Natural Hazards
https://doi.org/10.1007/s11069-025-07725-y

ORIGINAL PAPER

Integrating stakeholder perspectives in flood risk assessment: a case study in mobile bay, Alabama

Md. Munjurul Haque[1,2,3] · **Wanyun Shao**[1,2,3] · **Hemal Dey**[1,2]

Received: 7 May 2025 / Accepted: 15 September 2025

Abstract

Flooding is a dynamic and multifaceted hazard that poses significant challenges to risk mitigation efforts. Given the involvement of multiple stakeholders in flood management, it is essential to incorporate diverse perspectives in assessing flood risk and subsequently designing sustainable flood risk management strategies. This study demonstrates an effective approach to integrate stakeholder input into flood risk assessment, using Mobile Bay, Alabama, as a case study. An extensive literature review was conducted to identify research gaps and to highlight key flood risk indicators. Based on this review, a structured questionnaire was developed and distributed to individuals with varying roles in flood management in the Mobile Bay area. A purposive sampling method was employed to capture a broad range of stakeholder perspectives. The findings reveal that geographical location and historical flood events were regarded by stakeholders as prominent contributors to flood risk. Input from multiple stakeholders, collected through questionnaire surveys, was then used to weigh various flood risk indicators. Relevant secondary data were obtained from various sources to develop a comprehensive flood risk map for the study area. The approach used by this study demonstrates an effective way to involve multi-stakeholder perspectives in flood risk assessment, and the findings offer valuable insights for policymakers seeking to enhance flood risk mitigation and build more resilient, evidence-based strategies.

Keywords Flood risk assessment · Stakeholder perspective · Indicator-based assessment · Integrated approach

✉ Wanyun Shao
wshao1@ua.edu

1 Department of Geography and the Environment, The University of Alabama, Tuscaloosa, AL, USA

2 Alabama Water Institute, Tuscaloosa, USA

3 Institute for Social Science Research, The University of Alabama, Tuscaloosa, USA

Published online: 09 October 2025

1 Introduction

Flooding is one of the most common and destructive global hazards. Annually, millions of people are displaced, and billions are affected by flooding to different degrees (McDermott 2022). From 1990 to 2022, 4713 flooding events have been reported around the world, having affected 3.2 billion individuals with nearly 1.3 trillion USD economic losses (Liu et al. 2024). Coastal cities are highly vulnerable to flooding due to climate change and high population density (Dada et al. 2024). Spatial analysis of flood exposure reveals that the United States Gulf Coast exhibits a particularly high level of exposure (Qiang 2019). This region also displays heightened social vulnerability to flooding (Shao et al. 2020). To minimize flood losses, it is thus imperative to adopt effective flood mitigation measures. The first crucial step then is to conduct a comprehensive flood risk assessment.

Traditional flood risk assessments have predominantly relied on quantitative and modeling approaches. Geographic Information Systems (GIS) have been instrumental in quantifying flood risks and are widely applied in global assessments (Efraimidou and Spiliotis 2024; Hagos et al. 2022; Zhang et al. 2020). In addition to GIS, remote sensing (RS) technologies have gained prominence for flood risk mapping due to their capabilities to integrate advanced machine learning algorithms for flood prediction (Munawar et al. 2022; Farhadi and Najafzadeh 2021). More recently, machine learning and other data-driven techniques have been increasingly utilized to model and quantify flood risks (Kumar et al. 2023; Chen et al. 2021). These approaches largely depend on physical indicators such as elevation, slope, proximity to water bodies, precipitation, land use, vegetation indices, built-up areas, and topographic variables.

While these physical factors are undeniably essential for flood risk assessment, they often overlook social, economic, and local contextual dimensions (Lechowska 2022). Consequently, decision-making tends to be technology-driven and may lack understanding of community-level perspectives. Given that flood risk is a complex and multidimensional phenomenon, effective assessment must consider physical, social, economic, and institutional dimensions (Ghasemzadeh et al. 2021; da Silva et al. 2020). Incorporating local knowledge and social perspectives is as crucial as integrating physical and technological data (Hermans et al. 2022; Hadlos et al. 2022). Therefore, an integrative approach to flood risk assessment requires collaboration across multiple sectors involved in risk management (Pasquier et al. 2020). However, existing research in this field often neglects participatory and collaborative methodologies, resulting in less effective outcomes (Gebremedhin et al. 2020).

Extensive studies across various regions including Australia (Rogers et al. 2020), New Zealand (Elkhidir et al. 2022), Europe (Ciampa et al. 2021), Africa (Miller et al. 2022), Asia (Ishiwatari 2019), and the United States (Tate et al. 2021a, b) highlight the significance of collaborative, multi-stakeholder approaches in enhancing the effectiveness of flood risk management. Given the diversity of stakeholders involved, incorporating their varied inputs is vital to make the assessment process more equitable, resilient, and impactful.

International frameworks such as the United Nations Office for Disaster Risk Reduction (UNDRR) emphasize the need for multi-level stakeholder involvement and advocate for integrated flood risk assessment methods that incorporate physical, social, economic, local, and scientific perspectives. Stakeholder perceptions significantly influence flood preparedness and response, making it critical to understand and include inputs from all levels ranging from households to policymakers. Individuals with higher awareness and understanding of flood risks are more likely to engage in proactive behaviors, such as adopting early warning systems and contributing to community resilience (Hudson et al. 2020; Calvo-Solano and Quesada-Román 2024). A deeper comprehension of flood risks enhances stakeholder commitment to prevention and resilience-building efforts (Morrison et al. 2018).

Key stakeholders such as policymakers, international organizations, emergency managers, community leaders, and engineers tend to emphasize different facets of vulnerability. This diversity ensures that flood management strategies are better aligned with community needs (Manandhar and McEntire 2014). Clear and transparent communication among these actors fosters trust, encourages ownership, and enhances the implementation of risk reduction measures (UNDESA, 2023).

Global research demonstrates the effectiveness of multi-level stakeholder engagement. In England, local capacity and self-responsibility played pivotal roles in integrating community needs into national policy (Thaler and Levin-Keitel 2016). Participatory workshops in South Africa, involving community members and policymakers, enhanced early warning systems through shared knowledge and responsibility (Mugari et al. 2025). Collaborative modeling in European nations advanced flood risk awareness via social learning (Evers et al. 2012), while co-production strategies in the Netherlands emphasized the value of local self-organization in partnership with government entities (Edelenbos et al. 2017). During climate-related crises in Australia, inter-stakeholder collaboration mitigated resource constraints and improved disaster response (McAllister et al. 2014). Italy's collaborative flood mapping efforts not only updated risk maps but also embedded lived experiences and local knowledge into mitigation and adaptation planning (Gnecco et al. 2024).

Building on these successful case studies, the present study aims to illustrate an approach integrating diverse stakeholder inputs into the flood risk assessment for the Mobile Bay, AL, along the U.S. Gulf Coast. Flooding is a persistent and historical issue in the Mobile Bay area, driven by its geographical location, diverse socio-economic conditions, heavy rainfall events, and rapid urbanization (Shao et al. 2019). These factors, compounded by a persistent increase in community vulnerability, continue to exacerbate flood risks in the Mobile Bay region (Dey et al. 2024a).

To address the pressing flooding challenges in the Mobile Bay area, this study incorporates input from a diverse range of stakeholders actively engaged in local flood risk management. These stakeholders include emergency managers, policymakers, urban planners, resilience officers, engineers, and representatives from non-governmental organizations. While stakeholder engagement in flood risk decision-making has been explored in other case studies, this study distinguishes itself by directly integrating input from multiple stakeholder groups into the flood risk mapping process, resulting in a more representative map that reflects a broader range of flood-related perspectives and priorities. Unlike previous studies where risk maps were developed primarily through expert judgment or technical assessments, this research uses a structured quantitative survey to collect input from multiple stakeholder groups. The survey responses were analyzed to derive weights that reflect the diverse perspectives, contextual needs, and decision-making roles of these stakeholders. These weights were then applied to the spatial flood risk mapping process. By embedding stakeholder-derived priorities into the mapping methodology, this study introduces a novel and inclusive approach to flood risk assessment that enhances the relevance and applicability of the resulting maps for decision-makers in the Mobile Bay area. This collaborative, bottom-up strategy addresses the complex and multifaceted nature of flood risk, while also underscoring the limitations of traditional top-down assessment methods.

