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Who is responsible for climate change adaptation?

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Supplementary material for this article is available online

Abstract

The mixture of socio-economic classes, ethnicities, and cultures that characterizes many cosmopolitan urban areas can contribute to unequally perceived impacts of extreme weather events and, hence, need and responsibility for adaptation. Awareness of these differences is, as we argue, decisive for effective adaptation. This study explores the relationship between person-specific, socio-economic characteristics that are frequently associated with social vulnerability and the perception of current affectedness by extreme weather events, future impact severity as well as adaptation need and adaptation responsibility. We use a large online questionnaire survey from New York City studying two extreme weather events, heatwaves and heavy rainstorms. We find that previous harm is the most important factor across all tested models for both weather events. However, previous harm and affectedness do not well explain the perception of future impacts, whereas they correspond to views about adaptation responsibility; respondents who felt significantly more affected in the past perceive the community to be in charge of adaptation. Women (during both weather events) and the elderly (during heatwaves) state largest affectedness during past events, and see the community as being responsible for future adaptation. Hispanic and African American respondents, on the other hand, were identified to perceive adaptation to be more of an individual task—potentially related to previous experience with (a lack of) local government services in their areas. Our findings evoke equity questions, and can aid urban decision makers aiming to implement effective and just adaptation measures, targeting vulnerable socio-economic groups in New York City and potentially other cosmopolitan areas.

1. Introduction

Over the last 20 years extreme weather events, such as storms, extreme temperature events, and floods were the deadliest weather-related phenomena in the world [1]. These three weather-related events are also the most deadliest in the United States [2] with heatwaves topping the list of the 30 year average, storms being number one of the 10 year average, and floods having caused the most fatalities in 2017. Urban areas are particularly susceptible to weather-related hazards since they are densely populated, reliant on transportation and vulnerable to utility outages [3]. For example, New York City (NYC), the largest metropolis of the United States faces the largest future health risks from increasing temperatures/heatwaves and coastal storms with flooding [4].

Impacts of heatwaves and coastal storms are usually stratified across the population, in particular in cities—characterized by a diversity of people regarding socio-economic backgrounds, ethnicities, and cultures—with a strong relation to social vulnerability

[5]. For example, heat-related risk is linked to both intrinsic person-specific factors (e.g. age, sex, ethnicity, disabilities, and medical status) and extrinsic socio-economic factors (e.g. socio-economic status, gender, education, living and working location and conditions) [6, 7]. Romero-Lankao, Qin [8] found altogether 13 variables commonly used to examine vulnerability to temperature-related hazards, including hazard magnitude (i.e. temperature level), population density, age, income, gender, pre-existing medical conditions, minority status, education, poverty, acclimatization, and access to home amenities such as air conditioning and swimming pools. Similar factors are often assumed to influence the vulnerability to rainstorms, but with a stronger focus on locational factors, such as the presence of impermeable surfaces, the scarcity of green spaces, inadequate or clogged drainage systems, and the ill-advised development of housing on marshlands, flood plains and other natural buffers [7].

Climate change adaptation, 'the process of adjustment to actual or expected climate and its effects' [9, p 1758], is well underway in NYC [10]. Influenced, among other reasons, by experiences with hurricane Sandy and to a lesser extent hurricane Irene recent adaptation planning concentrated on the rehabilitation and stabilization of the waterfront. Both events demonstrated the devastating impacts a lack of preparedness to coastal storms can have in terms of human health and well-being as well as property damage. The city of New York is also slowly but increasingly acknowledging the potential of serious impacts of heat. It has recently implemented various heat preparedness actions and, for example, operates cooling shelters throughout the five boroughs during heat emergencies [11, 12].

However, although in particular heatwaves pose a major future climate-related hazard in NYC, adaptation planning and policy actions to the risk of heatwaves as compared with heavy rainstorms is far less extensive. Local planning documents to heat adaptation are fewer, although climate projections suggest that heatwaves will approximately triple in frequency by the end of the century compared to current conditions [13]. Excess heat-related deaths due to heatwaves are expected to increase by 47%–95%—with a mean of 70%—for the NYC area from 1990 to 2050 [14]. Precipitation is expected to decrease overall for the North-Eastern region of the United States [15]. However, seasonal increases in winter precipitation may in some instances put a burden on areas that are already exposed to flooding and other rain-related hazards [16].

Moreover, it is documented that some adaptation measures already in place in NYC, e.g. cooling centers, are only used by a fraction of those in need, e.g. the vulnerable populations [11, 12]. Although heatwaves pose a major risk to urban populations [17], particularly when air conditioning and other short-term remedies fail, it might be perceived as less of a risk as their impacts are subtle, private, and not structural [18]. We need to conclude that the adaptation challenge is enormous [19–21], in particular with regard to the documented underutilization of existing adaptation measures.

Scholars argue that, in order to deliver effective adaptation, adaptation actors need to assume specific and clear roles [22, 23]. The question on roles and responsibilities is crucial, in particular with regard to the protection of the most vulnerable that may lack the means to protect themselves, evoking the question 'whether the protection of vulnerable individuals should be an individual or a collective responsibility' [24, p 1065]. Eisenack and Stecker [25] and Eisenack, Stecker [26] define three types of actors based on location factors: the exposure unit, the operator, and the receptor of adaptation. Mees, Driessen [22] see responsibilities as mainly divided by type of governance entity (public versus private)—the most common distinction. According to that division and a study of European and North-American cities, local governments play the primary role in adaptation while private entities have a less pronounced role [22, 27]. This reflects the widely held assumption in adaptation science that adaptation should take place at the local government level [28]. However, while such a division is seldom clearly defined in practice, it reflects a corresponding debate among citizens, as, e.g. found with respect to the responsibility for health care in the Netherlands [24]. And, while local governments may be in the driving seat in the stage of policy emergence [27, p 374] it is envisaged that 'with the maturation of the policy field and the expected acceleration of climate impacts … local public authorities need to more actively engage the different private actors such as citizens, civil society and businesses' [27, p 374]. This would allow responsibilities to be shared and all of society's resources to be fully exploited: 'active involvement of all societal actors might overcome problems of inefficiency and raise the legitimacy of adaptation action' [22, p 305].

