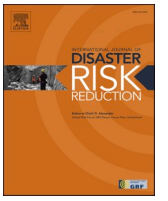
International Journal of Disaster Risk Reduction 127 (2025) 105680

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

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



# Post-traumatic stress disorder in adult population of La Palma (Spain) after the 2021 Tajogaite eruption: Environmental and sociodemographic predictors

Lisa Fourgassie [a,*], María Cristo Rodríguez-Pérez [b], Manuel Enrique Fuentes Ferrer [b,c], Elena Zwirner [a], Agnès Borbon [d], Aurélie Colomb [d], Francisco Jose Perez Torrado [e], David Jessop [f], Séverine Moune [f], Raphaël Paris [f], Lucie Sauzéat [f,g], Ines Tomašek [f,g], David Damby [h], Guillaume Dezecache [i,1], Julia Eychenne [f,g,1]

[a] Université Clermont Auvergne, CNRS, LAPSCO, Clermont-Ferrand, France
[b] Research Unit University Hospital Nuestra Señora de Candelaria and Primary Care Authority of Tenerife, Canary Health Service, Santa Cruz de Tenerife, Spain
[c] Preventive Medicine Department, University Hospital Nuestra Señora de Candelaria, Canary Health Service, Santa Cruz de Tenerife, Spain
[d] Université Clermont Auvergne, CNRS, LaMP, OPGC, F-63000 Clermont-Ferrand, France
[e] Instituto de Estudios Ambientales y Recursos Naturales (i-UNAT), University of Las Palmas de Gran Canaria, 35017-Las Palmas de Gran Canaria, Spain
[f] Université Clermont Auvergne, CNRS, IRD, OPGC, Laboratoire Magmas et Volcans, F-63000, Clermont-Ferrand, France
[g] Université Clermont Auvergne, CNRS, INSERM, Institut Génétique, Reproduction et Développement, F-63000, Clermont-Ferrand, France
[h] U.S. Geological Survey, Volcano Science Center, Moffett Field, CA, USA
[i] UMI SOURCE, Université Paris-Saclay, UVSQ, IRD, Guyancourt, France

ARTICLE INFO

*Keywords:*
Volcanic eruption
Disaster
Post-traumatic stress disorder
La Palma
Air quality

ABSTRACT

The adverse mental health effects of exposure to disasters have long been recognized. Concerning PTSD and volcanic eruptions specifically, most studies have highlighted risk factors related to demographic and social factors (e.g., gender, age, and education), mental health, and those associated with the experience of the volcanic eruption (e.g., having evacuated). Establishing the demographic scope of those more likely to suffer PTSD following volcanic eruptions, as well as understanding the aggravating factors, is key to optimizing precautionary measurements and psychological interventions. In this study, we complement these analyses by exploring the role of environmental contaminants (specifically, exposure to tephra falls and exposure to $SO_2$) together with demographic, health, and hazard experiences in contributing to PTSD. We focus on data collected after the 2021 eruption of the Tajogaite volcano (La Palma, Spain). Our results show that in addition to sex, education, distance from the volcano, evacuation status, health issues related to the eruption, mental health antecedents, and exposure to poor air quality (i.e., $SO_2$ concentrations) are associated with higher scores of reported symptoms associated with PTSD. Our findings establish a picture of the prevalence of reported PTSD symptoms in various demographics groups and aggravating factors following the 2021 eruption of the Tajogaite volcano. Next steps could include an extended investigation of the role of air quality (as a potential

* Corresponding author. Université Clermont Auvergne, CNRS, LAPSCO, Clermont-Ferrand, France.
*E-mail address:* l.fourgassie@gmail.com (L. Fourgassie).
[1] indicate shared Senior authorship.

https://doi.org/10.1016/j.ijdrr.2025.105680
Received 25 November 2024; Received in revised form 5 June 2025; Accepted 1 July 2025
Available online 3 July 2025

synergic hazard) in shaping mental health following exposure to a primary hazard, such as a volcanic eruption.

## 1. Introduction

On September 19, 2021, the Tajogaite volcano began erupting on the Cumbre Vieja ridge on the island of La Palma in the Canary archipelago (Spain). The eruption lasted 85 days, making it the longest in the island's history [1,2]. During this period, the volcanic activity was characterized by the constant emission of a gas and particle plume into the atmosphere and the production of a sustained lava flow that reached the ocean one week into the eruption [3–5]. In addition to its unprecedented duration, this eruption was also the most destructive ever recorded on La Palma, having caused significant disruption to the lives of the island's inhabitants (see Fig. 1 for an illustration) and material damages estimated at 1 billion € [1,2].

First, the eruption caused serious disruption to day-to-day life and operations. Thousands of habitations were destroyed by the lava flow or buried under tephra (i.e., the volcanic material emitted in the plume, transported through the air and deposited on the ground), causing the evacuation of more than 7000 residents [2,6]. Public facilities such as schools and roads were also badly damaged [2,7,8]. The destruction of the main road linking the west to the south of the island increased travel time between some regions of La Palma by up to a factor of eight [2,6], likely isolating parts of the population.

Second, the Tajogaite eruption halted the island's main economic activities, notably agriculture (especially banana cultivation), fishing, and tourism [2]. Lava and pyroclastic flows damaged more than 950 ha of agricultural land [2]. Fishing was prohibited after the eruption and many crops were destroyed by the lava flow and tephra falls. Also, the number of tourists visiting the island after the eruption fell far below the level observed before the COVID-19 pandemic, despite a general sharp increase in the other Canary Islands [2].

Finally, and in addition to the economic and material losses, the emission of volcanic gases and ash (i.e., tephra smaller than 2 mm in size) [9,10] significantly degraded the air quality on the island [11], potentially endangering the health of the island's inhabitants [12]. This decrease in air quality also prompted the confinement and evacuation of populations in some areas, with some restrictions still in place at the beginning of 2023 [6].


**Fig. 1.** Examples of impact of the Tajogaite eruption on habitations and banana plantations. a) Garden and b) habitation buried by tephra in Las Manchas, May 2022. Photos by L. Fourgassie and J. Eychenne. c) Banana plantation covered by tephra in Todoque, October 2021. Photo by I. Tomasek. d) Banana plantation and habitation destroyed by the lava flow, Todoque, October 2021. Photo by I. Tomasek.

The shock, disruption, and loss caused by volcanic eruptions and other socio-natural disasters, that is, disasters resulting from the interaction between natural hazards and social, political, and economic conditions that render certain populations more vulnerable to harm [13,14], in general can pose a serious threat to mental health [15–18]. People living in the western areas of La Palma, those closest to the eruptive center and where lava flows and the majority of tephra accumulation occurred, reported heightened levels of psychological distress, with insomnia, anxiety, and depression being the most commonly reported symptoms [12].

### 1.1. The impact of disaster on mental health

In order of prevalence, PTSD, depression and anxiety are the most common mental health effects observed following socio-natural disasters [17,18]. PTSD is a disorder that arises from exposure to a traumatic event, whether through direct experience or witnessing it. This disorder is characterized by various symptoms, such as intrusive thoughts about the event, avoidance of reminders of the event, emotional numbing, and hypervigilance [19].

The increase in PTSD, depression, and anxiety following disasters has been documented in various types of socio-natural disasters such as earthquakes [20–22], floods [23], tsunamis [24], hurricanes [25] or volcanic eruptions [12,26–31]. The prevalence of PTSD following socio-natural disasters can range between 5 % and 60 % of the sampled population in the first two years post-disaster [16]. A study conducted in flooded areas of the UK found that almost a third (27.9 %) of respondents from affected communities had scores that met the criteria for a PTSD diagnosis, and a similar rate was observed for depression [23]. Comparable rates of PTSD symptoms have been observed in the aftermath of other types of disasters, such as earthquakes or hurricanes [21,32,33].

The detrimental impact of socio-natural disasters on mental health can persist over time. Residents living the closest to Mount Merapi (Indonesia) continued to experience PTSD two years following the 2010 volcanic eruption [31]. Similarly, three years after the eruption of Eyjafjallajökull volcano in Iceland, researchers observed a higher prevalence of medication use for anxiety, depression, and sleep problems among residents in highly exposed areas compared to those in less exposed areas [29]. Understanding risk factors of PTSD following socio-natural disasters is crucial for enhancing psychological interventions aimed at mitigating symptom severity.