2 Study area

Mobile Bay, Alabama has been selected for this pilot study (Fig. 1). Mobile Bay is an important area situated in the southeastern region of the United States, particularly in the state of Alabama. It is a wide estuary that is formed by the confluence of two major rivers: the Mobile and Tensaw Rivers (Dey et al. 2024a). In addition, numerous smaller rivers and streams flow into the bay. Since the bay opens into the Gulf of Mexico, it is a vital area for trade, transportation, and natural resource management (Shao et al. 2019). Mobile Bay is extensive geographically, covering an area of approximately 413 square miles (1,069 square kilometers). However, Mobile Bay is vulnerable to a set of challenges related to floods. With a humid subtropical climate, the area is well known for having large amounts of precipitation each year due to its location along the Gulf Coast. Rainfall is consistently distributed throughout the year, with noticeable monthly totals and a slight uptick during the summer months (Shao et al. 2019). In addition, Mobile, a bustling city in Alabama, faces similar challenges confronting other coastal cities with its vulnerability to storm surge. This vulnerability is made worse by the growing threats of rising sea levels. The risk is further amplified

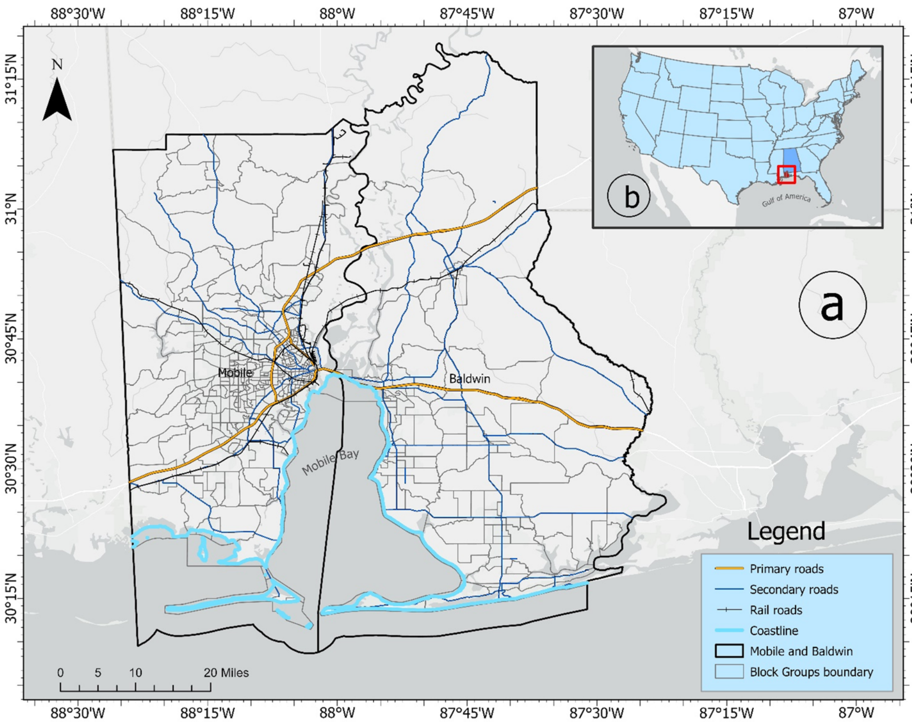

Fig. 1 Study area map **a** administrative map of Mobile Bay **b** the location of Mobile Bay and Alabama State in the context of CONUS

by the city's increasing population, ongoing urban development, and the concentration of valuable assets along the coast (Shao et al. 2019).

Mobile Bay and its surrounding communities are naturally prone to coastal and compound flooding due to their coastal location. Moreover, updated flood maps highlight that thousands of houses of Mobile County and Baldwin County reside within 100-year flood zones, which clearly indicates the need for flood risk mitigation. Due to its diverse characteristics, historical vulnerability to flooding, and importance as a coastal region, Mobile Bay presents a critical opportunity to examine the perceptions of various stakeholders in flood risk assessment and mitigation. This area serves as an ideal case study to demonstrate how multiple stakeholder engagement contributes to effective flood mitigation strategies, considering the unique local challenges and the potential to improve resilience against future flooding events.

3 Data and methods

Both primary and secondary data were used in this study. Primary data were collected using the Qualtrics survey. Secondary data were utilized to integrate perspectives from stakeholders with diverse backgrounds to produce the flood risk map. Input from a diverse group of stakeholders is crucial for enhancing flood risk mitigation efforts. First, an extensive literature review was conducted to identify crucial flood risk indicators (Table 1). Using these indicators, we designed a structured questionnaire consisting of 19 questions. The goal was to evaluate the priority and selection patterns of different indicators among various stakeholders which would assist us to understand the different priorities held by various stakeholders and the reasons.

3.1 Sampling strategy and data collection

The 47 respondents in this study were selected using a purposive sampling approach, which targeted key professionals involved in flood risk management within the Mobile Bay area. This group included emergency managers, resilience officers, engineers, and policymakers, ensuring the inclusion of individuals with direct experience and expertise in flood risk. However, the non-random nature of the sample means that it may not fully capture the diversity of perspectives from other stakeholder groups, such as residents or private sector entities, and the findings may not be directly applicable to other geographic regions or to all individuals involved in flood management. Future studies could address this limitation by incorporating a broader, more representative sample of stakeholders. However, the survey was distributed via Qualtrics to various stakeholders working in flood risk mitigation in Mobile Bay. The data collection was conducted from early March to late April 2023. After collecting the responses through Qualtrics, we used Qualtrics data analysis tools and Excel software to analyze and visualize the survey data. It is important to note that the sample size needed to achieve statistical significance depends on various indicators, such as the population size, the level of precision desired, and the confidence level chosen. Generally, the larger the sample size, the more reliable the results will be. The minimum sample size required to obtain meaningful insights in exploratory surveys of targeted professional groups is often considered to be around 30 respondents (Braun and Clarke 2021; Guest et

Table 1 Indicators collected from different sources and used in this study

Indicator	Specific Variables	Justification	Unit	Dimension of Flood risk	Studies used similar indicators
Geographic Location and proximity to flood-prone areas	Distance from River or Coast	Location close to flood-prone rivers or coasts increases Hazards likelihood.	Kilometer	Hazard	(Haque et al. 2023; Cutter et al. 2012; Tate 2012; Cutter and Finch 2008)
	Elevation	Low-lying areas more prone to flooding	Meter		
Past Historical Flood Events	Flood Damage Location	Past flood history increases flood risk perception	-		
Demographic characteristics	Age over 60	Older people are more vulnerable	Percentage of individuals aged 60 + per census block group (%)	Vulnerability	(Haque et al. 2023; Tate 2012; Shah et al. 2018; Tate et al. 2021a, b)
	Age under 18	Children are more vulnerable to flooding	Percentage of individuals under 18 per census block group (%)		
Disabilities	Disability	Movement restrictions enhance vulnerability to flooding	Percentage of individuals with a disability per census block group (%)		
Language and cultural barriers	Language spoken	Language barriers enhance vulnerability	Percentage of individuals who do not speak English per census block group (%)		
Access to communication and transportation	Own vehicle	Having a vehicle reduce vulnerability	Percentage of households with at least one vehicle per census block group (%)		
Access to emergency services and resources	Emergency shelter location	Emergency shelters nearby decrease vulnerability	-		
Financial Condition	Poor housing – old houses	Poor housing increase vulnerability. Older houses are generally more susceptible to structural damage during floods due to age-related deterioration, outdated building codes, and lower resilience standards.	Percentage of housing units built before 1950 per census block group		
	Income	Lower-income groups are more vulnerable	Median household income per census block group (USD)		

Table 1 (continued)

Indicator	Specific Variables	Justification	Unit	Dimension of Flood risk	Studies used similar indicators
Awareness or Preparedness	Population Density	Higher density leads more peoples exposed	People per square kilometer per census block group	Exposure	(Yaseen et al. 2023; Haque et al. 2022; Shah et al. 2018)
	Household density	More dense housing exposed a community to flooding	Households per square kilometer per census block group		

al. 2006; Malterud et al. 2016; Robinson 2014). Our study collected 47 complete responses, providing adequate coverage of key stakeholders in the Mobile Bay area. It should be noted that while this sample allows for a robust representation of professional perspectives, it is not intended to be statistically generalizable to all stakeholders beyond the study context. This study used a purposive sampling strategy because our targeted respondents were mainly stakeholders in flood management in the Mobile Bay area. Due to the limited number of targeted respondents in the study area, a total of 47 complete responses were collected from these stakeholders. Data cleaning operation was performed on Qualtrics. Incomplete survey responses were excluded from the dataset. Most of the outcomes were demonstrated using descriptive statistics. Based on the muti-stakeholders input, the indicators were computed in percentage scale (Eq. 1) and used as weights for flood risk mapping.

