

Peer Review File

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Overall changes

Given the comments and questions from the reviewer, we have significantly changed the text, tables, and figures of this paper. We have re-done our analysis and developed a different framework for flood vulnerability mapping than previously submitted. This new method avoids several of the issues brought up by the reviewer as well as those identified in the literature.

The paper also has been restructured and rewritten. The text (without references) is now approximately 9,500 words (3,300 words longer than the first version) in an attempt to fully describe, discuss, and explain our work including methods, literature review, results, and discussion. We have added 55 new references, 5 new tables, and 5 new figures (as well as edited all previous tables and figures). We have edited the text in an attempt to reduce typos, incorrect statements, and grammatical mistakes. We thank the reviewer for their careful reading of the text and hope that we responded adequately to all comments and concerns. We remain ready to respond to further comments and questions.

Given the large number of changes and some of the general comments of the reviewer, rather than place large amounts of text in the responses, we refer to the areas of the new text in our answers.

Reviewer A

In the reviewed paper, the authors describe a study to assess flood vulnerability in NYC. While this is a worthy endeavor, the manuscript has a number of shortfalls.

- The language needs to be edited to improve grammar, be more clear, and make the style more formal. Many buzz words and jargon are used without defining them in the context of this work.
- The methods described herein are vague and unclear.
- There is limited description or discussion of the results.
- And there are numerous typos and incorrect information provided (included in the comments below). As an example, the authors make an interesting argument in stating that the use of “three sensitive groups (minorities, elderly and immigrants) present a way to provide specialized attention to their differential needs”, however they do not provide enough clear information on the methods to allow the reader to understand how these three groups were determined and clustered.

More specific comments and questions are below:

1. It would help if the authors define vulnerability in the context of this paper. More specifically, is this an assessment of vulnerability to experiencing a hazard (incorporating hazard and exposure) or vulnerability to impact from the hazard (incorporating sensitivity and adaptive capacity). Is the vulnerability in question related to what happens during an event itself (i.e. preventing acute impacts to health and safety) or capacity for post-event recovery, or both?

Reply: We have defined different uses of the term vulnerability in the text and have highlighted why we use our chosen definition. Please see the new Literature review sub-section entitled, 2.2 The Concept of Vulnerability.

2. Line 65: “Together Henri and Ida caused the worst cases of pluvial flooding in the city’s history (14). Most of the severely affected were already disadvantaged communities (15, 16).” – the citations listed are

both for hurricane Sandy, not Ida or Henri. Did Ida and Henri mostly effect disadvantaged communities? Is this even known? Please edit for clarity.

Reply: We removed this statement.

3. Line 77: “The results section provides the findings of the study. This is followed by the discussion section that outlines the implications of the research. We summarize the major findings in the conclusions.” – readers will already know and understand this as it is standard for papers to be structured this way, don’t need to state it here.

Reply: We have removed the paragraph as requested.

4. Line 43: “Obviously, those closest to the seashore and at lowest elevation are the most exposed to storm flooding.” -This is not necessarily true, please edit, especially the use of the word “obviously”. (1) This would depend on if the flood in question was a precipitation related floods or caused by storm surge – these should be treated differently. (2) Those at the coast are more susceptible to tide related floods, but not necessarily precipitation related. Floods related to precipitation are impacted by many factors, including pervious pavement, relative local elevation (i.e. not necessarily absolute lowest elevation), drainage system design, etc., and can happen even at higher elevation if there a local area that has a relatively lower elevation.

Reply: The statement was removed.

5. Line 48 – the use of the descriptor of NYC being a “global city” is not proper motivation for its use as a case study. Further, what defines a “global city”?

Reply: The reference of New York City as a global city was removed and also taken out of the title.

6. Line 49: “Arguably, as a global city in a northern country one might consider New York City (NYC) immune from the impacts of catastrophic flooding. – There are few, if any, people that would argue that NYC is immune to impacts of flooding.

Reply: We have removed the statement.

7. Line 83: “inter alia” – what does this mean?

Reply: According to Webster’s dictionary, *inter alia* means “among other things.” This is how it is used in the text.

