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1 **Post-Traumatic Stress Disorder in Adult Population of La Palma (Spain) after the 2021**
2 **Tajogaite Eruption: Environmental and Sociodemographic Risk Factors**

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54

Abstract

55 The adverse mental health effects of exposure to disasters have long been recognized.
56 Concerning PTSD and volcanic eruptions specifically, most studies have highlighted risk
57 factors related to demographic and social factors (e.g., gender, age, and education), mental
58 health, and those associated with the experience of the volcanic eruption (e.g., having
59 evacuated). Establishing the demographic scope of those more likely to suffer PTSD
60 following volcanic eruptions, as well as understanding the aggravating factors, is key to
61 optimizing precautionary measurements and psychological interventions. In this study, we
62 complement these analyses by exploring the role of environmental contaminants (specifically,
63 exposure to tephra falls and exposure to SO₂) together with demographic, health, and hazard
64 experiences in contributing to PTSD. We focus on data collected after the 2021 eruption of
65 the Tajogaite volcano (La Palma, Spain). Our results show that in addition to sex, education,
66 distance from the volcano, evacuation status, health issues related to the eruption, mental
67 health antecedents, and exposure to poor air quality (i.e., SO₂ concentrations) are associated
68 with higher scores of reported symptoms associated with PTSD. Our findings establish a
69 picture of the prevalence of reported PTSD symptoms in various demographics groups and
70 aggravating factors following the 2021 eruption of the Tajogaite volcano. Next steps could
71 include an extended investigation of the role of air quality (as a potential synergic hazard) in
72 shaping mental health following exposure to a primary hazard, such as a volcanic eruption.

73 **Keywords:** Volcanic eruption; Disaster; Post-traumatic Stress Disorder;; La Palma; Air
74 quality

75

1. Introduction

76 On 19 September 2021, the Tajogaite volcano began erupting on the Cumbre Vieja ridge on
77 the island of La Palma in the Canary archipelago (Spain). The eruption lasted 85 days, making

78 it the longest in the island's history [1,2]. During this period, the volcanic activity was
79 characterized by the constant emission of a gas and particle plume into the atmosphere and the
80 production of a sustained lava flow that reached the ocean one week into the eruption [3,4,5].
81 In addition to its unprecedented duration, this eruption was also the most destructive ever
82 recorded on La Palma, having caused significant disruption to the lives of the island's
83 inhabitants (see Figure 1 for an illustration) and material damages estimated at 1 billion €
84 [1,2].

85 First, the eruption caused serious disruption to day-to-day life and operations.
86 Thousands of habitations were destroyed by the lava flow or buried under tephra (i.e., the
87 volcanic material emitted in the plume, transported through the air and deposited on the
88 ground), causing the evacuation of more than 7,000 residents [2,6]. Public facilities such as
89 schools and roads were also badly damaged [2,7,8]. The destruction of the main road linking
90 the west to the south of the island increased travel time between some regions of La Palma by
91 up to a factor of eight [2,6], likely isolating parts of the population.

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

98 Finally, and in addition to the economic and material losses, the emission of volcanic
99 gases and ash (i.e., tephra smaller than 2 mm in size) [9,10] significantly degraded the air
100 quality on the island [11], potentially endangering the health of the island's inhabitants [12].
101 This decrease in air quality also prompted the confinement and evacuation of populations in

102 some



areas,
with
some
restrict
ions
still in
place
at the
beginn
ing of
2023
[6].

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

121 The shock, disruption, and loss caused by volcanic eruptions and other socio-natural
122 disasters, that is, disasters resulting from the interaction between natural hazards and social,

123 political, and economic conditions that render certain populations more vulnerable to harm
124 [13,14], in general can pose a serious threat to mental health [15,16,17,18]. People living in
125 the western areas of La Palma, those closest to the eruptive center and where lava flows and
126 the majority of tephra accumulation occurred, reported heightened levels of psychological
127 distress, with insomnia, anxiety, and depression being the most commonly reported symptoms
128 [12].

