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ENVIRONMENTAL ANALYSIS OF FLOOD RISK IN URBAN PLANNING: A CASE STUDY IN LAS QUEMADILLAS, CÓRDOBA, SPAIN

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Abstract

This paper presents a mapping procedure for determining the environmental impact of flooding in spatial planning. This procedure is applied to a section of the Guadalquivir River in the Quemadillas sector of Córdoba, southern Spain, where flood risks are of great importance because of improper riverside planning and the absence of prevention measures. We performed a comprehensive environmental analysis in conjunction with hydrological and hydraulic modelling using GIS techniques, allowing us to evaluate the flood hazard phenomena and the environmental impact based on the vulnerability and exposure of human activities. Hec-Ras application is implemented in GIS with GeoHecRas and we simulated flooding processes different flows for return period of 2, 100 and 500 years. Three-dimensional models are made for flood analysis and isobath and isotach maps. These low-cost maps are effective in the prevention and mitigation of flood risks, which makes them useful in the early stages of urban planning.

Key words: environmental impacts, environmental planning, flood risk, risk mapping, urban planning

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1. Introduction

Flooding is a natural disaster with great socio-economic impact over time, causing both damage to material and loss of life (Lewin, 2013; Slapinska et al., 2016; Theilen-Willige et al., 2012). Flood danger is reflected in EC Directive 60 (2007), which describes the assessment and management of flooding and aims to reduce the risks flooding entails (EC Directive 288, 2007). This directive's fundamental objective is to reduce the impact of floods on human health, the environment, cultural heritage and economic activity.

Flooding is a worldwide problem in both developed and developing countries. Though the number of victims in the last century has decreased thanks to protective measures and alarm systems, even the latest forecasting techniques cannot predict sudden catastrophic floods and lightning, which can lead to great human and material losses. The importance of flood risk has forced international cooperation programs, such as UNDRO (UNDRO, 1991), to create performance criteria in response to flooding and to set aside disaster aid. Two trends indicate an increased risk of flooding in Europe. First, it is likely that the magnitude and frequency of floods will increase in the future due to climate change (e.g., higher intensity of rainfall and rising sea level). Second, human occupation of areas at risk of flooding has increased.

In Europe, following the 2002 floods in Central Europe, the European Union Solidarity Fund created a specific financial instrument to grant rapid financial assistance in case of a major disaster, defined as costing over 3 billion Euros or 0.6% of gross national income in direct damage. The goal of this fund is to help the affected areas recover normal living conditions as quickly as possible. Because flooding

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commonly results in loss of life and property in Spain, the fight against flooding has been a constant in water policy and civil protection. In places, Spain has defined floodplains in which some uses of the riverbanks are prohibited. Moreover, the State Department of Civil Protection provides special plans in case of floods, which emphasize the need for the administration to consider flood risks in planning and potential land use zoning. Therefore, the department has launched a program called National Flood Zone Mapping within the Ministry of Environment. With this program, Spain has become one of the first European countries to implement Directive 2007/60/EC for the assessment and management of flooding. One of the program's aims is to develop flood risk maps and public outreach for sustainable decision making, allowing the exclusion of urban areas at risk from flooding. The risk maps provide essential information to the public but are also important tools for planners and the private insurance industry. Risk mapping with GIS techniques is closely linked to EU initiatives related to the collection, storage and exchange of environmental data (Martínez-Graña et al., 2013, 2016, 2018; Raaijmakers et al., 2008).

As an example of a common stance against the risks of flooding, several member states, such as Austria, Finland, Spain, Ireland and the Netherlands, have established levels of flood protection in the form of official guidelines or by law. Generally, the levels of protection are based on the number of people and the economic and cultural development in areas at risk of flooding. Additionally, many member states have developed or are developing flood risk maps. The objectives, structure and character of these maps are different, but generally, all are used in land use planning and to increase the awareness of danger zones. It is therefore necessary to prepare risk maps and implement flood risks plans.

The traditional response to flood risk is the construction of structural solutions, **such as levees, dams or conveyance options**. However, in recent decades, these methods have been supplemented with rational land management, civil protection plans, early warning systems, improved watershed hydrological-forestry and sustainable planning measures (Mebarki et al., 2012; Obradovic et al., 2017; Silva et al., 2017; Valencia Ortiz et al., 2018; Veleda et al., 2017). Proper land use is a rational, sustainable, and economical flood hazard reduction method, especially on a local scale. For this reason, studies of flood prediction are critical and investment in these projects is justified, especially over the long term (IGME, 2004, 2006).

The aim of this study is to present an easy and useful mapping procedure that can be applied in areas with flood risks at different scales. This mapping procedure aims to assess flood risks in compliance with existing regulations and to generate a database that meets INSPIRE Directive (EC Directive 108, 2007) protocols for use in the environmental analysis of flood risk. The procedure is applied to the Guadalquivir River, in the Quemadillas area (Córdoba, Spain), to identify the areas of greatest risk. To accomplish this task, we have modelled the height of potential floods at periods of 2, 100 and 500 years in the Guadalquivir River and established the environmental impact on areas by identifying increased hazards, vulnerability and risk exposure.

In Spain there are in use the periods of 2, 5, 10, 25, 100 and 500 years in the elaboration of the maps of risk for flood (EC Directive 60, (2007) on the evaluation and management of the floods; and art. 8 of the national law: Decree 903 (2010), of evaluation and management of risks of flood), with a geostatistical treatment of normal information (series of information of more than 20 complete consecutive years), the height of the area being considered to be a flood area up to where the water sheet comes with return period of 500 years.

