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➢ Referee #1

<u>Overall comments</u>

The authors present a study titled "Integrating flood-induced population movements into future flood damage estimates in Japan." The manuscript introduces a novel framework for quantifying and predicting population relocation in response to flood events, incorporating climate change effects, to evaluate future population distribution and flood risk in Japan. Overall, I find the study to be well-constructed and the manuscript clearly written. The integration of statistical causal inference with long-term land-use and population projections offers a valuable contribution to socio-hydrological modeling. However, I have identified several critical areas regarding spatial resolution, flood typology, and the modeling of relocation "pull" factors that warrant further attention. I am recommending major revisions to address these methodological limitations and scope concerns. Pending these revisions, I believe the manuscript would be a strong candidate for publication in Natural Hazards and Earth System Sciences (NHESS).

Response:

We sincerely thank the reviewer for their careful reading of our manuscript and constructive evaluation of our study. We are grateful for the positive comments on the novelty of the framework and its contribution to socio-hydrological modeling. In response to the reviewer's comments, we revised the manuscript to clarify the scope of the flood types considered, added a discussion of spatial-resolution limitations, expanded the limitations regarding relocation destinations and pull factors, and clarified the treatment of flood-induced population movements in the proposed framework. We also revised the terminology throughout the manuscript to specify more clearly that the future damage assessment focuses on fluvial flood damage. Detailed responses to each specific comment are provided below.

Comment 1

Methodological Detail (Line 295): The authors cite Yanagihara et al. (2024) for the fluvial flood damage model. However, the current manuscript lacks sufficient detail regarding this model's internal mechanics. Please include a concise summary of the model's core equations or assumptions to ensure the reader can follow the assessment without referring exclusively to prior work.

Response:

We thank the reviewer for this helpful comment. We agree that the original manuscript did not provide sufficient detail on the fluvial flood damage model used to estimate future damage costs. We added a concise summary of the model structure and key assumptions so that readers can understand the assessment without relying exclusively on Yanagihara et al. (2024). The added text describes the inundation model, the condition under which inundation occurs, how rainfall–runoff processes are represented, the limitation that pluvial flooding processes and inland water drainage facilities are not explicitly simulated, and the procedure used to estimate damage costs.

Original text	Revised text
Future damage costs were estimated using an existing fluvial flood damage model (Yanagihara et al., 2024) that considered rainfall changes associated with climate change and land use changes associated with population changes across Japan for the baseline period, the near future, and the end of the 21st century. The costs were evaluated as expected annual values derived from damage calculations for return periods of 30, 50, 100, and 200 years. Maximum inundation depths were calculated using a fluvial flood inundation analysis on a 250 m grid, and corresponding damage costs were estimated based on these depths using depth-specific damage rates. The effects of rainfall changes were incorporated by adjusting the input rainfall used in the fluvial flood inundation analysis. (p. 12, lines 296–302 in the original manuscript)	○ **p. 14, lines 310–320 in the revised manuscript** Future fluvial flood damage costs were estimated using an existing fluvial flood damage model (Yanagihara et al., 2024) that considered rainfall changes associated with climate change and land use changes associated with population changes across Japan for the baseline period, the near future, and the end of the 21st century. In this model, flood inundation is simulated using a two-dimensional unsteady flow model uniformly applied to rivers and floodplains across Japan. Inundation occurs when simulated floods exceed the flood control safety level assigned to each river section. Although rainfall is applied over each river basin and converted into runoff in the model, the model does not explicitly simulate pluvial flooding processes or inland water drainage facilities. The costs were evaluated as expected annual values derived from damage calculations for return periods of 30, 50, 100, and 200 years. Maximum inundation depths were

	calculated using a fluvial flood inundation analysis on a 250 m grid. Damage costs were then estimated by overlaying inundation depths with land-use and asset-value data and applying depth-specific damage rates for each asset category. The effects of rainfall changes were incorporated by adjusting the input rainfall used in the fluvial flood inundation analysis.

Comment 2

Flood Typology and Title: The study focuses exclusively on fluvial flooding. Given the significance of pluvial and coastal flooding in Japan, the title should be more specific. In the title, I suggest changing "future flood damage" to "future fluvial flood damage" with corresponding adjustments in the Abstract and throughout the text to avoid over-generalization.

Response:

We thank the reviewer for this important suggestion. We agree that the original title and terminology could have implied a broader scope than intended. We therefore revised the title by changing "future flood damage" to "future fluvial flood damage." We also revised the terminology throughout the Abstract and main text to specify "fluvial flood damage costs" where the future damage assessment is discussed. At the same time, we did not replace all instances of "flood" with "fluvial flood," because the observed flood-related data used to estimate FIPMs do not fully separate fluvial and pluvial components. We therefore used "fluvial" when referring to the future damage assessment, while retaining "flood" or "flooding" when referring to observed flood events, flood exposure, and flood-related damage records.

Original title	**Revised title**
Integrating flood-induced population movements into future flood damage estimates in Japan	Integrating flood-induced population movements into future fluvial flood damage estimates in Japan

Comment 3

Spatial Resolution: The use of a 250 m flood grid is relatively coarse for a national-scale study seeking municipal-level precision. This resolution likely misses localized flood risks and micro-topographical features that influence individual relocation decisions. This should be addressed as a limitation in Section 6.3.

Response:

We thank the reviewer for this helpful comment. We agree that the 250 m spatial resolution of the fluvial flood inundation analysis may not fully capture localized flood hazards and micro-topographic features that can influence FIPMs. We have therefore added this point to the limitations.

Added text

- **p. 21, lines 473–478 in the revised manuscript**

Second, the 250 m spatial resolution of the fluvial flood inundation analysis may limit the representation of localized flood hazards and micro-topographic features. Although this resolution is appropriate for maintaining consistency in a nationwide assessment, it may miss small-scale variations in inundation depth and flow velocity that can influence FIPMs. Therefore, this uncertainty should be considered when interpreting fine-scale spatial variations in FIPMs. Future studies should use higher-resolution inundation data, where available, to better assess fine-scale relationships between flood exposure and population movements.

Comment 4

Multimodal Flooding Impacts: The observational dataset used to quantify FIPMs includes residents affected by various water-related disasters (pluvial, coastal, etc.), yet the predictive model only simulates fluvial events. The authors should discuss the net effect of this discrepancy near Line 375 and in the limitations. Specifically, how does the exclusion of pluvial and coastal flood projections affect the estimated impact of FIPMs the results of the study?