129 **1.1 The impact of disaster on mental health**

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

135 The increase in PTSD, depression, and anxiety following disasters has been
136 documented in various types of socio-natural disasters such as earthquakes [20,21,22], floods
137 [23], tsunamis [24], hurricanes [25] or volcanic eruptions [12,26,27,28,29,30,31]. The
138 prevalence of PTSD following socio-natural disasters can range between 5% to 60% of the
139 sampled population in the first two years post-disaster [16]. A study conducted in flooded
140 areas of the UK found that almost a third (27.9%) of respondents from affected communities
141 had scores that met the criteria for a PTSD diagnosis, and a similar rate was observed for
142 depression [23]. Comparable rates of PTSD symptoms have been observed in the aftermath of
143 other types of disasters, such as earthquakes or hurricanes [21,32,33].

144 The detrimental impact of socio-natural disasters on mental health can persist over
145 time. Residents living the closest to Mount Merapi (Indonesia) continued to experience PTSD
146 two years following the 2010 volcanic eruption [31]. Similarly, three years after the eruption
147 of Eyjafjallajökull volcano in Iceland, researchers observed a higher prevalence of medication

148 use for anxiety, depression, and sleep problems among residents in highly exposed areas
149 compared to those in less exposed areas [29]. Understanding risk factors of PTSD following
150 socio-natural disasters is crucial for enhancing psychological interventions aimed at
151 mitigating symptom severity.

152 **1.2 Risk factors contributing to PTSD following socio-natural disasters**

153 The literature has highlighted several risk factors that have been linked to higher odds of
154 developing PTSD symptoms following socio-natural disasters. The risk factors identified
155 include previous mental health disorders [16,33] and sociodemographic characteristics such as
156 socioeconomic status, gender, age, ethnicity, or marital status [16,17,18,34]. More than
157 individual characteristics, these factors encapsulate deeper structural inequalities that shape
158 disaster experiences. Being a woman has consistently been associated with psychological
159 distress after disasters [15,27,28,31,33,35]. This relationship may be explained by the
160 willingness to report psychological distress and by gender roles [36]. Their role as caregivers
161 could make them more likely to stay indoors to protect the family and to carry the family's
162 needs in the aftermath of disasters [36,37]. Socioeconomic status factors such as having a
163 lower level of education [27,28,33] and having a lower income [28,38,39] consistently
164 increase the likelihood of developing PTSD after a socio-natural disaster. Factors such as age
165 and marital status show more inconsistent patterns: older age sometimes seems to act as a risk
166 factor [28,39], but it can also be protective [27,31]. Similarly, some studies have found a
167 higher prevalence of PTSD symptoms among married individuals [27,40], while others have
168 observed this relationship among unmarried individuals [38,39].

169 Other risk factors are related to the experience of the disaster. Individuals who have
170 lost a family member or a relative [41] can be particularly susceptible to developing PTSD.
171 Also, people who have been evacuated and relocated [15,23,28,42] tend to exhibit more
172 PTSD symptoms. Furthermore, the rate of PTSD symptoms seems to be correlated to the

173 degree of proximity and involvement with the disaster [16]. It is therefore not surprising that
174 more PTSD symptoms are observed in people who live closer to the source of the hazard [31],
175 [33] or those acting as rescue workers [16]. Living closer to the source of the hazard could be
176 linked to PTSD as it may increase the risk of becoming a direct victim (e.g., being injured,
177 witnessing others being injured, and suffering property damage), but also to experience
178 frequent reminders of the event afterwards (e.g., tephra deposits, reconstruction, damaged
179 infrastructure), and suffer material deprivation. Inadequate access to water, sanitation, and
180 electricity after a disaster has been associated with an increased risk of developing PTSD [35].