The information of flows has been obtained in the gauging stations near to the zone (located in Capital Cordoba) where was observed that the frequency of the most catastrophic floods due to the human occupation of the fluvial margins they were every 2 years, and for it split of this return period. Nevertheless, the methodology has been applied for the rest of return periods though in this zone the major probability of flood is that of 2 years, major that of the return period of 5 and 10 years, the average probability of food it corresponds with 100 years and the low probability of flood corresponds with return period of 500 years. With regard to geographic location, the study area is located in the Quemadillas region on the outskirts of the city of Córdoba in southern Spain (Fig. 1A). The lack of sound and sustainable planning in this area has resulted in structures being built very close to the river. This poor planning exemplifies the need to carry out environmental impact studies and proper spatial planning to reduce the risk of floods.

2. Material and methods

The mapping process for the environmental assessment of flood risk is a comprehensive analysis of the physical environment combined with hydrologic-hydraulic modelling using GIS techniques. The results of the analysis and modelling have enabled the development of hazard and vulnerability maps, which have contributed to exposure risk mapping and environmental assessment (Fig. 1B). The physical environmental parameters analysed included climate, geology, geomorphology, hydrology, hydrogeology and land use. The Köppen climate classification indicates that the region has a temperate climate with hot, dry summers. The geological setting is dominated by limestones and shales in the northern sector and scattered outcrops of arkoses, shales and sandstones elsewhere. Covering this bedrock are quaternary deposits of gravel, sand, silt and clay from fluvial sedimentation. Geomorphological analysis plays an important role in the study of the origin and spread of flooding.

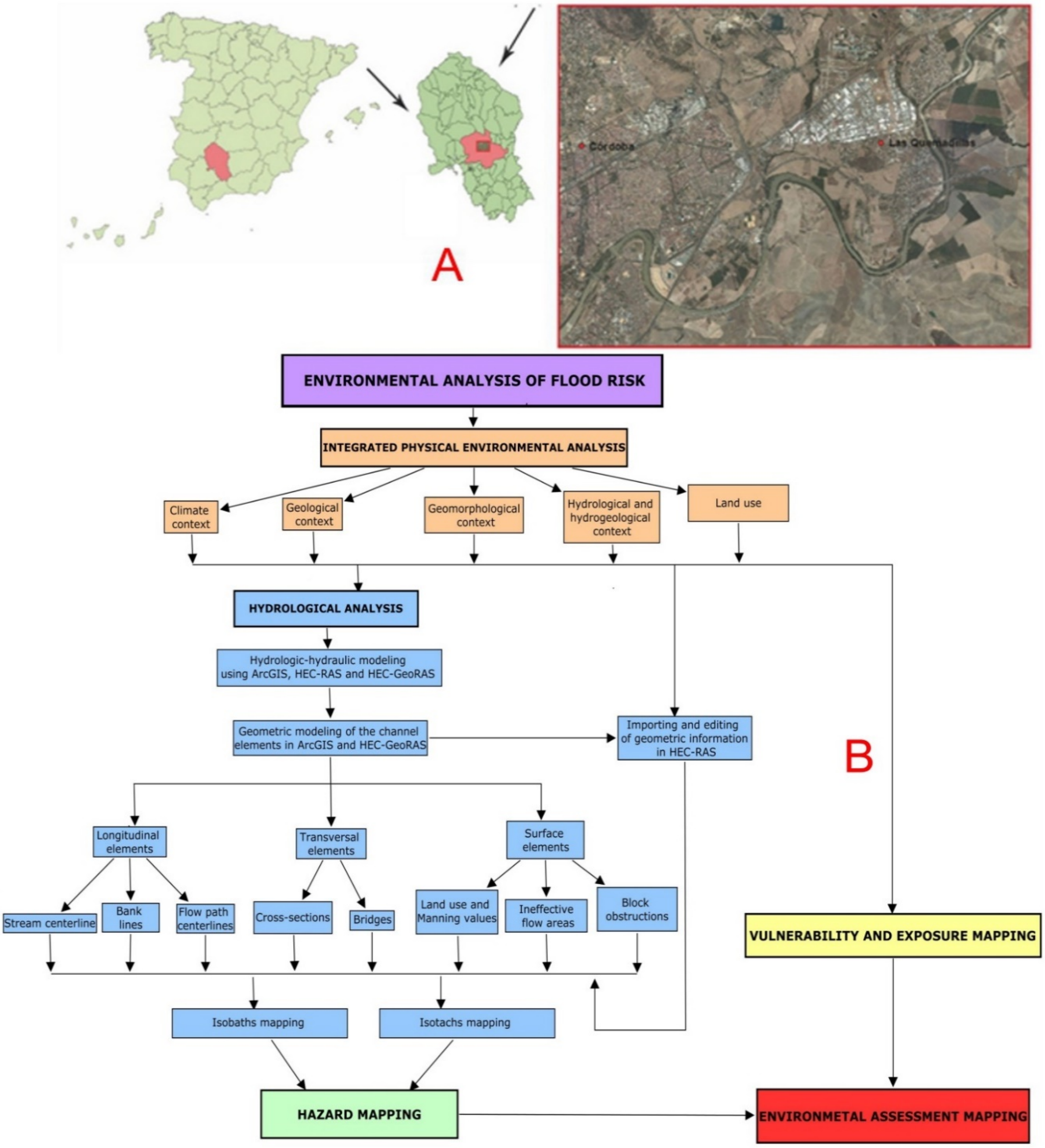

Fig. 1. Study area (A) and schematic of the mapping procedure for calculation of flood hazards (B)

The east-west flowing Guadalquivir River is characterized by a meandering path. The displacement of the river has led to the formation of a river valley with various forms and deposits characteristic of flood events such as alluvial fans left on the floodplain and glacis-slopes. The present floodplain contains channel bars (marginal, longitudinal and transverse) and ancient courses of the river (oxbows) (Fig. 2A).

Photo interpretation analysis has allowed mapping of the dynamic nature of the river channel during past and future flood events and has identified processes that determine the future behaviour of extraordinary flood events. The study and mapping of different terraces allows us to trace the evolution of the terrace fluvial geomorphology. There are two terrace levels above the present course of the river (elevation 110 m). The first terrace level is 120 m in elevation (+10 m above the bed), and the second level is at an elevation of 128 m (+18 m). These terrace levels can be identified from the topographic profile morphologies present in the north – south transect (Fig. 2B).

