International Journal of Disaster Risk Reduction 138 (2026) 106117

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Sociodemographic factors in the perception and understanding of weather warnings and the activation of emergency plans in the Canary Islands (Spain)

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ARTICLE INFO

Keywords:
Weather warning
Risk perception
Risk communication
Early warning system
Education
Impact

ABSTRACT

The effectiveness of weather warning systems is directly related to citizens' understanding and response. This research analyses risk perception, level of understanding, and trust in weather warnings issued by Spain's State Meteorological Agency (AEMET) and in the activation bulletins of civil protection emergency plans in the Canary Islands, through a structured survey of 902 respondents. Drawing on established research on warning effectiveness, the study examines whether increased awareness and understanding necessarily lead to appropriate protective behaviour.

The analysis explores the role of sociodemographic factors, including age, gender, and educational level, in shaping risk perception and decision-making uncertainty. The results show that while 73.9% of respondents are familiar with AEMET warning levels, only 41.4% clearly distinguish them from civil protection activation bulletins, and 36.1% report uncertainty about what actions to take. Statistical analyses reveal that risk perception increases with age and educational level, while confusion is more prevalent among younger respondents and those with lower educational attainment. Latent class analysis identifies four distinct warning-perception profiles, including a large group of "informed but confused" individuals who possess technical knowledge of warnings but struggle to translate that knowledge into action. These findings support existing evidence that message comprehension alone does not guarantee behavioural response and highlight the persistence of a knowledge–action gap in public warning communication. The results underline the need to move from purely informative warnings towards clearer, action-oriented and institutionally coordinated messages that enhance public response during extreme weather events.

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https://doi.org/10.1016/j.ijdrr.2026.106117
Received 18 December 2025; Received in revised form 22 February 2026; Accepted 24 March 2026
Available online 27 March 2026

1. Introduction

It is a function of national meteorological agencies to produce weather forecasts; the challenge is to make them understandable to the public, especially during extreme events [1]. Official early warning systems constitute an essential pillar for disaster risk reduction, as established by the United Nations' "Early Warning for All" initiative [2]. However, various studies have highlighted a communication gap between the institutional issuance of the message and its interpretation by the public [3–5], such that the effectiveness of an alert depends not only on the technical accuracy of the forecast but also on how it is received and interpreted by the public [6].

In this context, various issues have been identified, most notably the underestimation or misinterpretation of alerts which has led to the public failing to adopt preventive measures [7]. Diakakis et al. [8] found a statistically significant correlation between various demographic and cognitive factors, including age, gender, level of risk knowledge and perceived self-efficacy, and the perceived reliability and effectiveness of warnings. These variables influence how threatened people feel by the announced phenomenon and their motivation to adopt preventive measures [9,10]. Ultimately, the gap between alerting and protection is largely due to human factors such as perceptions, beliefs, knowledge, trust and understanding. Addressing these elements in communications is as important as improving the forecasts themselves [11–13].

Message clarity is a key aspect, as alerts that confuse citizens have been detected on multiple occasions. Christian et al. [14] argue that even when people understand there is a threat, the way the warning is worded may not prompt action. In addition to impact-based approaches, a substantial body of U.S.-based research has examined the effectiveness of public warning messages delivered through short-message channels and mobile alert systems (Sutton & Kuligowski, 2024; Bean, 2019; [15]). This literature demonstrates that message characteristics such as clarity, specificity, length, and actionability significantly influence comprehension and intended protective behaviour. However, these studies also show that cognitive understanding does not automatically translate into behavioural response, highlighting a –persistent knowledge–action gap in warning communication. Building on these insights, the present study explores how such dynamics operate in the Canary Islands (Spain), where meteorological warnings and civil protection activation bulletins coexist within a multi-level institutional framework. Similar approaches have also been developed within community- and impact-based early warning system frameworks, which emphasise site-specific risk information and locally tailored communication [16]. Within this broader evolution of warning communications, the impact-based warning approach has gained momentum over conventional phenomenon-based approaches, as has been implemented, for example, in New Zealand [5] and the United Kingdom. The latter reformed its Met Office warnings so that its yellow, amber, and red alerts include descriptions such as "risk of flooding of homes and power outages" along with advice such as "avoid non-essential travel during the peak of the storm." Alerts formulated with information about the potential consequences of the phenomenon generated a greater perception of risk than those that only communicated technical parameters. Choi et al. [17] empirically demonstrated the benefits of this approach in South Korea, and international bodies such as the World Meteorological Organization (WMO) are actively promoting the inclusion of such information both in the alerts issued by national meteorological agencies [14] and in the civil protection activation bulletins issued by various authorities (Fig. 1), in line with the WMO Guidelines on Multi-hazard Impact-based Forecast and Warning Services [18].

Fig. 1 can be interpreted as an operational representation of key components described in established warning and response models, including the Warning Response Model (WRM) and the Protective Action Decision Model (PADM), as synthesised by Kuligowski et al. (2024). These models conceptualise warning effectiveness as a sequential process involving: (i) reception of the warning; (ii) message comprehension and interpretation; (iii) formation of risk perception and beliefs; (iv) evaluation of protective action options, and (v) behavioural response. The elements shown in Fig. 1—message clarity, impact-based information, geographic specificity, institutional consistency, and actionable guidance—map directly onto these stages. Specifically, clarity and institutional consistency support message interpretation, impact-based and geographic information shape risk perception, and actionable guidance

Fig. 1. Key elements of an effective alert message.
Source: own elaboration based on the Civil Protection Risk Communication Guidelines (2025).

facilitates protective action decision-making. Thus, Fig. 1 synthesises these theoretical models into a practical framework for the design of effective weather warnings and civil protection alerts.

In many countries, the responsibility for alerting the public to the impact of adverse weather phenomena rests with national agencies such as the meteorological and civil protection services, as well as with local or regional authorities. Consistency between these levels is essential to avoid confusing the public. An example of good practice comes from France, where Météo-France issues weather warnings by department (green, yellow, orange, and red), and simultaneously the local prefectures activate civil protection plans according to those levels, ensuring that all authorities speak "the same alert language" [19]. In contrast, a lack of coordination can be disastrous: after the catastrophic floods in Germany in 2021 and, although forecasts and early warnings were available, heterogeneity was found in the local issuance of alerts as well as communication failures between levels, which contributed to the population being caught off guard by the magnitude of the event [20]. To avoid these gaps, mechanisms such as the Common Alerting Protocol (CAP), promoted by the WMO, enable all the concerned authorities to disseminate consistent, simultaneous information during an emergency [14]. Application of the CAP means that, with a single standardized format, the alert can be broadcast across all media (radio, TV, apps, SMS, websites) with the same essential content: what is happening, where, when, with what certainty and severity, and what actions to take [14]. Countries such as Canada, Australia, and some Latin American nations have already adopted CAP in their national alert platforms.

