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Using the Environmental Health Disparities Framework to understand Black and Latino perspectives of a local fertilizer plant fire

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Abstract

In February 2022, a fertilizer plant fire burned for four days and displaced thousands of residents, who were mainly low-income and Black or Latino, from their homes in Winston Salem, NC. In partnership with Black and Latino residents and nonprofit organizations, we sought to understand Black and Latino resident perceptions of the chronic and acute health risks, as well as the emotional and financial effects that resulted from the fire, which included the release of nitrous dioxide. We used the Environmental Health Disparities Framework to guide this community-engaged research study, capturing through semi-structured interviews: 1) how residents perceived their community before and after the fire, 2) how the fire impacted physical and mental health, and 3) how individuals coped with stress. We used thematic analysis to analyze the data and identified seven major themes. Participants: 1) perceived their neighborhood positively, 2) were unaware of the potential dangers of the fertilizer plant before the fire, 3) experienced adverse health and financial effects from the fire, 4) took action to protect themselves from the impacts of the fire, 5) raised concerns about the environmental impacts of the fire, 6) raised concerns about the city's response to the fire, and 7) provided recommendations for future city response.

Keywords Community-based participatory research, Older adults, Children, Health disparities, Environmental justice, Environmental crisis, Air pollution

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Background

Racial and ethnic minority communities in the United States (US) often bear a disproportionate burden of environmental hazards that impact health, a phenomenon rooted in public policy, zoning practices, and land-use decisions [1–3]. Across the US, racial and ethnic minority communities live near industrial zones and facilities handling hazardous materials, subjecting residents to heightened health risks associated with pollution exposure and possible environmental disasters [3, 4]. Chemical explosions, particularly those caused by ammonium nitrate (AN), have resulted in significant human and infrastructure loss [5, 6].

Nitrous dioxide (NO_2) is a chemical released while burning ammonium nitrate, and its odor warns of acute exposure. NO_2 can damage the lungs by altering macrophage and immune function and can cause symptoms of abdominal pain, nausea, headache, coughing, and fatigue [7]. In addition, toxic dust from a chemical fire can settle on surfaces and the ground in surrounding and downwind areas. Since 1916, precipitating factors that led to ammonium nitrate (AN) blasts included storage techniques (e.g., confinement, piling), absence of adequate ventilation, humidity, exposure to an ignition source (e.g., fire), and mixtures with other chemicals [5–9]. Urban storage of AN in any facility in proximity to residential areas greatly increases the risk of death and injury to the surrounding communities [10].

On January 31st, 2022, a large fire occurred at the Winston Weaver Company fertilizer plant, which stored approximately 600 tons of ammonium nitrate in Winston-Salem, North Carolina [11–13]. Comparatively, in 2016, the West Waco fertilizer plant, which held 40–60 tons of AN, exploded and caused a 2.1 magnitude earthquake; in 2020, a warehouse holding 2,750 tons of AN exploded in Beirut (Lebanon), claiming the lives of 220 people and injuring 6,500 others [8, 14, 15]. The Weaver fertilizer plant fire occurred within city limits and was adjacent to a residential area with over 6,000 community members. The fire raised many environmental concerns, highlighting several hazards of residing near industrial facilities [12, 16].

Although research has emphasized the intersectional relationship between income, race, and environmental hazards, gaps remain in understanding the impacts specific to AN-related disasters, including perceptions of chronic and acute health risks and the emotional and financial effects [17]. Through mixed methodology, including qualitative inquiry, our research aimed to explore the multilevel impacts of the Weaver fertilizer plant fire on Black and Latino residents with children or older adults in the household who lived within a two-mile radius of the Weaver fertilizer plant during the fire,

assessing 1) how affected residents perceived their community before and after the fire, 2) how the fire impacted residents' physical and mental health, and 3) individual experiences coping with stress.

Methods

Theoretical framework

This study is anchored in the socio-ecological perspective offered by the Environmental Health Disparities (EHD) Framework [18]. The EHD is a theoretical lens through which researchers can better understand and analyze health disparities, including the multilevel connections between race, environment, and health. The EHD Framework emphasizes the complex interplay between various levels of influence, including community-specific stressors, individual-level stressors, coping mechanisms, and environmental disasters. It highlights how historical inequities, such as discriminatory zoning policies, exacerbates risks faced by marginalized communities in the context of environmental disasters like chemical fires [18].

Using this framework, our study delves into the intersection of environmental and psychological stressors and their cumulative impact on health outcomes. Unlike traditional models that often simplify the relationship between exposure and disease, the EHD Framework offers a more nuanced approach. It highlights how factors such as community resources, pollution levels, individual stressors, coping strategies, and even environmental disasters, like the Weaver fertilizer plant fire, are interconnected and contribute to health disparities within communities [18].

