



Who is vulnerable and who is resilient to coastal flooding? Lessons from Hurricane Sandy in New York City

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Abstract

Social vulnerability and resilience indices identify populations who are at risk from hazards in order to guide policy to build resilience. This study investigates which of the indicators that commonly comprise the indices reflect vulnerability and resilience to coastal flooding in urban areas based on primary data that document the impacts of and recovery from Hurricane Sandy in New York City. The study constructs measures of vulnerability and resilience that are *independent* of proposed indicators and uses regression analysis to investigate which indicators influence these measures. The analysis finds that (1) middle- and low-income homeowners are less financially resilient than are poorer renters. The recovery cost middle- to low-income homeowners 2.4 times their annual per capita incomes, while renters paid out about half of their per capita incomes. Resilience increases with income but conditional on ownership of assets that are at risk. (2) Disabled and/or chronically ill residents are more vulnerable and less resilient by many outcome measures. (3) Non-white households experience longer disruptions of access to food. (4) Information, hazard-specific capacities of community groups, and pre-hazard access to services such as food and health care are important indicators of vulnerability and resilience. (5) The evidence that other commonly proposed indicators are correlated with independent measures of vulnerability and resilience to flooding is weak. The study yields hypotheses for further research on how relevant indicators differ across hazards and contexts.

Keywords Social vulnerability · Resilience · Indicators · Extreme events · Hazards · Coastal flooding

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1 Introduction

Coastal flooding is one of the most costly extreme events in terms of both mortality and property damage, and climate change is intensifying the hazard (Frumhoff et al. 2007; Parker 2010; Rappaport 2014). Along the densely populated, urban, northeastern coast of the USA, current 100-year flood events will become approximately 30-year flood events by 2080 under central estimates of sea level rise (Horton et al. 2015; Orton et al. 2019). Hurricane Sandy was an unusual storm, but the record flood levels that devastated the greater New York City (NYC) area on October 29, 2012, will accompany more frequent storms as sea levels rise. The experience with the storm provides lessons for reducing vulnerability and improving resilience to coastal flooding (Rosenzweig and Solecki 2014).

The literature proposes indicators that are hypothesized to reflect the social vulnerability and/or resilience of populations to hazards, and therefore are expected to identify populations who are most at risk. Common indicators are demographic and socio-economic characteristics, such as income, gender, and age, as well as features of communities, institutions, infrastructure, and the environment (reviews include Ngo 2001; Cutter et al. 2009, 2014; Winderl 2014).

Indicators that reflect vulnerability and resilience should be correlated with independently measured vulnerability and resilience outcomes. This study contributes new, outcome-based measures of vulnerability and resilience that are *independent* of the proposed indicators, and uses regression analysis to investigate which indicators influence the measures. The focus is on the risk posed for urban populations by storm-driven, high-impact flooding. The measures are based on outcomes experienced by residents of two areas of NYC after Hurricane Sandy, such as damage to homes, disruption of access to basic needs, duration and costs of rebuilding, and preparation for future storms. The team collected data through a household survey of a random sample of residents and interviews with community leaders. The two study areas, Rockaway and East Shore of Staten Island, suffered similar, extensive damages during Hurricane Sandy but have different physical and socio-economic characteristics.

We analyze each outcome measure separately, rather than creating an index, in order to clarify which dimensions of vulnerability and resilience are correlated with which indicators and how the relationships should guide policy. The indicators include those commonly proposed in the literature as well as several suggested by the interview data: access to information, capacities of community groups, and features of geography and infrastructure that influence access to services.

The research contributes to the empirical foundation for indicators of vulnerability and resilience. The few studies that analyze the relationships between indicators and vulnerability outcomes focus on one outcome: mortality related to disasters (Adger et al. 2004; Brooks et al. 2005; Zahran et al. 2008). Related studies use household data to explore how particular dimensions of vulnerability or resilience are related to selected characteristics of the population (Peacock et al. 1997; Elliott and Pais 2006; Grineski et al. 2019; Collins et al. 2019; Flores et al. 2020). Furthermore, this study suggests how indicators may differ across hazards and contexts.

2 Indicators and outcome-based measures of vulnerability and resilience

2.1 Definitions

This study adopts a narrow definition of vulnerability, proposed in Cutter et al. (2008), that includes the exposure to a hazard and susceptibility to harm from exposure. A more commonly

used definition, such as in Cutter et al. (2009), also includes the ability to recover. The narrower definition permits the construction of separate outcome-based measures of vulnerability and resilience. This choice aids the exposition but does not affect the substance of the conclusions, because dimensions omitted from vulnerability are included in resilience. Under the broader definition of vulnerability, most of the outcome-based measures would be measures of both vulnerability and resilience.

This paper follows Cutter et al. (2008) to define resilience as the ability to cope with the damage incurred as a result of a hazard and to recover, including learning to build greater future resilience into the recovery. The term “resilience” is used generally to denote a return of the system to a pre-hazard state. In the context of resilience of populations to environmental stresses, the term has been re-defined to include learning, developing coping strategies, and building the capacity to recover (Manyena et al. 2011).

2.2 Potential indicators of vulnerability and resilience

Indicators identify antecedent characteristics of populations that are believed to reflect the vulnerability and resilience of those populations. The assumption is that the proposed indicators capture well the underlying individual and community capacities that determine vulnerability and resilience. Decision-makers use the indicators to identify populations who are at risk and interventions needed to reduce vulnerability and improve resilience.

The most common indicators of both vulnerability and resilience in the literature comprise individual demographic and socio-economic characteristics such as income, age, gender, and health status (Clark et al. 1998; Wu et al. 2002; Cutter et al. 2003, 2008, 2014; Sherrieb et al. 2010). Cutter et al. (2014) propose 6 types of resilience. Individual characteristics such as those listed above reflect social and economic resilience, while additional variables reflect community, institutional, housing/infrastructure, and environmental resilience.

This study investigates two related questions. (1) Which indicators represent the vulnerability and/or resilience of urban residential communities to coastal flooding? Several studies raise this question generally, for all contexts (Eriksen and Kelly 2007; Winderl 2014). (2) How universally do the indicators apply across different contexts and hazard types? We select indicators that are most commonly used in the literature and those that we identify as potentially important through interviews with individuals involved in recovery efforts after Hurricane Sandy, community leaders, and residents. Panel A of Table 1 lists the proposed indicators. The survey data document values of indicators *before* Hurricane Sandy struck.

2.3 Outcome-based measures of vulnerability and resilience

The study integrates survey data and information from interviews to construct measures of vulnerability and resilience based on outcomes experienced by residents in the study areas after Hurricane Sandy. Vulnerability and resilience are latent, generally unobservable capacities. However, they should manifest in observable outcomes after a hazard. Greater vulnerability should result in greater exposure and harm. Greater resilience should result in better coping with the harm and therefore faster, easier, less expensive recovery, and improved preparation for future hazards. The measures capture these outcomes that depend on individuals’ and communities’ vulnerability and resilience.