In the case of Spain, the management of information related to meteorological risks and the activation of emergency plans through the declaration of alert situations involve both the State Meteorological Agency (AEMET)—responsible for issuing weather warnings—and the civil protection services (national, regional, island, and municipal), which are responsible for activating emergency plans and declaring the various alert or emergency situations. Although both systems are interrelated, they have distinct purposes, responsibilities, and audiences. The weather warnings issued by AEMET constitute the first layer of the early warning system [21]. Their objective is to inform the public and civil protection agencies of the probability of an adverse weather event, based exclusively on technical and probabilistic criteria. These warnings are classified according to the potential risk level [21] using a colour code harmonized at the European level (MeteoAlarm), as shown in Table 1.

Each alert includes information on the expected phenomenon, its geographic scope, validity period, forecast intensity levels, and probability of occurrence. It does not necessarily imply immediate administrative action but rather serves as the technical basis for decision-making by civil protection authorities. AEMET weather warnings are disseminated primarily through national-level communication channels, including the AEMET website and mobile application, official social media accounts, subscription-based alert services, and national and regional media outlets. These warnings provide general, technical information about the probability and severity of adverse meteorological phenomena.

By contrast, civil protection activation bulletins are issued only once an emergency plan has been activated by the competent authority. These messages are disseminated mainly through regional and local government channels, including official websites, social media accounts, press releases, and, in certain situations, public alerting systems such as cell broadcast, SMS, or other emergency notification platforms. Civil protection messages therefore tend to be more operational and locally specific, translating meteorological information into guidance on protective actions (Fig. 3).

Once AEMET has issued the warning, the civil protection agencies of the various autonomous communities are responsible for activating the corresponding phases of the territorial emergency plans, based on the expected risk and the protocols established in each plan.

2. Aims and scope of the study

2.1. Research objectives

As noted in the preceding section, in Spain the management of information on meteorological risks and the activation of emergency plans through the declaration of alert situations involve, in an initial phase, AEMET as the agency responsible for forecasting and providing technical communication of the phenomenon, while the decision to activate operational measures, coordinate resources, and subsequently convey instructions to the public falls to the civil protection services of the various competent authorities. Although the two systems are interrelated, they do not share the same objectives: AEMET provides scientific and technical information on the hazard, while civil protection agencies translate that information into concrete actions for emergency management and citizen self-protection. Any possible confusion between the two systems constitutes the subject of this research, which is based on the hypothesis that such confusion exists and is one of the main causes of public misinterpretation. This research analyses the structure, content, and format of the various weather alerts issued by state agencies and of the statements in civil protection alert bulletins, evaluating their influence on the perception and response of the population of the Canary Islands.

Table 1
Classification of weather warnings by potential risk level.

Colour	Alert level	Description of risk
Yellow	Moderate	Uncommon weather phenomena, but no danger to the general population.
Orange	Severe	Unusual weather phenomena with the potential to cause damage and pose a risk to specific activities.
Red	Extreme	Exceptional phenomena of very high intensity with a significant risk to the general population.

Source: own elaboration based on Agencia Estatal de Meteorología [21] and Meteoalarm (2025).

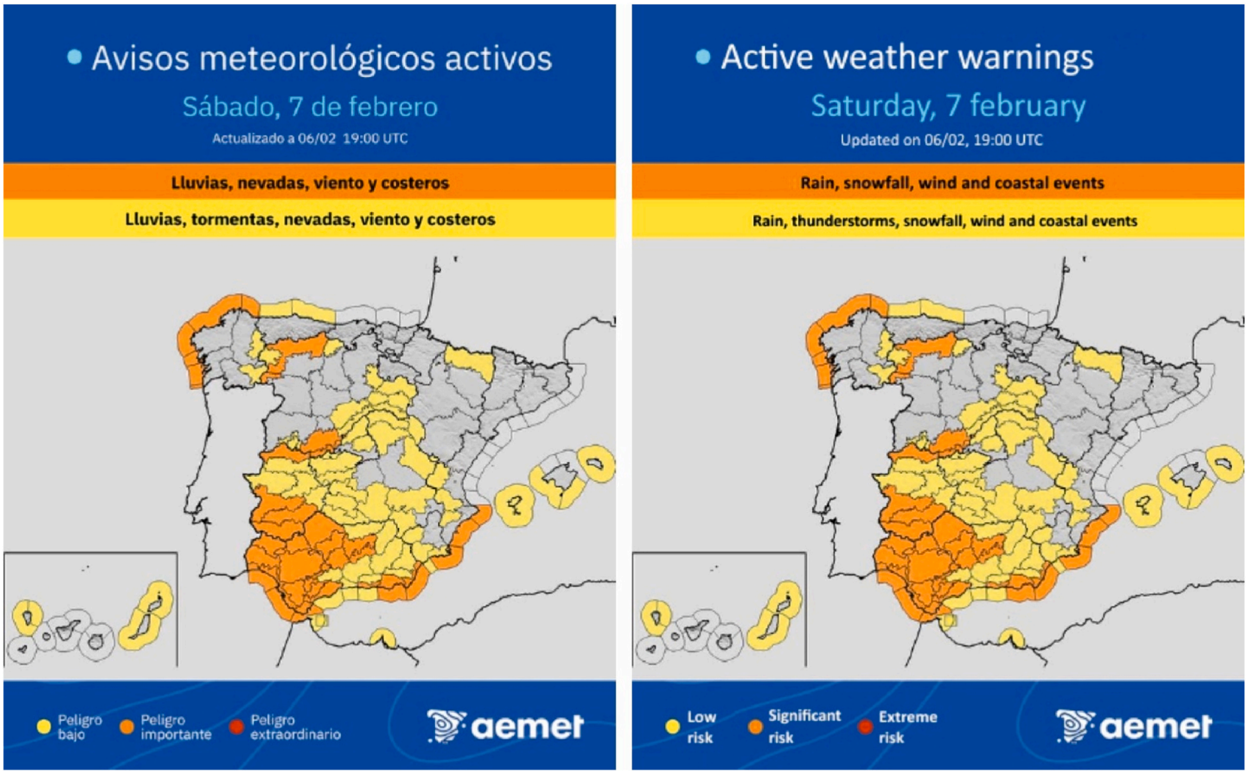


Fig. 2. Example of active meteorological warnings issued by AEMET showing colour-coded risk levels and spatial distribution of hazards across Spain (Fig. 2).
Source: Agencia Estatal de Meteorología (AEMET), official website.

