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Article

Physical Health Symptoms and Perceptions of Air Quality among Residents of Smoke-Damaged Homes from a Wildland Urban Interface Fire

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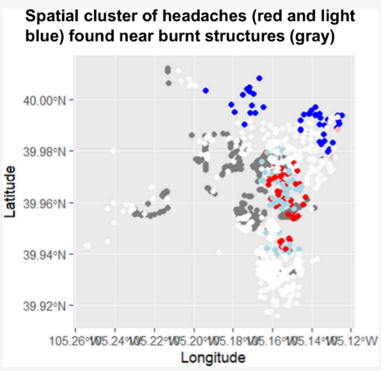
ABSTRACT: The Marshall Fire was a wildland urban interface (WUI) fire that destroyed more than 1000 structures in two communities in Colorado. High winds carried smoke and ash into an unknown number of buildings that, while not incinerated, were significantly damaged. We aimed to understand whether smoke or ash damage to one's home was associated with physical health impacts of the fire event for people living in and around the fire zone whose homes were not completely destroyed. We analyzed data collected from participants who responded to Wave 1 (six months postfire; $N = 642$) or Wave 2 (one-year postfire; $N = 413$) of the Marshall Fire Unified Research Survey. We used self-reported exposure to smells and ash in their homes as measures of exposure and also created spatial exposure measures based on proximity to destroyed structures. Reporting a headache was statistically significantly associated with all exposure metrics (self-reported and spatial proximity), and reporting a strange taste in one's mouth was also significantly associated with having more destroyed buildings within 250 m of the home. Study findings can inform response planning for future WUI fires to protect the health of residents of smoke-damaged homes.



KEYWORDS: *wildfire smoke, physical health symptoms, wildland urban interface, air quality, ash damage*

■ INTRODUCTION

Wildfires have increased in frequency and intensity in western North America in the past few decades,[1] and climate change projections show that wildfire risk will continue to increase.[2] Smoke from wildfires is an increasing contributor to air pollution,[3−5] and there are well-documented health effects of exposure to air pollution from wildfires.[6−8] In the past few years, wildfires have increased within the wildland urban interface (WUI). These WUI fires burn not just vegetation, but also human-made materials, such as buildings and vehicles. Incineration of human-made materials has higher emissions factors of some metals, polycyclic aromatic hydrocarbons (PAHs), and volatile organic compounds (VOCs) than burnt biomass.[9,10] Smoke and ash from WUI fires can infiltrate nearby nonburnt homes. Although news organizations have highlighted the smells and symptoms reported by residents who return to these unburned yet smoke-affected homes,[11] the impacts have not been documented in a systematic way.

Previous studies document health harms from exposure to VOCs,[12] metals,[13] and PAHs,[14] yet we know of no studies that explore the health impacts from exposure to these compounds in smoke-damaged homes after a wildfire or WUI fire. Exposure levels in previous studies may be different than the levels and exposure mechanisms from living in or cleaning out a smoke or ash damaged home.

Our study aims to understand the reported air quality and health impacts of a WUI fire among people whose homes were smoke-damaged during the Marshall Fire. The fire started the morning of December 30, 2021, in western Boulder County, CO. High speed winds, with gusts up to 100 miles per hour[15] caused this fire to spread eastward across grasslands and into residential neighborhoods. After the winds shifted, causing the fire to die down, the first snow of the season fell, which cleared the air of visible smoke. Over 1000 buildings burned, yet many homes in the area that were not destroyed were severely smoke-affected. Within a few days of the fire, local air pollution scientists started gathering data on indoor air quality and ash in

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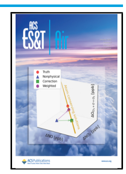

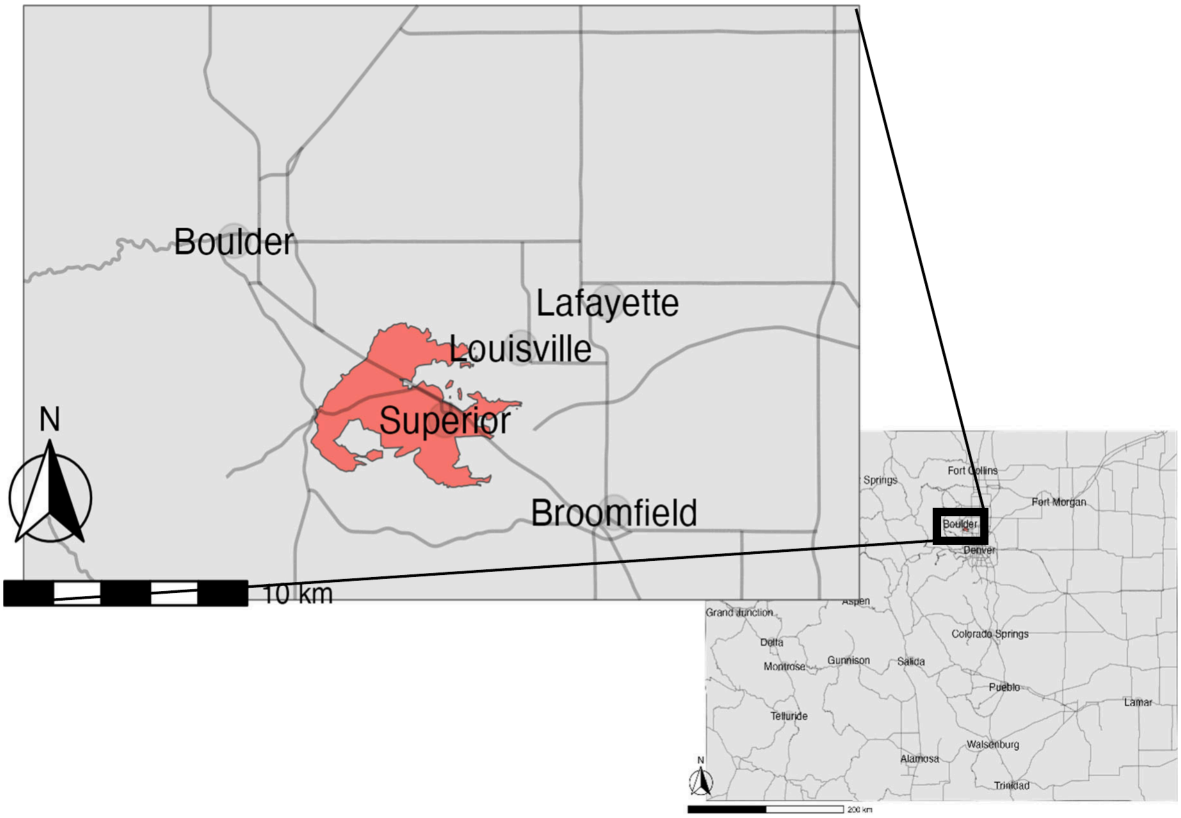

Figure 1. Marshall Fire Boundary, shown in red, within Boulder County, CO.

smoke-affected homes. The samples from smoke-affected homes showed elevated levels of metals and PAHs in dust from this fire[16] and elevated VOCs in airborne samples (Dresser et al. 10.1021/acsestair.4c00259). Another recent study on this fire found elevated levels of certain metals in burned soils compared to unburned soils.[17] Resuspension of soils or dust inside homes and the off-gassing of VOCs within smoke-affected homes could affect the health of residents, although this has yet to be explored.

