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Reply on RC1

Jiachang Tu et al.

Author comment on "Assessment of building damages and risk under extreme flood scenarios in Shanghai" by Jiachang Tu et al., Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2021-382-AC1, 2022

Dear Reviewer,

The authors thank the reviewer for reviewing our manuscript. We appreciate the time and effort that the reviewer dedicated to providing feedback on the manuscript and we are grateful for the insightful comments and suggestions. We diligently went through your remarks and corrected our manuscript accordingly.

Please find our response and revised text blocks (in black italics) below your comments (in black bold).

General Comments

Thank you for inviting me to review the manuscript entitled 'Assessment of building damages and adaptation options under extreme flood scenarios in Shanghai'. This manuscript assesses possible exposure and damage losses of buildings in Shanghai and provides a detailed description of the technical methods and results using the case study. It is well written, and the results are clearly presented. However, my primary concern is about its theoretical or methodological contributions to the field of flood risk assessment, which are not sufficiently articulated or developed. Assessing very extreme flood scenarios (e.g., return period = 5,000 years) is not innovative enough by itself.

Response: First of all, thank you so much for pointing out that the theoretical or methodological aspects of the flood risk assessment are not sufficient. To introduce the methodology more clearly, we re-constructed and rewrote the paper. For example, we deleted the section “data and methods” and added the new sections “Study area” and “Materials and methods”. We have also rewritten other parts of the manuscript. For the new section “Materials and methods”, we included one graphic at the beginning of the section to clarify our methodological procedure:

In our study, the flood damages in Shanghai are estimated using three different steps (Figure 2): first, extreme flood scenarios with a return period of 1/200, 1/500, 1/1000, and 1/5000-years are simulated by a hydrodynamic model. This was done in a previous work by Wang et al., (2019). Our study builds upon these results and estimates the damages based on the obtained flood hazard maps. Finally, the overall flood risk and its spatial pattern for buildings in Shanghai, described as the estimated average annual loss

(AAL), is calculated using a polynomial regression analysis. More details of the assessment are introduced in the following sections 3.1 to 3.3.

Figure 2. Risk analysis chain

Second, we provide a better explanation on what a two-dimensional MIKE is in the new section 3.1 “Flood hazard modeling”:

The study builds on the results of Wang et al. (2019), which applied a hydrodynamic modelling approach to simulate compound flooding for the region of Shanghai. Four scenarios with return periods of 200, 500, 1000, and 5000 years were simulated considering storm surge, extreme precipitation, high tide, and river flooding at a resolution of 60 m. For this purpose, several models were applied and coupled: 1) the Fujita model simulating the atmospheric conditions; 2) the TELEMAC model simulating ocean movement; 3) the TOMAWAC model simulating the propagation of waves; and 4) the MIKE 21 model simulating the hydraulic processes.
These models were calibrated using rainfall and river discharge measurement data from Typhoon Winnie. Typhoon Winnie brought the highest recorder water level of 5.72 meters since 1900, which caused the collapse of 148 meters of floodwalls and overflowed 57 km of floodwalls and 69 km of sea dikes.

In order for readers to grasp our equation, we provide two tables as samples to present the calculation process: 1) 'building asset value'; 2) 'the damage values':

Then, the asset value of one building can be approximated by the following function:

$W_n = S_n \times P_n$ (1)

Where W_n *(USD) is the asset value for one building which belongs to the building type n,* S_n *is the surface area of building n,* P_n *is the average construction cost (USD/m^2) for the specific type of building n. The surface area is the whole construction area (including wall area and floor area).*
Table 2. Building asset value for the four selected building types.

Building id	Building type n	Surface area (m^2)	Average construction cost (USD/m^2)	Asset Value (USD)
1	Residential building	1662	874	1452588
2	Commercial building	1347	1407	1895229
3	Office building	776	1157	897832
4	Industrial building	2463	486	1197018

The damage values of buildings were estimated:

The damage values of one building can be expressed by the following function:
$D_n=E_n \times P_n \times T_n$ (2)
Where D_n *represents building damage for building type n,* E_n *represents the exposed area of buildings for building type n,* P_n *is the construction cost (USD/m^2) for the specific type of building n,* T_n *represents the damage proportion from stage-damage function for*

building n under different water-level depths.

Table 4. Exemplary damage values for the four building types at an inundation level of 0.5-1 m.