If private actors are to be more actively engaged in adaptation processes one question is whether and how citizens see and perceive their role in adaptation. In particular it was argued that understanding perceptions of adaptation responsibility and roles may help explain the documented lack in using of provided adaptations in New York [11, 12] and other cities [29]. Research in Australia shows that citizens may not view themselves as passive players in climate adaptation—results of a climate change engagement program showed that many people want to act and be engaged [21]—but that residents lack procedural knowledge of or have diverging views on how to adapt [30]. For example, in a coastal community in central Victoria, opinion among community members ranged between: 'retreat is the only option' and 'there will not be much leaving' [30, p 350].

Such diverging views may be related to differential impacts across various socio-economic groups of residents and across different weather events [31], as local experiences of impacts play an important role in adaptation [22, 23, 30, 32–35]. Indeed, whereas a growing body of research in NYC focusses on quantifying mostly infrastructural, sectoral impacts of heat and coastal storms [36–40], the public perceptions of the related risks and vulnerabilities as well as attitudes towards adaptation needs and responsibilities are yet to be understood [41, 42]. Views of stakeholders and perceptions of residents constitutes a vitally important aspect for the effectiveness and the legitimacy of adaptation [22, 30]. Therefore, we ask: (1) How were impacts of heatwaves and rainstorms perceived by different socio-economic groups in NYC in the recent past?, (2) According to citizens views, which sectors are most impacted and therefore most in need of adaptation in the future?, (3) What is the perceived responsibility of citizens and of communities in adaptation?

To do so, we investigate experienced impacts and perceived future impact severity, adaptation needs and adaptation responsibility for heatwaves and heavy rainstorms in NYC, and how these factors are influenced by different levels of social vulnerability. NYC serves as case study due to its diverse demographics and experiences with extreme weather in the recent past.

2. Materials and methods

2.1. Data collection and processing

The main data source is an online questionnaire survey on the perception of impacts and adaptation responsibility of heatwaves and heavy rainstorms conducted in NYC. The term heavy rainstorm was used in reference to both hurricanes and Nor'easters, the most numerous weather conditions entailing storms with flooding in NYC (see above). We used the term heavy rainstorm in a generic way drawing on the perception of the respondents, instead of providing a scientific definition that would relate the hazard to an abstract, scientific concept.

The survey was conducted from 5 November to 8 December, 2013, and supported by the Center for Research on Environmental Decisions (CRED), Columbia University, protocol IRB-AAAK2162 (Y1M04). The implementation of the online questionnaire survey was done by Qualtrics Survey Providers, using their survey software and sample procedures [43].

The sampling frame consists of the five counties and boroughs of NYC—Bronx, Kings (Brooklyn), New York (Manhattan), Queens (Queens), and Richmond County (Staten Island), initially targeting 100 respondents from Staten Island (the maximum number of respondents Qualtrics could assure to generate there) and 200 respondents from the other boroughs. The survey was conducted with a randomly selected sample—representative of the NYC adult population with regard to gender and age (supplementary material (SM) 1 is available online at stacks.iop.org/ERL/14/014010/mmedia). However, as in other online surveys, it is difficult to make an informed judgment about the response rate [44]. Survey providers do not provide this information. The software registered more than 1200 attempts (complete and incomplete questionnaires), of which 935 were completed correctly—meaning that approximately 22% of respondents did not finish. After rigorous automated and manual quality control the sample contained $N = 762$ fully completed and valid responses. Automated quality control included checks of the IP address, a captcha code, a valid ZIP code and attention questions as well as the need for completeness. Manual quality control comprised of checking the understanding, truthfulness (sorting out respondents that put in a random selection of letters, such as 'asdddrftsfgg') and reliability of responses (via internal consistency, asking for similar aspects in two different questions). Automated and manual quality control reduces concerns about the quality of the online questionnaire data to a minimum.

Respondents were compensated according to Qualtrics policy, and received 4 US$ per completed questionnaire. The survey lasted for about 30 min. It was drawn independently of any other sample drawn for surveys in the area previously. Participants had to provide informed consent. The questionnaire comprised of maximum 68 questions (depending on previous answers the questionnaire differed in length), open- and closed-ended, multiple or single choice. Questions were clustered into groups/sub-groups, each providing indicators of either impacts (or impact interactions, not analyzed here), adaptation, or socio-economic characteristics of the respondents. Order effects were accounted for, i.e. answers for multiple-response questions were randomized and blocks of questions regarding extreme events (i.e. asking for heatwaves or heavy rainstorms) were shuffled. The questionnaire is provided as SM5. Table 1 provides an overview of variable dimensions, time horizons, variables, indicators and data types.

2.2. Data analysis

Tests for associations between the dependent variables, i.e. impact and adaptation dimensions (#1, #2, #4–#7 in table 2) and the independent, socio-economic variables (#8 to #14 in table 2) included:

(1) Linear regression (testing associations between a continuous dependent variable given two or more independent variables assuming a normal probability distribution).

(2) Ordinal logistic regression (testing associations between an ordinal dependent variable given one

Table 1. Overview of variables and indicators used. We acknowledge that some of the indicators are highly place-specific, i.e. indicative of the NYC socio-economic environment. Source: Authors' draft; Data: Authors' survey.