Our project has three main aims: (1) to understand what physical health symptoms people living in smoke-affected homes experienced after the Marshall Fire and if those symptoms persisted or improved over time, (2) to describe and assess spatial clustering of postfire perceptions of air quality or physical health symptoms, and (3) to assess what proxies of physical exposures were associated with reported symptoms.

■ METHODS

Study Population. The study population is comprised of respondents to the Marshall Fire Unified Research Survey.[18] This survey was sent out to all addresses within the Marshall Fire boundary (Figure 1) and a random sample of all addresses within 2 miles beyond the fire boundary. Wave 1 was administered by mail between May 12 and July 21, 2022 (about six months postfire). 859 people responded to at least half of the survey in Wave 1, a 25% response rate. Wave 2 was sent to all of the people who had responded to Wave 1. 577 people (70% of Wave 1 respondents) responded at least partially to Wave 2 between November 11, 2022, and March 27, 2023, a period encompassing the one-year anniversary of the fire. Participants were given gift cards at each wave for responding to the survey.

Due to our interest in the impacts of the fire on individuals whose homes were smoke affected, we removed from our sample individuals whose homes were completely destroyed, leaving people whose homes remained, only some of whom reported smoke or ash damage. One respondent's address could not be geocoded. This left 642 individuals in our analytical sample from Wave 1 and 413 in Wave 2.

Survey Data. The survey asked respondents many questions related to perceptions of air quality in their neighborhood and in their home (Table 1). In Wave 1, respondents reported on their air quality perceptions before the fire, and questions about perceptions at the time of the survey were included in Waves 1 and 2.

Proximity to Destroyed Buildings. We also calculated metrics of proximity to burned structures near the home as indicators of smoke and ash damage. We calculated the number of destroyed buildings within 100, 250, and 500 m radial buffers of a survey respondent's home, the Euclidean distance between a respondent's home and the nearest destroyed building, the distance to the nearest destroyed building to the west (within 225 and 315 radial degrees because the wind was predominantly blowing from the west to the east during the fire), and the number of destroyed buildings to the west within 1000m of respondents' homes. We used geocoded participant addresses and the locations of burned homes and businesses[19] to calculate these measures. We geocoded participants' addresses using Google's API Service in RStudio Google API Service using the R package ggmap.[20]

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ACS EST Air 2025, 2, 13−23

Table 1. Survey Questions Used in This Study with Response Options and Which Population Was Asked Each Question

survey question	response choices	population and survey wave responding to the question
Before the Marshall Fire, I was confident that the air in my neighborhood was safe to breathe.	strongly disagree somewhat disagree neither agree nor disagree somewhat agree strongly agree do not know	people whose homes were not destroyed (Wave 1)
Before the Marshall Fire, I was confident that the air inside my home was safe to breathe.	strongly disagree somewhat disagree neither agree nor disagree somewhat agree strongly agree do not know	people whose homes were not destroyed (Wave 1)
Currently, I am confident that the air in my neighborhood is safe to breathe.	strongly disagree somewhat disagree neither agree nor disagree somewhat agree strongly agree do not know	people whose homes were not destroyed (Waves 1 and 2)
Currently, I am confident that the air inside my home is safe to breathe.	strongly disagree somewhat disagree neither agree nor disagree somewhat agree strongly agree do not know	people whose homes were not destroyed (Waves 1 and 2)
When you returned home after the fire, did it smell differently inside your home than it did before the Marshall Fire?	yes no not sure/do not remember	people whose homes were not destroyed (Wave 1)
How would you describe the smell inside of your home when you returned after the fire? Select all that apply.	like a campfire like chemicals or a chemical fire other:________ - selected choice	people who responded that their home smelled differently when they returned home postfire (Wave 1)
How has the smell inside your home changed since you first returned?	improved stayed the same gotten worse	people who responded that their home smelled differently when they returned home postfire (Wave 1)
Why do you think the smell inside your home has improved since you first returned? Select all that apply.	hiring a cleaning/remediation company increasing temperatures decreasing temperatures	people who responded that their home smelled differently when they returned home postfire (Wave 1)

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ACS EST Air 2025, 2, 13−23

Table 1. continued

survey question	response choices	population and survey wave responding to the question
	my own cleaning	
	the passage of time	
	air cleaners being used in the home	
	other	
When you returned to your home, was there ash inside that you could see?	yes	people who had returned to live in their homes postfire (Wave 1)
	no	
Where did you find the ash? Select all that apply.	inside the doors on the floor	people who responded that they found ash in their homes (Wave 1)
	on windowsills	
	in the HVAC filter	
	in the attic	
	in the garage	
	other	
Have you experienced any of the following health symptoms that you think may be related to smoke or air quality impacts of the Marshall Fire? Select all that apply. If you had a symptom but do not think it was related to the fire, do not select it.	dry cough	all participants (Waves 1 and 2)
	wet cough	
	wheeze	
	itchy or watery eyes	
	sore throat	
	headache	
	shortness of breath	
	difficult or labored breathing	
	sneezing or stuffy nose/ nasal congestion	
	nausea or vomiting	
	allergic skin reaction	
	strange taste in one's mouth none of these	

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Spatial Autocorrelation. For each survey wave, we assessed spatial autocorrelation of participants' air quality perceptions and symptoms using Moran's *I*. Moran's *I* measures the correlations of a variable only within defined neighbors per the equation below:

$$I = \frac{N}{W} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

where x_i and x_j represent the values of x in neighboring cells and $\bar{x}$ is the global mean of x. w_{ij} represents the weights, which denote whether cells i and j are neighbors. N is the count of all cells and W is the sum of all of the weights. I provides the autocorrelation of x only among its spatial neighbors. Because this depends on how neighbors are defined, we calculated Moran's *I* with multiple neighbor definitions and looked for consistency in statistical significance of Moran's *I* across these definitions. We defined neighbors as the five nearest neighbors by Euclidean distance to a given house, the ten nearest neighbors, all survey respondents whose home addresses were within 1829.616 m (thus allowing every respondent to have at least one neighbor), and all neighbors within 500 m (which drops six respondents from the analysis). We calculated statistical significance using 999 Monte Carlo simulations per test using the spdep package in R.[21]