181 Some studies investigate the role of environmental factors in mental health disorders
182 following disasters [43] though evidence is scarce. In La Palma, environmental contaminants,
183 may have contributed to harm mental health. The eruption left a significant amount of tephra
184 on the ground and rooftops (see Figure 1). The ongoing visibility of tephra may have
185 reinforced the traumatic experience in several ways. First, it could have perpetuated the
186 stressor, continuously reminding individuals of the volcanic eruption and possible future
187 volcanic eruptions [43]. Second, tephra accumulation may have hindered the return to pre-
188 disaster routines, obstructing daily activities. Third, structural damages, such as roof collapses
189 or the threat thereof [44], may have heightened anxiety and distress [43]. Finally, concerns
190 about potential health risks associated with tephra exposure may have further contributed to
191 psychological strain. Additionally, volcanic gases and tephra degraded air quality [6,11].
192 Exposure to volcanic air pollution has elsewhere been associated with detrimental health
193 effects [12,45,46,47]. Exposure to air pollution and other contaminants, in general, has also
194 been associated with mental health issues (including depression and anxiety; [48,49,50,51]),
195 although much controversy has been sparked [52]. Although our research is not designed to
196 investigate specific mechanisms underlying the relationship between air pollution and PTSD,
197 there are several potential pathways through which exposure to air pollution may impact

223 **2.1 Participants**

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

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

Table 1.

Demographic Characteristics of the Respondents (N = 976)

Characteristics	<i>n</i> (%)
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.

243 **2.2 Material and procedure**

244 **2.2.1 Epidemiological questionnaire**

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

257 *2.2.2 PTSD symptoms measure*

258 The questionnaire included a validated Spanish version of the Treatment-Outcome
259 Posttraumatic Stress Disorder (TOP-8) scale [53], a shortened version of the SI-PTSD [54].
260 The TOP-8 contains eight items grouped into three dimensions: intrusion (e.g., intrusive
261 thoughts, recurrent nightmares), avoidance and emotional numbness (e.g., avoiding places
262 that may trigger recollection of the event, detachment from others), and hypervigilance (e.g.,
263 feeling jumpy, feeling on guard). The severity of each symptom was rated on a 5-point scale
264 (0 = no/never to 4 = extremely serious). We derived two scores from this scale. The first is a
265 symptom severity score, calculated as the sum of all reported symptoms, to capture the overall
266 intensity of PTSD-related symptoms. The second is a binary indicator reflecting whether
267 participants met the threshold suggestive of possible PTSD. Following previous research
268 using similar screening tools (e.g., PTSD-8; [19]), we considered individuals to meet this
269 threshold if they reported a score of 3 or higher on at least one item within each of the three

270 symptom clusters [19,55]. It is important to note that this method is intended as a screening
271 indicator only; individuals meeting this criterion may have PTSD, but would require a clinical
272 assessment to further confirm the PTSD diagnosis. The scale showed a high level of reliability
273 as measured by McDonald's omega ($\omega = 0.87$) (measured using the 'omega' function of R
274 package 'psych' (version 2.4.3, [56])).

275 **2.2.3 Risk factors**

276 **2.2.3.1 Sociodemographic variables**

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

291 **2.2.3.2 Experiences during the eruption.**

292 We analyzed data on participants' living conditions during the eruption, focusing on
293 evacuation and participation in eruption-related work. Specifically, for evacuation, we used

294 the variable reporting whether respondents had to evacuate (yes/no), and we also calculated
295 the duration of evacuation. This was done by subtracting the date of evacuation from the date
296 of return reported by the respondents. If no date of return was given, we subtracted the date of
297 evacuation from the date of the interview. Regarding involvement in eruption-related work,
298 participants were asked whether they had worked as a responder in the exclusion zone during
299 the volcanic eruption, including the duration of their involvement.

300 **2.2.3.3 Eruption-related health symptoms**

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

309 **2.2.3.4 Exposure to the eruption or the aftermath**

310 To assess exposure to the eruption and its aftermath, we use three indices. The first index
311 measured the distance (in kilometres) from the respondent's address at the time of the eruption
312 to the volcano. The other two indices, air quality (i.e., SO₂ concentrations), and tephra
313 fallout, were related to environmental disturbances caused by the eruption.