The relationship between the indicators and the measures tests whether the indicators indeed reflect vulnerability and/or resilience. The measures are not necessarily desirable

Table 1 Indicators and outcome-based measures of vulnerability and of resilience

Row no.	Panel A: Indicators that this study tests	
1	Economic status	<ul style="list-style-type: none"> • Whether respondent owns the home • Annual per capita household income
2	Household structure	<ul style="list-style-type: none"> • No adult male in the home • Whether household head is married
3	Age	<ul style="list-style-type: none"> • Presence of residents aged 65 or older • Presence of children aged 5 or younger • Presence of children aged 6 to 18
4	Education	<ul style="list-style-type: none"> • Presence of a female college graduate • Presence of a male college graduate
5	Health	<ul style="list-style-type: none"> • Whether anyone is disabled or has a chronic health condition
6	Ethnicity	<ul style="list-style-type: none"> • Whether household head and partner (if there is a partner) are both white
7	Geography and infrastructure	<ul style="list-style-type: none"> • Whether respondent resides in Rockaway
8	Information	<ul style="list-style-type: none"> • Access to information needed to recover and to prepare for future storms • Whether the respondent is aware of future flood risk
9	Community organization	<ul style="list-style-type: none"> • Relevant capacity in community organizations
	Panel B: Measures of vulnerability and resilience	
10	Vulnerability	<ul style="list-style-type: none"> • Height of floodwater in the home (ft) • Categories of damage to the home: <ul style="list-style-type: none"> ○ Not affected: There were no impacts on the home that required repair. ○ Minorly affected: The home could be lived in and the structure required minor repairs, or required treatment of mold, or replacement or repair of utilities such as the boiler or hot water heater. ○ Affected: The structure required major repairs but was safe to live in. The house may have been unsafe to live in because of the mold but not because the structure was unsound. ○ Majorly affected: The structure was unsafe and could not be lived in but it could be repaired. ○ Destroyed: The home could not be repaired. It had to be rebuilt from the ground up. • Whether the household was displaced from the home • Whether the household's access to food was disrupted • Whether the household's access to health care was disrupted
11	Resilience	<ul style="list-style-type: none"> • The amount of money that the household spent on the recovery out of pocket, unreimbursed, as a fraction of annual per capita income • Whether the household had flood insurance when Sandy struck • Whether anyone in the household lost a job as a result of the storm • The decline in household savings as a result of the recovery • Whether the household is in debt as a result of the recovery • Whether the home is rebuilt to at least its pre-Sandy state • How much time was required to rebuild the home • How long the household had mold in the home • How long the household was displaced from a permanent home • How long disruption in access to food continued • Whether the respondent took any actions to reduce future flood damage to the home

Whether or not a household resides in Rockaway is a proxy for the pre-existing differences between Rockaway and Staten Island in geography, infrastructure, and community organizations. It takes value 1 if the household resides in Rockaway and 0 if the household resides on Staten Island. Whether or not the household had flood insurance is an outcome measure since insurance is a coping strategy, which can be viewed as a consequence of underlying resilience. We do not consider the length of unemployment because all respondents who lost jobs had found a new job within several months.

replacements for the indicators since data on measures can be collected only when a hazard occurs and the data collection can be challenging, while data on many indicators is independent of hazard events and readily available.

The *measures of vulnerability*, listed in panel B of Table 1, include level of flooding in the home, damage to and displacement from homes, and disruption of access to food and health care. Damage to homes is a qualitative variable that places the severity of damage in one of the five categories described in the table. Disruption of access to food and health care occurred as a result of damage to buildings that housed grocery stores and health care facilities and/or owners' and employees' residences.

The *measures of resilience*, listed in the same table, include completeness, cost, and length of different dimensions of the recovery. There are several notable omissions from the list of resilience measures. We did not document the amount of time that residents missed from work and the resulting income losses. Few respondents had their own businesses, and the study does not document the recovery of local businesses. The study does not analyze the impacts of the storm on physical or mental health. No respondents report physical injury or death during the storm. Attributing mortality and morbidity that occurred after the storm to storm impacts is a complex endeavor that is beyond the scope of the paper (see for example Lane et al. 2013; Subaiya et al. 2014).

3 Analysis

3.1 Survey data

The survey data document impacts and recovery from Hurricane Sandy on the Rockaway peninsula and East Shore of Staten Island, two of the most heavily impacted areas in NYC. Figure 1 shows the study areas. A United States Geological Survey (USGS) monitoring sensor at Great Kills on Staten Island recorded a maximum water elevation of 14.3 ft over the North American Vertical Datum of 1988 (NAVD88) during the storm. USGS high water marks varied from 14.1 ft over NAVD88 at the southern end of the island to 12.7–12.9 ft further north. In Rockaway, a USGS gauge at Rockaway inlet recorded a maximum water elevation of 11.7 ft, while USGS high water marks varied from 10.3 to 11.2 ft along the peninsula. Survey respondents in Rockaway and on Staten Island report very similar average levels of water in the home (see panel A of Table 2).

We restrict attention to residents in low-rise housing, limited to buildings that contain no more than 10 residential units, which include about 50% of residential units in the study area in Rockaway and about 75% on Staten Island. The most extreme damage during Hurricane Sandy happened in low-rise housing. The City of New York 2013 reports that single-story buildings were less than 25% of the structures flooded in Hurricane Sandy but accounted for 75% of the buildings that suffered the most severe damage (p. 75). The focus on low-rise housing excludes the disadvantaged residents of the high-rise apartment buildings owned by the New York City Housing Authority (NYCHA) in Rockaway.¹ Similarly low-income residents occupy low-rise housing in neighboring areas, including in single occupancy residence (SRO) units.

The study drew a random sample of 249 addresses in Rockaway, with 151 addresses in the final sample and a response rate of 60%. The random sample of 250 addresses on Staten Island

¹ The sample size required to represent residents of high-rise housing exceeded the available resources.

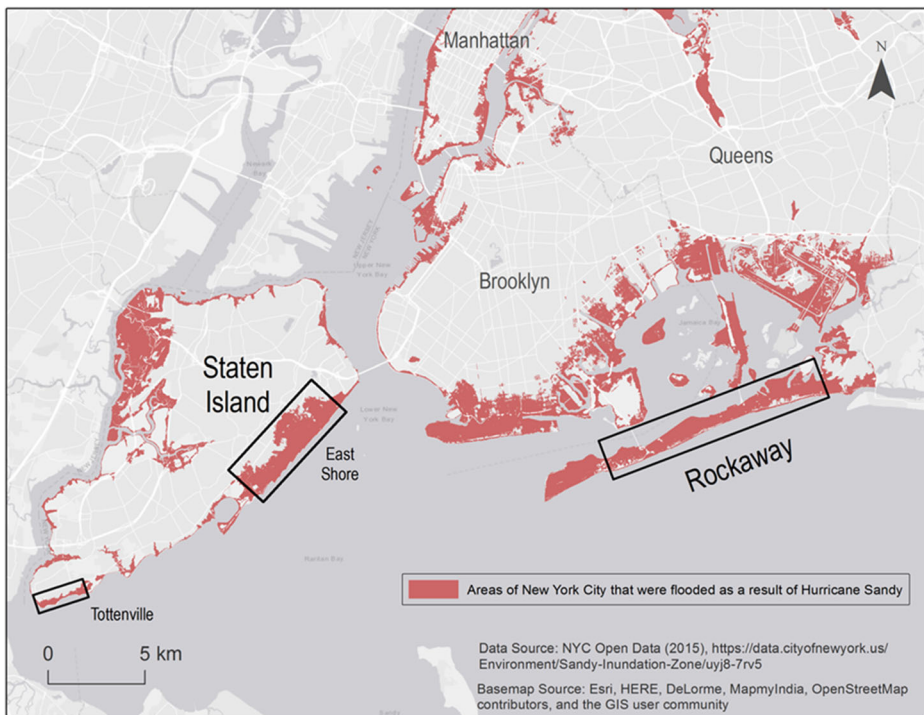


Fig. 1 Map of Hurricane Sandy inundation and study areas in New York City. The three rectangles mark the study areas. Area inundated by Hurricane Sandy is in red

yielded a final sample of 141 addresses with a 56% response rate. Panel A of Table 2 describes household characteristics, exposure, and damage. The Rockaway sample is more diverse ethnically, with 49% white households versus 86% on Staten Island, and has a larger percentage of renters. Appendix Section A.1 presents more details about the selection of the sample, compares the survey sample to study area residents based on data from the American Community Survey, and provides information about the surveys and interviews.