Regression Analysis. We used simple logistic regression to assess whether self-reported air quality perceptions from survey or spatial exposures to burned material were associated with reporting a symptom for Wave 1. We calculated Pearson correlations between air quality perceptions, reporting smells or ash in one's home, and spatial exposure to destroyed homes (Table S1). Based on these correlations, we chose a subset of exposures to use in regression analyses to minimize the analysis of exposures measuring the same construct. Air quality perception measures used in regression analyses include binary indicator of perceiving poor neighborhood air quality at Wave 1, binary indicator of perceiving poor in home air quality at Wave 1, home smell change 1 week postfire, and finding ash inside home upon return postfire. Spatial measures of exposures used in regression analysis included count of destroyed buildings within 250m of respondent's home, distance to nearest destroyed building, count of destroyed buildings to the west of respondent's home within 1000m, and distance to nearest destroyed building to the west of respondent's home. Table S2 provides descriptive statistics on the retained exposure variables. Due to the large number of regressions done, we used Bonferroni correction[22] to reduce the chance of false positive results. We had 12 symptoms by 8 exposure variables and thus adjusted for 96 comparisons.

Statistical Programming and IRB. Our project was approved for human subjects' research by the University of Colorado Boulder Institutional Review Board protocol #22-0464 and the Colorado Multiple Institutional Review Board protocol #22-0085. We used the R programming language[23] within Rstudio for the geographical and statistical analyses.

■ RESULTS

Study Population. We provide descriptive statistics of our study population by study wave in Table S3. The study sample heavily represents responses by white, highly educated, employed, and higher income women. Demographics did not differ for those reporting smoke or ash upon return home and those who did not (Table S4). Those who reported symptoms in Wave 1 were not more likely to respond to Wave 2 (Table S5), with the exception of people who reported having an allergic skin reaction that they thought was due to the fire. Those reporting worse perceptions of air quality or reporting of home smell or ash in the home postfire in Wave 1 were not more likely to respond to Wave 2 (Table S6).

Symptoms Reporting. The most reported symptoms six months postfire (Wave 1) were itchy or watery eyes (33%), headache (30%), dry cough (27%), sneezing (26%), and sore throat (23%). These remained the most reported symptoms one year postfire (Wave 2) yet at lower rates. The decrease in symptom reports between the two waves was statistically significant for all symptoms except allergic skin reaction, wheeze, and nausea/vomiting; however, these symptoms were reported less frequently compared to other symptoms (Table 2).

Table 2. Symptom Reporting by Wave of the Survey

variable[a]	1, N = 579[b]	2, N = 389[b]	p-value[c]
dry cough	156 (27%)	78 (20%)	0.014
wet cough	11 (1.9%)	6 (1.5%)	0.7
wheeze	33 (5.7%)	13 (3.3%)	0.091
itchy eyes	191 (33%)	81 (21%)	<0.001
sore throat	136 (23%)	46 (12%)	<0.001
headache	172 (30%)	52 (13%)	<0.001
shortness of breath	48 (8.3%)	17 (4.4%)	0.017
difficulty breathing	29 (5.0%)	2 (0.5%)	<0.001
sneezing	148 (26%)	71 (18%)	0.008
nausea or vomiting	15 (2.6%)	4 (1.0%)	0.086
allergic skin reaction	27 (4.7%)	19 (4.9%)	0.9
strange taste in mouth	64 (11%)	10 (2.6%)	<0.001
reported no symptoms	259 (45%)	262 (67%)	<0.001

[a]N = 63 respondents in Wave 1 and N = 24 in Wave 2 did not answer symptoms question. [b]N (%). [c]Pearson's Chi-squared test.

Although symptoms improved from Wave 1 to Wave 2, some survey respondents continued to experience the same symptoms in both waves. The most common persisting symptoms within an individual from six months to one year postfire were itchy or watery eyes, dry cough, sneezing, headache, and sore throat. Respondents reporting dry cough, itchy or watery eyes, and sneezing were statistically significantly more likely to be people whose homes were smoke or ash damaged than people whose homes were not smoke or ash damaged (Table S7).

Spatial Clustering of Symptoms. Moran's *I* tests indicated statistically significant spatial clustering of sneezing across all four definitions of neighbors in Wave 1 (Table S8) meaning that people who reported sneezing were more likely to live near others reporting that same symptom than would be expected by chance. We also observed statistically significant spatial clustering of reporting headaches and sore throat with three of four definitions of neighbors for each of those symptoms (Figure S1). This could imply a common spatial cause of these symptoms within the first six months after the fire. Maps of symptom reporting can be found in Figure S2.

Air Quality Perceptions. The majority of survey respondents reported that they had been confident (either strongly or somewhat) in their neighborhood and home air quality before the fire, but this confidence declined at Wave 1 ("currently" for that wave; Figure 2). However, at Wave 2, confidence in neighborhood and home air quality was mostly