8. Line 93: “We define vulnerability as a function of the intensity of the shock, the exposure to the event for population or infrastructure, the sensitivity of the population or infrastructure to that shock and the adaptive capacity of the system to avoid or ameliorate the shock” – it is unclear what the authors chose this definition over the definitions described above, and unclear from the discussion of this literature review why the authors chose to use one framework (scientific) over another. Additionally, could the authors describe what they mean by “intensity of the shock” in this context.

Reply: We have rewritten the entire literature review to define vulnerability and emphasize our viewpoint. It isn’t that the social vulnerability or contextual perspective is better than the scientific perspective. They are different. In choosing one we highlight different aspects of vulnerability and subsequently different policies to reduce vulnerability. Please see the new Literature review subsection entitled, 2.2 The Concept of Vulnerability.

Also, we have now presented two different exposure intensities (moderate and extreme) for both coastal and pluvial flooding.

9. The literature review is not fully fleshed out to be definitively described as a literature review – for example, the authors describe that many framings of vulnerability exist, but only provide details of scientific framing and not the others. This section would also benefit from better definition of the terms and buzzwords used throughout, within the context of this work.

10. Line 99: “For example, the shares of the older population (> 64) are considered sensitive to flooding as they move slower than younger people and often need help to get away from exposed areas.” – is this a generally held view of why older populations are more sensitive to flooding (as opposed to other reasons why they may be more sensitive)? Is there a citation for this?

Reply: We have fleshed out the literature review and added new references to highlight some of the reasons why we believe that the variables chosen provide a proxy for hazard sensitivity.

11. When describing sensitivity and adaptive capacity, are the authors referring to these traits during a flood event or afterwards for recovery efforts, or both? Line 106-108 suggest that they are considering actions during a flood event only.

Reply: We have clarified that hazard sensitivity refers to behaviors and characteristics related to coping mechanisms before, during, and after the flooding shock. We attempted to include examples when appropriate. We hope that we were clearer.

12. Line 122: “One of the earliest studies attempts to identify accurate numbers of populations exposure to flooding. The authors present a technique to disaggregate population data at the census tracts level to sub-units (31).” – for statements like this, past tense should be used.

Reply: We attempted to change the tense of statements when appropriate. We use the past tense the most of the sentences in our methods section. In other sections, we try to use the present tense, although have used the past tense when appropriate, such as the one identified. This statement was removed.

13. Line 156: “Our study proposes to add to this growing body of literature by focusing on three new aspects of flood vulnerability mapping in NYC.” – it is unclear what the gaps are in previous research were that led the authors to be motivated to try a new approach

Reply: We have identified the contribution of our study. For example, we emphasize that reviews identify challenges in social vulnerability analyses in terms of weighting, aggregation, and standardization methods. Our method avoids these problems to present a clear identification of locations of high vulnerability.

14. Line 160: “we break up publicly provided adaptive capacities into four groupings” – what is meant by “publicly provided adaptive capacities”?

Reply: We define what we now call community resources for adaptive capacity. We define the term in the text. Please see the new sub-section entitled, 3.1.2 Adaptive Capacity Variables and Themes.

15. Line 162: “This is due to the availability of new maps created after Hurricane’s Henri and Ida.” – these maps were created and released in May 2021, before Henri and Ida came to NYC. Please edit

Reply: This statement was removed.

16. What is meant by “socially sensitive demographic groups”(line 167)? “Socially sensitive” is not a standard or particularly descriptive term?

Reply: We removed this term from the text. We identify “hazard-sensitivity” as potential negative effects on individuals and communities caused by external stresses from natural, or other forms of hazards.

17. Line 171: “For the adaptive capacity portion of the study, a weighted ranking of distances to the nearest census tract that has adaptive capable provisions defines adaptive capacity for the tract.” – what are the “provisions” referenced here?

Reply: We have completely changed our methods. We removed this statement from the text. We have also further described our methods in each case.

18. Line 190: “While the CDC normalizes these variables by percentage to create their index, we use the absolute values to identify areas of highest numbers of socially vulnerable populations.” – it is unclear how using the absolute values indicates the greatest number of vulnerable individuals – please elaborate. Additionally, by using absolute values instead of normalized values or an index, is there a possibility of biasing the ranking towards areas of analysis with greater population density or greater land area?

Reply: While we start with absolute values (rather than transforming them into percentages) we centered and scaled (z-score) our data before analysis. We then develop a correlation matrix and perform the PCA with those values. Given the scaling, centering, and use of the correlation matrix, there is little to no data-related bias in the analysis.