Variable dimension	Time horizon		Variable (data type)	Indicator (data basis)
Impacts	GENERAL	1	Affectedness by weather event (ordinal)	• Affectedness by (weather event) (Likert scale)
		2	Average affectedness by secondary impacts (Ø of Likert scale; continuous)	• Affectedness of respondent by (weather event) impacts (max. 8) (Likert scale)
	PAST → Experiences	3	Total previous harm/damage (last 10a) (count)	• Harm/damage over last 10 years 1. Damage to your property (yes/no) 2. Lost income (yes/no]) 3. Health-related damage (yes/no) 4. Other (yes/no) 5. (No harm) (yes/no)
		4	Worry about future (ordinal)	• Worry about future impacts next 20 years (Likert scale)
	FUTURE → Perception and Opinion	5	Average severity of future impacts (Ø of Likert scale; continuous)	• Severity of perceived future impacts on certain sectors: 1. You personally (Likert scale) 2. Our family (Likert scale) 3. Neighborhood (Likert scale) 4. Borough (Likert scale) 5. NYC (Likert scale) 6. Future generations (Likert scale) 7. Plants and animals (Likert scale) 8. Public property (Likert scale) 9. Private property (Likert scale)
Adaptation		6	Adaptation responsibility of individuals (ordinal)	• Citizens should do more or less to protect themselves (ordinal)
		7	Adaptation responsibility of communities (Ø of Likert scale; ordinal)	• Communities' importance to protect certain sectors 1. Water supply system (Likert scale) 2. Public health (Likert scale) 3. Drainage and sewer system (Likert scale) 4. Subway and rail system (Likert scale) 5. Electricity system (Likert scale) 6. Building stock (Likert scale) 7. Greenery and parks (Likert scale) 8. Road system (Likert scale)
Socio-economic characteristics		8	Gender (dichotomous)	• Male/female [0/1]
		9	Age (continuous)	• Age (years)
		10	Ethnicity (dichotomous)	• Ethnicity 1. White/Caucasian (yes/no) 2. Black or African American (yes/no) 3. Hispanic or Latino (yes/no) 4. Asian (yes/no) 5. American Indian, Alaska Native, Native Hawaiian, other Pacific Islander (yes/no)
		11	Household structure (continuous)	• People in the household (free text) • Dependent children in the household (free text)
		12	Social networks (continuous)	• People you know and could ask for help in your building (max 50) (free text) • People you know and could ask for help in your neighborhood (max 100) (free text)
		13	Building conditions (dichotomous)	• A/C in house (yes/no)
		14	Income (continuous)	• Total household income last year (ordinal) • Total personal income last year (ordinal)

or more independent variables assuming a multinomial probability distribution).

(3) Loglinear regression (testing associations between a dependent variable that consists of 'count data' given one or more independent variables assuming a Poisson probability distribution) [45].

Detailed descriptions to the definition and processing of the dependent and independent variables are provided in SM1. The independent predictors are either categorical variables (dichotomous or multinomial) and therefore entered as factors (gender, ethnicity, building conditions, income) or continuous (scale or interval) and therefore treated as covariates (age, household structure, social networks, previous harm). Factors are transformed into dummy variables (of 0/1) to allow an easier interpretation of the results. For example, income (household and personal income) is treated as categorical data of two categories, testing differences between low versus medium-high incomes. For personal income, 'low' is defined as income up to 20.000 US$/year and medium-high is defined as income above 20.000 US$ per year[5] while the respective cut-off for households is 50.000 US $/year. 'Previous harm/damage (last 10a)' was treated as socio-economic characteristic and added as independent covariate, as it relates to social vulnerability decreasing a person's adaptive capacity in the future [47, 48]. It is defined as either 'damage to the property', 'lost income', 'health-related damage', and/or 'other harm' having occurred during a heatwave or heavy rainstorm over the last ten years.

The model as a whole was evaluated via an omnibus test, checking whether all the independent variables collectively improve the model over the intercept-only model (reported as Likelihood Ratio Chi square with p values). Tests of significance of individual regression coefficients are performed via the Wald chi-square statistic. We report the standardized coefficient *Exp(B)*, the odds ratio, as well as the exact p values. Other test parameters, such as Wald Chi-square and confidence intervals can be found as SM3. The analysis was carried out using SPSS Statistics 23.0.

3. Results

Figure 1 shows descriptive statistics for indicators relating to past experiences. Overall, respondents feel having been more affected by heatwaves than by heavy rainstorms—even though more respondents claimed harm/damages from heavy rainstorms. For example, 19% of respondents reported to be very much affected by heat (1a), and 14% by its secondary impacts (1b); while these numbers are 12% and 10%, respectively, for heavy rainstorm. Harm/damages from heatwaves were mostly health-related (49% of heat damages; 1d). In contrast, heavy rainstorms caused more damage to property and resulted in more lost income (41% and 31% of damages, respectively; 1d).

Descriptive statistics to perception-related questions about the future are shown in figure 2. Respondents were slightly more worried about impacts of heavy rainstorms than heatwaves (14% and 12%, respectively) in the next 20 years (2a), although most respondents were only *somewhat worried* about these (approximately, 24%). This co-aligns with the perception to the severity of future impacts. Personal and family impacts due to both heatwaves and heavy rainstorms in the future are perceived to be *not very* to *somewhat* severe ($M = 2.43$ and $M = 2.49$, respectively). The largest future impact of heatwaves was perceived to relate to plant and animal species ($M = 3.21$); the largest impact of heavy rainstorms was perceived to affect NYC in general ($M = 3.22$; 2b).