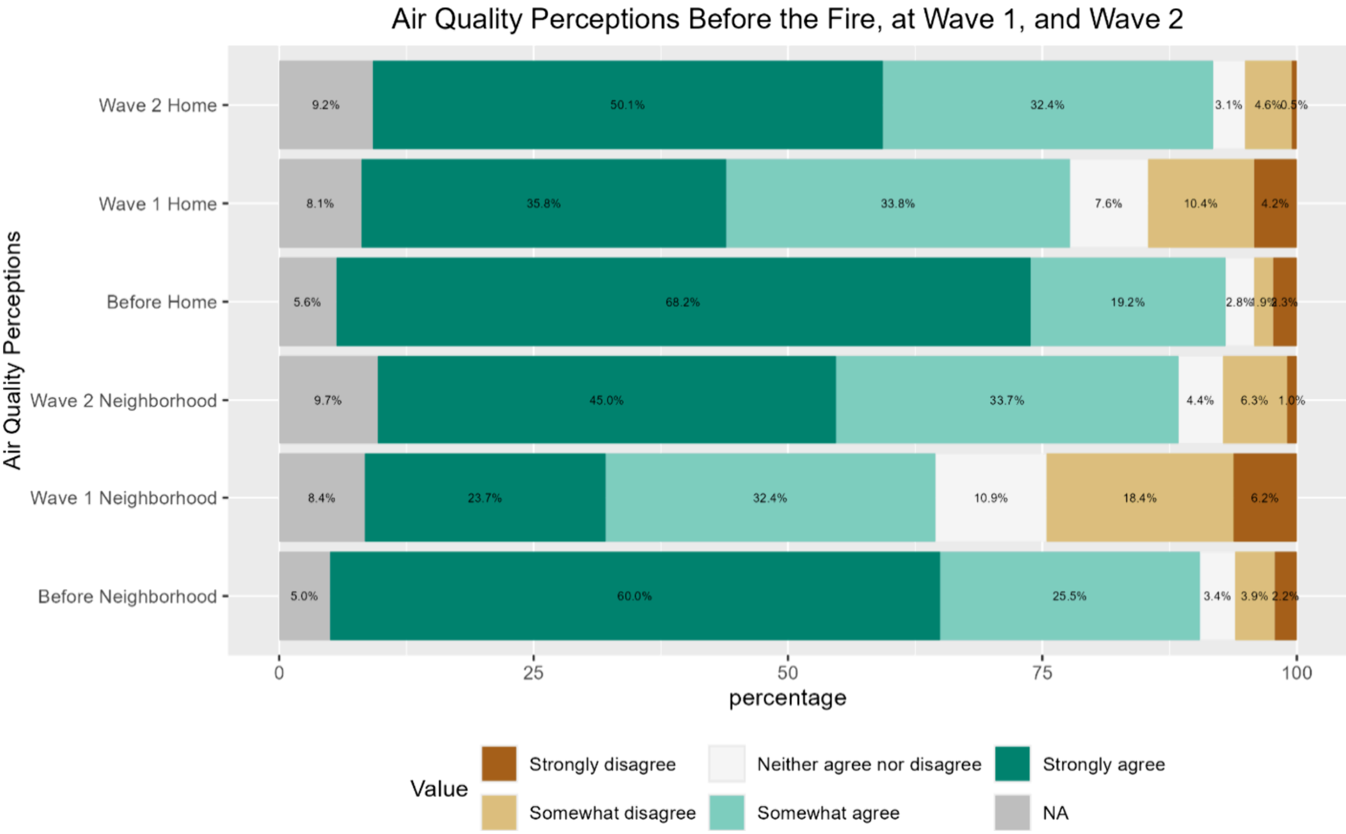

Figure 2. Perceptions of air quality confidence within the home and neighborhood before the Marshall Fire and during Wave 1 (N = 642) and Wave 2 (N = 413). NA in this plot indicates respondents who left the question blank but were asked the question.

back to the levels prior to the fire. Our previous work to analyze outdoor air pollution levels during and after the fire did not find outdoor $PM_{2.5}$ concentrations to be elevated after the fire and they could not be assessed during the fire because power was cut to most the $PM_{2.5}$ monitors in the area during that time.[16]

Smoke Impacts on Home. 61.2% (N = 393) of the study sample reported that their home smelled differently 1 week after the fire. Of those, 59.5% (N = 234) said that their home smelled like a campfire, 27.7% (N = 109) said that it smelled like chemicals or a chemical fire, and 12% (N = 47) said it smelled like something else. Most of the people who responded with "other," described that it smelled like both a campfire and a chemical fire. Many stated that it "smelled like a campfire and burnt plastic" or that it was "Both of above [campfire and chemical fire] and other smells that I never smelled before" or "Yes, like a campfire, plus more." Others said that it smelled smoky, but not like a campfire, with many mentioning that it smelled like an ashtray. Some others stated that there was a smoky smell, but it was not strong, with comments such as "mild smoke smell" or "smoky, but not as strong as a campfire." Given our findings in a sampling of homes just after the fire that there were elevated levels of VOCs in those homes[16] (Dresser et al. 10.1021/acsestair.4c00259), we presume that the reported smells are similar to the smells we observed in those other smoke-damaged homes, however, we could not put sensors into all of the homes of survey respondents due to cost challenges.

Of those who reported that they had noticed a change in home smell one-week postfire, 368 (93.6%) said that the smell had improved over time. Only n = 5 (1.3%) said that the smell had gotten worse, and n = 16 (4%) said that it had stayed the same. Of those who said that the smell improved over time, most attributed the improvement in smell to the passage of time (72%), their own cleaning (71.2%), using air cleaners in the home (68.3%), and hiring a cleaning/remediation company (59.4%). Of the 12% who said there was another reason that was not provided in the survey, many listed that what improved the smell was removing things from the house that may have absorbed chemicals and gases such as carpet, textiles, and furniture, while others reported that opening windows, replacing furnace filters, and cleaning surfaces and air ducts improved the smell.

Ash Impacts on Homes. Only people who were living in their home (whether damaged or not) at Wave 1 were asked if they found ash when they returned to their home postfire. Of these people, 65.7% (N = 378 out of 575) reported that they found ash inside of their home. 71% found ash inside the doors of their home on the floor, 94% found ash on the windowsills, 53% in their HVAC filter, 55% in their attic, 82% in their garage, and 27% in another spot. These other locations included many responses of surfaces, including countertops and tables, but also on beds, furniture, and carpet, on the walls, in vents, in the yard (one respondent reported "6+ in. in the backyard"), in insulation, and miscellaneous locations, including "on microwave dish" and "inside boxes stored in closets". People commented that the ash came in through stove vents and dryer vents, and a few commented that there was a "thin film" of ash everywhere within their homes.

Spatial Clustering of Air Quality Perceptions. We found consistent statistically significant spatial clustering of perception of home smell changes one-week postfire and

Table 3. Odds Ratios and 95% Confidence Intervals (Using Bonferroni Adjustment) Associated with Each Exposure from Simple Logistic Regressions[a]

