Analysing flash flood risk perception through a geostatistical approach in the village of Navaluenga, Central Spain

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Abstract
Flash floods are unexpected events, which evolve rapidly and affect relatively small areas. The short time available for minimising risks requires preparedness and active response. In this context of risk management, the flood risk perception of the local population is the first step towards achieving resilience of people and communities. Although flood risk perception has intrinsic spatial variability, few previous studies take this into account. This paper explores the spatial variability of flash flood risk perception in the village of Navaluenga in Central Spain, using nonparametric and multivariate geostatistical tools. How local people perceived the flash flood risk to their homes was assessed interviewing a representative sample. Results show that considering these flash flood risk related spatial variables enhances people's psychological interpretation of risk perception: the perception of flash flood risk in a short time event is congruent with those spatial variables. These findings determine priority areas for future risk communication plans. They could also be extrapolated to other urban areas with a similar hydrographic configuration, when there is a flood hazard from a main river and potentially flooded minor water courses, which are even closer to houses but are not considered dangerous by the local population.

KEYWORDS
flash flood, natural flood management, resilience, risk communication

1 | INTRODUCTION

1.1 | Risk perception and community resilience

All the recent international frameworks and agreements for action on the reduction of risks due to natural hazards (e.g., Hyogo 2005; Sendai 2015; Sustainable Development Goals 2015) have introduced the concept of resilience in the context of disaster risk reduction, unifying environmental sustainability and civil protection concepts (Briceno, 2015; Toseroni, Romagnoli, & Marincioni, 2016; Zimmermann & Keiler, 2015). Development and risk reduction organisations are working to design programs...
that take into account an understanding of perception of risk to encourage protective action in communities at risk from multiple, overlapping threats (Sullivan-Wiley & Gianotti, 2017). Risk perception (RP) of local people is a first step towards achieving resilient inhabitants and communities, improving both prevention and response to an emergency (Lumbroso, Brown, & Ranger, 2016; Muzenda-Mudavanhu, Manyena, & Collins, 2016). Hence, early and timely disaster forecasts and warnings are important. It is also fundamental to understand how people perceive risks due to natural hazards and what factors influence their responses to warning information (Morss, Mulder, Lazo, & Demuth, 2016).

In compliance with the European Directive 60/2007/EC on the assessment and management of flood risks management, river basin authorities have recently completed the first flood risk management cycle (2009–2014) developing the following items: preliminary flood risk assessment, hazard and risk maps, and flood risk management plans (FRMP). Transposed to Spain’s legislation, and in its technical recommendations as a Member State, the aims of these recently developed plans prioritise increased RP of local inhabitants. More specifically, the advance FRMP for the Tajo River basin (CHT, 2014), which includes the village of Navaluenga studied here, highlights the following general objective 1: “Increased perception of flood risk and self-protection strategies in citizens and in the social and economic agents”.

Research on RP began in the 1940s, when Gilbert White published his groundbreaking thesis on human adaptation to floods in the United States (White, 1945). Over the following years, RP research evolved to include psychological experiments and public surveys, where people’s awareness could be assessed and preferences expressed. This led to the development of several approaches (see the review by Kellens, Terpstra, & De Maeyer, 2013): (a) the Psychometric Paradigm attempts to quantify individuals’ RP and attitudes using questionnaires; (b) Heuristic approaches, or simple and efficient rules of thumb, with four types (availability, representativeness, adjustment, and affect); (c) nontheoretical approaches, using a different set of multiple questions or items to measure various aspects of RP. This development on RP research has led to consider not only an interventionist approach, but also a participatory one such as the social capacity building framework (Höppner, Whittle, Bründl, & Buchecher, 2012; Kuhllicke et al., 2011).