The EHD framework goes beyond conventional models by considering the cumulative impact of multiple levels of influence on health, including structural inequalities, environmental policies, and community resilience. This approach ensures that research captures the direct health effects of the fire and the broader societal and systemic factors that contribute to disparities [3, 19, 20].

Study overview

Setting and participants

Constructed in 1939, the Winston Weaver Company fertilizer plant adhered to the building codes from 1936, which lacked specific provisions for storing hazardous materials or fire mitigation strategies, such as a sprinkler system [11]. At the time of the fire, adjacent rail cars were reported to hold 100 of the total 600 tons of AN [11]. Modern building codes forbid the outside placement of rail cars containing such materials and require fire mitigation strategies. However, the Weaver fertilizer plant was grandfathered based on the 1936 building codes. Although it had successfully met contemporary fire and

safety inspection criteria, it was not required to comply with modern building codes [21].

The fire took place in a community in which 80% of the individuals living within a two-mile radius were racial and ethnic minority groups, with over 70% classified as low-income [12]. During the fire, the fire department initiated a voluntary evacuation covering a one-mile radius due to the potential explosion hazard, diverting residents to a community shelter [22]. After the fire was resolved, the city contracted with a local non-profit organization to reimburse displaced community members or those who incurred expenses during the fire. To qualify for reimbursement, residents had to live within one mile of the fertilizer plant and have financial impacts, including expenses related to food or shelter [23]. Receipts and documentation were required for residents to be reimbursed for up to \$1,000 per family; families without receipts were guaranteed an affidavit of up to \$300 [23]. Of the 6,500 evacuated community members, 656 families received reimbursement funds [23]. A review of payments found that only about \$240,000 of the 1 million allocated for displaced community members has been spent after two years [23].

We included English or Spanish-speaking Black or Latino residents who had either children or older adults living in the home and who lived within two miles of the Weaver fertilizer plant at the time of the fire. This approach aimed to focus on the unique experiences of these racial and ethnic groups, who comprise most of the population in this neighborhood and are often disproportionately affected by environmental disasters due to longstanding social and environmental inequities. We also focused on households with children or older adults, who experience greater health and social effects from ecological disasters and are often under-represented in research [24, 25]. Specifically, children are of shorter stature, have a higher respiratory rate, and have a lower body mass than adults, which puts them at greater risk for toxic absorption and inhalation of heavy gases. Additionally, prior studies have shown that older adults are at increased risk for morbidity from disasters [24, 25].

Data collection

Our team co-developed a semi-structured interview guide based on the EHD with community advisors, stakeholders for individual, in-person, and phone interviews [18]. Compared to focus groups, individual interviews were most conducive to enabling participants to share and describe their experiences due to questions exploring personal physical and mental health (see Supplementary File 1). Due to convenience, we included one dyad interview, which included a mother and son who lived in the same household. We co-designed questions in

partnership with community leaders, non-profit organizations, and residents from the affected area, using the EHD framework as a conceptual basis for the guide. The interview guide was reviewed and modified through an iterative process for this study. We also engaged with Black and Latino-led community-based partners using community-based participatory research (CBPR) guided principles to help recruit participants from the community around the Weaver fertilizer plant [26]. Our research team and community partners recruited a convenience sample of participants by sending flyers and newsletters through local community organization listservs, canvassing neighborhoods, and talking about the study at local community meetings. Participants elected to participate in the study by self-selecting after reviewing a community flyer and calling our research team to set up an interview or agreeing to an interview when approached within the community by our study team. Study coordinators confirmed that participants lived within a two-mile radius of the Weaver fertilizer plant during the fire.

We trained six expert community members as a part of the study team to recruit, obtain consent, and interview participants. The community interviewers received training through the Wake Forest Baptist Comprehensive Cancer Clinic's Qualitative and Patient Reported Outcomes (QPR-O) shared resource, a professional qualitative research service. They conducted two practice interviews with two co-investigators to review and refine the interview guide. Expert community interviewers with concordant ethnic and language backgrounds conducted interviews with participants to help facilitate trust. Another study co-investigator interviewed three Black participants.

After verbal consent, the interviews, conducted between August 2022 and June 2023, ranged from 8 to 49 min, averaging 21 min. The interviews took place via phone, in a private community-based setting, or the participant's home with the interviewer. While we recognize community expertise has a considerably higher value, participants were compensated with a \$50 gift card for participating in the interviews via mail if completed by phone or immediately after the in-person interview. The interviews were audio recorded and transcribed verbatim. Certified translators translated Spanish-language interviews into English, and a bilingual Q-PRO researcher reviewed the translation for accuracy. The Wake Forest School of Medicine Institutional Review Board approved the study.