$$\boldsymbol{Percentage} = \left(\frac{\boldsymbol{Number\ of\ Responses\ for\ Specific\ Indicators}}{\boldsymbol{Total\ Number\ of\ Responses}}\right) *100 \quad (1)$$

3.2 Stakeholder derived weights and risk mapping

This study integrated stakeholder perspectives directly into the flood risk mapping workflow using a frequency-based weighting approach. First, we compiled a list of flood risk indicators from an extensive literature review and circulated it to practitioners involved in flood risk mitigation through Qualtrics survey. Respondents could select one or more indicators they considered the most important. For each indicator, we calculated the percentages of responses (Eq. 1) and used them as weights, as these percentages directly reflect stakeholder's priorities. To operationalize the IPCC risk framework, we collected spatial datasets to represent hazard, exposure, and vulnerability, respectively from reliable sources including USGS, FEMA, county offices, and the U.S. Census. Each indicator was normalized using min-max standardization method to bring values onto a common 0–1 scale, making them comparable across indicators. Each indicator layer in the GIS was multiplied by its corresponding weight within each dimension of hazard (Eq. 2), exposure (Eq. 3), and vulnerability (Eq. 4), respectively. The three indices were then multiplied (Eq. 5) to produce the final flood risk map, which was classified into five categories for cartographic display.

$$\boldsymbol{H} = \sum_{i=1}^{n} \boldsymbol{Wi*Zi} \quad (2)$$

$$\boldsymbol{E} = \sum_{j=1}^{m} \boldsymbol{Wj*Zj} \tag{3}$$

$$\boldsymbol{V} = \sum_{k=1}^{p} \boldsymbol{Wk*Zk} \tag{4}$$

$$\boldsymbol{R} = (\boldsymbol{H*E*V}) \tag{5}$$

Where,

H, E and V = Weighted indices for hazard, exposure, and vulnerability.
n, m, p = Number of indicators in hazard, exposure, and vulnerability.
Zi, Zj, Zk = Normalized values of the respective indicators.
Wi, Wj, Wk = Corresponding weights of each indicator.
R = Risk.

3.3 Weighting rationale

We adopted a frequency- and rating-based weighting approach because it provides a transparent, direct translation of stakeholder preferences into quantitative values. This method allowed the priorities of diverse professional groups to be reflected in a way that is easily interpretable for both technical and non-technical users. While more sophisticated methods such as the Analytic Hierarchy Process (AHP), Principal Component Analysis (PCA), or entropy-based weighting are widely used in multi-criteria decision analysis, these techniques require either pairwise comparisons or larger datasets. Given our pilot study's relatively small sample size and its emphasis on inclusivity and transparency, the frequency/rating approach was the most pragmatic option. Future studies with larger samples may apply AHP or PCA to validate and refine the weight structure.

4 Results

4.1 Respondents background

This study aimed to incorporate insights from a diverse group of stakeholders involved in flood risk mitigation efforts in the vulnerable Mobile Bay area.

To understand the varying priorities and the rationale behind them, the study engaged professionals actively working in the region, including emergency managers, NGO workers, engineers, resilience officers, city planners, policymakers, and others (Fig. 2). Among the participants, emergency managers constituted the largest group. The professional roles of respondents are particularly significant, as occupational priorities and experiences shape how individuals perceive and respond to flood risks. These backgrounds influence the identification of key risk factors. The diverse background enabled us to incorporate multiple stakeholders' perspectives into flood risk assessment.

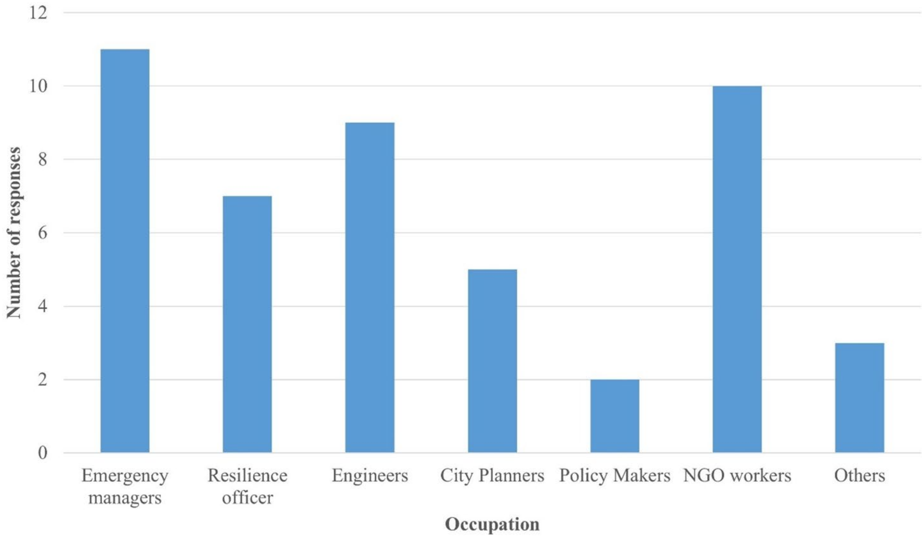

Fig. 2 Professional backgrounds of respondents categorized by occupation

4.2 Stakeholders' perceptions regarding climate change

Based on the analysis of the responses, it is evident that stakeholders hold the belief that the coastal ecosystem has experienced noticeable impacts due to climate change over the preceding three decades. 56% of respondents exhibited a strong concurrence with this notion, while 44% expressed a general agreement. Looking forward to the next three decades, stakeholders anticipate even more pronounced effects of climate change on the coastal ecosystem. A significant 52% of respondents strongly agreed that climate change will severely impact the coastal ecosystem along with disasters, whereas 32% of respondents somehow agreed with the notion and the rest of 16% stakeholders expressed a neutral opinion regarding that (Fig. 3). These findings offer valuable insights into the prevailing perceptions of stakeholders regarding the historical and anticipated future influences of climate change on coastal ecosystems (Cass et al. 2023). As such, they contribute to the growing body of knowledge concerning the dynamic interactions between climate change and ecologically sensitive regions.

4.3 Indicator-based flood risk assessment

As the impacts of climate change become increasingly evident and disasters more unpredictable, proactive measures are essential. Accordingly, after gathering stakeholders' perspectives on the impacts of climate change, the study aimed to explore their views on commonly utilized disaster assessment methods. Indicator-based flood risk assessment is a technique that involves identifying, quantifying, and analyzing key indicators to determine the probability and severity of flood incidents. This method involves evaluating various indicators, such as precipitation patterns, river discharge, topography, land use, population density, infrastructure, and emergency response preparedness, to create a comprehensive framework

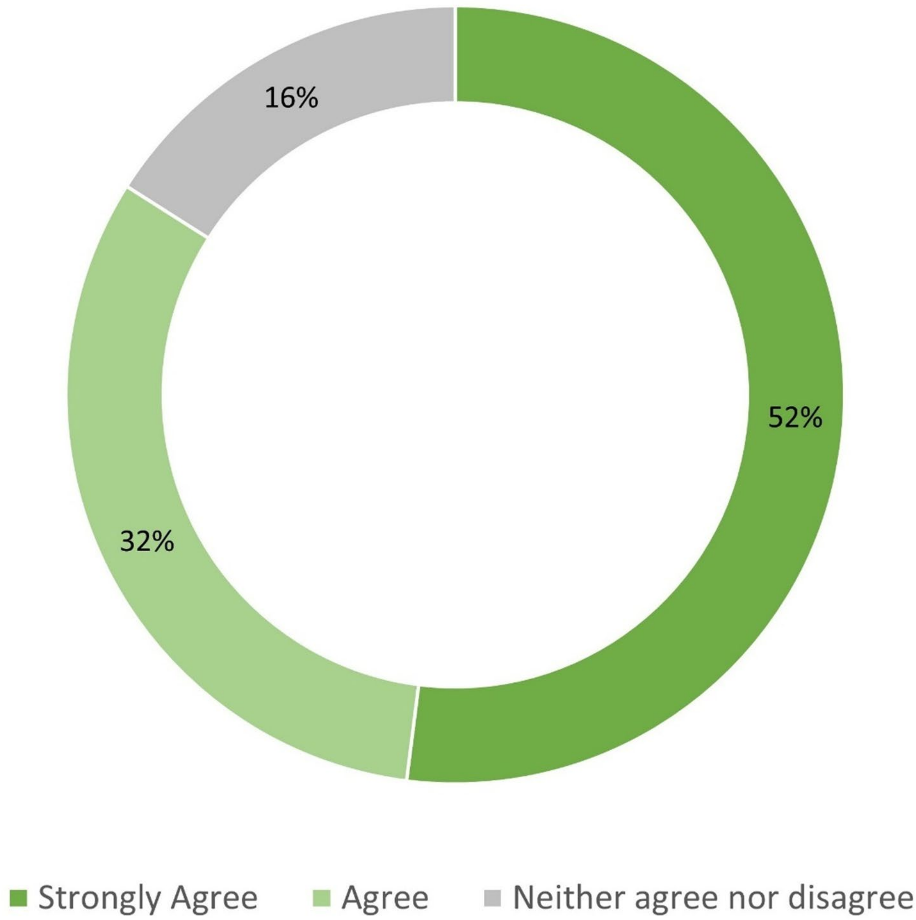

Fig. 3 Distribution of stakeholder agreement on future climate change impacts to coastal ecosystems