### 1.2. Risk factors contributing to PTSD following socio-natural disasters

The literature has highlighted several risk factors that have been linked to higher odds of developing PTSD symptoms following socio-natural disasters. The risk factors identified include previous mental health disorders [16,33] and sociodemographic characteristics such as socioeconomic status, gender, age, ethnicity, or marital status [16–18,34]. More than individual characteristics, these factors encapsulate deeper structural inequalities that shape disaster experiences. Being a woman has consistently been associated with psychological distress after disasters [15,27,28,31,33,35]. This relationship may be explained by the willingness to report psychological distress and by gender roles [36]. Their role as caregivers could make them more likely to stay indoors to protect the family and to carry the family's needs in the aftermath of disasters [36,37]. Socioeconomic status factors such as having a lower level of education [27,28,33] and having a lower income [28,38,39] consistently increase the likelihood of developing PTSD after a socio-natural disaster. Factors such as age and marital status show more inconsistent patterns: older age sometimes seems to act as a risk factor [28,39], but it can also be protective [27,31]. Similarly, some studies have found a higher prevalence of PTSD symptoms among married individuals [27,40], while others have observed this relationship among unmarried individuals [38,39].

Other risk factors are related to the experience of the disaster. Individuals who have lost a family member or a relative [41] can be particularly susceptible to developing PTSD. Also, people who have been evacuated and relocated [15,23,28,42] tend to exhibit more PTSD symptoms. Furthermore, the rate of PTSD symptoms seems to be correlated to the degree of proximity and involvement with the disaster [16]. It is therefore not surprising that more PTSD symptoms are observed in people who live closer to the source of the hazard [31,33] or those acting as rescue workers [16]. Living closer to the source of the hazard could be linked to PTSD as it may increase the risk of becoming a direct victim (e.g., being injured, witnessing others being injured, and suffering property damage), but also to experience frequent reminders of the event afterwards (e.g., tephra deposits, reconstruction, damaged infrastructure), and suffer material deprivation. Inadequate access to water, sanitation, and electricity after a disaster has been associated with an increased risk of developing PTSD [35].

Some studies investigate the role of environmental factors in mental health disorders following disasters [43] though evidence is scarce. In La Palma, environmental contaminants, may have contributed to harm mental health. The eruption left a significant amount of tephra on the ground and rooftops (see Fig. 1). The ongoing visibility of tephra may have reinforced the traumatic experience in several ways. First, it could have perpetuated the stressor, continuously reminding individuals of the volcanic eruption and possible future volcanic eruptions [43]. Second, tephra accumulation may have hindered the return to pre-disaster routines, obstructing daily activities. Third, structural damages, such as roof collapses or the threat thereof [44], may have heightened anxiety and distress [43]. Finally, concerns about potential health risks associated with tephra exposure may have further contributed to psychological strain. Additionally, volcanic gases and tephra degraded air quality [6,11]. Exposure to volcanic air pollution has elsewhere been associated with detrimental health effects [12,45–47]. Exposure to air pollution and other contaminants, in general, has also been associated with mental health issues (including depression and anxiety; [48–51]), although much controversy has been sparked [52]. Although our research is not designed to investigate specific mechanisms underlying the relationship between air pollution and PTSD, there are several potential pathways through which exposure to air pollution may impact mental health [49]. A direct pathway could be the alterations in brain function and development, particularly via the olfactory bulb, nasal epithelium, and inflammatory responses triggered by lung irritation [49]. An indirect pathway could be that the recommendations to wear protective equipment (such as goggles and masks; [6]), the social stigmatization (whole areas deemed "toxic") [51] and the health problems associated with the

eruption such as cough, respiratory disorder, nausea, headache, ocular irritation [12], may have further increased psychological distress.

In this paper, we investigated the prevalence and risk factors (elements that increase the likelihood of reporting PTSD symptoms) associated with reported PTSD symptoms among residents of La Palma following the Tajogaite volcanic eruption. Using the data collected from the ISVOLCAN epidemiological study on the health impacts of the Tajogaite eruption [12] we examined the prevalence of reported PTSD symptoms and their association with several predictors of PTSD following disasters (e.g., gender, age, socioeconomic status, evacuation status). In addition, we considered environmental factors associated with the eruption itself, such as exposure to $SO_2$ and the accumulation of tephra on the ground, as potential contributors to reported PTSD symptoms.

## 2. Method

This study uses data collected as part of the ISVOLCAN epidemiological study [12] and analyses were pre-registered (see https://osf.io/nq75v/?view_only=a45d2835a1b24f8e936103db15038701). The analyses presented in this paper were conducted using

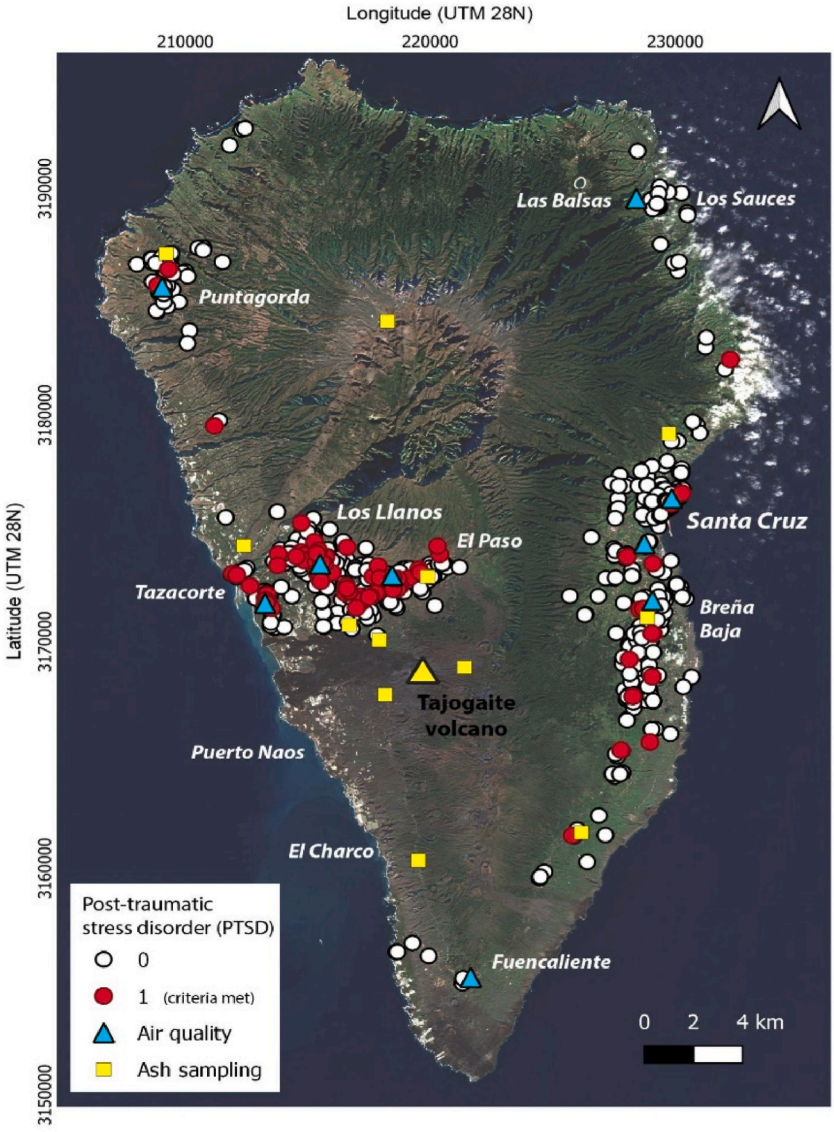



**Fig. 2.** Image of La Palma Island showing the distribution of participants based on whether their reported symptoms met the suggested threshold for PTSD based on the TOP-8 screening tool.**Note.** The red dots indicate the location of participants whose symptom levels suggest possible PTSD, while white dots indicate those who do not meet the threshold. The yellow triangle marks the location of the volcanic vent, blue triangles indicate the location of air quality monitoring stations, and yellow squares show ash sampling sites. The delineated lines represent study area boundaries and do not correspond to official national borders.

secondary data (i.e., data collected initially for different research purposes), so the data had already been collected, but not yet analyzed, at the time of pre-registration. Note that the original data were from a study [12] that received authorization from the health authorities and the Provincial Ethics and Medicines Committee (ref. CHUNSC_2021_88).

### 2.1. Participants

The ISVOLCAN study is a prospective observational cohort study conducted among a randomly stratified selected adult general population across municipalities in La Palma Island's western and eastern regions. In addition, members of various professional or volunteer groups involved in different tasks related to the eruption were also included. The methodology of the study has been published [12]. Briefly, the study is structured in two phases: the initial phase, spanning 2022 to 2023, involved the recruitment of participants, administration of an epidemiological questionnaire via telephone, and a health-center visit for physical examinations, pulmonary function tests, and venous blood extraction. The subsequent phase will monitor the cohort at intervals of 2, 5, and 10 years. The epidemiological questionnaire (www.estudioisvolcan.com) was administered by primary care professionals by phone. In this paper, data from January 2022 to June 2024 were analyzed.

