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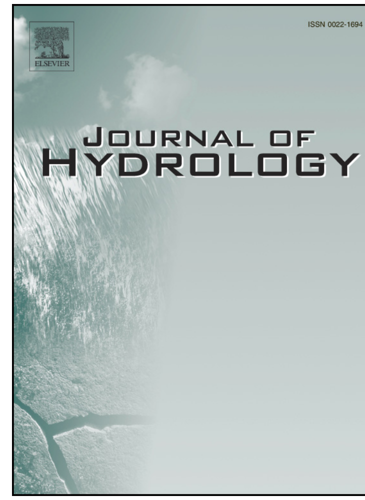

Improvement of resilience of urban areas by integrating social perception in flash-flood risk management

J.M. Bodoque, M. Amerigo, A. Díez-Herrero, J.A. García, B. Cortés, J.A. Ballesteros-Cánovas, J. Olcina

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Improvement of resilience of urban areas by integrating social perception in flash-flood risk management

Bodoque, J.M.[1*]; Amerigo, M.[2]; Díez-Herrero, A.[3], García, J.A.[2]; Cortés, B.[2], Ballesteros-Cánovas, J.A.[4,5]; Olcina, J[6].

[1] *Castilla-La Mancha University, Dept. of Mining and Geological Engineering, Toledo, Spain.*
[2]*Castilla-La Mancha University, Research Group on Environmental Psychology. Spain*
[3]*Geological Hazards Division, Geological Survey of Spain, Madrid, Spain*
[4] *Institute for Environmental Sciences, University of Geneva, chemin de Drize 7, 1227 Carouge, Switzerland*
[5]*Dendrolab, Institute of Geosciences, University of Bern, Switzerland*
[6]*University of Alicante, Dept. of Regional Geographical Analysis, Spain*

[*]Corresponding author. Tel.: +34 925268800; fax: +34 925268840.
E-mail address: josemaria.bodoque@uclm.es (J.M. Bodoque).

Abstract

In urban areas prone to flash floods, characterization of social resilience is critical to guarantee the success of emergency management plans. In this study, we present the methodological approach that led to the submission and subsequent approval of the Civil Protection Plan of Navaluenga (Central Spain), in which the first phase was to analyse flood hazard by combining the Hydrological Modelling System (HEC-HMS) and the Iber 2D hydrodynamic model. We then analysed social vulnerability and designed measures to put into practice within the framework of the Civil Protection Plan. At a later phase, we assessed citizens' flash-flood risk perception and level of awareness regarding some key variables of the Civil Protection Plan. To this end, 254 adults representing roughly 12% of the population census were interviewed. Responses were analysed descriptively, comparing awareness regarding preparedness and response actions with the corresponding information and behaviours previously defined in the Civil Protection Plan. In addition, we carried out a latent class cluster analysis aimed at identifying the different groups present among the interviewees. Our results showed that risk perception is low. Specifically, 60.8% of the interviewees showed low risk perception and low awareness (cluster 1); 24.4% had high risk perception and low awareness (cluster 2), while the remaining 14.8% presented high long-term risk perception and high awareness (cluster 3). These findings suggest the need for integrating these key variables of social risk perception and local tailored information in emergency management plans, especially in urban areas prone to flash-floods where response times are limited.

Keywords: Flash flood; Risk; Emergency management plan; Social resilience; Central Spain

1. Introduction

Small and medium size catchments, i.e., catchments with a drainage area up to a few hundred square kilometres (Kelsch, 2001), often respond rapidly to intense rainfall events and/or orographic forcing of precipitation because of the strong connectivity between their high slopes and quasi-circular morphology (Ruiz-Villanueva et al., 2010). Additional physical properties, such as the fraction of impervious area, land uses and soil types, together with time-varying states like soil moisture, will also help to modulate the flash flood potential of heavy rainfall (Hapuarachchi et al., 2011).

The context described above is highly prone to extreme precipitation events, in terms of both total volume and intensity. The resulting floods have a rapid hydrological response, characterized by “peaky” hydrographs (i.e., short lag time). The flow peaks are reached within a few hours, thus giving little or no advance warning to mitigate flood damage (Borga et al., 2007; Borga et al., 2008). This hydrological response leads to the occurrence of a typology of floods known as flash floods because of their rapid onset, i.e., within six hours of rainfall (Ogden et al., 2000; Delrieu et al., 2005; Marchi et al., 2010; Hapuarachchi et al., 2011; Naulin et al., 2013; Ballesteros-Canovas et al., 2015).

Because of the rapidity and suddenness of their onset and their high intensity over a relatively small geographic area, flash floods pose a significant threat to human systems world-wide. Compared to river flooding, flash floods provoke a higher average mortality as they are usually unexpected events which evolve rapidly and affect relatively small areas. In contrast, river flooding affects considerably larger areas and many more people, but results in lower casualties per event (Jonkman, 2005; Jonkman and Vrijling, 2008). Therefore, the characteristic hydrological response in flash floods may result in high social risk, as occurred, for instance, in northern Venezuela in December 1999, where a high-magnitude storm triggered debris flows and flash floods that killed about 15,000 people (Larsen and Wieczorek, 2006), or in the 1997 Biescas disaster in the Central Pyrenees, Spain, in which a flash-flood caused the loss of 87 lives at a camp site located on an active alluvial fan (Benito et al., 1998). In fact, according to Barredo (2007), 40% of flood-related casualties in Europe between 1950 and 2005 were caused by flash-floods.

The main difficulty in flash-flood risk management is related to their rapid occurrence and the spatial dispersion of the urban areas that may be affected by this typology of water-related hazard. As a result, the socio-economic environment is impacted on a spatio-temporal scale that implies short warning lead times (Creutin et al., 2009). In this respect, the short time available for minimizing risks requires preparedness and response actions to be put into practice (Faulkner and Ball, 2007). This management strategy is mainly focused on emergency management or civil protection actions involving the implementation of coordinated actions, both to prevent flash-floods from happening and to minimize their effects once a given event has occurred (Alexander, 2002; Zerger and Smith, 2003). Within this framework, three levels of action can be identified: i) monitoring and forecasting, aimed at detecting threats by determining threshold runoff estimates (Verkade and Werner, 2011), ii) prevention measures comprising either structural or non-structural actions; and iii) the development of emergency response plans to evacuate and rescue people in the context of a flash-flood hazard (Wilhelmi and Morss, 2013).

However, risk management based solely on the technocratic approach described above may give people a false sense of security (Adams, 1995), since the social dimension of flash-flooding is not integrated in the management process (Lara et al., 2010). Therefore, understanding the characteristics of local communities should be a priority in order to enhance community resilience during a flash-flood. In this regard, the extent to which a community can demonstrate resilience after a flood largely depends on human perception, which in turn is related to the social context in which a given event occurs (Wickes et al., 2015). Moreover, the social perception of flash-flood risk depends on different psychological variables, including intuitive evaluation of risk and qualitative reflections such as fear and trust in decision makers (Figueiredo et al., 2009).

This paper aims to assess the flash-flood risk perception of the inhabitants of the village of Navaluenga (Central Spain), as well as the level of awareness of civil protection and emergency management strategies developed with the main objective of safeguarding people and assets exposed to particular threats derived from flash-flood occurrence.

2. Materials and methods

2.1. The study area and its problems with relation to flash-floods

The municipality of Navaluenga is located in Central Spain on the banks of the Alberche River, between the Sierra del Valle (eastern range of Gredos, Spanish Central System) and the Sierra de la Paramera (40º 24' 30'' N; 4º 42' 17'' O; 761 m.a.s.l; Figure 1). According to the National Statistics Institute of Spain, Navaluenga has a population of 2027 inhabitants (data corresponding to 2014).

The Alberche River rises in the eastern section of the Sierra de Gredos at roughly 1800 m.a.s.l. It runs for 70 km before reaching Navaluenga, its time of concentration (Tc) is around 8.5 hrs and it drains an area of 717 km^2. In this reach the flow regime is totally natural. The Alberche is partially canalized where it crosses the town and has several weirs (i.e. natural pools) that are used by local people as recreation areas in summer. In this area, several torrents flow into the Alberche River from the Sierra del Valle and the Sierra de la Paramera. Especially noteworthy is the Chorrerón stream (Tc≈ 3 hrs), which crosses the urban area perpendicularly from north to south to flow into the Alberche.

The village of Navaluenga has suffered flood events linked to the Alberche River and the Chorrerón Stream since at least the Early Middle Ages, as attested by documentary records that existed in the late fifteenth century. The most recent events in the 1990s and the early 2000s caused important economic losses and put part of the local population at risk (Díez-Herrero, 2004).

2.2. Analysis of flash flood risk

2.2.1. Hydrological model

HEC-HMS 4.0 (USACE, 2013) was implemented to simulate the hydrological response of the basin. To this end, we used data stored in 18 rain gauges (which have provided a time series dataset ranging between 32 and 52 years) installed in the basin itself and in its surroundings. Double-mass analysis (Chang and Lee, 1974) was used to check consistency between different precipitation time series. Precipitation return periods were derived from the statistical analysis of daily rainfall datasets, applying the two-parameter SQRT-exponential type distribution of maximum (SQRT-ET-max distribution) (Etoh, 1986). Sub-daily rainfall data was not available at the study site, thus return periods of daily rainfall (i.e. high probability, T=50 yr; medium probability, T=100 yr; low probability or extreme events, T=500 yr) were disaggregated by considering an hourly time step based on the official Spanish IDF curves and using the alternating blocks method (Chow et al., 1988) to obtain the design hyetographs.

The curve number method (CN) was applied to determine losses (Misra and Singh, 2003). Excess precipitation was transformed into runoff using the SCS dimensionless unit hydrograph method (Chow et al., 1988). Channel routing was simulated, using the Muskinghum-Cunge method (Ponce and Yevjevich, 1978). For the baseflow, the recession method was used (Tallaksen, 1995).The hydrological model calibration and validation was limited by the short time series and the lack of information from hydrographs and hyetographs. Three events were used to calibrate the model, while two more were employed for validation, by way of an automatic calibration routine in which the percentage error in peak discharge and the unvaried method (Haberlandt et al., 2008) were used as the objective function and the search algorithm, respectively.