Data analysis

Two research team members, AA and AS, reviewed the transcripts and developed a codebook to capture concepts found in the textual data using a combined

inductive-deductive approach. First, deductive codes were created to align with a priori domains of interest, including concepts from the EHD framework, and then open coding was conducted on a subset of transcripts to identify additional, emergent codes inductively.

Data were managed with ATLAS.ti software [27]. AA and AS independently coded the transcripts in groups of 4–6 transcripts and met to compare after each group was coded. The codebook was modified iteratively based on discussions of code meanings and applications. Discrepancies in coding were discussed and resolved by consensus. Researchers reviewed text segments separately by participant demographic group (Black and Latino) to maintain language integrity and then summarized text segments by code. Summaries were synthesized into themes using the principles of reflexive thematic analysis [28]. Summaries were compared by participant demographic group to identify common and unique themes and capture unique experiences per demographic group (see Fig. 1).

Using I-Poems for validation

We invited Black and Latino community members to a member-checking event, presenting data as I-poems [29]. I-Poems are a tool to highlight participant voices and promote researcher reflexivity [30]. To create the I-Poems, three researchers (RZ, AA, AS) read through each interview transcript and identified all “I” or “We” statements. We organized the statements by thematic area and iteratively constructed stanzas that communicated the most salient themes and best represented the entire dataset (see Fig. 2) [30]. We presented the

I-poems to community members who attended the event ($n=4$ Black participants, no Latino participants), allowing them to reflect on the findings in a way that elevated community member voices and fostered healing in the community. We also partnered with local nonprofits, Authoring Action, and the Piedmont Environmental Alliance to participate in and lead iterative creative writing exercises, allowing participants to write out and read aloud their writings together to help the participants process data and express and discuss their emotions safely.

Research team reflexivity

The research team members are all current residents of the city where the Weaver Fertilizer Plant fire occurred and resided in the town at the time of the fire. Therefore, we were exposed to media coverage surrounding the fire and its aftermath. However, unlike the community participants, none of the researchers or community interviewers resided in the area affected by the fire, nor had their home, family, health, or employment directly impacted. The Latino community interviewers worked with organizations connected to the communities affected by the fire, which helped to foster trust with the Latino study participants. One of the Black community interviewers was a community member who was the executive director of a service-oriented community-based organization serving the local community affected by the fire. The other interviewers were community members and academic researchers unknown to the study participants.

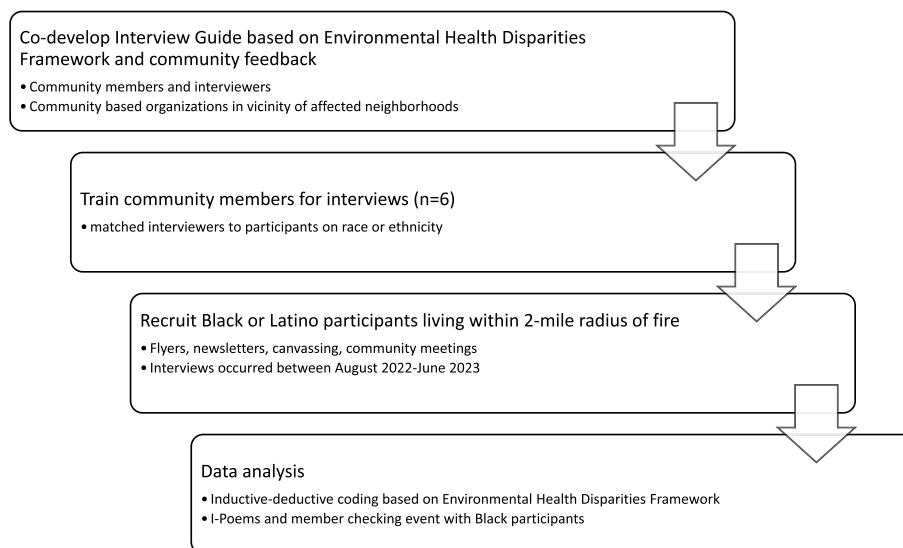


Fig. 1 Flow diagram of methods

Weaver Fire Community I Poem (English version)