Response:

We thank the reviewer for raising this important point. We agree that the relationship between the observational flood-related data used to quantify FIPMs and the predictive fluvial flood damage model required clearer explanation. We revised the Methods to clarify that the observed flood data used in the DiD analyses do not fully separate fluvial and pluvial components. For the grid-cell-level analysis, the flood inundation maps provide estimates of inundated areas and inundation depths during the target heavy rainfall events but do not distinguish between fluvial and pluvial flooding. For the municipality-level analysis, the household damage indicators were calculated to represent household damage associated with both fluvial and pluvial flooding. We also expanded the limitations to discuss how this treatment of flood types may affect the results. The future damage assessment focuses primarily on fluvial flood damage, and coastal flooding is outside the scope of the predictive damage assessment. As described by Yanagihara et al. (2024), the fluvial flood inundation model used for future projections partly includes the effect of pluvial flooding through basin-scale rainfall–runoff processes, but it does not explicitly account for inland water drainage facilities. Therefore, the estimated impacts of FIPMs may be uncertain in areas where drainage-related pluvial flooding or coastal flooding strongly influences population movements. We clarified that the results should be interpreted as an assessment of the impact of FIPMs on future fluvial flood damage, rather than as a comprehensive assessment of all flood types. We note that the text around Line 375 in the original manuscript referred to the IDMC dataset, which was used only for validation and not for the DiD analyses. Therefore, here we focused on clarifying the relationship between the flood-related data used in the DiD analyses and the predictive fluvial flood damage model; the interpretation of the IDMC dataset is addressed separately in our response to Comment 6.

Original text	Revised text
For grid cells in the treatment group, the maximum inundation depth was calculated based on values provided in the flood inundation maps. Details regarding the total population data at the 500 m grid-cell level, data on areas affected by water-related disasters, and flood inundation maps are provided in Sect. S2.	○ **p. 5, lines 123–128 in the revised manuscript** For grid cells in the treatment group, the maximum inundation depth was calculated based on values provided in the flood inundation maps. The flood inundation maps provide estimates of inundated areas and inundation depths during the

(p. 4, lines 92–95 in the original manuscript)	target heavy rainfall events and do not distinguish between fluvial and pluvial flooding. Therefore, the grid-cell-level analysis uses the estimated inundation without separating fluvial and pluvial components. Details regarding the total population data at the 500 m grid-cell level, data on areas affected by water-related disasters, and flood inundation maps are provided in Sect. S2.
To represent flood magnitude, we used the following municipality-level indicators: the proportion of households affected below floor level by flooding, the proportion of households affected above floor level by flooding, and the proportion of households that were completely destroyed (including washed away) by flooding. These indicators were expressed as percentages of the total households, following the method of Okamoto et al. (2023). (pp. 5–6, lines 134–138 in the original manuscript)	○ **p. 7, lines 165–170 in the revised manuscript** To represent flood magnitude, we used the following municipality-level indicators: the proportion of households affected below floor level by flooding, the proportion of households affected above floor level by flooding, and the proportion of households that were completely destroyed (including washed away) by flooding. These indicators were calculated to represent household damage associated with both fluvial and pluvial flooding. They were expressed as percentages of the total households, following the method of Okamoto et al. (2023).

Added text

○ **p. 21, lines 478–488 in the revised manuscript**

Third, the treatment of flood types requires careful interpretation. This study focuses primarily on future fluvial flood damage. As described by Yanagihara et al. (2024), the fluvial flood inundation model used for future projections partly includes the effect of pluvial flooding through basin-scale rainfall–runoff processes, but it does not explicitly account for inland water drainage facilities. To maintain consistency with this modeling framework, the flood data used in the DiD analyses were treated without separating fluvial and pluvial components. Thus, neither the observational data nor the predictive model fully separates fluvial and pluvial components, although their treatment of flood types is not identical. Coastal flooding is outside the scope of the predictive damage assessment. This limitation may introduce uncertainty in areas where drainage-related pluvial flooding or coastal flooding strongly influences population movements. Therefore, the results should be interpreted as an assessment of the impact of FIPMs on future fluvial flood damage, rather than as a comprehensive assessment of all flood types.

Comment 5

"Pull" Factors and Relocation Dynamics: The current framework assumes that populations relocate proportionally to existing density. In reality, migration is driven by specific "pull" factors such as employment hubs and family networks—as seen in historical precedents like Hurricane Katrina in the USA, where displacement from New Orleans was highly concentrated in specific regions (e.g., Houston) rather than dispersed uniformly. This simplification should be explicitly noted as a limitation in Section 6.3.

Response:

We thank the reviewer for this important comment and for providing a concrete example. The original manuscript noted that the framework does not explicitly consider the specific destinations of population movements and instead uniformly scales population distributions. However, we agree that the implications of this simplification and the role of destination-specific pull factors were not sufficiently explicit. We therefore revised the limitation to provide examples of pull factors and clarify that the current framework cannot represent cases in which post-flood population movements are concentrated in specific destination areas.

Original text	Revised text
Third, while integrating FIPMs into future population projections, the current framework does not explicitly consider the specific destinations of population movements. Instead, population distributions were uniformly scaled by applying adjustment factors across areas to ensure consistency with overall national or municipal totals. Recent studies have developed population migration models capable of explicitly incorporating pull factors influencing migration (Niu, 2022). Future research should utilize these models to explicitly consider the destinations of population movements, thereby enhancing the methodological framework. (p. 18, lines 436–441 in the original manuscript)	○ **pp. 21–22, lines 492–500 in the revised manuscript** Fifth, while integrating FIPMs into future population projections, the current framework does not explicitly consider the specific destinations of population movements. Instead, population distributions were uniformly scaled by applying adjustment factors across areas to ensure consistency with overall national or municipal totals. This approach does not represent destination-specific pull factors, such as employment opportunities and family or social networks. Therefore, the framework cannot capture cases in which post-flood population movements are concentrated in specific destination areas. Recent studies have developed population migration models capable of explicitly incorporating pull factors influencing migration (Niu, 2022). Future research should utilize these models to explicitly

	consider the destinations of population movements, thereby enhancing the methodological framework.

Comment 6

Temporal Resolution and Validation Discrepancy: Since the model relies on 5-year census data, it inherently captures long-term permanent displacement while overlooking short-term movements. This temporal mismatch may explain the significant discrepancy between the model's 2020 estimate (~16,000 movements) and the IDMC data (~212,000 movements). This distinction between "forced displacement" and "permanent migration" needs a more thorough treatment in the Discussion.