2.2.2. Hydraulic model

Hydrodynamic simulation was carried out by applying IBER two-dimensional hydrodynamic software (Bladé et al., 2012; www.iberaula.es). IBER is a numerical tool for 2D simulation of turbulent free surface unsteady flow and sediment transport in water-courses. IBER uses the finite volume method, which is widely used in computational fluid dynamics (Versteeg and Malalasekera, 2007) as a numerical method to solve depth-averaged 2D shallow water equations, also known as Saint

Venant equations. Thus, the solution considers variations in both dimensions of the horizontal plane, while variations in velocity or other variables of interest in the vertical water column are averaged and are assumed to have a unique value.
To solve the hydrodynamics, the finite volume method with a second order Roe Scheme (time explicit scheme) was used on unstructured mesh. This method is especially suitable for flows in mountainous rivers (Bodoque et al., 2014), where shocks and discontinuities may occur, giving very sharp hydrographs. The IBER 2-D model implemented here worked with an unstructured mesh of elements. To obtain this mesh, a detailed Digital Elevation Model (DEM) of the reach to be simulated and the associated floodplain was produced with available LiDAR data, together with a topographical survey aimed at obtaining detailed bathymetry of the channel (~0.3 points m^{-2}). The above enabled to obtain a mesh formed by 100,979 triangle elements and 50,932 nodes. The roughness coefficient (Manning's *n*) was obtained from the delineation of homogeneous land units in terms of their roughness. Each homogeneous unit delimited in the field was digitized using ArcGIS 9.2, and was afterwards assigned a possible rank of values of Manning's *n* following the criteria defined by Chow (1959). Hydraulic calibration was based on the rating curve available in the studied reach and tree scars, according to the method proposed by Ballesteros et al. (2011).

2.2.3. Hazardousness mapping

In accordance with the methodological approach proposed by Diez-Herrero et al. (2009), three differentiated hazardousness areas were established by means of GIS tools:

- High Hazardousness Zone (HHZ): This matches to territory where there is risk to people's physical integrity either because the depth of the flooding area (y) is higher than or equal to 1m, the flow velocity (v) is higher than or equal to 1m s^{-1}, or the multiplication of both factors defines values higher than or equal to 0.5 m^2 s^{-1} (Martín-Vide, 1997). This roughly coincides with the hydraulic public domain defined by the National Flood Zone Mapping System of Spain, SNCZI. It corresponds to the 50-year flood.

- Medium Hazardousness Zone (MHZ): This is the area prone to flooding within the 50 and 100-year flood plain, though it defines depths and velocities that do not imply risk to human life (i.e. $y<1m$; $v<1m\ s^{-1}$; $y*v<0.5m^2\ s^{-1}$). The MHZ must contain the zone of preferential flow, defined according to SNCZI criteria, though omitting the part that is in the HHZ area. In addition, the MHZ is the envelope of the frequent and occasional flooding areas (50-year and 100-year flood plains, respectively), according to the Basic Guidelines for Civil Protection in Spain.

- Low Hazardousness Area (LHA). This is the area prone to flooding within the 500-year flood plain, but without risk to human life. It covers the low probability flooding area according to the EU flood directive and roughly coincides with the exceptional flooding area according to the SNCZI and the Basic Guidelines for Civil Protection planning in Spain.

2.2.4. Social exposure and vulnerability to flash floods

Social exposure analysis was conducted by collecting data on the exposed population and then intersecting it with flash-flood hazard areas. Data sources were taken from official statistics (e.g. population census, municipal register, surveys carried out on tourists) and the local population was interviewed on different issues specifically related to flash-flood risk.

Social vulnerability analysis was based on consideration of those factors that increase population fragility regarding flood risk (Díez-Herrero et al., 2008) and on the use of magnitude-damage functions that enabled people's risk levels to be differentiated according to depths and velocities during flooding (Díez-Herrero et al., 2009). The data sources were the same as those used to analyse social exposure. We considered both the demographic distribution of the population (i.e. age pyramid, sex *vs* age) and its density. We also analysed both the parameters that increase individual vulnerability, such as age, disability, chronic illness, dependency and unfamiliarity with the Spanish language, and the variables that increase collective vulnerability, such as the lack of evacuation zones, the possibility of homes without communication, the accessibility of buildings, the number of storeys and the topography, both above and below ground. In order to analyse exposure and social vulnerability, GIS tools were used to generate geo-referenced databases which were subsequently intersected with the hazardousness map of Navaluenga by means of map algebra.

2.3. Analysis of social perception

2.3.1. Procedure and instruments

The integration of social dimensions in the analysis of flash flood risk in Navaluenga was carried out by means of a survey conducted by trained interviewers. An *ad hoc* questionnaire in three sections was designed. The first section assessed the level of awareness (real and perceived) about actions to take: a) before the flood in order to avoid negative consequences, that is, preparedness behaviour (PB); b) during the flood, that is, evacuation routes (ER), meeting points, protective actions (PA) and actions to take before leaving the house (ABL); and c) after the flood, that is, actions taken on the house after flooding (AAF). Participants were asked if they knew what measures to take in each case (yes/no). If they answered yes, they were asked what these were. The total number of correct responses was drawn from those that coincided with the actions defined in the Civil Protection Plan. The second section assessed the social perception of risk by adjusting a general measure consisting of four items (Bourque et al., 2013) that considered the possible risk of flooding in the locality and the home itself, both in the short term (the next five years) and the long term (lifetime). This was measured used a 5-point Likert scale, ranging from highly improbable to highly probable. The third and final section included a series of relevant socio-demographic and experiential characteristics, such as age, gender, family status, type of dwelling and previous experience with flooding. In addition, the participant residential area was coded as to whether or not it was a flood area, based on the flood hazard map of Navaluenga.

2.3.2. Participants

Two hundred and fifty-four adults took part in the study. These were either permanent or temporary residents of Navaluenga and constituted a representative sample of the locality as the sample size was more than 12% of the number of inhabitants. The participants were selected using a quota sampling procedure with age and gender as quota control variables. Those who lived there all year round made up 71.3% of the respondents, while the rest were temporary residents (holidays, weekends, etc.) Of the total sample, 53.5% were women, 19.7% were between 18 and 34 years old, 41.7% were between 35 and 54 years old, and 38.6% were 55 or older. With respect to family status, 36.6% lived alone or as a couple, 16.5% had dependants in their care, either children under 12 years old, elderly people or people with disabilities, 30.3% lived with children over 12 years old and 16.6% lived in 'another situation'. With respect to the type of dwelling, 18.1% lived on a ground floor, 42.1% had a house with two storeys above ground level and of these, 18.9% also had a cellar. Finally, 20.9% lived in flats. With regard to experience of flooding events, 85.8% responded that they personally had not suffered any flood damage, and 51.6% said they knew no one who had. Those who had experienced flooding in the past made it clear that it was the contents of the house (furniture and other belongings) and the building itself (walls, ceilings, etc.) that had been most affected.

2.3.3. Data analysis

The data analysis plan included: 1) an initial descriptive analysis of the main variables related to awareness of the preventive and protective actions to take before, during and after a flood, and their comparison with those defined in the Civil Protection Plan; 2) a t-test for equality of means; and 3) a latent class cluster analysis, a model-based probabilistic clustering approach used to define different groups within a sample according to a set of indicators and covariates that allow the different groups identified to be characterized (Vermunt and Magidson, 2002).

The analytical approach used in this last analysis is shown in Figure 2. The variables considered as indicators were: (1) perception of short term risk (5 years) and lifetime risk, both in Navaluenga and in the actual home; (2) level of awareness according to: preparedness behaviour, evacuation routes and meeting point, protective actions and actions taken on the house after flooding. The covariates initially considered were sociodemographic ones and certain covariates related to previous experiences of flooding. The first step in the analysis was to identify the number of existing groups. Five models incorporating from one to five groups were considered. Analyses were carried out with Latent Gold® 4.5.

3. Results

3.1. Analysis and management of flash-flood risk

3.1.1. Hazardousness analysis

Hazard analysis conducted with the methodological approach described in section 2.2.3. (Figure 3) enabled the identification of points of conflict where areas of high depths or flow velocities form. The highest depths are located upstream of structures that are transverse to the river flow, such as bridges and weirs. The confluence of the Chorreron Stream with the Alberche River may also play an important role, especially if both are simultaneously provoking a flood. As a result, the highest depths in the channel is 8.6 m, while in the flooded area is 7.3 m. Outside the area of influence of the points of conflict described above, maximum depths are 6.9 m in the channel and 5.4 in the flooded area. Fluctuations in flow velocities occur where there are changes in the flow regime (i.e. from subcritical to supercritical). These are mainly due to narrowing of the channel cross-sections caused by the bridges on the urban reach of the Alberche River. In the river channel, maximum flow velocities of 3.8 m s^{-1} are given, while the minimum ones (i.e. 1.8 m s^{-1}) are found close to the river banks. Within the urban area flow velocities are between 0.1 m s^{-1} and 1.3 m s^{-1}.

3.1.2. Analysis of social vulnerability

The demographic structure reveals the existence of a middle-aged population with a clear aging trend. It is worth noting that the dependency ratio in Navaluenga (the ratio of the number of people younger than 15 plus people aged 65 and older to the number aged 15 to 64) reaches 60%. On the other hand, total housing in the municipality is estimated at 4,311 dwellings, of which 3,392 are considered to be second homes (data corresponding to 2012). The population of Navaluenga undergoes a significant increase during the summer months, when it reaches approximately 20,000 inhabitants. Therefore, the exposed population may multiply 10-fold during the summer period, and may be anything from doubled to quintupled on weekends and holidays (to between 5,000 and 10,000 inhabitants).

