

LAS HUELLAS DE LOS HURACANES: UNCOVERING HURRICANE MARIA-RELATED POST-TRAUMATIC STRESS DISORDER SYMPTOM PROFILES AND RELATED CORRELATES AMONG YOUTHS OF PUERTO RICO

LAS HUELLAS DE LOS HURACANES: DESCRUBRIENDO LOS PERFILES DE SÍNTOMAS
DE TRASTORNO DE ESTRÉS POSTRAUMÁTICO RELACIONADO CON EL
HURACÁN MARÍA Y SUS CORRELATOS ENTRE LA JUVENTUD DE PUERTO RICO

Recibido: 13 de febrero de 2025 | Aceptado: 8 de agosto de 2025
DOI: <https://doi.org/10.55611/rep.3602.03>

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ABSTRACT

This study identified PTSD symptom patterns among youths of Puerto Rico after Hurricane Maria and examined hurricane-related stressors. Latent profile analyses revealed three PTSD symptom profiles: (a) Predominantly Intrusion/Avoidance, (b) Predominantly Arousal/Reactivity and Negative Cognition/Mood, and (c) Low PTSD. The Predominantly Intrusion/Avoidance profile showed higher rates of clinically elevated PTSD scores and exposures to hurricane-related stressors. Through machine learning algorithms, we identified the most significant correlates for the Predominantly Intrusion/Avoidance (top classifier: thinking they could die) and Predominantly Arousal/Reactivity and Negative Cognition/Mood (top classifier: violence in the home or neighborhood) profiles. Our findings underscore the need for trauma-informed care and policy that address varied stress responses following natural disasters.

KEYWORDS: PTSD, youths, natural disaster, latent profile analysis, machine learning.

RESUMEN

Este estudio identificó perfiles de síntomas del trastorno de estrés postraumático (TEPT) en la juventud de Puerto Rico tras el huracán María y examinó los estresores relacionados con el huracán. Los análisis de perfiles latentes revelaron tres perfiles sintomáticos de TEPT: (a) Predominantemente Intrusión/Evitación, (b) Predominantemente Activación/Reactividad y Cognición/Estado de ánimo Negativos, y (c) bajo TEPT. El perfil Predominantemente de Intrusión/Evitación mostró tasas más altas de síntomas clínicamente elevados de TEPT y mayor exposición a estresores relacionados con el huracán. Mediante algoritmos de aprendizaje automático, identificamos los correlatos más significativos de los perfiles Predominantemente Intrusión/Evitación (clasificador principal: pensar que podían morir), y Predominantemente Activación/Reactividad y Cognición/Estado de ánimo negativos (clasificador principal: violencia en el hogar o vecindario). Nuestros hallazgos subrayan la necesidad de atender con atención informada en trauma y de políticas que aborden las variadas respuestas al estrés tras los desastres naturales.

PALABRAS CLAVE: TEPT, juventud, desastre natural, análisis de perfiles latentes, aprendizaje automático.

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Extreme weather events have been increasing in frequency, severity, and the range of impact due to human driven climate change (Crimmins et al., 2016). As a result, hurricanes have become more intense with a rise in the prevalence of major storms being observed since the 1980s (i.e., category 4 and 5; Crimmins et al., 2016). These natural disasters often expose youths to traumatic hurricane-related stressors, potential physical harm, and exposure to significant loss of property and life, which can have cascading effects on mental health (Crimmins et al., 2016). Symptoms of post-traumatic stress disorder (PTSD) are commonly reported following exposure to natural disasters, particularly among youths, who have PTSD prevalence rates ranging from 4.5% to 57%, with approximately 35% of youths exposed to hurricanes developing subsequent symptoms of PTSD (Substance Abuse and Mental Health Services Administration [SAMHSA], 2018). However, little is known regarding common patterns of PTSD symptoms that emerge among youths following exposure to natural disasters such as hurricanes, and how such patterns relate to characteristics of youths and exposure to hurricane-related stressors. Improving our understanding of common presentations of PTSD following a natural disaster and its related risk factors can improve post-disaster mental health screening and intervention efforts for youths.

The Impact of Hurricane Maria on Puerto Rico and its Youths

Puerto Rico is particularly susceptible to extreme weather events due to its geographic location and social vulnerability resulting from colonial neglect (e.g., underdeveloped infrastructure, limited resources; Adil et al., 2025; Fischbach et al., 2020; Joseph et al., 2020). Recently, Puerto Rico has been affected by several major hurricanes, including Hurricane Maria, which made landfall on September 20, 2017 (Category 5 storm), just two weeks after Hurricane Irma struck the island (Category 5; Fischbach et al., 2020). Hurricane Maria brought heavy rainfall, devastating winds, and severe flooding,

leading to significant loss of property and life, and exposed youths of Puerto Rico to significant hurricane-related stressors and hardship (Orengo-Aguayo et al., 2019). An island-wide needs assessment conducted five to nine months after Hurricane Maria found that youths of Puerto Rico experienced damage to their homes (45.7%) and belongings (31.0%), shortages of food and water (32.3%), injuries to themselves (4.1%) and other known individuals (e.g., friends, family, neighbors; 16.0%); thought they could die (29.9%), and knew people who died because of the storm (6.6%; Orengo-Aguayo et al., 2019). As a result of Hurricane Maria, 7.2% of youths exhibited clinically elevated PTSD symptoms up to 9 months after the storm (Orengo-Aguayo et al., 2019).

Youths in Puerto Rico were not only impacted by exposure to Hurricane Maria, but also by the complex sociopolitical factors shaping the aftermath. Puerto Rico has a history of resource scarcity and underinvestment, which made the island particularly vulnerable to both the storm and its aftermath (Joseph et al., 2020; Moleti et al., 2020). These challenges were intensified by the delayed and inadequate response of the U.S. federal government and Federal Emergency Management Agency (FEMA), leading to a lack of access to basic resources such as food and water. As a result, people were driven to desperation, crime rates increased, and youths were further exposed to potentially traumatic events (Joseph et al., 2020; Moleti et al., 2020). Thus, it is crucial to consider the contextual factors that affected Puerto Ricans during and after Hurricane Maria to fully understand the storm's impact on mental health of youths on the archipelago.