I love my neighborhood
I have been here for a long time
I love that it's quiet
I know my neighbors
We all get along, look out for one another
We were asleep
We heard the fire truck coming up the street saying evacuate
We didn't know what was going on at first
We didn't really see anything except for the smoke
I thought somebody in the neighborhood's house was on fire
I knew nothin' of the Weaver plant
We did what they said, evacuated
I wasn't gonna stay in the situation
We just started packing clothes and some needed items, and we left
We didn't have anywhere to go at first
We called around to see who would take us in for that night
We were all holding our breath that it didn't blow up
We were taking turns keeping an eye on the news
I know that my neighbors didn't leave
They're senior citizens
I was very concerned about them
I was nervous to come home
We didn't come outside
We just stayed in
I had gotten a report that it was all clear, and Air Quality Control had been in
I'm like, "Well, no. I don't agree with that."
I think that fear of the unknown is the problem
I will be somewhat scared for the long-term effect of what that thing has done
I think [the city] could have done a better job
I would've had more for the residents to protect them
I think better shelter options would have been a nice resource to have
I think about all my elderly people who live over here who could not leave
I think it's important to have a preparedness plan for seniors
We did use finances because of the fire
We had to spend so much money eatin' [out]
I had to stay outta work for three days
I did apply for reimbursement for food
I was never compensated
I find out that the money that the city gave ESR, all of it wasn't spent
I'm like, "What happened to the rest of the money?"
I am trying to be more aware of the things that are in our neighborhood
I never knew a fertilizer company could be that dangerous in a residential area
I haven't heard an apology from [Weaver Fertilizer]
I feel like where's the accountability?
I still love where I live, but I'm glad that company is not in business anymore

Fig. 2 Weaver fire community I Poem (English version)

Results

Participants

We interviewed 18 Latino and 21 Black participants; however, one interview with a Black study participant was excluded as no audio recording was available due to faulty recording equipment, resulting in a final sample of 20 Black participants. Most participants in both demographic groups were female (Table 1). About half of the Black and Latino participants were over 50. Most Black participants had resided in their neighborhood for 15 or more years, whereas most Latino participants had lived there for five or fewer years.

Qualitative themes

We identified seven major themes within the domains of the EHD framework (Gee & Payne-Sturges, 2004). Participants: 1) perceived their neighborhoods positively, 2) were unaware of the potential dangers of the Weaver fertilizer plant, 3) experienced adverse health and financial effects from the fire, 4) took action to protect themselves from the impacts of the fire, 5) raised concerns about the environmental impacts of the fire, 6) raised concerns about the city’s response to the fire, and 7) provided recommendations for future city response. We provide

representative quotes below, with additional quotations mapped to the EHD framework in Table 2.

Perceived their neighborhoods positively

Participants of both groups described generally positive experiences living in their communities before the fire. Many participants described their neighborhood as quiet, with peaceful and friendly neighbors who “all look out [for] one another” (Black participant (BP), 13). Some Black participants also mentioned how they appreciated the neighborhood’s proximity to local stores.

Despite generally positive perceptions about their neighborhood, both groups expressed concerns about crime and disrespectful behavior, such as littering, loud noise, people driving too fast, firearm violence, and property destruction. A few Black participants explained that they felt their neighborhood had been abandoned and divested both before and after the fire. Specifically, they were concerned about the poor quality of local schools and the resulting diminishment of local educational opportunities for children. One Black participant noted that the city had stopped maintaining their local neighborhood park or roads over the past few years. She explained that the park used to be a place for kids to play, and now there are “trees, weeds, and one rusty broken-down sliding board” (BP, 10).

Table 1 Demographics of participants

	Black Participants (N=20)	Latino Participants (N=18)
Sex		
Female	15 (75%)	14 (78%)
Male	5 (25%)	4 (22%)
Age		
18–25	1 (5%)	0
26–30	1 (5%)	1 (6%)
31–40	2 (10%)	4 (22%)
41–50	2 (10%)	4 (22%)
51–60	8 (40%)	3 (17%)
61–70	4 (20%)	4 (22%)
71–80	1 (5%)	2 (11%)
80+	1 (5%)	0
Time in Community		
1–5 years	2 (10%)	11 (61%)
6–10 years	2 (10%)	4 (22%)
10–15 years	1 (5%)	1 (6%)
15+ years	15 (75%)	2 (11%)
Distance		
< .5 mile	5 (25%)	7 (39%)
< 1 mile	9 (45%)	1 (6%)
1 mile	6 (30%)	10 (56%)

Were unaware of the potential dangers of the Weaver fertilizer plant

Most participants were unaware of the potential hazards of the Weaver fertilizer plant, and some did not know that the fertilizer plant existed. One participant pointed out that they thought the fertilizer stacks on site were “cement sacks” (Latino participant (LP), 03). One Black participant expressed surprise, stating, “I knew Weaver was in our neighborhood, but...I never knew a fertilizer company could be that dangerous” (07). Another participant admitted to initially dismissing evacuation calls, thinking it was a prank due to the lack of awareness about the plant (BP, 01).

After the fire, community awareness of potential hazards increased. Both Black and Latino participants acknowledged a heightened sense of vigilance, with some describing the fire as a “wake-up call” that made them more “alert” and “cautious” about their surroundings.

