



# Unequal social vulnerability to Hurricane Sandy flood exposure

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## Abstract

Disparities exist in post-disaster flooding exposure and vulnerable populations bear a disproportionate impact of this exposure. We describe the unequal burden of flooding in a cohort of New York residents following Hurricane Sandy and assess whether the likelihood of flooding was distributed equally according to socioeconomic demographics, and whether this likelihood differed when analyzing self-reported or FEMA flood exposure measures. Residents of New York City and Long Island completed a self-administered survey 1.5–4.0 years after the storm. Multivariable logistic regressions were performed to determine the relationship between sociodemographic characteristics and flood exposure. Participants ( $n = 1231$ ) residing in areas of the lowest two quartiles of median household income experienced flooding the most often (FEMA/self-reported: <\$40,298: 65.3%/42.0%, \$40,298–\$67,188: 43.3%/32.1%), and these areas contained the highest proportions of non-White participants (<\$40,298: 39.1%, \$40,298–\$67,188: 36.6%) and those with ≤high school education (<\$40,298: 35.5%, \$40,298–\$67,188: 33.6%). Both self-report ( $p < 0.05$ ) and FEMA ( $p < 0.05$ ) flood measures indicated that older participants were more likely to live in a household exposed to flooding, while those living in higher-income areas had decreased likelihood of flooding ( $p < 0.0001$ ). Socioeconomic and age disparities were present in exposure to flooding during Hurricane Sandy. Future disaster preparedness responses must understand flooding from an environmental justice perspective to create effective strategies that minimize disproportionate exposure and its adverse outcomes.

**Keywords** Flooding · Disparities · Environmental justice.

## Introduction

An environmental justice approach to natural disasters aims to determine if specific disadvantaged populations bear a disproportionate impact of the event [1, 2]. Research has commented that racial/ethnic minorities and lower-income populations are more likely to live in close proximity to

environmental hazards [3, 4], and that this is likely to result in a disproportionate impact of the exposure in these populations [3, 5]. After Hurricane Katrina, research identified that Black and low-income residents of New Orleans were exposed to a disproportionate amount of flooding, displacement from their homes, and long-term mental health concerns [6–10]. After Hurricane Harvey, non-Hispanic Black and socioeconomically deprived residents faced a higher burden of flood exposure, suggesting that racial, ethnic, and socioeconomic disparities existed [5]. In addition to identifying vulnerable populations and risk factors for exposure, disaster preparedness efforts must identify these disparities in order to appropriately address the consequences of a traumatic event. Here, we describe the unequal burden of flooding in a cohort of New York residents following Hurricane Sandy. The objective of this analysis was to determine whether the likelihood of flooding was distributed equally in the study sample according to demographics, with a particular focus on median household income, and whether this likelihood differed when studying self-reported flood exposure or Federal Emergency Management Agency (FEMA) flood exposure measures.

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## Methods

### Participants

The full study methodology has been described previously [11]; residents of Long Island, Queens, and Staten Island who lived in areas ranging from mildly to heavily affected by Hurricane Sandy consented and completed a self-administered survey 1.5–4.0 years after the storm. While convenience sampling was utilized for recruitment, demographic characteristics of study participants were consistently compared to the demographic distribution of the county assessed from census data, and adjustment in recruitment strategies was performed when the comparability of the study sample to the distribution of residents living in that location was not met [11]. At the end of the recruitment, the recruited population was congruous to the 2010 census data for the sampled geographies [11]. Approval for this study was given by the institutional review board of the Feinstein Institute for Medical Research at Northwell Health and the Icahn School of Medicine at Mount Sinai.

### Survey variables

The survey queried demographics, hurricane exposure, and medical/behavioral health status, including questions regarding their mental health history before and after Hurricane Sandy. Participants also recorded if they experienced flooding (yes/no) at their residence during Hurricane Sandy, and if they resided in an apartment building (yes/no). Participant addresses lived in during Hurricane Sandy were then geocoded as previously described [11]. Median household income for 2012 at the zip code tabulation area (ZCTA) level was downloaded from American Community Survey 5-year estimates [12], and each participant was assigned a median household income value for the ZCTA they resided in during Hurricane Sandy.

### Outcome variables

Two binary measures of flood exposure were considered in the current analysis. Survey values on flood exposure (yes/no) was used to define self-reported exposure while flood data from the FEMA Modeling Task Force Hurricane Sandy Impact Analysis was utilized to provide a comparative measure of flood exposure [13]. Geocoded addresses for each participant were assigned a binary flood value (yes/no) according to FEMA data.