314 For air quality, exposure to SO₂ was calculated by averaging the number of days
315 participants were exposed to 24-hour mean SO₂ concentrations above 40 µg/m³ (as
316 recommended by the World Health Organization [WHO]) based on the nearest air quality
317 station (see locations in Figure 2) to the participant's home address (*Median distance* = 775

318 m, Interquartile range [IQR] of distance = 353.37-1522.34). Data from the regulatory air
319 quality monitoring network of the Canarian Government was used
320 (<https://www3.gobiernodecanarias.org/medioambiente/calidaddelaire/inicio.do>) to determine
321 SO₂ concentrations. The cumulative mass of tephra deposited per square meter over the entire
322 duration of the eruption was used as a proxy for exposure to tephra fallout, based on the
323 nearest tephra collection point (see locations in Figure 2) to the participant's home address
324 (Median distance = 2521 m, IQR = 1548.87-2984.99).

325 **2.2.3.5 Time since the eruption**

326 Given that data collection occurred over several months, we calculated the time since the
327 eruption by subtracting the date of the interview from the start date of the eruption (September
328 19, 2021).

329 **2.2.4 Statistical analysis**

330 The statistical analysis was carried out using R (version 4.3.3) and RStudio (version
331 2024.04.02).

332 We ran a multivariate linear model (using the function 'lm' of base R, version 4.3.3)
333 with mean PTSD score as a dependent variable, and with sex, age, education, evacuation
334 status, participation to eruption-related work, distance to the volcano, antecedents of
335 depression, eruption-related health symptoms, time since the eruption, exposure to tephra
336 fallout and air quality as predictors. The model's equation (Eq. 1) was as follows (equation
337 generated using the 'equatiomatic' package, version 0.3.3, [58])

338 **Equation 1.**

339 PTSD score = $\alpha + \beta_1(\text{sex}) +$
340 $\beta_2(\text{age}) + \beta_3(\text{education}) + \beta_4(\text{evacuation}) + \beta_5(\text{eruption} - \text{related work}) +$

341 $\beta_6(\text{distance}) + \beta_7(\text{depression}) + \beta_8(\text{physical symptoms}) + \beta_9(\text{time}) +$
342 $\beta_{10}(\text{tephra}) + \beta_{11}(\text{air quality}) + \epsilon$

343 We assessed the fit of the model to the data using the ‘performance’ package (version
344 0.12.2; [59]). The residuals of PTSD scores were not normally distributed, but regressions in
345 large samples may be unaffected by such a violation [60]. The Maximum Variance Inflation
346 Factor (VIF) was 1.70, suggesting no collinearity issues. Only one outlier was detected on
347 standardized residuals (SDR = 4.15). A heteroscedasticity check revealed that the assumption
348 of normal distribution of error terms was violated. To account for heteroscedasticity in our
349 regression analysis, we employed robust standard errors using the ‘sandwich’ package
350 (version 3.1.0; [61]), with the HC3 adjustment [62]).¹

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

356 We also performed a logistic regression (using the ‘glm’ function of base R), using the
357 same predictors to assess the factors that were significantly associated with reaching the
358 threshold for a potential PTSD diagnosis (i.e., having at least one symptom rated above three

¹ 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).

359 in each subdimension on the TOP-8 screening tool). The model's equation was as follows
360 (Eq. 2):

361 **Equation 2.**

$$\begin{aligned} 362 \quad & \log \left(\frac{P(\text{PTSD diagnosis}=0)}{1-P(\text{PTSD diagnosis}=0)} \right) = \alpha + \beta_1(\text{sex}) + \\ 363 \quad & \beta_2(\text{age}) + \beta_3(\text{education}) + \beta_4(\text{evacuation}) + \beta_5(\text{eruption} - \text{related work}) + \\ 364 \quad & \beta_6(\text{distance}) + \beta_7(\text{depression}) + \beta_8(\text{physical symptoms}) + \beta_9(\text{time}) + \\ 365 \quad & \beta_{10}(\text{tephra}) + \beta_{11}(\text{air quality}) \end{aligned}$$