Experienced adverse health and financial impacts because of the fire

During the fire, community members experienced intense emotions such as panic, terror, shock, and fear of potential explosions and for the safety of their homes. One mother expressed concern about the possibility of chemicals reaching their area, “They were

Table 2 Findings mapped to environmental health disparities framework

EHD Domain	Theme	Subtheme	Impactful Quotes
Community Level Vulnerability	Neighborhood Resources	<ul style="list-style-type: none"> Perceived their neighborhoods positively and were unaware of the potential dangers of the Weaver Fertilizer plant 	<ul style="list-style-type: none"> "I feel pretty safe now that the plant is gone." (PB20) "I still love where I live, but I'm glad that company is not in business anymore." (PB07) "Everybody been out here like 50-plus years...It's good." (PB14) "We all get along...look out for one another." (PB13)
		Community Stressors	<ul style="list-style-type: none"> Concerns about crime and disrespectful behavior Felt that neighborhood had been abandoned and divested by the city
Structural Factors		<ul style="list-style-type: none"> Most were unaware of the potential dangers of the Weaver Fertilizer Plant Since the fire, there has been an increased awareness of potential dangers in the community 	<ul style="list-style-type: none"> "I knew Weaver Fire was in our neighborhood, but... I never knew a fertilizer company could be that dangerous." "I was afraid because there's a gas station nearby. I thought "if that gas station explodes. Something that could burst because there's gas... in the depths of the earth." (PL01) "We could hear everything. We knew there was a fire... but we didn't know what had exploded...we didn't know it was chemicals and that we were being exposed to that." (PL11) "My daughter told me 'Mommy, something fell down behind the trailer, there was even a tremor. 'Oh, don't exaggerate' I told her. I never imagined it was something so serious." (PL04)

Table 2 (continued)

EHD Domain	Theme	Subtheme	Impactful Quotes
Individual Level Vulnerability	Environmental Hazards and Pollution	<ul style="list-style-type: none"> Concerns about smoke and water pollution after the fire Distrust of city's clean-up efforts after the fire Mainly negative experiences with the process of the fire evacuation 	<ul style="list-style-type: none"> "...there were some environmental issues (before) but none life threatening." (PB11) "As long as the smoke was in the air... The coughing was just ridiculous. I couldn't sit outside." (PB20) "The water smells like sewer. I'd rather buy bottles of water to cook than to actually use the water... You can taste the difference." (PB12) "it smelled like acid... it made your nose hurt" (PL12) "I've noticed that the trees don't look as beautiful as before." (PL09) "I don't think it'll ever be cleaned up properly... I understand when you dig something or cover something up, it don't go away and putting dirt on it can't fix it." (PB11)
		<ul style="list-style-type: none"> Evacuated self and/or family to another location Prayed to a higher power Adjusted home environments for safety 	<ul style="list-style-type: none"> "My family decided to go to a hotel b/c I was doing really bad, my chest. My son has asthma and allergies, so we couldn't stay in the apt." (PL11) "My mama said she wasn't goin' nowhere. I had to stay home with her." (PB15) "My mom helped feed us while we was there 'cause we didn't have no food" (PB13) "We did not go out... unless it was an emergency." (PB15) "I just prayed to God... I prayed that he would enlighten us so this would be solved." (PL18)
Individual Level Coping	Took action to protect themselves from the impacts of the fire		

Table 2 (continued)

EHD Domain	Theme	Subtheme	Impactful Quotes
Health Effects of Stressors	<ul style="list-style-type: none"> Experienced adverse health and financial effects from the fire 	<ul style="list-style-type: none"> Many experienced adverse mental and physical health effects Financial impacts were widespread and varied 	<ul style="list-style-type: none"> "I thought, 'Well, maybe I need to change the type of filter, because I had my son tested for allergies to figure out what was causing him to have reactions... He had to go on a nebulizer" (PB06) "I feel that we're (neighbors) closer now...there's more communication. We're more united." (PL14) "Prior to Weaver fire, it was more like seasonal allergies in the spring. After...I noticed he (son) had to go on a nebulizer because he couldn't breathe. He would cough a lot." (PB06) "I feel nervous, desperate—anxious, sometimes I feel like I want to start running away and disappear. Doctors ask me, do you feel this? I say no, because they don't really care, but I do. I feel desperate sometimes." (PL13) "You no longer sleep well" (PL13) "...I'm not the same now." (PL17) "Headaches. It's like almost every day" (PB12) "We started seeing neighbors go to the hospital...it was a back-to-back thing" (PB12)

saying that an explosion could reach several kilometers away. I worried because we are very close. If the chemicals exploded, the distance they were giving went beyond the area where we live. I got very worried for my girls" (LP, 14). Several Black participants expressed concern for older neighbors, with some unable to evacuate, prompting worries about their well-being. "Some people couldn't leave because of the elderly, so I think about all my elderly people who lived here who could not or did not have access to leave" (BP, 20).

