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# Experience of localized flooding predicts urban flood risk perception and perceived safety of nature-based solutions

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Understanding community members' flood risk perceptions is critical for developing new approaches to managing flood risks for climate resilience. "Risk as feelings" has informed research on how people perceive flood risks based on intuition and personal experiences, complementing experts' technical assessment. However, attention has been primarily on riverine and coastal flooding. We expand the "risk as feelings" concept to investigate community members' risk perceptions of urban pluvial flooding as well as perceived safety of novel vs. familiar nature-based solutions (NBS). For the novel practice, we focus on floodable sites that temporarily inundate urban open spaces under storm conditions. For the familiar practice, we focus on retention ponds that store excessive runoff under storm conditions. Data were collected through visualization-assisted surveys of residents from high and low flood hazard areas in three US cities ($N = 884$). We found that over half of respondents indicated some degree of worry about stormwater-related damage, and overall, respondents perceived floodable as less safe than retention ponds under storm conditions. Further, respondents who had more frequently experienced localized flooding near their homes were more worried about potential property damage caused by flooding. They also perceived floodable sites as less safe under storm conditions. However, more frequent experience of localized flooding was not associated with perceived safety of retention ponds under storm conditions. Some other contextual and socio-demographic factors (e.g., prior stormwater-related property damage, knowledge of and involvement in stormwater management issues, gender, age, race, and having children) also had notable effects on flood risk perception and perceived safety of NBS. We discuss the implications of these findings for urban flood risk management and NBS development.

KEYWORDS

**urban flooding, stormwater management, nature-based solution (NBS), flood risk perception, community resilience, landscape design, climate change adapataion**

## Introduction

Climate change, coupled with urban development and aging infrastructure, is driving more pluvial flooding in cities (Berndtsson et al., 2019; National Academies of Sciences Engineering and Medicine, 2019; O'donnell and Thorne, 2020). The management of urban stormwater and flooding risks increasingly aims for *resilience*, the capacity to absorb, recover from, and adapt to extreme storm events and their uncertain impacts (Liao, 2012; Disse et al., 2020; Mcclymont et al., 2020). Such a shift calls for changes in urban landscapes to make space for water, and many government agencies and organizations are developing nature-based solutions (NBS) as a promising approach (Hobbie and Grimm, 2020; Axelsson et al., 2021). NBS include various practices (e.g., retention ponds, detention swales and basins, constructed wetlands) that seek to use natural processes to manage stormwater and mitigate flooding while offering other societal benefits (Lennon et al., 2014; Hobbie and Grimm, 2020; O'donnell et al., 2020).

One increasingly discussed NBS innovation is floodable sites, urban spaces designed to accommodate different dry and wet weather functions (Palazzo, 2019; Ashley et al., 2020; Kuang and Liao, 2020; La Loggia et al., 2020). In dry weather, they are used for everyday activities (e.g., recreation, parking, light traffic); in wet weather, they are temporarily inundated to manage excessive storm runoff and mitigate flooding (Mariano and Marino, 2018; Silva and Costa, 2018; Lund et al., 2019; Rogers et al., 2020). Floodable sites can include diverse types of urban spaces for stormwater and flood risks management. Some scholars have also argued that introducing such practices may help urban residents observe and learn about stormwater, thus encouraging a shift in social-cultural norms to "live with water" (Lennon et al., 2014; Silva and Costa, 2018; Kuang and Liao, 2020; Mcclymont et al., 2020).

However, scant research exists on how community members perceive novel NBS practices like floodable sites. There are anecdotes of residents calling a water plaza designed as a floodable site a "drowning plaza" (Silva and Costa, 2018). In cities, drainage systems have long been adopted to discourage standing water, treating stormwater as a nuisance that can disturb daily activities (Tempels and Hartmann, 2014; Ashley et al., 2020; Kuang and Liao, 2020). The visible ponding and puddling in typically dry floodable sites might feel unpleasant and unsafe to urban residents. This can undermine public acceptance of novel NBS practices despite their environmental benefits (Derkzen et al., 2017; Frantzeskaki, 2019; Han and Kuhlicke, 2019; Anderson and Renaud, 2021; Li and Nassauer, 2021).

To offer new insights for managing urban flooding through NBS, this study uses "risk as feelings" as an organizing framework to investigate community members' risk perceptions. This concept is embedded in a broader theory in cognitive psychology and neuroscience which asserts that humans use both affective and cognitive processing—a "dual process" model—to comprehend the world (Loewenstein et al., 2001; Slovic et al., 2004). Affective processing, which occurs when people perceive something as good or bad, is often labeled experiential, intuitive, and automatic; cognitive processing, which occurs when people use explicit reasoning, is often labeled analytical and deliberative (Epstein, 1994; Kahneman, 2011). Both processes are now recognized as critical to decision-making. When faced with risk or uncertainty, though, people are prone to make judgements driven by how they feel about an outcome rather than by deliberation about its probability and consequences (Slovic, 1987; Slovic et al., 1998; Disse et al., 2020). For example, if people have unfavorable feelings toward using pesticides, they tend to perceive high risk and low benefit of pesticides; if they have favorable feelings, they tend to perceive the opposite (Alhakami and Slovic, 1994). The risk perception of a phenomenon can be strongly affected by past experiences of the same phenomenon or one with similar perceptible characteristics (Loewenstein et al., 2001). Through lived experience and learning, certain sights, sounds, smells, ideas, and words can become associated with positive and negative feelings, forming "affective images" that guide responses in future situations (Slovic et al., 1998).