Response:

We thank the reviewer for this important comment. We agree that the distinction between event-based forced displacement and longer-term population or migration changes should be explained more explicitly, because this temporal difference partly explains the discrepancy between our estimate and the internal displacement number from the IDMC dataset. We also note that this study uses two types of demographic data: five-year census data for the grid-cell-level analysis and annual resident registration data for the municipality-level analysis. We have clarified this point in the methodological framework section. We have revised the Discussion to clarify that the IDMC dataset captures event-based forced displacement, including both short-term and longer-term movements, whereas our estimates mainly capture longer-term changes in population distribution and registered migration that remain visible in demographic datasets. We also clarified that our estimates should not be interpreted as the total number of people displaced by flood events, nor as strictly permanent migration.

Original text	Revised text
FIPMs were quantified at both the grid-cell and municipality levels utilizing available demographic data to capture population movements occurring within and between municipalities in response to varying flood magnitudes. Detailed methodologies for quantifying FIPMs are presented in Sect. 3, while methodologies for the subsequent processes of the framework are described in Sect. 4. (p. 4, lines 77–80 in the original manuscript)	○ **pp. 4–5, lines 101–112 in the revised manuscript** FIPMs were quantified at both the grid-cell and municipality levels using available demographic data to capture population movements occurring within and between municipalities in response to varying flood magnitudes. Specifically, FIPMs were quantified using two types of observed datasets that combine flood-related and demographic information. Within-municipality population changes were estimated using flood inundation maps for areas affected by Typhoon Hagibis (2019) and the heavy rainfall event of July 2020, together with 500 m grid-cell population data. Inter-municipality population movements were estimated using municipality-level flood damage records and annual migration

	data. These data were used to estimate empirical relationships between flood magnitude and FIPMs, rather than to directly extrapolate the observed events themselves. The areas covered by the flood inundation maps used in the 500 m grid-cell-level analysis and the treated municipalities used in the municipality-level DiD analysis are shown in Figs. S1 and S2, respectively. Detailed methodologies for quantifying FIPMs are presented in Sects. 2.2 and 2.3, while methodologies for the subsequent processes of the framework are described in Sects. 2.4–2.6.
This discrepancy is largely attributable to the fact that the IDMC dataset includes displacements caused by various types of flooding, capturing all forced movements regardless of duration. In contrast, our estimates are based on total population data at five-year intervals, excluding individuals who returned after displacement events within these intervals. Similarly, our municipality-level estimates rely on annual net migration rates derived from resident registration data, thus excluding short-term evacuees who returned without registering a new address. (pp. 16–17, lines 385–389 in the original manuscript)	○ **p. 19, lines 412–424 in the revised manuscript** This discrepancy is largely attributable to differences in what our estimate and the IDMC internal displacement number represent. First, in terms of flood types, the IDMC dataset may include displacement caused by various flood-related hazards, including coastal flooding. However, displacement corresponding specifically to the flood types represented in our estimates could not be extracted from the IDMC dataset, as noted above. Second, the IDMC dataset captures event-based forced displacement, including both short-term and longer-term movements, irrespective of whether displaced people later returned. In contrast, our estimates are based on total population data at five-year intervals and annual resident registration data, and therefore primarily capture longer-term changes in population distribution and registered migration. Individuals who were temporarily displaced but returned within the census interval, or who did not register a new address, are not captured in our estimates. Thus, our estimates should not be interpreted as the

	total number of people displaced by flood events, nor as strictly permanent migration, because the available data do not directly identify whether movements are permanent. Rather, they should be interpreted as longer-term population changes that remain visible in demographic datasets and can affect future population distribution, land use, and fluvial flood damage estimates.

Comment 7

Code and Data Availability: The current statements stating "available upon request" do not appear to meet the journal's submission guidelines (https://www.natural-hazards-and-earth-system-sciences.net/submission.html). The authors must deposit the underlying research data and code in a public repository or provide a formal explanation as to why it cannot be made publicly accessible.

Response:

We thank the reviewer for this important comment. We agree that the original "available upon request" statement was insufficient under the journal's code and data policy. We understand that research data supporting the findings should be deposited in a reliable FAIR-aligned repository and that software, algorithms, and model code are encouraged to be deposited whenever possible. In response, we have prepared a Zenodo repository containing the code and data supporting this study and revised the "Code and data availability" section accordingly. The Zenodo repository will be published upon acceptance of the manuscript. During the review process, the repository can be previewed using the Zenodo preview URL provided in the Assets section. The Zenodo repository provides code, redistributable input data, and results for the 500 m grid-cell-level and municipality-level DiD analyses; population and household projection outputs; flood magnitude indicators; estimates of population changes due to FIPMs; land-use projection code and projected land-use data; estimated fluvial flood damage costs; and aggregated data used to create the figures. The repository is cited in the revised manuscript using its DOI. We also added a formal explanation for model implementations that cannot be redistributed. The full implementation of the fluvial flood damage model is not redistributed because it is a pre-existing research model developed and used in previous studies, rather than a model newly developed for the present study. Instead, the repository provides the estimated fluvial flood damage costs generated and used in the present study. The full implementation of the population projection model is also not redistributed because it depends on code developed by NIES, which was used by the authors under an agreement, and public redistribution of that code has not been separately authorized. Therefore, the repository provides the projection outputs and related derived data used in this study rather than the full implementation. Requests regarding access to the non-redistributed model implementations may be directed to the corresponding author and will be considered subject to the necessary approvals.

Original text	Revised text
Code availability The code used in this study is available from the corresponding author upon reasonable request. **Data availability** The sources of the statistical datasets used in this	○ **p. 23, lines 531–543 in the revised manuscript** **Code and data availability** Code and data supporting this study are available from Zenodo (Yanagihara et al., 2026). The repository contains code, redistributable input

study are provided in the Supplement. Other data supporting the findings of this study are available from the corresponding author upon reasonable request. (p. 19, lines 462–466 in the original manuscript)	data, and results for the 500 m grid-cell-level and municipality-level DiD analyses; population and household projection outputs; flood magnitude indicators; estimates of population changes due to FIPMs; land-use projection code and projected land-use data; estimated fluvial flood damage costs; and aggregated data used to create the figures. The full implementation of the fluvial flood damage model is not redistributed in this repository. This model is a pre-existing research model developed and used in previous studies, rather than a model newly developed for the present study. Instead, the repository provides the estimated fluvial flood damage costs generated and used in the present study. The full implementation of the population projection model is also not redistributed in this repository. The model depends on code developed by NIES, which was used by the authors under an agreement. Public redistribution of that code has not been separately authorized; therefore, the repository provides the projection outputs and related derived data used in this study rather than the full implementation. Requests regarding access to the non-redistributed model implementations may be directed to the corresponding author and will be considered subject to the necessary approvals.