Building id	*Building type n*	*Exposed area (m^2)*	*Average construction cost (USD/m^2)*	*Damage proportion*	*Building damage (USD)*
1	*Residential building*	*123*	*874*	*0.06*	*6450*
2	*Commercial building*	*342*	*1407*	*0.09*	*43180*
3	*Office building*	*539*	*1157*	*0.07*	*43653*
4	*Industrial building*	*29*	*486*	*0.08*	*1127*

On the other hand, we have removed the section "Exposed building values" to simplify the manuscript and direct the readers' attention to the building damage, risk, and its pattern in Shanghai.

Please see below, for a point-by-point response to the reviewers' comments and concerns.

Other general comments

1. Why is it needed to assess extreme flood scenarios with return periods of 5,000 years?

Thank you for this point. We understand that Shanghai has not experienced an extreme flood with return periods of 5,000 years so far. However, it is necessary to have an assessment on such a low probability-high impact scenario that is increasingly possible to happen in the future:

- Shanghai may suffer from extreme compound flood threats in the next few decades considering risks from typhoons, sea level rise, heavy precipitation, and riverine flows due to its physical environment and location.
- Shanghai currently relies extensively on hard measures of flood protection. But the seawalls and levees can be easily destroyed because of the multiunit constructions and standards used during the long construction process.
- The seawalls and levees can't protect Shanghai from extreme flood events especially considering the fast population growth and social economic development that aggregate flood risk. We have enhanced the description of this point in "Section 1 Introduction".

2. Please can you provide more information about what each extreme flood scenario is like in Shanghai (e.g., their discharge or precipitation)?

We have rewritten and enhanced the description of the discharge/inundation of the extreme flood scenario from the previous study in paragraph 3 in "Section 1 Introduction". In section 4.1, we present and compare the flood scenarios of the result of our flood hazard modelling.

Reviewing the current literature shows that various flood scenarios have been widely developed and validated for measuring flood risks in Shanghai. For example, according to the trend of relative sea level rise and the harmonic analysis of storm surges along the Shanghai coast, Yin et al. (2011) forecasts flood scenarios in 2030 and 2050, and the result shows that a possible maximum tide level of 9.82 m by 2030 and 10.04 m by 2050. All river embankment crests in Shanghai would be exceeded and destroyed by flood intrusion, according to the results. The MIKE 21 Flow Model is a modelling system for 2D free-surface flows. It has been applied for simulating future combined effects (sea level *rise, land subsidence, and storm surges) of flood scenarios in 2030, 2050, and 2100 which inundate 1.5 %, 37%, and 50% of Shanghai, respectively (Wang et al., 2012). Fluvial floods from the Huangpu River were also simulated, considering land subsidence, sea level rise, and storm tide, in considering the return periods of 20, 50, 100, 200, 500, and 1000 years in Shanghai, respectively (Yin et al., 2013). The findings show the inundation area reaches 0 km^2,111.30 km^2, 124.73 km^2, 143.74km^2, 177.96 km^2, and 195.77 km^2 in Shanghai under the present physical environment. Incorporated with three anthropogenic variables (land subsidence, urbanization, and flood defence), Yin et al. (2015) used a numerical 2D modelling approach for the return periods of 10, 100, and 1000 years. In general, the flood scenarios produced in most existing studies tended to focus on the possible future flood scenario changes rather than extreme events, e.g., the concern floods over a 1000-year return period.*

3. What is the implication of this study to other cities or future research?

The methodology of this research paper can be commonly used for flood risk assessment in other areas. Especially, this study developed a method to assess the damage values of different buildings in Shanghai in four extreme flood scenarios. This method is useful for other coastal cities that have high population and are in fast urbanization, e.g., in Southeast Asia, in Africa coasts, in East coast of North America. In addition, the estimation of different building damages could inform future flood damage studies to consider various assets with more precise evaluations.

4. Have you considered validating your simulated results or comparing them with other Shanghai flood risk assessments?

Thank you for pointing this out. Other Shanghai flood risk assessments have different methodologies and assessment objectives. We have validated our results in section 5.3. Wu et al. (2019) and Shan et al. (2019) have building and residential building flood risk assessments for Shanghai, respectively.

Specific comments

1. Line 39. Why do you think Shanghai 'should increasingly install flood protection, with a focus on hard measures'? Please can you justify or provide evidence?