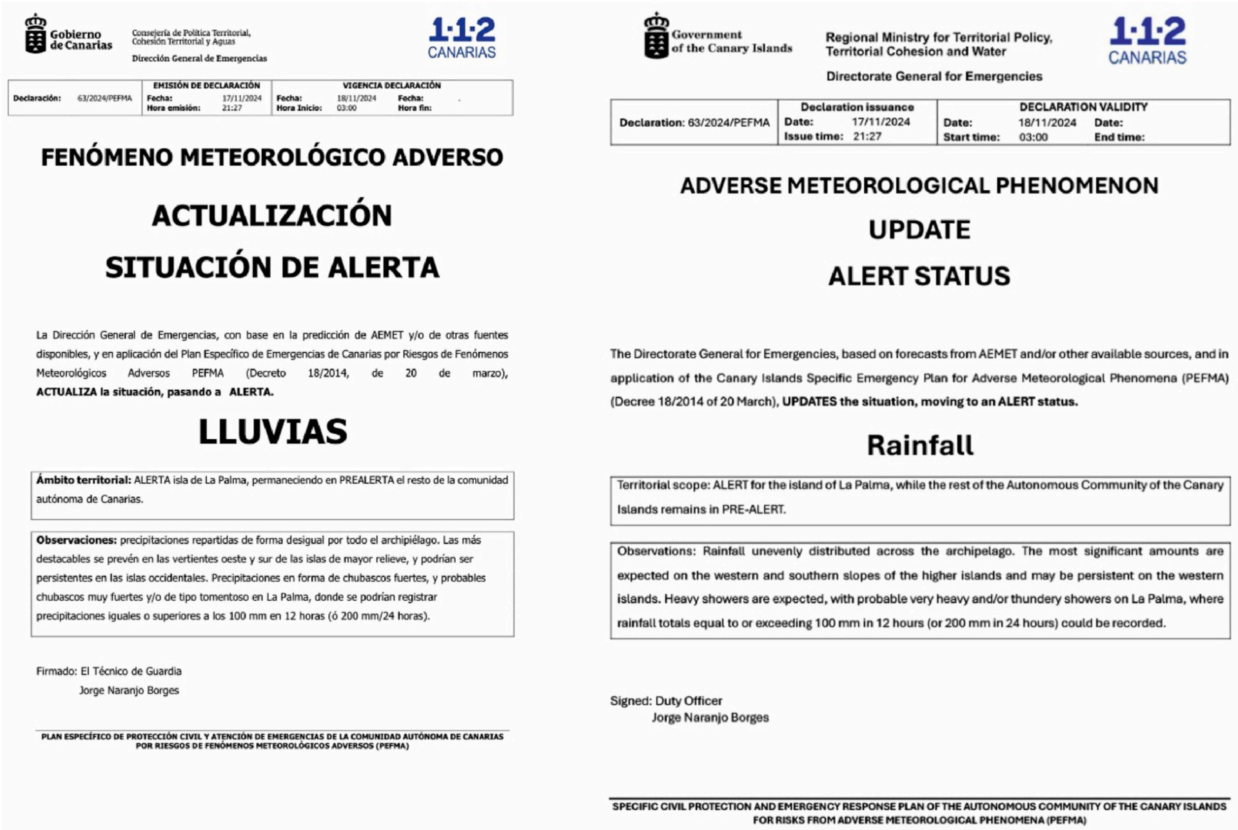
This study does not aim to assess the degree to which Spanish officials are explicitly aware of specific theoretical models such as the (WRM) or tools such as FEMA's Message Design Dashboard, nor does it analyse internal institutional message design processes. Rather, the study focuses on citizens' perception, understanding, and response to weather warnings and civil protection activation bulletins. Nevertheless, the research acknowledges that current warning communication practices in Spain are increasingly shaped by internationally promoted principles—such as impact-based warnings and the Common Alerting Protocol (CAP)—which are conceptually consistent with the core assumptions of established warning and response models.

In this context, the objectives of this study are: (i) to identify the communicative and sociodemographic factors that influence the understanding, risk perception, and clarity of weather warnings issued by Spain's State Meteorological Agency (AEMET), as well as the bulletins accompanying the activation of emergency plans issued by civil protection agencies; and (ii) to analyse the differences among the various stakeholders in informing the public and issuing recommendations.

2.2. Study area

The territorial scope chosen to address these objectives is the Canary Islands, one of Spain's 16 autonomous regions, recognized by the European Union as an outermost region due to its location northwest of the African continent, 97 km off the west coast of Africa, and 1400 km from the Iberian Peninsula (Fig. 4). The archipelago consists of seven major islands and five minor ones, all of volcanic origin, with a total area of 7447 km^2, of which Tenerife is the largest at 2034 km^2 and El Hierro the smallest at 268.7 km^2. The values of the different climatic elements vary according to the topography of each island, with altitude and slope orientation being the determining factors for identification of the various topoclimates present on the islands [22]. The total population of the islands stands at 2,238,754 inhabitants, with Tenerife and Gran Canaria having the largest populations: 967,575 and 875,205 inhabitants, respectively [23]. Although they are known as a top-tier tourist destination, partly because of their favourable climate, with over 17.7 million tourists in 2024 (ISTAC, 2025), torrential rainfall, wind and sea storms, extreme heat events, and Saharan air intrusions bringing haze or suspended dust are not uncommon, and can have serious consequences for the population and their activities [24–26].

With regard to the civil protection services, the Autonomous Community has a general framework for emergency management: the Territorial Civil Protection Emergency Plan of the Autonomous Community of the Canary Islands (PLATECA), approved by Decree 98/2015 of May 22. This plan defines the hierarchical structure, coordination bodies such as the Island Operational Coordination Centres (CECOPIN), the Local Operational Coordination Centres (CECOPAL), or the Emergency and Security Coordination Centre (CECOES 1-1-2), and the operational activation levels: Pre-Alert, Alert, Maximum Alert, and Emergency.



Gobierno de Canarias
Consejería de Política Territorial, Cohesión Territorial y Aguas
Dirección General de Emergencias
1·1·2 CANARIAS

Declaración: 63/2024/PEFMA	EMISIÓN DE DECLARACIÓN		VIGENCIA DECLARACIÓN			
	Fecha: 17/11/2024	Hora emisión: 21:27	Fecha: 18/11/2024	Hora Inicio: 03:00	Fecha: .	Hora fin:

FENÓMENO METEOROLÓGICO ADVERSO

ACTUALIZACIÓN

SITUACIÓN DE ALERTA

La Dirección General de Emergencias, con base en la predicción de AEMET y/o de otras fuentes disponibles, y en aplicación del Plan Específico de Emergencias de Canarias por Riesgos de Fenómenos Meteorológicos Adversos PEFMA (Decreto 18/2014, de 20 de marzo), **ACTUALIZA la situación, pasando a ALERTA.**

LLUVIAS

Ámbito territorial: ALERTA isla de La Palma, permaneciendo en PREALERTA el resto de la comunidad autónoma de Canarias.