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

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

371 **3. Results**

372 **3.1 Prevalence of reported symptoms associated with PTSD in La Palma**

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

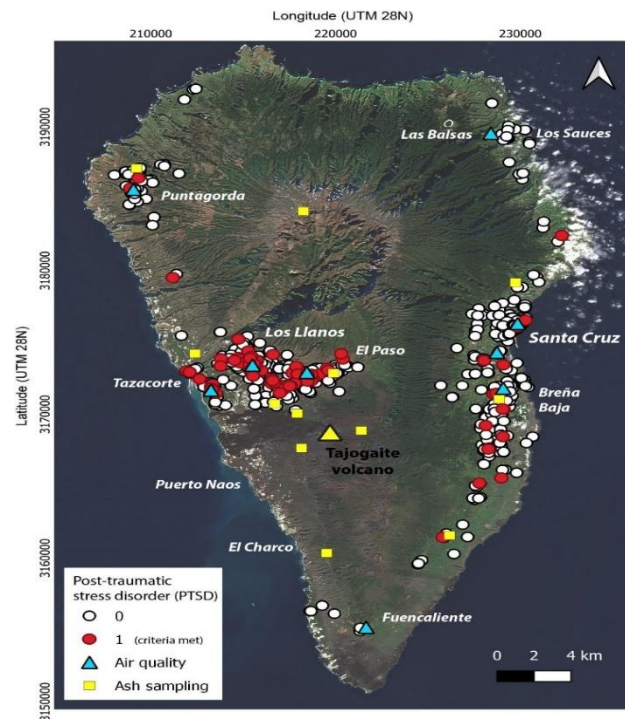


Figure 2

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.

379 **3.2 Risk factors associated with reported symptoms associated with PTSD**

380 **3.2.1 Reported PTSD symptoms**

381 In this model, we aimed to explore how the severity of reported PTSD scores (calculated as
 382 the sum of symptom ratings related to PTSD) were predicted by the listed factors. Overall, our
 383 model explained 23.38% of the variance in the total PTSD score (Multiple $R^2 = 0.23$). The
 384 score of reported PTSD symptoms was significantly predicted by sex, education level,
 385 evacuation status, distance to the volcano, history of anxiety and/or depression, physical

386 health issues related to the eruption, and SO₂ exposure (see Table 2). Factors that were
 387 associated with an increase in reported PTSD scores were being a woman, having a lower
 388 level of education, having evacuated, having personal antecedents of anxiety and/or
 389 depression, experiencing health issues attributed to the volcanic eruption, and higher exposure
 390 to SO₂. Distance was associated with a decrease in PTSD scores. Age, working in exclusion
 391 areas, the time elapsed since the beginning of the eruption, and tephra fallout were not
 392 significantly associated with PTSD scores. We also explored the association between
 393 subjective poverty and reported symptoms related to PTSD. Because the question on
 394 subjective poverty was added later in the data collection process, we only had 545
 395 observations for this variable. Therefore, to assess the effect of subjective poverty, we ran the
 396 same model on this subset of the sample, including subjective poverty as an additional
 397 predictor. We found no association between subjective poverty and reported PTSD
 398 symptoms.²

Table 2

Risk Factors of reported PTSD symptoms Following the 2021 Tajogaite Eruption in La Palma

Risk factor	β	t	η^2p	Direction of effect
Evacuation status (Yes vs. No)	-0.23	-5.71***	.06	Evacuated \uparrow PTSD
Health issues related to the eruption (Yes vs. No)	-0.17	-5.96***	.03	
History of anxiety/depression	-0.13	-3.66***	.02	
Education	-0.12	-3.77***	.02	
Distance from the volcano	-0.12	-3.47***	.01	

² Details can be found in the supplementary analyses file at https://osf.io/t62va/?view_only=f39d0f1da75442808311be3bcfe125a0

SO ₂ exposure	0.11	3.06**	.01	More SO ₂ exposure ↑ PTSD
Sex (Women vs. Men)	0.10	3.29**	.01	Women ↑ PTSD
Age	-0.06	-1.89	.003	ns
Working in exclusion areas	0.01	0.49	.0002	ns
Time elapsed since the eruption	-0.02	-0.70	.0004	ns
Tephra fallout	0.07	1.48	.003	ns
Subjective poverty	-0.01	-0.15	< 0.001	ns