"Risk as feelings" has informed many studies on flood risk perception—the perceived likelihood and potential damage of flooding (Botzen et al., 2009; Kellens et al., 2013; Wachinger et al., 2013; Birkholz et al., 2014; O'neill et al., 2016; Lechowska, 2018). Flood risk perception often differs from expert technical assessments of flood risks and is consistently reported to relate to past experiences of flooding (Botzen et al., 2009; Kellens et al., 2013; Wachinger et al., 2013; Birkholz et al., 2014; O'neill et al., 2016; Lechowska, 2018). For example, Botzen et al. (2009) found that individuals who had experienced or been evacuated from a historic flood event in the Netherlands reported a higher perceived probability of flooding. Besides flood experience, socio-demographic characteristics (e.g., age, gender, income, education, having young children) may also influence flood risk perception, though their reported effects are not consistent (Kellens et al., 2013; Wachinger et al., 2013; Lechowska, 2018). For example, some studies found that people with higher education perceived lower flood risks (Botzen et al., 2009; Bradford et al., 2012), whereas other studies reported no association betweeen eduction and risk perception (Kellens et al., 2011; O'neill et al., 2016).

While the growing literature on flood risk perception provides important insights for flood risk communication and management, most studies have focused on major riverine and coastal flooding. Urban pluvial flooding, which results from overwhelmed drainage systems and occurs more frequently, calls for more investigation (Netzel et al., 2021). Further, risk perception related to novel NBS that are designed to manage urban pluvial flooding has not yet been examined, to our knowledge.

This study investigates the risk perception of localized flooding and the perceived safety of novel and familiar NBS practices. We examine how people with different past experiences with localized flooding perceive the risk of urban pluvial flooding as well as the perceived safety of novel and familiar NBS under storm conditions. We compare perceptions of floodable sites, a novel NBS practice that temporarily inundates urban landscapes under the storm condition, with perceptions of stormwater retention ponds, a familiar NBS practice that can hold excess water under the storm condition. We also explore whether other contextual (e.g., residence location relative to flood zone, environmental knowledge) and socio-demographic factors are associated with perceived flood risk and perceived safety of NBS practices. Specifically, we address four questions:

1) What are community members' perceptions of localized flooding risks?
2) How safe are floodable sites (a novel NBS) and retention ponds (a familiar NBS) perceived to be under storm conditions? Are floodable sites perceived as less safe than retention ponds?
3) Are community members' flood risk perception and perceived safety of NBS practices under storm conditions associated with their experience of localized flooding?
4) What other contextual and socio-demographic factors may relate to community members' flood risk perception and perceived safety of NBS practices under storm conditions?

# Materials and methods

## Study area

We conducted a mail survey in three US cities: Ann Arbor, Michigan, South Bend, Indiana, and Knoxville, Tennessee (Figure 1). All three cities have experienced severe urban flooding within the past 4 years. Further, with climate change, these cities all face growing flood risks. Projections by the First Street Foundation (2022) based on factors including flood hazards, property and parcel conditions, future climate scenarios, and local adaptation predict that, for the next 30 years, Ann Arbor has a moderate risk of flooding, with 4% of properties having over a 26% chance of being severely affected by flooding. South Bend and Knoxville have a major risk of flooding, with 11% of properties having over a 26% chance of being severely affected by flooding.


FIGURE 1
Three US cities were sample areas for this study.

## Sampling method

To include respondents with potentially varied experiences of flooding, we used a stratified random sampling method to recruit respondents for our survey. First, we categorized census blocks in each city into four strata, considering combinations of low/high flood hazards and low/high income. High vs. low flood hazards was based on whether a census block intersected with the Special Flood Hazard Area (100-year flood) and the moderate flood hazard areas (500-year flood) designated by the US Federal Emergency Management Agency (FEMA) (https://msc.fema.gov/portal/home). High vs. low income of a block was based on the income of the block group it was in. Census block groups with median household income higher than the city's median household income were designated as high income, while census block groups with median household income lower than the city's median household income were designated as low income. We excluded census block groups with a median age under 25 to avoid recruiting substantial numbers of students who are temporary residents living near universities in each city.