Besides the classical heuristic processes in taking decisions or making judgements (Tversky & Kahneman, 1974), mentioned above in point (b), other cognitive biases have recently been adopted to understand RP processes. The study by Luís et al. (2015) concludes that normalising perception reduces coastal RP through the illusion of positive control. An example of this conclusion can be found in people living in coastal areas prone to be flooded, who tend to experience a sense of control and an unrealistic optimism about flood hazard. According to Uzzell (2000), environmental hyperopia enables “environmental problems to be perceived as more serious the further away they are from the perceiver”. In line with this result, Gifford et al. (2009) reported a spatial optimism effect in 15 of 18 countries, and a temporal pessimism effect in 17 of them when assessing 20 environmental problems. According to their results, participants tended to perceive current environmental conditions as more positive at a local level compared with national and global ones; and regardless of spatial variability, most of the countries were pessimistic about the distant future (25 years). Therefore, most people from different countries tended to assess distant (spatial and temporal) environmental conditions worse than close conditions. Schultz et al. (2014) also reported a strong environmental spatial bias across participants from 22 countries: the seriousness of environmental problems were perceived as greater at a global level compared with at their local level. The same results were obtained in a second study with eight countries (Schultz et al., 2014). These results have been explained based on the Construal Level Theory (CLT) proposed by Liberman and Trope (2008). When people are asked to assess a surrounding reality, such as one specific environmental problem, they have to transcend to think about that. That scenario turns this mental reality into a psychologically distant object. According to CLT, the interpretation of the surrounding reality becomes more abstract the larger the distance from the perceiver, and this is called psychological distance bias. This bias enables people to make predictions about a distant reality, because it is represented in an abstract way (high-level construal). As reality gets close, the interpretation of that reality becomes more concrete and detailed (low-level construal). In this way, an event can be interpreted at different levels of construal, depending on its distance from the perceiver on four dimensions: geographical or spatial (global or local; close or far), temporal (present or future), social (similar or different people), and hypothetical (greater or lesser probability of occurrence).

Other “Examining Behaviour” studies have observed people’s behaviour in response to their exposure to risk due to natural hazards, with various adaptive measures (mitigation and preparedness). But most previous works have studied RP in slower onset floods in great river basins, and only a few studies have investigated these issues for flash floods in medium and small watersheds (Knocke & Kolivras, 2007; Wagner, 2007; Coles, 2008; Ruin, Creutin, Anquetin, & Lutoff, 2008; Lazrus, Morss,
Demuth, Lazo, & Bostrom, 2016; see compilation in Morss et al., 2016).

1.2 Spatial variability of flash flood risk perception

There is no doubt that flood RP has enormous spatial variability. However, although there are many studies on social perception in the field of environmental psychology and civil protection, very few consider the spatial variability of RP within a single population, addressing an entire municipal district, province, or nation as a single unit of analysis (O’Neill, Brereton, Shahumyan, & Clinch, 2016).

Data from sociodemographic databases and survey questionnaires are usually applied to descriptive or multivariate statistical analyses (Morss et al., 2016). Some studies which consider the spatial component of perception do so with simple interpolation using tools implemented in geographic information systems (GIS) (Mulder, 2012; Ruin, Gaillard, & Lutoff, 2007). Normally they consider proximity to hazard source in relation to flash floods (Ruin et al., 2007) and river flooding (Miceli, Sotgiu, & Settanni, 2008). However, they are limited to situating the elements surveyed on a map or in a georeferenced database (Morss et al., 2016) or to the spatial distribution of a starting variable, but do not consider the results of perception analysis. Hence, these analyses do not exploit the available spatial information to the maximum and their interpretation does not allow data extraction of interest for analysing perception, improving risk prevention and resilience. Other works include the spatial component in the flood RP analysis. Botzen, Aerts, and Van Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP, while on the contrary Pagneux, Gísladóttir, and Den Bergh (2009) found distance and elevation to river to be main determinant in shaping a respondent’s flood RP.

Geostatistics is a branch of statistics currently applied in many fields of Earth Sciences (groundwater hydrology, meteorology, etc.) and Engineering Earth Sciences (mining or environment). Other previous studies of using geostatistics in RP focused on social, environmental or technological risks: industrial risks and how sensitivity to risk depends on various factors, including the landscape dimension and the visibility of industrial components (Bonnet, Amalric, Cheve, & Travers, 2012). In the study by Vangeli, Koutsidou, Gemitzi, and Tsagarakis (2014) Kriging, a standard geostatistical tool, was used to analyse the spatial distribution of RP in an industrial accident with environmental impacts. However, there are very few studies (or none in the available international literature) in which nonparametric or multivariate geostatistical tools are applied to evaluate the spatial variability of flood RP.

1.3 Objectives

In response to the apparent lack of previous studies of spatial analysis of flash flood RP with geostatistical tools, and to the problem of flash floods in Navaluenga, the aim is to study the relationship between physical indicators of the flash flood hazard and both flood RP and the awareness of protective actions at the vicinity of two different types of streams in the urban nucleus of Navaluenga. This aim has a twofold objective: On the one hand and from a basic research perspective, this work proposes to integrate psychosocial theory and geostatistics in the risk analysis research to explore involved psychological processes. On the other hand and from an applied perspective, this research targets to get flash flood RP maps, which are highly valuable to different types of plans (FRMP, updates of the Civil Protection Plan and urban planning).