Observaciones: precipitaciones repartidas de forma desigual por todo el archipiélago. Las más destacables se prevén en las vertientes oeste y sur de las islas de mayor relieve, y podrían ser persistentes en las islas occidentales. Precipitaciones en forma de chubascos fuertes, y probables chubascos muy fuertes y/o de tipo tormentoso en La Palma, donde se podrían registrar precipitaciones iguales o superiores a los 100 mm en 12 horas (ó 200 mm/24 horas).

Firmado: El Técnico de Guardia
Jorge Naranjo Borges

PLAN ESPECÍFICO DE PROTECCIÓN CIVIL Y ATENCIÓN DE EMERGENCIAS DE LA COMUNIDAD AUTÓNOMA DE CANARIAS POR RIESGOS DE FENÓMENOS METEOROLÓGICOS ADVERSOS (PEFMA)

Government of the Canary Islands
Regional Ministry for Territorial Policy, Territorial Cohesion and Water
Directorate General for Emergencies
1·1·2 CANARIAS

Declaration: 63/2024/PEFMA	Declaration issuance		DECLARATION VALIDITY			
	Date: 17/11/2024	Issue time: 21:27	Date: 18/11/2024	Start time: 03:00	Date:	End time:

ADVERSE METEOROLOGICAL PHENOMENON

UPDATE

ALERT STATUS

The Directorate General for Emergencies, based on forecasts from AEMET and/or other available sources, and in application of the Canary Islands Specific Emergency Plan for Adverse Meteorological Phenomena (PEFMA) (Decree 18/2014 of 20 March), **UPDATES the situation, moving to an ALERT status.**

Rainfall

Territorial scope: ALERT for the island of La Palma, while the rest of the Autonomous Community of the Canary Islands remains in PRE-ALERT.

Observations: Rainfall unevenly distributed across the archipelago. The most significant amounts are expected on the western and southern slopes of the higher islands and may be persistent on the western islands. Heavy showers are expected, with probable very heavy and/or thundery showers on La Palma, where rainfall totals equal to or exceeding 100 mm in 12 hours (or 200 mm in 24 hours) could be recorded.

Signed: Duty Officer
Jorge Naranjo Borges

SPECIFIC CIVIL PROTECTION AND EMERGENCY RESPONSE PLAN OF THE AUTONOMOUS COMMUNITY OF THE CANARY ISLANDS FOR RISKS FROM ADVERSE METEOROLOGICAL PHENOMENA (PEFMA)

Fig. 3. Example of an official Civil Protection activation bulletin issued under the PEFMA during an adverse meteorological event in the Canary Islands.
Example of an official activation bulletin issued under the PEFMA by the Dirección General de Emergencias, showing the declaration of an alert situation, the territorial scope of application, and the main characteristics of the expected adverse meteorological phenomenon.
Source: Dirección General de Emergencias, Gobierno de Canarias.

The various civil protection plans are integrated within this system and include most notably the PEFMA (Specific Civil Protection and Emergency Response Plan for the Risk of Adverse Meteorological Phenomena), approved by Decree 18/2014 of March 20. The PEFMA specifically develops activation procedures in the face of meteorological hazards (wind, rain, waves, high temperatures, etc.), in line with the alerts issued by AEMET, but introduces an additional operational assessment based on: (i) the vulnerability of the territory; (ii) the exposure of people and infrastructure; (iii) local response capacity; and (iv) the need for inter-administrative coordination. This coexistence of AEMET weather alerts and PEFMA activations explains the frequent public confusion, since both systems use similar codes and risk levels but serve different purposes: AEMET's warnings are informational, while the Canary Islands Government's declarations under the PEFMA are operational in nature and aimed at civil protection.

3. Date and materials

3.1. Data

To address the objectives set forth in this research, a questionnaire was designed and distributed digitally via Google Forms to the university community of the Canary Islands, specifically at the University of La Laguna (ULL) and the University of Las Palmas de Gran Canaria (ULPGC) and remained active from October 1 to October 25, 2025. According to the ULPGC's 2023/24 academic report, the university community comprises 16,077 students, 1665 faculty members, and 831 management, administrative and service staff, totalling 18,573 individuals. For its part, the academic report for the same course at the University of La Laguna lists 20,502 students, 1650 faculty members, and just over 800 management, administrative and service staff, bringing its university community to around 22,900 people. In total, the two public universities comprise over 39,000 people. The research adopted a quantitative and descriptive approach, using a structured questionnaire to explore the perception, understanding, and credibility of weather alert messages.

The questionnaire was developed using a theory-informed but exploratory approach grounded primarily in the (PADM) and related warning response frameworks. These models conceptualise warning effectiveness as a multi-stage process involving message reception, comprehension and interpretation, formation of risk perception, evaluation of protective action options, and behavioural