The intersection between the exposed and vulnerable population and flood hazard areas (i.e. high probability, T=50 yr; medium probability, T=100 yr; low probability or extreme events, T=500 yr —Table 1), is shown in Table 2. Since Navaluenga is of medieval origin, with a compact urban structure made up of irregular closed street blocks, two storey buildings are predominant. As a result, more than 50% of people are within the zone of influence of flooding. Furthermore, the only evacuation routes run through flooded ground floors, which, together with the demographic structure of the population (24.3% over 65 years old and 16.5% under 16 years old), significantly increases the vulnerability of people with difficulties related to mobility or autonomy.

As regards the intersection between social vulnerability indicators and different flood hazard areas (Table 3), about half the people whose homes are in the risk zone cannot swim. In addition, almost 90% of elderly people who live exposed to flood risk have chronic illnesses and need continuous medication.

3.1.3. Civil Protection Plan

The data sources and methodology for developing the Civil Protection Plan against flood risk in Navaluenga were determined by the Spanish legislation on this matter. The aims addressed in the local civil protection plan were in accordance with the basic guidelines on civil protection planning for flood risk in Spain (Spanish Ministry of Justice, 2010) and were: *i*) to analyse the assumptions of risk and its causes and effects, as well as the areas that might be affected by floods; *ii*) to take the necessary measures to avoid or reduce hazard situations with the means available; *iii*) to coordinate and direct intervention by the administration with respect to civil protection components for protecting and rescuing people.

Results relating to the first aim are shown in sections *3.1.1.* and *3.1.2.* of this paper. With regard to protection measures, the optimal evacuation route during flooding was derived from the methodology proposed by Díez and Pérez (2003) (Figure 4). It consisted of delineating an optimum evacuation route from friction surfaces and cost distances obtained automatically using GIS tools. Additional factors considered in this methodology are: street width, flooding depth, direction and velocity of flow, and the fording capability of emergency vehicles.

3.2. Analysis of flash-flood risk perception

3.2.1. Descriptive and bivariate analysis

Firstly, the level of awareness, both perceived and real, was analysed regarding the actions to take at different moments in the event of possible flooding. With respect to preparedness behaviour (PB) (before flood occurrence), approximately half the sample (51.6%) declared they would not know what to do to avoid the negative consequences of possible flooding. Although the rest responded that they would know, the majority of measures in their responses were not included in the Civil Protection Plan, resulting in this category being designated as “not considered” (Table 4). A qualitative analysis of responses included in this category revealed that rather than measures to be adopted at personal level, most responses referred to measures out of the control of the individual, such as keeping the river and riverbed clean and unblocked.

The next step was to analyse familiarity with different actions to take in the event of the municipality suffering serious flooding (during flood occurrence). With regard to awareness of evacuation routes (ER), most of the respondents affirmed that they knew which way to go to leave the municipality (82.7%). Nevertheless, when they were asked to give details of specific routes, 24% gave one right answer (that is, a route included in the Civil Protection Plan) and only 0.8% gave two. The answers that were not included in any of the 'correct' categories were grouped as not considered (Table 4). A qualitative analysis of this category showed that the majority indicated directions for leaving the municipality, but not specific routes. Likewise, they also affirmed that they did not know the exact place to go to be attended by Civil Protection; only about 20% knew exactly where it was. With regard to protective actions (PA), the majority (76.4%) said they knew what to do in the event of an emergency flood warning. However, when asked to give details of specific actions for self-protection, most answers did not coincide with those included in the Civil Protection Plan (53.9%). The measures that obtained the highest percentage of correct answers were: use of the emergency telephone number and assembling at a pre-established place (Table 4). The results on what to do before leaving the house (ABL) were similar to those relating to the level of perceived awareness mentioned above. Nevertheless, in this case the level of correct awareness (real awareness) was greater, since more than 80% mentioned at least one of the three actions included in the Protection Plan. Moreover, a large majority of participants suggested actions not included in the plan (Table 4). These largely referred to actions based on searching for and making contact with family members and pets, issuing warnings and gathering everyone together.

The final analysis examined the level of awareness related to actions to take once flooding occurred and the granting of permission by the relevant authorities to return home (AAF).Most respondents said they knew what to do at this stage (90.2%) and more than 40% gave two specific actions included in the Civil Protection Plan: carry out an inspection to eliminate the risk of building collapse, and begin the cleaning-up process on the upper floors (Table 4).

With respect to risk perception, Figure 5 shows that this is generally low, although it is higher when the municipality as a whole is considered than when it relates to each individual's home. Analysis of the flooded area, both floodable and not, shows that residents in the floodable zone perceived a greater risk when asked to assess the possibility of their own home being flooded in the next 5 years ($t = -2.93$; $p<.01$; $\eta^2 = .04$) or in their lifetime ($t = -3.79$; $p<.01$; $\eta^2 = .06$). In all other aspects there were no statistically significant differences between the residents in the two areas.

3.2.2. Latent class cluster analysis

With respect to the covariates considered, only age, family status, house type and the flooded area were significant. In accordance with the consistent Akaike information criterion (CAIC), it was determined that the optimum number of groups in the sample was three. The data from Table 5 show a higher Entropy R^2 (equal to .90) for the three-group model, which implying a good fit of this model. It is possible to describe a profile of each of the groups from Table 6. It should also be noted that all the indicators considered were statistically significant when it came to discriminating between the three groups ($p<.05$). The respective profiles of the groups could be classified as follows:

Cluster 1. Low risk perception and low awareness: This group represents 60.8% of the total sample. It is characterized by being made up of individuals with the lowest perception of risk in three of the four indicators considered. In addition, it also shows the lowest levels of awareness of the different actions to take before a flood event.

With respect to its socio-demographic characteristics, more than 50% live in a two-storey house, they form the oldest group (43.3% are over 55 years old) and almost 40% live alone or in a couple. As regards area of residence, more than 65% live in the flood free zone.

Cluster 2. High risk perception and low awareness: This group, representing 24.4% of the sample, has a greater perception of risk, both long and short term, but a very low level of awareness regarding what actions to take. It does not have a clearly defined type of housing and is made up largely of middle-aged people (49%) who live with sons and daughters over 12 years old (41.6%). More than 60% of the people in this group live in the flood zone.

Cluster 3. High long-term risk perception and high awareness. This last group represents 14.8% of the sample and its main defining feature is the high perception of long-term risk. Furthermore, these are the people who have the highest level of awareness by far about actions to take before, during and after a flood. A higher percentage of people in this group live in single-storey houses and more than 35% of them are between 18 and 34 years old, making this the youngest group. Most people live alone or as a couple (37.1%), or with dependants in their care (19.3%).They are relatively evenly distributed between those who live in the flood zone and those who do not, with a predominance of the former (53.7%).

4. Discussion

In this study, we assessed the level of social perception in an urban area prone to flash floods, and the local population's degree of awareness of the Civil Protection Plan (Figure 6), recently approved thanks to research carried out in the area over the last few years (Díez-Herrero, 2004; Ballesteros Canovas et al., 2011; Ballesteros et al., 2011; Bodoque et al., 2011; Ballesteros-Canovas et al., 2013). It is important to analyse social perception in order to determine the resilience of an urban area for coping with the occurrence of floods, a conclusion reached by the Hyogo Framework for Action and the Global Platform for Disaster Risk Reduction (UN/ISDR, 2010). Both forums established that strengthening the resilience of a community is one of the pillars on which to base risk mitigation. Spain is a country where most of the casualties derived from extreme hydrometeorological events are the direct consequence of flash floods (Gaume et al., 2009). However, the Spanish Administration does not consider social perception as a factor to be included in emergency management plans, and neither has this issue been extensively addressed at research level in Spain. In fact, there are few papers in which social perception is analysed in connection with flash floods (e.g. Lara et al., 2010). Furthermore, none of them incorporates an analysis of awareness with regard to emergency management during the phase in which emergency response techniques and methods are being implemented, which is critical to ensure the effectiveness of mitigation measures, due to the limited time available for putting them into place when a flash-flood occurs. Therefore, social perception and awareness are fundamental for inferring the level of effectiveness of emergency plans and determining whether strategies of communication and education need to be put into practice to improve the social resilience of the community.

4.1. Analysis and management of flash-flood risk

4.1.1. Flash flood risk

Previous research on flooding in Navaluenga was conducted by running the HEC-RAS one-dimensional model (Díez-Herrero, 2004), which has conceptual limitations since it is not able to properly represent the hydraulic complexity of urban areas (Syme et al., 2004). Ballesteros et al. (2011) subsequently used MIKE 21, which is suitable for use in urban areas as it is a two-dimensional hydraulic model. Its implementation was based on urban topography (CAD format) at scale 1:1000. However, owing to certain inaccuracies in the original topography, the data had to be filtered, thereby reducing the accuracy of the original topographic dataset. In this research, we used the Iber two-dimensional hydrodynamic model based on LiDAR data supplemented with a bathymetry of the channel along the reach flowing through the urban area. This enabled 2-D modelling to be addressed fully and a more accurate prediction of flood extent to be obtained through better representation of the complex hydraulic processes occurring during a flood. As a result, we obtained flood hazard mapping at a much finer resolution and greater accuracy than the methodological approaches previously practised. Nevertheless, some uncertainty in the hazard analysis still remains because of the low number of flash flood events available for calibration and the short length of the precipitation time series used for estimating flood return periods (i.e. around 30 years in most cases).

As far as exposure and social vulnerability are concerned, some inconsistency is derived from differences in the structuring and discrimination of data sources. While the census is organized into census tracts, covering a whole urban area (i.e. equivalent to a postal district) and is updated every 10 years, the Municipal Register and specific surveys are carried out house to house, with annual updates to the Register, but data from surveys is obtained only when these are performed. This situation creates problems when the data from these sources are crossed, which may generate errors in social risk assessment. The results obtained lead to the conclusion that it is advisable to update the data on exposure and vulnerability more often, taking advantage of economic data published by the public administration, and performing periodic surveys in the area at risk of flooding. This would provide a geo-referenced database of the population at risk. Furthermore, in the context of global warming and its effects on the Iberian peninsula, where an increase in the frequency of extreme hydrometeorological events is forecast (AEMET, 2015), the task of frequently diagnosing risk is an essential consideration in any decision-making at municipal level aimed at reducing vulnerability and exposure (March et al., 2014).