Recent research has examined the impact of Hurricane Maria-related stressors on symptoms of PTSD among youths of Puerto Rico. Navarro Flores et al. (2025) found a dose-response relationship exists between exposure to hurricane-related stressors and PTSD symptoms, with greater exposure to hurricane-related stressors associating with higher levels of PTSD severity and increased

odds of reporting clinically elevated PTSD symptoms. Additionally, exposure to hurricane-related stressors was found to differentially influence the severity and clinical elevation of PTSD symptoms, with stressors such as perceived threat to life, home or community violence, and limited access to food or water exerting a stronger influence in explaining PTSD symptom severity and differentiating between youths with clinically elevated and non-elevated symptoms (Navarro Flores et al., 2025). Another study, utilizing network analysis to understand the associations between PTSD symptoms and maladaptive coping through substance among youths, identified two symptom clusters following exposure to Hurricane Maria: (a) arousal and reactivity, negative alterations in cognition and mood, and substance use, and (b) avoidance and intrusion (Vázquez et al., 2024). Combined, these findings highlight the potential to advance etiological understanding by examining PTSD symptoms at a finer-grain level involving specific clusters of symptoms, rather than conceptualizing dysfunction as manifestations of a single construct (i.e., total PTSD severity and clinically significant levels). These methods may also facilitate understanding of cumulative and individual effects of hurricane-related stressors that contribute to heterogeneity in PTSD symptom presentations among youths following natural disasters, which could assist in guiding screening, treatment planning, and clinical interventions for youths exposed to hurricane-related stressors.

PTSD and Symptom Criteria Typologies

The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5) describes criteria for PTSD as exposure to actual or threatened death, serious injury, or sexual violence, accompanied by various symptoms grouped into four criteria: (a) intrusive symptoms (e.g., flashbacks, nightmares), (b) avoidance of trauma-related stimuli (e.g., memories, thoughts, feelings, external reminders), (c) negative alterations in

mood and cognition (e.g., distorted thoughts, negative emotional state), and (d) heightened arousal or reactivity (e.g., hypervigilance, exaggerated startle response; American Psychiatric Association, 2013). Most research on PTSD symptoms focuses on severity or clinical significance of PTSD symptoms, overlooking the nuanced ways in which PTSD symptoms may manifest (e.g., patterns of PTSD symptoms criteria based on their co-occurrence). The diverse presentations within the guidelines for what constitutes a PTSD diagnosis can have implications for screening and increase the effectiveness of individualized treatment (Campbell et al., 2020). Thus, more research studies uncovering the patterns of PTSD that do not rely solely on categorical taxonomy are warranted.

Latent profile analysis (LPA) is an advanced, person-centered statistical approach that identifies unobserved subgroups (e.g., latent profiles) based on patterns in continuous data. This approach is especially useful for uncovering within group heterogeneity by clustering individuals based on shared characteristics (Saunders et al., 2020). Despite the utility of this approach to exploring etiological risk factors, few studies have applied LPA to analyze PTSD symptom patterns in youths affected by hurricanes. Consistent with the broader body of PTSD research, extant studies of post-hurricane impact have generally focused on the severity of PTSD symptoms, the co-occurrence of PTSD with other disorders (e.g., anxiety, depression), and PTSD trajectories (Lai et al., 2015; Self-Brown et al., 2013).

A few studies have used latent class analysis (LCA) to explore these questions, which employs dichotomous indicators to uncover classes based on patterns of PTSD criteria-specific symptoms (i.e., individual PTSD symptom typologies). This has entailed research on adults living in the United States (U.S.) mainland and World Trade Center attack responders exposed to a range of non-natural disaster-related traumatic experiences (Campbell et al., 2020; Horn et al., 2016;

Pietrzak et al., 2014) and disaster-exposed Chinese adolescents (Cao et al., 2019). It is notable that common patterns of PTSD symptomology have been identified despite these studies using different versions of the DSM to derive PTSD symptoms and diagnoses. For adults, a High Symptom class (i.e., high probabilities of all or most PTSD symptoms) and a Dysphoric class have been consistently identified across multiple studies (Campbell et al., 2020; Horn et al., 2016; Pietrzak et al., 2014). Two studies using DSM-IV criteria described the Dysphoric class as involving emotional numbing and dysphoric arousal (Horn et al., 2016; Pietrzak et al., 2014), while a study using DSM-5 criteria characterized this class with a wider range of symptoms (e.g., intrusive thoughts, cognitive/affective and situational avoidance, negative cognitions, negative affect, feelings of isolation, numbing, irritability, sleep/concentration difficulties; Campbell et al., 2020). A Threat or Threat-Reactivity class (e.g., high symptoms of re-experiencing and hypervigilance) was also identified in two studies, with the study utilizing DSM-5 symptom criteria also noting moderately high self-blame and negative affect, and relatively low levels of isolation, numbing, and irritability (Campbell et al., 2020; Horn et al., 2016). Lastly, one study identified a Low Symptom class (i.e., low levels of all PTSD symptoms; Campbell et al., 2020) and another an Anxious-Re-experiencing class (e.g., high probabilities of anxious arousal, re-experiencing, and avoidance symptoms; Pietrzak et al., 2014). Similar classes have been observed in youths exposed to earthquake disasters using DSM-IV PTSD criteria: (a) High Symptoms, (b) Re-experiencing/Hypervigilance, (c) Dysphoria, and (d) Low Symptoms (Cao et al., 2019). However, despite these burgeoning findings, the degree to which these class analyses generalize to youths of Puerto Rico exposed to hurricane-related stressors remains unknown.

Pursuit of additional inquiry in this area is critical due to potential variation in PTSD symptom typologies depending on the amount

and type of exposure to traumatic events and characteristics of the youths (e.g., age or sex). Hurricane-related stressors such as perceived life threat (e.g., fearing for one's life), life-threatening events (e.g., injury or death of loved ones, or destruction of homes), and losses/disruptions (e.g., damage to belongings, limited access to food, water, shelter, or community violence) have been identified as key contributors to the development of PTSD symptoms (Vernberg et al., 1996). Similarly, presentation of PTSD symptoms has also been found to differ based on the individual effects of hurricane-related stressors. For example, individuals who experienced perceived life threat and community violence during Hurricane Katrina in the U.S. have been shown to more often be in PTSD classes with worse symptoms (e.g., higher symptom severity, PTSD symptoms comorbid with depression; Lai et al., 2015; Self-Brown et al., 2013). Understanding the impact of individual hurricane-related stressors may assist the development of preventive programs in natural disaster situations and aid clinicians in the assessment of trauma-related symptoms. However, there is limited research examining how individual hurricane-related stressors relate to PTSD typologies, particularly within the symptom criteria of a PTSD diagnosis. Exposure to cumulative overall trauma has been found to relate differently to PTSD symptom typologies among U.S. adults, with Dysphoric and High Symptom classes showing higher exposure to life stressors (Campbell et al., 2020). Additionally, while no significant sex or age differences in PTSD typologies have been found among hurricane-exposed youths (Lai et al., 2015; Self-Brown et al., 2013), research in adults suggests such differences may exist. Specifically, younger individuals and males have been found to be more likely to be represented in the Dysphoric class, while females were more represented in the High Symptom class, and older adults in the Threat-Reactivity class (Campbell et al., 2020). Recent research among youths of Puerto Rico exposed to Hurricane Maria also suggests that small differences exist in