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

399

400 As pre-registered, because evacuation status and the presence of physical symptoms
401 associated with the eruption were significant predictors, we further examined the relationship
402 between the PTSD scores and these predictors. Among those who evacuated, there was a
403 positive correlation between the duration of evacuation and PTSD scores ($r(122) = .26, p =$
404 $.004, \eta^2 = .07$). Among respondents who reported physical symptoms related to the eruption, a
405 significant positive correlation was found; the more symptoms they reported, the higher their
406 PTSD scores ($r(974) = .39, p < .001, \eta^2 = .15$).

407 ***3.2.2 Reported symptoms meeting the threshold of possible PTSD based on the TOP-8*** 408 ***screening tool***

409 This model tested whether the listed factors were associated with meeting the threshold for a
410 potential PTSD diagnosis (i.e., having at least one symptom rated above three in each
411 subdimension on the TOP-8 screening tool). Overall, the model explained about 5% of the
412 variance (Nagelkerke $\eta^2 = 0.046$). The results revealed that education, evacuation status,
413 distance to the volcano, antecedents of depression/anxiety, and the presence of symptoms

414 related to the eruption were significant predictors (see Table 3). More specifically, having
415 evacuated, having antecedents of anxiety/depression, lower levels of education, experiencing
416 health issues attributed to the volcanic eruption were associated with higher odds of meeting
417 the threshold for a potential PTSD diagnosis based on the TOP-8 screening tool. Living
418 further away from the volcano was significantly associated with lower odds of reaching the
419 threshold for a potential PTSD diagnosis. None of the other predictors was significant.

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	<i>z</i>	<i>OR</i>	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			
History of anxiety/depression	-2.61**	0.44			
Education	-3.20**	0.57			
Distance from the volcano	-2.38*	0.89			
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. β = 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.

4. Discussion

421
422 In this study, we report on a secondary data analysis based on a representative sample of 976
423 residents of La Palma who were confronted with the historic eruption of Tajogaite in 2021,
424 the longest eruption in the island's history [1,2]. The experience of disasters such as eruptions
425 and their direct (e.g., physical injuries, evacuation, material damage) and indirect (e.g.,
426 evacuation and resettlement) consequences are otherwise associated with an increased risk of
427 PTSD [15,16,43]. We hence investigated the prevalence and contributors of reported
428 symptoms associated with PTSD among La Palma residents using this dataset. Extending past
429 research on the socio-environmental impact of volcanic eruptions, we included volcanic
430 emissions (air contamination and tephra fallout) as potential contributors to PTSD
431 symptomatology.

432 Overall, our results indicate that reported symptoms associated with PTSD, as
433 recorded by the TOP-8 screening tool, were relatively common among the respondents
434 following the Tajogaite eruption in September 2021. This prevalence (~8%) was in the range
435 observed in other relevant studies (e.g., 2-6.9% in [27] for the 2010 Eyjafjallajökull eruption;
436 27.6% in [63] for the 1991 Mount Pinatubo eruption). It should be noted that factors tied to
437 the disaster such as its severity [64] or cultural factors [65] may play a role in shaping post-
438 disaster PTSD, potentially explaining differences observed in the prevalence of PTSD across
439 eruptions. Besides, the measures and timing of measurement of PTSD and sampling
440 techniques may vary across studies [18] further complicating comparisons.

441 Regarding the prevalence and severity, our results otherwise concur with some of the
442 previously identified patterns observed in the literature [15,16,43]. Namely, reported
443 symptoms associated with PTSD were more severe in women, in participants who had
444 evacuated, who had lower education, who were living closer to the hazard, and who had a
445 history of depression (PTSD and depression are comorbid; [66]). In contrast to other studies

446 linking PTSD and exposure to disasters [39], we found no association between socioeconomic
447 status (approximated by subjective poverty) and PTSD.