4.2. Risk perception and awareness

Among the inhabitants of Navaluenga, there is generally a clear difference between the levels of self-assessed awareness (perceived awareness) and what they really know about flood risk and hazard awareness. Those participating in the study believe they know what measures to adopt, both before, during and after a flood, but these measures do not concur with the contents of the Civil Protection Plan. This should be taken into account when designing how the Plan should be communicated to the people, who may not be motivated to take part in any preparatory action because they overestimate their own levels of awareness regarding prevention and protection.

In particular, it is interesting to note that most measures for avoiding the negative consequences of a possible flood (preparedness behaviour) mentioned by participants but not included in the Plan were those that were out of their personal control and had to do with prevention by the relevant authorities (such as keeping the river and riverbed clean). According to Kellens et al. (2013), this would be included as a passive protection measure that people cite at moments that are prior to and detached from a flood event. It would therefore be advisable to carry out a detailed analysis of possible social beliefs that hinder the enhancement of social resilience by placing responsibility exclusively on flood risk agencies, to the detriment of the importance of actions of self-protection. It is also worth adding that in comparative terms there is lower awareness of preventive and preparatory behaviours (PB) than of actions to take when the danger is imminent (ABL and AAF). In this case, according to the classification mentioned by Kellens et al. (2013), people adopt such behaviours when the flood is just about to occur or even when it is taking place. These “active protection measures” may be more intuitive for people and explain their greater level of awareness.

On the other hand, what is noteworthy in the three groups identified by the latent class cluster analysis is the particular association between the variables of age and awareness levels. The largest group is the oldest group and the one with least awareness about preventive and protective actions. Nevertheless, it should be pointed out that this profile, which is also associated with a low perception of risk, coincides with that of the population who mostly live in non-floodable zones. Therefore, in order to achieve greater efficiency in communicating the Civil Protection Plan to people, it is advisable to focus attention on the sector of population living in the flood zone, who show a higher perception of flood risk but whose level of specific awareness as to what to do is as low as that of the previous group. Otherwise, the recently approved Civil Protection Plan may have little effect. This scenario could be reversed by organizing actions on social communication and educating for risk. This requires the design of programmes tailored to specific age groups, using different systems for disseminating information on adaptation and risk reduction to each one (March et al., 2014).

Conclusions

The social resilience level of the population of Navaluenga to the occurrence of flash floods was analysed by considering flood risk perception and the level of awareness of the recently approved Civil Protection Plan. The fact that both risk perception and awareness levels are low among the local people indicates that when the next flash flood event occurs the effectiveness of the Civil Protection Plan may be limited. These findings provide enough evidence to show the desirability of integrating social perception in emergency plans and designing communication strategies that increase risk perception and awareness in the community, thereby enhancing social resilience to flash floods.

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References

Agencia Estatal de Meteorología (AEMET), 2015. Proyecciones Climáticas para el siglo XXI en España. On line: http://www.aemet.es/es/serviciosclimaticos/cambio_climat . (Last view on April 19th, 2015).

Adams, J., 1995. Risk. University College London Press, London.

Alexander, D., 2002. Principles of Emergency Planning and Management. Terra Publishing, Harpenden.

Ballesteros-Cánovas, J.A., Eguibar, M.A., Bodoque, J.M., Díez-Herrero, A., Stoffel, M., Gutiérrez-Pérez, I., 2011. Estimating flash flood discharge in an ungauged mountain catchment with 2D hydraulic models and dendrogeomorphic palaeostage indicators. Hydrol. Process., 25(6): 970-979. DOI:10.1002/hyp.7888.

Ballesteros, J.A., Bodoque, J.M., Diez-Herrero, A., Sanchez-Silva, M., Stoffel, M., 2011. Calibration of floodplain roughness and estimation of flood discharge based on tree-ring evidence and hydraulic modelling. J. Hydrol., 403(1-2): 103-115. DOI:10.1016/j.jhydrol.2011.03.045.

Ballesteros-Canovas, J.A., Sanchez-Silva, M., Bodoque, J.M., Diez-Herrero, A., 2013. An Integrated Approach to Flood Risk Management: A Case Study of Navaluenga (Central Spain). Water Resour. Manag., 27(8): 3051-3069. DOI:10.1007/s11269-013-0332-1.

Ballesteros-Canovas, J.A., Czajka, B., Janecka, K., Lempa, M., Kacka, R.J., Stoffel, M., 2015. Flash floods in the Tatra Mountain streams: Frequency and triggers. Sci.Total Environ., 511: 639-648. DOI:10.1016/j.scitotenv.2014.12.081.

Bladé, E., Cea, L., Corestein, G., Escolano, E., Puertas, J., Vázquez-Cendón, M.E., Dolz, J., Coll, A., 2012. Iber – Herramienta de simulación numérica del flujo en ríos. Rev. Int. Metod. Numer., 30:1–10.

Barredo, J.I., 2007. Major flood disasters in Europe: 1950-2005. Nat. Hazards, 42(1): 125-148. DOI:10.1007/s11069-006-9065-2.

Benito, G., Grodek, T., Enzel, Y., 1998. The geomorphic and hydrologic impacts of the catastrophic failure of flood-control-dams during the 1996-Biescas flood (central Pyrenees, Spain). Z. Geomorphol., 42(4): 417-437.

Bodoque, J.M., Eguibar, M.A., Diez-Herrero, A., Gutierrez-Perez, I., Ruiz-Villanueva, V., 2011. Can the discharge of a hyperconcentrated flow be estimated from paleoflood evidence? Water Resour. Res., 47. DOI:10.1029/2011wr010380.

Bodoque, J. M., Díez-Herrero, A., Eguibar, M. A., Benito, G., Ruiz-Villanueva, V., Ballesteros-Cánovas, J. A., 2014. Challenges in paleoflood hydrology applied to risk analysis in mountainous watersheds–A review. J. Hydrol., http://dx.doi.org/10.1016/j.jhydrol.2014.12.004

Borga, M., Boscolo, P., Zanon, F., Sangati, M., 2007. Hydrometeorological analysis of the 29 August 2003 flash flood in the Eastern Italian Alps. J. Hydrometeorol., 8(5): 1049-1067. DOI:10.1175/jhm593.1.

Borga, M., Gaume, E., Creutin, J.D., Marchi, L., 2008. Surveying flash floods: gauging the ungauged extremes. Hydrol. Process., 22(18): 3883-3885. DOI:10.1002/hyp-7111.

Bourque, L.B., Regan, R., Kelley, M. M., Wood, M. M., Kano, M., Mileti, D. S., 2013. An Examination of the Effect of Perceived Risk on Preparedness Behavior. Environ. Behav., 45(5): 615-649. DOI:10.1177/0013916512437596.

Creutin, J. D., Borga, M., Lutoff, C., Scolobig, A., Ruin, I., Créton-Cazanave, L., 2009. Catchment dynamics and social response during flash floods: the potential of radar rainfall monitoring for warning procedures. Meteorol. Appl., 16(1): 115-125. DOI:10.1002/met.128.

Díez, A., Pérez, J.A., 2003. Los SIGs en el Plan de Protección Civil de Ámbito Local ante el riesgo de inundaciones de Navaluenga (Ávila, España). Seminario Euromediterráneo sobre Nuevas Tecnologías Aplicadas a la Gestión de Desastres. Foro Euromediterráneo sobre Prevención de Catástrofes, Madrid, Dirección Gral. de Protección Civil (Ministerio del Interior).

Díez-Herrero, A., 2004. Geomorfología e hidrología fluvial del río Alberche: modelos y SIG para la gestión de riberas. Universidad Complutense de Madrid, Servicio de Publicaciones.

Díez-Herrero, A., Garrote-Revilla, J., Baíllo-Calvo, R., Laín-Huerta, L., Mancebo-Mancebo, M.J., Pérez Cerdán, F., 2008. Análisis del riesgo de inundación para planes autonómicos de protección civil: RICAM. In: I. Galindo Jiménez, L. Laín Huerta and M. Llorente Isidro (Eds.), El estudio y la gestión de los riesgos geológicos. Publicaciones del Instituto Geológico y Minero de España, Serie: Medio Ambiente. Riesgos Geológicos, nº 12, Capítulo 4, 53-70, Madrid (Spain), IGME and Consorcio de Compensación de Seguros (MEH).

Díez-Herrero, A., Laín-Huerta, L., Llorente-Isidro, M.A., 2009. Handbook on flood hazard mapping methodologies. Spain Geological Survey, Madrid.

Delrieu, G., Nicol, J., Yates, E., Kirstetter, P.-E., Creutin, J.D., Anquetin, S., Obled, Ch., Saulnier, G.M., Ducrocq, V., Gaume, E., Payrastre, O., Andrieu, H., Ayral, P.-A., Bouvier, C., Neppel, L., Livet, M., Lang, M., Parent du-Châtelet, J., Walpersdorf, A., Wobrock, W., 2005. The catastrophic flash-flood event of 8-9 September 2002 in the Gard region, France: A first case study for the Cevennes-Vivarais Mediterranean Hydrometeorological Observatory. J. Hydrometeorol., 6(1): 34-52. DOI:10.1175/jhm-400.1.

Etoh, T., Murota, A., Nakanishi, M., 1986. SQRT—Exponential type distribution of maximum. In: Proceedings of international symposium on flood frequency and risk analysis. Louisiana, pp 235–265

Faulkner, H., Ball, D., 2007. Environmental hazards and risk communication: prologue. Environ. Hazards 7, 71–78.

Figueiredo, E., Valente, S., Coelho, C., Pinho, L., 2009. Coping with risk: analysis on the importance of integrating social perceptions on flood risk into management mechanisms - the case of the municipality of Agueda, Portugal. J. Risk Res., 12(5): 581-602. DOI:10.1080/13669870802511155.