correlations between PTSD symptoms that can contribute to different symptom presentations based on gender and academic level (Vázquez et al., 2024). Lastly, no research exists examining PTSD criteria-specific symptom typologies in relation to proximity to a hurricane's landfall or aid, as well as overall PTSD symptoms (i.e., severity and clinically elevated levels). Together, these findings underscore the potential importance of exposure to cumulative and individual hurricane-related stressors, sex, age, proximity to landfall of hurricane and aid, and overall PTSD symptoms in understanding PTSD criteria-specific symptom typologies, even though this has yet to be fully explored in hurricane-exposed youths.

The Present Study

The current study aimed to (a) uncover PTSD symptom profiles following exposure to a major hurricane (i.e., Hurricane Maria), (b) characterize youths who are members of each profile, and (c) examine cumulative and individual hurricane-related stressor exposures that best discriminate between membership in each profile as well as age and sex. We hypothesized that three to four PTSD criteria-specific symptom typologies would be identified based on prior research (Campbell et al., 2020; Cao et al., 2019; Horn et al., 2016; Pietrzak et al., 2014). Specifically, we anticipated uncovering profiles of Low PTSD Symptoms, High PTSD Symptoms, and one to two classes with mixed criteria-specific symptom (e.g., (a) heightened arousal or reactivity and negative alterations in mood and cognition [i.e., Threat-Reactivity], and (b) intrusive symptoms and avoidance of trauma-related stimuli [i.e., Anxious-re-experiencing]). We expected that greater cumulative exposure would be associated with worse PTSD criteria-specific symptom profiles (e.g., High Symptoms), and that individual hurricane-related stressors, particularly perceived life threat and community violence, would emerge as stressors of relatively high importance. Lastly, analyses examining differences in PTSD criteria-specific symptom profiles based on sex and age were

exploratory given the mixed findings in the literature.

METHOD

This study drew on de-identified survey data from 92,293 public school students (grades 3–12) throughout Puerto Rico. We administered the survey between February 1st and June 29th, 2018, as part of a Puerto Rico Department of Education-commissioned, island-wide needs assessment investigating Hurricane Maria-related stressors and PTSD symptoms among youths of Puerto Rico. Data collection took place approximately five to nine months after Hurricane Maria made landfall on September 20th, 2017. The Puerto Rico Department of Education oversaw distribution of paper-and-pencil surveys in classrooms by appointing representatives at each school to deliver survey materials, train teachers in administering the assessment, and mail completed forms for processing. We waived parental written consent because the surveys contained no identifying information and were gathered under the broader, de-identified needs assessment commissioned by the Puerto Rico Department of Education. Students provided oral assent and could withdraw at any time. The Puerto Rico Department of Education and the Medical University of South Carolina Institutional Review Boards approved the original data collection protocols. The University of Tennessee, Knoxville Institutional Review Board subsequently approved secondary analyses of the extant data.

Measures

Demographics

As part of the needs assessment, students indicated their grade (3–12) and binary sex (coded as *boy* [1] or *girl* [0]). Participants were then categorized as being enrolled in elementary (grades 3–6), middle (grades 7–9), or high school (grades 10–12) according to Puerto Rico's academic levels. Given the absence of individually identifiable data, grades also served as a proxy for age. We

calculated approximate distance from Hurricane Maria's landfall in miles, based on aerial measurements from Google Maps that depicted the distance between the geographic center of each school district's location and the center of the landfall site in Yabucoa, Puerto Rico (Orengo-Aguayo et al., 2019). To estimate proximity to aid, we calculated driving distances between each municipality's center to San Juan, where major relief efforts were concentrated following the hurricane, using Google Maps driving distance estimates (Orengo-Aguayo et al., 2019).

Hurricane Maria-specific Stressors and PTSD Symptoms

We measured Hurricane Maria-specific stressors and PTSD symptoms using the National Child Traumatic Stress Network Hurricane Assessment and Referral Tool (NCTSN-HART; Kronenberg et al., 2010). This 19-item questionnaire addresses hurricane-related stressors such as perceived life threat, actual life-threatening experiences, and post-storm disruptions or losses. We adapted these items from the Traumatic Experiences-Revised scale (Vernberg et al., 1996) to directly reference experience during and after Hurricane Maria, with responses scored *yes* (1) or *no* (0). We created a cumulative hurricane-related stressor score by summing all 19 items, with higher totals indicating greater exposure to hurricane-related adversity (Cronbach's $\alpha = .60$). We assessed PTSD symptoms using the University of California, Los Angeles Post-Traumatic Stress Reaction Index for Diagnostic and Statistical Manual of Mental Disorders-5 (DSM-5) Brief Form (RI-5-BF; Rolon-Arroyo et al., 2020). This 11-item assessment corresponds to a total scale and four DSM-5 PTSD symptom clusters—intrusion (Criterion B), avoidance (Criterion C), negative alterations in cognition and mood (Criterion D), and alterations in arousal/reactivity (Criterion E). We rated each item on a five-point Likert scale from *not at all* (0) to *very much* (4) and yields cluster-specific subscale scores (higher scores indicating greater symptomatology). In this sample, the

total scale had good internal consistency ($\alpha = .78$). The RI-5-BF demonstrated adequate internal consistency for intrusion ($\alpha = .69$), negative alterations in Cognition and Mood ($\alpha = .70$), and Arousal/Reactivity subscales ($\alpha = .49$). The two items comprising the Avoidance subscale were significantly correlated at a moderate level in the current sample ($r = .40$, $p < .01$). We translated to Spanish and cultural adapted the instruments for use in Puerto Rico (consistent with procedures outlined in Orengo-Aguayo et al., 2019).