for assessing flood susceptibility and potential impacts on communities (Li et al. 2023). By using this approach, stakeholders, policymakers, and researchers can make informed decisions regarding how to prioritize interventions, allocate resources, and develop strategies to reduce the adverse effects of flooding events (Yaseen et al. 2023). This method also helps to deepen our understanding of the complex interactions between environmental, climatic, and societal indicators, which is crucial for developing resilient and sustainable solutions in the face of a changing coastal landscape (Ma and Jiang 2023).

Based on our analysis of the literature, we include the following question: "Is variable-based vulnerability assessment an effective method for managing flood risk?" We discovered that 8% of respondents disagreed with the following statement, while 60% of stakeholders agreed (Fig. 4).

Nearly 32% expressed neural opinion, indicating various opinions among different stakeholder groups. Meanwhile, a majority (60%) of the respondents believe that conducting

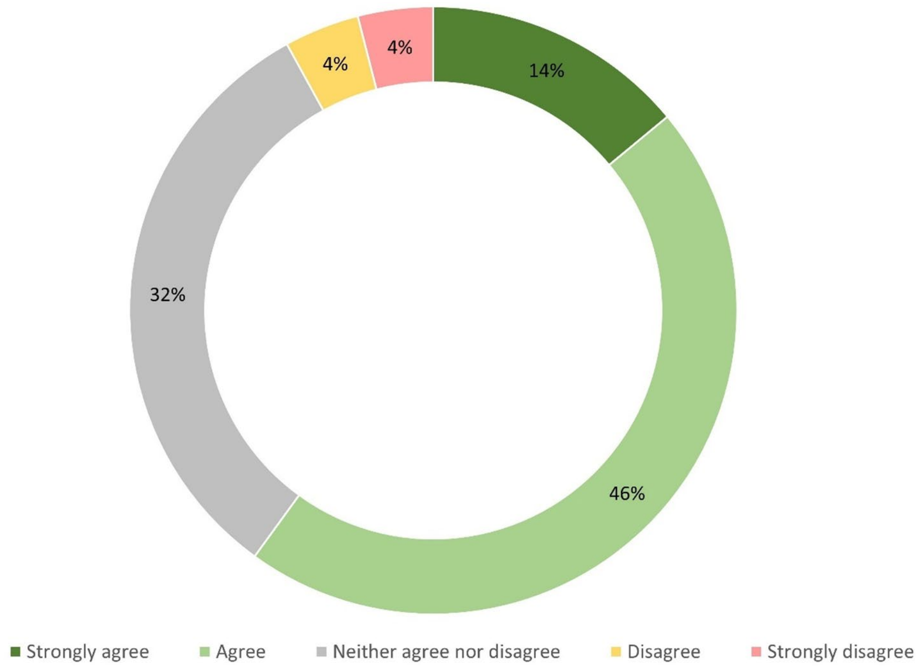

Fig. 4 Stakeholders' agreement levels on the effectiveness of indicator-based flood risk assessments

indicator-based flood risk assessments is significant, which is consistent with earlier study findings (Haque et al. 2023).

4.4 Relative importance of various flood risk indicators

This study conducted an extensive literature review to identify the flood risk indicators. Those indicators used in multiple previous studies were selected as important indicators and used in this study (Cutter et al. 2012; Tate 2012; Cutter and Finch 2008; Haque et al. 2022, 2023; Shah et al. 2018; Tate et al. 2021a, b; Yaseen et al. 2023). To understand the importance of different flood risk indicators, we developed a survey item and gathered opinions from stakeholders with expertise in flood risk mitigation. Respondents were asked to select the indicator/s they considered the most important. They were allowed to select more than one indicator. Their responses were then computed as percentages to reflect the relative importance of each indicator (Eq. 1). A similar approach to value weighting has been performed in other flood prone regions (Shah et al. 2018). The results from the survey indicating relative importance of each indicator are presented in Fig. 5.

The selection of the indicators highlighted that geographic location stands as the leading variable of risk to flooding (Fig. 5). Several studies have identified geographic location as a key determinant in flood risk assessment (Dey et al. 2024; Haque et al. 2022; Haque et al. 2023; Chakraborty et al. 2023). These findings not only underscore the consistent importance of geographic location and critical infrastructure availability but also provide a reliable empirical basis for understanding the flood risk indicators in the decision-making process. The resulting weights were then utilized to facilitate the development of a flood risk

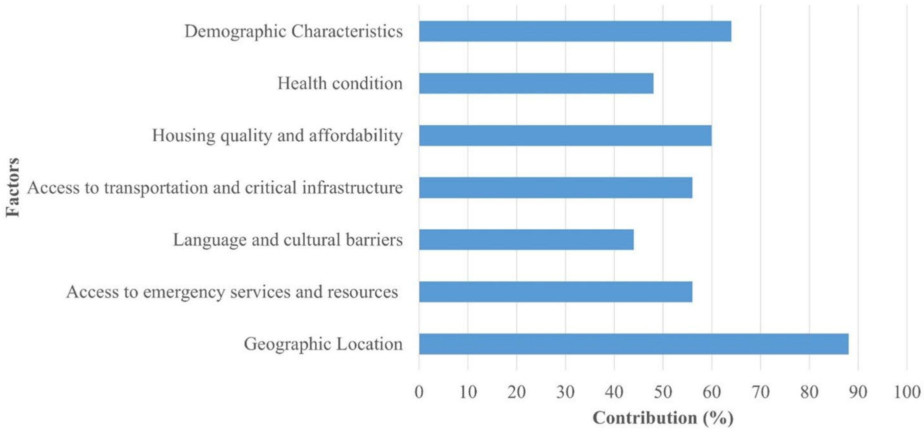

Fig. 5 Contribution of different indicators to flood risk assessment as perceived by stakeholders

Table 2 Stakeholders value weighting preferences based on survey responses

Approaches	Percentage
Expert opinion	18
Data Analysis	24
Stakeholder Input	20
Risk assessment	26
Following the existing best practice	12

map. Geographic location and past flood experience were found to be the most significant indicators of flood risk assessment. Similar findings were reported in another geographic context (Haque et al. 2023).

4.5 Stakeholder's opinions about the value-weighting in flood risk assessment

Indicator based flood risk assessment involves multiple indicators related to flooding and their respective weights. After asking stakeholders to select the most important indicator/s for flood risk, we were interested in what approach influenced their value weighting. Literature review assisted us to identify some common approaches that are being followed during the value weighting process. They include expert opinion, data analysis, stakeholder input, risk assessment, following the existing best practice. We asked respondents how they determined the relative importance of different indicators in flood risk mitigation. A diverse range of responses was obtained, with risk assessment and data analysis methods emerging as the most used approaches for determining the relative importance of flood risk indicators and guiding the value-weighting process (Table 2). Experts such as hydrologists, engineers, urban planners undoubtedly have the expertise to give relative weight. However, only dependent on their input is not sufficient to address the multifaceted nature of flood risk. They may offer valuable technical insights, but these need to be contextualized with local knowledge and input from other stakeholders to create a comprehensive and effective approach that can be accepted by a broader community. Similarly, data analysis is a widely used approach, but it might not capture community perceptions and the socio-political context of flooding.