The water resources of the Guadalquivir River basin under normal conditions amount to 7,022 Hm^3/year. The largest contributions to the river occur in the months of January to March, totalling 53% of the annual contribution. The period from June to October contributes only 7.5% of the annual total.

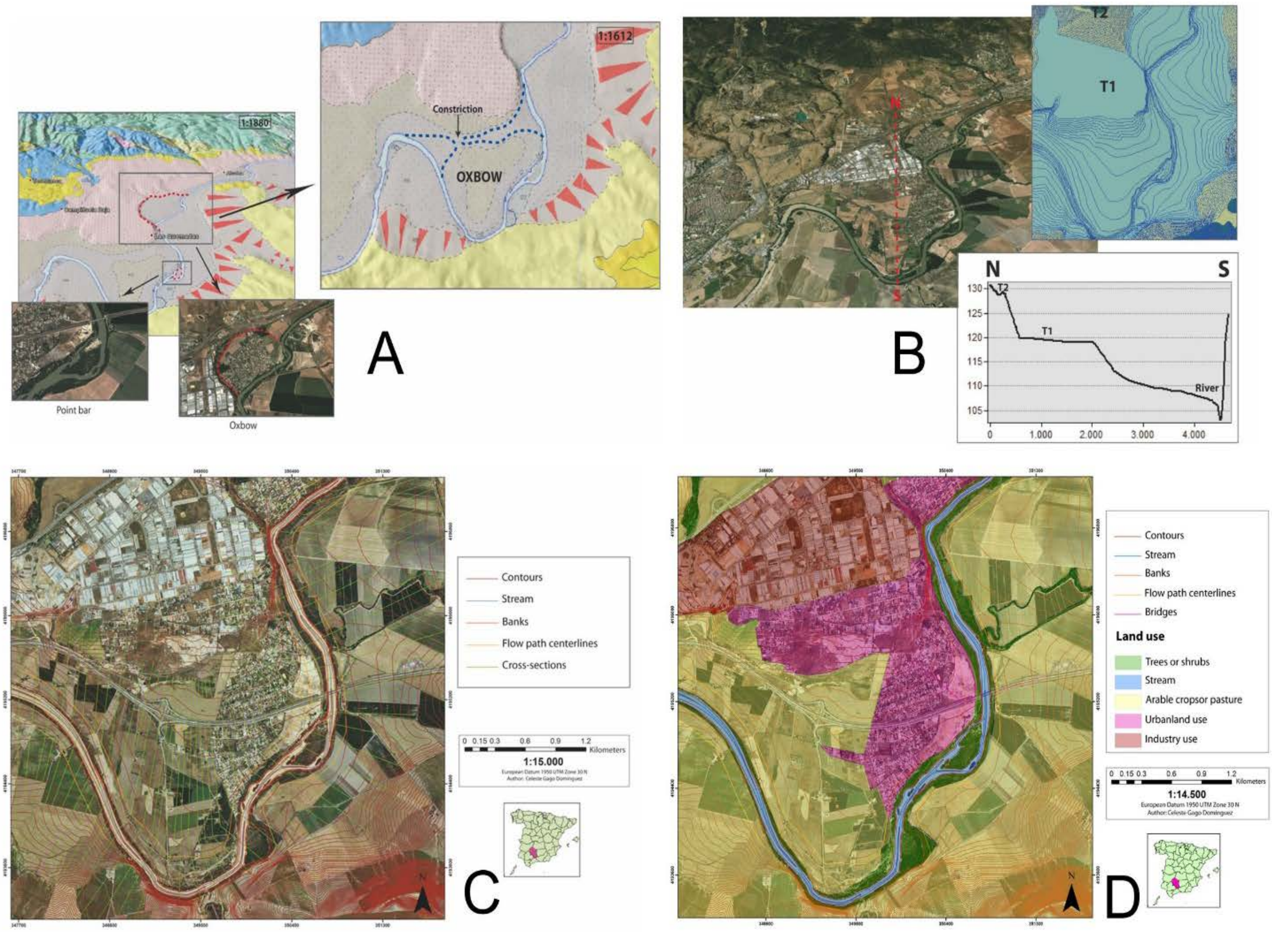

Fig. 2. (A) Capture of a strangulation and possible formation of oxbow, (B) Identification of levels of fluvial terraces from topographic profile, (C) Digitalization of longitudinal and land use, (D) Digitalization the channel cross members

In terms of hydrogeology, there are three distinct units: a Palaeozoic carbonate aquifer, an Early Miocene aquifer and the aquifer of the alluvial terraces of the Guadalquivir. The average annual recharge for all aquifers in the basin is estimated at 2,680 Hm^3/year, and the available resources are estimated to be 1,962 Hm^3/year.

The identification of different land uses is a very important step in the environmental assessment of flood risk. Knowledge of land use is essential to hydrological modelling and the mapping of flood vulnerability and exposure.

To identify land use, we used the European Corine Land Cover project maps at a scale of 1:50.000. Most of the study area closest to the channel is occupied by rain-fed and irrigated cropland (approximately 53% of total). Much of the land situated next to the riverbed is occupied by urban sprawl, which, together with the continuous urban fabric, represents 17% of the study area. The industrial and commercial areas of the northernmost area represent only 2% of the total area, but despite its small area, this is one of the most important industrial areas of the city of Córdoba (Fig. 2C).