Regarding adaptation, most respondents believe that *more* individual efforts are necessary to protect themselves against both, heatwaves and heavy rainstorms (26% and 27% of respondents; 2c). Fewer think *much more* individual adaptation is necessary (9% and 11% of respondents for heatwaves and rainstorms, respectively; 2c). Respondents perceive a higher need to individually prepare against rainstorms; accordingly, more respondents feel that they *do enough* when it comes to heatwave adaptation (13% of respondents feel to do enough, as compared with 11% for heavy rainstorm; 2c). In comparison, the need for communities to invest in adaptation is generally regarded *somewhat to very important* (2d). For heatwaves, respondents see the largest adaptation need when it comes to the electricity ($M = 3.76$), the water supply ($M = 3.72$) and the health sector ($M = 3.70$). The largest adaptation need for heavy rainstorms is related to the drainage and sewer system ($M = 3.86$), the electricity system ($M = 3.86$), and the subway and rail systems ($M = 3.85$; 2d).

Regression analyses (table 2, SM3 and SM4 for full results) reveal that for experiences with and perception of *heatwaves* are related to previous harm, ethnicity, income, gender, and age. Previous harm is significantly associated with all impact and adaptation dimensions tested and has large effects on the dependent variables. Previous harm is the most potent predictor in this study.

Ethnicity is decisive for the number of heatwave impacts mentioned, the perception of severity of future impacts from heatwaves as well as for individual adaptation responsibility. For example, being of *Hispanic* descent makes it [$Exp(B) = 2.345$] and 28% more likely to perceive future heatwave impacts as

[5] This is based on the poverty definitions of the American Community Survey (ACS, 2010) for a medium-sized household of 3–4 people. The data was drawn from the ACS. The mean number of household members in the sample is 3.6 person/household. However, this threshold is somewhat below the national official (23 624 US$, 2013) and the poverty threshold for NYC (31 156 US$, 2013) [46] (Mayor's Office of Operations, *NYC Government Poverty Measure 2005–2015*. 2017.).

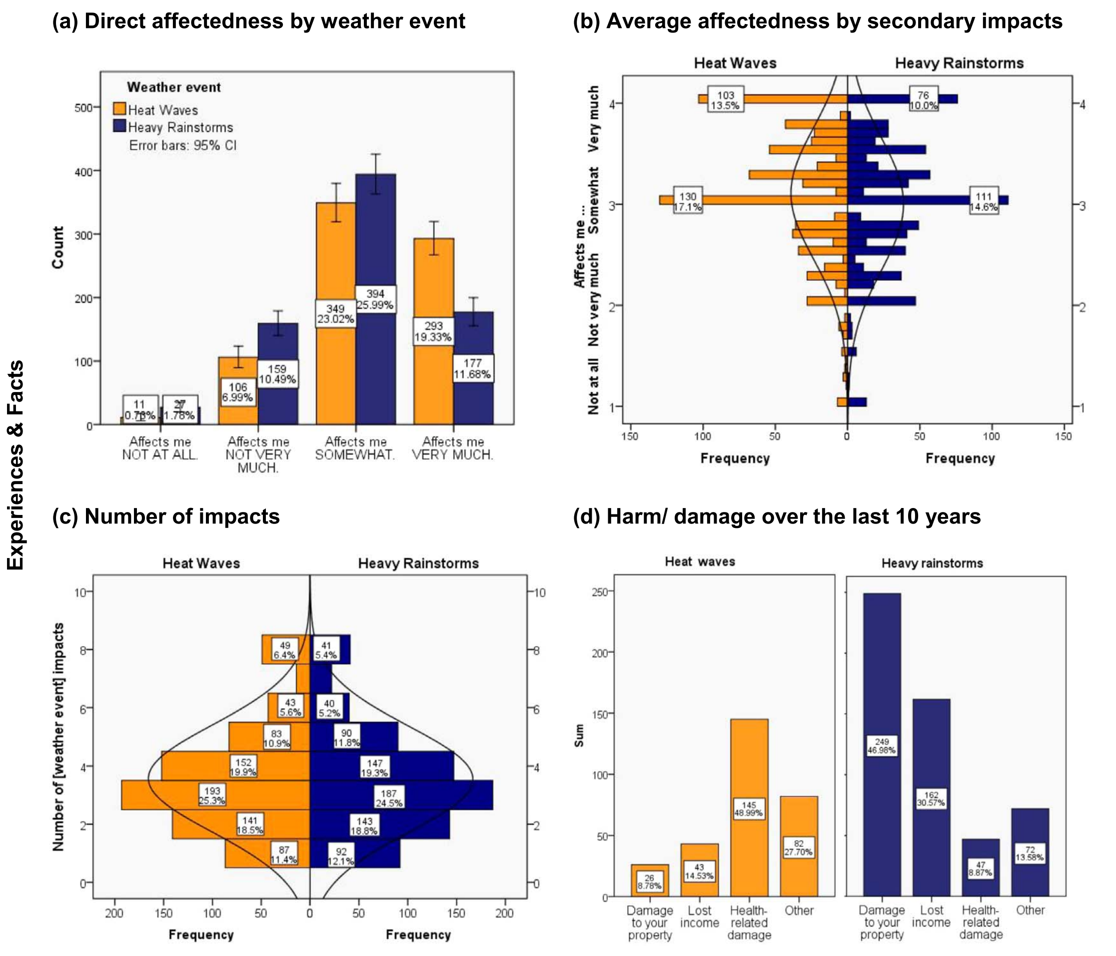

Figure 1. Descriptive statistics of the impact and adaptation indicators referring to past experiences, contrasting responses to heatwaves and heavy rainstorms. Data: authors' data; source: authors' draft.

more severe [*Exp*(*B*) = 1.280]. Being *African American* makes it 23% more likely to regard the severity of future impacts of heatwaves as higher [*Exp*(*B*) = 1.234]. *This means that respondents from both ethnicities expect future impacts to be high, though only Hispanics see the need for substantial individual adaptation.*

Income levels are important for the perception of future impacts. Respondents with larger household budgets are 12% less likely to perceive impacts as severe [*Exp*(*B*) = 0.888]. Age significantly relates to affectedness by heatwaves and its secondary impacts as well as to adaptation responsibility of communities. All three dimensions increase with age, though the effects are small.