The sample of participants was selected from the health card registry of the Canarian Health Service with a random stratified approach based on age and sex groups. This stratification was based on the 2020 municipal census data of the population residing in the western region (El Paso, Los Llanos, Tazacorte, and Puntagorda districts) and eastern region (Mazo, Santa Cruz de La Palma, and San Andrés y Sauces districts) of the island (see Ref. [12] for more details). In this paper, we used the data from the first 976 participants (see locations of participants on the island of La Palma in Fig. 2). The sociodemographic characteristics of the participants can be found in Table 1.

### 2.2. Material and procedure

#### 2.2.1. Epidemiological questionnaire

The questionnaire consisted of several sections. The first section collected sociodemographic information (age, sex, employment status, occupation type, education level; Table 1). The second section focused on exposure to the eruption, including details about residence before and during the eruption, whether evacuation took place and information on possible subsequent return to the usual residence, access to exclusion zones, involvement in volcanic ash cleaning activities, daily hours spent outdoors, and the use of respiratory masks and eye protection (goggles). The third section covered acute physical health symptoms experienced during the eruption, such as nausea, headache, eye irritation, cough, chest tightness, and visits to the doctor. The fourth and fifth sections collected information on lifestyle factors, including smoking habits and physical activity. Finally, the sixth section covered the personal history of physical and mental health conditions, such as diabetes, cardiovascular disease, asthma, and depression/anxiety.

#### 2.2.2. PTSD symptoms measure

The questionnaire included a validated Spanish version of the Treatment-Outcome Posttraumatic Stress Disorder (TOP-8) scale [53], a shortened version of the SI-PTSD [54]. The TOP-8 contains eight items grouped into three dimensions: intrusion (e.g., intrusive thoughts, recurrent nightmares), avoidance and emotional numbness (e.g., avoiding places that may trigger recollection of the event, detachment from others), and hypervigilance (e.g., feeling jumpy, feeling on guard). The severity of each symptom was rated on a 5-point scale (0 = no/never to 4 = extremely serious). We derived two scores from this scale. The first is a symptom severity score, calculated as the sum of all reported symptoms, to capture the overall intensity of PTSD-related symptoms. The second is a binary indicator reflecting whether participants met the threshold suggestive of possible PTSD. Following previous research using similar screening tools (e.g., PTSD-8; [19]), we considered individuals to meet this threshold if they reported a score of 3 or higher on at least one item within each of the three symptom clusters [19,55]. It is important to note that this method is intended as a screening indicator only; individuals meeting this criterion may have PTSD, but would require a clinical assessment to further confirm the PTSD diagnosis. The scale showed a high level of reliability as measured by McDonald's omega ($\omega = 0.87$) (measured using the 'omega' function of R package 'psych' (version 2.4.3, [56]).

#### 2.2.3. Risk factors

*2.2.3.1. Sociodemographic variables.* Data were collected on participants' age, sex, education, history of depression, and subjective poverty. Participants self-reported their sex as either 'female' or 'male'. Educational attainment was categorized into four levels: 'no studies', 'primary school', 'secondary school', and 'university education'. Participants reported whether they had ever experienced episodes of anxiety and/or depression. Subjective poverty was assessed with the question, "Which of the following situations best describes the economic situation of your household before the eruption?". Participants selected the answer from the following options: (1) I lived on borrowed money, credit, or debt (with much difficulty); (2) I spent savings to live (with difficulty); (3) I spent what was earned (with considerable difficulty); (4) I saved a bit (with considerable ease); (5) I saved a lot (with ease); or (6) I saved and invested (with great ease). This question, previously used in the context of the Canary Islands [57], was used to approximate the economic conditions of the participants before the eruption. As this question was introduced later in the data collection process, we only have 545 observations for this variable.

**Table 1**
Demographic characteristics of the respondents (N = 976).

| Characteristics | *n* (%) |
|---|---|
| **Mean age** | 49.70±15.48 SD |
| **Age groups** | |
| 18–24 | 51 (5.23) |
| 25–34 | 133 (13.63) |
| 35–44 | 177 (18.14) |
| 45–54 | 250 (25.61) |
| 55–64 | 209 (21.41) |
| 65+ | 156 (15.98) |
| **Sex** | |
| Men | 409 (41.91) |
| Women | 567 (58.09) |
| **Education** | |
| No studies | 41 (4.20) |
| Elementary | 241 (24.69) |
| Secondary education | 443 (45.39) |
| University degree | 224 (22.95) |
| **Employment (before eruption)** | |
| Retired | 140 (14.34) |
| Employee | 585 (59.94) |
| Unemployed with benefits | 89 (9.12) |
| Unemployed without benefits | 104 (10.66) |
| Temporary incapacity | 15 (1.54) |
| Permanent incapacity | 33 (3.38) |
| Student | 10 (1.02) |
| **Evacuation status** | |
| Yes | 124 (12.70) |
| No | 852 (87.30) |

**Note.** *SD* = standard deviation.

*2.2.3.2. Experiences during the eruption.* We analyzed data on participants' living conditions during the eruption, focusing on evacuation and participation in eruption-related work. Specifically, for evacuation, we used the variable reporting whether respondents had to evacuate (yes/no), and we also calculated the duration of evacuation. This was done by subtracting the date of evacuation from the date of return reported by the respondents. If no date of return was given, we subtracted the date of evacuation from the date of the interview. Regarding involvement in eruption-related work, participants were asked whether they had worked as a responder in the exclusion zone during the volcanic eruption, including the duration of their involvement.

*2.2.3.3. Eruption-related health symptoms.* We considered the report of physical health symptoms associated with the eruption: headaches, nausea, cough, dyspnoea, wheezing ('whistling' in the chest when breathing), sneezing, nasal discharge (rhinorrhoea), eye discomfort (conjunctivitis, irritation), muscle pain, chest pain and accidents (trauma, burns). Participants could declare up to three other symptoms. For each participant, we created a variable to determine the presence or absence of physical health issues related to the eruption (yes/no) and we also calculated the number of reported symptoms. We only considered symptoms related to physical health and discarded symptoms such as insomnia, anxiety, and depression as they are comorbid with PTSD.

*2.2.3.4. Exposure to the eruption or the aftermath.* To assess exposure to the eruption and its aftermath, we use three indices. The first index measured the distance (in kilometres) from the respondent's address at the time of the eruption to the volcano. The other two indices, air quality (i.e., $SO_2$ concentrations), and tephra fallout, were related to environmental disturbances caused by the eruption.

For air quality, exposure to $SO_2$ was calculated by averaging the number of days participants were exposed to 24-h mean $SO_2$ concentrations above 40 $\mu g/m^3$ (as recommended by the World Health Organization [WHO]) based on the nearest air quality station (see locations in Fig. 2) to the participant's home address (*Median distance* = 775 m, Interquartile range [IQR] of distance = 353.37–1522.34). Data from the regulatory air quality monitoring network of the Canarian Government was used (https://www3.gobiernodecanarias.org/medioambiente/calidaddelaire/inicio.do) to determine $SO_2$ concentrations. The cumulative mass of tephra deposited per square meter over the entire duration of the eruption was used as a proxy for exposure to tephra fallout, based on the nearest tephra collection point (see locations in Fig. 2) to the participant's home address (Median distance = 2521 m, IQR = 1548.87–2984.99).

*2.2.3.5. Time since the eruption.* Given that data collection occurred over several months, we calculated the time since the eruption by subtracting the date of the interview from the start date of the eruption (September 19, 2021).

*2.2.4. Statistical analysis*

The statistical analysis was carried out using R (version 4.3.3) and RStudio (version 2024.04.02).