3.2 Methods

We investigate the relationship between each measure of vulnerability and resilience and the proposed indicators using ordinary least squares (OLS) regressions for continuous measures and logistic regressions for binary measures. We consider a variable to be a valid indicator of vulnerability or resilience if we can reject the null hypothesis that the coefficient is equal to 0 at a level of confidence of 5% or less. The regressions estimate observed relationships, which may not be causal. Indicators reflect differences in vulnerability and resilience; they do not necessarily cause them.

The regression function takes the following form:

$$y_i = \beta_0 + \mathbf{d}_i\beta_1 + \mathbf{z}_i\beta_2 + \mathbf{x}_i\beta_3 + \varepsilon_i \quad i = 1, 2, \dots, N \quad (1)$$

where i indexes a household. All variables are defined in Table 3. In each regression, the dependent variable y_i is one of the 7 outcome measures of vulnerability or one of the 11

Table 2 Descriptive statistics of selected variables

Variables	Mean	Rockaway	Staten Island
Panel A: Indicators, exposure, and damage			
Level of floodwater (ft)	Overall (1) 4.57 (0.17)	(2) 5.45 (0.24)	(3) 5.25 (0.30)
Home “affected”	0.33 (0.03)	0.32 (0.04)	0.34 (0.04)
Home “majorly affected” or “destroyed”	0.22 (0.02)	0.27 (0.03)	0.18 (0.03)
Resides in Rockaway	0.50	NA	NA
Owens home	0.83 (0.02)	0.75 (0.04)	0.91 (0.02)
Persons older than 65 in the household	0.33 (0.03)	0.31 (0.04)	0.36 (0.04)
Children aged 5 or younger in the household	0.16 (0.02)	0.19 (0.03)	0.14 (0.03)
Children aged 6 to 18 in the household	0.36 (0.03)	0.36 (0.04)	0.36 (0.04)
Married	0.60 (0.03)	0.56 (0.04)	0.63 (0.04)
No adult male in the household	0.17 (0.02)	0.18 (0.03)	0.15 (0.03)
Male college graduate in the household	0.33 (0.03)	0.39 (0.04)	0.27 (0.04)
Female college graduate in the household	0.41 (0.03)	0.52 (0.04)	0.30 (0.04)
Disabled person or person with chronic health condition	0.46 (0.03)	0.43 (0.04)	0.49 (0.04)
Per capita annual income	30,493 (2204)	31,576 (2723)	29,449 (2986)
Household head (and partner) white	0.68 (0.02)	0.49 (0.04)	0.86 (0.03)
Number of households	291	150	141

Table 2 (continued)

Variables	Mean				
Panel B: Length of recovery processes					
Overall	Overall	Rockaway	Staten Island		
(1)	(1)	(2)	(3)		
2.76	2.76	4.15	1.37		
(0.22)	(0.22)	(0.38)	(0.23)		
2.48	2.48	2.56	2.41		
(0.27)	(0.27)	(0.39)	(0.38)		
7.12	7.12	6.51	7.81		
(0.59)	(0.59)	(0.81)	(0.87)		
19.14	19.14	19.68	18.71		
(1.94)	(1.94)	(2.54)	(2.85)		
5.53	5.53	6.49	4.61		
(0.41)	(0.41)	(0.61)	(0.56)		
291	291	151	140		
Panel C: Comparison of outcomes for homeowners and renters					
Overall	Overall	Rockaway	Staten Island	Homeowners	Renters
(1)	(1)	(3)	(5)	(4)	(6)
0.65	0.65	0.74	0.58**	0.72	0.85**
(0.03)	(0.03)	(0.04)	(0.04)	(0.08)	(0.10)
2.32	2.32	2.42	2.24	3.00	4.10
(0.27)	(0.27)	(0.35)	(0.39)	(1.16)	(1.17)
1	1	1	1	1	1
0.74	0.74	0.72	0.76	0.77	0.67
(0.03)	(0.03)	(0.04)	(0.04)	(0.09)	(0.16)
7.87***	7.87***	7.72***	8.00***	1.77***	2.00***
(0.65)	(0.65)	(0.95)	(0.90)	(0.64)	(0.71)
246	246	119	127	32	13

Data are from household surveys. The standard error of the mean estimate is in parentheses. The mean estimation uses sampling weights. In panel C: First, third, and fourth variables are binary. The length of time that the household was displaced is only for households who were displaced. The survey asked only those households who were displaced whether they had a permanent place to live at the time of the survey. We compare the means for the variables using the χ^2 test for binary variables and the t test for continuous variables. ***Denotes that we reject the null hypothesis that the difference between the values for renters and homeowners is the same at 1% level of significance or less. **Denotes level of significance of 5% or less

Table 3 Variables in the regressions

	Row no.	Dependent variables in regressions (outcome-based measures of vulnerability and resilience) (1)	Independent variables in regressions (2)
Measures of vulnerability	(1)	<ul style="list-style-type: none"> • Level of floodwater in the home (in ft) • Binary variable that is 1 if the damage to the home is in the “not affected” or “minorly affected” categories, as defined in Table 2 • Binary variable that takes value 1 if the damage to the home is in the “affected” category • Binary variable that is 1 if the damage to the home is in the “majorly affected” or “destroyed” categories • Difficulty with access to food* • Difficulty with access to health care* • Whether the household was displaced* 	Vector x_i (indicators): <ul style="list-style-type: none"> • Whether reside in Rockaway • Whether own the home • Presence of residents aged 65 or older • Presence of children aged 5 or younger • Presence of children aged 6 to 18 • Whether household head is married • No adult male in the home • Presence of a male college graduate • Presence of a female college graduate • Whether anyone is disabled or has a chronic health condition • Annual per capita household income • Whether household head and partner (if there is a partner) are both white
Measures of resilience	(2)	<ul style="list-style-type: none"> • Amount of own money spent on the recovery, unreimbursed, as a share of per capita annual income • Whether or not had flood insurance • Loss of job as a result of the storm • Decline in household savings • Incurred debt to recover • Whether rebuilt to pre-Sandy condition • Months required to rebuild home • How long the household had mold • How long until the house had a functioning boiler and/or hot water heater • How long household was displaced • Months until access to food returned to normal 	Vector x_i of indicator variables and: Vector d_i : <ul style="list-style-type: none"> • Level of floodwater the home (in ft) • Binary variable that takes value 1 if the damage to the home is in the “affected” category • Binary variable that takes value 1 if the damage to the home is in the “majorly affected” or “destroyed” categories Vector z_i : <ul style="list-style-type: none"> • Household received assistance with food and water from sources other than social networks • Household received assistance with clearing out the home from sources other than social networks • Household received assistance with rebuilding from sources other than social networks • Household received assistance with information from sources other than social networks • Household received financial assistance from sources other than social networks

All indicator variables (row 1, column 2) document household attributes on the eve of Hurricane Sandy

*The regressions for these variables include vector d_i

outcome measures of resilience. The 1×3 vector d_i comprises the number of feet of water in the house at the time of Hurricane Sandy and two measures of damage to the house as defined in Table 3; z_i is a 1×5 vector of variables that indicate whether household i received any of 5 types

of assistance from sources other than the household's social networks; \mathbf{x}_i is a 1×12 vector of indicator variables; and ε_i is the random error term. The values of all variables are reported by the respondent. The vector of coefficients on the indicator variables, β_3 , is of main interest.

The three main versions of the regression are as follows:

- (i) Regressions for the level of floodwater in the home and damage to the home omit the terms $\mathbf{d}_i\beta_1$ and $\mathbf{z}_i\beta_2$.
- (ii) Regressions for whether or not access to food or access to health care was disrupted after the storm include the term $\mathbf{d}_i\beta_1$ and they omit the term $\mathbf{z}_i\beta_2$ since these variables indicate disruption due to damage and could not be affected by assistance.
- (iii) Regressions for all other dependent variables include all terms in Eq. (1).