448 The intensity of reported symptoms related to PTSD is most strongly associated with
449 the individual's history of evacuation. Relocation can, in itself, constitute a traumatic
450 experience [67], adding to the traumatic experience of the initial exposure to the hazard and
451 disaster. In addition, the specific effect of experiencing the material destruction of one's home
452 may be partly responsible for the association between evacuation status and PTSD, with some
453 of the evacuees having to leave because they simply lost their homes to the effects of the
454 eruption and suffering from PTSD as a result of the material destruction, a contributing factor
455 to the experience of traumatic subjective distress [28,43]. In addition, not knowing whether
456 one's home is still standing may also contribute to the presence of such distressing thoughts
457 [28]. Similarly, evacuation status and distance to the volcano could be confounded with direct
458 experience with the eruption, another contributing factor to PTSD in other volcanic settings
459 [27,29]. Although we could not assess it with our dataset, evacuation may also disrupt social
460 networks and thus social support, making people vulnerable to PTSD. Low social support has
461 indeed been associated with more severe PTSD [15,16], and social support is otherwise
462 pivotal to the maintenance or restoration of mental health [68] as it notably offers
463 opportunities for affect regulation.

464 Interestingly, we found that poorer air quality (i.e., exposure to SO₂ concentrations)
465 was associated with higher PTSD related scores on the TOP-8 screening tool, with a moderate
466 effect size, suggesting a noticeable relationship. As previously discussed, the association
467 between mental health and air pollution is debated in the literature (see [49] for a recent
468 review). Whether this link is mediated by exposure to air quality information or lack thereof,
469 or whether it is caused by experiencing adverse health effects from exposure to high levels of
470 air contaminants, cannot be answered here and remains to be determined. One possibility is

471 that the observed association captures the psychological impact of risk perception on
472 symptoms associated with PTSD rather than the direct physiological effects of SO₂. Indeed,
473 as daily bulletins were issued [6], information about air quality and recommendations such as
474 wearing masks may have heightened risk perception, leading to increased stress and anxiety.
475 In this context, individuals exposed to more air-quality warnings may have experienced
476 greater psychological distress. Additionally, the link between SO₂ and symptoms associated
477 with PTSD may reflect the influence of physical symptoms or fear of developing symptoms.
478 The presence of physical symptoms related to the eruption was the second strongest predictor
479 of reported PTSD related symptoms in our study, suggesting that individuals experiencing
480 respiratory discomfort, headaches, or other health issues may have been more vulnerable to
481 psychological distress. Given that environmental contaminants can cause both objective
482 health effects and subjective distress, future research could disentangle the relative
483 contributions of direct physiological mechanisms and psychological responses to air pollution
484 exposure. The development of cost-effective air quality monitoring sensors [69], coupled with
485 surveys, may help uncover more subtle patterns between air quality and mental health in
486 future studies. Interestingly, tephra, which could be a source of concern regarding both health
487 risks and property damage, was not found to be associated with reported PTSD symptoms.

488 **4.1 Limitations**

489 While our study provides insights into PTSD related symptoms following the Tajogaite
490 volcanic eruption on the island of La Palma and adds to the literature on the effect of disasters
491 on mental health, several limitations should be acknowledged. Firstly, according to [12], of
492 those selected using a random stratified approach, approximately 36% were included in the
493 study, while the others either refused to participate or could not be contacted. This may
494 indicate a potential selection bias, as those who chose not to participate may have had
495 different characteristics to those who did. Second, we conducted our analyses on an existing

496 database, meaning that only a constrained number of predictors were considered, potentially
497 leaving out other important predictors (such as support from social networks). This implies
498 caution when drawing conclusions about predictors of symptoms related to PTSD after
499 disasters as some hidden predictors may explain or obscure some of the associations. Third, it
500 is important to note that the associations found between the predictors and reported PTSD
501 symptoms are purely correlational and do not directly address the causality of relationships.
502 Besides, although our results are consistent with previous findings on the effects of disasters
503 on PTSD [15], their generalizability to other disasters or regions may be limited. Fourth, and
504 finally (and as discussed above), the measurement of some of our variables (e.g., exposure to
505 SO₂) were not made directly near participants' households, but at closest measurement
506 stations.