2 MATERIALS AND METHODS

2.1 Case study

The village of Navaluenga, in the province of Avila, is located in the center of the Iberian Peninsula, with a permanent resident population of about 2,000, but with a floating population as high as 15,000 in the holiday season. Most inhabitants live on the banks and floodplain of the Alberche River (Tajo Basin) and its tributary the Chorrón Stream, which have fluvial regimes with strong inter-annual and intra-annual fluctuations, and flash floods multiplying the average annual flow by 60.

The continental Mediterranean climate of the study area is typical of Spanish medium mountain ranges. Torrential rainfall events, which usually occur in autumn and winter, result in abundant surface runoff and sediment mobilisation, triggering flash flood events.

During flash floods, with concentration and travel times of only a few hours, the river and its tributary flood the streets and buildings of Navaluenga, periodically causing important material damage and putting the population at risk. The last major flash floods took place in the 1990s; most of the younger generation in Navaluenga have not experienced these catastrophic phenomena; others have forgotten them and their RP is low (Bodoque et al., 2016).
The economic risk estimates for Navaluenga, calculating losses for certain scenarios (coincident flood peaks in the Alberche and the Chorrerón) with a 500-year return period, are more than one million euros (Ballesteros-Cánovas, Sánchez-Silva, Bodoque, & Díez-Herrero, 2013).

For emergency management, a Special Civil Protection Plan for Navaluenga local flood risk reduction action was drawn up and approved in 2014. This is a pioneer plan in the province of Ávila and one of the first in the region (Castilla y León). RP studies were carried out prior to and after the implementation of the Civil Protection Plan, and a risk communication plan was implemented in the village (Figure 1).

2.2 | Data collection

2.2.1 | Psychosocial survey

254 adults, representing roughly 12% of the census, were interviewed to obtain perception data. The participants were selected using a quota sampling procedure with age and gender as quota control variables. The questionnaires were administered by trained interviewers who met participants in their home during January 2015 (Table 1). 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. Figure 2 indicates the location of the surveyed houses (i.e., queries). These data are part of a previous work (Bodoque et al., 2016), in which an ad hoc questionnaire with three sections was designed. A first section assessed the level of awareness about actions to take, the second the social perception of risk and the third and final section included a series of relevant socio-demographic and experiential characteristics. The data analysis in that work included a t test for equality of means and a latent class cluster.

Following the findings of Botzen et al. (2009) and O’Neill et al. (2016) in relation to the role of elevation as a determinant of flood RP, calculated differences in ground level between the houses and the water courses were included in the present analysis.

Flash flood RP is assessed by adapting a general measure by Bourque et al. (2013) that considered the flood probability for the home, both in the short term (the next 5 years) and in the long term (lifetime). This was measured on 5-point scale levels, ranging from highly improbable (level 1) to highly probable (level 5). In order to measure preparedness intention, participants were asked to think of a flood in Navaluenga, and to assess to what extent (in 5-point scale levels ranging from “not at all” to “with absolute certainty”) they were intended to:

1. Acquire an emergency kit at home (including first-aid, battery powered radio, torch, etc.), and
2. Perform a household emergency plan (store in a safe place valuables, keep clean down-pipes, clear the way outside the house, etc.).

These measures were inspired by Terpstra and Lindell (2013).

2.2.2 | Spatial data

For the geostatistical analysis, four variables presenting a spatial relation with the flooded areas were selected (Table 2). The coordinates of the houses included in the survey were recorded in situ using a GPS device. The remaining spatial data (e.g., altitude or distance from the nearest river) were collected using GIS techniques, a digital elevation model (DEM), and digital cartography as data sources.
2.3 | Methods