Added reference

Yanagihara, H., Kazama, S., Gomi, K., Hiraga, Y., and Ikemoto, A.: Code and data supporting "Integrating flood-induced population movements into future fluvial flood damage estimates in Japan", Zenodo [data set], https://doi.org/10.5281/zenodo.20823575, 2026.

➢ Referee #2

<u>Overall comments</u>

Thank you for the opportunity to review this manuscript. The study aims to estimate the impact of two flood events on population movements in Japan, with the goal of assessing the effectiveness of flood mitigation strategies. Overall, the manuscript is well written and addresses an interesting and relevant research question. The empirical approach is generally sound, but I do have some concerns and suggestions for improvement. Below I provide several comments that could improve the paper. These points are presented in no particular order.

Response:

We sincerely thank the reviewer for carefully reviewing our manuscript and for the constructive comments. We are grateful for the positive evaluation of the writing, research question, and empirical approach. In response to the reviewer's comments, we revised the manuscript to clarify the data used to estimate the empirical relationships between flood magnitude and FIPMs, expand the explanation of the DiD method and its assumptions, improve the notation and definitions of variables in the equations, add supplementary figures showing the spatial coverage of the flood data used in the analyses, and clarify the temporal interpretation of the estimated FIPMs. Detailed responses to each specific comment are provided below.

Comment 1

My main concern relates to the timing of the analysis. The flood events occurred in 2019 and 2020, while population data are observed from 2005 to 2020 in five-year intervals. As a result, the study can only capture very short-term population movements in response to the floods. Since migration and population adjustments often occur gradually, it would be more informative to examine longer-term effects, for example by including population data for the period after 2020 (e.g., 2020–2025) if such data become available. As it stands, the analysis likely captures only immediate or short-run effects. This limitation also raises some concerns about the usefulness of conducting projections over several decades based on these short-term responses.

Response:

We thank the reviewer for this important comment. We agree that the temporal coverage of the available demographic data limits the interpretation of population adjustments after flood events. We therefore added this point to the limitations. In the added text, we clarify that the FIPMs quantified in this study should be interpreted as population changes and registered migration associated with flood exposure that are observable in the available demographic data, rather than as a complete representation of short-term evacuations or longer-term migration processes. We also clarify that the long-term projections in this study should not be interpreted as predictions of event-specific migration trajectories, but rather as scenario-based assessments of how empirical relationships between flood magnitude and FIPMs could affect future population distributions, land use, and fluvial flood damage estimates. Finally, we note that explicitly modeling these longer-term adjustment processes is outside the scope of the present framework and should be addressed in future research when post-2020 census and migration data become available.

Added text

- **p. 22, lines 500–509 in the revised manuscript**

Sixth, the temporal coverage of the demographic data limits the interpretation of population adjustments after flood events. The FIPMs quantified in this study should be interpreted as population changes and registered migration associated with flood exposure that are observable in the available demographic data. These datasets do not capture short-term evacuations or movements that occurred without changes in registered residence. Moreover, longer-term migration and population adjustment after flood events may be shaped by recovery processes, land markets, public investment, housing reconstruction, and changes in regional economies. Therefore, the long-term projections in this study should not be interpreted as predictions of event-specific migration trajectories, but rather as scenario-based assessments of how empirical relationships between flood magnitude and FIPMs could affect future population distributions, land use, and fluvial flood damage estimates. Explicitly modeling these longer-term adjustment processes is outside the scope of the present framework and should be addressed in future research when post-2020 census and

migration data become available.

Comment 2

The Introduction is well written and clearly outlines the research problem. However, the empirical strategy, namely the use of a difference-in-differences (DiD) approach, is not sufficiently introduced or motivated. It would be helpful if the authors explained why they chose a DiD framework and whether alternative empirical approaches could have been used. Placing the chosen method more explicitly within the existing literature would improve the paper.

Response:

We thank the reviewer for this helpful comment. We agree that the motivation for using the DiD approach was not sufficiently explained in the original Introduction. We therefore added a paragraph before stating the aim of this study to place our empirical strategy more clearly within the existing literature. In this paragraph, we discuss previous empirical approaches, including propensity score matching with regression-based statistical modeling and panel gravity models, and clarify that DiD is well suited for this study because incorporating FIPMs into future population projections requires estimating population responses relative to a counterfactual scenario in which flooding did not occur.

Added text

- **p. 3, lines 75–85 in the revised manuscript**

Previous studies have used empirical approaches to analyze relationships between flood exposure or natural-hazard-related damage and population dynamics. For example, Shu et al. (2023) used propensity score matching followed by regression-based statistical modeling to estimate the relationship between flood exposure and population change, while Ton et al. (2025) applied panel gravity models to county-to-county migration flows to analyze the relationship between economic damage from natural hazards and internal migration. These approaches provide important insights into population responses to flood exposure and natural-hazard-related damage. Incorporating FIPMs into future population projections requires estimating population responses relative to a counterfactual scenario in which flooding did not occur. For this purpose, the difference-in-differences (DiD) method, a statistical causal inference technique developed in the fields of econometrics and sociology, is well suited when its identification assumptions are plausible. It quantifies FIPMs by estimating population changes and migration responses attributable to flooding through comparisons between affected and unaffected areas before and after flood events.

Added reference

Ton, M. J., de Moel, H., de Bruijn, J. A., Reimann, L., Botzen, W. J. W., and Aerts, J. C. J. H.: Economic damage from natural hazards and internal migration in the United States, Nat. Hazards, 121, 4985–5005, https://doi.org/10.1007/s11069-024-06987-2, 2025.

Comment 3

It would be useful to clarify earlier in the Introduction that the analysis focuses on only two flood events. When reading the Introduction, I initially expected a broader analysis of the effects of floods on population movements across Japan, whereas the study is in fact closer to a case study. In addition, a map showing the locations of the flood events would be helpful. Then we could also see whether the affected areas overlap because I was wondering this when reading the manuscript.

Response:

We thank the reviewer for this helpful comment. We agree that the data used to estimate the empirical relationships between flood magnitude and FIPMs should be clarified earlier in the Introduction, while noting that the subsequent future population projections and fluvial flood damage cost estimates are conducted nationwide. In the original manuscript, the Introduction and methodological framework sections did not sufficiently explain that the grid-cell-level estimation of FIPMs was based on two observed flood events, whereas the municipality-level estimation used data from flood-affected municipalities during 2015–2020. To address this, we revised the Introduction and methodological framework sections to clarify the data used to estimate the empirical relationships between flood magnitude and FIPMs. We also clarified that these empirical relationships are applied to future population projections using flood magnitude indicators derived from future fluvial flood inundation analyses, rather than by directly extrapolating the observed events themselves. In addition, following the reviewer's suggestion, we added supplementary maps showing (i) the areas covered by the flood inundation maps used in the 500 m grid-cell-level analysis and (ii) the treated municipalities used in the municipality-level DiD analysis. These are now presented as Figs. S1 and S2.