After the fire, participants reported various new health issues, particularly respiratory problems. Many Latino and some Black participants had trouble breathing, coughing, congestion, frequent headaches, dizziness, body pain, and nausea. One mother described, "My son has some respiratory concerns. Before the Weaver fire, it was more like spring seasonal allergies. After the Weaver fire...I noticed that he had to go on a nebulizer and was given albuterol because he couldn't breathe. He would cough a lot." (PB 06) Skin irritation and allergy symptoms, such as itchy or watery eyes, were also common. Some noted worsened asthma due to smoke exposure. Concerns about long-term health effects from the fire were widespread among participants. Many Black and Latino participants reported enduring negative mental health effects, including anxiety, stress, and sleep disturbances. Some Latino participants described feeling traumatized or desperate, while others experienced depression and flashbacks when passing the site of the fire.

The financial impacts of fire were widespread and varied. Participants from both groups highlighted the financial strain caused by medical expenses and medication needed due to the fire's health effects. Specifically, Latino participants mentioned the economic burden of increased medical appointments necessitated by post-fire symptoms, adversely affecting their financial well-being. One explained, "It affected me a lot. I got an infection that clogged my nasal cavities. From the fire in January until July, when the doctor saw me since I don't have insurance, it's pricey. They referred me to the hospital. I had [nasal] surgery" (LP, 17). Some participants described the cost as a barrier to receiving healthcare, and they did not access healthcare for themselves or their families due to cost.

Nearly all Latinos and about half of the Black participants reported some economic impact from the fire, mostly losing income from being unable to work for one or more days. One Latino participant lost his job, eventually finding another job that paid him less. "I lost that job because I didn't go for a week. They were paying me 15 an hour... [Now,] I'm only making 13 dollars an hour" (04). Participants who evacuated faced additional expenses,

including food, housing, and replacement of perishable groceries left behind.

Taking action to protect themselves from the impacts of the fire

Participants employed various evacuation and home modification strategies for protection during the fire. Most Black and Latino participants evacuated, with nearly all Latino participants staying with family or friends. Those who evacuated remained away from their homes for up to two weeks.

Some participants near the Weaver fertilizer plant could not evacuate due to financial constraints or physical limitations and opted to stay indoors. They discussed taking protective measures in their homes, such as sealing doors and windows, wearing face masks, and drinking bottled water. Some participants also replaced air filters and expressed that they relied on their faith, with one participant mentioning prayer as a protective measure, noting that she prayed, "Lord, just watch out for me" (BP, 15).

Several Latino participants treated their respiratory problems with natural remedies, including lemon, ginger, cinnamon, and herbal teas, to help with coughing and congestion. Some "gargled with lemon and vinegar," and others used "ginger and lemon tea" (09 and 15). Others sought medication treatment through health care providers or purchased inhalers, nasal sprays, and allergy medication to alleviate their symptoms.

Raised concerns about the fire's environmental impacts, including smoke and water pollution

Most participants identified smoke clouds and the smell of smoke as the primary source of pollution during the fire. Some described the odor as rotten or chemical, reaching two miles away and lingering for weeks to months. One participant mentioned it took about a month to remove the "rotten smell" from their home; they explained that their home "smelled like chemicals" (BP, 05). Another participant noted changes in air quality, stating, "I feel like, after the fire, the air was different" (BP, 06).

Some noticed differences in the tap water's taste after the fire. They expressed concern about the safety of the water and began drinking bottled water instead of water from the tap. "The water smells like sewer. I would rather buy bottles of water to cook than to use the [tap] water... You can taste the difference" (BP, 12). Another Latino participant noted, "The trees don't look as beautiful. I don't know if it was all the smoke because it was there for many days and wouldn't go away. I don't know if it affected the trees that much. It's not the same now" (09).

Raised concerns about the city’s response to the fire

Participants described mainly negative experiences and feelings of injustice associated with the fire evacuation process and reimbursement methods. One person explained, "We’re human beings. We’re not just a number. How’s that [fire] going to affect my children or any of these children?" (PB, 05).

Both Black and Latino participants expressed dissatisfaction with evacuation procedures, citing issues such as lack of resources and confusion. Many described feeling stressed due to not knowing where to evacuate or confused about what happened during the evacuation. Few participants went to a shelter organized by the city for evacuees, but those who did found it ill-equipped and chose to sleep in their car or return home instead of staying there. One person explained, "When you got to the Coliseum [shelter], they didn’t even have cots. They didn’t have anything for us. We just went up there, and there was nowhere to sit. There was nowhere to lie. My husband and I just sat in our car." (PB 05).