We ran a multivariate linear model (using the function 'lm' of base R, version 4.3.3) with mean PTSD score as a dependent variable,

and with sex, age, education, evacuation status, participation to eruption-related work, distance to the volcano, antecedents of depression, eruption-related health symptoms, time since the eruption, exposure to tephra fallout and air quality as predictors. The model's equation (Eq. (1)) was as follows (equation generated using the 'equatiomatic' package, version 0.3.3, [58])

$$\text{PTSD score} = \alpha + \beta_1(sex) + \beta_2(age) + \beta_3(education) + \beta_4(evacuation) + \beta_5(eruption - related\ work) + \beta_6(distance) + \beta_7(depression) + \beta_8(physical\ symptoms) + \beta_9(time) + \beta_{10}(tephra) + \beta_{11}(air\ quality) + \epsilon \quad (1)$$

We assessed the fit of the model to the data using the 'performance' package (version 0.12.2; [59]). The residuals of PTSD scores were not normally distributed, but regressions in large samples may be unaffected by such a violation [60]. The Maximum Variance Inflation Factor (VIF) was 1.70, suggesting no collinearity issues. Only one outlier was detected on standardized residuals (SDR = 4.15). A heteroscedasticity check revealed that the assumption of normal distribution of error terms was violated. To account for heteroscedasticity in our regression analysis, we employed robust standard errors using the 'sandwich' package (version 3.1.0; [61]), with the HC3 adjustment [62]).[2]

For this model, we report on the multiple r-squared (as a measure of the proportion of the variance in the dependent variable that can be explained by the predictor variables), and detail the significant factors (at α level $p < .05$), with the parameter coefficient estimates ($b$), the $t$-test of coefficient ($t$) followed by the related degree of freedom and associated p-value ($p$), and the effect size using partial eta-squared ($\eta^2$p).

We also performed a logistic regression (using the 'glm' function of base R), using the same predictors to assess the factors that were significantly associated with reaching the threshold for a potential PTSD diagnosis (i.e., having at least one symptom rated above three in each subdimension on the TOP-8 screening tool). The model's equation was as follows (Eq. (2)):

$$log\left(P\left(\frac{PTSD\ diagnosis = 0}{1 - P\ (PTSD\ diagnosis = 0}\right)\right) = \alpha + \beta_1(sex) + \beta_2(age) + \beta_3(education) + \beta_4(evacuation) + \beta_5(eruption - related\ work) + \beta_6(distance) + \beta_7(depression) + \beta_8(physical\ symptoms) + \beta_9(time) + \beta_{10}(tephra) + \beta_{11}(air\ quality) \quad (2)$$

The model did not suffer from excessive collinearity. No outlier was detected based on the studentized residuals.

For this model, we report on the Nagelkerke pseudo r-squared ($\eta^2$), and detail the significant factors (again - at α level $p < .05$), the odds ratio (OR) and their 95 % confidence intervals (CI), the z-tests ($z$) and associated p-values ($p$).

## 3. Results

### 3.1. Prevalence of reported symptoms associated with PTSD in La Palma

The average score of reported PTSD related symptoms was 5.51 ($SD = 6.94$), with a median score of 3 out of 32 as a maximum. Out of the 976 respondents, 81 individuals (8.3 %) reported symptoms that met the threshold for possible PTSD based on the TOP-8 screening tool. The spatial distribution of respondents across the island, based on whether they met the PTSD diagnostic threshold, is shown in Fig. 2.

### 3.2. Risk factors associated with reported symptoms associated with PTSD

#### 3.2.1. Reported PTSD symptoms

In this model, we aimed to explore how the severity of reported PTSD scores (calculated as the sum of symptom ratings related to PTSD) were predicted by the listed factors. Overall, our model explained 23.38 % of the variance in the total PTSD score (Multiple $R^2 = 0.23$). The score of reported PTSD symptoms was significantly predicted by sex, education level, evacuation status, distance to the volcano, history of anxiety and/or depression, physical health issues related to the eruption, and $SO_2$ exposure (see Table 2). Factors that were associated with an increase in reported PTSD scores were being a woman, having a lower level of education, having evacuated, having personal antecedents of anxiety and/or depression, experiencing health issues attributed to the volcanic eruption, and higher exposure to $SO_2$. Distance was associated with a decrease in PTSD scores. Age, working in exclusion areas, the time elapsed since the beginning of the eruption, and tephra fallout were not significantly associated with PTSD scores. We also explored the association between subjective poverty and reported symptoms related to PTSD. Because the question on subjective poverty was added later in the data collection process, we only had 545 observations for this variable. Therefore, to assess the effect of subjective poverty,

[2] We deviated from our pre-registered analysis plan in two ways. First, while we initially planned to apply a log transformation to the PTSD score in case of non-normal residuals, we ultimately chose to retain the untransformed data. Given the large sample size ($N = 976$), regression models are generally robust to violations of normality [60], and the presence of numerous zero values in the PTSD score made logarithm transformation less appropriate. Importantly, the results remained largely consistent between the transformed and untransformed models, with the only notable difference being that the effect of time became significant in the log-transformed model ($t(937) = 2.79$, $p = .01$). Second, we pre-registered the exclusion of outliers; however, since their removal did not affect the results, we opted to retain the full sample to minimize unnecessary data modifications. The analyses, with data transformation (log) and without corrections for heteroscedasticity, are provided in the supplementary material available at (https://osf.io/t62va/?view_only=f39d0f1da75442808311be3bcfe125a0).

**Table 2**
Risk Factors of reported PTSD symptoms Following the 2021 Tajogaite Eruption in La Palma.

| Risk factor | $\beta$ | $t$ | $\eta^2p$ | Direction of effect |
|---|---|---|---|---|
| Evacuation status (Yes vs. No) | −0.23 | −5.71*** | 0.06 | Evacuated ↑ PTSD |
| Health issues related to the eruption (Yes vs. No) | −0.17 | −5.96*** | 0.03 | Health issues ↑ PTSD |
| History of anxiety/depression | −0.13 | −3.66*** | 0.02 | History of anxiety/depression ↑ PTSD |
| Education | −0.12 | −3.77*** | 0.02 | Lower level of education ↑ PTSD |
| Distance from the volcano | −0.12 | −3.47*** | 0.01 | Living closer to the volcano ↑ PTSD |
| $SO_2$ exposure | 0.11 | 3.06** | 0.01 | More $SO_2$ exposure ↑ PTSD |
| Sex (Women vs. Men) | 0.10 | 3.29** | 0.01 | Women ↑ PTSD |
| Age | −0.06 | −1.89 | 0.003 | ns |
| Working in exclusion areas | 0.01 | 0.49 | 0.0002 | ns |
| Time elapsed since the eruption | −0.02 | −0.70 | 0.0004 | ns |
| Tephra fallout | 0.07 | 1.48 | 0.003 | ns |
| Subjective poverty | −0.01 | −0.15 | <0.001 | ns |

**Note.** $\beta$ = standardized regression coefficient; $t$ = t-statistic; ***$p < .001$; **$p < .01$; *$p < .05$; $\eta^2p$ = partial eta squared (effect size); ns = not significant; The effect of subjective poverty was tested in a subsample of 545 participants.

we ran the same model on this subset of the sample, including subjective poverty as an additional predictor. We found no association between subjective poverty and reported PTSD symptoms.[3]

As pre-registered, because evacuation status and the presence of physical symptoms associated with the eruption were significant predictors, we further examined the relationship between the PTSD scores and these predictors. Among those who evacuated, there was a positive correlation between the duration of evacuation and PTSD scores ($r(122) = 0.26$, $p = .004$, $\eta^2 = 0.07$). Among respondents who reported physical symptoms related to the eruption, a significant positive correlation was found; the more symptoms they reported, the higher their PTSD scores ($r(974) = 0.39$, $p < .001$, $\eta^2 = 0.15$).

#### *3.2.2. Reported symptoms meeting the threshold of possible PTSD based on the TOP-8 screening tool*

This model tested whether the listed factors were associated with meeting the threshold for a potential PTSD diagnosis (i.e., having at least one symptom rated above three in each subdimension on the TOP-8 screening tool). Overall, the model explained about 5 % of the variance (Nagelkerke $\eta^2 = 0.046$). The results revealed that education, evacuation status, distance to the volcano, antecedents of depression/anxiety, and the presence of symptoms related to the eruption were significant predictors (see Table 3). More specifically, having evacuated, having antecedents of anxiety/depression, lower levels of education, experiencing health issues attributed to the volcanic eruption were associated with higher odds of meeting the threshold for a potential PTSD diagnosis based on the TOP-8 screening tool. Living further away from the volcano was significantly associated with lower odds of reaching the threshold for a potential PTSD diagnosis. None of the other predictors was significant.

## 4. Discussion

In this study, we report on a secondary data analysis based on a representative sample of 976 residents of La Palma who were confronted with the historic eruption of Tajogaite in 2021, the longest eruption in the island's history [1,2]. The experience of disasters such as eruptions and their direct (e.g., physical injuries, evacuation, material damage) and indirect (e.g., evacuation and resettlement) consequences are otherwise associated with an increased risk of PTSD [15,16,43]. We hence investigated the prevalence and contributors of reported symptoms associated with PTSD among La Palma residents using this dataset. Extending past research on the socio-environmental impact of volcanic eruptions, we included volcanic emissions (air contamination and tephra fallout) as potential contributors to PTSD symptomatology.