Original text	Revised text
Against this background, this study aims to evaluate the impacts of FIPMs on future flood damage costs in Japan. To achieve this, we propose a methodological framework for projecting future population and estimating flood damage costs that accounts for FIPMs. To quantify population movements between and within municipalities in response to varying flood magnitudes, this study employs the difference-in-differences (DiD) method – a statistical causal inference technique developed in the fields of econometrics and sociology. (p. 3, lines 66–70 in the original manuscript)	○ **p. 3, lines 86–93 in the revised manuscript** Against this background, this study aims to evaluate the impacts of FIPMs on future fluvial flood damage costs in Japan. To achieve this, we propose a methodological framework for projecting future population and estimating fluvial flood damage costs that accounts for FIPMs. Specifically, we use the DiD method to quantify FIPMs between and within municipalities in response to varying flood magnitudes and incorporate the estimated relationships into future population and land-use projections. These empirical relationships are estimated using grid-cell-level data from two

	flood events in 2019 and 2020 and municipality-level data from flood-affected municipalities during 2015–2020. They are then applied to future population projections using flood magnitude indicators derived from future fluvial flood inundation analyses, rather than by directly extrapolating the observed events themselves.
FIPMs were quantified at both the grid-cell and municipality levels utilizing available demographic data to capture population movements occurring within and between municipalities in response to varying flood magnitudes. Detailed methodologies for quantifying FIPMs are presented in Sect. 3, while methodologies for the subsequent processes of the framework are described in Sect. 4. (p. 4, lines 77–80 in the original manuscript)	○ **pp. 4–5, lines 101–112 in the revised manuscript** FIPMs were quantified at both the grid-cell and municipality levels using available demographic data to capture population movements occurring within and between municipalities in response to varying flood magnitudes. Specifically, FIPMs were quantified using two types of observed datasets that combine flood-related and demographic information. Within-municipality population changes were estimated using flood inundation maps for areas affected by Typhoon Hagibis (2019) and the heavy rainfall event of July 2020, together with 500 m grid-cell population data. Inter-municipality population movements were estimated using municipality-level flood damage records and annual migration data. These data were used to estimate empirical relationships between flood magnitude and FIPMs, rather than to directly extrapolate the observed events themselves. The areas covered by the flood inundation maps used in the 500 m grid-cell-level analysis and the treated municipalities used in the municipality-level DiD analysis are shown in Figs. S1 and S2, respectively. Detailed methodologies for quantifying FIPMs are presented in Sects. 2.2 and 2.3, while methodologies for the subsequent processes of the framework are described in Sects. 2.4–2.6.

Added figures

○ **pp. 12–13 of the revised Supplement**

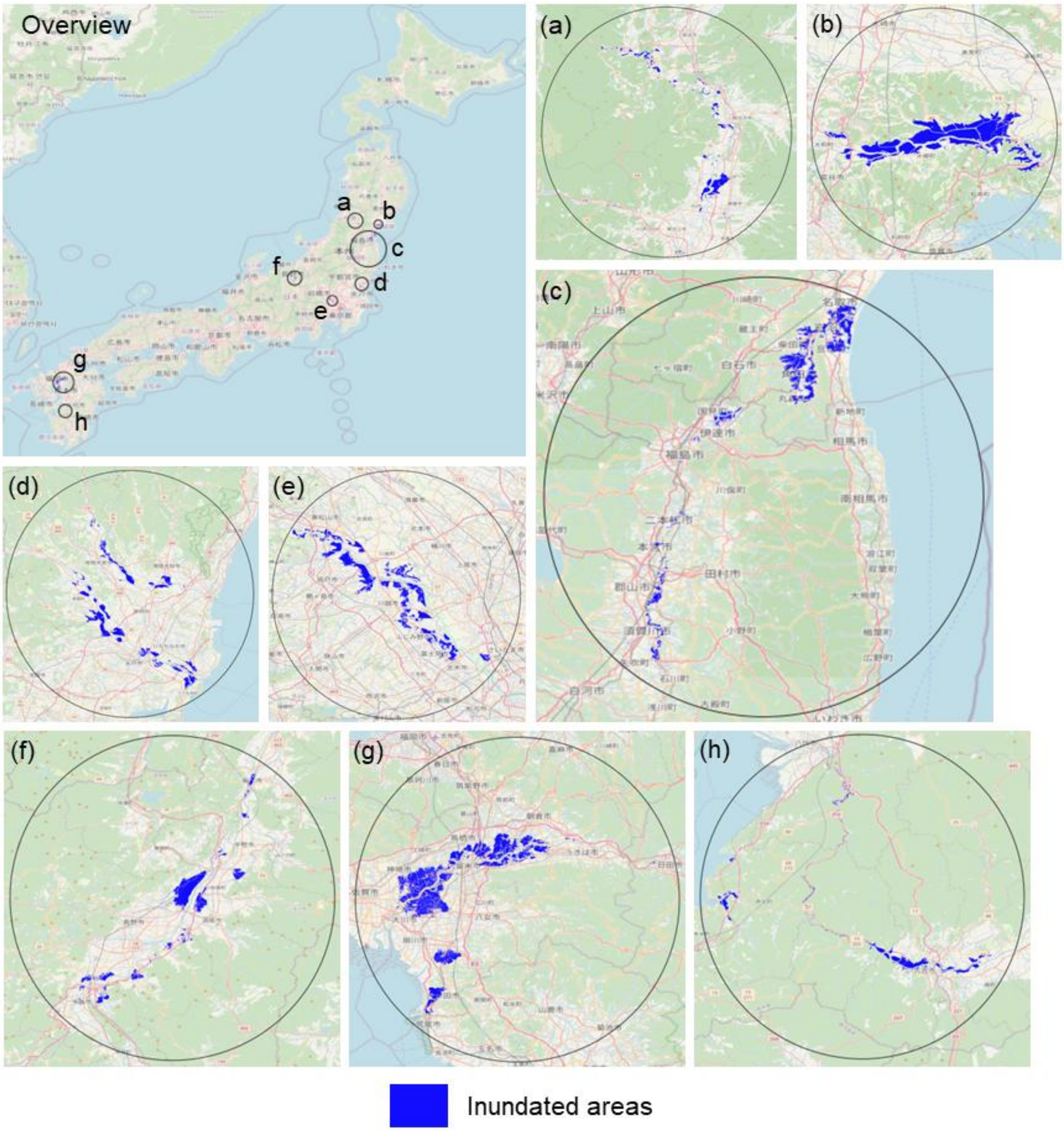

Figure S1: Inundated areas used in the 500 m grid-cell-level analysis. The blue areas indicate inundated areas identified from the flood inundation maps for Typhoon Hagibis (2019) and the heavy rainfall event of July 2020. The overview map shows the locations of the enlarged panels (a)–(h). Panels (b)–(f) correspond to Typhoon Hagibis (2019), whereas panels (a), (g), and (h) correspond to the heavy rainfall event of July 2020. Nearby mapped regions were grouped for display. Basemap: © OpenStreetMap contributors.