For the hydrologic-hydraulic analysis of the Guadalquivir River, we used several geometric modelling elements, combining GIS techniques (ArcGis), the program Hydrologic Engineering Centers River Analysis System (Hec-Ras) and the extension GeoHec-Ras, which implements the geometric information of the channel and exports/imports data between Hec-Ras and GIS. The results of this hydrologic-hydraulic analysis provide a comprehensive picture of the physical environment and the distribution of water surface height and velocities for three periods: 2, 100 and 500 years. The data are then used to produce isobath and isotach maps. These maps, together with the mapping of vulnerability and exposure, allow us to obtain an environmental assessment of flood risk for use in zoning and civic planning.

Contours, spot heights and georeferenced GPS obtained from Triangulated Irregular Network (TIN) terrain modelling and orthophotos were used to map the geospatial distribution of the Guadalquivir River's channel and surrounding uses of land. With these new data, we modelled the geometric elements of the channel. To do so, we used digitised longitudinal (axis of the channel, edge lines and flow lines), transverse elements (cross sections and bridges) and surface elements (land and Manning values, and obstructed channels) (Fig. 2D).

The topographic analysis of the area complements itself with the information of a model

3D of the area realized with technologies LIDAR (Light Detection and Ranging), with spatial resolution of 0.5 meters for pixel. By means of two field campaigns the forms of the area have been recognized verifying the information topographic survey on the ground, taking some points with GPS (Global Positioning System) and precision altimeter for a major detail of some cross sections, being georeferenced and interpolated in the final model of the area to validate the assigned levels in the GIS.

We subsequently edited and corrected the geometric channel information with Hec-Ras. The longitudinal reference information was incorporated into the channel and flow lines, and information on the morphology of the terrain, including Manning value distribution and infrastructure, was incorporated into the cross sections of the bridge section. The bridge in the study area was edited and corrected by geometric editing tool Hec-Ras (Fig. 3A).

There have been in use different values of the number of Manning according to the different uses of the soil (agricultural crops, urban zones, industrial areas) and the presence or not of vegetation. In the zone of study the zones and values that have been in use are zones with trees and shrubs: value 0.09, riverbed without vegetation: value 0.04, zones of herbaceous crops and pastures: value 0.05, residential areas out of urban area: 0.08, urban areas: value 0.09 and industrial areas: value 0.1.

The different land use have been validated in the first campaign of field in the area determining the number of Manning for every sector depending on the category of land use. We then conducted simulated flooding processes different flows for each period: T = 2 years with Q = 1.347 m^3/s, T = 100 years with Q = 4.014 m^3/s, T = 500 years with Q = 6.897 m^3/s. These flows were obtained from a nearby gauging station. This analysis was carried out in steady flow conditions, in which the flow rates were constant for each location and were subcritical.

3. Results and discussion

Using the techniques and procedures explained in the previous section, we obtained the results on the analysis of flooding within the Guadalquivir River study area. First, using georeferenced orthophotos, we produced three-dimensional spatial predictions of the extent of flooding due to extreme precipitation events corresponding to periods of 2, 100 and 500 years (Fig. 4). Second, the model generated a database with all speed values for each channel cross section for each period (Fig. 3B). The velocity distribution varies from 4 m/s in the centre section to 0 m/s at the margins. Higher speeds and greater speed variation are concentrated in the central section of the channel, while on the floodplain, flow velocities are very slow or almost zero. From the results obtained by GeoHec-Ras, the model also produced spatial predictions of flood height, water depth and the distribution of flow rates for each model period. Compiling these predictions created isobath maps, which provide information on the spatial distribution of water depth, and isotach maps, with information on the spatial distribution of flow rates (Fig. 5). Third, we mapped hazard zonation with three rankings of hazard in the study area by using the distribution water depth (bottom contour mapping) and the distribution of flow rates (isotach mapping) (Fig. 5).

The highest danger zone corresponds to areas where the model predicts water depths of 1 m or higher and current velocities of 1 m/s or faster, or areas of special circumstances. The Guadalquivir floodplain is within this zone even in the modelled 2-year run and therefore has a high probability of experiencing hazardous flood conditions.

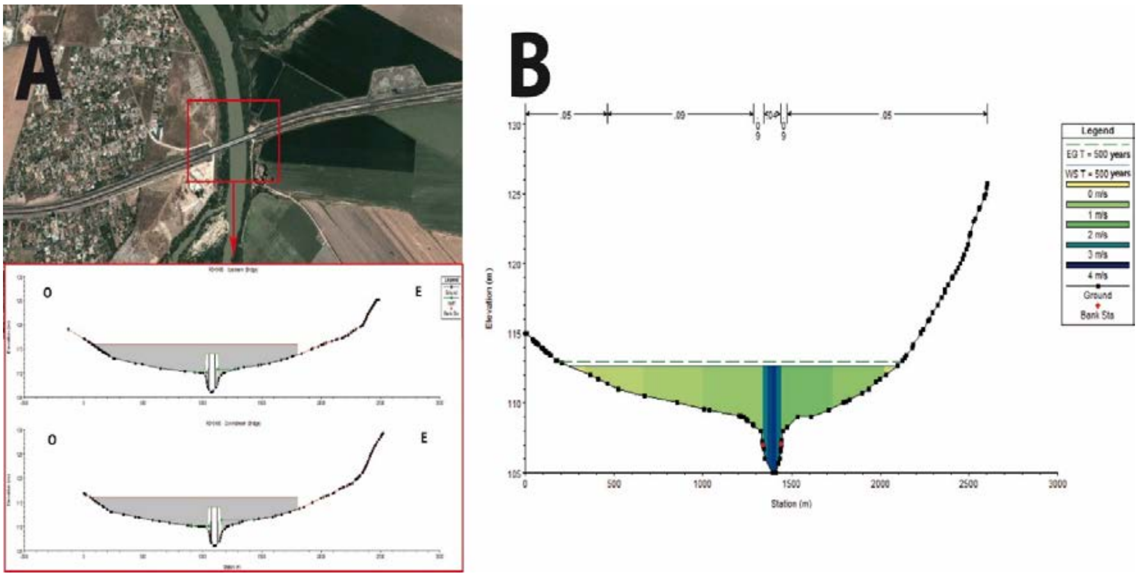

Fig. 3. Definition of the geometrical structure of infrastructure: bridges (A) and profile of the sheet of water at T = 500 years (B)