Next, we randomly selected 336 household addresses within each of the 12 strata (3 cities × 2 income levels × 2 flood hazard levels) to receive the survey invitation, resulting in a mail sample of a total of 4,032 household addresses. This sample size was estimated to be sufficient to yield a minimum of 200 completed surveys per city based on requirements for structural equation modeling (Kline, 2015) and an estimated response rate of 15% given previous studies on green infrastructure that also used a mail survey (Ambrey et al., 2017; Williams et al., 2019).

## Survey design

### Landscape visualizations to represent NBS practices

For survey respondents to see novel and familiar NBS practices under storm conditions, we developed landscape visualizations of floodable sites and stormwater retention ponds. Visualizations are widely used to study visual perception of landscapes (Jorgensen et al., 2002; Sevenant and Antrop, 2011). Moreover, realistic visual imagery may help ground information,

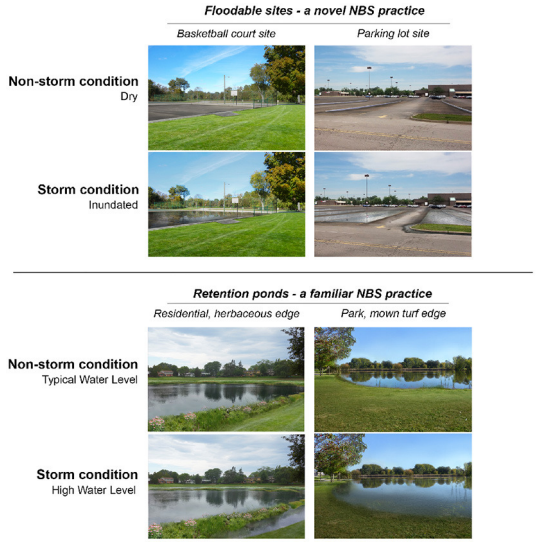


FIGURE 2
Examples of visualizations for floodable sites, a novel NBS practice, and retention ponds, a familiar practice, under storm and non-storm conditions. Image credit: The Landscape Ecology, Perception, and Design Lab, University of Michigan (https://www.joan-nassauer.com/).

broaden respondents' experiences, and facilitate understanding of new landscape futures (Sheppard, 2005). This is particularly useful for representing novel NBS, such as floodable sites that are unfamiliar to the general public.

Our team manipulated photos of 10 potential sites for NBS development in the three study cities in Adobe Photoshop CC to create 34 sets of visualizations. Each visualization set realistically depicted a floodable site or a retention pond under both storm and non-storm conditions (Figure 2). Floodable sites were shown as both dry non-storm conditions and inundated storm conditions in two locations (i.e., basketball courts in greenspace and parking lots around building complexes), with two replicate sites for each location. Retention ponds were shown at both typical water level non-storm conditions and high water-level storm conditions with 15 landscape design choices (varied by types of surrounding plants, basin slope, and land use context), with two replicate sites for each design choice.

## Questionnaire

The survey questionnaire consisted of two parts. The first part showed visualizations for retention ponds and floodable sites under storm and non-storm conditions. For each NBS practice, visualizations were color-printed in high resolution (8.3 × 12.5 cm) and laid out on a single page to show different storm conditions. There was a short description of the site for stormwater management practice that respondents were seeing (e.g., "This is a basketball court. It holds water only temporarily, after a storm."). Respondents were asked about their perceptions of how safe each picture looked on a 5-point Likert scale. The second part of the questionnaire asked respondents about their experiences with flooding, worry about potential damages caused by stormwater, knowledge and behaviors related to general environmental and stormwater issues, and socio-demographic characteristics. Section 2.4 further explains questionnaire items that were used as measures in this study.

To avoid attention fatigue from seeing all 34 sets of visualizations for NBS practices, we created eight versions of questionnaires. Each version included five retention ponds selected from the 30 options and randomly ordered, followed by one floodable site selected from the four options. Within each of the 12 respondent sampling strata, all eight versions of the questionnaire were randomly assigned to household addresses.

## Survey procedure

We administered the survey *via* the US postal mail in 2019, with approval by the University of Michigan Institutional Review Board. To increase the response rate, we first introduced the project and upcoming survey to the selected households by postcard. Next, we mailed the questionnaire with an explanatory letter, an informed consent document, a pre-paid return envelope, and a $1 pre-incentive. The letter provided information about the survey and invited a household member at least 18 years old to participate. A US $10 token of appreciation was offered to respondents who completed and returned the survey.

# Measures

To address our first research question, we operationalized flood risk perception by asking respondents to rate how much they would worry about potential damages to their home or property when noticing standing water caused by water from rain or melting snow near home. We used a 4-point Likert scale (Do not worry at all = 1, Worry a little = 2, Worry some = 3, Worry a lot = 4). This is similar to how some previous studies measured flood risk perception (Kellens et al., 2013; O'neill et al., 2016).

To address our second research question, we operationalized perceived safety of NBS practices under storm conditions by respondents' ratings on how safe the visualizations they saw on a 5-point Likert scale (Dangerous = 1, Somewhat dangerous = 2, Neither = 3, Somewhat safe = 4, Safe = 5). Specifically, perceived safety of floodable sites used the rating of the single site that each respondent viewed whereas perceived safety of retention ponds was based on the average rating across the five retention ponds that each respondent viewed (Cronbach's alpha = 0.86).