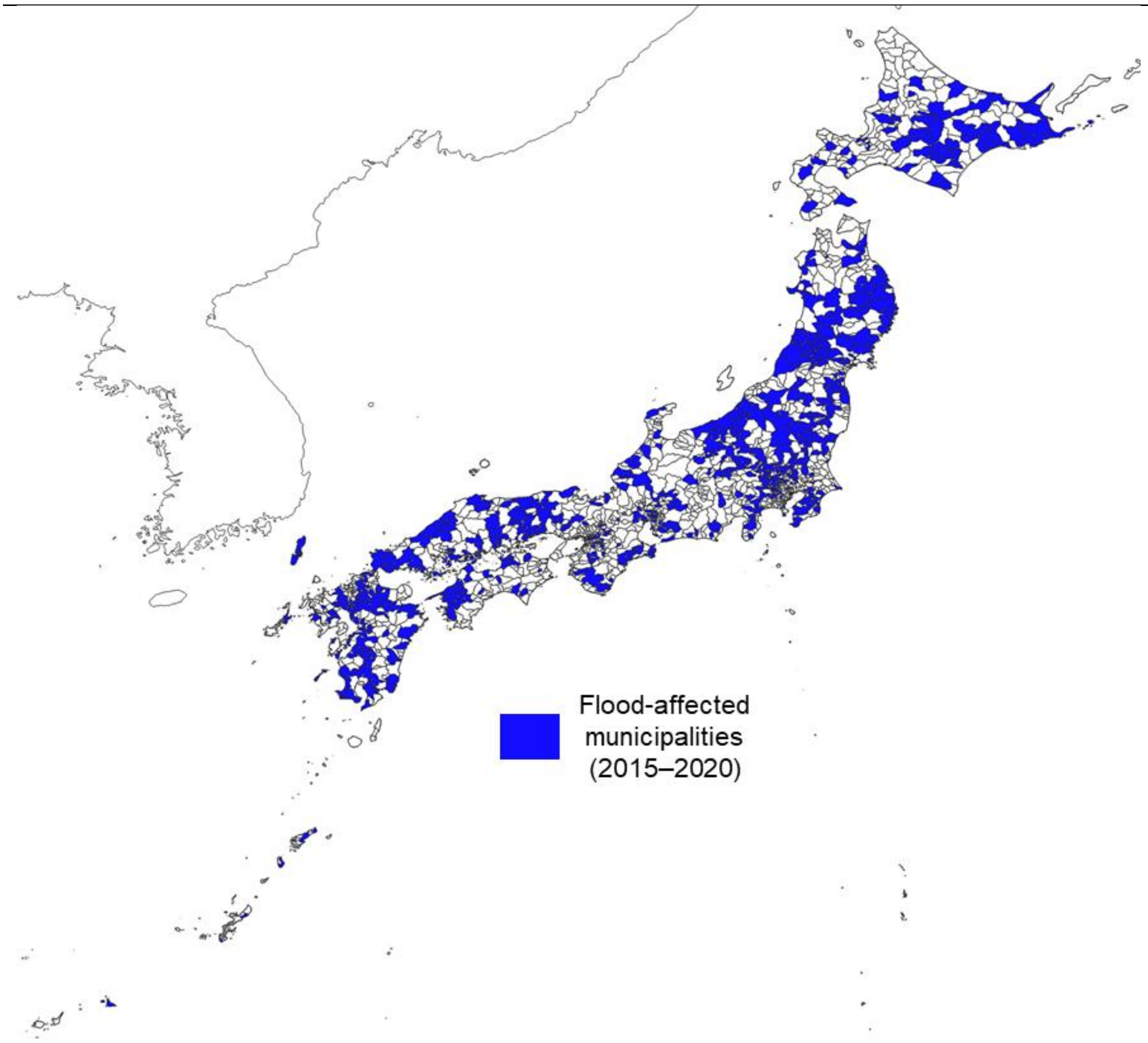

Figure S2: Municipalities affected by flood disasters during 2015–2020 and included as treated municipalities in the municipality-level DiD analysis.

Comment 4

A large part of the methodology is devoted to explaining the variables, coefficients and fixed effects, which makes the paper somewhat difficult to follow. I would encourage the authors to have another look at the equations and see where they can simplify the notation. For example, ¥delta_{bf}^{mun} R_{i', t', g'}^{bf} is not very readable. The equations might become clearer if the authors use simpler notation for coefficients, such as ¥beta_{0}, ¥beta_{1} and ¥beta_{2}, and call the variables BF, AF and CD, for example. Reducing the number of subscripts and superscripts would likely improve readability. Another suggestion would be to present the variables, coefficients, and fixed effects in a table or in a bullet-point list, so that the reader has a more clear overview.

Response:

We thank the reviewer for this helpful suggestion. We agree that the notation in the original equations was difficult to follow because many variables, coefficients, fixed effects, subscripts, and superscripts were defined directly in the text. We therefore revised the notation in the DiD regression equations throughout the main text and Supplement to improve readability and avoid overlapping symbols. Specifically, we removed superscripts where possible and simplified the notation for the treatment variables with reference to the reviewer's suggestion. At the same time, we retained the subscripts needed to identify the panel structure required for the DiD analysis, such as spatial unit, year, and year-specific dataset. To further improve readability, we moved the definitions of variables and parameters in Eqs. (1) and (2) to Tables 1 and 2, respectively.

Added tables

○ **pp. 6 and 8 of the revised manuscript**

Table 1: Definitions of variables and parameters in Eq. (1).

Symbol	Definition
i	Grid-cell index, $i = \{1, 2, \ldots, n\}$
n	Number of grid cells analyzed
t	Census year, $t = \{2005, 2010, 2015, 2020\}$
$P_{i,t}$	Total population (persons)
γ_i	Grid-cell fixed effects
τ_t	Year fixed effects
$\rho_i t$	Grid-cell-specific linear time trends
$\boldsymbol{Z}_{i,t-5}$	Covariate vector excluding time-invariant covariates
$\boldsymbol{\eta}$	Parameter vector for $\boldsymbol{Z}_{i,t-5}$
$H_{i,t}$	Maximum inundation depth (m)
ϕ	Parameter for $H_{i,t}$
$u_{i,t}$	Error term

Table 2: Definitions of variables and parameters in Eq. (2).