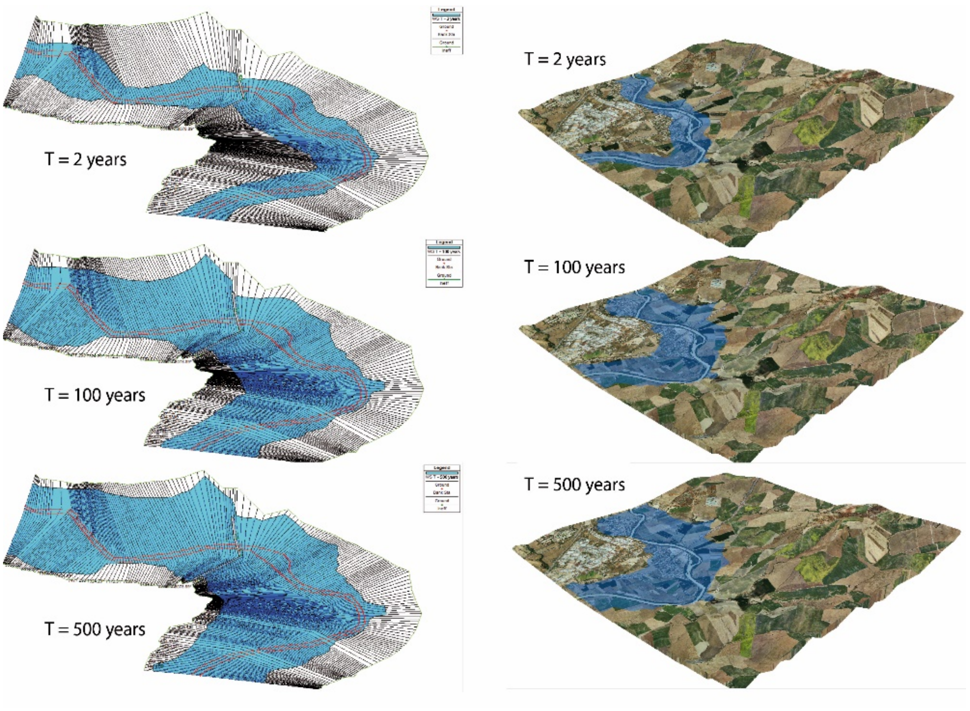

Fig. 4. Three-dimensional models of flood analysis

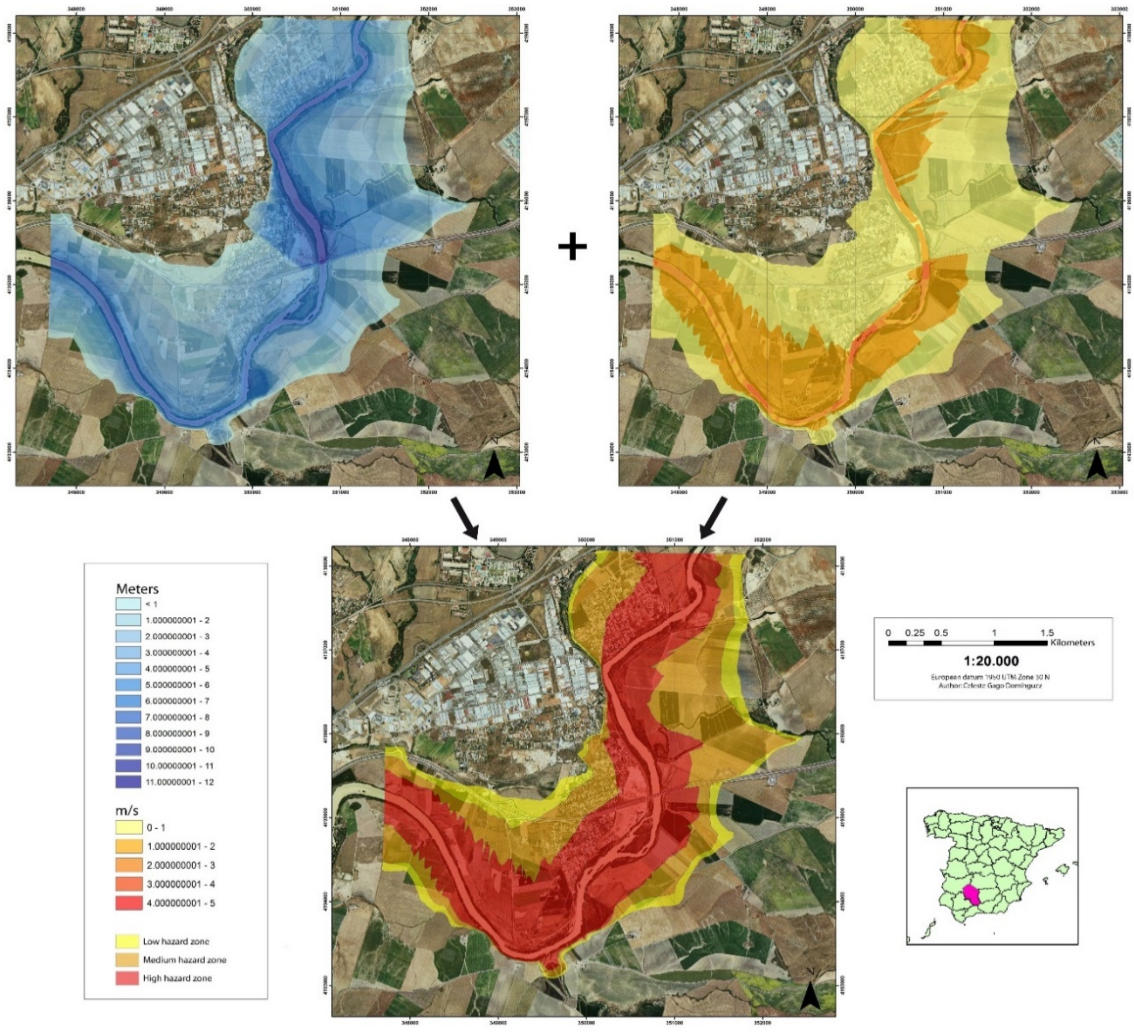

Fig. 5. Cartographies of isobaths and isotachs for T = 500 years (top) and flood hazard mapping (below)