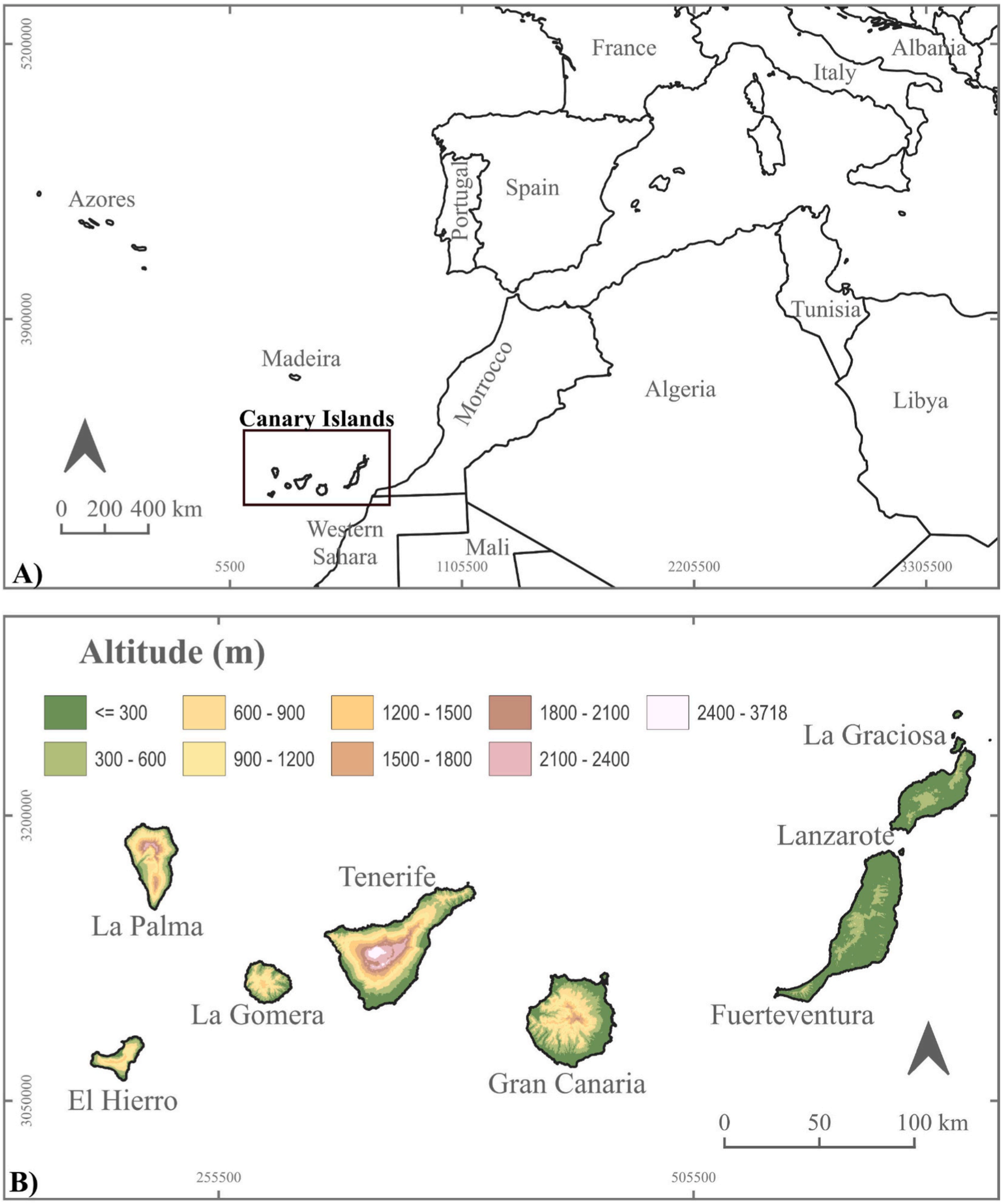


Fig. 4. Geographic location and topographic features of the Canary Islands. *(A) Location of the Canary Islands in the North Atlantic region. (B) Altitude distribution by island.*
Source: own elaboration based on GIS data from GRAFCAN [27] and Copernicus DEM [28].

response.

Accordingly, survey items were designed to operationalise key components of this process: receiver characteristics (sociodemographic variables), prior knowledge and institutional awareness (knowledge of AEMET warning levels and awareness of civil protection activation bulletins), message comprehension (clarity of terminology, geographic specificity, and clarity of social media bulletins), risk perception, and behavioural translation (confusion about what actions to take after receiving an alert).

The wording of the items was further informed by previous empirical research on public warning message effectiveness and adapted to the institutional configuration of Spain and the Canary Islands, where meteorological warnings and civil protection activation bulletins coexist.

The questionnaire consisted of four thematic blocks.

1. Prior knowledge and experience of weather alerts.
2. Level of comprehension and perceived clarity of official messages.
3. Degree of institutional trust and perceived usefulness.
4. Reactions and self-protection measures in hypothetical alert situations.

3.2. Methodology

To better understand the factors influencing risk perception and the interpretation of weather warnings, the analysis employs three complementary multivariate techniques. Following Trujillo-Falcón [29], bivariate association tests are initially employed to identify systematic relationships between sociodemographic characteristics and warning-related outcomes, prior to estimating multivariable models.

For relationships involving ordinal or continuous variables, such as age and perceived risk, we use Spearman's rank correlation coefficient (ρ). Spearman's rho is appropriate because it does not assume normality or linearity, and it captures monotonic associations, which are typical of perceptual and attitudinal measures in hazard research. The coefficient is defined as:

$$\rho = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2-1)}$$

where d_i denotes the difference between the ranks of paired observations and n is the number of observations.

For associations between categorical variables, such as educational level and reported confusion after receiving an alert, we apply Pearson's chi-squared test (χ^2), which assesses whether the observed response distributions differ significantly from those expected under independence. This approach is widely used in studies examining heterogeneity in warning reception and comprehension across population groups [29,30]. The chi-square statistic is computed as:

$$\chi^2 = \sum_{i=1}^{r}\sum_{j=1}^{c} \frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}}$$

where O_{ij} and E_{ij} represent the observed and expected frequencies in cell (i,j), respectively.

Then, a multinomial logistic regression model is fitted to estimate the probability of each risk category given a set of predictor variables X (Li et al., 2024). This model estimates K−1 logistic equations, comparing each response category against a reference category (Low, $k = 1$). The probability of being in category k compared to the reference category is modelled using logarithmic odds ratio (log-odds):

$$\ln\left(\frac{P(Y=k)}{P(Y=1)}\right) = \beta_{k0} + \sum\nolimits_{j=1}^{p} \beta_{kj} X_j$$

where β_{k0} is the intercept; β_{kj} is the j-th predictor; and X_j is the regression coefficient showing, for a one-unit change in the predictor X_j, the change in the log-odds of category k versus the reference category. The model fit was assessed using the likelihood ratio test and the pseudo R^2.

Beyond variable-centred analyses, the study adopts also an individual-centred approach through Latent Class Analysis (LCA), implemented via Gaussian Mixture Modelling (GMM), to identify unobserved respondent profiles based on warning perception patterns.

Let $\mathbf{x}_i$ denote the vector of perception indicators for individual i. The probability density is modelled as a finite mixture of K latent classes:

$$f(\mathbf{x}_i) = \sum_{k=1}^{K} \pi_k \, \mathcal{N}(\mathbf{x}_i | \boldsymbol{\mu}_k, \boldsymbol{\Sigma}_k)$$

where π_k is the mixing proportion of class k ($\sum_k \pi_k = 1$), and $\boldsymbol{\mu}_k$ and $\boldsymbol{\Sigma}_k$ are class-specific means and covariance matrices.

Class membership probabilities are obtained via maximum likelihood estimation using the expectation–maximisation algorithm. Individuals are assigned to the class with the highest posterior probability. Models with two to five classes are compared using the Bayesian Information Criterion (BIC), along with interpretability of class profiles and a minimum class size threshold of 5%. The selected solution balances statistical fit with substantive interpretability.

Prior to administering the survey, the study was designed to be exploratory yet theory informed. Rather than specifying strong directional expectations regarding particular sociodemographic groups, the analytical framework was guided by the PADM. This model conceptualises receiver characteristics as conditioning warning interpretation, risk perception and behavioural readiness. Consequently, the analysis aimed to identify any systematic differences and latent perception profiles that emerged empirically, rather than testing narrowly defined a priori predictions.

4. Results

The survey was distributed to members of two public universities in the Canary Islands. After data cleaning, a final analytical sample of 915 respondents was obtained. Fig. 5 shows how the responses were distributed across the key perception variables relating to knowledge, clarity, risk perception and behavioural uncertainty.