Gaume, E., Bain, V., Bernardara, P., Newinger, O., Barbuc, M., Bateman, A., Blaškovicová, L., Blöschl, G., Borga, M., Dumitrescu, A., Daliakopoulos, I., Garcia, J., Irimescu, A., Kohnova, S., Koutroulis, A., Marchi, L., Matreata, S., Medina, V., Preciso, E., Sempere-Torres, D., Stancalie, G., Szolgay, J., Tsanis, I., Velasco, D., Viglione, A., 2009. A compilation of data on European flash floods. J. Hydrol., 367(1-2): 70-78. DOI:10.1016/j.jhydrol.2008.12.028.

Haberlandt, U., von Eschenbach, A.D.E., Buchwald, I., 2008. A space-time hybrid hourly rainfall model for derived flood frequency analysis. Hydrol. Earth Syst. Sc., 12(6): 1353-1367.

Hapuarachchi, H.A.P., Wang, Q.J., Pagano, T.C., 2011. A review of advances in flash flood forecasting. Hydrol. Process., 25(18): 2771-2784. DOI:10.1002/hyp.8040.

Jonkman, S.N., 2005. Global perspectives on loss of human life caused by floods. Nat. Hazards, 34(2): 151-175. DOI:10.1007/s11069-004-8891-3.

Jonkman, S.N., Vrijling, J.K., 2008. Loss of life due to floods. J. Flood Risk Manag., 1(1): 43-56. DOI:10.1111/j.1753-318X.2008.00006.x.

Kellens, W., Terpstra, T., De Maeyer, P., 2013. Perception and Communication of Flood Risks: A Systematic Review of Empirical Research. Risk Anal., 33(1): 24-49. DOI:10.1111/j.1539-6924.2012.01844.x.

Kelsch, M., 2001. Hydro-meteorological characteristics of flash floods. In Coping with Flash Floods, NATO Science Series, Environmental Security, Gruntfest E, Handmer J (eds). Kluwer Academic Publishers: Dordrecht, Boston; 77: 181–193.

Lara, A., Sauri, D., Ribas, A., Pavon, D., 2010. Social perceptions of floods and flood management in a Mediterranean area (Costa Brava, Spain). Nat. Hazards Earth Syst. Sci., 10(10): 2081-2091. DOI:10.5194/nhess-10-2081-2010.

Larsen, M.C., Wieczorek, G.F., 2006. Geomorphic effects of large debris flows and flash floods, northern Venezuela, 1999. Z. Geomorph. N.F. suppl.-vol. 145:147–175. Stuttgart, Berlin.

Martín-Vide, J.P., 2009. Ingeniería fluvial. Univ. Politèc. de Catalunya.

Mishra, S. K., Singh, V.P., 2003. Soil conservation service curve number (SCS-CN) methodology (Vol. 42). Springer Science & Business Media.

March, H., Sauri, D., Olcina, J., 2014. Rising Temperatures and Dwindling Water Supplies? Perception of Climate Change Among Residents of the Spanish Mediterranean Tourist Coastal Areas. Environ. Manage., 53(1): 181-193. DOI:10.1007/s00267-013-0177-7.

Marchi, L., Borga, M., Preciso, E., Gaume, E., 2010. Characterisation of selected extreme flash floods in Europe and implications for flood risk management. J. Hydrol., 394(1-2): 118-133. DOI:10.1016/j.jhydrol.2010.07.017.

Naulin, J.P., Payrastre, O., Gaume, E., 2013. Spatially distributed flood forecasting in flash flood prone areas: Application to road network supervision in Southern France. J. Hydrol., 486: 88-99. DOI:10.1016/j.jhydrol.2013.01.044.

Ogden, F. L., Sharif, H. O., Senarath, S. U. S., Smith, J. A., Baeck, M. L., Richardson, J. R., 2000. Hydrologic analysis of the Fort Collins, Colorado, flash flood of 1997. J. Hydrol., 228(1-2): 82-100. DOI:10.1016/s0022-1694(00)00146-3.

Ponce, V.M., Yevjevich, V., 1978. Muskingum-Cunge method with variable parameters. Journal of the Hydraulics Division-Asce, 104(12): 1663-1667.

Ruiz-Villanueva, V., Díez-Herrero, A., Stoffel, M., Bollschweiler, M., Bodoque, J. M., Ballesteros, J. A., 2010. Dendrogeomorphic analysis of flash floods in a small ungauged mountain catchment (Central Spain). Geomorphology, 118(3-4): 383-392. DOI:10.1016/j.geomorph.2010.02.006.

Spanish Ministry of Justice, 2010. The directorate general of civil protection and emergencies. Available from URL: http://www.interior.gob.es/documents/642317/1202620/The+Directorate+General+of+Civil+Protection+and+Emergencies+%28NIPO+126-10-017-2%29.pdf/5f4d1f5d-5b8c-4b7e-bc10-117bf4a5b6d1

Syme, W.J., Pinnell, M.G., and Wicks, J.M. 2004, Modeling Flood Inundation of Urban Areas in the UK Using 2D/1D Hydraulic Models, Proceedings, 8th National Conference on Hydraulics in Water Engineering, The Institution of Engineers, Australia.

Tallaksen, L.M., 1995. A review of baseflow recession analysis. J. Hydrol., 165(1-4): 349-370. DOI:10.1016/0022-1694(95)92779-d.

United Nations International Strategy for Disaster Reduction (UNISDR), 2010. 2010–2011 World Disaster Reduction Campaign, Campaign Kit. UNISDR, Geneva http:// www.unisdr.org/english/campaigns/campaign2010-2011/ documents/campaign-kit.pdf (Consulted 3.11.10).

US Army Corps of Engineers (USACE). 2013. HEC-HMS 4.0 User Manual. US Army Corps of Engineers Hydrologic Engineering Center: Davis, CA.

Verkade, J.S., Werner, M.G.F., 2011. Estimating the benefits of single value and probability forecasting for flood warning. Hydrol. Earth Syst. Sci., 15(12): 3751-3765. DOI:10.5194/hess-15-3751-2011.

Versteeg, H.K., Malalasekera, W., 2007. An introduction to computational fluid dynamics: the finite volume method. Pearson Education.

Vermunt, J.K., Magidson, J. (2002). Latent class cluster analysis. In: J.A. Hagenaars and A.L. McCutcheon (Eds.), Applied Latent Class Analysis (pp. 89-106), Cambridge, Cambridge University Press.

Wickes, R., Zahnow, R., Taylor, M., Piquero, A.R., 2015. Neighborhood Structure, Social Capital, and Community Resilience: Longitudinal Evidence from the 2011 Brisbane Flood Disaster. Soc. Sci. Q., 96(2), 330-353. DOI: 10.1111/ssqu.12144.

Wilhelmi, O.V., Morss, R.E., 2013. Integrated analysis of societal vulnerability in an extreme precipitation event: A Fort Collins case study. Environ. Sci. Policy, 26: 49-62. DOI:10.1016/j.envsci.2012.07.005.

Zerger, A., Smith, D.I., 2003. Impediments to using GIS for real-time disaster decision support. Comput. Environ. Urban Syst., 27(2), 123-141. DOI:10.1016/S0198-9715(01)00021-7.

Figure captions

Figure 1. a) Location of the study site; b) aerial view of Navaluenga showing the course followed by the Chorrerón Stream. CP1, CP2 and CP3 are conflicting points, which increase flood hazardousness. The first two are associated with bridges. The third is located at the confluence of the Chorrerón Stream and the Alberche River. Pictures c) and d) show floods that occurred in Navaluenga. .

Figure 2. Analysis procedure to assess citizens' perception of flood risk and awareness.

Figure 3. Maps of depths and velocities corresponding to the 100-year flood. Figure below represents the hazardousness map of Navaluenga

Figure 4. Four-stage process to obtain optimal evacuation routes for assistance and/or evacuation of population affected by floods.

Figure 5. Bar graph with 95% confidence interval for mean value. It shows risk perception depending on the timescale and whether the interviewee is resident or non-resident in the flooded area.

Figure 6. Proposed framework approach for managing flash flood risk at local level.

Table captions

Table 1. Discharges corresponding to the Alberche River and the Chorreron Stream for return periods of 50, 100 and 500 yrs.

Table 2. Size of population at risk (social exposure) for the different flood hazard areas. Data included represent the total number of people living in areas prone to be flooded.

Table 3. People exposed and vulnerable to flood hazard areas in Navaluenga, according to certain parameters and variables influencing resilience to flash flooding. Data were obtained from interviews to people representing a sample of the total population living in areas prone to be flooded.

Table 4. Percentage of awareness (correct and incorrect responses). Data included here are based on results obtained from 254 interviews.

Table 5. Model fit summary of latent class cluster models tested.

Table 6. Profiles of population clusters: indicators and covariates.