Gender plays a role for direct heatwave affectedness and adaptation responsibility. Females are 34% more likely to be more affected during heatwaves than men [*Exp*(*B*) = 1.336] and 16% more likely to view the community as being (one unit) more important for adaptation than men [*Exp*(*B*) = 1.161].

Regarding *heavy rainstorms* a number of predictors are similar. For example, previous harm is again the most important factor, being significant across all impact and adaptation dimensions tested. The strongest relation also exists with regard to worry about the future [*Exp*(*B*) = 2.041], though being slightly weaker than as compared with heatwaves.

As regards *ethnicity, being of African American descent* makes it 115% more likely to regard adaptation during heavy rainstorms as (one unit) more of an individual task [*Exp*(*B*) = 2.154]. Similarly to heatwaves, an ethnic dimension is the second most potent and influential factor among all models tested for heavy rainstorm.

Household and personal income are also potent predictors for heavy rainstorms, particularly relating to the impact dimensions. Interestingly, as for heatwaves, a large *household income* decreases the likelihood to worry about the future [*Exp*(*B*) = 0.679] and the perceived severity of future impacts [*Exp*(*B*) = 0.872], but a large *personal income* increases these aspects [*Exp*(*B*) = 1.960; *Exp*(*B*) = 1.140, respectively].

Gender is influential and significantly influences more impact and adaptation dimensions during heavy rainstorms as compared with heatwaves. Women are 38% more likely to be more affected during heavy rainstorms than men [*Exp*(*B*) = 1.384], 42% more likely to worry more about the future [*Exp*(*B*) = 1.423] and 13% more likely to regard future impacts as being (one unit) more severe [*Exp*(*B*) = 1.127].