Overall, our results indicate that reported symptoms associated with PTSD, as recorded by the TOP-8 screening tool, were relatively common among the respondents following the Tajogaite eruption in September 2021. This prevalence (~8 %) was in the range observed in other relevant studies (e.g., 2–6.9 % in Ref. [27] for the 2010 Eyjafjallajökull eruption; 27.6 % in Ref. [63] for the 1991 Mount Pinatubo eruption). It should be noted that factors tied to the disaster such as its severity [64] or cultural factors [65] may play a role in shaping post-disaster PTSD, potentially explaining differences observed in the prevalence of PTSD across eruptions. Besides, the measures and timing of measurement of PTSD and sampling techniques may vary across studies [18] further complicating comparisons.

Regarding the prevalence and severity, our results otherwise concur with some of the previously identified patterns observed in the literature [15,16,43]. Namely, reported symptoms associated with PTSD were more severe in women, in participants who had evacuated, who had lower education, who were living closer to the hazard, and who had a history of depression (PTSD and depression are comorbid; [66]). In contrast to other studies linking PTSD and exposure to disasters [39], we found no association between socioeconomic status (approximated by subjective poverty) and PTSD.

The intensity of reported symptoms related to PTSD is most strongly associated with the individual's history of evacuation. Relocation can, in itself, constitute a traumatic experience [67], adding to the traumatic experience of the initial exposure to the hazard

[3] Details can be found in the supplementary analyses file at https://osf.io/t62va/?view_only=f39d0f1da75442808311be3bcfe125a0.

**Table 3**
Risk Factors of Reaching PTSD Diagnostic Threshold based on the TOP-8 screening tool Following the 2021 Tajogaite Eruption in La Palma.

| Risk factor | *z* | *OR* | 95 % CI (Lower) | 95 %CI (Upper) | Direction of effect |
|---|---|---|---|---|---|
| Evacuation status (Yes vs. No) | −4.46** | 0.28 | 0.16 | 0.49 | Evacuated ↑ PTSD |
| Health issues related to the eruption (Yes vs. No) | 2.47* | 2.42 | 1.20 | 4.87 | Health issues ↑ PTSD |
| History of anxiety/depression | −2.61** | 0.44 | 0.24 | 0.82 | History of anxiety/depression ↑ PTSD |
| Education | −3.20** | 0.57 | 0.40 | 0.80 | Lowet level of education ↑ PTSD |
| Distance from the volcano | −2.38* | 0.89 | 0.81 | 0.98 | Living closer to the volcano ↑ PTSD |
| $SO_2$ exposure | 0.56 | 1.00 | 0.99 | 1.02 | ns |
| Sex (Women vs. Men) | 1.43 | 1.51 | 0.87 | 2.72 | ns |
| Age | −1.40 | 0.99 | 0.97 | 1.01 | ns |
| Working in exclusion areas | 0.79 | 1.41 | 0.63 | 3.61 | ns |
| Time elapsed since the eruption | 1.02 | 1.00 | 0.99 | 1.00 | ns |
| Tephra fallout | −0.08 | 1.00 | 0.97 | 1.03 | ns |
| Subjective poverty | 0.58 | 1.09 | 0.82 | 1.47 | ns |

**Note.** $\beta$ = standardized regression coefficient; $z$ = z-statistic; ***$p < .001$; **$p < .01$; *$p < .05$; *OR* = Odds Ratio (effect size); ns = not significant; The effect of subjective poverty was tested in a subsample of 545 participants.

and disaster. In addition, the specific effect of experiencing the material destruction of one's home may be partly responsible for the association between evacuation status and PTSD, with some of the evacuees having to leave because they simply lost their homes to the effects of the eruption and suffering from PTSD as a result of the material destruction, a contributing factor to the experience of traumatic subjective distress [28,43]. In addition, not knowing whether one's home is still standing may also contribute to the presence of such distressing thoughts [28]. Similarly, evacuation status and distance to the volcano could be confounded with direct experience with the eruption, another contributing factor to PTSD in other volcanic settings [27,29]. Although we could not assess it with our dataset, evacuation may also disrupt social networks and thus social support, making people vulnerable to PTSD. Low social support has indeed been associated with more severe PTSD [15,16], and social support is otherwise pivotal to the maintenance or restoration of mental health [68] as it notably offers opportunities for affect regulation.

Interestingly, we found that poorer air quality (i.e., exposure to $SO^2$ concentrations) was associated with higher PTSD related scores on the TOP-8 screening tool, with a moderate effect size, suggesting a noticeable relationship. As previously discussed, the association between mental health and air pollution is debated in the literature (see Ref. [49] for a recent review). Whether this link is mediated by exposure to air quality information or lack thereof, or whether it is caused by experiencing adverse health effects from exposure to high levels of air contaminants, cannot be answered here and remains to be determined. One possibility is that the observed association captures the psychological impact of risk perception on symptoms associated with PTSD rather than the direct physiological effects of $SO_2$. Indeed, as daily bulletins were issued [6], information about air quality and recommendations such as wearing masks may have heightened risk perception, leading to increased stress and anxiety. In this context, individuals exposed to more air-quality warnings may have experienced greater psychological distress. Additionally, the link between $SO_2$ and symptoms associated with PTSD may reflect the influence of physical symptoms or fear of developing symptoms. The presence of physical symptoms related to the eruption was the second strongest predictor of reported PTSD related symptoms in our study, suggesting that individuals experiencing respiratory discomfort, headaches, or other health issues may have been more vulnerable to psychological distress. Given that environmental contaminants can cause both objective health effects and subjective distress, future research could disentangle the relative contributions of direct physiological mechanisms and psychological responses to air pollution exposure. The development of cost-effective air quality monitoring sensors [69], coupled with surveys, may help uncover more subtle patterns between air quality and mental health in future studies. Interestingly, tephra, which could be a source of concern regarding both health risks and property damage, was not found to be associated with reported PTSD symptoms.

### *4.1. Limitations*

While our study provides insights into PTSD related symptoms following the Tajogaite volcanic eruption on the island of La Palma and adds to the literature on the effect of disasters on mental health, several limitations should be acknowledged. Firstly, according to Ref. [12], of those selected using a random stratified approach, approximately 36 % were included in the study, while the others either refused to participate or could not be contacted. This may indicate a potential selection bias, as those who chose not to participate may have had different characteristics to those who did. Second, we conducted our analyses on an existing database, meaning that only a constrained number of predictors were considered, potentially leaving out other important predictors (such as support from social networks). This implies caution when drawing conclusions about predictors of symptoms related to PTSD after disasters as some hidden predictors may explain or obscure some of the associations. Third, it is important to note that the associations found between the predictors and reported PTSD symptoms are purely correlational and do not directly address the causality of relationships. Besides, although our results are consistent with previous findings on the effects of disasters on PTSD [15], their generalizability to other disasters or regions may be limited. Fourth, and finally (and as discussed above), the measurement of some of our variables (e.g., exposure to $SO_2$) were not made directly near participants' households, but at closest measurement stations.

### 4.2. Conclusion and Perspectives

By 2015, over 1 billion people (14.3 % of the global population) resided within 100 km of a volcano active in the last 10 000 years, and the population density around volcanoes has increased since 1975, with a growing number of people living in high-risk areas [70]. Given the impact of volcanic eruption on mental health [43] it is crucial to better understand their aggravating factors. This study underscores the impact of the Tajogaite volcanic eruption on mental health, revealing that certain populations are disproportionately affected, particularly women, people with lower education, with antecedents of mental health, those suffering from health issues, and those who had to evacuate. Our study adds to the existing body of research on PTSD and volcanic hazards, and could one day enable, together with other reports, the conduct of a comprehensive meta-analysis on their impacts on mental health, in addition to the existing systematic reviews [15,43]. The identification of aggravated vulnerability factors (demographics and otherwise) is critical to the establishment of more targeted support and intervention strategies [15]. For example, some programs specifically address the needs of vulnerable populations, such as older adults [71] or adolescents [72]. Beyond recovery efforts, understanding the factors associated with PTSD can also inform disaster response planning. In our study, evacuation status was the strongest predictor of reported PTSD related symptoms, underscoring the need for well-designed evacuation procedures and communication strategies to minimize psychological distress. Additionally, the associations between PTSD and demographic factors such as sex and education level go beyond individual differences; they reflect deeper structural inequalities that shape disaster experiences. Women, for instance, often face increased mental health risks after disasters due to pre-existing social and economic disparities that influence both their exposure to and recovery from such events [36]. Integrating these considerations into disaster preparedness efforts could help reduce the psychological impact of future eruptions. Finally, the study highlights the potential role of environmental factors, with air quality linked to PTSD, suggesting this is an important agenda for future research.