19. Line 192: “Data are from the 2020 Decennial Census or the American Community Survey, 5-year average estimates (2016-2020)” – does this mean that the authors did not use the CDC SVI, but instead created their own vulnerability index using similar criteria? ALSO, what scale were data collected on (census tract?), and what exactly are the variable names used in this data set that correspond to each category listed below?

Reply: We attempted to clearly state that while we used the variables identified by the CDC we collected our own data, which is from the up-dated Census in many cases. The one except in the case of housing cost burden, which we use from the CDC.

20. Line 208: “Minority communities in the US, including Black and Hispanic neighborhoods, are socially and economically marginalization” – this whole paragraph needs a language edit.

Reply: The paragraph was edited.

21. Line 218: “Many of those that died during Hurricane Ida were living in crowded basement apartments” – It was not the crowding, but the aspect of being in a basement apartment that caused mortality in this situation. The basement apartments were located in particularly hazardous areas, with respect to flash flooding. Additionally, there is no mention in the cited article that the basement apartments were overcrowded – what evidence do the authors have that crowding caused mortality in this specific instance?

Reply: This statement was removed and new references were added.

22. Rent Burden – related to rent burden, what about the impact to home owners who have household

expenses (mortgage, taxes, fees, etc) greater than 30% of income?

Reply: Yes, we added appropriate references and discussed homeowner burdens, although according to our reading, the number of homeowners with cost burdens has been decreasing while those with rent burdens have been increasing.

23. Table 1: Basic statistics of variables for New York City used in the analysis. – at what scale are these numbers collected? Census tract? NTA? Zip code?

Reply: Social statistics were collected at the Census tract level. All analysis was performed using this unit scale and we have attempted to clarify this in the text throughout the document. However, please note that the exposure data were estimated at the building lot level and then aggregated to the Census tract level.

24. Line 313: “All other adaptive capacity data were extracted from the New York City Open Data system – could the authors please describe which datasets and which metrics were extracted and used

Reply: We have mentioned the different datasets that we used in the text and described each in more detail. These data are also identified in a table. Finally, we have provided URLs where the data can be found.

25. Table 2: Indicators created for four different adaptive capacity themes. – the authors state “Indicators may be constructed from several variables“. Could the authors please provide more details related to what this means.

Reply: We have re-written this section. We use the 8 variables to create the 4 categories (themes) of adaptive capacity.

26. Line 334: In addition to providing stormwater runoff mitigation, green infrastructure can provide ecological and social benefits, as well as physical and psychological benefits that contribute to community health and resilience. This helps build community rapport in times of crisis when city officials are unable to attend to a given community’s needs” – is there evidence that green infrastructure (GI) could provide these kinds of resiliency measures in a meaningful way? If not, please reconsider their inclusion here. While GI can help with hazard mitigation, this would be included in the assessment of flood hazards, and possibly already included in the NYC stormwater maps, and not related to an individual’s adaptive capacity.

Reply: We do not remove the mitigation aspects of adaptive capacity for the following reasons: First, as mentioned above and now clearly in the text, we emphasize community resource adaptive capacity, not individual capacity, as the reviewer implies. Mitigating floods is an important community adaptation measure and can reduce hazard sensitivity. Second, we provide citations for our statement (see below). Third, in our analysis, to our knowledge GI is not included in either the coastal storm or pluvial flooding maps used in this study (for PFIRM see <https://dcp.maps.arcgis.com/apps/webappviewer/index.html?id=1c37d271fba14163bbb520517153d6d5>, which only mentions elevation and topography; for the stormwater flood maps, the documentation states that the flooded areas “assume that rain occurs uniformly across the city, that the drainage network is functioning as designed (for example, that catch basins do not have leaves matting over the tops), and that large properties, such as airports, have their own on-site drainage systems. They do NOT account for the potential benefits of coastal protection projects currently under design or construction.” (their emphasis) (<https://experience.arcgis.com/experience/6f4cc60710dc433585790cd2b4b5dd0e>). If the review has other knowledge about the creation of these maps we would be interested in knowing. Finally, the

stormwater planning for the city includes several different infrastructure projects that will combat this flooding, strongly suggesting that this work is not included in the current maps (see <https://www.nyc.gov/site/dep/whats-new/rainfall-ready-nyc.page>)