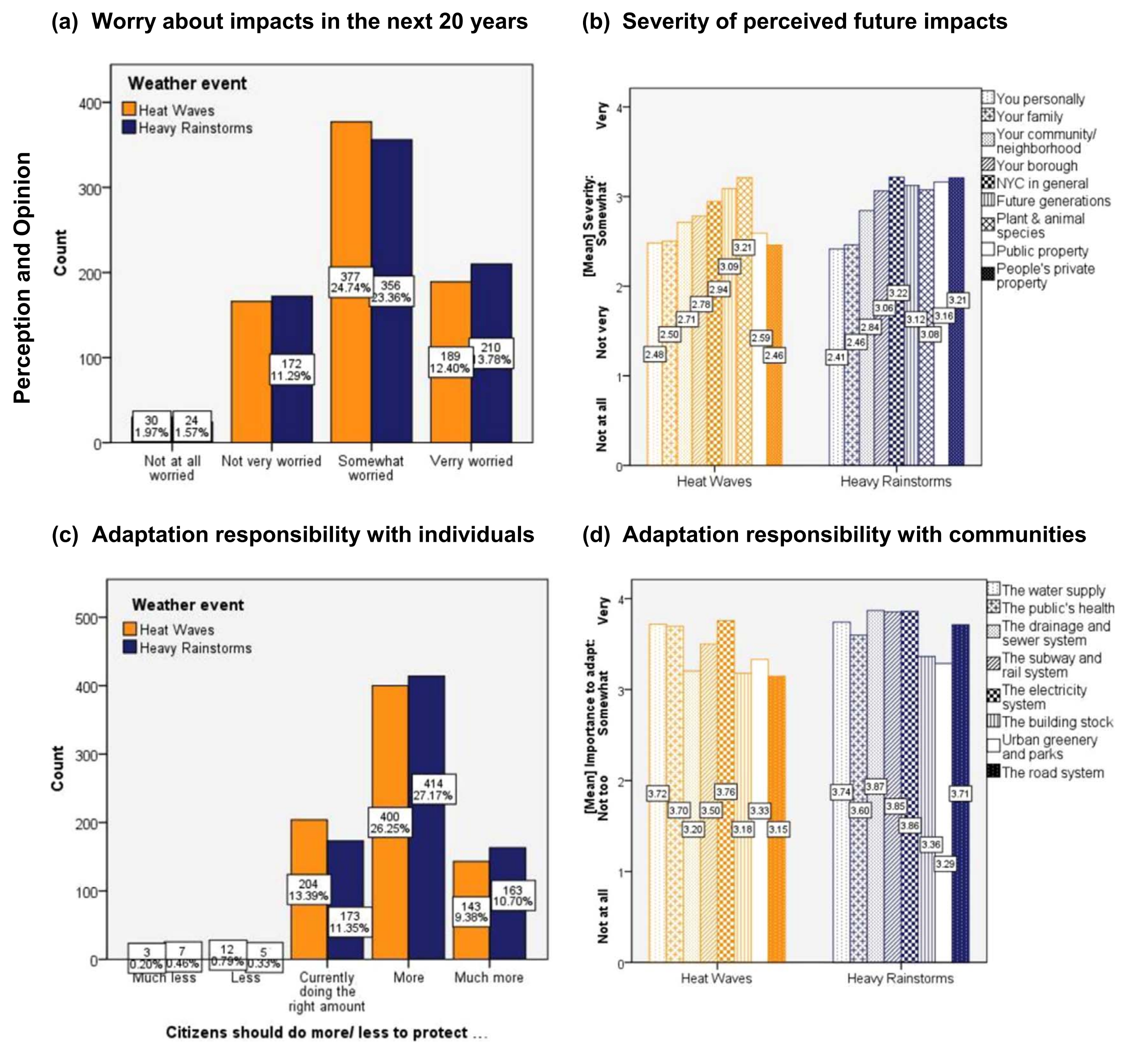

Figure 2. Descriptive statistics of the impact and adaptation indicators referring to perceptions and opinions about impacts in the future and adaptation responsibilities, contrasting responses to heatwaves and heavy rainstorms. Data: authors' data; source: authors' draft.

Comprehensibly, women view adaptation as being more of a community responsibility than men [$Exp(B)$ = 1.112]; being a women raises that likelihood by 11%.

The associations between past affectedness and the perception of future impacts and adaptation responsibility also reveal interesting patterns. Table 2 shows that affectedness does not well explain the perception of future impacts, but correspond to views about the role of communities in adaptation. Respondents who felt significantly more and directly affected by past heatwave and heavy rainstorm events believe that the community should invest more in and hence is responsible for adaptation.

4. Discussion

The study was driven by three research questions, which will structure the discussion section.

(1) How were impacts of heatwaves and rainstorms perceived by different socio-economic groups in NYC in the recent past?

The analysis reveals that more people are very much affected by heatwaves as compared to rainstorms, but that rainstorms affect more people somewhat. Impacts of heatwaves should therefore not be underestimated; they are different in nature. Heatwaves cause more health-related damages—which apparently are perceived as a stronger effect—than, e.g. property damages and lost income, as seen during rainstorms. This is an important policy-relevant finding and shows that impacts should not only be measured in terms of structural damage, but also other outcomes such as health and well-being [49]. After all, heatwaves cause more fatalities in the United States than other climate hazards [50, 51].

Gender, age, the number of friends in the building, and personal income significantly determine the strength of affectedness. Females perceive to

Table 2. Parameter estimates of the tested models using regression analysis. The dependent variables are listed in the top row; while the independent predictors are shown in the first column; shaded cells show significant indicators, based on significance levels $\alpha < 0.05$. Key: LR—Likelihood Ratio; HH—household; NH—Neighborhood; A/C—Air conditioning; Note: other parameter estimates (unstandardized *B*; and all 95% confidence intervals) are shown as supplementary material 4.

Dependent variable	Affectedness by weather event		Affectedness by secondary impacts		Worry about future		Severity future impacts		Adaptation responsibility with individuals		Adaptation responsibility with communities	
Independent variable	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*
					Heatwaves							
Female	1.336	0.048	1.007	0.883	1.179	0.256	1.023	0.635	0.930	0.617	1.161	0.000
Male	1	.	1	.	1	.	1	.	1	.	1	.
Age	1.012	0.019	1.004	0.026	1.005	0.366	1.001	0.408	1.000	0.981	1.005	0.000
White/Caucasian	0.669	0.125	0.941	0.452	.746	0.249	0.969	0.714	0.951	0.842	0.977	0.726
	1	.	1	.	1	.	1	.	1	.	1	.
African American	1.257	0.415	1.060	0.499	1.279	0.369	1.234	0.021	1.483	0.153	1.010	0.887
	1	.	1	.	1	.	1	.	1	.	1	.
Hispanic	1.005	0.985	1.022	0.794	1.327	0.280	1.280	0.005	2.345	0.001	1.108	0.133
	1	.	1	.	1	.	1	.	1	.	1	.
Asian	0.923	0.798	1.032	0.751	1.088	0.784	1.178	0.110	1.684	0.093	1.062	0.457
	1	.	1	.	1	.	1	.	1	.	1	.
Native	1.154	0.765	0.970	0.845	0.725	0.499	1.038	0.815	0.947	0.911	1.068	0.600
	1	.	1	.	1	.	1	.	1	.	1	.
#People/HH	1.043	0.499	1.009	0.648	0.948	0.377	1.039	0.058	0.940	0.305	1.002	0.897
#Children/HH	0.953	0.313	1.003	0.814	1.057	0.220	0.993	0.627	1.091	0.066	1.004	0.737
#Friends/Bldg.	0.997	0.869	0.998	0.714	0.999	0.953	1.002	0.655	1.011	0.535	.999	0.762
#Friends/NH	1.000	0.953	1.001	0.509	0.999	0.908	1.000	0.919	0.998	0.718	1.002	0.148
A/C	0.948	0.832	0.979	0.792	1.291	0.311	1.098	0.265	0.960	0.875	1.126	0.067
	1	.	1	.	1	.	1	.	1	.	1	.
HH income	0.779	0.128	0.941	0.239	0.779	0.121	0.888	0.028	0.902	0.527	0.947	0.203
(high versus low)	1	.	1	.	1	.	1	.	1	.	1	.
Personal income	0.980	0.906	1.013	0.819	1.192	0.303	1.043	0.466	0.868	0.409	1.007	0.871
(high versus low)	1	.	1	.	1	.	1	.	1	.	1	.
Previous harm	2.059	0.000	1.305	0.000	2.665	0.000	1.339	0.000	1.675	0.000	1.082	0.011
OMNIBUS TEST	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*
	60.759	0.000	63.643	0.000	86.794	0.000	95.873	0.000	49.471	0.000	50.476	0.000
					Heavy rainstorms							
Female	1.384	0.027	1.080	0.100	1.423	0.015	1.127	0.011	1.265	0.108	1.112	0.000
Male	1	.	1	.	1	.	1	.	1	.	1	.