### Statistical analysis

Univariate comparisons in FEMA and self-reported flood exposures and in median household income according to

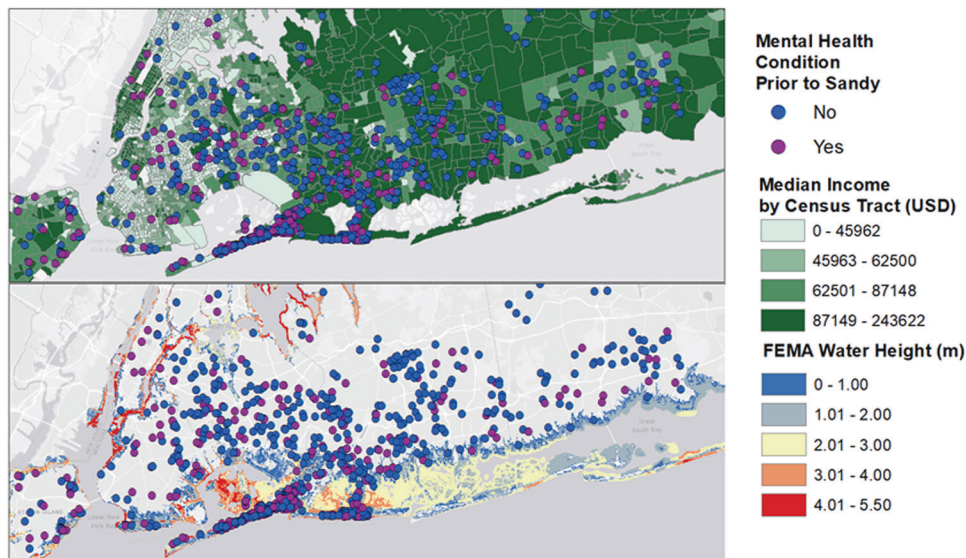
dichotomized study variables were performed using Chi-square tests. Associations between demographic variables and flood exposure were investigated using multivariate logistic regression, adjusting for the following covariates: age (quartiles 18–27, 28–45, 46–58, and 58+ years), race (White, non-White), education ( $\leq$ high school and  $>$ high school completed), existing mental health conditions prior to Hurricane Sandy (yes/no), living in an apartment during Hurricane Sandy (yes/no), and median household income according to 2012 US ZCTAs (quartiles  $<$ \$40,298, \$40,298–\$67,188, \$67,189–\$89,684, and  $>$ \$89,684). Existing mental health conditions were defined as reporting at least one of the following mental health issues: anxiety disorder, depression, post-traumatic stress disorder (PTSD), schizophrenia, bipolar, substance/alcohol abuse, substance/prescription abuse, or other mental health problems. All significant findings are reported at the level of  $p < 0.05$  or  $p < 0.001$ . Statistical analyses were performed using SAS (version 9.4; SAS Institute Inc., Cary, NC). Code for analyses can be made available by contacting the corresponding author.

## Results

Participants ( $n = 1231$ ) were sampled from areas of varying median household incomes and flood exposure across New York City and Long Island (Fig. 1). At univariate analysis, the lowest two income quartiles contained a disproportionate number of those who experienced flooding in both self-reported ( $<$ \$40,298 income quartile: 65.3% experienced flooding; \$40,298–\$67,188: 43.3%; \$67,189–\$89,684: 29.2%;  $>$ \$89,684: 12.7%;  $p < 0.0001$ ) and FEMA measures ( $<$ \$40,298: 42.0%; \$40,298–\$67,188: 32.1%; \$67,189–\$89,684: 31.3%;  $>$ \$89,684: 18.4%;  $p < 0.0001$ ; Table 1). Non-White participants were more likely to experience flooding (45.2%) than White participants (36.3%) according to the FEMA measure ( $p = 0.0017$ ). Older adults, including those aged 46–58 years, were the largest group experiencing flooding under both measures (Table 1). A greater proportion of participants with an existing mental health condition prior to Hurricane Sandy self-reported flooding compared to those not reporting an existing mental health condition (38.0% vs 28.9%,  $p = 0.0010$ ), as well as experienced flooding according to the FEMA measure (47.0% vs 36.7%,  $p = 0.0004$ ). A greater proportion of those with  $\leq$ high school education (50.8%) compared to those with  $>$ high school education (33.6%) were more likely to experience flooding using the FEMA measure ( $p < 0.0001$ ). This difference was not reported for those self-reporting flooding: 33.8% of participants with  $<$ high school education reported flooding and 31.2% of participants with  $>$ high school education reported flooding ( $p = 0.3496$ ).