A second danger zone corresponds to areas likely to be flooded frequently but with depths and speeds not likely to endanger human life (less than 1 m deep and slower than 1 m/s). These areas experience flooding during the 100-year model period and have an average flooding likelihood. Finally, a third zone of low hazard corresponds to areas where floods occur only in extraordinary circumstances and at low frequencies. These areas experience flooding only in the 500-year model run and have a low probability of flooding.

Our fourth result is the mapping of the potential environmental impact caused by flooding, taking into account the vulnerability in the study area. Vulnerability is determined by exposure, degree of natural predisposition of the area to flooding, and by sensitivity, the population of potential victims and the amount of infrastructure and property. This generates vulnerable areas (areas with human activities located in flood hazard areas) or non-vulnerable areas (absence of human activities located in flood hazard areas). Exposure is determined by the importance of human or material damage likely to be generated by flooding in vulnerable areas. The term vulnerability has been widely debated by great number of authors (Barroca et al., 2006; UNDRO, 1991) In this work it does not try to enter the above-mentioned questions by what the meaning is established both of vulnerability and of exhibition to the risk, so that they understand each other easily and allow to establish clearly different degrees of valuation. The qualitative valuation is the one that habitually is in use in studies of vulnerability and hazards for risks of fluvial and coastal flood (Balica et al., 2012; Cançado et al., 2008; Ramieri et al., 2011; Wisner et al., 2003; Wu et al, 2002).

In the preparation of vulnerability and risk exposure maps, the degree of vulnerability/exposure was weighted by taking into account the population of potential victims and, to a lesser degree, the amount of infrastructure and property. We determined the weight of the different factors by assessing the factor's overall importance against the risk of flooding. Each land use category was assigned a quantitative value weighted in terms of the type of human presence associated with that category. With some simplification, this categorisation established three zones of high, medium and low vulnerability and exposure to flood hazard (Table 1).

To determine the impact of different values, a matrix was developed with the values of all possible combinations of risk associated with vulnerability and exposure, which led to five impact categories (Table 2).

Table 1. Criteria of zoning of the area of study, with the description of the vulnerability according to the presence or absence of human activities, type of presence, quantitative value (meaning) and qualitative (value) of vulnerability and exposure depending on the group of the category of land uses

Vulnerability and exposure				
Criteria	***Description***	***Value***	***Category of land use***	***Meaning***
Urban areas	Areas with high risk by human presence constant	5	Continuous urban areas	High
			Discontinuous urban areas	
Infrastructures	Areas with medium risk by human presence eventual	3	Industrial or commercial	Medium
			Road and rail networks and associated land	
			Airports	
			Mining extraction	
			Construction Zones	
			Sports and Recreational areas	
Natural Environment	Uninhabited areas	1	Rainfed farmland	Low
			Permanently irrigated land	
			Olives	
			Meadows and pastures	
			Crop mosaic	
			Mainly agricultural land	
			Agroforestry	
			Broadleaf forests	
			Coniferus forests	
			Mixed forest	
			Natural grass	
			Sclerophyllous scrub	
			Transitional woodland scrub	
			Rivers	
			Water sheets	

Table 2. Matrix of impact

		Vulnerability and exposure		
		High	***Medium***	***Low***
Hazard	High	Very High	High	Medium
	Medium	High	Medium	Low
	Low	Medium	Low	Very Low

The impact matrix is a double entry matrix, which produced nine areas with different degrees of impact. These nine areas were simplified to five areas with very high, high, medium, low and very low environmental impact flood risk. The degree of the environmental generated impact, considering the man as it is a logical an integral part of the natural environmental, is organized into a hierarchy by means of the crossing of 3 levels of hazards (high, medium and low) with three degrees of vulnerability and exposure (high, medium and low).

In this matrix of impacts there are obtained nine areas that are identified on the cartography where the sectors of the territory are established and the impact for risks of flood is very high and high (zones there are human important presence and illegal accessions). The areas of very high and high impact constitute areas that should be catalogued by the municipal managers like of total prohibition of human accessions. The areas of impact medium and low are areas where there can be realized human activities (agricultural crops, recreative areas…) which presence humanizes can be temporarily but no to establish human stable accession. Finally the areas of very low impact might devote one human settlements bearing in mind corrective measures and of prevention of the risk. Zones of environmental impact associated with the riverbanks of the Guadalquivir River were produced from different GIS techniques that combine maps and algebra (Fig. 6).