Table 1

Return period (yrs)	Alberche River at Navaluenga	Chorreron Stream
	Discharge (m^3 s^{-1})	Discharge (m^3 s^{-1})
50	749	75
100	1019	100
500	2006	163

Table 2

Type of residence	Flood hazard areas		
	High probability	Medium probability	Low probability
Primary residence (habitual)	100	120	200
Second home (temporary)	40	50	70

Table 3

EXPOSURE AND VULNERABLE POPULATION	FLOOD HAZARD ZONES		
	High T=50 yr	Medium T=100 yr	Low T=500 yr
Primary residence	28	41	91
Swimmers	14	19	37
Non-swimmers	14	22	54
Physically disabled	1	4	15
Mentally disabled	0	0	6
Minor (<18 years old)	3	3	9
Elderly (> 65 years old)	13	17	35
With chronic illnesses	11	13	27
Need continuous medication	12	14	29
Collaborators in case of emergency	15	18	41
Owners of ATVs, tractor...	1	1	3
With availability to welcome and accommodate people affected (for housing)	10	11	28
Know the location of the nearest ambulatory (by housing)	12	15	33
Know the emergency phone (by housing)	8	10	25

Table 4

Percentage of correct responses to PB items (Before flood occurrence)	%
Is informed about the level of risk.	6.7
Has a first aid box available.	9.4
Keeps toxic products out of the reach of water.	1.6
Keeps valuables and personal documents together in a safe place.	4.3
Has a radio and torch with batteries at hand.	2.4
Makes sure drainpipes and water pipes are kept clear.	11.8
Keeps the outside of the house free of objects that could be washed away.	5.1
Knows the location of routes and places of evacuation.	6.3
Knows the location of meeting points.	5.1
Knows the means to use and the tasks to be carried out by each member of the family.	2.4
Not considered	74.0
Percentage of correct responses to evacuation routes (ER)	%
Confluence of Las Eras Street with Santa Teresa Street.	4.7
Juan Pablo II Street.	2.0
Ranas Street.	1.6
La Fragua Street as far as the Plaza de España and from there to La Iglesia Street (main street) as far as La Travesía.	17.3
Not considered	37.8
Percentage of correct responses to PA items (During flood occurrence)	%
Pay attention to the alarm signal and keep the radio or television tuned for information from the Meteorological Institute or Civil Defence.	2.8
Only use the telephone to inform the authorities, for example, by ringing 112 or the municipal services.	15.0
Disconnect all electrical equipment. Ration provisions and be sparing with heating.	6.7
Be prepared to leave the house and go to a pre-established place if you consider the situation to be dangerous or if ordered to do so by the relevant authorities.	18.9
Not considered	53.9
Percentage of correct responses to ABL items (During flood occurrence)	%
Gather together documentation, warm clothing, small items of value, a torch and a radio.	57.9
Disconnect the electricity, gas and water. Do not touch electrical appliances if they are wet.	36.2
Close and lock windows and doors.	28.7
Not considered	84.6
Percentage of correct responses to AAF items (After flood occurrence)	%
Carry out a preliminary inspection to eliminate the risk of structural collapse.	50.0
Do not drink water from the tap.	10.2
Remove animals killed by the flood.	5.1
With regard to the cleaning-up process and the consumption of foodstuffs, follow the basic rules on health and hygiene stipulated by the relevant authority.	4.3
Begin the cleaning-up process on the upper floors.	40.9
Leave personal belongings that have been damaged beyond use out on the pavement or in the road but without hindering the movement of people or traffic.	2.4
Help the rescue teams and cleaning crews to clear the stretch of street outside your house.	6.3
Not considered	72.4

Table 5

Model	Log-likelihood (LL)	CAIC (LL)	L-squared (L^2)	CAIC (L^2)	Degree of freedom (df)	Classification errors	p-value Bootstrap	Entropy R-squared
One cluster	-2660.69	5582.88	4487.91	3088.92	214	.00	.27	1.00
Two clusters	-2510.79	5407.28	4188.10	2913.32	195	.02	.27	.89
Three clusters*	-2412.53	5334.97	3991.58	2841.01	176	.03	.23	.90
Four clusters	-2378.69	5391.51	3923.91	2897.55	157	.09	.18	.82
Five clusters	-2345.07	5448.47	3856.67	2954.52	138	.08	.14	.85

Notes: CAIC: consistent Akaike information criterion, *Best model according to CAIC.

Table 6

Variable	Cluster1 (60.8%)	Cluster2 (24.4%)	Cluster3 (14.8%)	Robust Wald statistic	p-value	R^2
Indicators (*M*)						
Flood risk perception						
How likely is it that a flood will occur … (5-point Likert scale, ranging from 1 to 5)						
in Navaluenga in the next 5 years?	1.95	2.56	1.87	10.96	.00	.07
in Navaluenga in your lifetime?	2.62	3.43	3.69	25.09	.00	.12
that affects your home in the next 5 years	1.00	2.38	1.64	155.27	.00	.48
that affects your home in your lifetime?	1.08	2.83	2.97	60.92	.00	.58
Awareness						
(percentage of correct responses)						
Preparedness behaviour	2.09	2.41	24.58	41.18	.00	.53
Evacuation routes and meeting point	5.64	5.07	11.67	8.02	.02	.04
Protective actions	6.81	6.01	36.47	34.82	.00	.39
Actions before leaving the house	34.51	32.82	80.58	39.01	.00	.33
Actions taken on the house after flooding	13.90	12.84	36.76	44.11	.00	.38
Covariates (%)						
Age				10.73	.03	n.a.
18-34 years	15.59%	20.14%	35.79%			
35-54 years	41.15%	48.98%	32.20%			
> 54 years	43.26%	30.87%	32.01%			
Family status				12.45	.04	n.a.
Single or living as a couple	39.42%	29.27%	37.14%			
Living with children over 12	26.70%	41.63%	26.56%			
Living with dependant people (children younger than 12, elderly...)	18.34%	10.37%	19.27%			
Other status	15.54%	18.73%	17.03%			
House type				26.38	.00	n.a.
Ground floor house	11.23%	18.93%	45.08%			
Two-storey house	51.30%	30.16%	24.05%			
House with basement	14.37%	29.74%	19.71%			
Flat	23.10%	21.18%	11.17%			
Flooded area				17.10	.00	n.a.
No	66.78%	36.14%	46.32%			
Yes	33.22%	63.86%	53.68%			

Hightlights

- We analyse social perception of flash flood risk at the local level.
- We assess level of awareness of a specific emergency civil protection plan.
- Risk communication must be implemented to improve risk perception and awareness.
- Increasing risk perception and awareness will improve resilience of the community.

Figure 1

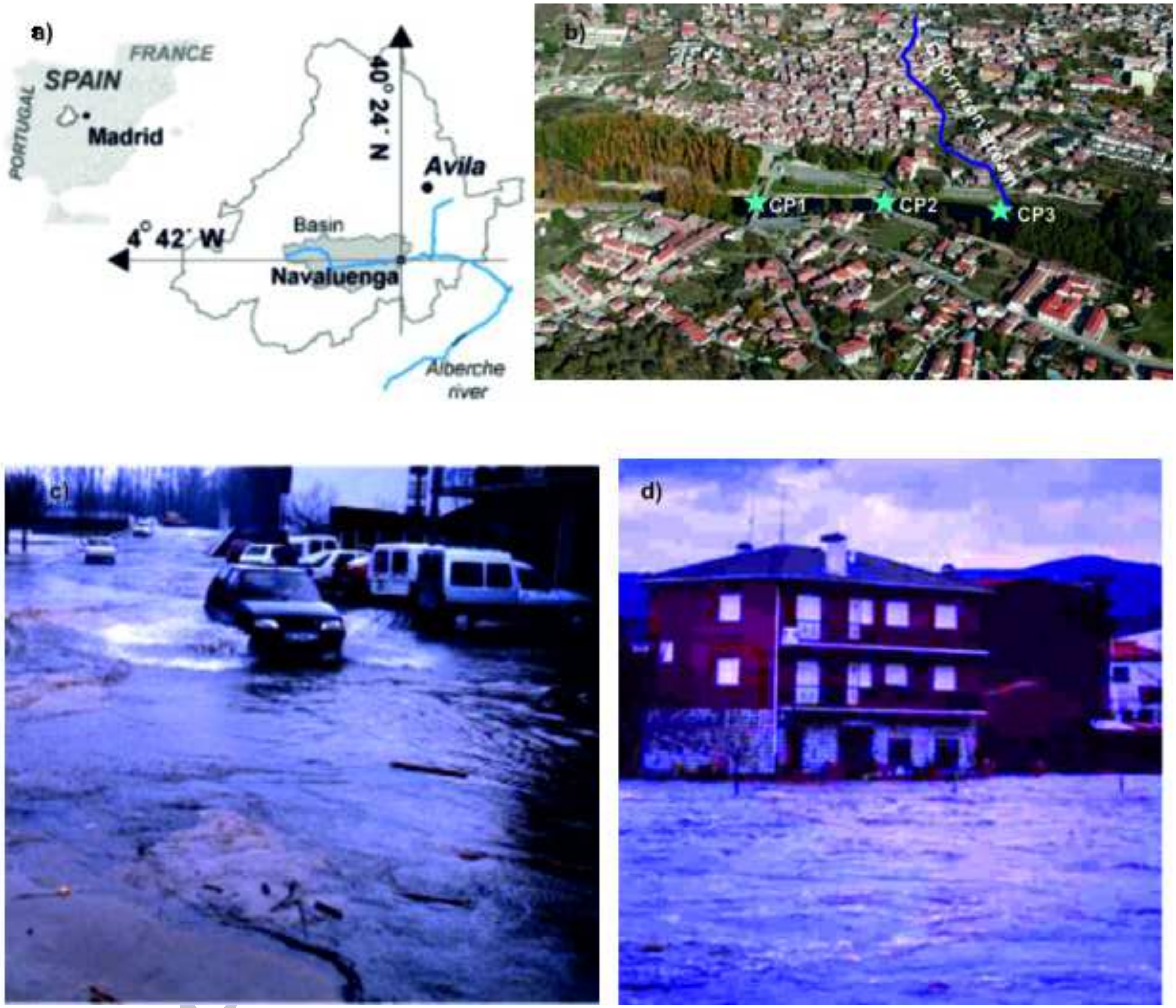

a)
FRANCE
SPAIN
PORTUGAL
Madrid
40° 24' N
Avila
Basin
4° 42' W
Navaluenga
Alberche river
b)
CP1
CP2
CP3
c)
d)