Analytic Plan

Prior to analyzing the data, we assessed the pattern of missing data. Although 41.0% of participants had at least one missing response on study variables of interest, only 3.0% of total responses were missing overall. We used Chi-square tests of independence to examine patterns of missingness. Through analyses, we found that participants' responses on Hurricane Maria-related stressors and PTSD items were largely significantly associated with the propensity for missingness ($p < .001$), in that students reporting fewer stressors and fewer PTSD symptoms were more likely to have missing data. Thus, missingness appeared to be missing not at random (MNAR). Because listwise deletion in MNAR contexts can exacerbate bias (Enders, 2022), we imputed missing data via a random forest algorithm, which leverages observed values to estimate missing responses by generating a forest of classification and regression trees (Tang & Ishwaren, 2017). Random forest imputation accommodates complex variable interactions and can impute both predictors and outcomes (Tang & Ishwaren, 2017).

We conducted a latent profile analysis (LPA) to identify subgroups of youths who exhibit distinct patterns of PTSD symptoms (RI-5-BF criteria B–E; Rolon-Arroyo et al., 2020). We selected the optimal model based on lower Akaike information criterion (AIC) and Bayesian information criterion (BIC), entropy with values closer to 1, and/or bootstrapped likelihood ratio test (BLRT)

indicating that additional profiles would provide superior fit relative to a model with one less profile (Morgan et al., 2016). Once we identified the optimal solution, we used descriptive statistics to characterize each profile subgroup by examining differences in demographics (e.g., sex and academic level), distance from landfall, proximity to aid, cumulative exposure to hurricane-related stressors, averaged PTSD symptom severity, and PTSD status (clinically elevated versus normative; i.e., chi-square tests of independence, Kendall's tau correlations, and Kruskal-Wallis rank sum tests for non-normal continuous and categorical data).

We then used an area under the receiver operating characteristic curve (AUC) analysis (with 1,000 bootstrap iterations) to determine how well hurricane-related stressors discriminated between youths within an identified profile and those in a comparison group (e.g., high versus low PTSD symptom severity groups). AUC values below .70 indicated poor discrimination; .70–.80, acceptable; .80–.90, excellent; and above .90, outstanding (Hosmer & Lemeshow, 2000). We employed the Youden index to identify the optimal cutoff by combining sensitivity and specificity into a single measure, where higher values indicate better classification (Youden, 1950).

Next, we used the elastic net algorithm to identify high-value hurricane-related stressors that improved the classification of group membership for identified profiles. Elastic net is a penalized linear regression approach that yields parsimonious models while preserving intercorrelated predictors with unique predictive value (Kuhn & Johnson, 2013). Following best practices, we trained the algorithm on all available data (Riley et al., 2020). We used bootstrapping (1,000 iterations) to estimate model performance and assess the relative importance of each hurricane-related stressor in relation to PTSD profiles (Riley et al., 2020). Higher variable importance signified stronger explanatory power or improved classification accuracy. We assessed model performance based on AUC values (Kuhn & Johnson, 2013).

Because machine learning algorithms often struggle with outcomes that have a low base rate, we employed downsampling by randomly reducing the higher frequency group to the same size as the lower base-rate group (Kuhn & Johnson, 2013).

RESULTS

Participants were students in various academic levels (elementary 37.0%, $n = 34,186$; middle 34.3%, $n = 31,671$; high school 28.6%, $n = 26,436$), and were nearly evenly split by sex (girls 51.6%, $n = 47,655$; boys 48.4%, $n = 44,638$). On average, youths reported exposure to nearly five hurricane-related stressors ($M = 4.41$; $SD = 2.44$, range = 0–18). In terms of PTSD symptom clusters, average scores on intrusion ($M = 0.55$, $SD = 0.79$), avoidance ($M = 0.64$, $SD = 0.92$), negative mood/cognition ($M = 0.68$, $SD = 0.90$), and arousal/reactivity ($M = 0.77$, $SD = 0.80$) were generally low within the sample. Increases in cumulative hurricane-related stressor exposure was associated with greater intrusion ($r = .29$, $p < .01$), avoidance ($r = .25$, $p < .01$), negative mood/cognition ($r = .18$, $p < .01$), and arousal/reactivity symptom severity ($r = .21$, $p < .01$).

Latent Profile Analysis of PTSD Criteria-Specific Symptoms

The LPA model fit was evaluated for solutions ranging between two to nine profiles. The BLRT suggested that additional profiles provided improved fit up to five profiles and when discriminating between eight to nine profiles. However, the three-profile solution had the best fit according to the lowest AIC and BIC values, which both increased as we introduced additional profiles beyond the three-profile solution. The two-profile solution had marginally higher entropy (.91) relative to the three-profile solution (.90) with a significant subsequent drop in entropy as additional complexity was introduced beyond three profiles. These metrics suggested that the three-profile solution was the optimal model, with labels corresponding to PTSD symptom presentations as follows: (a)

Predominantly Intrusion/Avoidance; (b) Predominantly Arousal/Reactivity and Negative Cognition/Mood, and (c) Low PTSD. We

included model fit statistics in Supplemental Table S1 and Figure 1 for the three-profile LPA model.