Input from a diverse group of stakeholders provides the necessary qualitative insights to interpret and act upon data effectively. Risk assessment metrics often combine expert opinion, data analysis and modelling to provide a comprehensive assessment of risks. Involving stakeholder input would make this assessment more inclusive, leading to more targeted mitigation strategies. Lastly, following the existing best practices is also good practice but the nature of best practice must be evolved with the evolving nature of disasters (Maldonado 2016). Incorporating local perspectives can make sure the best practices are up to date to reflect present realities and community specific challenges (Osei et al. 2024; Cumming et al. 2022). Hence it is very important to incorporate or combine all those efforts to plan for effective flood risk mitigation.

4.6 Flood risk mapping

According to IPCC "*the risk from flooding to human and ecological system is caused by the flood hazard*, *the exposure of the system affected and the vulnerability of the system*" (IPCC 2021). With the combination of hazard, exposure, and vulnerability in measuring flood risk, we collected relevant indicators representing the three dimensions, respectively. Based on the 13 indicators listed in Table 3, we developed a flood risk map (Fig. 7) to visualize the spatial dimension of flooding in the study area.

Elevation data was collected from the USGS website, emergency service location data was collected from the two counties (Mobile County and Baldwin County) office websites, past flood data were derived from FEMA flood damage records related to the flooding event caused by Hurricane Nate in 2017 and distance from river was calculated using the Euclidean distance measurement tools in ArcGIS platform. From the US Census Bureau, we collected the relevant data for the expected indicators and standardized it using the min-max formula. For each flood risk indicator, we developed a spatial layer highlighting areas of high and low values based on the variance within the dataset. Since the value ranges varied across different indicators, using data variance allowed for a standardized approach to consistently represent the relative level of flood risk in each layer (Fig. 6). Finally, we multiplied all the standardized values with the derived weights to demonstrate Mobile Bay's flood risk. The uniqueness of this map is we incorporated the input of multiple levels of flood risk management stakeholders in risk mapping along with the objective data. The flood risk map was classified into five distinct categories using the equal interval method. These categories are very high risk (red: 11.7 to 41.3), high risk (orange: −17.9 to 11.7), moderate risk (yellow: −47.4 to −17.9), low risk (light green: −77.1 to −47.4), and very low risk (dark green: −106.6 to −77.1). This classification, applied to both Mobile and Baldwin Counties (Fig. 7), allows for a clear spatial visualization of risk levels across the region. This enables targeted mitigation efforts, where resources can be prioritized for regions exhibiting higher risks.

"Calculate geometry" is a widely used tool in ArcGIS to calculate the volume of geometry, and this study utilized it to determine the area at risk due to flooding (Table 4). Almost 45% of the Mobile Bay area is under considerable risks, among them 5.21% is at a very high level of risk. A recent study (Dey et al. 2024) conducted in the same study area using a data analysis-driven approach made similar findings.

Table 3 Flood risk indicators categorized under hazard, exposure, and vulnerability, with corresponding data sources

Category	Indicator	Definition	Data source	Years
Hazard	Elevation	Low-lying areas more prone to flooding	USGS	
	Distance from River or Coast	Closer proximity increases flood hazard	JRC Global Surface Water	2020
	Past Flood History	Areas with past flooding have a higher hazard	FEMA flood damage data (2017 Hurricane Nate event)	2017
Exposure	Population Density	More people exposed to potential flood hazards	Census Bureau	2023
	Household Density	Denser housing increases exposure to flood risk	Census Bureau	2023
Vulnerability	Age Over 60	Elderly populations are more susceptible to harm	Census Bureau	2023
	Age Under 18	Children are more vulnerable to flood impacts	Census Bureau	2023
	Poor Housing	Substandard housing is more prone to damage	Census Bureau	2023
	Income	Lower-income groups face greater difficulty in coping	Census Bureau	2023
	Own Vehicle	Lack of vehicle limits evacuation ability	Census Bureau	2023
	Disability	Higher vulnerability due to mobility and access issues	Census Bureau	2023
	Language Spoken	Language barriers hinder access to warnings and instructions	Census Bureau	2023
	Emergency Service Location	Proximity to service location reduces vulnerability	Mobile & Baldwin County office website	2023

5 Discussion

This study emphasizes the importance of stakeholder input in decision-making and integrates perspectives from multiple groups into flood risk assessment. Stakeholders expressed diverse views regarding climate change, its impacts on the Mobile Bay ecosystem, and their

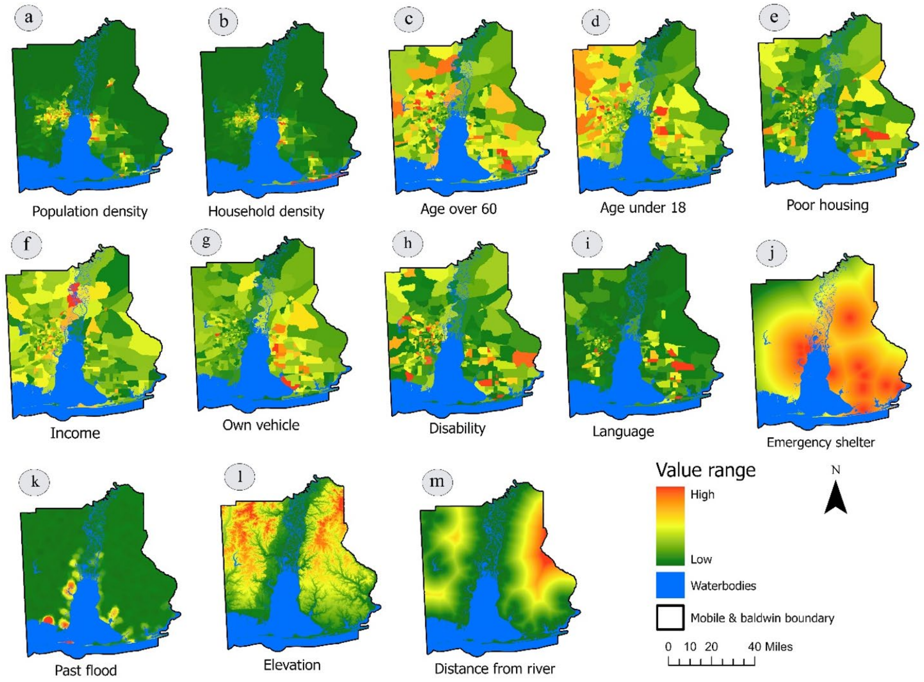

Fig. 6 Flood risk indicators categorized under three major components: Exposure, Vulnerability, and Hazard. Exposure indicators: **a** Population density, **b** Household density; Vulnerability indicators: **c** Age over 60, **d** Age under 18, **e** Poor housing, **f** Income, **g** Own vehicle, **h** Disability, **i** Language, **j** Emergency shelter; Hazard indicators: **k** Past flood events, **l** Elevation, **m** Distance from river

long-term implications. These perspectives highlight the growing need for collaboration to achieve effective flood risk mitigation. Flooding is a multifaceted hazard that requires a multidisciplinary approach, integrating scientific, technical, economic, social, and cultural perspectives. Each stakeholder group brings unique expertise and priorities, which often differ significantly (Manandhar and McEntire 2014). For example, hydrologists focus on hydraulic modeling tools to simulate flood scenarios, predict flooding, and guide infrastructure development (Kumar et al. 2023), whereas community organizations emphasize building resilience through education, awareness, and preparedness (McEwen et al. 2018). Both approaches are essential for sustainable flood risk management. Collaboration among these diverse groups is therefore not only beneficial but indispensable to addressing the complexities of flood risk comprehensively. The distinct roles of stakeholders have also been highlighted in prior studies. Emergency managers typically concentrate on infrastructure and operational readiness, while community leaders emphasize social cohesion and the well-being of vulnerable populations (O'Sullivan et al. 2013). Policymakers prioritize regulatory frameworks and resource allocation, whereas engineers focus on infrastructure resilience (Manandhar and McEntire 2014). These varying roles illustrate the multifaceted nature of flood risk mitigation and further underscore the necessity of collaborative, integrated approaches.