Including level of floodwater in the home and the indicators for the amount of damage to the home in regressions that analyze resilience outcomes enables us to distinguish relationships between indicators and vulnerability from relationships between indicators and resilience. For example, lower-income homeowners may spend more money out-of-pocket as a share of per capita income on the recovery either because they suffered more damage or because their incomes are lower or both. Regressing damage on income investigates the former explanation, while regressing expenditure as a share of income on income while controlling for exposure and damage examines the latter.

Regression equations for all measures of resilience include variables that document whether or not the household received any one of several types of assistance from sources other than social networks. If we did not control for assistance and assistance is correlated with indicators, the coefficients on indicator variables would include the protective effect of assistance. When the assistance is from sources that are external to the individual and/or the community, and that the communities do not influence, we do not consider the effect of those sources of assistance on outcomes to reflect the residents' underlying resilience (Cutter et al. 2008). We exclude assistance from social networks from the variables that control for the effect of assistance because assistance from social networks does reflect resilience.

Assistance from social networks is a potential indicator of resilience. However, all but 5 respondents who receive assistance from social networks also receive assistance from external sources. Therefore, we cannot identify the effect of assistance from social networks on outcomes. On the other hand, a number of households who receive each type of assistance from external sources do not receive help from social networks.

Regressions estimate the relationships between 12 potential indicators and 18 outcome measures, for a total of 216 tests. The tables report naïve p values for the hypothesis tests that each coefficient is equal to 0. Some of these tests will be statistically significant by chance due to the large number of tests (Kling et al. 2007). We reduce the likelihood that we erroneously consider a relationship to be statistically significant when it is not by focusing on indicators that have a strong basis in the literature (Casey et al. 2012), considering indicators that are correlated with at least two outcome measures, and by restricting the level of significance that indicates a statistically significant relationship to 5% or less.

The response rates to the survey differed across three sections of Rockaway from which the study sampled, the western, the middle, and the eastern. The regression includes sampling weights that result in equal influence being given to the respondents in each of the three sections.

The analysis pools data from Rockaway and Staten Island in order to examine whether the indicators characterize vulnerability and resilience in the full population, as is commonly

assumed in the literature. It is possible, and perhaps likely, that relevant indicators differ across contexts. Chow tests indicate that the relationship between indicators and outcomes differs between Rockaway and Staten Island for two out of seven measures of vulnerability and three out of eleven measures of resilience. We analyze these outcomes separately in data from Rockaway and from Staten Island. We report the differences in the discussion of results, while analytical details and full regression results are in Appendix Section A.2.2 and Table A.3.

The data collection occurred 2 years after Hurricane Sandy in Rockaway and a year later on Staten Island, and all data are based on respondents' recall. The difference in timing of surveys between Rockaway and Staten Island could affect results if residents of Staten Island recall the outcomes more poorly than do residents of Rockaway because of the passage of time or if recovery was in different stages in the two areas. One component of the recovery was not complete at the time of the surveys, rebuilding of homes, for up to 25% of residents.² Problems with recall could attenuate the statistical significance of regression coefficients, and they could bias the coefficients if they are correlated with any of the independent variables. The main concern is if recall problems differ between the study areas because the distributions of several variables differ between the study areas. The investigation of outcomes separately in Rockaway and in Staten Island, based on Chow tests, addresses concerns due to the timing of surveys and potential recall problems.

Given the objective to estimate the observed relationships in the population rather than a behavioral model, the regression coefficients are unbiased and consistent estimators of the population regression coefficients as long as the true population regression function is linear (Deaton 1997). The coefficients in the weighted regression would not be unbiased or consistent if the model were a behavioral one. The standard errors are computed using a linearized variance estimator based on a Taylor series first-order approximation that corrects for heteroskedasticity (Wolter 2007), which is a version of the Huber-White estimator (Wooldridge 2010).

The information gathered through interviews and in meetings with recovery groups serves to identify measures of vulnerability and resilience as well as potential indicators, and to understand how and why these indicators affect outcomes. The study team transcribed the interviews, coded the transcribed text to locate categories of information, and analyzed the coded text using Nvivo.³

4 Results

4.1 Socio-economic and demographic characteristics as indicators of vulnerability and resilience

4.1.1 Vulnerability

Three out of nine commonly used indicators are correlated with two or more outcome-based measures of vulnerability in the full population: homeownership, health status, and income.⁴

² Panel B of Table 2 reports the duration of each recovery process.

³ Nvivo software is widely used to organize and analyze qualitative data. See for example "Introduction to using Nvivo" at <http://www.docs.is.ed.ac.uk/skills/documents/3766/3766.pdf>.

⁴ The nine indicators are listed in the first 6 rows of Table 1, considering the two variables that identify the presence of children and the two education variables as one indicator each.

Table 4 Indicators of vulnerability

Indicators (independent variables)	Outcome-based measures of vulnerability (dependent variables)						
	Level of floodwater OLS (1)	Home “not affected” or “minorly affected” Logistic (2)	Home “affected” Logistic (3)	Home “majorly affected” or “destroyed” Logistic (4)	Difficulty with access to food/water Logistic (5)	Difficulty with access to health care Logistic (6)	Whether household was displaced Logistic (7)
Level of floodwater (ft)	–	–	–	–	1.06 (0.07)	1.14 (0.10)	1.03 (0.08)
Home “affected”	–	–	–	–	1.56 (0.64)	0.30** (0.19)	2.09 (0.87)
Home “majorly affected” or “destroyed”	–	–	–	–	0.79 (0.37)	0.46 (0.28)	12.90*** (8.45)
Resides in Rockaway	0.28 (0.44)	0.87 (0.29)	0.95 (0.30)	1.25 (0.48)	2.55*** (0.89)	4.75*** (2.56)	1.24 (0.47)
Owens home	2.28*** (0.59)	0.36** (0.17)	3.62*** (1.85)	0.88 (0.44)	0.49 (0.28)	0.54 (0.34)	0.36 (0.24)
Persons older than 65 in the household	–0.12 (0.46)	1.78 (0.62)	0.65 (0.21)	0.81 (0.32)	0.69 (0.25)	1.20 (0.64)	1.23 (0.54)
Children aged 5 or younger	0.11 (0.55)	2.26 (0.95)	0.50 (0.21)	0.89 (0.43)	0.70 (0.34)	0.75 (0.46)	3.73*** (1.95)
Children aged 6 to 18 in the household	0.54 (0.43)	1.05 (0.36)	1.33 (0.43)	0.59 (0.22)	1.57 (0.55)	1.27 (0.64)	1.50 (0.58)
Married	0.52 (0.46)	0.68 (0.25)	1.70 (0.62)	0.84 (0.35)	0.62 (0.23)	2.42 (1.27)	1.05 (0.44)
No adult male in the household	0.94 (0.63)	0.24*** (0.12)	2.38 (1.12)	1.91 (0.89)	0.59 (0.32)	1.14 (0.70)	2.06 (1.23)
Male college graduate in the household	0.54 (0.46)	0.75 (0.27)	1.34 (0.48)	0.95 (0.46)	1.48 (0.60)	0.52 (0.28)	0.63 (0.26)
Female college graduate in the household	0.32 (0.42)	0.51 (0.18)	1.42 (0.48)	1.54 (0.61)	0.97 (0.39)	1.10 (0.51)	1.09 (0.42)

Table 4 (continued)

Indicators (independent variables)		Outcome-based measures of vulnerability (dependent variables)						
Level of floodwater		Home “not affected” or “minorly affected”	Home “affected”	Home “majorly affected” or “destroyed”	Difficulty with access to food/water	Difficulty with access to health care	Whether household was displaced	
OLS (1)	Logistic (2)	Logistic (3)	Logistic (4)	Logistic (5)	Logistic (6)	Logistic (7)		
Disabled person or person with chronic health condition	0.82** (0.41)	1.21 (0.38)	1.97 (0.68)	1.33 (0.45)	5.93*** (2.80)	1.15 (0.43)		
Household head (and partner) is (are) white	0.40 (0.43)	0.62 (0.21)	0.98 (0.41)	0.28*** (0.11)	0.62 (0.29)	1.62 (0.68)		
Per capita annual income	-9.06E-6 (7.90E-6)	1.00 (5.22E-6)	1.00 (8.61E-6)	1.00 (5.29E-6)	1.00 (7.06E-6)	1.00001** (6.66E-6)		
Constant	1.31 (0.82)	1.92 (1.16)	0.29 (0.20)	4.67** (3.38)	0.03*** (0.03)	0.22 (0.19)		
N	230	231	231	230	230	230		
R ²	0.12	–	–	–	–	–		
F statistic	2.63	1.93	1.15	2.37	2.21	2.26		