symptom reported six months post-fire	perceived bad neighborhood AQ 6 months postfire (N = 588)	perceived bad home AQ 6 months postfire (N = 590)	home smelled differently 1-week postfire (N = 610)	saw ash inside home upon return home post-fire (N = 570)	count of destroyed buildings within 250 m of home[b] (N = 642)	distance to nearest destroyed building[b] (N = 642)	count of destroyed homes west of home (and within 1000 m)[c] (N = 642)	distance to nearest destroyed building to the west[c] (N = 642)
allergic skin reaction	3.84 (0.90, 16.3)	3.14 (0.70, 14.1)	15.52 (0.44, 550)	6.49 (0.49, 86.3)	1.20 (0.87, 1.64)	0.87 (0.69, 1.10)	1.05 (0.96, 1.13)	0.97 (0.89, 1.05)
difficulty breathing	3.51 (0.85, 14.5)	2.12 (0.43, 10.5)	8.04 (0.61, 106)	2.92 (0.43, 20.0)	1.15 (0.83, 1.59)	0.93 (0.79, 1.10)	1.01 (0.92, 1.11)	1.00 (0.96, 1.05)
dry cough	**3.21 (1.56, 6.63)**	**3.18 (1.36, 7.44)**	**3.94 (1.71, 9.10)**	2.12 (0.95, 4.70)	1.13 (0.94, 1.37)	0.93 (0.86, 1.01)	1.03 (0.98, 1.07)	0.99 (0.97, 1.02)
headache	**3.98 (1.94, 8.15)**	**3.46 (1.49, 8.05)**	**3.83 (1.73, 8.45)**	**3.33 (1.44, 7.67)**	**1.21 (1.01, 1.46)**	**0.89 (0.82, 0.97)**	**1.05 (1.00, 1.10)**	**0.97 (0.94, 1.00)**
itchy or watery eyes	**3.67 (1.81, 7.43)**	**3.46 (1.49, 8.07)**	**3.10 (1.5, 6.43)**	1.89 (0.92, 3.91)	1.17 (0.97, 1.40)	0.94 (0.88, 1.00)	1.02 (0.98, 1.07)	0.98 (0.96, 1.01)
nausea	4.07 (0.51, 32.3)	5.85 (0.75, 45.8)	3.72 (0.26, 53.5)	4.68 (0.12, 187)	1.17 (0.77, 1.78)	0.79 (0.51, 1.23)	1.06 (0.97, 1.17)	1.00 (0.94, 1.07)
shortness of breath	**3.83 (1.25, 11.7)**	**3.37 (1.01, 11.2)**	3.01 (0.75, 12.0)	1.38 (0.38, 4.94)	1.08 (0.81, 1.43)	0.95 (0.84, 1.07)	1.02 (0.94, 1.09)	1.00 (0.97, 1.04)
sneezing	**2.96 (1.43, 6.14)**	**2.66 (1.13, 6.27)**	**2.62 (1.20, 5.75)**	1.65 (0.76, 3.55)	1.06 (0.87, 1.28)	0.93 (0.86, 1.00)	1.00 (0.95, 1.05)	0.98 (0.96, 1.01)
sore throat	**3.20 (1.51, 6.76)**	**3.56 (1.50, 8.43)**	**3.65 (1.51, 8.80)**	2.26 (0.94, 5.41)	1.20 (0.99, 1.46)	0.92 (0.85, 1.00)	1.04 (0.99, 1.09)	0.98 (0.95, 1.01)
strange taste in mouth	**4.85 (1.81, 13.0)**	**6.14 (2.20, 17.2)**	**4.43 (1.14, 17.2)**	2.43 (0.64, 9.17)	**1.26 (1.00, 1.60)**	0.86 (0.73, 1.01)	1.03 (0.97, 1.10)	0.98 (0.93, 1.02)
wet cough	1.2 (0.11, 13.68)	2.41 (0.21, 27.7)	0.97 (0.11, 8.86)	0.42 (0.05, 3.53)	0.49 (0.10, 2.43)	1.00 (0.82, 1.22)	0.78 (0.43, 1.42)	1.02 (0.97, 1.08)
wheezing	2.6 (0.69, 9.79)	1.47 (0.28, 7.69)	3.30 (0.59, 18.44)	1.64 (0.35, 7.73)	1.13 (0.83, 1.55)	0.94 (0.81, 1.10)	1.03 (0.95, 1.11)	0.97 (0.91, 1.04)

[a]Bolded values are statistically significant at $p < 0.05$ using the Bonferroni adjustment. Underlined values showed statistical significance ($p<0.05$) with the FDR method. [b]ORs and 95% confidence intervals per 10 units increase in destroyed buildings. [c]ORs and 95% confidence intervals per 100 m increase in distance from the nearest destroyed building.

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clustering of reporting ash in the home postfire using four different definitions of neighbors in Moran's I calculations (Table S9). We found no spatial autocorrelation of perception of air quality in the neighborhood or the home before the fire, but we found some evidence of spatial clustering of neighborhood and home air quality perception at Wave 1 (six months postfire), depending on the neighbor definition used (Figure S3). Maps of air quality perceptions can be found in Figures S4 and S5.

Impact of Air Quality Perceptions and Spatial Exposures on Physical Symptoms Reported. Multiple symptoms were statistically significantly associated with perceived and GIS-based exposure metrics in Wave 1 (Table 3). Reporting a headache was statistically significantly associated with each of the eight exposure measures we used, all in the hypothesized direction. People who reported a headache at Wave 1 were more likely to live closer to destroyed buildings, have found ash in their home, and report that their home smelled differently postfire. They were also more likely to not be confident that the air in their home or neighborhood was safe at six months postfire. Many symptoms, including dry cough, headache, itchy or watery eyes, sneezing, sore throat, and strange taste in one's mouth were statistically significantly associated with a change in home smell after the fire. Importantly, these findings are statistically significant even after the conservative Bonferroni adjustment for multiple testing. If we were to use the less stringent False Detection Rate (FDR) method to adjust for multiple testing, dry cough and sore throat would additionally be significantly associated with seeing ash in the home upon return postfire, as would itchy or watery eyes, sneezing, sore throat, and strange taste in mouth with distance to nearest destroyed building (Table 3).

DISCUSSION

Our study aimed to understand air quality perceptions and physical health impacts of the Marshall Fire for people whose homes were not destroyed. Many people returned to homes that were damaged by smoke and/or ash. Indeed, in our study sample, over 61% (N = 393 out of 610) reported that their home smelled differently and over 65% (N = 378 out of 575) reported that they found ash when they returned after the fire. Our analyses showed that reporting smoke or ash impacts was spatially clustered. We also found a clear decline in confidence in neighborhood and home air quality at six months postfire compared to before the fire (as reported at Wave 1) that mostly improved by Wave 2. Physical health symptoms were reported more often by people whose homes were damaged by smoke or ash. Some of these symptoms, specifically sneezing, headaches, and sore throat, were spatially clustered and significantly associated with reporting their home smelled differently postfire. Physical health symptoms were statistically significantly associated with perceived air quality (dry cough, headache, itchy or watery eyes, shortness of breath, sneezing, sore throat, and a strange taste in one's mouth) and spatial measures of proximity to burned structures (headache, strange taste in mouth). Additionally, reporting a headache after the fire was statistically significantly associated with finding ash in one's home and living closer to more destroyed buildings, particularly those in the direction from which the winds blew during the fires. Reporting a strange taste in one's mouth was associated with living near more destroyed buildings. These findings suggest that residents of smoke- and ash-damaged homes may have experienced lingering air quality and physical health challenges that persisted for months after the fire.

These findings are the first, to our knowledge, to scientifically document physical health harm of smoke and ash damage from a WUI fire. The symptoms are consistent with chemical exposures that would be expected from burning structures and vehicles,[9] which was most of what burned during this fire.[24]

Respondents who found visible ash in their homes were over three times more likely to report headaches than people who did not find ash in their homes. With a slightly less conservative approach to multiple testing, dry cough and sore throat were also statistically significantly associated with finding ash in one's home postfire. We should note that the analyses of this exposure did not include survey respondents who were not living in their homes at the time of the survey, which gives us less power to detect significant associations than our other exposure metrics. In-home measurements that our team collected just after the Marshall Fire showed significant enhancement of copper, zinc, and moderate enhancement of arsenic and high concentrations of PAHs in ash from smoke-affected homes as compared to nonsmoke-affected homes,[16] although these samples cannot be linked to survey responses. A study from another research group found elevated levels of copper, zinc, lead, and chromium in soils in burnt areas near homes affected by the Marshall Fire as compared to nonburnt soil.[17] Our prior work also showed that indoor $PM_{2.5}$ levels increased when homes were being cleaned, implying resuspension of ash/dust[16] during cleaning could be a pathway of exposure among people in homes with fire ash whether they returned to live in the homes or not. Copper and zinc, while helpful to the body in low doses, can be associated with headaches if ingested at higher concentrations,[25,26] and copper inhalation has been associated with irritation to nose and throat.[27] PAHs in indoor dust have been associated with sick building syndrome which includes symptoms such as headache, throat irritation and more.[28] Because we do not have data on concentrations of these chemicals in the homes of our survey respondents, we cannot assess associations between specific exposures and reported symptoms.