Given this importance, the present study incorporated multiple stakeholders' inputs into the risk assessment process. The approach is particularly relevant in areas where local per-

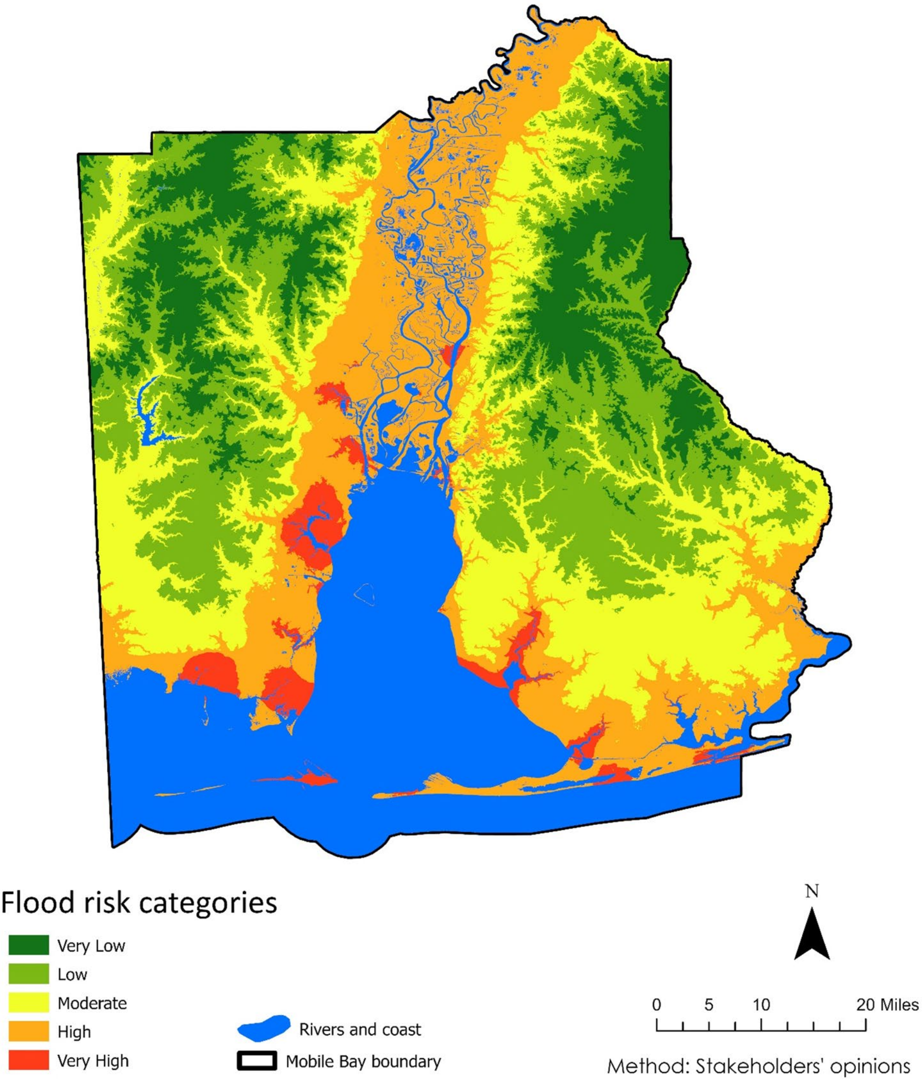

Fig. 7 Flood Risk Map of Mobile Bay. The map illustrates the spatial distribution of flood risk zones across Mobile Bay, categorized into five levels: very low (green), low (light green), moderate (yellow), high (orange), and very high (red)

Table 4 Area-wise flood risk percentage

Risk categories	Area (sq. km)	Area (%)
Very low	1020.31	11.36
Low	1962.86	21.86
Moderate	1889.82	21.03
High	3642.21	40.54
Very high	467.37	5.21
Total	8982.57	100

spectives are often overlooked in traditional expert-driven models. Its flexibility allows for scalability, making it suitable for coastal cities, urban areas, and rural flood-prone regions where community engagement is vital for resilience planning. Conventional flood risk assessment models are often expert driven, relying on quantitative data and physical indicators (e.g., elevation, land use, historical flood data). While these models are essential for understanding the physical dynamics of flooding, they often neglect local knowledge and socio-economic factors that are critical to understanding community vulnerability. By contrast, the stakeholder-informed method applied in this study incorporates diverse local perspectives, producing flood risk maps that combine objective physical data with the contextual priorities of those most affected. This participatory approach enhances both the legitimacy and local relevance of risk assessments, making them more effective for community-driven flood mitigation strategies.

Survey results further revealed that nearly 60% of respondents strongly agree that indicator-based flood risk management is effective. This preference suggests growing recognition of the importance of structured, data-driven methods. Such approaches inherently encourage the inclusion of diverse stakeholders, as they integrate climatic, environmental, social, and economic indicators essential for comprehensive risk assessment. This finding aligns with global frameworks such as the Sendai Framework for Disaster Risk Reduction (UNDRR 2015) and the Paris Agreement (UNFCCC 2015), both of which emphasize inclusive, multi-level collaboration in addressing climate-related disasters.

Among the indicators assessed, geographic location emerged as the most significant factor influencing flood risk mitigation. This underscores the context-specific nature of flood risks and vulnerabilities and highlights the need to include stakeholders from diverse geographic settings. For example, residents and authorities in riverine areas may prioritize levees or early warning systems due to frequent flooding (Perera et al. 2020), whereas coastal stakeholders may advocate for sea walls or nature-based solutions such as wetland restoration. Consequently, living in a flood-prone region strongly shapes stakeholder decisions. Incorporating such diverse perspectives ensures strategies are tailored to the specific challenges of different regions, contributing to more effective and enduring mitigation measures.

Other factors such as historical flooding experiences, professional backgrounds, and political perspectives also shape decision-making at various stakeholder levels (O'Sullivan et al. 2013). Flood management authorities with extensive local experience may prioritize interventions based on past flood events, while engineers may emphasize infrastructure such as dams, levees, roads, and hospitals. Social scientists, in contrast, focus on building community resilience through education, awareness campaigns, and social cohesion. These differences highlight the importance of integrating multiple perspectives to ensure well-rounded and effective mitigation strategies. The study also shows that value-weighting in indicator-based assessments is influenced by such factors. While stakeholders may have differing metric preferences, combining them produces a more comprehensive and robust assessment.

A key outcome of this study is the development of a stakeholder-informed flood risk map, which aligns with findings from previous studies in similar regions (Dey et al. 2024a). Although formal quantitative validation was not performed, the study conducted a qualitative comparison with historically flooded areas, such as those impacted by Hurricane Nate in 2017, and found good alignment. Furthermore, stakeholder experts, including engineers and emergency managers, reviewed the maps and provided feedback to improve their accuracy and relevance. Future work should build on this by incorporating formal validation methods, such as field assessments or comparisons with actual flood damage data, to further strengthen the robustness of the results.

Researchers across disciplines use a variety of methods to map flood hazards. Traditional approaches often rely solely on physical indicators such as elevation, slope, rainfall, and proximity to rivers, alongside hazard simulations such as HEC-RAS (Khatooni et al. 2025), SWAT (Karami et al. 2024), or machine learning classifiers (Bentivoglio et al. 2022; Mudashiru et al. 2021; Dey et al. 2024b, c). While effective in identifying areas of biophysical susceptibility, these methods tend to underrepresent social and institutional vulnerabilities (Vojtek 2023). The stakeholder-informed approach presented here complements these models by embedding local expertise and practitioner perspectives directly into the indicator-weighting process. Although our results such as the concentration of high-risk areas in low-lying coastal zones are broadly consistent with hazard-driven maps of Mobile Bay (Dey et al. 2024a), the novelty of this method lies in generating a composite risk surface that reflects both objective hazard data and subjective stakeholder priorities. This added dimension improves the interpretability and acceptance of the maps among decision-makers, thereby increasing their usefulness for policy and planning. Future research could further test predictive performance through direct comparison with physically based hydrologic models. Although this study used a frequency- and rating-based weighting approach for simplicity and transparency, future research could apply more advanced techniques such as the AHP or PCA with larger datasets to refine stakeholder-derived weights and enhance the robustness of the mapping process.

Overall, this study reinforces the argument that the inclusion of diverse stakeholders and their perspectives is decisive for effective flood risk assessment. By integrating expertise and priorities across disciplines, it is possible to create strategies that are both comprehensive and sustainable. Incorporating input from multiple stakeholders into factor identification, prioritization, and weighting allowed this study to develop a stakeholder-informed flood risk map for the Mobile Bay area. Such inclusive approaches ensure that flood risk mitigation strategies are responsive to diverse needs and contexts, ultimately contributing to a more resilient and adaptive future.