- **Li D, Newman G, Zhang T, Zhu R, Horney J. Coping with Post-Hurricane Mental Distress: The Role of Neighborhood Green Space. Social Science & Medicine. 2021;281:114084.**
- **Schmeltz MT, González SK, Fuentes L, Kwan A, Ortega-Williams A, Cowan LP. Lessons from Hurricane Sandy: A Community Response in Brooklyn, New York. Journal of Urban Health. 2013;90(5):799–809**

27. Line 342: “Access to nearby medical services during a flooding disaster is essential in case of life-threatening injuries that cannot be treated at home” – what kind of injuries are being considered here? Flood related or general medical emergencies that may coincide?

Reply: We would assume that all medical services are important during a hazard! A trip and fall, burn or other accidents or perhaps heart failure may be as critical as near drowning.

28. Line 360: “flood zones that are either denoted with A, AE, AO, or VE, known as SFHAs, are high-risk areas” - what do each of these acronyms mean?

Reply: We have now defined these.

29. Line 386: “PCA is a statistical dimensionality reduction method, which retains as information of the original data as possible. – what was the motivation for the authors to decide to use PCA here? What was PCA used to do?

Reply: We’re not exactly sure what is being asked. PCA reduces data dimensionality as clearly stated. We believe it is difficult to juggle the relative importance of 15 or more different variables in any equation. PCA reduces the number of variables without losing the variation amongst all of them. For example, our 4 components include 78% of the variation of all 15 variables. PCA is often used in vulnerability assessments for this very reason. We have attempted to clearly state this in the text.

30. Line 387: “The first is to create a correlation matrix from the raw data to identify both high and low correlations among variables so that they can be removed. – so that what can be removed? And why?

Reply: We explained our process more clearly in the text.

31. Line 390: “Variables that are not correlated to other variables in the dataset are not related and therefore are not useful. – why are they not useful? Is there a potential that two metrics can be unrelated, but that each is useful for its own reasons?

Reply: We explain our reasons for reducing the number of variables used in the PCA. The technique used is standard and we provide citations.

32. Line 392: “Doing so, the variables “households with no vehicles”, “persons in group quarters” and “number of mobile homes” were removed from further analysis. – why were each of these removed?

Reply: We explained specifically why each variable was removed. Several variables have very low correlations to many other variables. Therefore, they are not useful to the analysis. Some variables

have very high correlations and present multicollinearity issues. These were also removed.

33. Lines 394-404 – a clear description of the PCA related analyses and how they help to determine which metrics to include in the analysis is needed

Reply: We attempted to explain the PCA analysis and how it helped to determine the metrics we used.

34. Lines 413: “We then calculated the Euclidean distance from each census centroid to each tract that had adaptive capacity services or facilities and found the shortest distance from each census tract to a census tract with an adaptive capacity service.” – how was this conducted if the facilities being evaluated were located within the tract being evaluated?

Reply: We are interested in the shortest distance to a facility or service. Those facilities located within a Census tract therefore received a 0 distance. Once we identified the shortest distances to each Census tract, we could then identify locations that had the longest way to go to a service.

35. Line 418: “Finally, we created a scaled measure for each themed capacity by finding the percentile ranking within NYC. The final weighted distance ranking for each adaptive capacity category were considered to be the adaptive capacity scores for the specific theme for each census tract.” – the description provided is unclear. Is the weighted distance ranking the percentile? Do lower numbers or greater numbers indicate increased adaptive capacity? How are services within the census tract treated? This is hard to understand – a figure and/or equation describing the methodology may help

Reply: We attempted to clarify our method and no longer use the percentile ranking method. We have moved away from a single measure index and removed any reference to a single measure. After reviewing the literature, we do not believe that these single measures are as helpful as the methods we developed. This is referenced in the various reviews we cite in the text. We have come to this conclusion after examining several different reviews.

36. Line 424: “...if 15% or more of the total area of a census tract intersects with the extreme stormwater flooding dataset...” - in the text above, the authors referred to using the moderate scenario, not the extreme. Which was used? And if the extreme was used, is the analysis focused on extreme events only, and not more chronic low level flood events? Why was 15% chosen? Additionally, is this a binary ranking of exposure (ie yes there is flood risk (1) vs no there is no flood risk(0))?