2.3.1 | Flooded area calculation

Flooded areas (Figure 2) were obtained by first generating an urban Triangulated Irregular Network (TIN) from Laser Imaging Detection and Ranging (LiDAR; Liu, 2008) data (density 0.5 points/m²), complemented with the river bathymetry obtained from a field survey (density 0.3 points/m²). The TIN was subsequently improved by adding breaklines, which are elements that define interruptions in surface smoothness (e.g., streets, riverbanks; Bodoque, Guardiola-Albert, Aroca-Jiménez, Eguibar, & Martínez-Chenoll, 2016), and was finally transformed into a raster with 2 m spatial resolution. Secondly, a 2D hydrodynamic model based on different flood return periods of 50, 100, and 500 years was implemented using Iber software (Bladé et al., 2012). For boundary conditions, discharges corresponding to 500-, 100-, and 50-year return periods in the Alberche and Chorrerón were obtained from Spanish flood-prone area maps (available online: http://www.mapama.gob.es/es/agua/temas/gestion-de-los-riesgos-de-inundacion/snczi/mapa-de-caudales-maximos/, accessed on September 1, 2017). Following Arcement & Schneider (Arcement &
Schneider, 1989), the roughness coefficient was obtained from official land cover mapping (scale 1:25,000 and then the corresponding Manning’s $n$ value was assigned to every land cover unit).

### 2.3.2 Descriptive statistics

The analysis of questionnaire results started with descriptive statistics of the four variables chosen in this study (Figure 3): flash flood RP for houses over the next 5 years (short term), or over the whole lifetime (long term), and the other two about preparedness intention (to one self/family or to the house). Box plots were used to explore the distribution behaviour of different levels of flash flood RP affecting homes and preparedness intentions. More specifically, possible relationships between RP and awareness were checked with seven flood-related spatial variables: (a) distance from the closest stream (Alberche or Chorrerón), (b) distance from the Alberche River, the biggest watercourse in the village, (c) difference in ground level between the house and the nearest stream (Alberche or Chorrerón), (d) difference in ground level between the house and the Alberche, (e) distance from floodable areas with a 50-year return period, (f) distance from floodable areas with a 100-year return period, and (g) distance from floodable areas with 500-year return period. The closest point and distance from each home to streams, or to any of the floodable areas, were computed using the Near Arcmap tool (ESRI, 2011). R software was used to perform descriptive and graphical statistical analysis with the basic R package (R Development Core Team, 2009) and the ggplot2 R package (Wickham, 2009).

### 2.3.3 Spatial analysis with Variogram

The experimental variogram, defined within the framework of second order stationarity hypothesis, can provide an empirical description of the spatial continuity (i.e., spatial correlation) of one variable, here RP and preparedness. If the questionnaire result variables (e.g., $z(x)$)

| Variable under study                                      | Source     | Type      | Units     | Range          |
|----------------------------------------------------------|------------|-----------|-----------|----------------|
| X coordinate (UTM ETRS89)                                | DEM        | Numerical | m         | 354,301–354,010|
| Y coordinate (UTM ETRS89)                                | DEM        | Numerical | m         | 4,473,944–4,475,545|
| Altitude of the area                                      | DEM        | Numerical | m.a.s.l.  | 751.8–781.6    |
| Preparedness intentions                                   |            |           |           |                |
| Acquire an emergency kit                                  | Survey     | Categorical| –        | 1–5            |
| Perform a household emergency plan                        | Survey     | Categorical| –        | 1–5            |
| Flash flood risk perception                               |            |           |           |                |
| Affecting home in the next 5 year                         | Survey     | Categorical| –        | 1–5            |
| Affecting home in the lifetime                            | Survey     | Categorical| –        | 1–5            |
| House ground level minus elevation of the closest river    | DEM        | Numerical | m         | 0–28.28        |
| House ground level minus elevation of the Alberche        | DEM        | Numerical | m         | 0–36.8         |
| Distance from the closest river                           | Geographic map | Numerical | m         | 4.3–532.42     |
| Distance from the Alberche                                | Geographic map | Numerical | m         | 30.5–1,090.7   |
| Distance from the 50 year return period flooded area      | FHA        | Numerical | m         | 0–434.14       |
| Distance from the 100 year return period flooded area     | FHA        | Numerical | m         | 0–422.3        |
| Distance from the 500 year return period flooded area     | FHA        | Numerical | m         | 0–389.2        |

**Abbreviations:** DEM, Digital elevation model; FHA, flood hazard analysis; m.a.s.l., metres above sea level; 1–5, from 1 (low) to 5 (high).
are considered as values of punctual regionalised variables (i.e., \( z \) is a numeric function of geographic location \( x \); Matheron, 1965), the experimental variogram \( \gamma(h) \) measures half the variance of differences between values \( z(x_i) \) and \( z(x_j) \) of pairs of surveyed houses \((x_i, x_j)\) separated by a vector \( h \) (Chilès & Delfiner, 1999):

\[
\gamma(h) = \frac{1}{2N(h)} \sum_{i \neq j} \frac{(z(x_i) - z(x_j))^2}{\|x_i - x_j\|} \quad \text{(Equation 1)}
\]

where \( N(h) \) is the number of houses data pairs at locations \( x_i \) and \( x_j \), which are separated by a vector \( h \).