Symbol	Definition
j	Municipality index, $j = \{1, 2, \dots, n_g\}$
g	Year-specific dataset index, $g = \{1, 2, \dots, 6\}$
n_g	Number of municipalities analyzed within each year-specific dataset
y	Year, $y = \{2014, 2015, \dots, 2020\}$
$N_{j,y,g}$	Net migration rate (%)
$\mu_{j,g}$	Municipality fixed effects for each year-specific dataset
$\nu_{y,g}$	Year fixed effects for each year-specific dataset
$\kappa_{j,g}y$	Municipality-specific linear time trends within each year-specific dataset
$\boldsymbol{W}_{j,y-1,g}$	Covariate vector excluding time-invariant covariates
$\boldsymbol{\lambda}$	Parameter vector for $\boldsymbol{W}_{j,y-1,g}$
$BF_{j,y,g}$	Proportion of households affected below floor level by flooding (%)
$AF_{j,y,g}$	Proportion of households affected above floor level by flooding (%)
$CD_{j,y,g}$	Proportion of households that were completely destroyed by flooding (%)
β_1	Parameter for $BF_{j,y,g}$
β_2	Parameter for $AF_{j,y,g}$
β_3	Parameter for $CD_{j,y,g}$
$v_{j,y,g}$	Error term

Comment 5

In Equations (1) and (2), the authors include a time trend for each cross-sectional unit (grid cells in Equation 1 and municipalities in Equation 2). At the same time, the paper emphasizes the importance of satisfying the parallel trends assumption so that the estimated effect can be attributed to the flood rather than to other factors. The manuscript presents evidence suggesting that the parallel trends assumption holds. Given this, it is unclear why unit-specific time trends are still included in the regression. While the supplementary information cites one study that adopts a similar specification, this alone does not justify the modeling choice. I would like to see a clearer rationale for including these trends, or even better, a robustness check presenting results without the unit-specific time trends, especially since time fixed effects are already included.

Response:

We thank the reviewer for this important comment. We agree that the rationale for including unit-specific linear time trends was not sufficiently explained in the original Supplement. We revised the Supplement to clarify, using the grid-cell-level model as an example, that these trends were included to reduce the risk that heterogeneous pre-existing demographic trends are attributed to flooding. Specifically, we clarified that year fixed effects control for shocks common to all grid cells in each census year, whereas grid-cell-specific linear time trends control for gradual, pre-existing population trends that differ across grid cells, such as urbanization or depopulation. Although this explanation is provided for Eq. (1), the same rationale applies to the municipality-specific linear time trends in Eq. (2), which are included to account for gradual pre-existing trends that differ across municipalities. We also clarified that the indirect validation of the parallel trends assumption supports the absence of statistically significant pre-flood differences between the treatment and control groups. The inclusion of unit-specific linear trends further reduces the risk of attributing such pre-existing trends to flooding. In addition, following the reviewer's suggestion, we conducted sensitivity analyses without unit-specific linear time trends and added the results to Tables S12 and S13. We revised the main text to briefly report these additional analyses and to clarify that the estimates that were statistically significant in Tables S10 and S11 remained statistically significant and retained the same signs. Although we do not further discuss the changes in coefficient magnitudes in the manuscript to avoid over-interpreting the sensitivity analyses, the statistically significant estimates became larger in the negative direction at both the grid-cell and municipality levels when unit-specific linear time trends were omitted. This pattern is consistent with our concern that estimates without unit-specific linear time trends may be more susceptible to gradual pre-existing demographic trends, particularly in a country such as Japan where many areas face population decline. We therefore retain Eqs. (1) and (2), which include unit-specific linear time trends, as our main models.

Original text	**Revised text**
In the basic DiD model shown in Eq. (S1), the	○ **p. 3, lines 63–71 in the revised**

third term on the right-hand side of Eq. (1) was not included. However, if the time trends in the total population differ between the treatment and control groups, the basic DiD model fails to satisfy the parallel trends assumption. To address this issue, we followed Angrist and Pischke (2015) and added the third term to control for grid-cell-specific linear time trends and enhance the validity of the parallel trends assumption. (p. 3, lines 63–66 in the original Supplement)	**Supplement** In the basic DiD model shown in Eq. (S1), the third term on the right-hand side of Eq. (1) was not included. However, if the time trends in the total population differ between the treatment and control groups, estimates from the basic DiD model may be affected by heterogeneous pre-existing demographic trends. To reduce this risk, we followed Angrist and Pischke (2015) and included the third term to control for grid-cell-specific linear time trends. Year fixed effects control for shocks common to all grid cells in each census year, whereas grid-cell-specific linear time trends control for gradual, pre-existing population trends that differ across grid cells, such as urbanization or depopulation. The indirect validation of the parallel trends assumption in Sect. S6 supports the absence of statistically significant pre-flood differences between the treatment and control groups. Including grid-cell-specific linear trends further reduces the risk of attributing such pre-existing demographic trends to flooding.
Detailed results of parameter estimation for Eqs. (1) and (2) can be found in Tables S10 and S11. (p. 13, lines 326–327 in the original manuscript)	○ **p. 15, lines 345–348 in the revised manuscript** Detailed results of parameter estimation for Eqs. (1) and (2) can be found in Tables S10 and S11. As a sensitivity analysis, we also estimated Eqs. (1) and (2) without unit-specific linear time trends; the results are shown in Tables S12 and S13. The statistically significant estimates in Tables S10 and S11 remained statistically significant and retained the same signs in this sensitivity analysis.

Added tables

- **pp. 28–29 of the revised Supplement**

Table S12: Estimated parameters for Eq. (1) without grid-cell-specific linear time trends.

	Parameter (standard error)
Maximum inundation depth	−0.042*** (0.006)
Adjusted R^2	0.963
Within adjusted R^2	0.060
Sample size	19,120

Note: ***, **, and * indicate statistical significance at the 1 %, 5 %, and 10 % levels, respectively. Robust standard errors clustered at the grid-cell level are reported in parentheses. Results are shown for the maximum inundation depth; other results are omitted.

Table S13: Estimated parameters for Eq. (2) without municipality-specific linear time trends within each year-specific dataset.