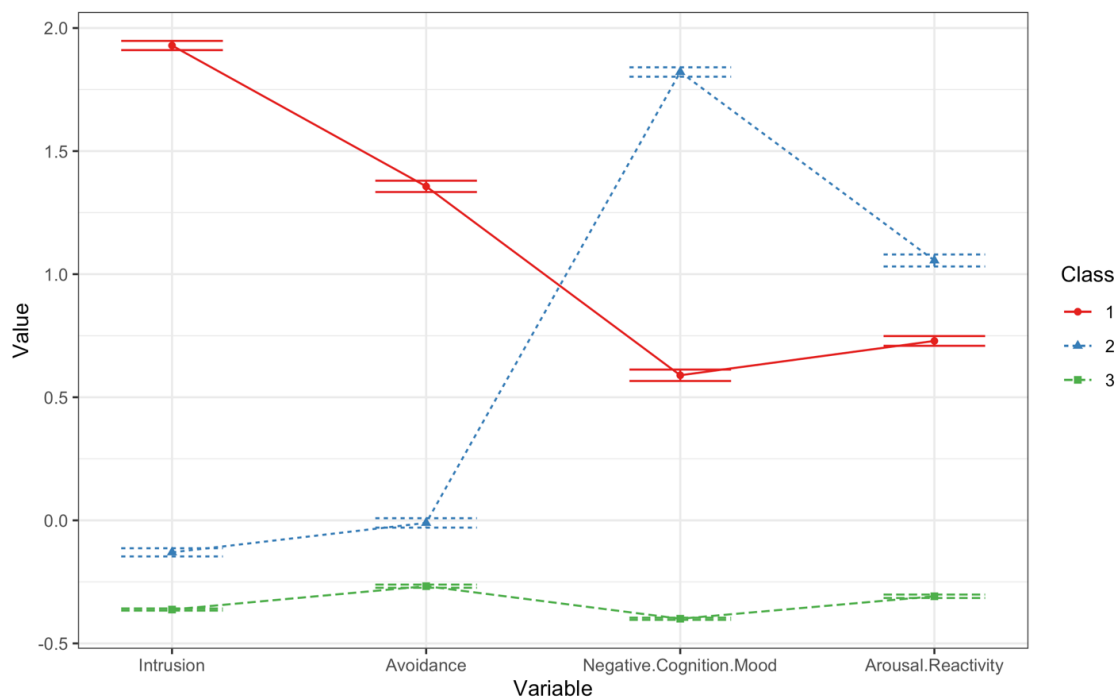


FIGURE 1. Three-Profile Model for Hurricane-related PTSD Symptoms.

Note. 1 = Predominantly Intrusion/Avoidance, 2 = Predominantly Arousal/Reactivity and Negative Cognition/Mood, 3 = Low PTSD, PTSD = posttraumatic stress disorder.

Results indicated that girls were more likely to be represented in the Predominantly Arousal/Reactivity and Negative Cognition/Mood profile (61.3%, $n = 6,232$) and boys were most likely to be in the Low PTSD group (50.4%, $n = 34,629$). Additionally, youths in elementary school were most represented in the Predominantly Intrusion/Avoidance profile (60.8%, $n = 8,157$). Middle school students were most frequently in the Predominantly Arousal/Reactivity and Negative Cognition/Mood (35.9%, $n = 3,643$) and Low PTSD groups (36.6%, $n = 25,143$). High school students were most frequently represented in Predominantly Arousal/Reactivity and Negative Cognition/Mood profile (40.8%, $n = 4,146$). Regarding individual hurricane-related stressors, distance from landfall was marginally closer among youths in the Predominantly Intrusion/Avoidance ($M = 37.71$, $SD = 24.79$) and Predominantly Arousal/Reactivity and

Negative Cognition/Mood groups ($M = 38.03$, $SD = 24.65$) relative to those in the Low PTSD group ($M = 39.81$, $SD = 25.52$). Youths in the Low PTSD group were furthest away from hurricane relief aid ($M = 40.65$, $SD = 33.58$). Predominantly Intrusion/Avoidance profile had the highest cumulative hurricane-related stressor exposure ($M = 6.16$, $SD = 2.59$). Youths with elevated PTSD symptoms were largely in the Predominantly Intrusion/Avoidance group (30.4%, $n = 4,080$). In Table 1, we include PTSD symptom profiles by sample characteristics. Individual hurricane-related stressors were largely less frequently endorsed in the Low PTSD group relative to the other two profiles ($p < .05$). In Supplemental Table S2, we include details for individual hurricane-related stressor frequencies and associations with PTSD profiles.

TABLE 1.
 PTSD Profiles by Imputed Sample Characteristics.

Variables	Total Frequency/Mean (%/SD)	Predominantly Intrusion/Avoidance (1)	Predominantly Arousal/Reactivity and Negative Cognition/Mood (2)	Low PTSD (3)	p-value
	(N = 92,293)	(n = 13,422)	(n = 10,159)	(n = 68,712)	
Sex					<.001
Girls	47,655 (51.6%)	7,340 (54.7%)	6,232 (61.3%)	34,083 (49.6%)	
Boys	44,638 (48.4%)	6,082 (45.3%)	3,927 (38.7%)	34,629 (50.4%)	
Academic level					<.001
Elementary	34,186 (37%)	8,157 (60.8%)	2,370 (23.3%)	23,659 (34.4%)	
Middle	31,671 (34.3%)	2,885 (21.5%)	3,643 (35.9%)	25,143 (36.6%)	
High	26,436 (28.6%)	2,380 (17.7%)	4,146 (40.8%)	19,910 (29%)	
Landfall (miles)	39.31 (25.33)	37.71 (24.79)	38.03 (24.65)	39.81 (25.52)	<.001
Proximity to aid (miles)	40.06 (33.46)	38.59 (32.74)	37.97 (33.39)	40.65 (33.58)	<.001
Cumulative hurricane stressors	4.42 (2.44)	6.16 (2.59)	5.02 (2.45)	3.98 (2.23)	<.001
PTSD symptom severity	7.54 (6.75)	18.19 (5.63)	14.98 (4.25)	4.37 (3.45)	<.001
PTSD status					<.001
Clinically Elevated	5,210 (5.6%)	4,080 (30.4%)	1,130 (11.1%)	0 (0%)	
Normative	87,083 (94.4%)	9,342 (69.6%)	9,029 (88.9%)	68,712 (100%)	

Note. PTSD = posttraumatic stress disorder, p-values from comparisons between categorical variables represent chi-square test and otherwise represent Kruskal-Wallis rank sum tests, SD = Standard deviation.

Cumulative Hurricane-Related Stressors and PTSD Criteria-Specific Symptoms Profiles

A downsampled representation of the data set was constructed to equally represent members of the Low PTSD ($n = 13,422$) and Predominantly Intrusion/Avoidance groups ($n = 13,422$). Cumulative exposure to hurricane-related stressors correctly classified 74.1% of participants in the Predominantly Intrusion/Avoidance profile relative to the Low PTSD profile. A cut-point of 5 or more hurricane-related stressors offered the best distinction between these profiles (Sensitivity = .722, Specificity = .638, Youden Index = .36). The same process was applied to constructing another downsampled data set representing equal numbers of members for the Low PTSD ($n = 10,159$) and Predominantly Arousal/Reactivity and Negative Cognition/Mood groups ($n = 10,159$). Cumulative exposure to hurricane-related stressors correctly classified 62.4% of participants in the Predominantly Arousal/Reactivity and Negative Cognition/Mood profile relative to the Low PTSD profile. As with the first downsampled analysis above, a

cut-point of 5 or more hurricane-related stressors offered the best distinction between these profiles (sensitivity = .549, specificity = .631, Youden index = .18).