The experimental variogram is usually an increasing function of distance \( \|h\| \) since the values of the study variables (RP and preparedness) for houses closer together are likely to be more similar than values for houses far apart. At large distances the experimental variogram may reach a sill, which is an indicator of the spatial variability of the data. The range is the distance at which the variogram reaches the sill. The behaviour of the variogram near the origin is an important property which reflects the continuity of the variable under study. In particular, a discontinuity of the variogram at the origin, or nugget effect, can be related to the presence of non-correlated spatial features. A model can also be fitted to the experimental variogram (Figure 3), but the theoretical variogram has to be a valid mathematical function, also known as an authorised model (Chilès & Delfiner, 1999; Wackernagel, 2003). The indicative goodness of fit (IGF) statistic was computed for all the fitted variograms (Pannatier, 1996), which values close to zero indicate a good adjustment of the model.

For the two perception and two preparedness variables studied, computation of the experimental variogram and fit of the variogram model was performed using the free SGems geostatistical software (Remy, Boucher, & Wu, 2009).

2.3.4 Indicator Kriging

The general term of Kriging refers to the geostatistical interpolator which gives the best estimator as a linear combination of the available data, without bias and with minimum error variance (Journel & Huijbregts, 1978). To calculate the weights of this linear estimator, Kriging uses a model of spatial variability through the variogram.
Cokriging requires satisfying the same conditions as Kriging, but demands more variography (i.e., three cross-variograms), modelling and computation time. These technical drawbacks motivated the use of different software from that used to perform Simple Indicator Kriging and so cross-variogram and Cokriging computations were performed using non-free ISATIS geostatistical software (Geovariances, 2011). ISATIS has a graphical fitting aid that SGems does not have. Risk analysis maps from the Cokriging interpolation were produced with ArcMap software (ESRI, 2011).

3 | RESULTS AND DISCUSSION

3.1 | Descriptive statistical analysis

Boxplots showing summary statistics for the chosen variables at each house surveyed (e.g., distance from or ground level difference with closest streams, Alberche River or flooded areas) are plotted, differentiating between the perception and the preparedness 5-point scale levels (Figure 4). To better understand these boxplots it is necessary to recall that level 1 corresponds to “highly improbable” or “not at all”, and level 5 means “highly probable” or “with absolute certainty”. In this figure, greys are used to highlight a median visually assessed trend for the RP level. Short term flash flood RP for houses over the next 5 years shows a spatial-structured congruent pattern (Figure 4, column 1); flash flood RP is low for longer distances or greater differences in ground level (dark grey), and high for shorter distances or smaller differences in ground level (light grey). The same is observed with the distance from flooded areas (graph at the foot of Figure 4, column 1).

These results are in agreement with the findings of Botzen et al. (2009) and O’Neill et al. (2016). Nevertheless, this congruent pattern is not observed in RP level 2, and it is highlighted in plots in Figure 4, column 1, not colouring the boxplots. The explanation for this outlier is that 70% of the houses responding to flash flood RP level 2 have more than one floor or elevation in relation to ground level, reducing people’s perception of the flash flood. On the other hand, when this RP refers to people’s lifetime (Figure 4, column 2), this relationship with distance or ground level difference also appears. However, in this case, this trend is not so clear for intermediate RP levels, and hence the corresponding boxes are not coloured in Figure 4.

