Vehicular traffic interruptions due to flooding graded according to the size of the population affected.
Map Vp 3: Other infrastructures affectable by flooding or isolation

Problem 2: Isolation of the population

Map Vp 4: Amount of population with the possibility of being isolated located inside and outside the flooding area, graded according to their level of isolation.

Map 4.1 Vp Population with the possibility of being isolated within the flooding area graded on the basis of to their degree of isolation
Vp Map 4.2: Population outside the flooding area capable of being isolated due to vehicular traffic interruptions, graded according to their degree of isolation.
Vp Map 4.3: Major workplaces involving population concentrations prone of being isolated (industrial, services), graded according to their degree of isolation

Problem 3: Relief and assistance difficulties

Map Vp 5: Sections of the territory with special potential needs of relief (rescue, assistance, surveillance) graded according to the accessibility to these services.
Map Vp 5.1. Sections of the territory with special potential needs of rescue (dependent population, buildings without shelter)
Map 5.2 Vp Sections of the territory with special assistance needs (water pumping, unblocking drains, removal of materials) (basements, roads with drainage difficulty)
Map 5.3 Vp Sectors of the territory with special security surveillance needs during the crisis (disorder, looting).
Map 5.4 Vp: Relief and assistance services accessibility to some sectors of the territory with higher potential needs.

Problem 4: risky or unsafe behaviors of the population. Information needs.

Map Vp 6: Collectives with special needs of information about what to do against catastrophe. Map Vp 7: Highly vulnerable road paths (high concentration of traffic) during times of maximum alert and hazard.

Problem 5: Affectations to high sensible goods or sectors of the territory.

Map Vp 8: Goods of special value for the community (patrimonial, natural, landscape, identitarian, etc.) exposed to flooding, graded by the importance of its value.
Map Vp 9: Particularly fragile goods to cope with flooding from a physical point of view (fragile homes, cars and other goods)

Problem 6: Affectation of elements of the territory by pollution and other risks associated with flooding.

Map Vp 10: Especially sensitive land-use types to contaminated flood waters or to consequences of other hazards associated with flooding.

IV.2.2. Maps aimed to solving problems related to vulnerability to loss and to resilience (Vr):Problem 7: High cost of replacing goods after loss

Map Vr 11: Economic potential loss of different land-uses (agriculture, buildings, vehicles)
Map Vr 11.1: Economic potential loss of agricultural land
Map Vr 11.2: Economic potential loss of effectible buildings
Map Vr 11.3: Economic potential loss of vehicles

Problem 8: Specific difficulties for recovery after impact

Map Vr 12: Economic level Indicators of the population living in the flood-prone area.Map Vr 13: Capacity of economic resilience of populations that live in households with the highest possibility of affectation

Table 1
SUMMARY OF VARIABLES AND SOURCES USED IN THE DEVELOPMENT OF MAPPING CATALOG

Thematic Block		Maps		Variables	Source
Exposure	Population exposure	Volume of affectable population by flooding or isolation. (Ep1)		Number of inhabitants affected in each population center (by flooding and / or isolation)	DERA
		Volume of affectable population by flooding or isolation (density). (Ep2)		Density of population affected (by flooding and / or isolation)	DERA
		Points of spatial concentration of exposed population. (Ep3)		Malls, schools, hospitals, airports, ports, train stations,, etc. affected in the floodable area	DERA
	Goods and services exposure	Agricultural land uses. (Eb4)		Number of cultivated hectares in the floodable area	SIOSE
		Livestock land uses. (Eb5)		Number of hectares of livestock land uses in the floodable zone.	SIOSE
		Industrial land uses. (Eb6)		Number of hectares of industrial land uses in the floodable zone.	SIOSE
		Residential and services land uses. (Eb7)		Number of hectares of residential or services land uses in the floodable zone	SIOSE
		Infrastructure and equipment land uses. (Eb8)		Number of hectares of infrastructure and equipment or facilities in the floodable zone	SIOSE
		Protected areas or patrimonial assets land uses. (Eb9)		Number of hectares of protected areas or patrimonial assets in the flood zone	SIOSE
Vulnerability	Basic territorial services interruption	Basic services affected by flooding or isolation (Vpe1)	Relief and assistance service (Vp 1.1)	Fire, police, civil guard, ambulances (hospitals and health centers) and red cross facilities affected by flooding or isolation.	DERA
			Equipment and basic services (Vp 1.2)	Hospitals, health centers, educational centers, public administration centers (police stations, etc) affected by flooding or isolation.	DERA
			Transport infrastructure. (Vp 1.3)	Airports, ports, highways / motorways, railways, roads affected by flooding or isolation, graded according to their level of scope (local, regional, national or international)	DERA
		Traffic intensity interrupted. (Vpe2)	ADT affected. (Vp 2.1)	Vehicle Average Daily Traffic (ADT) interrupted.	DERA
			Population affectable by traffic disruption. (Vp 2.2)	Number of inhabitants likely to be isolated by traffic disruption	E.P.
		Interrupted sanitation and supply services. (Vp 3)		Supply and sanitation networks affected by flooding or isolation	DERA