Table 2. (Continued.)

Dependent variable	Affectedness by weather event		Affectedness by secondary impacts		Worry about future		Severity future impacts		Adaptation responsibility with individuals		Adaptation responsibility with communities	
Independent variable	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*	*Exp (B)*	*p*
Age	1.002	0.639	0.999	0.572	1.008	0.120	0.999	0.686	1.003	0.521	1.001	0.165
White/Caucasian	0.877	0.613	0.951	0.543	0.942	0.818	0.982	0.822	1.448	0.144	0.986	0.774
	1	.	1	.	1	.	1	.	1	.	1	.
African American	1.290	0.364	1.042	0.640	1.146	0.620	1.045	0.620	2.154	0.005	1.067	0.221
	1	.	1	.	1	.	1	.	1	.	1	.
Hispanic	1.249	0.403	1.011	0.898	1.231	0.431	1.112	0.211	1.592	0.078	1.083	0.120
	1	.	1	.	1	.	1	.	1	.	1	.
Asian	1.610	0.132	1.070	0.497	1.176	0.605	1.027	0.788	1.465	0.209	0.982	0.762
	1	.	1	.	1	.	1	.	1	.	1	.
Native	0.466	0.111	0.851	0.300	0.465	0.105	0.934	0.659	0.688	0.426	1.007	0.938
	1	.	1	.	1	.	1	.	1	.	1	.
#People/HH	1.126	0.054	1.024	0.219	1.062	0.307	1.039	0.052	1.067	0.294	1.009	0.463
#Children/HH	0.991	0.837	1.011	0.459	1.033	0.444	1.011	0.479	1.051	0.299	1.007	0.412
#Friends/Building	1.039	0.025	1.010	0.072	1.008	0.634	1.009	0.094	1.030	0.085	1.000	0.994
#Friends/NH	0.993	0.230	0.998	0.314	0.998	0.737	0.997	0.102	1.002	0.743	1.001	0.289
A/C	1.489	0.108	1.071	0.390	1.089	0.727	1.191	0.031	1.274	0.353	1.014	0.772
	1	.	1	.	1	.	1	.	1	.	1	.
HH income	0.831	.261	0.915	0.089	0.679	0.016	0.872	0.009	0.885	0.451	0.953	0.130
(high versus low)	1	.	1	.	1	.	1	.	1	.	1	.
Personal income	1.189	0.327	1.122	0.040	1.960	0.000	1.140	0.020	1.063	0.728	1.037	0.281
(high versus low)	1	.	1	.	1	.	1	.	1	.	1	.
Previous harm	1.994	0.000	1.246	0.000	2.041	0.000	1.279	0.000	1.418	0.000	1.034	0.080
OMNIBUS TEST	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*	LR χ^2	*p*
	84.466	0.000	75.779	0.000	89.695	0.000	99.146	0.000	38.394	0.001	34.138	0.005

be significantly more affected than men during both weather events. Age is (only) significantly related to the impact of heatwaves. This is in line with other studies of heat risk in major US cities [52, 53] and around the globe [6, 7]. Number of friends is (only) significantly related to heavy rainstorms, and may show that recent hurricane Sandy affected residents in larger buildings and larger households (not statistically significant), though not necessarily families. Also a large personal income is positively related to affectedness by (secondary) impacts of rainstorms. Previous research on the issue is not conclusive. A recent study on post-Hurricane Sandy recovery has indicated that middle-income homeowners were most vulnerable to flooding [54]. Other studies indicate that lower income individuals and families have experienced more substantial impact as a result of Hurricane Sandy [40, 55–58], as well as Hurricane Katrina [59–61].

As a form of triangulation we included previous harm, a slightly differing but related indicator to affectedness. It is strongly related to past affectedness (as one would expect) and is the most important predictor for all the heatwave and heavy rainstorm dimensions. Further probing of the harm/damage indicator reveals that, for heatwaves, it is related to age [$Exp(B) = 1.013$] and friends in the neighborhood [$Exp(B) = 1.009$] (SM4)—the latter potentially being a reference to Hispanic and African American communities. One year of age as well as one more friend increase the likelihood of having experienced one unit of more harm by about 1%. However, the model is not very robust [$LR\ \chi2 = 24.297$; $p = 0.042$]. For heavy rainstorms, a more robust model could be predicted [$LR\ \chi2 = 42.287$; $p = 0.000$]. Harm from heavy rainstorms is significantly associated with the number of people living in the household [$Exp(B) = 1.124$] and with personal income [$Exp(B) = 1.488$]. One more person in the household increases the likelihood of having experienced one more unit of harm by 12%, while being within the higher income category makes it 49% more likely to have experienced more harm during past rainstorm events. With that result, our study supports the finding that Hurricane Sandy has probably impacted middle-income households more than others [54].

(2) According to citizens views, which sectors are most impacted and therefore most in need of adaptation in the future?

Respondents are slightly more worried about heavy rainstorms than heatwaves in the future—despite the contrary as regards affectedness in the recent past. Such findings may be influenced by the recent damages of Hurricane Sandy, which are vividly remembered and not yet overcome [55]. It also suggests that affectedness does not directly correspond to perceptions of future impacts. Such finding may be explained with an optimism bias or valence effect—a cognitive bias that causes a person to believe that they are less at risk of experiencing a negative event compared to others [62, 63]—or to the cognitive bias called gambler's fallacy [64]—the mistaken belief that, if something happens more frequently than normal during some period, it will happen less frequently in the future. These and other cognitive biases have been frequently documented in perception studies on climate change [33, 34].