TABLE 1 Explanatory variables related to contextual and socio-demographic factors and their measurement scales.

| Variable | Description | Measurement scale |
|---|---|---|
| **Contextual factors** | | |
| Stormwater-related property damage | Whether a respondent has spent money due to damages caused by stormwater in any locations including basement, home, driveway, and yard in the past 2 years. | Binominal: 1 = Yes, 0 = No |
| Living in high flood hazard areas | Whether a respondent was sampled from one of the 6 sampling strata with high flood hazards periods for consistency. | Binominal: 1 = Yes, 0 = No |
| Perceived home location relative to flood zone | Whether a respondent thinks that their home is located in an officially designated flood zone. | Binominal: 1 = Yes, 0 = No |
| Knowledge of local water quality | How much a respondent knows about quality of water in nearby in nearby lakes, rivers, and streams. | Interval, range 1–4: 1 = Nothing, 2 = A little, 3 = Some, 4 = A lot. |
| Participation in activities to address flooding/stormwater management issues | Whether a respondent has wrote a letter or made a phone call, attended or arranged a public meeting, or talked to a manager face to face to influence issues or policy related to flooding/stormwater management in their community in the past 2 years. | Binominal: 1 = Yes, 0 = No |
| Participation in activities to promote stormwater management | Whether a respondent has supported flooding or stormwater management through donation, volunteering, organization leadership, or voting in the past 2 years. | Binominal: 1 = Yes, 0 = No |
| Participation in activities to promote environmental sustainability in general | Whether a respondent has supported environmental sustainability through donation, volunteering, organization leadership, or voting in the past 2 years. | Binominal: 1 = Yes, 0 = No |
| **Socio-demographic factors** | | |
| Age | A respondent's age in 2019. | Interval |
| Gender | Whether a respondent self-identifies as female. | Binominal: 1 = Yes, 0 = No |
| Race | Whether the race of a respondent is non-white (i.e., Black, Latino, Native America or Alaskan Native, or Asian or Pacific Islander). | Binominal: 1 = Yes, 0 = No |
| Education attainment | The highest grade of school or year of college a respondent has completed. | Interval: 1 = Less than high school, 2 = High school or equivalent, 3 = Some college or Associate's degree, 4 = Bachelor's degree, 5 = Post-graduate degree |
| Household Income | The total income of a respondent's household before taxes in 2019. | Interval: 1 = <$20k, 2 = 20–35k, 3 = 35–50k, 4 = 50–65k, 5 = 65–80k, 6 = 80–100k, 7 = More than 100k |
| Have children of age 12 or younger in the household | Whether there is anyone of age 12 or younger living at a respondent's address. | Binominal: 1 = Yes, 0 = No |

To address our third question about the impact of flood experience, we operationalized experience of localized flooding by the frequency of noticing flooding or standing water in locations near one's home in the past 2 years when there was rain or snow melting. We used a 4-point Likert scale (Never = 1, Sometimes = 2, Often = 3, Always = 4) and averaged ratings across five locations near each respondent's home (i.e., home driveway, home yard, neighbor's property, street, and nearby block) for a composite measure (Cronbach's alpha = 0.81).

To address our fourth research question, we considered some contextual and socio-demographic factors as explanatory variables (Table 1). Based on previous studies, we included variables related to flooding-induced damage (Kellens et al., 2013; Lechowska, 2021) and residence location (Botzen et al., 2009; O'neill et al., 2016). We also included variables related to environmental knowledge and behavior, which may affect perceptions of NBS (Feng and Nassauer, 2022). We examined socio-demographic factors of age, gender, race, education, and household income based on reviews of research on flood

risk perception (Kellens et al., 2013; Wachinger et al., 2013; Lechowska, 2021) and reviews of research on public perception of NBS (Flotemersch and Aho, 2021; Feng and Nassauer, 2022). We also examined whether respondents had young children in their household given that perceived safety of NBS practices can relate to concerns about drowning hazards (Bastien et al., 2012; Jarvie et al., 2017; Williams et al., 2019).

## Data analysis

The overall survey response rate was 24.2% (974/4,032). For this study, we excluded respondents who did not provide information on their addresses or reported addresses outside our sampling area. We used the resulting sample ($N = 884$) in subsequent data analysis, which was conducted in R 4.0.2 (R Core Team, 2020).

To address our first research question, we calculated descriptive statistics for the extent of worry about potential stormwater-related damages to home or property among respondents. To address our second research question, we calculated descriptive statistics for perceived safety of both NBS practices under storm and non-storm conditions, followed by inferential statistics to compare the mean ratings for perceived safety of floodable sites and retention ponds using $t$-test.