Relative Importance of Individual Hurricane-Related Stressors and PTSD Criteria-Specific Symptoms Profiles

We trained machine learning models on the previously described downsampled data sets to facilitate comparison between models. The elastic net algorithm accurately discriminated between 77.8% of participants in the Predominantly Intrusion/Avoidance and Low PTSD profiles (sensitivity = .696, specificity = .730, Youden index = .425). The item assessing respondents' belief that they could have died due to exposure to the hurricane was the variable with the highest importance in improving the accuracy of the classifier. This was followed by their family struggling to find food or water and fights or violence in their neighborhood. Similarly, the elastic net algorithm accurately discriminated between 64.8% of participants in the Predominantly Arousal/Reactivity and Negative Cogni-

tion/Mood and Low PTSD profiles (sensitivity = .597, specificity = .619, Youden index = .216). Fights or violence in their neighborhood was the variable with the highest importance

in improving the accuracy of the classifier, followed by the belief that they could have died (Figure 2).

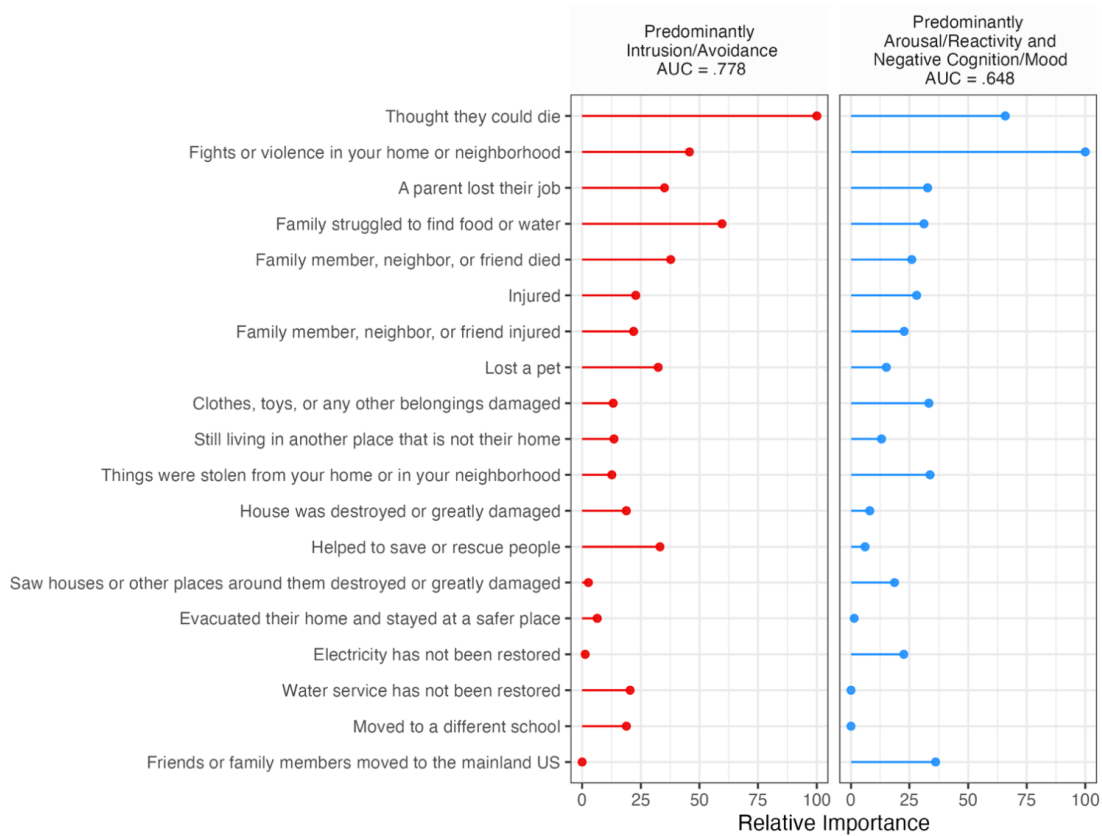


FIGURE 2. Top Discriminators PTSD Profiles According to the Elastic Net Algorithm. Note. AUC = Area Under the Curve, PTSD = posttraumatic stress disorder. Predictors arranged by average relative importance across outcomes.

DISCUSSION

The present study expands our understanding of PTSD symptom typologies and related correlates. It provides high value screening questions that could aid post-disaster mental health service triage and inform tailored mental health services that target specific youths' symptom presentation. The LPA revealed three PTSD profiles that accounted for 90.0% of youths' PTSD criteria-specific symptoms following exposure to a major hurricane, including: (a) Predominantly Intrusion/Avoidance, (b) Predominantly Arousal/Reactivity and Negative Cognition/Mood, and (c) Low PTSD. This builds on prior work investigating non-disaster-related traumatic events among adults and youths,

and youths exposed to earthquake disasters (Campbell et al., 2020; Cao et al., 2019; Horn et al., 2016; Pietrzak et al., 2014) by expanding similar approaches in a large sample of youths exposed to a major hurricane in Puerto Rico. To date, no studies have examined profiles of PTSD among youths of Puerto Rico exposed to major hurricanes, making the present study one of the first to address this critical gap in the literature and to elucidate specific patterns of posttraumatic stress within this population. Our findings are consistent with prior studies examining PTSD taxonomies, as we identified similar PTSD symptom typologies observed in these studies (e.g., low PTS class, Threat-Reactivity class [i.e., heightened arousal or reactivity and negative alterations in mood

and cognition], and Anxious-Re-experiencing [i.e., intrusive symptoms and avoidance of trauma-related stimuli]; Campbell et al., 2020; Pietrzak et al., 2014).