A final note should be made on the fact that the eruption took place during the COVID-19 pandemic, which greatly impacted the island, and likely contributed to mental distress before the eruption, as occurred in other regions of overseas Spain [73]. While conclusions cannot be drawn from the data collected in this study, PTSD scores observed in the dataset may have been partially contaminated by the experience of the COVID-19 crisis that affected the island [73], with the eruption being an additional stressor to another ongoing crisis. Although the PTSD questionnaires were related to the experience of the eruption, prior exposure and vulnerabilities due to COVID-19 episodes could have exacerbated people's susceptibility to post-traumatic stress disorder, through a complex trauma [74]. For instance, residents of Fort McMurray (Canada) who experienced COVID-19 and a natural hazard (e.g., flood) were ten times more likely to display symptoms of PTSD than respondents experiencing only COVID-19 [75]. In the case of La Palma, the mental health burden from the COVID-19 pandemic could have intensified the effects of the volcanic eruption, as residents may have had heightened concerns about health, hospitalization, and economic security, especially considering the island's dependence on tourism, which had already been severely impacted by the pandemic [2]. As it appears, COVID-19 may have also prepared the population for disaster response, with mask-wearing potentially serving a dual purpose during both crises. Given the increasing likelihood of compound disasters in the future and their impact on both disaster response [76] and recovery [75], future studies could consider not only the direct impacts of a single disaster but also the cumulative effects of ongoing and past crises on mental health. This approach could offer valuable insights into how disaster response and recovery can be adapted to better support affected populations.

## CRediT authorship contribution statement

**Lisa Fourgassie:** Methodology, Conceptualization, Writing – original draft, Data curation, Writing – review & editing, Formal analysis. **María Cristo Rodríguez-Pérez:** Data curation, Methodology, Resources, Conceptualization, Writing – review & editing. **Manuel Enrique Fuentes Ferrer:** Methodology, Conceptualization, Writing – review & editing, Data curation, Resources. **Elena Zwirner:** Conceptualization, Writing – review & editing, Methodology. **Agnès Borbon:** Conceptualization, Writing – review & editing, Methodology. **Aurélie Colomb:** Writing – review & editing, Conceptualization, Methodology. **Francisco Jose Perez Torrado:** Conceptualization, Writing – review & editing, Resources. **David Jessop:** Writing – review & editing, Methodology, Conceptualization. **Séverine Moune:** Methodology, Writing – review & editing, Conceptualization. **Raphaël Paris:** Writing – review & editing, Visualization, Methodology, Conceptualization. **Lucie Sauzéat:** Methodology, Conceptualization, Writing – review & editing. **Ines Tomašek:** Methodology, Conceptualization, Writing – review & editing. **David Damby:** Methodology, Writing – review & editing, Conceptualization. **Guillaume Dezecache:** Methodology, Writing – review & editing, Conceptualization, Writing – original draft, Data curation. **Julia Eychenne:** Funding acquisition, Writing – review & editing, Methodology, Resources, Conceptualization, Supervision.

## Data accessibility statement

The data that support the findings of this study are not openly available due to reasons of sensitivity. The R script and supplementary analyses can be found at the following link: https://osf.io/t62va/?view_only=f39d0f1da75442808311be3bcfe125a0.

## Declaration of generative AI in scientific writing

During the preparation of this work, the authors used ChatGPT and DeepL Write to enhance readability and language. The authors carefully reviewed and edited the content as necessary and take full responsibility for the final version of the published article.

## Funding and acknowledgments

We are grateful to the PEVOLCA committee for permission to work within the exclusion zone during the 2021 Tajogaite eruption. This work was funded by the Agence Nationale de la Recherche of the French government through the program "Investissements d'Avenir" (16-IDEX-0001 CAP 20–25). This is Contribution N° 710 of the ClerVolc Program of Excellence of the International Research Centre of Disaster Science and Sustainable Development. We thank the editor in chief Kerstin Eriksson for handling our manuscript, as well as the reviewers Francisca Vergara-Pinto and an anonymous reviewer for their constructive feedback, which greatly improved the quality of our work. We also extend our thanks to Jack R. Friedman and the reviewers from the USGS for their valuable comments on the manuscript. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

## 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.2025.105680.

## Data availability

The data that has been used is confidential.

## References

[1] J.C. Carracedo, et al., The 2021 eruption of the Cumbre Vieja volcanic ridge on La Palma, Canary Islands, Geol. Today 38 (3) (2022) 94–107, https://doi.org/10.1111/gto.12388.
[2] V.R. Troll, et al., The 2021 La Palma eruption; social dilemmas resulting from living close to an active volcano [Online]. Available: https://eartharxiv.org/repository/view/5961/, Sep. 2023. (Accessed 21 May 2024).
[3] C. Bonadonna, et al., Physical characterization of long-lasting hybrid eruptions: the 2021 tajogaite eruption of cumbre vieja (La palma, Canary Islands), J. Geophys. Res. Solid Earth 127 (11) (2022), https://doi.org/10.1029/2022JB025302.
[4] C. Bonadonna, et al., Tephra sedimentation and grainsize associated with pulsatory activity: the 2021 Tajogaite eruption of Cumbre Vieja (La Palma, Canary Islands, Spain), Front. Earth Sci. 11 (May 2023), https://doi.org/10.3389/feart.2023.1166073.
[5] J.E. Romero, et al., The initial phase of the 2021 Cumbre Vieja ridge eruption (Canary Islands): products and dynamics controlling edifice growth and collapse, J. Volcanol. Geotherm. Res. 431 (Nov. 2022) 107642, https://doi.org/10.1016/j.jvolgeores.2022.107642.
[6] T. Rey, et al., "L'éruption du Tajogaite (Cumbre Vieja) à La Palma. Canaries : De L'Éruption Volcanique À La Crise Territoriale, EchoGéo, Jun. 2023, https://doi.org/10.4000/echogeo.24450.
[7] Comisión mixta para la reconstrucción, recuperación y apoyo a la isla de La Palma (CMRRA), "Informe Sobre Las Actuaciones Y Medidas Emprendidas Tras La Erupción Del Volcán De Cumbre Vieja (La Palma), Seis Meses Después Del Inicio De La Emergencia.,", 2022 [Online]. Available: https://www.mpr.gob.es/prencom/notas/Documents/2022/060622-informe_palma.pdf.
[8] Gestión y Planeamiento Territorial y Medioambiental of the Canarian Government (GESPLAN), Informe Sobre Las Edificaciones Y Parcelas Afectadas En El Ámbito De La Colada, Gobierno de Canarias, 2022 [Online]. Available: https://pre-servicios.sitcan.es/portal/sharing/rest/content/items/c54c18e085c0415f85c2e5e73613e47b/data. (Accessed 15 November 2024).
[9] B. Bonechi, M. Polacci, F. Arzilli, J. Romero, J. Fellowes, M. Burton, Magma residence time, ascent rate and eruptive style of the November ash-laden activity during the 2021 Tajogaite eruption (La Palma, Spain), Volcanica 7 (1) (Jan. 2024) 1, https://doi.org/10.30909/vol.07.01.5165.
[10] M. Burton, Tajogaite 2021 Gas Team, Exceptional eruptive CO2 emissions from intra-plate alkaline magmatism in the Canary volcanic archipelago [Online]. Available: https://meetingorganizer.copernicus.org/EGU24/EGU24-5990.html. (Accessed 16 February 2025).
[11] C. Milford, et al., Impact of the 2021 La Palma volcanic eruption on air quality: insights from a multidisciplinary approach, Sci. Total Environ. 869 (Apr. 2023), https://doi.org/10.1016/j.scitotenv.2023.161652.
[12] M.C. Rodríguez-Pérez, et al., Health impact of the Tajogaite volcano eruption in La Palma population (ISVOLCAN study): rationale, design, and preliminary results from the first 1002 participants, Environ. Health 23 (1) (Feb. 2024) 19, https://doi.org/10.1186/s12940-024-01056-4.
[13] A. Maskrey, *Los Desastres No Son Naturales*, La Red De Estudios Sociales En Prevención De Desastres En América Latina, 1993.
[14] P. O'Keefe, K. Westgate, B. Wisner, Taking the naturalness out of natural disasters, Nature 260 (5552) (Apr. 1976) 566–567, https://doi.org/10.1038/260566a0.
[15] O. Malas, M.-D. Tolsá, The impact of volcano eruption on mental health: a systematic review, Int. J. Disaster Risk Reduct. 113 (Oct. 2024) 104863, https://doi.org/10.1016/j.ijdrr.2024.104863.
[16] S. Galea, A. Nandi, D. Vlahov, The epidemiology of post-traumatic stress disorder after disasters, Epidemiol. Rev. 27 (1) (Jul. 2005) 78–91, https://doi.org/10.1093/epirev/mxi003.
[17] C.S. North, J. Oliver, A. Pandya, Examining a comprehensive model of disaster-related posttraumatic stress disorder in systematically studied survivors of 10 disasters, Am. J. Public Health 102 (10) (Oct. 2012) e40–e48, https://doi.org/10.2105/AJPH.2012.300689.
[18] F.H. Norris, M.J. Friedman, P.J. Watson, C.M. Byrne, E. Diaz, K. Kaniasty, 60,000 disaster victims speak: part I. An empirical review of the empirical literature, 1981–2001, Psychiatry Interpers. Biol. Process. 65 (3) (Sep. 2002) 207–239, https://doi.org/10.1521/psyc.65.3.207.20173.
[19] M. Hansen, T.E. Andersen, C. Armour, A. Elklit, S. Palic, T. Mackrill, PTSD-8: a short PTSD inventory, Clin. Pract. Epidemiol. Ment. Health 6 (1) (Sep. 2010) 101–108, https://doi.org/10.2174/1745017901006010101.
[20] C. Carmassi, et al., PTSD in the aftermath of a natural disaster: what we learned from the Pisa-L'Aquila Collaboration project, J. Psychopathol 26 (Feb. 2020) 99–106, https://doi.org/10.36148/2284-0249-377.