They emphasized the need for a more inclusive evacuation plan, particularly for older adults and people with disabilities. A couple of participants noted, "Some people just couldn’t leave because of the elderly, so I think about all of my elderly people that live over here that could not leave or did not have access to leave." (BP, 20); "Our neighbors were elderly, and no one supported getting them out of their property during the fire. Ultimately, they remained in the home, and that was very dangerous for them." (BP, 19) Some Latino participants mentioned that they did not understand the English language evacuation orders. They described hearing the fire department’s evacuation orders over a loudspeaker or seeing emergency services personnel in their neighborhood but not comprehending what was being communicated. One Latino participant recounted, "I don’t speak English, but I imagine they were evacuating people. Now, I realize they were evacuating people" (07).

Participants shared varying experiences with the city’s reimbursement process. Some heard about the possibility of being financially reimbursed from community meetings, friends, neighbors, or through television advertisements. Barriers to applying for reimbursement included a lack of process awareness, fear of immigration status exposure, fragmented communication, lack of response or follow-up, and limited reimbursement amounts or explanations about the reimbursement process. One participant explained, "I went to the meetings, but they just didn’t explain everything to us as well as we wanted it to be explained to us...They said that they would reimburse us, and we never heard anything back from them" (BP, 20). Another participant reported a significant financial impact and explained that their family could not be reimbursed for their expenses because they exceeded the \$1000 per household limit.

Latino participants described additional challenges with reimbursement processes due to language barriers or the need for guidance on asking for reimbursement. One Latino participant stated that they paid taxes but must "settle" and cannot make "demands" due to legal status. They expressed frustration with not being reimbursed, "I paid my taxes for ten years...but we can’t ask for much because we don’t have papers...and that’s why we keep quiet. That’s why we put up with everything that happens to us until we’re just resigned to it. That’s not freedom" (LP, 10).

Raised recommendations for future city response

Study participants had several recommendations for future city and community responses. (see Table 3).

Discussion

Our study qualitatively investigated the aftermath of the Weaver fertilizer plant fire in Winston-Salem, North Carolina, and revealed significant health and social impacts on Black and Latino participants. Key themes

Table 3 Participant recommendations

Participant Recommendations for Emergency Management	<p>Provide a diverse strategic notification process, including Spanish-speaking resources, during disasters to ensure timely and effective communication</p> <p>Implement evacuation procedures that prioritize the needs of individuals with disabilities and older adults and ensure their safety and well-being</p> <p>Improve the availability of shelter and lodging options in evacuation scenarios, catering to diverse needs and circumstances facing community members affected by disasters</p> <p>Address the economic impact of the disaster on affected individuals and families and provide additional avenues for reimbursement or compensation. Barriers to application processes should be removed</p> <p>Provide comprehensive information regarding the health and environmental implications of the fire, empowering residents to make informed decisions about their safety and well-being</p>
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we identified included: generally positive perceptions of neighborhoods before and after the fire, a lack of awareness about the potential dangers of the plant, adverse health and financial effects, proactive actions taken to protect against fire's impacts, concerns about the environmental impacts of the fire, dissatisfaction with the city's response to the fire, and recommendations for future disaster responses.

Importantly, our study focuses on families with children and older adults, populations that are disproportionately impacted by disasters [24]. Children are emotionally and psychologically vulnerable, relying on caregivers for safety, which heightens the trauma experienced during a disaster [24]. Similarly, numerous studies have shown that older adults are at increased risk for morbidity during public health emergencies, particularly those with chronic health conditions or functional disabilities [25]. Additionally, social isolation or limited support networks may hinder older adults from safely evacuating during emergencies [25].

Participant recommendations highlight the need for a more inclusive disaster response strategy that addresses the diverse needs of affected communities. For instance, implementing a notification system, that includes Spanish-language resources, would ensure timely and effective communication during future disasters. Tailoring evacuation procedures to prioritize the needs of people with cognitive or functional disabilities can help ensure the safe evacuation of vulnerable populations and provide support during and after a crisis. Further, participants suggested that shelters must be equipped with accessible facilities, cots, and essential amenities to accommodate individuals with health or mobility limitations. Addressing the financial burden of disasters through expanded reimbursement programs and streamlined application processes would alleviate economic stress on affected families. Additionally, clearer communication about potential health risks, environmental contamination, and protective measures taken during an environmental disaster is vital for fostering community trust and safety. Incorporating these strategic recommendations into disaster response plans could significantly improve the resilience and well-being of communities, especially historically marginalized and underserved populations. These findings contribute to the broader literature on disaster preparedness, emphasizing the importance of inclusive, equitable, and community-centered approaches in mitigating the impacts of environmental disasters.