We found differences based on demographic variables among the PTSD symptom profiles. Specifically, we observed sex-based differences in group representation, with girls more likely to present with Predominantly Arousal/Reactivity and Negative Cognition/Mood PTSD symptoms relative to boys, following exposure to hurricane-related stressors. The Predominantly Arousal/Reactivity and Negative Cognition/Mood PTSD symptoms profile was the second-most-often assigned category for boys, with the first being the Low PTSD group. While limited research exists on assessing PTSD symptom typologies among youths, prior work has found that girls tend to experience greater symptoms of PTSD as compared to boys, potentially helping explain why boys were more likely to be in the Low PTSD symptom group (Vernberg et al., 1996). Our findings also suggested differences in profile representation depending on academic grade level, which may represent different symptom presentations by age group. Youths in elementary school were more likely to present with symptoms that fall into the Predominantly Intrusion/Avoidance category. Alternatively, middle school students were more likely to fit the Predominantly Arousal/Reactivity and Negative Cognition/Mood or Low PTSD symptoms categories, whereas those in high school were more likely to display Predominantly Arousal/Reactivity and Negative Cognition/Mood symptoms. Our findings align with prior research indicating that school-aged youths often exhibit PTSD symptoms like re-experiencing and avoidance, while middle school youths are more likely to experience mood changes (e.g., depression, anxiety), possibly reflecting age-related developmental differences in cognitive and verbal abilities influencing PTSD symptom presentation (Dogan-Ates, 2010). We found that distance to landfall and hurricane relief were significantly associated

with symptom profiles, although the absolute difference in miles from landfall and aid distribution was minimal. Youths with Predominantly Intrusion/Avoidance and Predominantly Arousal/Reactivity and Negative Cognition/Mood were closer in distance to the landfall than those in the Low PTSD group. This potentially suggests that more direct exposure to the hurricane is related to experiencing some symptoms of PTSD. On the other hand, those further from hurricane relief aid were more represented in the Low PTSD category. This may be because hurricane relief aid centers were likely established closer to areas along the hurricane's path that were more severely affected. This is consistent with research suggesting that individuals further from aid centers had lower exposure to Hurricane Maria-related stressors (Orengo-Aguayo et al., 2019).

In identifying a cut-off score for cumulative exposures to hurricane-related stressors, we found that exposure to five or more stressors best distinguished the Low PTSD group from the Predominantly Arousal/Reactivity and Predominantly Arousal/Reactivity and Negative Cognition/Mood profiles. Prior research identified a higher threshold of seven or more hurricane-related exposures among youths of Puerto Rico as the best discriminator between individuals with elevated PTSD severity and those without (Navarro Flores et al., 2025). These findings suggest that symptom profiles characterized by groupings of DSM-5 PTSD criteria may emerge with fewer hurricane-related stressor exposures compared to overall severity and clinically elevated PTSD symptoms. In other words, while youths may require greater exposure to meet the full diagnostic criteria for PTSD, fewer exposures can trigger specific symptom clusters. Thus, screening based on symptom profiles, rather than strict PTSD diagnostic criteria, suggests a lower threshold for identifying functional impairment for exposure to potentially traumatic experiences. This finding is particularly important for early identification, as using a cut-off of five or more

exposures may aid early identification of youths with PTSD symptoms who may benefit from mental health services, even if they do not meet full diagnostic criteria.

Our elastic net analyses suggested that individual hurricane-related stressors varied in their importance for distinguishing between PTSD symptom profiles. The Predominantly Intrusion/Avoidance was most strongly associated with perceived threat to the respondent's life, while fights or violence in their neighborhood was the variable with the highest importance in differentiating the Predominantly Arousal/Reactivity and Negative Cognition/Mood profile from the Low PTSD profile. Our findings may point to the differential impact of underlying contributors to symptom presentations depending upon the type of potentially traumatic exposure during a major natural disaster. Thus, we can suggest that youths faced with a perceived threat to life, for example, may experience a shift in their cognitions in terms of ruminative distress or re-experiencing, whereas exposure to potential violence may result in hypervigilance to ongoing environmental threat.

Implications

Climate change has led to an increase in the frequency and severity of extreme weather events, such as hurricanes (Crimmins et al., 2016). Puerto Rico is particularly vulnerable to extreme weather events due to its geographic location, underdeveloped infrastructure, and colonialist policies that limit the flow of essential and basic resources following natural disasters (Adil et al., 2025; Fischbach et al., 2020; Joseph et al., 2020). Furthermore, delays and inadequate response efforts led by the U.S. federal government in the aftermath of Hurricane Maria have further exacerbated the short and long-term psychological consequences of the storm for youths of Puerto Rico (Fischbach et al., 2020; Joseph et al., 2020). Puerto Rico will continue to be impacted by extreme storms precipitated by human-driven climate change (Adil et al., 2025; Fischbach et al., 2020; Joseph et al.,

2020), which represents a persistent public health risk for youths residing on the island, particularly for hurricane-related traumatic stress disorders.

To support the wellbeing of Puerto Ricans and mitigate the mental health impacts of future hurricanes, greater federal and local investment is needed to strengthen Puerto Rico's infrastructure and disaster response capacity. This includes short-term support by ensuring immediate access to basic necessities (e.g., water, food, shelter, health-care), as well as long-term efforts focusing on investing in critical infrastructure (e.g., power and water systems, transportation, health-care) to enhance rapid and efficient response efforts, reduce the island's structural vulnerabilities, and promote resilience against hurricane-related stressors among youths (Alto et al., 2021; Chandra et al., 2020; Fischbach et al., 2020). Furthermore, efforts should be made to increase access to mental health services, which have been limited in Puerto Rico, by training paraprofessionals and mental health service providers in mental health first aid and trauma-informed care (Alto et al., 2021; Chandra et al., 2020; Fischbach et al., 2020). There is also a need to raise awareness of the impact of natural disasters on the mental health of youths of Puerto Rico and to address climate change through environmental actions that promote policies that reduce greenhouse gas emissions, particularly in the U.S. mainland and other developed countries (U.S. Department of State, n.d.). Additionally, it is important to promote civil engagement in national/local policies that promote disaster readiness—such as through voting and participating in advocacy efforts to improve infrastructure, relief efforts, and access to mental health services (Alto et al., 2021).

Our findings suggest that youths may present with different PTSD symptoms following a natural disaster. Youths presenting with Predominantly Arousal/Reactivity may be more likely to screen positive for PTSD and thus may be more likely to receive subsequent

mental health services. On the other hand, only 11.1% of the Predominantly Arousal/Reactivity and Negative Cognition/Mood had elevated PTSD, which may lead to these individuals with elevated symptomology being overlooked due to reliance on overall severity score. This underscores the limitations of our current diagnostic methods, which rely heavily on meeting specific criteria for a diagnosis, highlighting that failing to meet traditional diagnostic thresholds does not eliminate the possibility of underlying issues. Instead, these profiles may provide an alternative perspective for understanding symptoms outside the constraints of conventional diagnostic frameworks.