[21] C.L.W. Chan, et al., Posttraumatic stress disorder symptoms among adult survivors of the 2008 Sichuan earthquake in China, J. Trauma Stress 24 (3) (Jun. 2011) 295–302, https://doi.org/10.1002/jts.20645.
[22] Y.K. Yang, et al., Psychiatric morbidity and posttraumatic symptoms among earthquake victims in primary care clinics, Gen. Hosp. Psychiatry 25 (4) (Jul. 2003) 253–261, https://doi.org/10.1016/S0163-8343(03)00022-7.
[23] V. Mason, H. Andrews, D. Upton, The psychological impact of exposure to floods, Psychol. Health Med. 15 (1) (Jan. 2010) 61–73, https://doi.org/10.1080/13548500903483478.
[24] I. Irmansyah, S. Dharmono, A. Maramis, H. Minas, Determinants of psychological morbidity in survivors of the earthquake and tsunami in Aceh and Nias, Int. J. Ment. Health Syst. 4 (1) (Dec. 2010) 8, https://doi.org/10.1186/1752-4458-4-8.
[25] C.F. Weems, et al., The psychosocial impact of Hurricane Katrina: contextual differences in psychological symptoms, social support, and discrimination, Behav. Res. Ther. 45 (10) (Oct. 2007) 2295–2306, https://doi.org/10.1016/j.brat.2007.04.013.
[26] C. Cruz Manzano, I. Nieto, C. González-Sanguino, C. Marin Martin, Psychological Impact of the Volcanic Eruption in La Palma Spanish Island: predictors of Depression, Anxiety, Stress, and Well-Being, SSRN Electron. J. (2023), https://doi.org/10.2139/ssrn.4348229.
[27] Ó.S. Gissurardóttir, H. Hlodversdóttir, E.B. Thordardóttir, G. Pétursdóttir, A. Hauksdóttir, Mental health effects following the eruption in Eyjafjallajökull volcano in Iceland: a population-based study, Scand. J. Public Health 47 (2) (2019) 251–259.
[28] T. Goto, J.P. Wilson, B. Kahana, S. Slane, The miyake Island Volcano disaster in Japan: loss, uncertainty, and relocation as predictors of PTSD and depression, J. Appl. Soc. Psychol. 36 (8) (Aug. 2006) 2001–2026, https://doi.org/10.1111/j.0021-9029.2006.00091.x.
[29] H. Hlodversdottir, G. Petursdottir, H.K. Carlsen, T. Gislason, A. Hauksdottir, Long-term health effects of the Eyjafjallajökull volcanic eruption: a prospective cohort study in 2010 and 2013, BMJ Open 6 (9) (Sep. 2016) e011444, https://doi.org/10.1136/bmjopen-2016-011444.
[30] J.H. Shore, E.L. Tatum, W.M. Vollmer, Psychiatric reactions to disaster: the Mount St. Helens experience, Am. J. Psychiatry 143 (5) (May 1986) 590–595, https://doi.org/10.1176/ajp.143.5.590.
[31] S. Warsini, P. Buettner, J. Mills, C. West, K. Usher, Post-traumatic stress disorder among survivors two years after the 2010 M ount M erapi volcano eruption: a survey study, Nurs. Health Sci. 17 (2) (Jun. 2015) 173–180, https://doi.org/10.1111/nhs.12152.
[32] G. Ironson, et al., Posttraumatic stress symptoms, intrusive thoughts, loss, and immune function after Hurricane Andrew, Psychosom. Med. 59 (2) (1997) 128–141, https://doi.org/10.1097/00006842-199703000-00003.
[33] M. Başoğlu, E. Şalcioğlu, M. Livanou, Traumatic stress responses in earthquake survivors in Turkey, J. Trauma Stress 15 (4) (Aug. 2002) 269–276, https://doi.org/10.1023/A:1016241826589.
[34] B. Tang, Q. Deng, D. Glik, J. Dong, L. Zhang, A meta-analysis of risk factors for post-traumatic stress disorder (PTSD) in adults and children after earthquakes, Int. J. Environ. Res. Public. Health 14 (12) (Dec. 2017) 1537, https://doi.org/10.3390/ijerph14121537.
[35] S. Galea, M. Tracy, F. Norris, S.F. Coffey, Financial and social circumstances and the incidence and course of PTSD in Mississippi during the first two years after Hurricane Katrina, J. Trauma Stress 21 (4) (Aug. 2008) 357–368, https://doi.org/10.1002/jts.20355.
[36] A. Fothergill, The neglect of gender in disaster work: an overview of the literature, Int. J. Mass Emergencies Disasters 14 (Jan. 1996).
[37] J.E. Romero, F.V. Pinto, G. Aguilar, A. Garcés, S. Montserrat, Triggering factors, behavior, and social impact of the January 2021 hail-debris flows at the central valley of Chile, Landslides 19 (2022), https://doi.org/10.1007/s10346-021-01830-2.
[38] T.T. Pyari, R.V. Kutty, P.S. Sarma, Risk factors of post-traumatic stress disorder in tsunami survivors of Kanyakumari district, Tamil Nadu, India, Indian J. Psychiatry 54 (1) (Mar. 2012) 48, https://doi.org/10.4103/0019-5545.94645.
[39] M. Ali, N. Farooq, M.A. Bhatti, C. Kuroiwa, Assessment of prevalence and determinants of posttraumatic stress disorder in survivors of earthquake in Pakistan using Davidson Trauma Scale, J. Affect. Disord. 136 (3) (Feb. 2012) 238–243, https://doi.org/10.1016/j.jad.2011.12.023.
[40] B. Wang, et al., Posttraumatic stress disorder 1 month after 2008 earthquake in China: wenchuan earthquake survey, Psychiatry Res. 187 (3) (May 2011) 392–396, https://doi.org/10.1016/j.psychres.2009.07.001.
[41] H.K. Armenian, et al., Loss as a determinant of PTSD in a cohort of adult survivors of the 1988 earthquake in Armenia: implications for policy, Acta Psychiatr. Scand. 102 (1) (Jul. 2000) 58–64, https://doi.org/10.1034/j.1600-0447.2000.102001058.x.
[42] R. Acierno, et al., Psychological sequelae resulting from the 2004 Florida hurricanes: implications for postdisaster intervention, Am. J. Public Health 97 (Suppl 1) (Apr. 2007) S103–S108, https://doi.org/10.2105/AJPH.2006.087007.
[43] D.A. Mendoza, J.M. Reales, S. Ballesteros, Effects of volcanic eruptions on the mental health of exposed populations: a systematic review, Front. Public Health 12 (2024) 1475459, https://doi.org/10.3389/fpubh.2024.1475459.
[44] M.-P. Reyes-Hardy, et al., Temporal evolution of roof collapse from tephra fallout during the 2021-Tajogaite eruption (La Palma, Spain), Front. Earth Sci. 11 (Jan) (2024), https://doi.org/10.3389/feart.2023.1303330.
[45] P.J. Baxter, R. Ing, H. Falk, B. Plikaytis, Mount St. Helens eruptions: the acute respiratory effects of volcanic ash in a North American community, Arch. Environ. Health 38 (3) (1983) 138–143, https://doi.org/10.1080/00039896.1983.10543994.
[46] H.K. Carlsen, et al., Health effects following the Eyjafjallajökull volcanic eruption: a cohort study, BMJ Open 2 (6) (2012) e001851, https://doi.org/10.1136/bmjopen-2012-001851.
[47] C. Stewart, et al., Volcanic air pollution and human health: recent advances and future directions, Bull. Volcanol. 84 (1) (2021) 11, https://doi.org/10.1007/s00445-021-01513-9.
[48] I. Bakolis, et al., Mental health consequences of urban air pollution: prospective population-based longitudinal survey, Soc. Psychiatry Psychiatr. Epidemiol. 56 (9) (Sep. 2021) 1587–1599, https://doi.org/10.1007/s00127-020-01966-x.
[49] K. Bhui, et al., Air quality and mental health: evidence, challenges and future directions, BJPsych Open 9 (4) (Jul. 2023) e120, https://doi.org/10.1192/bjo.2023.507.
[50] J. Radua, M. De Prisco, V. Oliva, G. Fico, E. Vieta, P. Fusar-Poli, Impact of air pollution and climate change on mental health outcomes: an umbrella review of global evidence, World Psychiatry 23 (2) (2024) 244–256, https://doi.org/10.1002/wps.21219.
[51] H.J. Schmitt, et al., Chronic environmental contamination: a systematic review of psychological health consequences, Sci. Total Environ. 772 (Jun. 2021) 145025, https://doi.org/10.1016/j.scitotenv.2021.145025.
[52] J.P.A. Ioannidis, Air pollution as cause of mental disease: appraisal of the evidence, PLoS Biol. 17 (8) (Aug. 2019) e3000370, https://doi.org/10.1371/journal.pbio.3000370.
[53] J. Bobes, et al., [Evaluation of the psychometric properties of the Spanish version of 5 questionnaires for the evaluation of post-traumatic stress syndrome], Actas Esp. Psiquiatr. 28 (4) (2000) 207–218.
[54] J.R. Davidson, J.T. Colket, The eight-item treatment-outcome post-traumatic stress disorder scale: a brief measure to assess treatment outcome in post-traumatic stress disorder, Int. Clin. Psychopharmacol. 12 (1) (Jan. 1997) 41–45, https://doi.org/10.1097/00004850-199701000-00006.
[55] T.E. Andersen, M. Hansen, S.L. Ravn, R. Seehuus, M. Nielsen, H.B. Vaegter, Validation of the PTSD-8 scale in chronic pain patients, Pain Med. 19 (7) (Jul. 2018) 1365–1372, https://doi.org/10.1093/pm/pnx166.
[56] W. Revelle, Psych: procedures for psychological. Psychometric, and Personality Research, Jun. 27, 2024 [Online]. Available: https://cran.r-project.org/web/packages/psych/index.html. (Accessed 22 November 2024).
[57] D.D. Quintana, S.R. Feijoó, A.R. Caro, V. del P. González García, "Measuring Poverty in an Ultraperipheral Region: the Case of the Canary Islands,", presented at the 45th Congress of the European Regional Science Association: Land Use and Water Management in a Sustainable Network Society, Amsterdam, The Netherlands, Aug. 2005.
[58] D. Anderson, et al., Equatiomatic: transform models into "LaTeX" equations [Online]. Available: https://cran.r-project.org/web/packages/equatiomatic/index.html, May 26, 2024. (Accessed 18 November 2024).
[59] D. Lüdecke, et al., Performance: assessment of regression models performance [Online]. Available: https://cran.r-project.org/web/packages/performance/index.html, Oct. 18, 2024. (Accessed 18 November 2024).