Our study also mirrors findings from previous environmental disaster research. Ecological disasters, such as the Hurricane Katrina aftermath, disproportionately affected marginalized communities, and exposed stark disparities in disaster preparedness, response, and recovery efforts

[31–33]. Similar to the experiences documented in our study, the Flint water crisis revealed systemic environmental neglect, with predominantly Black residents bearing the brunt of the consequences [34]. These disasters underscore the complex interplay of race, socioeconomic status, and ecological vulnerability, highlighting how preexisting inequities exacerbate the impact of environmental hazards on minority communities [31, 35]. An underlying challenge mitigating and addressing impacts of disasters is public perception of health, which tends to focus on individual medical treatment and can obscure the role of environmental health. This lack of recognition can influence political decision-making and impede efforts to prioritize environmental health concerns [36].

The findings from this study indicate a need for policy interventions that address the multilevel vulnerabilities of marginalized communities in the context of environmental disasters. Policymakers should prioritize developing equitable disaster preparedness, response, and recovery plans that account for the unique needs of racial and ethnic minority populations. This includes enhancing communication strategies, ensuring accessible evacuation procedures, and providing comprehensive economic and health support systems. By addressing these disparities through policies that reduce social-ecological stressors, it is possible to mitigate the disproportionate impacts of environmental hazards on marginalized communities, promote better health outcomes, and improve resilience and equity in disaster management.

Our study aligns with several previous studies examining the mental and social impacts of ecological disasters. For example, a study focusing on the experiences of displaced residents after Hurricane Katrina found that income and access to support networks heavily influenced evacuation decisions, echoing our findings about the role of resources in evacuation behaviors [35]. Additionally, participants in both studies expressed feelings of abandonment by government officials, during and after the disaster [35]. Ecological disasters often inflict trauma that extends beyond physical harm, creating emotional and existential distress in communities already burdened by historical injustices [37]. Research on man-made disasters, such as the Gulf of Mexico spill, shows that these events can have more severe mental health impacts than natural disasters, with exposed residents reporting higher rates of anxiety, depression, and post-traumatic stress disorder [25, 38–41].

In the future, governments should implement plans that address both the psychological and physical needs of individuals affected by environmental and ecological disasters. Establishing networks that provide accessible mental health resources, financial assistance, and medical care before disaster exposure could mitigate

the long-term impacts on vulnerable communities. The extended repercussions of the Weaver fire on local residents have highlighted the need for sustained support and resources to build resilience.

Strengths and limitations

There were several strengths to our study. Theoretically, the study team exhibits a strong commitment to community engagement with CBPR principles and partnership with local community agencies active in fire response that were engaged throughout the process of this study. We also employed a rigorous approach to data collection, grounded in the EHD Framework, to allow for the examination of the multilevel influence on health outcomes following the fire. Methodologically, the study incorporated member-checking techniques, such as using I-poems and community validation events, to enhance the trustworthiness and authenticity of the findings. By involving participants in interpreting and validating the data, the study increased the credibility and relevance of the results. To accommodate for participants with transportation or mobility barriers, our team performed interviews via phone or in participant homes, which was a strength, but could also affect the quality of data collected.

Our study has potential limitations. First, interviews were completed over a year after the Weaver fertilizer plant fire, which may have contributed to recall bias. Second, while most interviewers were racially or ethnically congruent with participants (a strength), they were not residents of the affected area, and their occupations (e.g., a radio host, clergy member, university student, etc.) may have impacted how participants responded. Most of the participants were female, limiting the viewpoints captured by men affected by the fire. Additionally, one of the study co-investigators conducted several interviews with Black participants, and her role as a clinician and identity as White may have impacted participant trust. The participants were recruited via a convenience sample, which may disproportionately represent participants with strong opinions. Although our team held a member checking event, inviting both Black and Latino participants to review I-poems and provide feedback, only Black participants were present, limiting feedback.

Conclusions and next steps

Our findings underscore the urgent need for comprehensive disaster preparedness and response strategies that prioritize the needs of vulnerable and marginalized communities and are inclusive of people who have disabilities or language barriers. Moving forward, efforts should focus on improving communication, enhancing

support services, and addressing systemic inequities to mitigate the disproportionate impact that environmental disasters have on marginalized populations. Future research is needed to explore the longitudinal effects of the fire on the participants' physical and mental health.

Abbreviations

AN	Ammonium nitrate
CBPR	Community based participatory research
EHD	Environmental Health Disparities
QPRO	Qualitative Patient Reported Outcomes

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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Authors' contributions

RZ, AS, AA, led the interviews of participants and trained community interviewers, DP, KM, RZ, AH, CP, MY, JM, RK, CD, and CB all contributed to the design of this study and interpretation of findings. RZ was lead author and drafted the manuscript. All authors contributed to the forming, editing, and final approval of this manuscript.

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Availability of data and materials

Data is provided within Supplementary File 2.

Declarations

Ethics approval and consent to participate

Our study was approved by The Wake Forest School of Medicine Research Ethics Committee (approval no. 00083530). All participants provided verbal informed consent before enrollment in the study.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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