6 Conclusion

This study aimed to investigate the importance of incorporating multiple stakeholders in effective flood risk mitigation, given the diverse nature of flooding. Numerous studies argued for the role of different stakeholders at both individual and community levels, concluding that, in the context of climate change and the evolving nature of flooding, collaboration is essential. Every stakeholder has a role to play in managing flood risk, from the household level to government agencies. Effective risk mitigation requires all these entities to work in unison to tackle this complex problem. The roles of engineers, meteorologists, climatologists, policymakers, urban planners, sociologists, economists, emergency managers, community organizations, and NGOs are equally important because flooding impacts multiple sectors. Effective mitigation cannot occur without collaboration among stakeholders. For example, policymakers need to consult community members, local authorities, and other stakeholders before making decisions to ensure that policies address current challenges accurately. Similarly, sustainable planning requires input from the entire community to facilitate the sharing of resources, information, and knowledge. As a result, this study placed significant emphasis on incorporating the perspectives of diverse stakeholders in the flood risk mitigation process and developed a comprehensive flood risk map that integrated their input into the decision-making framework. In addition to stakeholder-derived insights, the flood risk map was qualitatively compared with past flood events to ensure its alignment with known flood-prone areas. Future research could further validate these maps with actual damage data and field assessments to strengthen their utility for risk management and policy decisions.

Along with the lack of quantitative validation, another important limitation of this study was the restricted inclusion of a broader range of stakeholders such as community members due to outreach constraints. Only emergency managers, policymakers, city planners, resilience officers, meteorologists, and NGO workers from the respective area participated. Involving a more diverse group of stakeholders could have produced more comprehensive flood risk assessment. This study advocates for future research that includes a wider range of stakeholders, particularly community members who are directly affected by flooding. This study highlights the critical importance of incorporating stakeholder input in flood risk assessments, ensuring that the resulting maps reflect local priorities and realities. While the method of assigning weights based on stakeholder preferences is effective for this pilot study, future work could consider more advanced techniques, such as the AHP or PCA, to refine and enhance the accuracy of the stakeholder-derived weights, particularly in studies with larger datasets.

While this study provides valuable insights into the flood risk perceptions of key professionals in the Mobile Bay area, the non-random, purposive sampling strategy limits the generalizability of the findings to the broader flood risk management community. Future research should consider including a more diverse set of stakeholders, such as residents and private sector representatives, to enhance the representativeness of the results and the generalizability of the flood risk maps. In addition to that, future flood risk maps can consider more physical and socioeconomic factors. Future studies could also incorporate qualitative insights through focus group discussions (FGDs) with community members and in-depth interviews with authorities, such as emergency managers and policymakers. The stakeholder-informed approach demonstrated in this study can be applied to other regions, particularly those with diverse flood risk management stakeholders, such as coastal cities or rural flood-prone areas, but needed to make sure a robust sampling includes wide range of stakeholders. Compared to conventional expert-driven models, this participatory method offers a more inclusive and locally relevant framework for flood risk assessment, ensuring that maps are not only scientifically rigorous but also aligned with local priorities. Most importantly, this study offers a compelling example of how diverse stakeholder input can be effectively integrated into flood risk mitigation efforts, paving the way for more inclusive and informed decision-making.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11069-025-07725-y.

Acknowledgements The research leading to these results was supported by funding from the Department of Treasury under Project 22-SFWS-248612-UAT. We gratefully acknowledge their support, which made this work possible. We would also like to extend our sincere thanks to all the respondents who, despite their busy professional commitments, took the time to participate and provide valuable insights into this study.

Author contributions The first and second authors contributed to the study's conception and design. Material preparation, data collection, analysis, and initial manuscript drafting were performed by Md Munjurul Haque. Hemal Dey contributed to data visualization and map creation. Wanyun Shao secured funding, provided manuscript proofreading, and supervised the overall work. All authors read and approved of the final manuscript.

Funding The research leading to these results was supported by funding from the Department of Treasury under Project 22-SFWS-248612-UAT. The second author has received the funding from the Department of Treasury.

Data availability Data will be available based on reasonable requests.

Declarations

Conflict of interests The authors have no relevant financial or non-financial interests to disclose.

References

Bentivoglio R, Isufi E, Jonkman SN, Taormina R (2022) Deep learning methods for flood mapping: a review of existing applications and future research directions. Hydrol Earth Syst Sci Dis 2022:1–50

Braun V, Clarke V (2021) To saturate or not to saturate? Questioning data saturation as a useful concept for thematic analysis and sample-size rationales. Qualitative Res Sport Exerc Health 13(2):201–216

Calvo-Solano O, Quesada-Román A (2024) Worldwide research trends and networks on flood early warning systems. GeoHazards 5(3):582–595

Cass E, Shao W, Hao F, Moradkhani H, Yeates E (2023) Identifying trends in interpretation and responses to hurricane and climate change communication tools. Int J Disaster Risk Reduct 93:103752

Chakraborty L, Thistlethwaite J, Scott D, Henstra D, Minano A, Rus H (2023) Assessing social vulnerability and identifying Spatial hotspots of flood risk to inform socially just flood management policy. Risk Anal 43(5):1058–1078

Chen J, Huang G, Chen W (2021) Towards better flood risk management: assessing flood risk and investigating the potential mechanism based on machine learning models. J Environ Manage 293:112810

Ciampa F, Seifollahi-Aghmiuni S, Kalantari Z, Ferreira CSS (2021) Flood mitigation in mediterranean coastal regions: Problems, solutions, and stakeholder involvement. Sustainability 13(18):10474

Cumming G, Campbell L, Norwood C, Ranger S, Richardson P, Sanghera A (2022) Putting stakeholder engagement in its place: how situating public participation in community improves natural resource management outcomes. GeoJournal 87(Suppl 2):209–221

Cutter SL, Finch C (2008) Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the national academy of sciences*, *105*(7), 2301–2306

Cutter SL, Boruff BJ, Shirley WL (2012) Social vulnerability to environmental hazards. Hazards vulnerability and environmental justice. Routledge, pp 143–160

da Silva LBL, Alencar MH, de Almeida AT (2020) Multidimensional flood risk management under climate changes: bibliometric analysis, trends and strategic guidelines for decision-making in urban dynamics. Int J Disaster Risk Reduct 50:101865

Dada OA, Almar R, Morand P (2024) Coastal vulnerability assessment of the West African Coast to flooding and erosion. Sci Rep 14(1):890

Dey H, Shao W, Pan S, Tian H (2024a) The Spatiotemporal patterns of community vulnerability in the US mobile Bay from 2000–2020. Appl Spat Anal Policy 17(1):371–392

Dey H, Shao W, Moradkhani H, Keim BD, Peter BG (2024b) Urban flood susceptibility mapping using frequency ratio and multiple decision tree-based machine learning models. Nat Hazards 120(11):10365–10393

Dey H, Haque MM, Shao W, VanDyke M, Hao F (2024c) Simulating flood risk in Tampa Bay using a machine learning driven approach. Npj Nat Hazards 1(1):40

Edelenbos J, Van Buuren A, Roth D, Winnubst M (2017) Stakeholder initiatives in flood risk management: exploring the role and impact of bottom-up initiatives in three 'Room for the river'projects in the Netherlands. J Environ Planning Manage 60(1):47–66

Efraimidou E, Spiliotis M (2024) A gis-based flood risk assessment using the decision-making trial and evaluation laboratory approach at a regional scale. Environ Processes 11(1):9

Elkhidir E, Mannakkara S, Henning TF, Wilkinson S (2022) Knowledge types and knowledge transfer mechanisms for effective resilience knowledge-sharing between cities–A case study of new Zealand. Int J Disaster Risk Reduct 70:102790

Evers M, Jonoski A, Maksimovič Č, Lange L, Rodriguez O, Teklesadik S, Makropoulos A, C (2012) Collaborative modelling for active involvement of stakeholders in urban flood risk management. Nat Hazards Earth Syst Sci 12(9):2821–2842

Farhadi H, Najafzadeh M (2021) Flood risk mapping by remote sensing data and random forest technique. Water 13(21):3115

Gebremedhin ET, Basco-Carrera L, Jonoski A, Iliffe M, Winsemius H (2020) Crowdsourcing and interactive modelling for urban flood management. J Flood Risk Manag, 13(2), e12602

Ghasemzadeh B, Zarabadi ZSS, Majedi H, Behzadfar M, Sharifi A (2021) A framework for urban flood resilience assessment with emphasis on social, economic and institutional dimensions: A qualitative study. Sustainability 13(14):7852

Gnecco I, Pirlone F, Spadaro I, Bruno F, Lobascio MC, Sposito S, Palla A (2024) Participatory mapping for enhancing flood risk resilient and sustainable urban drainage: A collaborative approach for the Genoa case study. Sustainability 16(5):1936