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	Thematic Block	Maps	Variables	Source
Vulnerability	***Population isolation. (Vp 4)***	*Isolated population in floodable areas. (Vp 4.1)*	*Number of inhabitants in the floodable zone graded according to their degree of isolation*	*E.P., DERA*
		Isolated population outside floodable areas. (Vp 4.2)	*Number of inhabitants isolated outside the floodable zone, graded according to their degree of isolation.*	*E.P., DERA*
		Isolated workplaces outside the flood area (Vp 4.3)	*Number of hectares of isolated services and industries outside the floodable plain, according to their degree of isolation.*	*E.P., SIOSE*
	Special needs of relief and surveillance (Vp 5)	*Rescue. (Vp 5.1)*	*Primary schools, day care centers, senior centers, special schools, disability care center, etc. affected*	*DERA*
			One floor buildings without roof	*DGC*
		Technical assistence. (Vp 5.2)	*Buildings and dwellings with basements (pumping)*	*DGC*
		Surveillance. (Vp 5.3)	*More susceptible shopping centers of being ransacked*	*DERA*
		Relief and assistance to critical population (Vp 5.4)	*Emergency services and assistance response isochronous to areas with special assistance needs.*	*E.P., SIOSE*
	Population with unsafe or risky behavior	*Population with information gaps about the crisis (Vp 6)*	*Population groups with communication difficulties: immigrants, tourists (hotels), foreign schools, housing estates with foreign population, foreign residents in isolated houses, etc.*	*E.P., DERA*
		Necessary transit routes during the crisis (Vp 7)	*Inward and outward routes to schools, centers of dependent population (elderly and disabled), parking and / or workplaces.*	*E.P., DERA*
	Affectations to particularly sensitive goods	*Goods of special value for the community. (Vp 8)*	*Patrimonial assets (cultural, natural or identitary)*	*DERA*
		Singularly fragile goods (Vp 9)	*Precarious buildings or in poor condition construction, and / or basement, and / or transverse arrangement to the flow direction; no permanent structures (outdoors markets, kiosks, etc.)*	*E.P., DGC*
			Vehicles parked in underground car parks	*E.P., DERA*

Table 1
SUMMARY OF VARIABLES AND SOURCES USED IN THE DEVELOPMENT OF MAPPING CATALOG

Thematic Block		Maps	Variables	Source
Vulnerability	***Affectations to particularly sensitive goods***	*Singularly fragile goods (Vp 9)*	*Street furniture (dumpsters, etc.)*	*E.P., DERA*
			Garden crops, livestock stables, greenhouses	*E.P.*
			Vials with special drainage problems (flood flow stagnation, sewage problems)	*E.P., DERA*
	Specially sensitive areas to contamination and other associated risks. (Vp 10)		*Protected natural areas (PNA, Sites of Special Scientific Interest [SSSI] o, Special Protection Areas for Birds, Sites of Community Importance [SCI]).*	*DERA*
			Catchments of water for human consumption and / or industry	*P.H.D. H.M.*
			Bath recreational areas	*DERA*
	High reposition cost of losses (Vr 11)	*Agrarian potential economic loss (Vr 11.1)*	*Type and number of hectares of crop affected by flooding*	*E.P., DGC*
			Estimation of potential economic losses (depending on size and type of crop)	*E.P., DGC*
		home potential economic loss (Vr 11.2)	*Square meters of housing affected by the flood*	*E.P., DGC*
			Estimation of potential economic losses (depending on the quality and extent of the housing and its average construction costs)	*E.P., DGC*
		vehicles potential economic loss (Vr 11.3)	*Number of parked vehicles in parking areas in the floodable zone.*	*E.P., DGC*
			Estimation of economic losses (as average market value)	*E.P., DGC*
	Difficulty of the population to recover from loss.	*Socioeconomic status of the population living in the flood-prone area (Vr 12)*	*Unemployment level*	*AVUE*
			Crime indicators	*AVUE*
			Quality indicators of housing: less than 30m², homes, no facilities or toilets, other	*AVUE*
		Resilience of the population living in flood-prone area (Vr 13)	*Socio economical status*	*E.P., AVUE*
			Housing conservation status	*AVUE*

Sources:
DERA: Spatial Reference Data of Andalusia 2016
EHCB: Hydraulic study for flood prevention and management of Bárbate river basin. General Directorate of Planning and Public Water Management, Ministry of Environment and Planning, Government of Andalusia. Year 2014
SIOSE: Land Occupation Information System of Spain. 2016.
E.P.: Own elaboration. Year 2016
DGC: General Directorate of Cadaster. Year 2016
P.H.D.H.M.: Hydrological Plan for the Hydrographic Demarcation of the Mediterranean. Year 2010
AVUE: Urban Vulnerability Atlas of Spain. 2016

V. CONCLUSIONS

Vulnerability cartography of the elements of territory against flooding constitutes a key factor for the implementation of solutions to the problem of flooding, an issue that shows a tendency for intensity increase in future climate change scenarios also associated to the extent of the urbanizing process. Furthermore, beyond the opportunity to apply preventive measures on hazards, to avoid the generation of damage in areas of future urban expansion, territorial reality of most countries shows that flooding problems in already established areas, where the risk is befallen and in which the main course of action is to reduce the vulnerability in territories inevitably exposed. The implementation of Flood Risk Management Plans in the field of Plans Local Scope is an unprecedented opportunity to effectively consolidate the proposed mitigation measures on vulnerability, and highlight the importance of the vulnerability is in the production of the catastrophe.

To clarify contents and terms involved in the concept of territory vulnerability against flooding, and the accuracy of the tasks that vulnerability cartography in the applied area is a matter that must necessarily be resolved and agreed upon in the field of scientific and academic reflection with the objective of rigorously undertaking the management phase and to apply mitigation measures on vulnerability. Provided that the procedure of vulnerability assessment in each ARPS is developed under different technical criteria, the potential of the tool would be invalidated.

The proposed cartographic catalog in this paper has provided criteria for scientific reflection on the conceptualization, consistency in transit between theory and application, and a strong applied sense to solving the problems of territory vulnerability to flooding. Therefore, it is shown as a complete and versatile tool, at the same time that is a useful and applicable tool for finding solutions to the impact of flooding.

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