To address the third and fourth research questions, we conducted multiple linear regression analysis to examine the effects of experience of localized flooding, as well as other contextual and socio-demographic factors on (1) flood risk perception, (2) perceived safety of floodable sites under storm conditions, and (3) perceived safety of retention ponds under storm conditions, using $p$-value $< 0.05$ as the threshold of significance. To model perceived safety of floodable sites and retention ponds under storm conditions, we controlled for perceived safety under non-storm conditions for both NBS practices. We then calculated the unstandardized ($b$) and standardized ($\beta$) coefficients for each of the three models.

# Results

## Survey respondents' socio-demographic profile, experience of localized flooding, and other contextual characteristics

The socio-demographic characteristics of the 884 survey respondents were similar to the characteristics of the study area population (Table 2). Our sample had slightly fewer people of age 18–44 and more people of age 65 and above. Also, it was slightly higher in the percentage of female, and slightly lower in the percentage of non-white and less than high school education.

461 among the 884 respondents (52.1%) were from census blocks identified with high flood hazards in our sampling frame (Table 3). This confirmed that the sampling of survey respondents in low vs. high flood hazard areas was well-balanced. Respondents reported a mean frequency of 1.93 out of 4 that they had noticed standing water in locations near their home in the past 2 years (with Never = 1, Sometimes = 2, Often = 3, Always = 4). Over one fifth of respondents also

TABLE 2 Respondents to our mail survey compared with the study area population.

| | Survey respondents ($N = 884$) | Study area population[a] |
|---|---|---|
| | % | % |
| Age (18–103) | 41.3 | 50.2 |
| *18–44* | | |
| *45–64* | 28.9 | 30.6 |
| *65 and above* | 29.9 | 19.2 |
| Gender (% female) | 57.2 | 52.3 |
| Race (% non-white) | 19.6 | 23.9[b] |
| Less than high school education | 3.5 | 9.0[c] |
| Have children under 12 in the household | 16.4 | 19.9[d] |
| Household income below $35k | 33.0 | 33.8[e] |

[a]The study area population data are pooled 5-year estimates (2015–2019) from the American Community Survey (U.S. Census Bureau, 2019). Data were aggregated across 378 census block groups that comprise the 12 strata in the sampling frame; [b]% of non-white of all residents in study area census block groups; [c]Include only residents of 25 years of age and older; [d]% of residents of 14 years of age and younger in all residents in sampling area census block groups; [e]percentage of households with income <$34,999 in the past 12 months (in 2019 inflation-adjusted dollars), average median household income of study area census block groups is $60,968.36, and median household income of survey respondents is 50–65k.

TABLE 3 Respondents' experience of localized flooding and other contextual characteristics.

| $N = 884$ | Mean (SD) | % |
|---|---|---|
| Frequency of noticing standing water near home in the past 2 years | 1.93 (0.66) (Range: 1–4) | |
| Having had stormwater-related property damage in the past 2 years | | 21.9 |
| Sampled from high flood hazard areas | | 52.1 |
| Perceiving home located in the flood zone | | 4.5 |
| Knowledge of local water quality | 2.28 (0.94) (Range: 1–4) | |
| Having participated in activities to address stormwater management issues | | 16.7 |
| Having participation in activities to promote stormwater management | | 21.3 |
| Having participation in activities to promote environmental sustainability in general | | 73.0 |

had stormwater-related property damage in the past 2 years. However, only 4.5% of the respondents identified themselves as living in an officially designated flood zone. We therefore excluded "perceived home location relative to flood zone" as an explanatory variable in further data analysis due to its low variability.

## Risk perception of urban pluvial flooding and perceived safety of NBS practices

### RQ1: What are community members' perceptions of localized flooding risks?

The majority (66.0%) of respondents worried at least a little about potential property damage when noticing standing water or flooding near their home (Table 4).

### RQ2: How safe are floodable sites and retention ponds perceived to be under storm conditions? Are floodable sites perceived as less safe than retention ponds?

Comparing storm vs. non-storm conditions, perceived safety was lower under storm conditions for both floodable sites and retention ponds (Table 5). Floodable sites were perceived as significantly less safe under storm conditions than under non-storm conditions (*paired t*-test, *95% CI [−1.79, −1.60], p < 0.001*). Retention ponds were also perceived as significantly less safe when under storm conditions than under non-storm conditions (*paired t*-test, *95% CI [−1.10, −0.97], p < 0.001*).

Comparing floodable sites and retention ponds, under non-storm conditions, floodable sites were perceived as significantly safer than retention ponds (*paired t*-test, *95% CI [−0.39, −0.22], p < 0.000*). In contrast, under storm conditions, floodable sites were perceived as significantly less safe than retention ponds (*paired t*-test, *95% CI [0.26, 0.45], p < 0.001*).