Guest G, Bunce A, Johnson L (2006) How many interviews are enough? An experiment with data saturation and variability. Field Methods 18(1):59–82

Hadlos A, Opdyke A, Hadigheh SA (2022) Where does local and Indigenous knowledge in disaster risk reduction go from here? A systematic literature review. Int J Disaster Risk Reduct 79:103160

Hagos YG, Andualem TG, Yibeltal M, Mengie MA (2022) Flood hazard assessment and mapping using GIS integrated with multi-criteria decision analysis in upper Awash river basin, Ethiopia. Appl Water Sci 12(7):148

Haque MM, Islam S, Sikder MB, Islam MS (2022) Community flood resilience assessment in Jamuna floodplain: A case study in Jamalpur district Bangladesh. Int J Disaster Risk Reduct 72:102861

Haque MM, Islam S, Sikder MB, Islam MS, Tabassum A (2023) Assessment of flood vulnerability in Jamuna floodplain: a case study in Jamalpur district, Bangladesh. Nat Hazards 116(1):341–363

Hermans TD, Šakić Trogrlić R, van den Homberg MJ, Bailon H, Sarku R, Mosurska A (2022) Exploring the integration of local and scientific knowledge in early warning systems for disaster risk reduction: a review. Nat Hazards 114(2):1125–1152

Hudson P, Hagedoorn L, Bubeck P (2020) Potential linkages between social capital, flood risk perceptions, and self-efficacy. Int J Disaster Risk Sci 11(3):251–262

Intergovernmental Panel on Climate Change (2021) Risk management and decision-making in relation to sustainable development: A guidance note. IPCC. https://www.ipcc.ch/site/assets/uploads/2021/02/Risk-guidance-FINAL_15Feb2021.pdf

Ishiwatari M (2019) Flood risk governance: Establishing collaborative mechanism for integrated approach. Progress Disaster Sci 2:100014

Karami M, Koupai A, J., Gohari SA (2024) Integration of SWAT, SDSM, AHP, and TOPSIS to detect flood-prone areas. Nat Hazards 120(7):6307–6325

Khatooni K, Hooshyaripor F, MalekMohammadi B, Noori R (2025) A new approach for urban flood risk assessment using coupled SWMM–HEC-RAS-2D model. J Environ Manage 374:123849

Kumar V, Sharma KV, Caloiero T, Mehta DJ, Singh K (2023) Comprehensive overview of flood modeling approaches: A review of recent advances. Hydrology 10(7):141

Lechowska E (2022) Approaches in research on flood risk perception and their importance in flood risk management: a review. Nat Hazards 111(3):2343–2378

Li Y, Han H, Sun Y, Xiao X, Liao H, Liu X, Wang E (2023) Risk evaluation of ice flood disaster in the upper Heilongjiang river based on catastrophe theory. Water 15(15):2724

Liu Q, Du M, Wang Y, Deng J, Yan W, Qin C, Liu J (2024) Global, regional and National trends and impacts of natural floods, 1990–2022. Bull World Health Organ 102(6):410

Ma Y, Jiang Y (2023) Ecosystem-based adaptation to address urbanization and climate change challenges: the case of china's sponge City initiative. Clim Policy 23(2):268–284

Maldonado J (2016) Considering culture in disaster practice. Annals Anthropol Pract 40(1):52–60

Malterud K, Siersma VD, Guassora AD (2016) Sample size in qualitative interview studies: guided by information power. Qual Health Res 26(13):1753–1760

Manandhar R, McEntire DA (2014) Disasters, development, and resilience: Exploring the need for comprehensive vulnerability management. *Disaster and development: Examining global issues and cases*, 19–37

McAllister RR, McCrea R, Lubell MN (2014) Policy networks, stakeholder interactions and climate adaptation in the region of South East Queensland, Australia. Reg Envriron Chang 14:527–539

McDermott TK (2022) Global exposure to flood risk and poverty. Nat Commun 13(1):3529

McEwen L, Holmes A, Quinn N, Cobbing P (2018) Learning for resilience': developing community capital through flood action groups in urban flood risk settings with lower social capital. Int J Disaster Risk Reduct 27:329–342

Miller JD, Vischel T, Fowe T, Panthou G, Wilcox C, Taylor CM, Cazenave F (2022) A modelling-chain linking climate science and decision-makers for future urban flood management in West Africa. Reg Envriron Chang 22(3):93

Morrison A, Westbrook CJ, Noble BF (2018) A review of the flood risk management governance and resilience literature. J Flood Risk Manag 11(3):291–304

Mudashiru RB, Sabtu N, Abustan I, Balogun W (2021) Flood hazard mapping methods: A review. J Hydrol 603:126846

Mugari E, Nethengwe NS, Gumbo AD (2025) A co-design approach for stakeholder engagement and knowledge integration in flood risk management in Vhembe district, South Africa. Front Clim 7:1517837

Munawar HS, Hammad AW, Waller ST (2022) Remote sensing methods for flood prediction: A review. Sensors 22(3):960

O'Sullivan TL, Kuziemsky CE, Toal-Sullivan D, Corneil W (2013) Unraveling the complexities of disaster management: A framework for critical social infrastructure to promote population health and resilience. Soc Sci Med 93:238–246

Osei K, Mikado S, Agyenim BE, Asante M (2024) Community natural resources management and resilience. Palgrave Encyclopedia Sustainable Resour Ecosyst Resil, 1–6

Pasquier U, Few R, Goulden MC, Hooton S, He Y, Hiscock KM (2020) We can't do it on our own!—Integrating stakeholder and scientific knowledge of future flood risk to inform climate change adaptation planning in a coastal region. Environ Sci Policy 103:50–57

Perera D, Agnihotri J, Seidou O, Djalante R (2020) Identifying societal challenges in flood early warning systems. Int J Disaster Risk Reduct 51:101794

Qiang Y (2019) Flood exposure of critical infrastructures in the united States. Int J Disaster Risk Reduct 39:101240

Robinson OC (2014) Sampling in interview-based qualitative research: A theoretical and practical guide. Qualitative Res Psychol 11(1):25–41

Rogers BC, Bertram N, Gersonius B, Gunn A, Löwe R, Murphy C, Arnbjerg-Nielsen K (2020) An interdisciplinary and catchment approach to enhancing urban flood resilience: a Melbourne case. Philosophical Trans Royal Soc A 378(2168):20190201

Shah AA, Ye J, Abid M, Khan J, Amir SM (2018) Flood hazards: household vulnerability and resilience in disaster-prone districts of Khyber Pakhtunkhwa province, Pakistan. Nat Hazards 93:147–165

Shao W, Keim BD, Xian S, O'Connor R (2019) Flood hazards and perceptions–A comparative study of two cities in Alabama. J Hydrol 569:546–555

Shao W, Moftakhari H, Moradkhani H (2020) Comparing public perceptions of sea level rise with scientific projections across five States of the US Gulf Coast region. Clim Change 163(1):317–335

Tate E (2012) Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Nat Hazards 63:325–347

Tate E, Decker V, Just C (2021a) Evaluating collaborative readiness for interdisciplinary flood research. Risk Anal 41(7):1187–1194

Tate E, Rahman MA, Emrich CT, Sampson CC (2021b) Flood exposure and social vulnerability in the united States. Nat Hazards 106(1):435–457

Thaler T, Levin-Keitel M (2016) Multi-level stakeholder engagement in flood risk management—A question of roles and power: lessons from England. Environ Sci Policy 55:292–301

United Nations Department of Economic and Social Affairs (UNDESA) (2023) *Enhancing public institutions' risk-informed communication to address multifaceted crises for disaster risk reduction, resilience, and climate action* (Policy Brief No. 156). https://desapublications.un.org

United Nations Framework Convention on Climate Change (2015) *Paris Agreement*. United Nations. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

United Nations Office for Disaster Risk Reduction (2015) *Sendai Framework for Disaster Risk Reduction 2015–2030*. United Nations. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

Vojtek M (2023) Indicator-based approach for fluvial flood risk assessment at municipal level in Slovakia. Sci Rep 13(1):5014

Yaseen M, Saqib SE, Visetnoi S, McCauley JF, Iqbal J (2023) Flood risk and household losses: empirical findings from a rural community in Khyber Pakhtunkhwa, Pakistan. Int J Disaster Risk Reduct 96:103930

Zhang D, Shi X, Xu H, Jing Q, Pan X, Liu T, Hou H (2020) A GIS-based Spatial multi-index model for flood risk assessment in the Yangtze river Basin, China. Environ Impact Assess Rev 83:106397