When data was analyzed according to quartiles of median household income, those with  $>$ high school education were

**Fig. 1** Distribution of participants ( $n = 1231$ ) according to the presence of mental health conditions prior to Hurricane Sandy and income (top) or FEMA flood exposure (bottom) across New York City and Long Island. Data were overlaid on 2012 median household income data from US census tracts downloaded from 5-year American Community Survey estimates, as well as the FEMA MOTF flood height layer [12].



**Table 1** Distribution of study characteristics according to FEMA and self-reported flood exposure ( $n = 1231$ ).

Variable	Categories	FEMA flooding			Self-reported flooding		
		No	Yes	<i>p</i> -Value	No	Yes	<i>p</i> -Value
Gender	Female	289 (60.6)	188 (39.4)	0.5837	333 (69.8)	144 (30.2)	0.2437
	Male	442 (59.0)	307 (41.0)		499 (66.6)	250 (33.4)	
Race	White	410 (63.7)	234 (36.3)	0.0017	447 (69.4)	197 (30.6)	0.1344
	Non-White	310 (54.8)	256 (45.2)		370 (65.4)	196 (34.6)	
Education	≤High school	231 (49.2)	239 (50.8)	<0.0001	311 (66.2)	159 (33.8)	0.3496
	>High school	474 (66.4)	240 (33.6)		491 (68.8)	223 (31.2)	
Existing mental health condition	No	496 (63.4)	287 (36.6)	0.0004	557 (71.1)	226 (28.9)	0.0010
	Yes	236 (53.0)	209 (47.0)		276 (62.0)	169 (38.0)	
Apartment Residence	No	422 (70.9)	173 (29.1)	<0.0001	411 (69.1)	184 (30.9)	0.3871
	Yes	311 (49.0)	324 (51.0)		424 (66.8)	211 (33.2)	
Age (years)	18–27	225 (73.8)	80 (26.2)	<0.0001	235 (77.1)	70 (22.9)	<0.0001
	28–45	170 (55.9)	134 (44.1)		197 (64.8)	107 (35.2)	
	46–58	125 (44.2)	158 (55.8)		164 (58.0)	119 (42.0)	
	>58	208 (63.2)	121 (36.8)		232 (70.5)	97 (29.5)	
Median household income (USD)	<\$40,298	124 (34.7)	233 (65.3)	<0.0001	207 (58.0)	150 (42.0)	<0.0001
	\$40,298–\$67,188	196 (56.7)	150 (43.3)		235 (67.9)	111 (32.1)	
	\$67,189–\$89,684	201 (70.8)	83 (29.2)		195 (68.7)	89 (31.3)	
	>\$89,684	213 (87.3)	31 (12.7)		199 (81.6)	45 (18.4)	

Age was treated as a categorical variable according to quartiles. Participants were assigned a median household income quartile according to 2012 ZCTA data. Comparisons were performed between each variable and each flood measure using Chi-squared tests, not across flood measures.

equally distributed among income quartiles (<\$40,298: 23.5%, \$40,298–\$67,188: 36.6%, \$67,189–\$89,684: 23.9%, >\$89,684: 23.2%), while the lowest two income quartiles contained a disproportionate amount of those with ≤high school education (<\$40,298: 35.5%; \$40,298–\$67,188: 33.6%, \$67,189–\$89,684: 16.6%, >\$89,684: 14.3%; Table 2). These lowest two income quartiles also contained the highest proportions of participants with an existing

mental health condition prior to Hurricane Sandy (<\$40,298: 34.2%, \$40,298–\$67,188: 27.6%). White participants were more represented in higher-income quartiles (\$67,189–\$89,684: 26.9%, >\$89,684: 32.8%), while non-White participants were most present in those lower-income quartiles (<\$40,298: 39.1%, \$40,298–\$67,188: 36.6%;  $p < 0.0001$ ). Those aged 28–45 and 46–58 years were most commonly found in the lowest quartiles of income, while those age

**Table 2** Distribution of characteristics of the study sample among quartiles of median household income ( $n = 1231$ ).