TABLE 4 Respondents' flood risk perception. Measured by their indicated level of worry about potential property damage when they noticed standing water or flooding near home.

| **Worry about potential stormwater-related damage $N = 884$** | |
|---|---|
| Do not worry at all = 1 | 32.2% |
| Worry a little = 2 | 30.0% |
| Worry some = 3 | 24.8% |
| Worry a lot = 4 | 11.2% |
| Did not respond | 1.8% |
| Mean (SD) | 2.15 (1.01) |

TABLE 5 Mean scores (SD) for perceived safety of different NBS practices under storm and non-storm conditions.

| | **Perceived safety of NBS practices** | |
|---|---|---|
| | **Non-storm conditions** | **Storm conditions** |
| | Dry | Inundated |
| Floodable sites, a novel NBS practice | 4.23 (1.09) | 2.54 (1.27) |
| | Typical water level | High water level |
| Retention ponds, a familiar NBS practice | 3.92 (1.01) | 2.88(1.10) |

### RQ3: Are community members' flood risk perception and perceived safety of NBS practices under storm conditions associated with their experience of localized flooding?

Respondents who more frequently noticed standing water or flooding near their homes indicated significantly greater worry about potential damages caused by stormwater (Table 6). They also perceived floodable sites under storm conditions as significantly less safe. In contrast, experience of localized flooding showed no significant effect on perceived safety of retention ponds under storm conditions.

### RQ4: What other contextual and socio-demographic factors may relate to community members' flood risk perception and perceived safety of NBS practices under storm conditions?

Respondents who had stormwater-related property damage in the past 2 years, participated in activities addressing stormwater management issues in the past 2 years, or knew more about local water quality, indicated significantly greater worry about potential stormwater-related damage to home or property (Table 6a). Female respondents also indicated significantly greater worry. In contrast, respondents who participated in activities to promote general environmental sustainability in the past 2 years indicated significantly less worry than those who did not participate in such activities.

Regarding perceived safety of NBS practices, respondents who were female or lived in high flood hazard areas perceived floodable sites under storm conditions to be significantly less safe (Table 6b). Respondents who were female, non-white, or with children under the age of 12 in their households perceived retention ponds under storm conditions to be significantly less safe, whereas older respondents perceived retention ponds under storm conditions to be significantly safer (Table 6c).

TABLE 6 Results from multiple linear regression models for (a) flood risk perception, (b) perceived safety of floodable sites under storm conditions, controlling for perceived safety under non-storm conditions, and (c) perceived safety of retention ponds under storm conditions, controlling for perceived safety under non-storm conditions.

| | (a) Flood risk perception | | (b) Perceived safety of floodable sites under storm conditions | | (c) Perceived safety of retention ponds under storm conditions | |
|---|---|---|---|---|---|---|
| | ***B*(SE)** | ***β*** | ***B*(SE)** | ***β*** | ***B*(SE)** | ***β*** |
| **Frequency of seeing flooding or standing water** | 0.40 (0.05)*** | 0.26 | −0.14 (0.07)* | −0.07 | −0.06 (0.05) | −0.04 |
| **Other contextual and socio-demographic factors** | | | | | | |
| Had stormwater-related property damage | 0.69 (0.08)*** | 0.29 | 0.04 (0.11) | 0.04 | 0.05 (0.08) | 0.02 |
| Sampled from high flood hazard area | −0.04 (0.06) | −0.02 | −0.22 (0.09)* | −0.17 | −0.09 (0.06) | −0.04 |
| Knowledge of local water quality | 0.08 (0.04)* | 0.07 | 0.08 (0.05) | 0.06 | 0.04 (0.04) | 0.04 |
| Participation in activities to address stormwater management issues | 0.22 (0.09)* | 0.08 | −0.01 (0.13) | −0.01 | 0.11 (0.09) | 0.04 |
| Participation in activities to promote stormwater management | −0.04 (0.09) | −0.02 | 0.06 (0.12) | 0.05 | 0.01 (0.08) | 0.00 |
| Participation in activities to promote general environmental sustainability | −0.17 (0.08)* | −0.07 | −0.02 (0.11) | −0.02 | 0.02 (0.08) | 0.01 |
| Age | −0.00 (0.00) | −0.01 | 0.00 (0.00) | 0.04 | 0.01 (0.00)** | 0.09 |
| Gender (female) | 0.19 (0.07)** | 0.09 | −0.22 (0.09)* | −0.18 | −0.24 (0.06)*** | −0.11 |
| Race (non-white) | 0.14 (0.08) | 0.06 | −0.05 (0.11) | −0.04 | −0.29 (0.08)*** | −0.10 |
| Education | −0.00 (0.03) | −0.01 | 0.04 (0.05) | 0.03 | −0.02 (0.03) | −0.02 |
| Household income | 0.01 (0.02) | 0.02 | 0.04 (0.02) | 0.07 | 0.02 (0.02) | 0.03 |
| Have children under age 12 in the household | 0.10 (0.09) | 0.04 | −0.05 (0.12) | −0.04 | −0.23 (0.09)** | −0.08 |
| **Control variables for perceived safety under non-storm conditions** | | | | | | |
| Perceived safety of floodable sites under non-storm conditions | | | 0.35 (0.04)*** | 0.30 | | |
| Perceived safety of retention ponds under non-storm conditions | | | | | 0.65 (0.03)*** | 0.58 |
| **Observations** | 780 | | 774 | | 783 | |
| $R^2$ | 0.238 | | 0.136 | | 0.401 | |
| **Adjusted $R^2$** | 0.225 | | 0.120 | | 0.390 | |

B (SE) denotes the unstandardized coefficients and standard errors, β denotes the standardized coefficients (***$p$-value < 0.001, **$p$-value < 0.01, *$p$-value < 0.05).