The table reports regressions based on versions of Eq. 1, which exclude the vector of assistance variables. Data are from household surveys. The table reports odds ratios for the logistic regressions. An odds ratio that is less than one denotes an inverse relationship between the dependent and the independent variable. For all regressions, standard errors are in parentheses. ***Denotes that we reject the two-sided null hypothesis that the coefficient is equal to 0 at 1% level of confidence or less. **Denotes 5% level of confidence or less

Two vulnerability outcomes exhibit different relationships with indicators in Rockaway than in Staten Island: likelihood of severe damage and disruption of access to health care. Ethnicity is correlated with one measure in the full population and a second measure in data from Staten Island only. Presence of children and household being headed by a single female are each correlated with one measure of vulnerability, while being elderly, marital status, and education do not influence any vulnerability outcomes. The results in the full population are based on regressions shown in Table 4, which are versions (i) and (ii) of Eq. (1).

Homeowners are more vulnerable than are renters even though they have higher incomes on average. For a given level of income, the odds of an owner-occupied home being in the lowest-damage category are 0.36 of the odds of a renter-occupied home being in the lowest-damage category, and the flood level is about 2.3 ft higher in owner-occupied homes.

The odds that households in which a member has a disability or a chronic health condition experience disrupted access to health care are 6 times as large as the odds that healthier households do so. They also experience about 1-ft higher floodwaters and are less likely to have only minimal damage.

Lower-income households experience the same severity of flooding as do wealthier households. However, lower-income homes are more likely to experience severe damage than are higher-income homes. The odds of a resident experiencing no damage or minor damage increase by 0.1% for every \$1000 increase in income. The results illustrate the importance of investigating a range of outcome measures and indicators. Analyzing the level of flooding and damage to the home separately distinguishes the effects of home location from the effects of the home structure and/or protection measures. Homeowners and renters have different vulnerabilities in addition to the effects of income on vulnerability within each of these groups.

Non-white households are more likely than white households to experience disrupted access to food in the full population (see column 5 of Table 4), and severe damage on Staten Island (see column 2 of Appendix Table A.3).

4.1.2 Resilience

Financial resilience Middle- and low-income homeowners are the least resilient population in financial terms even though they have higher incomes on average than do renters. The evidence has several components. First, homeowners' recovery expenses were an order of magnitude larger than renters' expenses because renters do not bear the costs of structural damages to their homes. The mean total cost of recovery among all homeowners was about \$62,000, and the median was \$49,000, while for renters, the mean was about \$9000 and the median \$5500 (see Table 5). Damage to owner-occupied homes is the largest economic harm that affected the greatest percentage of the population in the study neighborhoods.

Second, homeowners paid out-of-pocket, over and above any money recovered from insurance or from financial assistance, a larger share of per capita annual income than did renters based on survey data. Renters spent about \$3000 out of their own pockets or half of their annual per capita incomes on average. Low- to middle-income homeowners, whom we define as having annual household incomes below \$75,000, spent on average \$27,000 out of their own pockets, or 2.4 times their per capita annual income. Low- to middle-income homeowners' and renters' incomes are in the same range but the former are somewhat wealthier on average in our sample. Higher-income homeowners spent an average amount almost equal to their annual per capita income, a share which exceeds the share paid out by poorer renters but much less dramatically.

Table 5 Costs of recovery by homeownership status and income

Variable	Mean value for renters (1)	Mean value for low- to middle-income homeowners (2)	Mean value for upper-middle-income homeowners (3)
Level of flooding in the home (ft)	2.78	5.00***	4.95***
<i>N</i> (sample size)	(0.43)	(0.30)	(0.26)
	44	94	119
Fraction of households with minimal damage	0.56	0.38**	0.43
<i>N</i>	(0.08)	(0.05)	(0.05)
	45	94	119
Fraction of households with medium damage	0.15	0.37***	0.37***
<i>N</i>	(0.06)	(0.05)	(0.04)
	45	94	119
Fraction of households with severe damage	0.28	0.25	0.20
<i>N</i>	(0.07)	(0.04)	(0.03)
	45	94	119
Own money spent on the recovery (\$)	3037	27,141***	28,647***
<i>N</i>	(1247)	(3923)	(3331)
	43	93	114
Total financial assistance (\$)	3381	8528***	7889**
<i>N</i>	(578)	(1598)	(1331)
	37	89	102
Total amount received from all types of insurance (\$)	1858	26,138***	34,946***
<i>N</i>	(1112)	(4138)	(4181)
	45	79	105
Total cost of recovery (\$)	9167	62,565***	63,216***
<i>N</i>	(2781)	(7698)	(5978)
	35	76	88

The table reports variable means. Data are from household surveys. The observations used for this table include 258 respondents who replied to the question about income, out of the total 291 respondents. The value of income is not missing for any renters. The only differences that are statistically significant between homeowners who did not report their income and those who did are that the former are less likely to be in the severe damage category and they received less in financial assistance. Also, they are somewhat less likely to have flood insurance, but the difference is not statistically significant. Their out-of-pocket expenses are almost identical to the remainder of the sample. Renters' and low- to middle-income homeowners' annual household incomes are \$75,000 or below. However, mean income is higher for low- to middle-income homeowners than for renters. Upper-middle-income homeowners' incomes range from \$75,000 to \$500,000. Asterisks denote that we can reject the null hypothesis that the mean is the same for the group of homeowners marked with the asterisks and renters. We cannot reject the null hypothesis for any variable when comparing low- to middle-income homeowners to upper-middle-income homeowners. The mean comparison test is a χ^2 test for the binary variables and a *t* test for the continuous variables. Standard errors are in parentheses. Mean values that are different at the 1% level of significance are denoted with ***, and at 5% with **

Owning a home raised the share of per capita income paid out of pocket by 1.12, for a given level of income, height of flooding, and damage category, as the regression results show in column 1 of Table 6. The share of income paid out-of-pocket declines by 0.17 for every \$10,000 increase in per capita annual income for both homeowners and renters, as the negative coefficient on per capita income shows in column 1 of Table 6. A regression in which we interact annual per capita income with homeownership shows that there is no difference in the rate at which the share of income paid out-of-pocket declines for renters and for homeowners (see Appendix Table A.4).