Adaptation need, i.e. severity of future impacts, is influenced by ethnicity, gender, income and the availability of A/C. African American and Hispanic respondents see a significantly larger adaptation need during heatwaves, while being insignificant as regards rainstorms. Women indicated a significantly larger adaptation need and worry about the future for rainstorms. Interestingly, a large household income decreases the perceived severity of future impacts as well as worry about the future in our study, whereas a large personal income increases these aspects, respectively. The directional change in the relation might be an education effect or information bias, with more educated and informed people (usually having higher incomes) also being more worried.

(3) What is the responsibility of citizens and of communities in adaptation?

Overall, the perception of individual adaptation responsibility is regarded to be higher during heavy rainstorms and lower during heatwaves (figure 2(c)), contrary to stated previous harm and affectedness and although one would assume that the means of personal adaptation are higher when it comes to heatwaves. Community education programs, particularly with focus on explaining the life threatening impacts heat can have as well as the substantial steps individuals can take to prevent these could be beneficial for raising awareness [65]. Such programs can also increase utilization of heat adaptation measures currently in place, such as cooling centers [11, 12].

Ethnicity and previous harm are shown to significantly influence views on individual adaptation. Gender, age and previous harm are significantly related to views on community adaptation. With that, adaptation responsibility relates more to affectedness and previous harm than to the perception of future severity of heatwaves and rainstorms.

Respondents who state having been significantly more affected by heatwaves (elderly and females) and heavy rainstorms (mostly females) see the community in charge of adaptation, i.e. not the responsibility with the individual. This might e.g. explain why cooling centers are insufficiently used (going there is an individual action) and reflect an adaptation need that is currently not met. In contrast, people of Hispanic descent (during heatwaves) and African Americans (during rainstorms) regard adaptation to be more of an individual responsibility. Although these groups did not report to be significantly (more) affected they might be vulnerable. Martin [66] determined general social vulnerability factors in American cities through meta-analysis and found 'being of color' to be a particular driving force. Other studies also show that people of color are more at risk than other city dwellers because the housing they can afford tends to be located in environmentally riskier areas and of poorer quality [67], and because local governments overseeing such neighborhoods often fail to establish and maintain proper services [67]. As a consequence, people in such neighborhoods may choose to rely on themselves—an important finding. This is different from the results of other studies, e.g. in the UK and Ireland. There, the lack of government support led to a form of helplessness among citizens and subsequently unwillingness to take on personal responsibility for adaptation (in that case flood protection) [23].

The latter findings are important for two reasons: first, it is known from the disaster literature that extreme events are likely to have the most devastating impacts on the already vulnerable [66, 68–70]. Therefore, addressing the needs and improving the resilience of previously affected communities and subgroups is likely to be particularly beneficial in preventing impacts from repeated exposure to weather hazards [66]. Second, improving individual resiliency to heat and rainstorms among already affected populations may be particularly effective due to their increased sense of adaptation responsibility, in particular as regards community but also individual adaptation. The positive relation between harm from previous disasters and adaptation has also been shown in other studies [29, 32, 35], while potential future risk does not seem to play a substantial role in adaptation [71].

Our study has limitations that relate, e.g. to the use of online questionnaires. Online questionnaire surveys have found to be less likely than other survey forms to reach the elderly population, racial or ethnic minorities, unmarried, less educated, or highly affluent people [44]. In addition, females are often more likely to exhibit information-seeking behavior and participate in questionnaires [72, 73]. While our sample was not found to be under representative of the elderly population and had roughly the same distribution of males and females (SM2), it was under representative of the African American, Hispanic, Asian and Native American populations, similarly to other non-probability online surveys [44]. However, participants in our survey had a higher income compared to other online surveys [44]. It is possible that the participation of individuals with higher income is due to self-selection bias. Previous research has indicated that low income individuals ($\leqslant$\$30 000/year) can be less likely than higher income individuals ($>$\$30 000/year) to be aware of climate change [74]. Thus, higher income individuals may have been more interested in responding to our questionnaire. However, the data were not subsequently weighted for analysis. Moreover, we acknowledge that some of the indicators are highly place-specific, i.e. indicative of the NYC socio-economic environment.

5. Conclusion

This study investigated the relationship between experienced impacts, and perceived future impact severity, adaptation needs and adaptation responsibility for heatwaves and heavy rainstorms in NYC, and how these are influenced by different levels of social vulnerability. With that the study aims to support NYC authorities and individuals in climate change adaptation, in particular an increase in adaptation effectiveness and an equitable and just adaptation approach. Views of stakeholders and perceptions of residents constitute vitally important aspects for the effectiveness and the legitimacy of adaptation.

The findings show that working towards more equitable and just adaptation policies for heatwaves and rainstorms needs to address different social groups and vulnerability markers. Overall, effective and just adaptation is not an easy task and should not be understood as a one-size fits all activity—context matters [23]. We show that previous harm strongly affects views on adaptation responsibility—women and elderly, both groups significantly affected by previous events, see a greater responsibility of communities in adaptation. In contrast, Hispanics and African Americans perceive adaptation to be more of an individual responsibility, relying on themselves, potentially as a consequence of failing local government arrangements. Considering all findings and implications we conclude that in order for adaptation policies to be effective they need to consider previous harm and differential social vulnerability, specific to the weather event. This allows to harness an increased sense of adaptation responsibility among already affected populations, prevent impacts from repeated exposure, and leads to more just designs and implementation of adaptation measures.

Though we believe that the presented findings are relevant for other urban agglomerations, in particular in the US, similar studies to the conditions of adaptation effectiveness in other political, cultural and social contexts constitute an important direction of future research.

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