Variable	Categories	Quartiles of median household income (USD)				<i>p</i> -Value
		<\$40,298	\$40,298–\$67,188	\$67,189–\$89,684	>\$89,684	
Gender	Female	145 (30.4)	133 (27.9)	112 (23.5)	87 (18.2)	0.5629
	Male	207 (27.6)	213 (28.4)	172 (23.0)	157 (21.0)	
Race	White	126 (19.5)	134 (20.8)	173 (26.9)	211 (32.8)	<0.0001
	Non-White	221 (39.0)	207 (36.6)	108 (19.1)	30 (5.3)	
Education	≤High School	167 (35.5)	158 (33.6)	78 (16.6)	67 (14.3)	<0.0001
	>High School	168 (23.5)	181 (25.4)	199 (23.9)	166 (23.2)	
Existing mental health condition	No	202 (25.8)	223 (28.5)	195 (24.9)	163 (20.8)	0.0169
	Yes	152 (34.2)	123 (27.6)	89 (20.0)	81 (18.2)	
Apartment residence	No	104 (21.1)	105 (21.3)	200 (40.7)	83 (16.9)	<0.0001
	Yes	253 (39.8)	241 (38.0)	83 (13.1)	58 (9.1)	
Age (years)	18–27	46 (15.1)	101 (33.1)	94 (30.8)	64 (21.0)	<0.0001
	28–45	114 (37.5)	107 (35.2)	52 (17.1)	31 (10.2)	
	46–58	108 (38.2)	88 (31.1)	57 (20.1)	30 (10.6)	
	>58	84 (25.5)	48 (14.6)	81 (24.6)	116 (35.3)	

Age was treated as a categorical variable according to quartiles. Participants were assigned a median household income quartile according to 2012 US census data. Comparisons between median household income quartiles and each variable were performed using Chi-squared tests.

>58 years were most often in the highest income quartile (35.3%).

At multivariable analysis, some factors associated with flooding remained consistent across both FEMA and self-report flood measures, as older participants including those >58 years were more likely to live in a household exposed to flooding (FEMA model  $OR_{adj}$ : 1.71, 95% confidence interval: 1.16–2.53; self-report model: 1.57, 1.07–2.32). Those living in higher median household income ZCTAs had a decreased likelihood of experiencing flooding, and this trend was evident in both FEMA ( $p < 0.001$ ) and self-reported flooding ( $p < 0.001$ ), as median household income increased (Table 3). Other associated factors differed according to the type of flood measures utilized at multivariate analysis. Models using FEMA data reported that those with ≤high school education (1.59, 1.21–2.10) and White race (0.74, 0.55–0.98) was associated with an increased likelihood of flooding. This relationship between education (1.02, 0.78–1.34) and race (0.96, 0.73–1.27) were not present when using the self-reported flood measure. Similarly, participants with an existing mental health condition prior to Hurricane Sandy were at increased risk of self-reported flooding (1.36, 1.04–1.77), but not according to FEMA flooding data (1.21, 0.92–1.59), although the two odds ratios and confidence intervals are basically overlapping. Living in an apartment during Hurricane Sandy was inversely associated with self-reported flooding only (0.73, 0.54–0.98). A directed acyclic graph conveying the relationships among predictors and flood measures has been included as Supplementary Fig. 1.

## Discussion

Previous research has identified demographic disparities in flood exposure following a hurricane [5], and that minority populations are often located in close proximity to sites where environmental exposure is present or highly possible in the case of a natural or human-made disaster [3, 4, 14]. This analysis emphasizes disproportionate flood exposure in potentially vulnerable populations, such as the aging and less affluent, and the unequal social impacts that natural disasters have. Our analysis shows that higher median household income at the ZCTA level is independently associated with less flooding, when considering both the self-reported and the FEMA flood measures. This suggests that higher-income neighborhoods may be located in safer areas than lower-income neighborhoods, where flooding from a natural disaster is more likely to occur.

We have previously published that Hurricane Sandy and Hurricane Harvey exposures have long-term mental health consequences, particularly among populations who are most vulnerable, such as those with preexisting mental health conditions [15, 16]. Here, those with existing mental health conditions prior to the hurricane were more frequently living in lower-income areas, where the most flooding extent occurred. This integrates with literature reporting an increased vulnerability to natural disasters, and their consequences among those who report mental health difficulties prior to the storm [17] and among those of lower income [18, 19]. Older adults also face additional challenges during disasters [20, 21], including difficulty in evacuating their



**Table 3** Characteristics associated with FEMA flooding (yes/no) and self-reported flooding (yes/no),  $n = 1231$  participants.