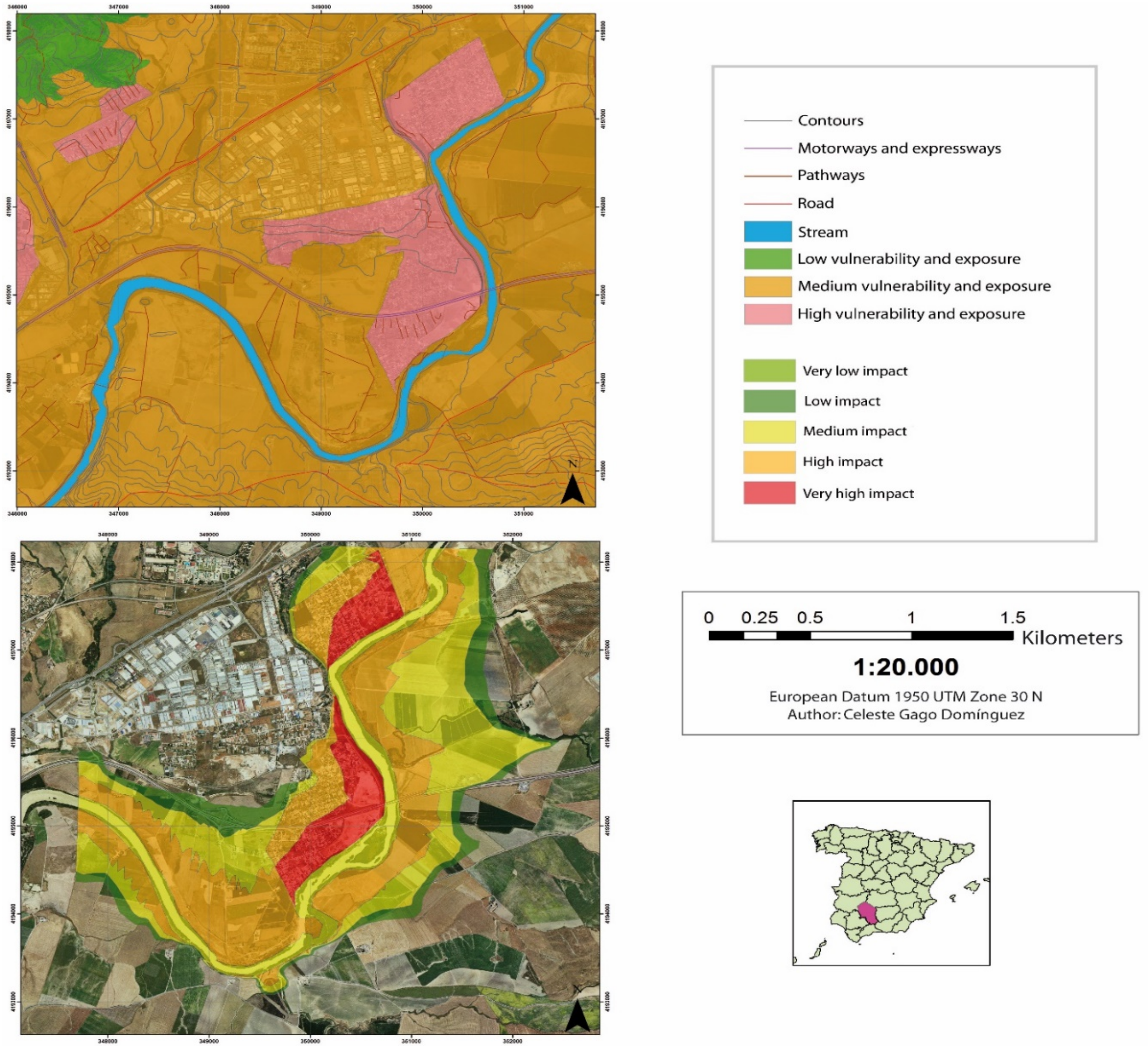

Fig. 6. Vulnerability and Exposure Map (above) and Environmental Impact Map (below)

The result of this process of flood risk analysis or better territorial planning produces five categories of impact. The very high impact zone covers an area of 1.17 km^2, which represents approximately 10% of the total area at risk from flooding. This area is located on the right bank of the river on the floodplain and contains areas with high population density and industrial activities. The zone characterized by high impact occupies areas close to both sides of the river, but the land is mostly uninhabited farmland. This area covers 4.41 km^2, which represents 39% of the total at-risk area. The largest area affected by flood risk is the medium impact zone, which has an area of 4.54 km^2, representing 40% of the total. This zone covers most remote areas of the channel, and the channel itself, but it is not inhabited in some areas.

Finally the zones with low and very low impacts are the most remote areas of the channel, where there is little to no risk to human activity or property. These zones comprise an area of 1.23 km^2, accounting for 11% of the total area.

4. Conclusions

The proposed methodology and techniques developed through GIS mapping generates digital georeferenced databases, which may be made available on web servers and libraries for use in local municipalities. This work will be very useful in creating strategic environmental assessment procedures because of the ability to represent different degrees of flood hazard risk, vulnerability and exposure.

This environmental analysis of flood risk has established zones based on the impact of flooding in the Quemadillas sector of Córdoba, Spain, by using GIS techniques.

The results show the existence of areas that have a very high degree of impact. These regions are urban areas that are very close to and found on both banks of the Guadalquivir River. The areas have high flood risk values for hazard, vulnerability and exposure. The risks can be heightened by the presence of civil works, such as bridges, pipelines and rivers and may be underestimated if this study has not properly modelled hydraulic behaviour over time and space.

Our analysis reveals that inappropriate land use (settlement building) has occurred along the Guadalquivir River. During extraordinary floods, there is not enough capacity to store floodwaters, given the river's channel dimensions, resulting in flooding of poorly positioned urban areas. This confirms the need for a review of urban planning as well as the need to adopt a series of measures to mitigate flood risk. Such measures should include weather forecasting and hydrological, corrective and preventive measures (both structural and non-structural) to reduce the risk and effects of flooding. One low-cost preventative measure is the mapping of environmental impacts. As recommended by the INSPIRE directive, the GIS technique methodology may be available for future multidisciplinary studies that encourage sound and sustainable land management and aim to reduce localised flood risk. This mapping helps implement post-disaster measures for evacuation; geospatially locates risk, based on the probability of flood occurrence; produces quantifiable calculations of flow rates; and ultimately strengthens warning systems.

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References

Balica S.F., Wright N.G., Van der Meulen F., (2012), A flood vulnerability index for coastal cities and its use in assessing climate change impacts, *Natural Hazards*, **64**, 73-105.