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## Discussion

This study aims to inform resilient approaches to urban flood risks and stormwater management that can better respond to growing extreme weather events under climate change. We investigated community members' risk perception of urban pluvial flooding and perceived safety of NBS practices, using "risk as feelings" to frame our research questions. To shed light on how perceived safety may vary by different design solutions for storing stormwater, we compared two types of practices: floodable sites, a novel NBS practice that temporarily inundates urban landscapes, and stormwater retention ponds, a familiar NBS practice that always has water. We also examined how flood risk perceptions and perceived safety of NBS practices are associated with experiences of localized flooding, as well as other contextual and socio-demographic factors.

The majority of our study respondents indicated some degree of worry about potential damage to property when noticing standing water near home. This result is somewhat expected. Recent studies have reported that community members are generally aware of urban flooding problems (Derkzen et al., 2017; Meerow et al., 2021). Regarding the question of perceived safety of NBS practices, this study indicates that community members may perceive NBS practices that visibly change stormwater levels in surrounding landscapes as unsafe. Both floodable sites and retention ponds were perceived as less safe under storm conditions than under non-storm conditions. Furthermore, ponds were perceived as safer than floodable sites under storm conditions. Reflecting on these results through the "risk as feelings" framework, we speculate that people might intuitively perceive inundated floodable sites that look like flooding events as less safe, whereas water level fluctuations in retention ponds are more expected because it is a natural-looking practice where water is typically present. While we did not directly measure feelings (e.g., through a psychometric paradigm or physiological change), our study provides a basis for future research to examine affective reactions to novel and familiar NBS practices that have noticeable water level changes. We also call for more research on why people view water level changes as unsafe and what influences such perceptions might have on well-being or support for the adoption of NBS practices.

Prior studies have shown associations between personal experiences of major riverine and coastal flooding and greater perceived risks and discussed how witnessing disastrous events may help people envision low-probability events and their consequences (Botzen et al., 2009; Kellens et al., 2011; O'neill et al., 2016). Importantly, we found that the experience of less intense localized events—seeing standing water and flooding near home—are also associated with greater flood risk perception. As "risk as feelings" implies, intuitive perceptions of risks involve affective processing and do not always reflect the actual magnitude of damage. Further, experience of localized flooding may also undermine perceived safety of floodable sites under storm conditions. However, we found no associations between such experience and perceived safety of retention ponds under storm conditions. This has important implications for stormwater management interventions that are more likely to gain support in communities having experienced localized flooding.

We also found notable effects of other contextual and socio-demographic factors on the risk perception of urban pluvial flooding and the perceived safety of NBS practices. Consistent with research focused on riverine and coastal flooding (Kellens et al., 2013; Lechowska, 2021), we also observed strong associations between gender (female) as well as past property damage and greater perceived risks of localized flooding. Different from previous studies (Botzen et al., 2009; Kellens et al., 2013), we did not find associations between higher education level and lower flood risk perception. However, our results suggest more nuanced effects of knowledge and behavior specifically related to stormwater. In this study, respondents who indicated more knowledge about local water quality or had participated in activities addressing stormwater management issues (i.e., wrote a letter or made a phone call, attended or arranged a public meeting, or talked to a manager face to face) in the past 2 years were more worried about potential stormwater-related damage. In contrast, respondents who had participated in activities promoting general environmental sustainability (i.e., made donations, volunteered or served in a leadership positions for an organization or advocacy group, voted for a candidate for public office) in the past 2 years were less worried about potential stormwater-related damage. Perhaps people who participate in activities to promote general sustainability are not necessarily interested in or well-informed about stormwater management and focus more on other environmental issues (e.g., greenhouse gas reduction, wildlife habitat). Research on flood risk perception should continue to investigate knowledge and behaviors related more specifically to stormwater and water systems to further understand their influences.

Perceived safety of floodable sites was associated with only one socio-demographic factor—gender, whereas perceived safety of retention ponds was associated with several socio-demographic factors. The lower perceived safety of both practices among female respondents might be attributed to social norms for males to not express worry (Sutton and Farrall, 2005). It might also relate to females' primary role in taking care of children and home. Future research may conduct more qualitative analyses of the potential gender differences in perceived safety of NBS practices for stormwater management. For retention ponds, respondents with children under the age of 12 in their households perceived retention ponds under storm conditions as less safe. This reflects concerns about drowning hazards and personal safety, especially for children, that have been observed in previous studies (Bastien et al., 2012; Jarvie et al., 2017; Williams et al., 2019). Moreover,

non-white respondents perceived retention ponds as less safe, while older respondents perceived retention ponds as safer. People of color may have less experience with well-maintained retention ponds given their often more limited access to high-quality, large greenspace (Rigolon, 2016). Older people may have more contact with nature and thus are more familiar with the fluctuation between typical and high water levels. These results point to potentially different causes that shape perceived safety of floodable sites and stormwater ponds under storm conditions.