Reply: We have changed our method. We now use two different maps for coastal and pluvial flooding. There may be those that disagree with what we consider moderate and what is extreme. This is our perception of flooding during current times. We then use different percentages of lot inundation to identify a range of exposure values.

37. Line 440: “Where V is the vulnerability score of p census tract; E is the exposure of the census tract (either for storm or pluvial or both); S is the principal component for the census tract with c factor score; and r is the rank of the summed adaptive capacity score.” – (1) is E binary 0 or 1? What does “S is the principal component for the census tract with c factor” mean and how does it relate to the sensitivity? (3) please elaborate on what is meant by r and the rank of summed adaptive capacity scored (rank relative to what)?

Reply: We removed this formula.

38. Line 442: “For each census tract the ranked sum of all the different adaptive capacities is subtracted from the sensitivity score” – why is this done and does it make sense to subtract a rank from a score if they

are calculated in different ways?

Reply: We removed this formula and method. Our new method is clearer, we believe, and not only more accessible, but we believe more applicable.

39. Line 447: “The provides a final vulnerability score for each individual census tract for each individual principal component.” – what does it mean that this is done for each “principal component” – what are the principle components?

Reply: We tried to explain what PCA is more clearly.

40. Line 462: “Given the large sample size (over 2200)” – what is this sample size referring to? Number of census tracts? Number of variables? Unclear

Reply: The sample size is data from Census tracts. There are over 2300 census tracts in NYC and we use most of them. We have included a footnote on this.

41. Section 4.1 Sensitivity scores – what do the findings in this section mean for which metrics are used in the vulnerability index?

Reply: We now clearly state how each of the metrics are used.

42. Line 490: “Our estimates suggest that approximately 6.1% of the total population is exposed to either storm or pluvial flooding.” – how was this estimated? The only methods describing this analysis in the methods section describe doing so on a census tract scale, and that almost half of all census tracts are potentially susceptible. Therefore, how was a number of only 6% determined?

Reply: We no longer use these estimates and explain clearly how we use our new ones.

43. Line 492: “We do this using the results from the first principal component, which suggests that between 64% of young persons, 47% of the elderly, 64% of those with disabilities, 75% of those in poverty and 90% of the minorities that are exposed are also highly vulnerable” – this sentence is unclear. How were these values determined? My interpretation of this sentence is that 64% of young persons exposed to floods are vulnerable but 36% of young persons exposed to floods are not vulnerable – is that correct? If this is not what the authors are trying to convey, then please edit language to be more clear.

Reply: We have removed this analysis and replaced it with a more reliable set of figures.

44. Figure 2 – how were the values and quintiles determined? The only thing discussed in the text was the PCA, not the generation of values or quintile groups describing vulnerability. Additionally, please describe in figure caption which metrics were included in each group.

Reply: Quintiles were created by dividing the distribution of values for each variable into 5 equal-sized categories. Therefore, the highest quintile includes the 20% largest or highest values (highest 80-100% values in the distribution). So, when dividing up the factor scores for each Census tract, we identify the Census tracts with the highest scores and they are considered the most sensitive. We attempted to describe this in the text.

45. Were figures 4 and 5 generated with the vulnerability equation presented in the text?

Reply: As mentioned above, we changed our method. All figures are now explained and yes, all

figures are created from the analysis.

46. Table 3: Principal component analysis component, variable loadings and summary statistics – what do numbers in this table mean or correspond to? How were they used in analysis?

Reply: We attempted to explain the values in Table 3 in the text and also in the description of the table.

47. Line 521: “As mentioned, pluvial flooding is new for New York City.” – pluvial flooding is not new, many places in NYC have been flooding for decades. Its only recently that there was an event that had more widespread and severe flooding that raised awareness that the impacts of pluvial flooding may increase with climate change.

Reply: We removed this statement.

48. Line 522: “The first ever flash flood emergency warning was generated during Hurricane Ida in 2022.” - Ida occurred in 2021.

Reply: Thanks for catching this typo, we have changed the statement.

Overall response

We thank the two reviewers for their careful read and thoughtful comments. As Reviewer A’s comments were part of the first review and we have responded to them in detail previously, we did not include them again in this submission.