Respondents who reported that their home smelled differently one-week postfire had significantly higher odds of reporting dry cough, headache, itchy or watery eyes, sneezing, sore throat, and strange taste in their mouth six months postfire. The change in smell could be due to off-gassing of VOCs from porous surfaces which we found to be significantly elevated in samples of smoke-affected homes a few weeks postfire.[16] VOCs are known to have strong smells. While we do not know the specific VOCs causing smells in the homes of our study participants, experimental studies show that homes emit more benzene per unit mass burned than biomass[9] and in the Marshall Fire, the predominant fuel was homes. While high level exposure to benzene can cause death or cancer, lower level benzene exposure, which is what we expect in these instances, is associated with headaches.[29] Exposure to other VOCs are associated with eye, nose and throat irritation, headaches, allergic skin reactions, nausea and more.[30] Knowing which VOCs were in these houses, for how long, and how much time people spent in their homes would be necessary to make a clear link between exposure and outcome. A recent experimental study of mitigation measures in a smoke-damaged home found that surface cleaning activities (such as vacuuming and mopping) were more effective in reducing

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ACS EST Air 2025, 2, 13−23

VOC concentrations in the home than air cleaners or opening windows[31] and another study on this same fire found that VOC concentrations were reduced by using air cleaners with carbon-activated filters and opening windows for a few weeks (Dresser et al. 10.1021/acsestair.4c00259).

Our study also provides information on what measures individuals found to be effective at removing smells postfire. These included cleaning the home, the passage of time, using air cleaners/purifiers, hiring a remediation company, opening windows, removing carpet, textiles, and furniture from the home, cleaning surfaces, and cleaning air ducts. In other work on experimental tests of mitigating indoor VOCs in smoke-affected homes of the Marshall Fire, opening windows, using air cleaners with carbon-activated filters, and the passage of time all were shown to help decrease VOC concentrations, which are likely associated with changes in smell in smoke-affected homes (Dresser et al. 10.1021/acsestair.4c00259). There has not been much research into perceived air quality exposures after wildfires. The Smoke Sense studies that have used an online app to assess people's exposures, symptoms, and behavior changes due to wildfires (but not necessarily WUI fires) provide some evidence of the validity of people's perceptions of smoke. They found that 80% of observations reporting smoke and 51% of observations of smelling smoke inside or outside of their home coincided with a smoke plume, as verified with the satellite imagery defined smoke polygons from the NOAA HMS project overlapping the home ZIP code.[32] While this could denote that there could be skepticism of people's perceptions of smoke, there is also documented evidence of discrepancies between the NOAA HMS smoke polygons and ground level $PM_{2.5}$ concentrations including high $PM_{2.5}$ when the polygons do not include any smoke.[33] In our study, it is important to note that, due to the unique aspects of this WUI fire in which snow cleaned the outdoor air just after the fire ended,[16] the main air quality concern was within homes rather than outside. Although we were able to sample the indoor air in eight smoke-damaged homes right after the fire,[32] it would be cost-prohibitive to have sampled in the homes of all 642 survey respondents used in our sample, thus we had to use proxy measures of exposure such as air pollution perceptions. We do not solely rely on perceptions of air quality but also on self-reported ash and smell change in the home and also proximity to burnt structures. Our finding that headaches and strange taste in the mouth were statistically significantly associated with count of destroyed buildings within 250m of the home (and that sore throat would be under the FDR method of multiple testing) and that headaches (and itchy or watery eyes, sneezing, sore throat, and strange taste in mouth using the FDR method for multiple testing) were statistically significantly associated with living closer to destroyed buildings bolsters our findings of significant symptom reporting that could be due to chemical exposure from smoke or ash damage to the home.

There are some important caveats in the findings in this study. First, we were not able to sample ash or indoor air quality in the homes of survey respondents, so we do not know the chemical content of the ash or the gases that may have caused the reported smells or health symptoms. We also do not have information on how much time the individuals spent in their homes or how they cleaned them postfire which could inform calculations of exposure to any potential chemicals. While our study provides evidence that ash and smells within damaged homes were associated with a higher reporting of symptoms that could have been caused by exposures to the fire at the aggregate level, we cannot infer those associations for any individual. Our analyses also could have failed to find linkages to symptoms that we did not ask about in our survey and that did not arise in the free response sections.

Some of our findings on linkages between exposures and health outcomes could be due to self-report bias and reverse causality; people who experienced symptoms may be more likely to report exposures than people who are not experiencing symptoms. Our findings that some symptoms were also associated with proximity to burned structures, however, bolsters our argument that these associations are not entirely due to self-report. It is also possible that some of the reported symptoms could be due to psychosomatic responses to the fire in addition to or instead of through physical pathways. We contend, however, that physical health symptoms, regardless of whether they are reported in part or wholly from psychosomatic processes, are no less real for the people experiencing them. Additional ongoing research focuses on the mental health impacts of the Marshall Fire. Another potential confounder is related to seasonality; Wave 1 of the survey took place during late spring/summer when allergies may have caused some of the reported symptoms (such as itchy or watery eyes or sneezing). Our consistent finding that headaches and strange taste in one's mouth were associated with multiple fire-related exposures, however, implies that are findings are unlikely to be confounded by seasonal allergies. Additionally, the symptom question in the survey did ask that respondents list only symptoms that they believed were due to the fire.

Despite these caveats and limitations, this study demonstrates the value of collecting perishable data on exposures and health impacts in a postdisaster context. Part of our research team quickly assembled to collect indoor air quality and ash samples from smoke-affected homes. For the survey work, members of our research team collaborated with a large network of local and national scientists as well as community organizations to conduct the Marshall Fire Unified Research survey to limit the number of surveys to which affected community members would be asked to respond. This unified survey included questions assessing perceptions of environmental impacts and physical health symptoms along with a wide range of other topics (e.g., evacuation experiences, relocation and rebuilding decisions, and mental health). To our knowledge, most other postdisaster survey efforts have been more limited in scope (e.g., assessing water quality perceptions post-Camp Fire).[34] The Natural Hazards Center, located close to the study area at CU Boulder, and funding from NSF's RAPID grants program were instrumental in facilitating this data collection. Postdisaster data collection requires overcoming significant challenges and minimizing burdens on disaster-affected communities. Thoughtful and trauma-informed approaches can inform community recovery efforts and contribute to more generalizable knowledge on disaster impacts.