From a theoretical perspective, the analysis is informed by the PADM and related warning response frameworks, which posit that receiver characteristics—such as age, education, and prior institutional knowledge—shape risk perception, message interpretation, and behavioural readiness. Accordingly, we expected that sociodemographic variables and knowledge of the warning system would be significantly associated with both perceived risk and post-alert uncertainty. The results presented below are interpreted in light of these theoretical expectations.

4.1. Preliminary analysis

Overall, 73.9% of respondents reported being familiar with AEMET's colour-coded warning levels (yellow, orange and red), 22.8% had heard of them but had an unclear understanding of them, and 3.3% were not familiar with the system. Only 41.1% of respondents indicated that they clearly understood the distinction between an AEMET weather alert and a civil protection emergency procedure activation bulletin while 58.9% did not. Regarding the clarity of civil protection activation terminology ('Pre-Alert', 'Alert', 'Maximum Alert'), 64.0% of respondents considered the terms to be understandable, 29.6% reported a partial understanding of them, and 6.3% found them unclear.

Perceptions of bulletin clarity varied across communication channels. Of those who had accessed social media bulletins, 28.6% described them as clear and actionable, while 41.1% reported a partial understanding. However, 26.4% stated that they had never accessed these messages and 3.8% found them unclear. Regarding geographic specificity, 58.9% of respondents reported a clear understanding of the affected area referenced in alert bulletins. Meanwhile, 25.7% reported unclear geographic information and 15.4% had never accessed the relevant content. Risk perception was concentrated in the moderate and high categories: 44.4% reported a moderate level of perceived risk (monitoring the situation but taking limited action), 32.0% reported a high level of perceived risk (taking immediate precautions), 21.1% perceived a low level of risk, and 2.5% reported no perception of risk (ignoring alerts). Finally, 36.1% of participants reported being confused about what actions to take after receiving a civil protection activation bulletin, while 63.9% said they were not confused.

4.2. Bivariate associations between sociodemographic factors and warning-related outcomes

Pearson's chi-square tests revealed statistically significant associations ($p < 0.05$) between risk perception and age, educational level, and knowledge of AEMET warning levels. Confusion following the receipt of a civil protection activation bulletin was significantly associated with education level and gender, indicating that socioeconomic characteristics shape not only perceived risk but also the ability to translate warnings into appropriate behavioural responses.

Spearman's rank correlation analysis showed a positive and statistically significant association between age and risk perception ($\rho = 0.318$, $p < 0.001$), indicating that older respondents tend to perceive weather-related risks as more severe than younger respondents.

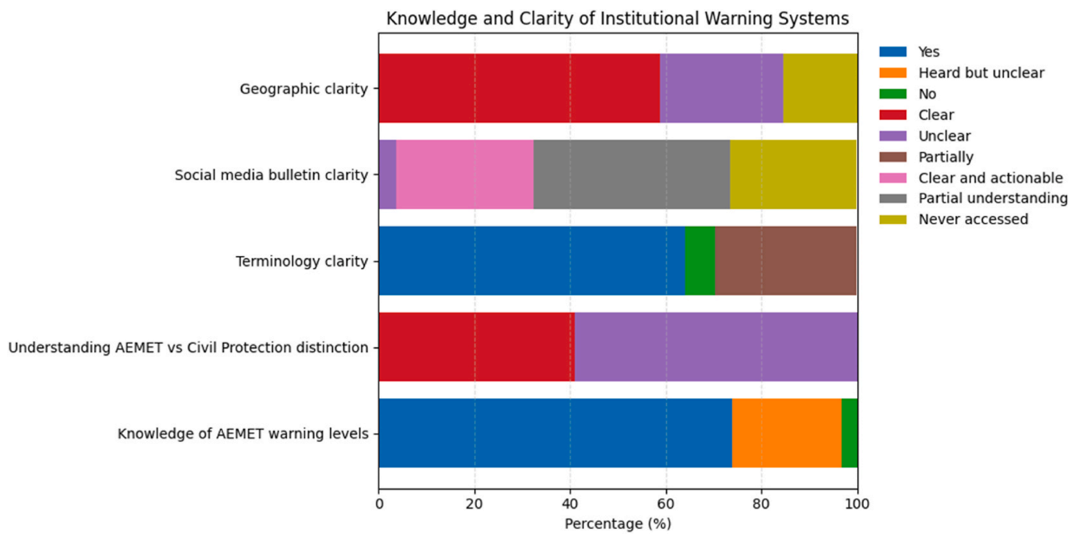


Fig. 5. Sample representation.

4.3. Multinomial logistic regression results

A multinomial logistic (MNL) regression was used to identify the main predictors of risk perception (low, moderate, high). This included the following regressors: age, gender, education and knowledge of AEMET alert levels. Overall, the model results were statistically significant (likelihood ratio $\chi^2 = 78.24$, $p < 0.001$), indicating that the predictors collectively help to explain risk perception. The pseudo R^2 of 0.211 indicates moderate predictive ability, which is typical in social sciences where psychological and situational factors also play a role (Li et al., 2024). Table 2 shows the regression coefficients (β), errors and p-values for each factor.

The age coefficient was positive and significant ($p < 0.001$) for both the moderate and high risk perception groups. This means that the older people are, the more likely they are to view weather events as hazardous. Older people, who are likely to have more experience of severe weather, tend to be more aware of potential dangers. This is consistent with the findings of Kox and Thieken [31], who found that experience helps people recognise weather hazards more effectively.

Knowing the AEMET warning system also had a clear effect, especially for the "High vs. Low" comparison ($\beta = 0.587$, $p = 0.016$). People familiar with the colour-coded alerts (yellow, orange, red) were more likely to see the situation as high risk. This shows that understanding warning systems directly boosts awareness of danger, linking official messages to personal understanding.

Education had a weaker but positive link to risk perception. Postgraduates were more likely ($p = 0.043$) to see weather events as high risk. This might be because they have more scientific knowledge or are more familiar with official risk information. Women also showed a slightly higher probability ($p = 0.031$) of viewing weather events as risk-generating. This supports previous studies showing women often take more precautions in relation to natural hazards and emergencies [6].

In order to complement the regression model and investigate the presence of latent behavioural profiles, a k-means clustering was applied to a subset of standardized perception variables: risk perception, clarity of information, knowledge of AEMET and confusion rate.

4.4. Latent class analysis (LCA) of warning perception profiles

The LCA implemented through GMM identified four distinct profiles of how respondents perceive warnings, indicating substantial heterogeneity in how they interpret and process official weather warnings. The four-class solution selected (BIC = −4727.9; entropy = 0.78) demonstrates a well-fitted separation and classification quality. As can be seen in Table 3, the classes form a clear gradient of engagement, primarily structured by institutional understanding, message clarity and sociodemographic characteristics, particularly age and education.