Figure 2

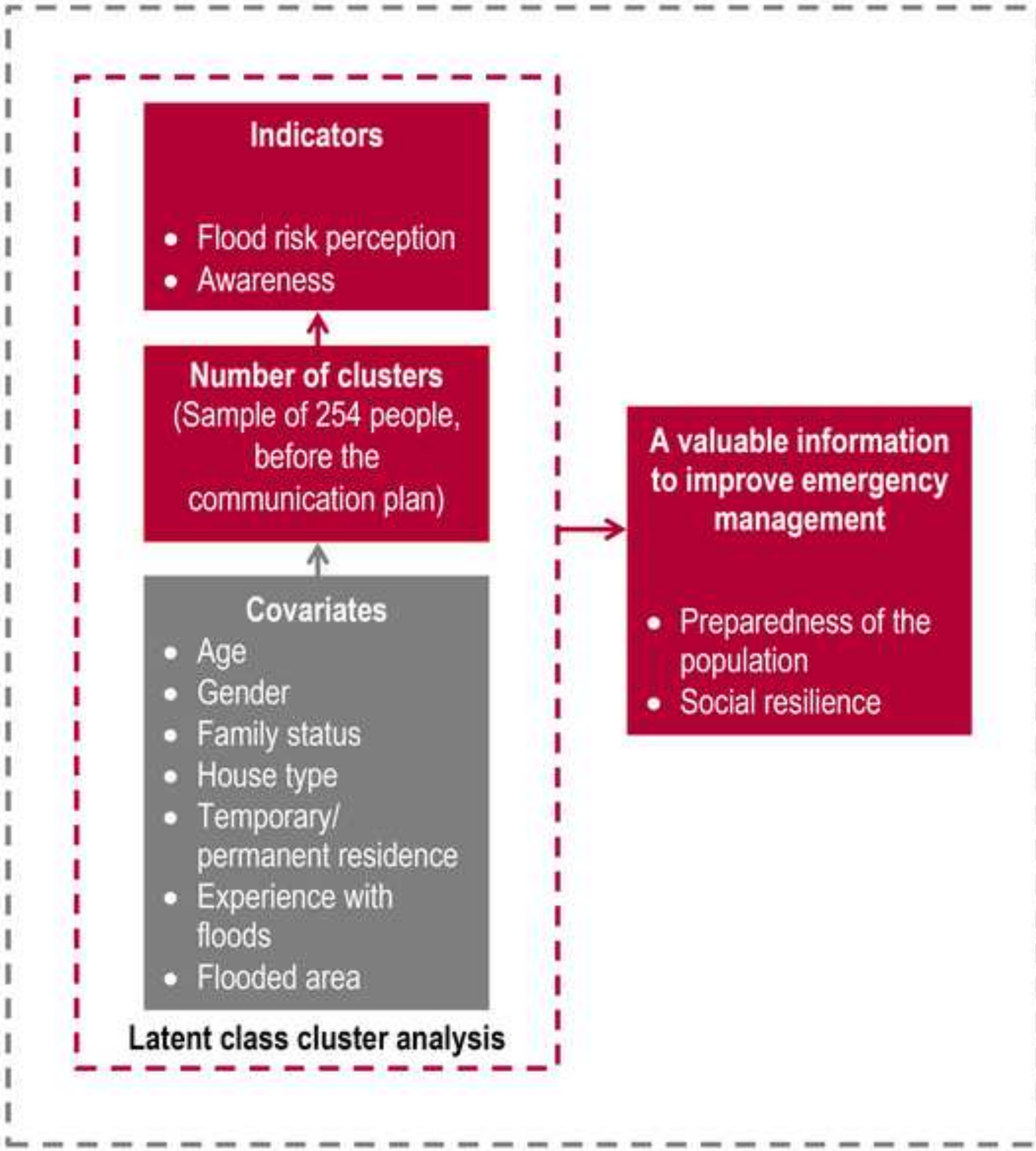

Indicators
Flood risk perception
Awareness
Number of clusters
(Sample of 254 people, before the communication plan)
Covariates
Age
Gender
Family status
House type
Temporary/ permanent residence
Experience with floods
Flooded area
Latent class cluster analysis
A valuable information to improve emergency management
Preparedness of the population
Social resilience

Figure 3

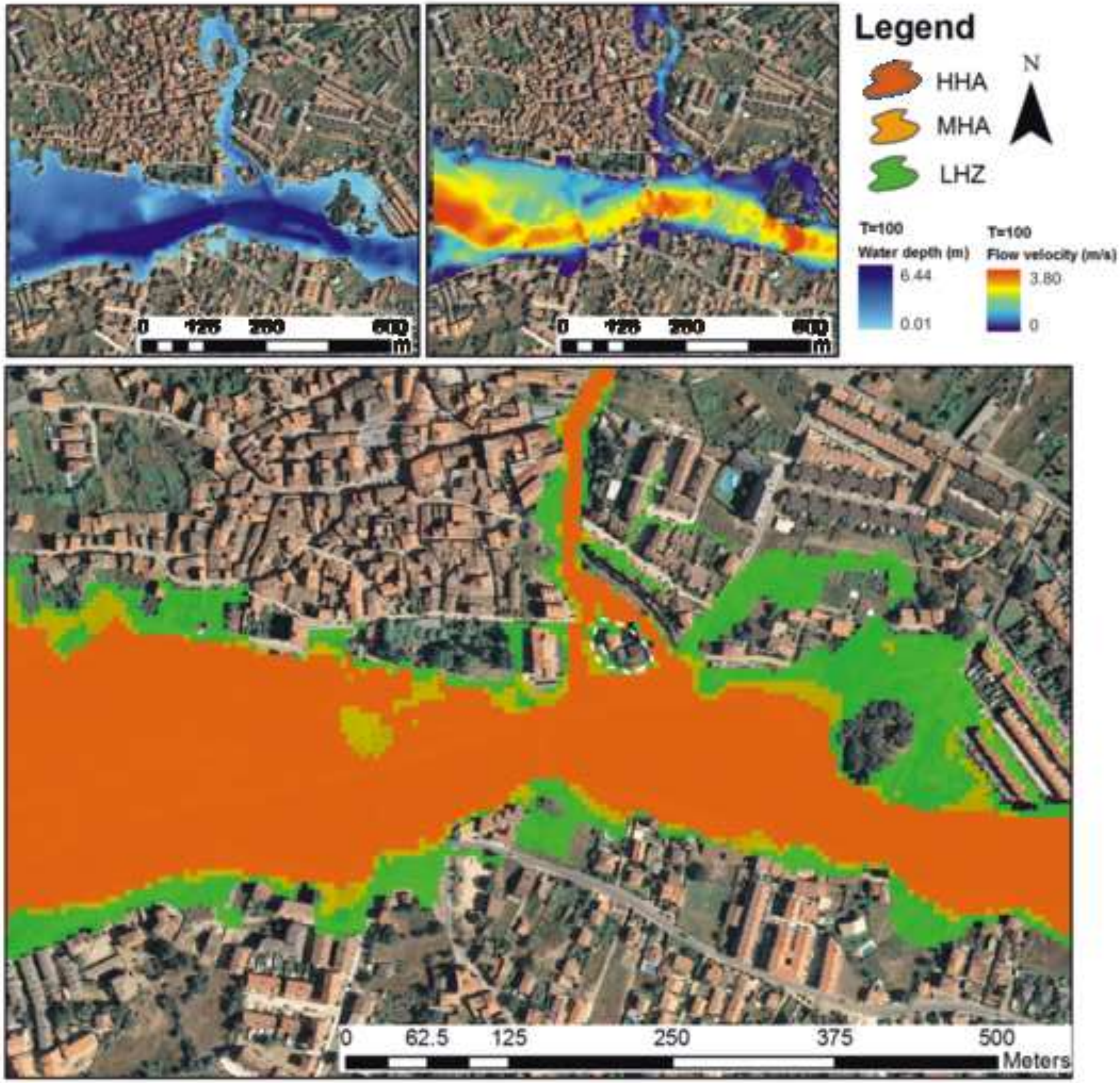

Legend
HHA
MHA
LHZ
N
T=100
Water depth (m)
6.44
0.01
T=100
Flow velocity (m/s)
3.80
0
0 62.5 125 250 375 500
Meters