Our findings of spatially clustered symptoms and air quality perceptions could inform more targeted interventions in the aftermath of a WUI fire. Given our findings of physical health symptoms that could be due to either inhalation of gaseous pollutants or resuspended dust in smoke or ash damaged homes, teams approaching communities with smoke-damaged homes could provide personal protective equipment (PPE) such as masks (preferably N95 or KN95 type masks that protect the user from the air around them), gloves, and gowns for use while cleaning a smoke-damaged home post fire.

To the best of our knowledge, this study is the first to document physical health symptoms within a population whose homes were smoke-damaged but not destroyed by a WUI fire. Our findings are important for numerous reasons. Previous work has shown that human-made materials, those that were predominantly burned during this WUI fire, often have more toxic emissions than the burning of vegetation[9] in wildfires. In addition to the increase in burned structures during wildfires in recent years,[35] evidence shows that removal of gas-phase chemicals such as VOCs, is difficult from smoke-damaged homes.[31] Many individuals whose homes were severely affected by smoke and ash following the Marshall Fire have faced significant challenges in accessing insurance and other resources to remediate their homes.[36] Uncertainty around the health impacts of WUI fires has contributed to a lack of clear guidance and regulations around home remediation and when it is safe to return to a smoke or ash damaged home. Recent legislation in Colorado will begin to address this issue by funding a study, to be conducted by the Division of Insurance, aimed at setting standards for the remediation of homes damaged in a fire.[37] Evidence of residents' experiences and reported health symptoms, including the results presented here, should inform the development of those standards. Since the Marshall Fire, there have been multiple other fires, including the Lahaina Fire in Maui in 2023, in which most of what burned was human-made, and many nearby homes were severely smoke damaged. To protect people's health, it is important to document the impacts of WUI fires to improve emergency response and remediation guidelines for people whose homes were damaged, but not destroyed, by a WUI fire.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acsestair.4c00258.

Results from additional analyses (PDF)

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Notes

The authors declare no competing financial interest.

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REFERENCES

(1) Abatzoglou, J. T.; Williams, A. P. Impact of Anthropogenic Climate Change on Wildfire across Western US Forests. *Proc. Natl. Acad. Sci. U. S. A.* **2016**, *113* (42), 11770−11775.

(2) Liu, Y.; Liu, Y.; Fu, J.; Yang, C.-E.; Dong, X.; Tian, H.; Tao, B.; Yang, J.; Wang, Y.; Zou, Y.; Ke, Z. Projection of Future Wildfire Emissions in Western USA under Climate Change: Contributions from Changes in Wildfire, Fuel Loading and Fuel Moisture. *Int. J. Wildland Fire* **2022**, *31* (1), 1−13.

(3) McClure, C. D.; Jaffe, D. A. US Particulate Matter Air Quality Improves except in Wildfire-Prone Areas. *Proc. Natl. Acad. Sci. U. S. A.* **2018**, *115* (31), 7901−7906.

(4) Childs, M. L.; Li, J.; Wen, J.; Heft-Neal, S.; Driscoll, A.; Wang, S.; Gould, C. F.; Qiu, M.; Burney, J.; Burke, M. Daily Local-Level Estimates of Ambient Wildfire Smoke PM2.5 for the Contiguous US. *Environ. Sci. Technol.* **2022**, *56*, 13607.

(5) O'Dell, K.; Ford, B.; Fischer, E. V.; Pierce, J. R. Contribution of Wildland-Fire Smoke to US PM2.5 and Its Influence on Recent Trends. *Environ. Sci. Technol.* **2019**, *53* (4), 1797−1804.

(6) Reid, C. E.; Brauer, M.; Johnston, F. H.; Jerrett, M.; Balmes, J. R.; Elliott, C. T. Critical Review of Health Impacts of Wildfire Smoke Exposure. *Env. Health Perspect* **2016**, *124* (9), 1334−1343.

(7) Gould, C. F.; Heft-Neal, S.; Prunicki, M.; Aguilera, J.; Burke, M.; Nadeau, K. Health Effects of Wildfire Smoke Exposure. *Annu. Rev. Med.* **2024**, *29*, 277−292.

(8) Cascio, W. E. Wildland Fire Smoke and Human Health. *Sci. Total Environ.* **2018**, *624*, 586−595.

(9) Holder, A. L.; Ahmed, A.; Vukovich, J. M.; Rao, V. Hazardous Air Pollutant Emissions Estimates from Wildfires in the Wildland Urban Interface. *PNAS Nexus* **2023**, *2* (6), pgad186.

(10) National Academies of Sciences, Engineering, and Medicine; Division on Earth and Life Studies; Board on Chemical Sciences and Technology; Committee on the Chemistry of Urban Wildfires. *Chemistry of Fires at the Wildland-Urban Interface*; The National Academies Collection: Reports funded by National Institutes of Health; National Academies Press (US): Washington (DC), 2022.

(11) Nelson, D. Air quality issues don't go away when the fire is out": Questions remain about long-term Marshall fire health effects. The Colorado Sun. http://coloradosun.com/2022/12/29/colorado-marshall-fire-air-quality-issues/ (accessed 2024−05−09).

(12) Liu, N.; Bu, Z.; Liu, W.; Kan, H.; Zhao, Z.; Deng, F.; Huang, C.; Zhao, B.; Zeng, X.; Sun, Y.; Qian, H.; Mo, J.; Sun, C.; Guo, J.; Zheng, X.; Weschler, L. B.; Zhang, Y. Health Effects of Exposure to Indoor Volatile Organic Compounds from 1980 to 2017: A Systematic Review and Meta-Analysis. *Indoor Air* **2022**, *32* (5), No. e13038.

(13) Chen, L. C.; Lippmann, M. Effects of Metals within Ambient Air Particulate Matter (PM) on Human Health. *Inhal. Toxicol.* **2009**, *21*, 1.

(14) Mallah, M. A.; Changxing, L.; Mallah, M. A.; Noreen, S.; Liu, Y.; Saeed, M.; Xi, H.; Ahmed, B.; Feng, F.; Mirjat, A. A.; Wang, W.; Jabar, A.; Naveed, M.; Li, J.-H.; Zhang, Q. Polycyclic Aromatic Hydrocarbon and Its Effects on Human Health: An Updated Review. *Chemosphere* **2022**, *296*, 133948.

(15) Fovell, R. G.; Brewer, M. J.; Garmong, R. J. The December 2021 Marshall Fire: Predictability and Gust Forecasts from Operational Models. *Atmosphere* **2022**, *13* (5), 765.