[60] U. Knief, W. Forstmeier, Violating the normality assumption may be the lesser of two evils, Behav. Res. Methods 53 (6) (Dec. 2021) 2576–2590, https://doi.org/10.3758/s13428-021-01587-5.
[61] A. Zeileis, T. Lumley, N. Graham, S. Koell, Sandwich: robust covariance matrix estimators [Online]. Available: https://cran.r-project.org/web/packages/sandwich/index.html, Sep. 15, 2024. (Accessed 18 November 2024).
[62] J.S. Long, L. Ervin H, Using heteroscedasticity consistent standard errors in the linear regression model, Am. Stat. 54 (3) (2000) 217–224, https://doi.org/10.1080/00031305.2000.10474549.
[63] W.T. Howard, F.R. Loberiza, B.M. Pfohl, P.S. Thorne, R.L. Magpantay, R.F. Woolson, Initial results, reliability, and validity of a mental health survey of Mount Pinatubo disaster victims, J. Nerv. Ment. Dis. 187 (11) (Nov. 1999) 661–672, https://doi.org/10.1097/00005053-199911000-00003.
[64] Z. Xie, J. Xu, Z. Wu, Mental health problems among survivors in hard-hit areas of the 5.12 Wenchuan and 4.20 Lushan earthquakes, J. Ment. Health 26 (1) (Jan. 2017) 43–49, https://doi.org/10.1080/09638237.2016.1276525.
[65] E. Heim, T. Karatzias, A. Maercker, Cultural concepts of distress and complex PTSD: future directions for research and treatment, Clin. Psychol. Rev. 93 (Apr. 2022) 102143, https://doi.org/10.1016/j.cpr.2022.102143.
[66] M.L. O'Donnell, M. Creamer, P. Pattison, Posttraumatic stress disorder and depression following trauma: understanding comorbidity, Am. J. Psychiatry 161 (8) (Aug. 2004) 1390–1396, https://doi.org/10.1176/appi.ajp.161.8.1390.
[67] L.M. Najarian, A.K. Goenjian, D. Pelcovitz, F. Mandel, B. Najarian, The effect of relocation after a natural disaster, J. Trauma Stress 14 (3) (Jul. 2001) 511–526, https://doi.org/10.1023/A:1011108622795.
[68] B. Lakey, E. Orehek, Relational regulation theory: a new approach to explain the link between perceived social support and mental health, Psychol. Rev. 118 (3) (2011) 482–495, https://doi.org/10.1037/a0023477.
[69] M.-E. Ionascu, M. Marcu, R. Bogdan, M. Darie, Calibration of NO, SO2, and PM using Airify: a low-cost sensor cluster for air quality monitoring, Atmos. Environ. 339 (Dec. 2024) 120841, https://doi.org/10.1016/j.atmosenv.2024.120841.
[70] S. Freire, A.J. Florczyk, M. Pesaresi, R. Sliuzas, An improved global analysis of population distribution in proximity to active volcanoes, 1975–2015, ISPRS Int. J. GeoInf. 8 (8) (Aug. 2019) 8, https://doi.org/10.3390/ijgi8080341.
[71] A. Gibson, J. Walsh, L.M. Brown, Disaster mental health services review of care for older persons after disasters, Disaster Med. Public Health Prep. 12 (3) (Jun. 2018) 366–372, https://doi.org/10.1017/dmp.2017.60.
[72] F. Kaligis, N. Sw, H. Diatri, S. Dharmono, Life skills program for improving adolescent mental health in the aftermath Mount Merapi eruption, Yogyakarta-Indonesia, ASEAN J. Community Engagem. 1 (1) (Jul. 2017), https://doi.org/10.7454/ajce.v1i1.61.
[73] N. Yárnoz-Goñi, A. Goñi-Sarriés, A. Díez-Suárez, G. Pírez, L. Morata-Sampaio, A. Sánchez-Villegas, COVID-19 posttraumatic stress disorder and mental health among Spanish adolescents: SESSAMO Project, J. Clin. Med. 13 (11) (Jan. 2024) 11, https://doi.org/10.3390/jcm13113114.
[74] E.J. Alessi, C. Hutchison, S. Kahn, Understanding COVID-19 through a complex trauma lens: implications for effective psychosocial responses, Soc. Work 67 (1) (Jan. 2022) 79–87, https://doi.org/10.1093/sw/swab045.
[75] B. Agyapong et al., "Cumulative trauma from multiple natural disasters increases mental health burden on residents of Fort McMurray," Eur. J. Psychotraumatology, vol. 13, no. 1, p. 2059999, oi: 10.1080/20008198.2022.2059999.
[76] M. Ishiwatari, T. Koike, K. Hiroki, T. Toda, T. Katsube, Managing disasters amid COVID-19 pandemic: approaches of response to flood disasters, Prog. Disaster Sci. 6 (Apr. 2020) 100096, https://doi.org/10.1016/j.pdisas.2020.100096.