Barroca B., Bernardara P., Mouchel JM., Hubert G., (2006), Indicators for identification of urban flooding vulnerability, *Natural Hazards and Earth System Science*, **6**, 553-561.

Cançado V., Brasil L., Nascimento N., Guerra A., (2008), *Flood Risk Assessment in an Urban Area: Measuring Hazard and Vulnerability*, 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK.

Decree 903, (2010), Royal Decree 903/2010, of 9 July, on flood risk assessment and management, On line at: http://hispagua.cedex.es/en/documentacion/legislacion/35235.

EC Directive 60, (2007), Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks, On line at: https://www.eea.europa.eu/policy-documents/directive-2007-60-ec-of.

EC Directive 108, (2007), Directive 2007/2/EC of the European parliament and of the council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), *Official Journal of the European Union*, 25 April 2007, L 108, 1-14, Brussels.

EC Directive 288, (2007), Directive 2007/60/CE of the European parliament and of the council of 23 October 2007 on the assessment and management of flood risks. *Official Journal of the European Union*, 6 November 2007, L 288, 27-3, Brussels.

IGME, (2004), *Losses Due to Earthquakes and Floods in Spain during the Period 1987-2001 and its Estimate for the Next 30 Years (2004-2033)*, Insurance Compensation Consortium (Ed.), Madrid, Unpublished.

IGME, (2006), *Hazard Maps of Floods and Floods. Methods, Experiences and Application*, Environmental Series, Geological Risk 7, Publications of the Geological Survey of Spain (IGME), Madrid.

Lewin J., (2013), Enlightenment and the GM floodplain, *Earth Processes and Landforms*, **38**, 17-29.

Martínez-Graña A.M., Goy J.L., Zazo C., (2013), *Flood Hazard Mapping of the Yeltes River Basin for the Planning of Natural Spaces of "Las Batuecas-Sierra de Francia" and "Quilamas" and their Influence Zone*

(Salamanca, Spain). In: *Management of Water Resources in Protected Areas (Chapter 4: Design and Management of Water Resource)*, Farfan González H., Corvea Porras J.L., De Bustamante Gutiérrez I., Lamoreaux J.W. (Eds.), Springer, La Habana-Cuba, 113-121.

Martínez-Graña A.M., Goy J.L., Zazo C., (2016), Geomorphological applications for susceptibility mapping of landslides in natural parks, *Environmental Engineering and Management Journal*, **15**, 1-12.

Martínez-Graña A., Gómez D., Santos-Francés F., Bardají T., Goy J.L., Zazo C., (2018), Analysis of flood risk due to sea level rise in the Menor Sea (Murcia, Spain), *Sustainability*, **10**, 780.

Mebarki A., Valencia N., Salagnac J.L., Barroca B., (2012), Flood hazards and masonry constructions: a probabilistic framework for damage, risk and resilience at urban scale, *Natural Hazards and Earth System Sciences*, **12**, 1799-1809.

Obradovic L., Lekovski R., Mikic M., Bogdanovic D., (2017), Restoration of degraded area by flotation tailings made by flood wave of Bor River, *Environmental Engineering and Management Journal*, **16**, 2247-2254.

Raaijmakers R., Krywkow J., Van Der Veen A., (2008), Flood risk perceptions and spatial multi-criteria analysis: an exploratory research for hazard mitigation, *Natural Hazards*, **46**, 307-322.

Ramieri E., Hartley A., Barbanti A., Duarte Santos F., Gomes A., Hilden M., Laihonen P., Marinova N., Santini M., (2011), Methods for assessing coastal vulnerability to climate change, European Environment Agency European Topic Centre on Climate Change Impacts, Vulnerability and Adaptation, ETC CCA Technical Paper 1/2011, Bologna, Italy, On line at: https://climate-adapt.eea.europa.eu/metadata/publications/methods-for-assessing-coastal-vulnerability-to-climate-change-etc-cca-technical-paper-1-2011.

Silva P.G., López M., Roquero E., Huerta P., Martínez-Graña A.M., (2017), Chronology of fluvial terrace sequences for Large Atlantic Rivers in the Iberian Peninsula (Upper Tagus and Duero drainage basins, Central Spain), *Quaternary Science Reviews*, **166**, 188-203.

Slapinska M., Chormanski J., Glinska-Lewczuk K., (2016), Relation between inundation frequency and habitat conditions of floodplain lakes - a case study of the lowland Biebrza River (NE Poland), *Environmental Engineering and Management Journal*, **15**, 1311-1321.

Theilen-Willige B., Savvaidis P., Tziavos I., Papadopoulou I., (2012), Remote sensing and geographic system (GIS). Contribution to the inventory of infrastructures susceptible to earthquake and flooding hazards in north-eastern Greece, *Geosciences*, **2**, 203-220.

UNDRO, (1991), Mitigation Natural Disaster: Phenomena, Effects and Action a manual for policy makers and planners, Office of the United Nations Disaster Relief Organization, Geneva, On line at: http://cidbimena.desastres.hn/pdf/eng/doc1028/doc1028-indice.pdf.

Valencia Ortiz J.A., Martínez-Graña. A.M., (2018), A Neural Network Model applied to Landslide Susceptibility Analysis (Capitanejo, Colombia). Geomatics, *Natural Hazards & Risk*, **9**, 1106-1128.

Veleda S., Martínez-Graña A.M., Santos-Francés F., Sánchez-San Roman J., Criado M., (2017), Analysis of the hazard, vulnerability, and exposure to the risk of flooding (Alba de Yeltes, Salamanca, Spain), *Applied Sciences*, **7**, 157.

Wisner B., Blaikie P., Cannon T., Davis I., (2003), *At Risk: Natural Hazards, People's Vulnerability and Disasters*, Routledge Taylor & Francis Group, Londres.

Wu S., Yarnal B., Fisher A., (2002), Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersey, USA, *Climate Research*, **22**, 255-270.