(16) Silberstein, J. M.; Mael, L. E.; Frischmon, C. R.; Rieves, E. S.; Coffey, E. R.; Das, T.; Dresser, W.; Hatch, A. C.; Nath, J.; Pliszka, H. O.; Reid, C. E.; Vance, M. E.; Wiedinmyer, C.; De Gouw, J. A.; Hannigan, M. P. Residual Impacts of a Wildland Urban Interface Fire on Urban Particulate Matter and Dust: A Study from the Marshall Fire. *Air Qual. Atmosphere Health* **2023**, *16* (9), 1839−1850.

(17) Jech, S.; Adamchak, C.; Stokes, S. C.; Wiltse, M. E.; Callen, J.; VanderRoest, J.; Kelly, E. F.; Hinckley, E.-L. S.; Stein, H. J.; Borch, T.; Fierer, N. Determination of Soil Contamination at the Wildland-Urban Interface after the 2021 Marshall Fire in Colorado, USA. *Environ. Sci. Technol.* **2024**, DOI: 10.1021/acs.est.3c08508.

(18) Dickinson, K.; Devoss, R.; Albright, E.; Crow, D.; Rumbach, A.; Bean, H.; Fraser, T.; Reid, C.; Bolhari, A.; Welton-Mitchell, C.; Andre, C.; Aldrich, D.; Morss, R.; Whelton, A.; Javernick-Will, A.; Irvine, L.; du Bray, M.; Rubenfeld, S.; Tillema, S. Marshall Fire Unified Survey, 2022. DOI: 10.17603/DS2-0YC8-4H27.

(19) Boulder County. Marshall Fire - Damage Assessment. https://bouldercounty.maps.arcgis.com/apps/webappviewer/index.html?id=9f3314c39ad64fac925101aae0bdd62c (accessed 2024−05−09).

(20) Kahle, D.; Wickham, H.; Jackson, S.; Korpela, M. Ggmap: Spatial Visualization with Ggplot2, 2023. https://cran.r-project.org/web/packages/ggmap/index.html (accessed 2024−05−29).

(21) Bivand, R. S.; Wong, D. W. Comparing Implementations of Global and Local Indicators of Spatial Association. *Test* **2018**, *27* (3), 716−748.

(22) VanderWeele, T. J.; Mathur, M. B. Some Desirable Properties of the Bonferroni Correction: Is the Bonferroni Correction Really so Bad? *Am. J. Epidemiol.* **2019**, *188* (3), 617−618.

(23) R Core Team. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, 2023. https://www.R-project.org/.

(24) Albidrez, A. B., Anthony. Why the Marshall Fire was bad for the health of "standing homes. The Boulder Reporting Lab, http://boulderreportinglab.org/2022/12/06/why-the-marshall-fire-was-bad-for-the-health-and-safety-of-standing-homes/ (accessed 2024−07−17).

(25) Mount Sinai Health System. Zinc Information | Mount Sinai - New York. Mount Sinai Health System, https://www.mountsinai.org/health-library/supplement/zinc (accessed 2024−06−18).

(26) Mount Sinai Health System. Copper Information | Mount Sinai - New York. Mount Sinai Health System, https://www.mountsinai.org/health-library/supplement/copper (accessed 2024−06−18).

(27) Agency for Toxic Substances and Disease Registry. Copper - ToxFAQs. 2024. https://www.atsdr.cdc.gov/toxfaqs/tfacts132.pdf.

(28) Mosallaei, S.; Hashemi, H.; Hoseini, M.; Dehghani, M.; Naz, A. Polycyclic Aromatic Hydrocarbons (PAHs) in Household Dust: The Association between PAHs, Cancer Risk and Sick Building Syndrome. *Build. Environ.* **2023**, *229*, 109966.

(29) Agency for Toxic Substances and Disease Registry. Benzene | Public Health Statement | ATSDR. https://wwwn.cdc.gov/TSP/PHS/PHS.aspx?phsid=37&toxid=14 (accessed 2024−06−18).

(30) US EPA, O. Volatile Organic Compounds' Impact on Indoor Air Quality. https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality (accessed 2024−06−18).

(31) Li, J.; Link, M. F.; Pandit, S.; Webb, M. H.; Mayer, K. J.; Garofalo, L. A.; Rediger, K. L.; Poppendieck, D. G.; Zimmerman, S. M.; Vance, M. E.; Grassian, V. H.; Morrison, G. C.; Turpin, B. J.; Farmer, D. K. The Persistence of Smoke VOCs Indoors: Partitioning, Surface Cleaning, and Air Cleaning in a Smoke-Contaminated House. *Sci. Adv.* **2023**, *9* (41), No. eadh8263.

(32) Rappold, A. G.; Hano, M. C.; Prince, S.; Wei, L.; Huang, S. M.; Baghdikian, C.; Stearns, B.; Gao, X.; Hoshiko, S.; Cascio, W. E.; Diaz-Sanchez, D.; Hubbell, B. Smoke Sense Initiative Leverages Citizen Science to Address the Growing Wildfire-Related Public Health Problem. *GeoHealth* **2019**, *3* (12), 443−457.

(33) Fadadu, R. P.; Balmes, J. R.; Holm, S. M. Differences in the Estimation of Wildfire-Associated Air Pollution by Satellite Mapping of Smoke Plumes and Ground-Level Monitoring. *Int. J. Environ. Res. Public Health* **2020**, *17* (21), 8164.

(34) Odimayomi, T. O.; Proctor, C. R.; Wang, Q. E.; Sabbaghi, A.; Peterson, K. S.; Yu, D. J.; Lee, J.; Shah, A. D.; Ley, C. J.; Noh, Y.; Smith, C. D.; Webster, J. P.; Milinkevich, K.; Lodewyk, M. W.; Jenks, J. A.; Smith, J. F.; Whelton, A. J. Water Safety Attitudes, Risk Perception, Experiences, and Education for Households Impacted by the 2018 Camp Fire, California. *Nat. Hazards* **2021**, *108* (1), 947−975.

(35) Higuera, P. E.; Cook, M. C.; Balch, J. K.; Stavros, E. N.; Mahood, A. L.; St. Denis, L. A. Shifting Social-Ecological Fire Regimes Explain Increasing Structure Loss from Western Wildfires. *PNAS Nexus* **2023**, *2* (3), pgad005.

(36) Flowers, T. More than 100 homes are still uninhabitable from Marshall fire smoke and ash contamination. The Colorado Sun. http://coloradosun.com/2023/04/19/marshall-fire-smoke-ash-home-uninhabitable/ (accessed 2024−08−09).

(37) Cutter, L.; Amabile, J.; Brown, K. Study on Remediation of Property Damaged by Fire. 2024. https://leg.colorado.gov/bills/hb24-1315#:~:text=The%20study%20focuses%20on%20existing,standards%20related%20to%20such%20remediation.