We identified specific individual and cumulative screening methods to help identify youths associated with both PTSD symptom profiles, which may enhance the efficiency and accuracy of post disaster mental health triage screenings. Youths who perceived they could have died, and their family struggled to find food and water during the storm may be more at risk for Predominantly Intrusion/Avoidance presentation of PTSD, while those who were exposed to fights or violence in their home or neighborhood may be at greater risk for Predominantly Arousal/Reactivity and Negative Cognition/Mood presentation of PTSD. Both presentations were associated with exposure to five or more cumulative hurricane-related stressors, which suggests that identification of individual stressors may be the optimal method of distinguishing various profiles. These screening methods may improve schools', mental health clinics', and community agencies' ability to identify at-risk youths following a major natural disaster, allowing for earlier intervention before symptoms become more severe. Thus, we recommend that individuals working with youths in Puerto Rico screen for those who endorse being exposed to five or more hurricane-related stressors. We suggest they aim to identify youths who endorse thoughts fearing they could have died during the storm, were exposed to fights or

violence in their home or neighborhood, and were struggling to find food or water. These youths are likely experiencing some symptoms of PTSD, and professionals working with this population can help triage them to receive trauma informed mental health care to reduce the symptoms developed after exposure to Hurricane Maria. Further, the PTSD symptom profiles we identified and risk factors that coincide with symptom clusters may inform future research needed to clarify mechanisms underpinning individually variable adjustment following exposure to a major natural disaster. More research is needed to improve our understanding of differential presentations of PTSD using longitudinal methods.

Our findings align with research that has highlighted the utility of person-centered mental health treatments for PTSD (Norrholm & Jovanovic, 2010). For example, the modular approach to therapy for children with anxiety, depression, trauma, or conduct problems (MATCH-ADTC; Chorpita & Weisz, 2009), provides symptoms specific interventions that can be prioritized based on youths PTSD symptom presentations (e.g., thought stopping and cognitive restructuring for negative cognitions, calming skills for arousal and reactivity, exposure for avoidance). Focusing on briefer targeted interventions could help increase access to mental health services post-disaster within a context with limited mental health service providers (Alto et al., 2021; Chandra et al., 2020). Our findings also highlight the need to prevent violence within homes and neighborhoods and ensure access to basic resources such as food and water following natural disasters in Puerto Rico. The destruction brought upon by Hurricane Maria, coupled with the limited access to material resources after the storm, exposed youths to increased community violence and crime (Fausset, 2017; Joseph et al., 2020; Moleti et al., 2020). Adequate aid from the U.S. federal government and FEMA could have mitigated these impacts (Joseph et al., 2020). However, U.S. policies like the Merchant Marine Act (Jones Act) of 1920,

which require maritime trade to go through U.S. ports could have impacted adequate relief efforts and increased the costs of goods for Puerto Rico after Hurricane Maria (Joseph et al., 2020). Thus, there is a need to address colonial neglect and policies that impact relief support following natural disasters to Puerto Rico (Joseph et al., 2020).

Limitations

This research should be viewed in light of several limitations. First, we used cross-sectional data which prevents the establishment of temporal order between predictors and outcomes. As a result, our findings should be interpreted as high value correlates of PTSD profiles. While participants were asked to report stressors related to Hurricane Maria, the present study could not control for stressors that may have been present prior to the storm (e.g., community violence and unreliable utilities). Moreover, because our data were gathered as part of a needs assessment, there were missing responses, and participants with greater hurricane-related stressors and PTSD symptoms were more likely to complete the survey. As a result, our sample may be skewed toward youths who experienced higher levels of stress and PTSD. In addition, our study did not incorporate measures of chronicity, severity, frequency, or the co-occurrence of various hurricane-related stressors—factors that could offer a clearer understanding of how extreme weather events affect mental health. Since we collected the data five–nine months after the hurricane, relying on binary indicators of exposure may have overlooked the complexity of the experiences faced by youths of Puerto Rico post-disaster. Future inquiries should therefore integrate multiple measures of hurricane-related stressors that capture these nuanced dimensions. As youths exposed to more severe and repeated hurricane-related stressors may be at greater risk for developing mental health problems, considering the multifaceted nature of hurricane-related stressors (e.g., chronicity, severity, and frequency) may provide greater

insights to guide the allocation of mental health services following natural disasters. Lastly, PTSD subscale assessing arousal/reactivity symptoms had poor internal consistency within the current sample. Future research should adapt existing brief questionnaires and/or create localized measures for assessing PTSD symptoms among youths to aid disaster relief efforts. Despite these limitations, our findings advance our limited understanding of post-hurricane PTSD symptom patterns among youths and associated hurricane-related stressors that can inform post-disaster mental health services interventions for youths.

Conclusions

This study highlights the importance of identifying PTSD symptom profiles and the limitations of current diagnostic methods, which often obscure underlying symptoms by relying on meeting rigid criteria and diagnostic thresholds. By uncovering distinct PTSD profiles—Predominantly Intrusion/Avoidance, Predominantly Arousal/Reactivity and Negative Cognition/Mood, and Low PTSD—among youths of Puerto Rico after Hurricane Maria, we provide insights into the nuanced presentations of trauma and offer an alternative framework focusing on symptom typologies for understanding symptoms. Screening for cumulative exposure to five or more stressors, as well as individual stressors like youths who feared for their lives, were exposed to violence, or lacked access to food and water during and following the storm, can improve early identification and triaging for trauma-informed care. Our findings also underscore the need for systemic changes, such as improving relief efforts following hurricanes and addressing colonial policies that limit resource accessibility. These can help mitigate the long-term psychological and social impacts of natural disasters. Future research should focus on longitudinal methods and a detailed assessment of hurricane-related stressors (e.g., chronicity, severity and frequency) to guide prevention and intervention strategies more effectively.

Research Ethics Standards

Funding: Drs. Orengo-Aguayo and Stewart were supported by the Substance Abuse and Mental Health Services Administration National Child Traumatic Stress Network grant 1U79SM063224.

Conflict of Interest: The authors declared no conflicts of interest.

Institutional Review Board (IRB) Approval for the Protection of Human Subjects in Research: The Puerto Rico Department of Education and the Medical University of South Carolina Institutional Review Boards approved the original data collection protocols as being exempt. Researchers for the present study worked with extant data and after review by The University of Tennessee, Knoxville Institutional Review Board it was determined that the project did not meet federal definitions of human subject research and does not require review from the Institutional Review Board.

Informed Consent: The need for parental written consent was waived as the surveys contained no identifying information and were gathered under the broader, de-identified needs assessment commissioned by the Puerto Rico Department of Education. Students provided oral assent and could withdraw at any time.

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