Given reviewer comments, we have expanded the paper, added several references, and re-worked most of the figures. We have kept the previous figures as supplemental. We did not change any of the tables as there were no comments regarded them. We have also edited the document for clarity and English mistakes. Finally, we have made edits to the author’s affiliations, restructured the abstract, consecutively numbered the figures in order of appearance, included an ethical statement in the Methods section, and edited the references to replace names with et al after the third author. We okay the edits made to the document by the journal. Specific responses to each reviewer’s comments are below.

Reviewer B

Summary: Flooding is a significant global natural hazard, accounting for 44% of all natural disasters. From 2000 to 2019, the world experienced over 3,200 floods, affecting over 1.5 billion people, killing over 100,000, and causing over \$650 billion in damages. Floods affect mental health, disrupt health services, and have knock-on effects on water supply, air pollution, and mold generation. There are several types of flooding events, each with a range of impacts. Climate change is projected to lead to more frequent, powerful, and longer rainfall and storm events, resulting in unprecedented levels of flooding. Cities and urban residents are particularly vulnerable to flooding due to physical changes and high population sizes. This study uses New York City as a case study, focusing on flood vulnerability in the city. The study aims to address

questions about hazard-sensitive communities, adaptive capacity facilities, and opportunities to provide adaptive capacity facilities to these communities.

The analysis is accomplished, and it includes several aspects that make an academic contribution. The superior methodology is a strong aspect of this paper. This study presents several advances over previous research by separating variables used to create social vulnerability indices into four groups of hazard-sensitive populations.

Response: Thank you!

Nonetheless, I have the following suggestions that I believe, will strengthen the impact of the paper:

1. Education section (line 298) need more attention. Lower level of education can impact income level, but not the coping strategy. Likewise, the role of Limited English speaking (306) , and automobile ownership (line 362) need to be justified and supported by suitable references.

Response: We have adjusted the three sub-sections to include a more detailed justification for these variables used in the project. In this regard we added over 10 new references.

2. The model is over-specified. Many predictors are redundant.

Response: This is a comment rather than a question. We agree that the original number of variables is large, and several were correlated. That is one of the reasons why we choose the PCA analysis. In our analysis we removed highly correlated and uncorrelated variables and then reduced the number of socio-economic sensitivity variables to four. We have also reduced the number of adaptive capacity variables to four.

3. As authors have admitted, that the measures of adaptive capacity rely on distance, which may not be the best measure of access or use of services.

Response: Agreed

I recommend for the acceptance of the paper.

Response: Thank you!

Reviewer C

1. The manuscript is very well written but is somewhat Materials and Methods heavy and Results and Discussion poor. I would suggest expanding the Results and, particularly, the Discussion sections to do justice to the needed work that has been accomplished.

Response: Our results section is large due to the original comments received during the first review that required detailed explanation of the methods. We would find it difficult ethically to now remove that information. For this review we have expanded both the Discussion and Results sections.

2. My comments are primarily philosophical and cosmetic.

Philosophically, PCA is difficult to understand in the best of circumstances and the use of multiple tables makes it even harder for the reader to ascertain the needed information. Being more concise in the text concerning the meaning of the analyses would be helpful.

Response: We have attempted to explain clearly in the discussion, the contribution of the research and particularly the PCA method. This includes a newly organized Discussion section. We have also expanded the results section where we present the new figures and describe them in more detail than previously. We hope this provides clarity to the work performed.

3. Cosmetically: A figure outlining the city's boroughs and other landmarks might be helpful for non-New Yorkers when using the subsequent maps.

Response: We have included a map of New York City with the city's counties outlined with the park system and labeled.

4. Information for Figures 2 and 3 is barely decipherable, Figure 4 is impossible to assess (too small). Figures 5 and 6 are the easiest to examine. Figures 7 and 8 are barely reviewable. The legend in Figure 9 cannot be read. Figure 10 is much too small to be useful.

I hesitate to ask for more figures but the reader has to be able to use the information. Perhaps, the authors could use example maps and place the remaining maps in supplementary materials.

Response We have edited Figures 2 and 3 for clarity. We have re-worked Figures 4, 7, 8, 9 and 10 so that readers can see them more clearly by using example maps as requested by the reviewer. In the process we have added a figure. All original small multiple figures are now included in a supplemental file.