Class 1 (High Engagement) represents the group with the highest level of knowledge and operational preparedness. Members have a full knowledge of AEMET warning levels and a complete understanding of the distinction between AEMET and civil protection bulletins. They also demonstrate maximal clarity and have the highest perceived risk (91%). This profile is associated with a higher age and level of education, suggesting that experience and informational capital reinforce comprehension and risk awareness. In contrast, Class 4 (Low Engagement) shows consistently low scores across all dimensions, including a lack of institutional knowledge and weak geographic clarity, as well as the lowest prevalence of high-risk perception (59%). This group is younger and less educated on average, which indicates potential disengagement or limited resonance of current communication formats.

The intermediate classes (Classes 2 and 3), which together account for over half of the sample, are particularly revealing. Class 2 (Partial Engagement) demonstrates a high level of awareness of AEMET warnings but is confused about the role of civil protection activation bulletins. This group still exhibits relatively high-risk perception. Class 3 (Moderate Engagement) shows the inverse pattern, with good institutional understanding, but reduced clarity of terminology and geographic scope. These configurations illustrate that high awareness does not necessarily translate into clarity of action, highlighting a knowledge–action gap in warning interpretation.

The ability to distinguish between AEMET meteorological warnings and civil protection activation bulletins emerges as the key differentiating factor across classes, even among groups with similar age and education profiles. The LCA results overall indicate that effective risk communication depends on increasing hazard awareness, improving institutional role clarity, and ensuring warning messages contain actionable content.

Table 2
Multinomial logistic regression results (dependent variable: risk perception level).

Predictor	Comparison (vs. Low)	β	Std. Error	z	p-value
Age	Moderate	+0.043	0.012	3.54	<0.001 ***
	High	+0.071	0.018	3.90	<0.001 ***
AEMET knowledge (1 = yes)	Moderate	+0.216	0.154	1.40	0.162
	High	+0.587	0.243	2.41	0.016 *
Educational level (1 = postgraduate)	Moderate	+0.264	0.175	1.51	0.131
	High	+0.419	0.207	2.02	0.043 *
Gender (1 = female)	Moderate	+0.183	0.141	1.29	0.198
	High	+0.354	0.165	2.15	0.031 *

Model fit: likelihood ratio $\chi^2 = 78.24$ (df = 8, $p < 0.001$); pseudo $R^2 = 0.211$; N = 859.
Significance: ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

Table 3
Latent class analysis (LCA) profiles of warning perception and sociodemographic characteristics.

Characteristic	Class 1: High Engagement	Class 2: Partial Engagement	Class 3: Moderate Engagement	Class 4: Low Engagement
Sample size	192 (21.0%)	327 (35.7%)	184 (20.1%)	212 (23.2%)
Understanding score	1.67/2.0	1.19/2.0	1.37/2.0	0.78/2.0
Clarity score	2.21/3.0	1.61/3.0	1.51/3.0	1.27/3.0
Risk perception	2.42/3.0	2.12/3.0	2.05/3.0	1.65/3.0
Knows AEMET levels	100%	100%	85%	0%
Knows AEMET vs Civil Protection	100%	0%	100%	0%
Terminology clear	100%	62%	39%	56%
Geographic clarity	100%	61%	44%	32%
High risk perception	91%	79%	77%	59%
Female	55%	66%	50%	52%
Postgraduate education	51%	47%	48%	25%
Mean age	44.9	38.1	39.2	27.9

5. Discussion

The results obtained enable the identification of consistent patterns in how different groups perceive, understand, and respond to AEMET weather warnings and civil protection emergency activation bulletins in the Canary Islands. In line with previous studies such as that by Potter et al. [5], it is confirmed that understanding the message does not always imply appropriate action. This situation has already been observed in the university community of Gran Canaria, where a significant portion of the population know the alert levels but still show uncertainty about how to respond to them [32,33]. In our study, 36.1% of respondents reported feeling confused about how to act in response to an alert. This percentage aligns with the findings of Choi et al. [17], who, in a trial study in South Korea, identified an improvement in risk perception with impact-based messages, although this did not always translate into a greater intention to act. This highlights a persistent gap between cognitive understanding and behavioural action.

Importantly, the confusion identified in this study should not be interpreted as a shortcoming of the technical design of AEMET weather warnings. AEMET alerts are intentionally informational and do not include operational protective instructions. Rather, the observed confusion reflects a broader issue of institutional differentiation. Many respondents appear not to clearly distinguish between the forecasting and informational role of AEMET and the operational decision-making role of civil protection authorities, leading to expectations of actionable guidance from any official alert. Thus, uncertainty arises primarily from the coexistence of two parallel but interdependent communication systems rather than from message inadequacy alone.

These findings are consistent with research conducted in the United States on public warning message effectiveness (Sutton & Kuligowski, 2024; Bean, 2019; [15]), which emphasizes that even well-designed warning messages do not guarantee protective action. Prior studies have demonstrated that clarity, impact framing, and actionable content improve intended compliance, yet behavioural uncertainty may persist due to cognitive, contextual, and institutional factors. Our results extend this literature by showing that, in the Canary Islands, confusion is not only related to message wording but also to the coexistence of two differentiated yet interdependent communication systems (AEMET warnings and civil protection authorities activations), which may amplify interpretative uncertainty. This theoretical consistency is further supported by our statistical results.

The chi-square (χ^2) analysis showed significant associations ($p < 0.05$) between risk perception and sociodemographic variables such as age, educational level, and knowledge of the AEMET warning system. Similarly, confusion after receiving an alert was significantly associated with educational level and gender, suggesting that socioeconomic factors influence how risk messages are interpreted and responded to. Spearman's correlation ($\rho = 0.318$, $p < 0.001$) confirmed a positive relationship between age and risk perception, indicating that older participants tend to perceive weather phenomena as more dangerous, in line with the idea that accumulated experience reinforces risk awareness [31].

The results of the MNL model, which were statistically significant ($\chi^2 = 78.24$, $p < 0.001$; pseudo $R^2 = 0.211$), provide robust evidence regarding the predictors of risk perception. Age was confirmed as the most decisive factor ($p < 0.001$), increasing the likelihood of belonging to the moderate or high risk perception groups as age increases. Likewise, knowledge of the AEMET warning system was significantly associated with higher risk perception ($\beta = 0.587$, $p = 0.016$ for the high vs. low risk perception group), demonstrating that familiarity with the colour-coded system (yellow, orange, red) reinforces awareness of the danger. Educational level also showed a positive relationship: individuals with a postgraduate education were more likely to perceive weather events as high risk ($p = 0.043$). Additionally, women showed a slight but significant tendency ($p = 0.031$) to rate events as riskier, in line with the findings reported by Taylor et al. [6] who noted a greater preventive disposition among women towards natural hazards.