These results are in line with one of the theorised dimensions of the psychological distance bias: the temporal distance bias, framed in the CLT (Liberman & Trope, 2008). Following this approach, the more psychologically...
distant an object is, the more it will be represented by an abstract, high-level construal. When people evaluate the probability of a flash flood in their home in the long term compared with the short term (next 5 years), this scenario will be time-distanced, and therefore related events will be represented by an abstract, high-level construal, with general decontextualised features. The reverse happens for events close in time, evaluated through a concrete, low-level construal comprised of specific contextual details (Liberman & Trope, 2008; Spence, Poortinga, & Pidgeon, 2012). According to this perspective, flash flood RP in a house in the short term would be based on specific characteristics such as distance of the house from the closest flood sources, or the difference in ground level. On the other hand, flash flood RP in a house over a lifetime would be based on more abstract and decontextualised characteristics, offering more polarised answers, such as those shown in Figure 4, column 2.
In the case of the two preparedness variables in the study (intention to acquire an emergency kit and perform a household emergency plan), no direct relationship was observed with distance from streams or flooded areas or difference in ground level between house and streams; median trends do not follow a clear rule (Figure 4, columns 3 and 4) and means are not significantly different for most of the cases. Results for the distance to flooded areas with 100- and 500-year return periods are not shown as they are very similar to the ones shown for flooded areas with a 50-year return period. These results (Figure 4) do not present a clear congruent pattern on preparedness considering spatial variability, which is perhaps counterintuitive. This is not what would be expected to happen, the less distance to the hazardous source, the more preparedness intention. Literature on psychological processes in risk perception offers some clues to understand these results, particularly on the risk normalisation effect (Luis et al., 2015). Several studies have shown that psychological proximity does not always lead to more action: some variables such as target behaviour, perceived efficacy or concern, among others, can mediate reducing the effect of psychological distance bias (McDonald, Chai, & Newell, 2015; Spence et al., 2012). These results indicate that more research on the relationships between preparedness behaviour and psychological distance is need. Additionally, they show the importance of risk communication strategies to improve preparedness behaviour to mitigate flash flood consequences (Spence et al., 2012).

3.2 | Variograms

The experimental variograms in Figure 5 show to what extent the variogram can depict the spatial heterogeneity of the questionnaire results. Both flash flood RP variables present spatial dependence as their corresponding experimental variograms evolve smoothly from origin and stabilise around a value (Figure 5a,b). Corresponding spherical models were fitted (Figure 5). Flash flood RP for houses during lifetime has a wider distribution of values than RP values for the next 5 years, as the variogram sill is higher. Figure 5a shows a better model fit for the 5-year RP than for the lifetime RP (Figure 5b). As mentioned above, a time distance bias can be applied to interpret these results.

Experimental variograms of preparedness variables do not have any spatial structure (Figure 5c,d), increasing...
rapidly at origin and reflecting a nugget effect behaviour (Chilès & Delfiner, 1999). As stated above, further research is necessary to take into account the effects of other relevant variables implied in preparedness intentions.

It was not possible to find any spatial correlation between flash flood RP over the next 5 years and the distance from the closest stream. The corresponding cross-variogram (Figure 6) did not present any clear spatial pattern. However, spatial correlation of flash flood RP in homes over the next 5 years with two other spatial variables (distance from the Alberche River and differences in ground levels) was geostatically quantified with the experimental cross-variograms and the corresponding models (Figure 7). Variograms of distance and ground level differences from houses to the Alberche River have no sill, with values increasing with separation (Figure 7). This is common in nonstationary variables (Atkinson & Lloyd Atkinson & LLoyd, 2007) and it is consistent with the fact that the Alberche River is in the south of the study area and these two variables increase from south to north. A power model (Journel & Huijbregts, 1978) was used to fit this nonstationary behaviour. The flash flood RP variogram was fitted using a spherical type model (Figure 7).

### 3.3 | Mapping interpolations

The “probability that the flash flood RP in homes for the next 5 years is low” was mapped first. Taking the lowest level of this flash flood RP (level 1) as an indicator variable, Simple Indicator Kriging results represent this probability (Figure 8). High probability values correspond to darker areas, representing houses where people feel safe with a high confidence level in the mapping process. There are very few dark areas near the Alberche. However, close to the Chorrerón, which can also flood, there are several darker areas showing the unjustified, low risk perception of people who feel they are safe.

The RP mapping was improved by using Cokriging because there is spatial correlation between flash flood RP in homes for the next 5 years and two other spatial variables. The experimental cross-variograms of the three variables were fitted (Figure 7) and used to perform Ordinary Cokriging interpolation (Figure 9a). Low flash flood RP areas are plotted with darker values, indicating again that, near the Chorrerón, people do not perceive significant exposure to flooding. Close to the Alberche, the RP is plotted with much lighter values, showing the flash flood risk awareness of people living close to the most important water course in the village. These outcomes concur with the results obtained by O’Neill et al. (2016), who found a mismatch between reality and perception: distance to the perceived flood zone is higher than the distance to the objective flood zone.