Thank you for this point. As the third paragraph of Section 1 describes, the seawalls and levees can easily be destroyed because of the multiunit structures' standards used during the long temporal construction process and the historical crest height in the Huangpu River growing from 1950 to 2000. This is the reason we focus on low probability-high impact flood scenarios. We have revised this sentence to make the statement clearer.

2. Line 53. Please explain what a two-dimensional MIKE 21 flow model is and its features as part of the introduction.

Thank you for pointing this out. As responded above, we have presented MIKE 21 flow model with more details in the introduction, and also under the first paragraph of section 3 "Materials and methods". The added description of the MIKE 21 flow model include:

MIKE 21 Flow Model is a modelling system for 2D free-surface flows. It is applicable to the simulation of hydraulic and environmental phenomena in lakes, estuaries, bays, coastal areas, and seas. It can be applied wherever stratification can be neglected. The hydrodynamic (HD) module, the basic module in the MIKE 21, simulates water level variations and flows in response to a variety of forcing functions in lakes, estuaries, and coastal region (MIKE, 2017).

Further information about the **MIKE 21** is available in the reference: MIKE: MIKE 21 flow model-hydrodynamic module user guide, 2017

3. Line 68. I agree with the authors that "Accurate loss data play an integral role in assessing the damages of buildings. But obtaining accurate data is a challenge shared in many areas (Middelmann-Fernandes, 2010), especially in assessing the damage of buildings." However, the challenge of obtaining accurate loss data is not the focus of this manuscript or hasn't been solved by this study. Therefore, I don't think they are directly relevant as part of the introduction. Consider moving it to the methodology section.

We agree with this comment, obtaining accurate data is not coherent in this manuscript. As the answer to the first question of the general comment, to demonstrate the methodology of our study, we have re-constructed the manuscript and have provided a detailed description.

4. Line 95. What does 'construction industry value' mean?

Thank you for pointing this out. The conception of 'construction industry value' is from the Shanghai statistical yearbook. It means the value of all the constructions in Shanghai. This contains various buildings, including residential buildings, office buildings, commercial buildings, and others.

5. Line 102. Three types of models were developed for the assessment, including atmospheric models, ocean models, and coastal models. Consider placing them in the methodology section instead of the data section. Again, more information about these models is expected.

Thank you for the suggestion. We have revised this section and provided more information of the models in section 3.1.

The study builds on the results of Wang et al. (2019), which applied a hydrodynamic modelling approach to simulate compound flooding for the region of Shanghai. Four scenarios with return periods of 200, 500, 1000, and 5000 years were simulated considering storm surge, extreme precipitation, high tide, and river flooding at a resolution of 60 m. For this purpose, several models were applied and coupled: 1) the Fujita model simulating the atmospheric conditions; 2) the TELEMAC model simulating ocean movement; 3) the TOMAWAC model simulating the propagation of waves; and 4) the MIKE 21 model simulating the hydraulic processes.
These models were calibrated using rainfall and river discharge measurement data from Typhoon Winnie. Typhoon Winnie brought the highest recorder water level of 5.72 meters since 1900, which caused the collapse of 148 meters of floodwalls and overflowed 57 km of floodwalls and 69 km of sea dikes.

6. Line 126, Table 1. How were the Average Construction Costs calculated? Were different building types weighted? Why is the Average Construction Cost (1157) smaller than the lower bound of the range (1228) for commercial buildings?

Thank you for bringing this to our attention. The comment is correct. Since the inaccurate number of the average construction cost was used, the asset value of buildings, damage estimation, and risk evaluation have all been recalculated. The Average Construction Cost for commercial buildings is updated to 1407 USD/m^2. The revised text reads as follows on:

Table 1. Common construction costs of various buildings in Shanghai.

	Building Type	*Construction Cost*	*Average Construction*

		(USD/m^2 CFA)	*Cost (USD/m^2)*
Residential	*Apartments, high rise, average standard*	*668-740*	*874*
	Apartments, high rise, high end	*1554-1697*	
	Terraced houses, average standard	*446-477*	
	Detached houses, high end	*666-740*	
Commercial	*Retail malls, high end*	*1228-1585*	*1407*
Office	*Medium/high rise offices, average standard*	*868-1156*	*1157*
	High rise offices, prestige quality	*1158-1445*	
Industrial	*Industrial units, shell only (Conventional single story framed units)*	*432-540*	*486*

7. Line 154. The 'W' in 'Where' should be in lowercase.

Thank you for pointing this out. However, the 'W' is not the ‘W’ in ‘Where’. The ‘W’ is a representative variable.