507 **4.2 Conclusion and Perspectives**

508 By 2015, over 1 billion people (14.3% of the global population) resided within 100 km of a
509 volcano active in the last 10 000 years, and the population density around volcanoes has
510 increased since 1975, with a growing number of people living in high-risk areas [70]. Given
511 the impact of volcanic eruption on mental health [43] it is crucial to better understand their
512 aggravating factors. This study underscores the impact of the Tajogaite volcanic eruption on
513 mental health, revealing that certain populations are disproportionately affected, particularly
514 women, people with lower education, with antecedents of mental health, those suffering from
515 health issues, and those who had to evacuate. Our study adds to the existing body of research
516 on PTSD and volcanic hazards, and could one day enable, together with other reports, the
517 conduct of a comprehensive meta-analysis on their impacts on mental health, in addition to
518 the existing systematic reviews [15,43]. The identification of aggravated vulnerability factors
519 (demographics and otherwise) is critical to the establishment of more targeted support and
520 intervention strategies [15]. For example, some programs specifically address the needs of

521 vulnerable populations, such as older adults [71] or adolescents [72]. Beyond recovery efforts,
522 understanding the factors associated with PTSD can also inform disaster response planning. In
523 our study, evacuation status was the strongest predictor of reported PTSD related symptoms,
524 underscoring the need for well-designed evacuation procedures and communication strategies
525 to minimize psychological distress. Additionally, the associations between PTSD and
526 demographic factors such as sex and education level go beyond individual differences; they
527 reflect deeper structural inequalities that shape disaster experiences. Women, for instance,
528 often face increased mental health risks after disasters due to pre-existing social and economic
529 disparities that influence both their exposure to and recovery from such events [36].
530 Integrating these considerations into disaster preparedness efforts could help reduce the
531 psychological impact of future eruptions. Finally, the study highlights the potential role of
532 environmental factors, with air quality linked to PTSD, suggesting this is an important agenda
533 for future research.

534 A final note should be made on the fact that the eruption took place during the
535 COVID-19 pandemic, which greatly impacted the island, and likely contributed to mental
536 distress before the eruption, as occurred in other regions of overseas Spain [73]. While
537 conclusions cannot be drawn from the data collected in this study, PTSD scores observed in
538 the dataset may have been partially contaminated by the experience of the COVID-19 crisis
539 that affected the island [73], with the eruption being an additional stressor to another ongoing
540 crisis. Although the PTSD questionnaires were related to the experience of the eruption, prior
541 exposure and vulnerabilities due to COVID-19 episodes could have exacerbated people's
542 susceptibility to post-traumatic stress disorder, through a complex trauma [74]. For instance,
543 residents of Fort McMurray (Canada) who experienced COVID-19 and a natural hazard (e.g.,
544 flood) were ten times more likely to display symptoms of PTSD than respondents
545 experiencing only COVID-19 [75]. In the case of La Palma, the mental health burden from

546 the COVID-19 pandemic could have intensified the effects of the volcanic eruption, as
547 residents may have had heightened concerns about health, hospitalization, and economic
548 security, especially considering the island's dependence on tourism, which had already been
549 severely impacted by the pandemic [2]. As it appears, COVID-19 may have also prepared the
550 population for disaster response, with mask-wearing potentially serving a dual purpose during
551 both crises. Given the increasing likelihood of compound disasters in the future and their
552 impact on both disaster response [76] and recovery [75], future studies could consider not
553 only the direct impacts of a single disaster but also the cumulative effects of ongoing and past
554 crises on mental health. This approach could offer valuable insights into how disaster
555 response and recovery can be adapted to better support affected populations.

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568 **6. Data accessibility statement**

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

572 **7. Declaration of interest**

573 The authors have nothing to declare.

574 **8. Declaration of generative AI in scientific writing**

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

578 **9. Author contributions: CRediT**

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580 Original Draft; **María Cristo Rodríguez-Pérez:** Conceptualization, Methodology, Data
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