Third, combined information from surveys and interviews suggests that low- to middle-income homeowners are the least resilient to future storms because the magnitude of out-of-

Table 6 Indicators of resilience

Outcome-based measures of resilience (dependent variables)											
Independent variables	Own money spent as share of per capita income	Had flood insurance	Lost job	Decline in savings (%)	Incurred debt	Home back to pre-Sandy condition or better	How long to rebuild the home (months)	How long had mold (days)	How long until had boiler/hot water heater (weeks)	How long was household displaced (months)	How long until access to food returned to normal (months)
	OLS (1)	Logistic (2)	Logistic (3)	OLS (4)	Logistic (5)	Logistic (6)	OLS (7)	OLS (8)	OLS (9)	OLS (10)	OLS (11)
Level of floodwater (ft)	0.09 (0.08)	1.31*** (0.10)	1.02 (0.12)	3.45*** (1.24)	0.73*** (0.06)	0.80*** (0.07)	0.51** (0.24)	2.12 (1.49)	0.54*** (0.17)	0.13 (0.10)	0.02 (0.11)
Home "affected"	0.63 (0.39)	1.44 (0.63)	4.07** (2.48)	-8.53 (6.98)	0.57 (0.25)	0.86 (0.40)	1.98 (1.57)	10.65 (6.47)	-0.26 (1.09)	0.53 (0.57)	-0.09 (0.60)
Home "majority affected" or "destroyed"	0.88 (0.55)	1.89 (0.95)	1.54 (1.03)	-7.76 (7.41)	0.44 (0.21)	1.12 (0.64)	1.43 (1.88)	3.55 (9.05)	2.39 (1.42)	2.89*** (0.90)	0.16 (0.71)
Resides in Rockaway	0.74 (0.51)	1.00 (0.37)	3.87*** (2.10)	-1.62 (5.81)	0.43** (0.16)	0.98 (0.36)	-1.96 (1.19)	-2.26 (7.93)	1.80** (0.89)	-0.34 (0.59)	1.91*** (0.53)
Owens home	1.12*** (0.41)	-	0.50 (0.40)	-1.20 (8.66)	0.80 (0.49)	2.26 (1.31)	3.80*** (1.29)	-12.73 (10.70)	0.36 (1.48)	-0.71 (0.74)	-0.12 (0.82)
Persons older than 65 in household	0.78 (0.53)	0.61 (0.24)	0.08*** (0.07)	-15.00*** (6.28)	3.66*** (1.50)	1.98 (0.89)	0.07 (1.31)	4.54 (8.38)	0.79 (0.99)	0.49 (0.64)	-0.35 (0.46)
Children aged 5 or younger	0.40 (0.65)	1.67 (0.78)	1.20 (0.88)	0.86 (6.81)	0.33** (0.16)	1.22 (0.64)	0.77 (1.61)	14.93 (13.03)	0.61 (0.87)	1.63 (0.87)	-0.98 (0.70)
Children aged 6 to 18	0.37 (0.53)	0.93 (0.34)	0.39 (0.22)	-7.41 (6.17)	1.03 (0.39)	1.60 (0.63)	-0.70 (1.11)	11.88 (9.12)	-0.21 (0.96)	-0.34 (0.39)	0.30 (0.54)
Married	0.56 (0.38)	1.77 (0.71)	0.32 (0.20)	-3.72 (5.95)	0.41** (0.18)	2.16 (0.94)	-0.53 (1.48)	-14.01 (8.54)	-1.10 (1.07)	0.42 (0.51)	-0.92 (0.58)
No adult male in household	0.03 (0.60)	1.63 (0.92)	0.39 (0.43)	13.35 (7.79)	0.67 (0.39)	1.41 (0.79)	-3.80** (1.88)	-9.55 (11.93)	-1.03 (1.29)	0.70 (0.90)	-0.68 (0.75)
Male college graduate	-1.10** (0.52)	0.89 (0.33)	1.19 (0.84)	-4.42 (6.89)	1.42 (0.59)	0.70 (0.28)	-4.75*** (1.47)	-8.91 (8.02)	-0.70 (1.01)	-0.49 (0.69)	0.57 (0.60)
Female college graduate	0.48 (0.60)	0.50 (0.18)	0.14*** (0.09)	1.29 (6.09)	1.93 (0.77)	0.72 (0.26)	2.34 (1.35)	6.73 (9.02)	-0.61 (1.16)	0.10 (0.69)	0.60 (0.50)
Person disabled or with chronic health condition	0.09 (0.35)	0.91 (0.37)	4.78** (3.01)	0.50 (6.13)	0.60 (0.24)	1.00 (0.42)	-0.50 (1.05)	14.97** (7.76)	2.16*** (0.82)	0.79** (0.38)	-0.05 (0.46)

Table 6 (continued)

Independent variables		Outcome-based measures of resilience (dependent variables)										
		Own money spent as share of per capita income	Had flood insurance	Lost job	Decline in savings (%)	Incurred debt	Home back to pre-Sandy condition or better	How long to rebuild the home (months)	How long had mold (days)	How long had boiler/hot water heater (weeks)	How long was household displaced (months)	How long until access to food returned to normal (months)
		OLS (1)	Logistic (2)	Logistic (3)	OLS (4)	Logistic (5)	Logistic (6)	OLS (7)	OLS (8)	OLS (9)	OLS (10)	OLS (11)
Household head is (are) white		-0.03 (0.45)	0.50 (0.21)	2.01 (1.06)	-16.05 (6.76)	1.17 (0.51)	1.08 (0.47)	-1.67 (1.37)	-0.31 (7.21)	-0.99 (1.07)	1.10** (0.47)	-1.65** (0.66)
Per capita annual income		-1.74E-5**** (5.47E-6)	1.00 (6.13E-6)	1.00 (1.19E-5)	-2.12E-4** (1E-4)	1.00 (6.28E-6)	1.00 (6.41E-6)	1.21E-6 (1.73E-5)	-7.85E-6 (7.53E-5)	-6.97E-6 (9.65E-6)	-1.27E-5 (6.83E-6)	-1.62E-5** (7.16E-6)
Constant		-1.24 (1.04)	0.23** (0.16)	0.16 (0.18)	59.37*** (13.35)	54.94*** (55.40)	5.45 (4.89)	1.91 (2.06)	6.30 (17.54)	0.44 (1.62)	-1.33 (0.89)	2.22 (1.63)
N		224	194	179	175	222	222	189	205	230	228	226
R ²		0.20	-	-	0.17	-	-	0.29	0.13	0.33	0.26	0.27
F statistic		2.64	2.55	2.25	2.32	2.10	1.33	4.28	1.88	6.88	4.38	3.33

The table reports regressions based on Eq. 1. The table omits coefficients on assistance variables. Data are from household surveys. The table reports odds ratios for the logistic regressions. An odds ratio that is less than one denotes an inverse relationship between the dependent and the independent variable. A negative relationship with percent decline in savings indicates that savings declined less for the group for which the coefficient is negative. For all regressions, standard errors are in parentheses. The table does not show coefficients for assistance variables. The full set of regressors is listed in Table A.4. ****Denotes that we reject the two-sided null hypothesis that the coefficient is equal to 0 at 1% level of confidence or less. ***Denotes 5% level of confidence or less.

pocket recovery costs relative to income is likely to be prohibitive given savings depleted by the recovery from Hurricane Sandy and outstanding debt. Homeowners and renters reduced their savings at similar rates, as shown in column 4 of Table 6, with the decline being inversely related to income for both groups.⁵ About 60% of both homeowners and renters incurred debt. Furthermore, interviews indicate that middle- and low-income homeowners' savings are primarily their homes, with limited resources in retirement accounts accumulated over decades even before Sandy. Low- to middle-income respondents reduced their savings by almost 60% on average. Recovery from future flooding will depend increasingly on the capacity to finance expenditures out of current income for low- to middle-income households as the frequency of significant floods rises.⁶

The heavy financial burden on homeowners reflects the fact that assistance with rebuilding homes was limited. Based on our survey data, only about 30% of homeowners who needed assistance with rebuilding received it, while over 80% of residents received all other types of assistance. Homeowners received about 2.5 times more in financial assistance than renters, but faced recovery expenses that were more than 6 times larger, as shown in Table 5. While flood insurance covered about the same share of expenses as out-of-pocket expenditures for the 50% of homeowners in our sample who had flood insurance on the eve of Sandy, those who had flood insurance spent more out of their own pockets and a higher share of their per capita incomes than did the uninsured, partly because their total recovery expenses were larger.⁷

In addition to homeownership and income, only being elderly and possibly education are associated with more than one measure of financial resilience in the full population. The elderly experience smaller reductions in savings and less chance of job loss, but they are more likely to incur debt. A male with a college degree in the household is correlated with less own money spent as a share of per capita income though the effect is marginally significant. Households with a female college graduate are less likely to experience job loss.