8. Line 154. What does 'surface area of building' mean? Does it include the wall as well? Line 164, Equation 2. f(x) means a function at an element x. However, an x is missing on the right to the equal sign. Please modify the equation and explain what x means. Line 175, Equation 3. More information is needed to explain Equation 3.

Thank you so much for taking the time to write such a thorough comment. As we answered question 2 of the general comments, we have rewritten the functions and have given examples in section 3.2. The revised equation and text read as follows:

Equation 1:

$W_n=S_n \times P_n \quad (1)$
Where W_n (USD) is the asset value for one building which belongs to the building type n, S_n is the surface area of building n, P_n is the average construction cost (USD/m2) for the specific type of building n. The surface area is the whole construction area (including wall area and floor area).

Equation 2:
$D_n=E_n \times P_n \times T_n \quad (2)$
Where D_n represents building damage for building type n, E_n represents the exposed area of buildings for building type n, P_n is the construction cost (USD/m^2) for the specific type of building n, T_n represents the damage proportion from stage-damage function for building n under different water-level depths.

Equation 3:
$AAL=\int xf(x)dx$ *(3)*
Where x is the return period of the flood scenario, f(x) is the damages value of a single type of building.

9. Line 178. Explain Getis-Ord.

Thank you for addressing this point. We combine the Getis-Ord Gi* to the new section "materials and method". The revised text reads as follows on:

The AAL of all sub-districts and their neighbours were compared with the AAL by Getis-Ord Gi in ArcMap 10.6. The Getis-Ord Gi*, also known as the hot spot analysis, measures the strength of spatial autocorrelation and tests the assumption of independence between surrounded features (Manepalli et al., 2011). According to the Getis-Ord Gi*, a feature with a positive value and intense clustering of high values, the feature corresponds to hot spot clusters; a feature with a negative value and intense clustering of low values, the feature corresponds to cold spot clusters. The results contain a significant range of high values (hot spots) and low values (cold spots). In our study, hot spots mean the flood risk of a sub-district has a high AAL value and is surrounded by other sub-districts with high values, and has a higher risk for extreme flooding. Cold spots indicate an opposite situation.*

Further information about the **Getis-Ord** is available in the reference: Manepalli, U. R., Bham, G. H., and Kandada, S.: Evaluation of hotspots identification using kernel density estimation (K) and Getis-Ord (Gi*) on I-630, in: 3rd International Conference on Road Safety and Simulation, Indianapolis Indiana, United States, 14 Sep 2011, 14-16, 2011.

10. Line 199. Is the building asset value for the first floor of all four building types?

The building asset value is calculated not only for the first floor, but for all floors. The asset value of the entire building is taken into account in this study.

11. Line 207, Figure 4 (also Line 231, Figure 5 and Line 251 Figure 6). Since the Average Construction Cost is used for each of the four building types, is it true in Figures 4-6 that the buildings with higher 'Building Asset Values' are buildings taking a larger land area?

The answer is yes if we compare 'Building Asset Values' in the same type of building. The reason for this is that the construction costs for the same type of building are the same, and the variable is only the surface area of one building. On the other hand, when we compare the 'Building Asset Values' in different types of buildings, the answer is no. Because there are two variables, one is the cost of construction, and the other is the building's surface area.

12. Line 329, Table 5. Table 5 provides a comparison of flood adaptation measures in Shanghai. However, how can these measures, especially the soft ones, be reflected in the simulations? The simulation results and the soft adaptation measures are disconnected, and more discussion is needed here.

Thank you for pointing this out. Table 5 provides a comparison of flood adaptation measures in Shanghai, but it is not calculated in the simulations. We aim to indicate some possible and feasible measures that can be adopted in the future to prevent the simulated damages in Shanghai. We agree it is certainly valuable to connect the measures within the simulation, but that is beyond of the scope of this study. Nevertheless, we have discussed this point in the section 5.3 as a direction for further studies.

We hope that with the changes made and the answers provided will sufficiently address your concerns. Thank you for your detailed review helping us to improve our manuscript.

Kind regards,

All Co-authors