Figure 4

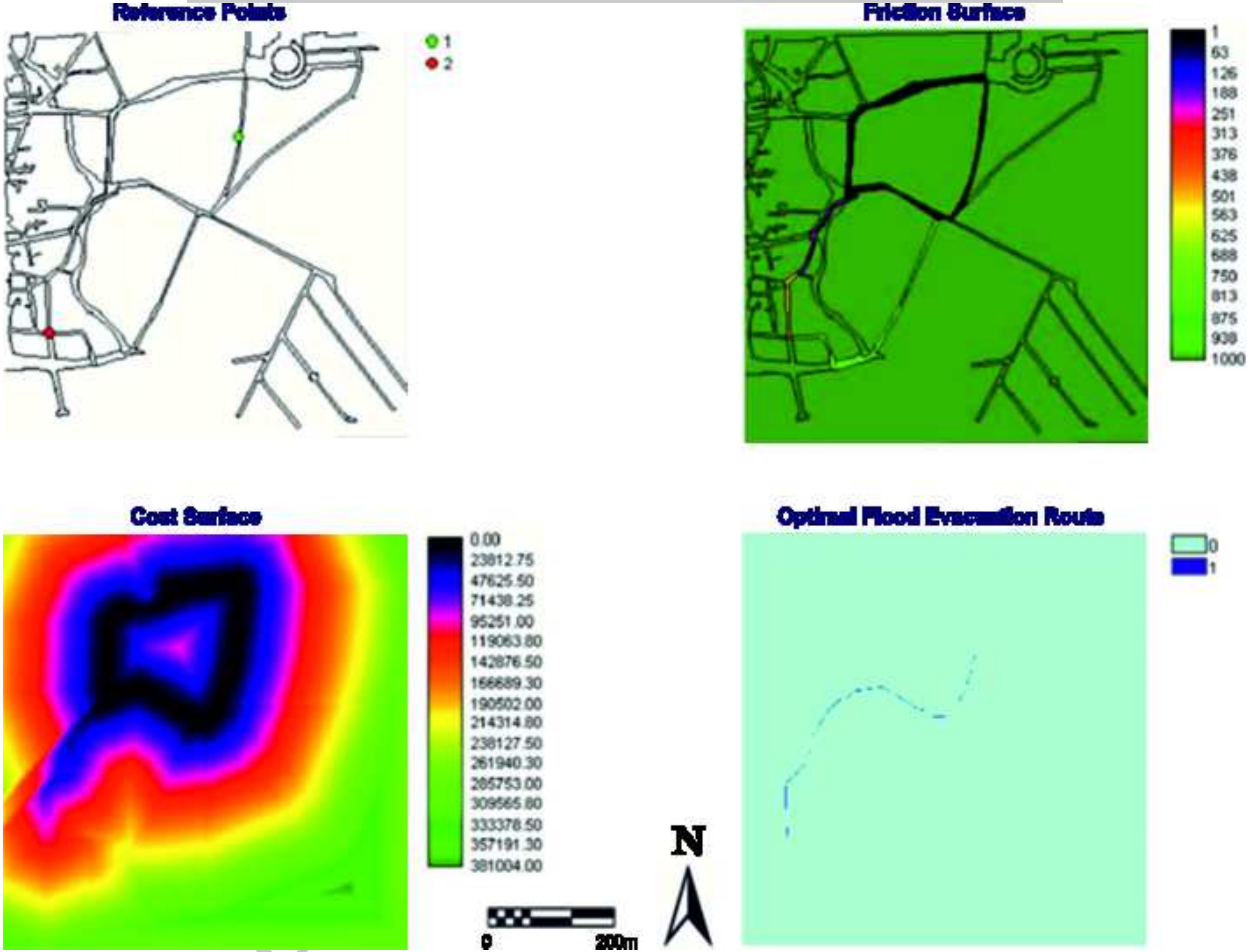
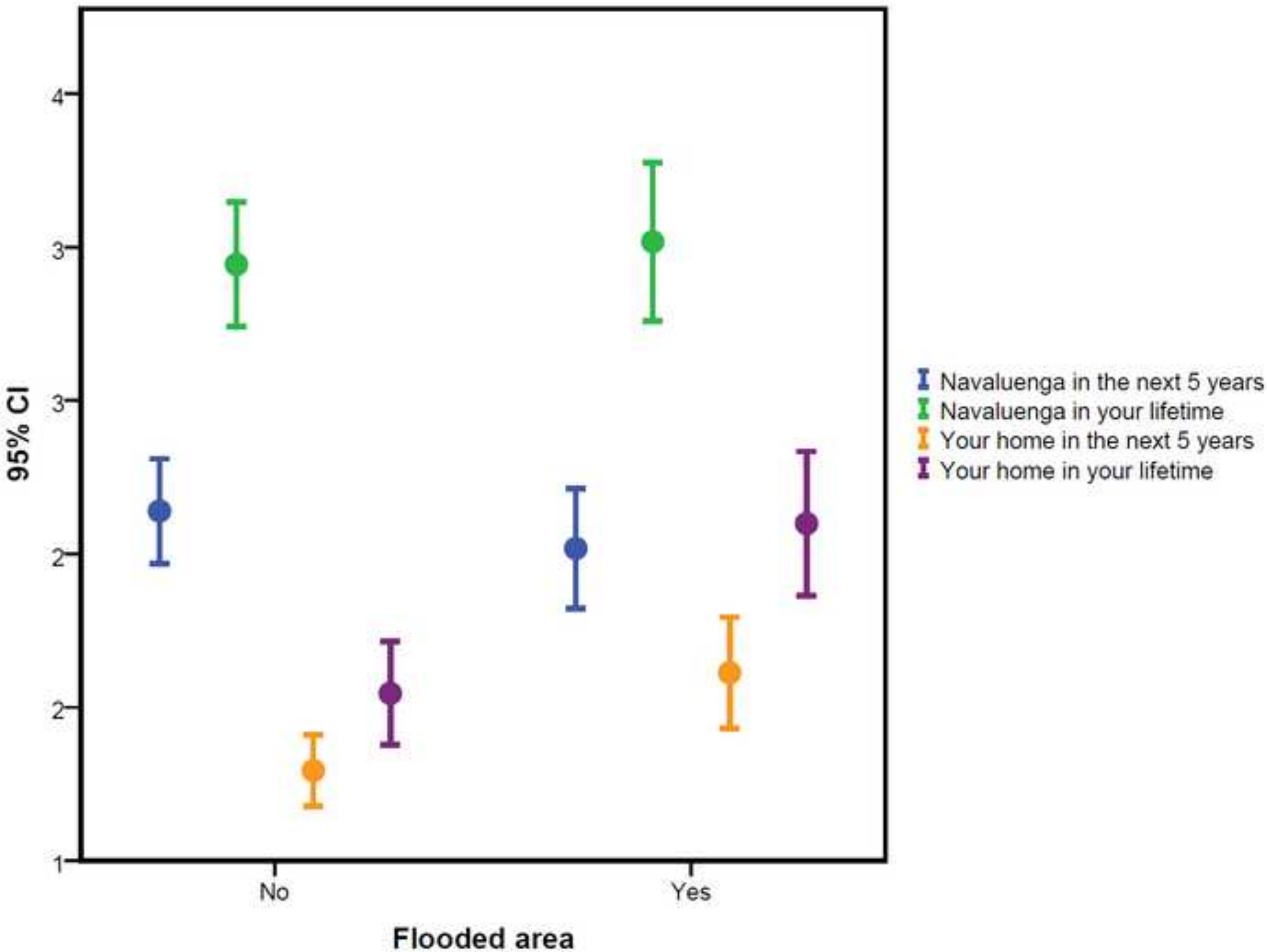
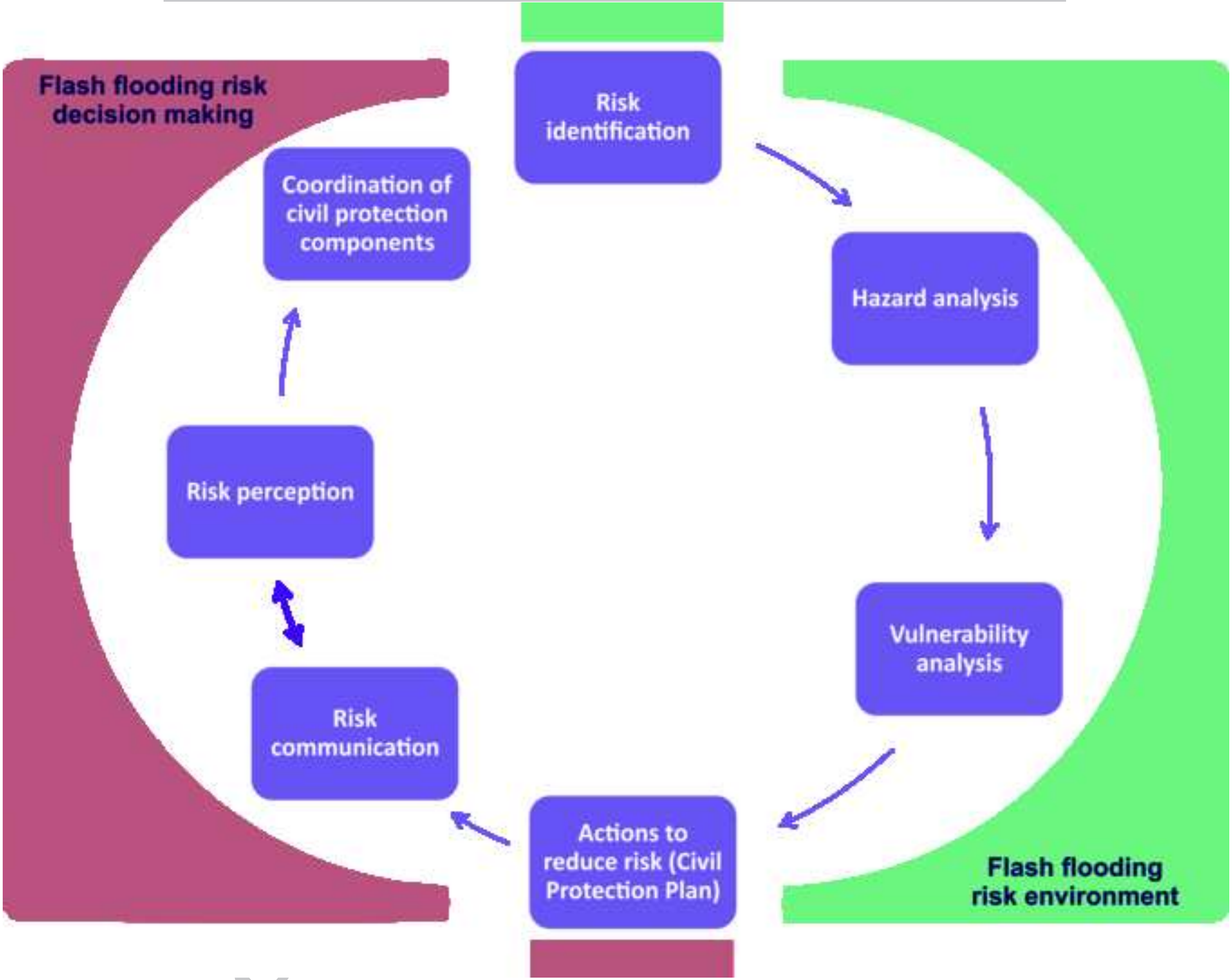

Reference Points
1
2
Friction Surface
1
63
126
188
251
313
376
438
501
563
625
688
750
813
875
938
1000
Cost Surface
0.00
23812.75
47625.50
71438.25
95251.00
119063.80
142876.50
166689.30
190502.00
214314.80
238127.50
261940.30
285753.00
309565.80
333378.50
357191.30
381004.00
0
200m
N
Optimal Flood Evacuation Route
0
1

Figure 5



95% CI
4
3
3
2
2
1
No
Yes
Flooded area
Navaluenga in the next 5 years
Navaluenga in your lifetime
Your home in the next 5 years
Your home in your lifetime

Figure 6


Flash flooding risk decision making
Risk identification
Coordination of civil protection components
Hazard analysis
Risk perception
Vulnerability analysis
Risk communication
Actions to reduce risk (Civil Protection Plan)
Flash flooding risk environment