Decline in savings is the only measure of financial resilience that exhibits a different relationship with indicators in Rockaway than in Staten Island. White households see smaller declines in Rockaway than do non-white ones (see column 5 of Table A.3).

The exclusion of high-rise buildings, including NYCHA, from the data is not likely to affect the analysis of financial resilience. Renters did not bear the costs of structural and mechanical repairs regardless of the type of apartment building, and renters in high-rise buildings were less likely to suffer damage to their homes than renters in low-rise buildings. The unique issues that arose in high-rise buildings, such as navigating dark stairwells during the electricity outage and access to running water, are beyond the scope of this study.

Displacement from home and rebuilding Homeowners paid much more to obtain outcomes that are similar or worse than experienced by renters, as panel C of Table 2 shows based on survey data. All of the respondents have found a permanent place to live. The home is in as good condition as it was before Sandy for a similar proportion of owners and renters. The

⁵ We do not have data on amounts of savings, only percentage by which savings changed from the eve of Hurricane Sandy to the survey as reported by respondents.

⁶ An important component of financial resilience, which remains for future research, is the change in value of homes in these increasingly flood-prone areas.

⁷ Average annual premium for a National Flood Insurance Program policy for homeowners who reside in the zone that has a 1% annual probability of flooding was \$1547 on the eve of Sandy, while it was \$506 outside the flood zone (Dixon et al. 2013). Few renters carry flood insurance, which covers only belongings and has a much lower premium.

length of time required for the home to return to pre-Sandy condition, among those that did, is over four times longer for owners than for renters.⁸

The data do not include residents who were displaced from their homes and did not return to the study areas. Finding affordable housing in NYC is challenging. In the study neighborhoods, a somewhat higher percentage of renters were displaced from their homes than homeowners and they remained displaced somewhat longer, but the differences are not statistically significant, as panel C in Table 2, column 7 in Table 4, and column 10 in Table 6 show.

Health and other indicators of resilience Regression results in Table 6 show that households in which someone has a disability or a chronic illness are substantially less resilient than are healthier households. They require about 2 weeks longer to repair utilities and have mold about 15 days longer. They are more likely to experience job loss. They remain displaced from home about a month longer.⁹

White households are displaced longer, which may be an indication of resilience if they can afford to remain displaced to rebuild their homes more thoroughly (column 10 of Table 6). Non-white households experience disrupted food access about 1.5 months longer (column 11 of Table 6). Since non-white households are also more likely to experience problems with access to food, flooding may exacerbate the effect of the well-documented, pre-existing lack of food stores in lower-income and minority areas (Whiteacre et al. 2009).¹⁰

Being elderly is correlated only with measures of financial resilience, which suggest that the elderly are more resilient than are younger households. The finding is consistent with Ngo (2001), who reports that the elderly did not suffer more adverse physical or psychological impacts during the floods associated with Hurricane Agnes in Pennsylvania, and the living situation improved after the floods for many.

No other commonly proposed indicators are correlated with multiple measures of resilience. The relationship with indicators differs in Rockaway and Staten Island for two non-financial resilience outcomes, duration of disruption in food access and of rebuilding the home. The results of separate regressions for each area are consistent with the reported results, as discussed in Appendix Section A.2.2.

4.2 Access to information as an indicator of resilience

Survey data and interviews suggest that access to information is an essential indicator of resilience.¹¹ Every interviewee discussed obstacles posed by lack of reliable *information about managing various recovery tasks*. Respondents needed information in three categories. First, they needed information about assistance, such as food, clothing, health care, clearing out damaged belongings and flood debris, rebuilding, and financial help, as well as the application processes, which were often complicated and required access to documents, which may have been lost or inaccessible due to flooding. Second, residents needed to know how to carry out various tasks such as eliminating the prevalent and rapidly growing mold and rebuilding.

⁸ See also coefficient on home ownership in regressions in columns 6 and 7 of Table 6.

⁹ See columns 3, 8, 9, and 10.

¹⁰ This result may be consistent with Flores et al. (2020), though they analyze the effect of ethnicity on “unmet needs,” which are broader than disrupted access to food.

¹¹ This indicator is not prominent in the literature, perhaps partly because of lack of data (Cutter 2016).

Third, they needed legal assistance related to filing insurance claims, appealing decisions, and aspects of rebuilding.

In a regression based on Eq. 1, residents on Staten Island who accessed assistance with information spent about \$12,000 less out of their own pockets on the recovery, for a given level of flooding and damage to the home. Information assistance has no effect on expenditures in Rockaway. The results are in Appendix Table A.5 and Section A.2.4 describes the regression. Assistance with information serves as a proxy for being informed in the regression. The relationship is not necessarily causal.

Lack of awareness of future flood risk and adaptation options combine with the financial impacts to compound lack of resilience among homeowners. Homeowners had the opportunity to reduce future flood damages to their homes when rebuilding, for example, by placing electric utilities such as boilers, hot water heaters, other appliances, and circuit breakers sufficiently high to avoid future flood damage. In our survey sample, about 5% of homeowners elevated all the electric utilities, and another 14% elevated some utilities but not all even though about 80% of owners had to replace their utilities after the storm. No one in the sample elevated the home. The homes are no better prepared for flooding than they were before Sandy, while the owners are in worse financial situations.

Limited information about flood risk and adaptation options may be one reason why residents rebuilt their homes as they were before Sandy. About 65% of respondents are not aware that coastal flood risk is growing. About half of the respondents whose homes can be elevated do not see any need to elevate. Similar lack of awareness is common elsewhere in the coastal United States (Ludy and Kondolf 2012). A contributing factor was the NYC's Rapid Repair program, which replaced boilers and hot water heaters where they were before Sandy.

4.3 Community characteristics as indicators of resilience

Residents of Rockaway and residents of Staten Island experienced substantially different outcomes after the storm, as the variable "Resides in Rockaway" shows in regression results in Tables 4 and 6. The variable is one of the most consistently statistically significant, with large coefficients. Information from interviews suggests several reasons why this variable is important.

Geography and infrastructure result in greater vulnerability manifested in more widespread disruption of access to food and health care in Rockaway than on Staten Island (see columns 5 and 6 of Table 4). Residents of the flooded East Shore of Staten Island continued to have access to services located outside the flooded zone. Rockaway, on the other hand, is a narrow peninsula, and the storm disrupted already limited transportation to other parts of the city. All food stores and most health clinics remained closed for many months. On the other hand, the predominantly low-income, non-white residents in eastern Rockaway were less likely to report problems with access to health care relative to wealthier and whiter areas mainly because the only hospital is in the eastern section, and it remained open.

Geography and infrastructure also contributed to lower resilience in Rockaway compared to Staten Island (see columns 3, 9, and 11 of Table 6). Residents of Rockaway spent on average \$15,000 more out of their own pockets for a given amount of damage to a home. They were more likely to lose a job. Utility repairs required about 2 weeks longer and difficulties with accessing food continued almost 3 months longer.

Capacities in community organizations that are relevant to preparation for and recovery from a given hazard may be a useful indicator of resilience. Most assistance offered after

Hurricane Sandy, except financial, came from social networks, community groups, and non-profit organizations (NGOs), as is common after disasters (Klinenberg 1999; Chandra and Acosta 2005; Morello-Frosch et al. 2011). Local community groups and NGOs can be considered a feature of the communities' inherent resilience (Cutter et al. 2008). Respondents in Rockaway report more community organizations that existed before the storm than do respondents on Staten Island, and more Rockaway residents participated in organizations before Sandy. However, there was more assistance available to rebuild entire homes on Staten Island than in Rockaway and that assistance came from local NGOs.

Every interviewee on Staten Island mentioned the value of skills, resources, and local knowledge in several local NGOs, which provided free, skilled construction assistance needed to rebuild homes. Interviewees in Rockaway discussed the lack of such assistance despite the greater number of organizations and participation rates in Rockaway. Rebuilding homes was the scarcest type of assistance.¹² In both study areas, most assistance came from social networks (see Fig. 2), which offered unskilled help for small projects. In Rockaway, the second-largest source of help was the city of NY, which mainly repaired utilities through Rapid Repair. On Staten Island, the local NGOs offered the most assistance after social networks, providing skilled help with large rebuilding projects.