To make Cokriging results useful for the improvement of the Civil Protection Plan, this geostatistical map can be overlaid on the map of buildings in Navaluenga to pinpoint houses where the inhabitants’ knowledge of the Civil Protection Plan must be improved. An example of this output is given in Figure 9b. In this map, Cokriging results are plotted over the orthophoto of the village of Navaluenga using a white to orange colour range within the 500-year return period flood-prone area. Darker areas indicate houses with potential flood risk, where the perception of the inhabitants is that they are safe.

### 3.4 | Highlights and limits

Even though flooding of the Alberche can cause more damage than the Chorrerón, the risk linked to this tributary stream is greater. In the Chorrerón, exposure and vulnerability is higher as there are more houses built in its immediate vicinity. There is also a high probability that it will generate damages in the built area when it floods, as the level of the Alberche River will not allow its correct drainage.

The relationship between geostatistical estimation and flash flood RP follows a congruent pattern when the psychological distance from the flood risk is low in terms of time. Risk communication strategies focused on the affected population help to bring flood risk closer and make geostatistical estimations more predictable.

There are several limitations to the present study and approach. First, the results presented here are constrained by the number and random spatial distribution of the questionnaires. Secondly, measures of short and long term flash flood RP were not counterbalanced. People were asked to
FIGURE 7  Variograms: three plots on the diagonal. Cross-variograms: three plots outside the diagonal. The indicative goodness of fit is given for variogram models

FIGURE 8  Probability that flash flood risk perception in the next 5 years is low
evaluate RP at home in the short term firstly, and then in the long term. Future research should consider this methodological aspect in order to draw more accurate conclusions about temporal distance bias. Thirdly, Kriging techniques also have some limitations that must be taken into account when interpreting results. Assigning parameters to the variogram model and computing the experimental variogram are subjective procedures with intrinsic practical problems (Armstrong, 1984). Consequently, there will always be uncertainties related to the geostatistical interpolated maps. In addition, regardless of the interpolation method, there will always be some errors in the results. This error can be influenced by many factors such as inaccurate base data (e.g., implementation faults, transcription mistakes, wrong data sources or bad measurements), human error (e.g., inaccuracy in getting the surveyed locations or incorrect use of the coordinates projection), or time changes between measurements (e.g., seasonal population dynamics), which in the present research have been minimised as far as possible.

3.5 Future prospects

The results and analyses obtained in the present study have multiple fields for practical application and future development. Two main types of applied studies can be derived from the geostatistical analysis of the flash flood RP in municipal areas such as Navaluenga, with two or more river courses in their urban nucleus:

**FIGURE 9** (a) Cokriging interpolated map for the flash flood risk perception in homes in the next 5 years. (b) Results from (a) are plotted over the Navaluenga orthophoto within the 500-year return period flooded area.
1. Determination of priority areas for future new risk communication plans. The local Civil Protection Plan for Navaluenga must be updated every 6 years. In view of the sectors where the largest population with low RP is concentrated, and of the conditioning factors of this low RP, special emphasis will be placed on these population sectors in future information and educational activities (Bodoque et al., 2016) included in the Civil Protection Plan update, to reverse the situation, and improve RP. For example, special attention should be paid to people living on the banks of the Chorrerón Stream, with specific plans and programs to adjust their RP. These actions must include meetings for showing the flood hazard maps, photographs and videos of past flood events in the tributary river and the urban planning situation of the buildings.

This second aspect, which includes the predictive capacity of this present study, and enables it to be extended to other population groups, is perhaps one of the main potential strengths of this research. In the case of a short term assessment of flash flood RP at home, the results would allow a preliminary evaluation of the RP spatial distribution from simple data sources such as those used here (DEM, river map, map of flood-prone zones, etc.), without RP surveys. This preliminary assessment, in conjunction with other losses estimation studies currently under development, could then be calibrated and validated with the results of previous episodes, to assess whether the damages and losses change in different municipal sectors with the same flood susceptibility.

2. Locating sectors with population with low flash flood RP in other urban centers. In view of the variables controlling perception in Navaluenga, and their spatial distribution, the potential RP can be predicted with geostatistical interpolators in other towns with a similar hydrographic configuration (i.e., with a main river versus seasonal tributary/ies).

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