Variable	Categories	FEMA flooding		Self-reported flooding	
		OR <sub>adj</sub>	95% Confidence interval	OR <sub>adj</sub>	95% Confidence interval
Gender	Female/male	1.11	0.84–1.40	1.09	0.83–1.42
Race	Non-White/White	0.74	0.55–0.98*	0.96	0.73–1.27
Education	≤High school/ >high school	1.59	1.21–2.10*	1.02	0.78–1.34
Existing mental health condition prior to Hurricane Sandy	Yes/no	1.21	0.92–1.59	1.36	1.04–1.77*
Apartment residence	Yes/no	1.28	0.95–1.71	0.73	0.54–0.98*
Age (years)	18–27	1.00	Ref	1.00	Ref
	28–45	1.45	0.99–2.12	1.67	1.14–2.44
	46–58	2.39	1.62–3.54	2.14	1.45–3.14
	>58	1.71	1.16–2.53 <sup>a</sup>	1.57	1.07–2.32 <sup>a</sup>
Median household income (USD)	<\$40,298	1.00	Ref	1.00	Ref
	\$40,298–\$67,188	0.42	0.30–0.58	0.67	0.49–0.93
	\$67,189–\$89,684	0.27	0.18–0.39	0.62	0.43–0.90
	>\$89,684	0.09	0.05–0.14 <sup>b</sup>	0.29	0.19–0.46 <sup>b</sup>

Existing mental health status was defined as reporting at least one of the following mental health issues: anxiety disorder, depression, PTSD, schizophrenia, bipolar disorder, substance/alcohol abuse, substance/prescription abuse, or other mental health problems prior to Hurricane Sandy. Age was treated as a categorical variable according to quartiles. Participants were assigned a median household income quartile according to 2012 US census data. Logistic regression models were adjusted for gender, race, education status, existing mental health status, residing in an apartment during Hurricane Sandy, quartiles of age, and quartiles of median household income.

\* $p < 0.05$ .

<sup>a</sup>Denotes  $p < 0.05$  for trend.

<sup>b</sup>Denotes  $p < 0.001$  for trend.

homes, lack of access to medical care and prescriptions, and loss of support networks and services [22, 23]. The present results highlight the heightened vulnerability of older populations during disasters and the need for comprehensive disaster planning to reduce flood exposure. Taken together, the results suggest that lower-income neighborhoods are likely to be more exposed to the effects of a natural disaster, and are at the same time home to those who are most vulnerable to the effects of a disaster, such as older adults and those who are less educated or have previous mental health issues.

The current work also highlights the discrepancies in understanding risk factors for flooding based on how flooding is assessed. Our prior research has emphasized that while FEMA measures are more objective in providing flood assessments, self-reported measures of flood exposure can be more valuable for understanding mental health outcomes as they rely on the individual's perception of his/her exposure to flooding [11]. The present work underscores this importance, and confirms that having a mental health difficulty prior to Hurricane Sandy was significantly associated with flooding in self-report measures, but not FEMA models, although the two-point estimates were very similar. We observed that the more objective FEMA measure of flooding suggest that lower

levels of educational attainment were associated with a significant increased likelihood of flooding, but this was not captured by self-reported flooding data. As educational attainment is one component of socioeconomic status, this finding could complement the association between higher household income and less flood exposure, and warrant further research in understanding disparities in flood exposure.

The study has some limitations: the study utilized convenience sampling, thus it is possible that individuals with lower socioeconomic status, more exposure to the hurricane, and more mental health difficulties will have been more likely to agree to participate, as all participants were receiving a small monetary token for their time. However, as we made an effort to match the demographics of the sample to the general population, the sample closely matched the 2010 United States Census data on race and ethnicity [11]. Additionally, flood exposure measures must be better refined to capture those residing in apartment units. While FEMA measures can provide a flood height for a specific location that contains an apartment building, it is likely that this flooding value does not apply to all units in the apartment building. Although, we have shown that self-reported flood measures can be powerful tools to capture

people's perception of flooding as it relates to their mental health [11], it is vital regardless to calculate accurate flood exposure measures for appropriate disaster response and future preparedness.

Socioeconomic and age disparities were present in exposure to flooding during Hurricane Sandy; it is likely that the most vulnerable groups of the population end up living in less favorable areas, more prone to flooding and natural disasters. While prior research has provided quantitative data on the individual experience after hurricane exposure, more research is needed to understand the differential impact of flooding exposure and the unequal vulnerability to adverse outcomes among the exposed population to guide disaster preparedness. As the frequency and intensity of climate change-related disasters will likely increase in the future, disaster preparedness responses must understand flooding from an environmental justice perspective to create appropriate and effective strategies that minimize disproportionate exposure, and its subsequent adverse outcomes among socioeconomically vulnerable populations.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

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