Interviews offer qualitative evidence that access to social networks is an indicator of resilience in both study areas. Social networks provide assistance to most households, mainly by offering a place to stay while rebuilding the home, information about sources of assistance, and labor to clean out flood debris and complete small rebuilding projects.

5 Conclusions and further research

The study identifies indicators of social vulnerability and resilience to coastal, storm-driven flooding in urban areas, focusing on low-rise housing, which is the most prone to flooding damage. Middle- and low-income homeowners emerge as least resilient to future flooding in financial terms. Renters are financially more resilient even when they are poorer. The caveat applies that we exclude high-rise, public housing though the financial impacts in this population are limited by lack of direct flood damage. Ownership of assets that are at risk of damage from the hazard is an important indicator of both vulnerability and resilience. These results are consistent with the discussion of earthquake impacts in Blaikie et al. (1994) and of flood impacts in Collins et al. (2018).

Resilience rises with income both among homeowners and among renters; the effect of income is *conditional* on ownership of assets that are at risk. A greater proportion of ethnic minority households experience disruption of access to food in the full population than do white households, as well as severe damage in some contexts. Disabled and/or chronically ill residents' households are more vulnerable and less resilient than are healthier households on many measures, even in the absence of data on health outcomes. Information is essential for recovery and for improving resilience to future hazards. It may reduce the costs of the recovery in some contexts. At the community level, two important indicators are hazard-specific

¹² Build It Back, a program organized by the city of NY to rebuild homes, reached few people at survey time. Few survey respondents received offers to buy out their homes. Respondents described the NYC buyout program in Rockaway as problematic. The NY Governor's Office for Storm Recovery New York Rising Buyout Program was a very effective effort that bought the homes of fewer than 500 residents in Staten Island neighborhoods of Oakwood Beach, Ocean Breeze, and Graham Beach (McGhee 2017).

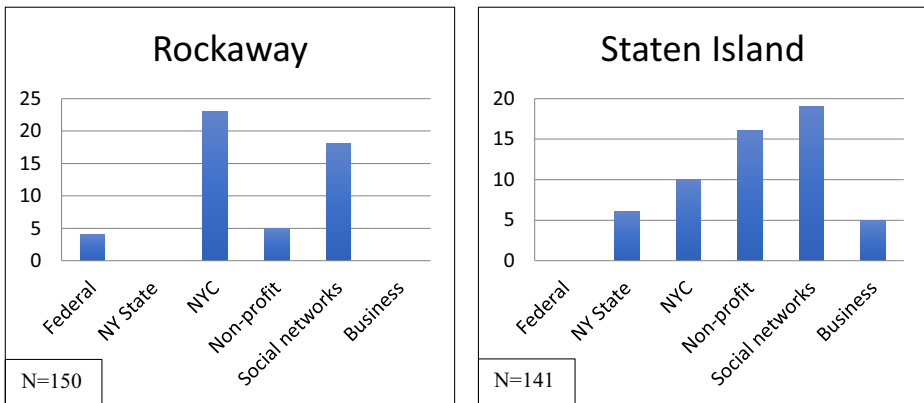


Fig. 2 Sources of assistance with rebuilding homes. The figure shows the number of households who received assistance with rebuilding from each source. The same household may have received assistance from multiple sources; therefore, the sum across the columns does *not* equal the number of households who received assistance with rebuilding. Data are from household surveys. Federal assistance includes FEMA and loans from the Small Business Administration. Assistance from NYC in Rockaway consists of 16 cases of repairs conducted by Rapid Repair and 5 cases of help from Build It Back, while on Staten Island, it consists of 6 cases of repairs by Rapid Repair and 5 cases of help from Build It Back. The non-profit category includes all community groups, volunteers, and NGOs. Social networks category includes family, friends, acquaintances, and colleagues. The business category includes private, for profit sources of assistance

capacities of community organizations and access to services, as determined by geography and infrastructure. The evidence that other commonly discussed indicators such as age, marital status, gender of household head, and education reflect vulnerability and resilience to flooding is weak in this study.

5.1 Further research

The study results imply that determinants of vulnerability and resilience, and therefore indicators that should guide decisions, may be different for different types of hazards and contexts, for example, because of differences in types of losses that result from the hazard. An important agenda for future research is to identify which indicators are relevant for different categories of hazards and contexts.

This study suggests several hypotheses for classifying hazards and contexts that may require different indicators. (1) Indicators may depend on the types of damage that the hazard causes. Homeownership can be an indicator of vulnerability and resilience for hazards that threaten damage to homes, for example, flood, wind, fire, and earthquake. It may not matter for heat waves. (2) Indicators may depend on the pattern of exposure. Rockaway and the East Shore of Staten Island feature uniformly high exposure to flooding among a diverse population. Results regarding exposure and damage echo for example results in Peacock et al. (1997) (p. 173) for Miami, Florida. The relationship with indicators may be different where groups that are traditionally considered more vulnerable have greater exposure, for example, as Collins et al. (2019) discuss for Houston, Texas. Uniform exposure may be increasingly common as climate change introduces new risks where the distribution of socio-economic subgroups reflects the lower historical risk. (3) Indicators may depend on the structure of housing and the distribution of the population across different housing types. The housing structure may affect the distribution of damage from a given hazard. Populations

in high-rise buildings are less vulnerable and more resilient to flooding than are populations in low-rise housing but they may be more vulnerable to pandemics or fires. The elderly may be more resilient to flooding in low-rise housing, while they may be immobilized by electricity outages in high-rise buildings.

Further research should verify the results of this study in larger samples and other urban contexts. Post-hazard access to basic needs in populations that include residents of public housing requires additional evidence.

Future research should investigate indicators that can measure progress toward reducing vulnerability and improving resilience that results from adaptation. Outcome measures such as cost of recovery as a share of income can measure such progress but only after a hazardous event. A potential candidate that can be measured at any time is the present value of future projected damages relative to the present value of future income.

Another challenge for future work is to collect data on relevant indicators that are consistent across contexts (Cutter 2016). The usefulness of indicators depends on the capacity to collect data on those indicators that are relevant.

5.2 Policy implications

This research has several policy implications that could inform investments in resilience to coastal flooding in NYC and other urban centers:

- (1) Coastal residents' capacity to plan for flood risk, including the financial implications, may contribute significantly to resilience. Programs that improve understanding of current and future risks, benefits and costs of adaptation options, including relocation, flood insurance, and likely future recovery resources would help residents to make informed decisions. Such programs, for example, building on [FloodHelpNY.org](https://www.floodhelpny.org) in NYC, should be designed differently for homeowners than for renters.
- (2) Planning for flooding should tailor policies depending on who is responsible for the recovery of assets that are at risk, financially and operationally. For example, policies should address the financial resilience of homeowners. Grant or loan programs could assist homeowners whose savings are depleted by the recovery from previous flood events with investing in reducing future flood damages. The National Flood Insurance Program could broaden the range of investments in damage reduction that lower the flood insurance premia. Policy design should build in incentives for homeowners and investors to consider whether continued residence in the coastal area is sustainable based on projected costs of future flood damages.
- (3) Preparedness programs, such as the NYC Emergency Management Ready NYC tool, take into account the special needs of households with chronically ill or disabled members. Recovery plans and efforts to build resilience are much less responsive to the needs of this group.
- (4) Recoveries from major hurricanes suggest that community groups and NGOs have the organizational structures and capacities to gather and act on local information that improve the efficiency and equity of recovery (Chandra and Acosta 2005; Morello-Frosch et al. 2011). Public planning could integrate community groups and NGOs into preparedness and recovery programs.

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