These results complement the initial descriptive findings. This pattern of heterogeneity across social groups is consistent with broader evidence showing that cultural values, belief systems, and social contexts shape how individuals interpret risk information and respond to institutional messages [34]. At the descriptive level, confusion remains highest among non-binary individuals (61.5%) and those aged 25 to 34 (44%), further expanding the evidence on less documented communicative vulnerabilities. Regarding risk perception, those over 55 years of age report the highest values (52.9%), followed by individuals with postgraduate degrees (44.4%). However, even among educated groups, a significant level of confusion persists (34.9%), suggesting that technical knowledge alone does not guarantee an adequate response when institutional roles and recommended actions remain unclear.

The LCA reveals substantial heterogeneity in how the population interprets and responds to official weather warnings, moving beyond simplified dichotomies of informed versus uninformed audiences. The four engagement profiles identified reflect a clear gradient of institutional understanding, message clarity, and behavioural readiness. While the high-engagement class demonstrates that comprehensive institutional knowledge, message clarity, and elevated risk perception can translate into preparedness, the two intermediate classes highlight distinct manifestations of a persistent knowledge–action gap. One group exhibits strong awareness of AEMET meteorological warnings but limited understanding of the operational role of civil protection activation bulletins, whereas the other shows adequate institutional differentiation but reduced clarity regarding terminology and geographic scope. These findings indicate that high hazard awareness alone does not guarantee effective protective action and that breakdowns may occur at different stages of the warning interpretation process, consistent with the PADM.

Recent discussions in *Natural Hazards Review* emphasise ongoing debate about how warning message effectiveness should be measured, particularly regarding the relative value of self-reported intention, observed protective action, and intermediate cognitive indicators [15,35]. Our findings contribute to this debate by showing that substantial variability exists at intermediate stages of the warning response process, including institutional understanding, message clarity, and behavioural certainty. This supports the view that warning effectiveness should be conceptualised as a multi-stage process in which comprehension and interpretative clarity are necessary precursors to action, rather than assuming a direct translation from message exposure to behaviour.

The low-engagement class, characterised by younger age and lower educational attainment, reflects broader challenges of message reach and resonance among disengaged audiences. Overall, the results suggest that warning effectiveness depends not only on increasing hazard awareness, but also on improving institutional role clarity and embedding actionable guidance within alert messages, reinforcing recent calls for impact-based and action-oriented warning communication.

5.1. Novelty, expectations, and significance of the findings

Several findings align with theoretical expectations and prior evidence on warning response. For example, the positive association between age and risk perception, and the role of education in shaping warning interpretation, mirror established warning response frameworks and empirical studies suggesting that receiver characteristics condition both perceived risk and behavioural readiness (e.g., Ref. [15,35–37]).

At the same time, the present study provides novel insights by demonstrating that, in a context characterised by multiple institutional actors, *institutional differentiation* is a key determinant of interpretative clarity. Many respondents struggled to distinguish between the informational role of meteorological warnings and the operational role of civil protection activations, which helps explain persistent uncertainty in how to act. Moreover, the latent class profiles reveal heterogeneous patterns of engagement that extend prior research on warning message effectiveness by showing that similar levels of hazard awareness may nonetheless diverge in terms of clarity and behavioural readiness.

An additional element of novelty lies in the geographical and cultural context of the study. The Canary Islands constitute an insular, peripheral territory with strong topographic contrasts, fragmented administrative scales, and a distinctive risk culture shaped by recurrent exposure to volcanic, meteorological, and coastal hazards. Empirical evidence on warning interpretation and response in such island settings remains limited. By focusing on this context, the study contributes new knowledge on how early warning systems operate in territorially constrained and highly exposed regions.

These findings support the view that warning effectiveness should be conceptualised as a multi-stage process in which comprehension, interpretative clarity, and institutional differentiation are necessary precursors to protective action, rather than assuming a direct and immediate translation from message exposure to behaviour. The significance of these contributions lies in their implications for both theory and practice, suggesting that improving warning communication requires not only clearer, impact-based and action-oriented content, but also explicit communication of the roles and responsibilities of different institutions.

Finally, although institutional trust was not measured directly, the results suggest its indirect influence: groups with greater confusion also tend to be unaware of official systems, which may point to lower perceived legitimacy or a greater distance from the issuing institutions. As the literature points out [6,38], trust in the issuing authority is a critical determinant of action.

5.2. Practical implications and future research

Taken together, the findings reinforce the idea that weather risk communication must evolve towards more inclusive, visual, and action-oriented models. As future lines of research, performing longitudinal studies following real alert episodes would be invaluable, as well as experiments with bulletin redesigns that incorporate interactive maps, inclusive language, and operational recommendations. A/B testing applied to different demographic groups could provide solid evidence to improve the effectiveness of early warning systems in the Canary Islands and other vulnerable regions.

6. Conclusions

The study reveals that, while there is a good general awareness of AEMET's weather warning systems and the civil protection authorities' alert bulletins, significant gaps persist in the communication and understanding of the information. Only half of the public clearly distinguishes between an AEMET weather warning and a civil protection alert, which can lead to false expectations or confusion about the severity of the situation. Furthermore, a significant proportion of the public is not entirely clear about the language or the geographic area to which the weather warnings and alerts refer, which limits the effectiveness of the message. Improving linguistic clarity and adding more explicit geographic references—such as maps—could significantly increase comprehension.

Risk perception tends to be low among younger age groups and individuals with lower levels of education, which is concerning since they may underestimate the risk of not preparing adequately. Raising that perception through tailored education and communication strategies could foster a more preventive response. In turn, the confusion about what actions to take after receiving an alert—reported by more than one-third of the sample—highlights the need to include concrete, actionable instructions in the messages. In this regard, it is recommended to move towards impact-based communication systems that not only inform about the expected weather phenomenon but also clearly indicate what the public should do. This strategy, already adopted by several countries, would help close the gap between understanding and action.

Ultimately, improving weather risk communication involves not only informing people about the "what" (phenomenon, level, area), but also about the "and now what" (how to proceed). In the future, strengthening alert education—from schools to public campaigns—segmenting messages by demographic profile (youth, adults, education level, etc.), and providing clear, tailored action guides will be essential steps towards achieving a more prepared and safer population in the face of extreme events.

As future lines of research, the performing of follow-up studies after actual alert events would be invaluable, as well as experimenting with redesigns of the bulletins that incorporate interactive maps, inclusive language, and practical recommendations. Evaluating their effect through A/B testing with different demographic profiles could provide evidence for a substantial improvement in weather risk communication in the Canary Islands and other vulnerable regions.

CRediT authorship contribution statement

Fernando Medina Morales: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alessandro Indelicato:** Writing – review & editing, Writing – original draft, Validation, Formal analysis, Data curation, Methodology. **Pablo Máyer Suárez:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Lorenzo Quesada Ruíz:** Writing – review & editing, Visualization, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2026.106117.

Data availability

Data will be made available on request.

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