Further, the adjusted R-squared for the perceived safety model of floodable sites (12.0%) is smaller than that for the model of retention ponds (39.0%), indicating a lower explanatory power. Therefore, factors besides the contextual and socio-demographic variables examined in this study, such as landscape design choices and environmental values, may impact the perceived safety of floodable sites, and more research is needed.

## Implications for urban flood risk management and NBS development

This study has several implications for resilient urban flood risk management and NBS development. First, based on our finding on the widely present worry about potential stormwater-related damage and its association with experiences of localized flooding near home, we call for more attention to pluvial flooding in urban flood risk management. Urban pluvial flooding is less addressed than riverine and coastal flooding. This in part results from the lack of local data for fine-scale built environment characteristics such as stormwater infrastructure inadequacies and impervious surfaces that contribute to pluvial flooding (National Academies of Sciences Engineering and Medicine, 2019). Therefore, publicly available data are needed to more precisely map areas prone to pluvial flooding at the local scale and identify priorities for developing interventions to manage stormwater. Further, when NBS practices are proposed for stormwater management, their relevance to reducing flood risks should be more clearly communicated to the public (Derkzen et al., 2017).

Second, we caution that when developing NBS practices, local community members' perceptions should be considered in addition to stormwater management functions. Different from experts, community members may intuitively perceive NBS practices that introduce noticeable water level changes as unsafe, especially for novel practices like floodable sites. Based on our finding that floodable sites were perceived as less safe than retention ponds, we recommend that renovating familiar NBS practices (e.g., retention ponds) to increase their storage capacity may be preferable to developing novel NBS practices that temporarily inundate urban spaces (e.g., floodable sites). In intensely developed areas where floodable sites are more feasible or desirable, more research is needed to inform design guidelines that can help increase perceived safety. In this study, we treated floodable sites as a homogeneous category without accounting for variations in possible design choices. Additional studies are needed to understand how various types of floodable sites (e.g., parking lots, recreational sites, minor streets, blue roofs, parks, and urban plazas) and the frequency of inundation may affect perceived safety of floodable sites. Studies can also test whether communicating floodable sites' functions, for example, through signages, education programs, or demonstration of pilot sites, may improve perceived safety.

Further, engagement with local communities should anticipate that perceptions of NBS practices may vary by flood experience and socio-demographic groups. This study shows that females, people of color, and families with children are likely to have more safety concerns. However, we only examined individuals' perceptions and their associations with individual experiences of localized flooding and socio-demographic characteristics. Given that flooding often disproportionately affects underserved communities (National Academies of Sciences Engineering and Medicine, 2019; Eakin et al., 2022), more research is needed to understand whether and how communities with varied flood experiences and socio-demographic status may differ in perceptions of flood risks and NBS practices.

# Conclusion

We assert that urban flood risk management should engage with social science theories such as "risk as feelings" to account for peoples' affective responses and intuitive perceptions. Drawing on the concept of "risk as feelings," this paper deepens the understanding of how community members perceive urban pluvial flooding by highlighting the effects of experience of localized flooding and other contextual and socio-demographic factors. It also provides new insights into developing nature-based solutions (NBS) for managing urban stormwater by elucidating how noticeable stormwater level changes in novel and familiar NBS practices can elicit safety concerns. Notably, we found that, under storm conditions, floodable sites, a novel NBS practice that temporarily inundates urban spaces to manage stormwater, were perceived as less safe than retention ponds, a familiar NBS practice that always has water. Further, community members with more experiences of localized flooding perceived floodable sites as less safe, while those who were younger, non-white, or had children in their households perceived retention ponds as less safe. The difference in perceived safety of these two types of NBS practices have implications for

public support for their adoption. We call for inter and trans-disciplinary collaborations in designing new landscape interventions to address extreme weather events and the increasing urban flood risks. Pervasive adoption of NBS must consider potential impacts on people's everyday experiences in their neighborhoods and communities, in addition to stormwater management objectives, to gain broad societal support.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

The studies involving human participants were reviewed and approved by Institutional Review Boards, University of Michigan. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

JL: conceptualization, methodology, formal analysis, data curation, and writing—original draft preparation. JN: conceptualization, methodology, funding acquisition, supervision, and writing—review and editing. NW: methodology, investigation, funding acquisition, and writing—review and editing. SP: conceptualization, data interpretation, and writing—review and editing. LM: investigation, funding acquisition, and writing—review and editing. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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