	Parameter (standard error)
Proportion of households affected below floor level by flooding	0.012 (0.034)
Proportion of households affected above floor level by flooding	−0.041 (0.037)
Proportion of households completely destroyed by flooding	−0.098*** (0.021)
Adjusted R^2	0.685
Within adjusted R^2	0.023
Sample size	5,512

Note: ***, **, and * indicate statistical significance at the 1 %, 5 %, and 10 % levels, respectively. Robust standard errors clustered at the municipality level for each year-specific dataset are reported in parentheses. Results are shown for the proportions of households affected by flooding; other results are omitted.

Comment 6

Equations (3), (4), and (5) are also somewhat difficult to follow. The notation b,c = {1,2,3,4,5} is not immediately clear. It might be simpler and more transparent to refer directly to the corresponding years instead of using index notation.

Response:

We thank the reviewer for this helpful suggestion. We agree that the notation was not sufficiently clear in the original manuscript. Regarding b and c, directly replacing these indices with calendar years would be difficult because the corresponding years depend on the projection year T. We therefore retained the index notation but revised the explanation to clarify its meaning. Specifically, we clarified that b and c represent annual-step indices within each five-year projection interval rather than fixed calendar years. We also added an example showing how these indices correspond to years within a projection interval. In addition, we summarized the variables and parameters in Eqs. (3) and (4) in Table 3 to improve readability. Because the variables in Eq. (5) are fewer and are explained immediately after the equation, we retained the original explanatory format for Eq. (5).

Added text
○ **p. 10, lines 233–236 in the revised manuscript**
The indices b and c represent annual-step indices within each five-year projection interval rather than fixed calendar years. For example, when $T = 2020$, $b = 1$ represents the one-year population change from 2020 to 2021, whereas $b = 5$ represents the change from 2024 to 2025. The same interpretation applies to c.

Added table

○ p. 11 of the revised manuscript

Table 3: Definitions of variables and parameters in Eqs. (3) and (4).

Symbol	Definition
T	Starting year of each five-year projection interval, $T = \{2015, 2020, \ldots, 2095\}$
b, c	Annual-step indices within each five-year projection interval, $b, c = \{1, 2, 3, 4, 5\}$
S	Sex
X	Lower bound of each five-year age group
$C_{T+b-1 \to T+b, S, (X+b-1 \text{ to } X+b+3) \to (X+b \text{ to } X+b+4)}$	Population changes due to FIPMs over one year from year $T + b - 1$ to $T + b$, representing individuals of sex S who are aged $X + b - 1$ to $X + b + 3$ in year $T + b - 1$ and transition to ages $X + b$ to $X + b + 4$ in year $T + b$, within each municipality (persons)
$\hat{\beta}_1$	Change in the net migration rate at the municipality level per 1 % increase in the proportion of households affected below floor level by flooding (percentage points)
$\hat{\beta}_2$	Change in the net migration rate at the municipality level per 1 % increase in the proportion of households affected above floor level by flooding (percentage points)
$\hat{\beta}_3$	Change in the net migration rate at the municipality level per 1 % increase in the proportion of households that were completely destroyed by flooding (percentage points)
$\widehat{BF}_{T+b}$	Expected annual proportion of households affected below floor level by flooding in year $T + b$ (%)
$\widehat{AF}_{T+b}$	Expected annual proportion of households affected above floor level by flooding in year $T + b$ (%)
$\widehat{CD}_{T+b}$	Expected annual proportion of households that were completely destroyed by flooding in year $T + b$ (%)
$P^{\text{mun}}_{T+b-1, S, X+b-1 \text{ to } X+b+3}$	Population of sex S, aged $X + b - 1$ to $X + b + 3$ in year $T + b - 1$, within each municipality (persons)
$C_{T \to T+5, S, (X \text{ to } X+4) \to (X+5 \text{ to } X+9)}$	Population changes due to FIPMs over the five-year period from year T to $T + 5$, representing individuals of sex S who are aged X to $X + 4$ in year T and transition to ages $X + 5$ to $X + 9$ in year $T + 5$, within each municipality (persons)
$C_{T+c-1 \to T+c, S, (X+c-1 \text{ to } X+c+3) \to (X+c \text{ to } X+c+4)}$	Population changes due to FIPMs over one year from year $T + c - 1$ to $T + c$, representing individuals of sex S who are aged $X + c - 1$ to $X + c + 3$ in year $T + c - 1$ and transition to ages $X + c$ to $X + c + 4$ in year $T + c$, within each municipality (persons)

➢ Referee #3

Overall comments

This study quantifies flood-induced population movements (FIPMs) between and within municipalities in response to varying flood magnitudes from heavy precipitation events, using the difference-in-differences (DiD) method, a statistical causal inference technique. The influence of these movements on projected future flood damages from heavy precipitation is then assessed, revealing modest effects at the national level (1–2%) but considerably stronger impacts in some individual municipalities (above 10%). The authors conclude that locally concentrated effects suggest that FIPMs are particularly relevant for flood risk management and policy evaluation at the municipal scale. I have the following comments:

Response:

We sincerely thank the reviewer for carefully reviewing our manuscript and for the concise summary of our study. We are grateful for the constructive comments on the interpretation and presentation of the results. In response to the reviewer's comments, we revised the manuscript to clarify the flood types considered in the analysis, specify that the future damage assessment focuses on fluvial flood damage, better explain how empirical relationships estimated from observed flood data are applied to future projections, and clarify the interpretation of increases and decreases in estimated damage costs due to FIPMs. Detailed responses to each specific comment are provided below.

Comment 1

Make explicit throughout that only precipitation-induced flooding (not riverine or coastal) is analysed – currently this is missing in the title, abstract and introduction. At l. 51, consider whether riverine flooding is also relevant to your framing – if it is excluded, state so explicitly; if it is partially covered, clarify the scope.

Response:

We thank the reviewer for this important comment. We revised the manuscript to clarify the flood types considered in the study. In response to this and related comments, we changed the title and terminology throughout the manuscript to specify that the future damage assessment focuses on fluvial flood damage. We also revised the Introduction to make the fluvial flooding focus explicit in the framing of the study in Japan. At the same time, the observed flood-related data used to estimate FIPMs are based on heavy precipitation events and do not fully separate fluvial and pluvial components. Therefore, we retained "flood" or "flooding" when referring to observed flood events, flood exposure, and flood-related damage records, while using "fluvial flood damage" when referring to the future damage assessment. We further clarified this point in the limitations. Specifically, we clarified that the DiD analyses use observed flood-related data without separating fluvial and pluvial components, whereas coastal flooding is outside the scope of the predictive damage assessment. We also clarified that the fluvial flood inundation model used for future projections partly includes the effect of pluvial flooding through basin-scale rainfall–runoff processes, but it does not explicitly account for inland water drainage facilities. This clarification is intended to distinguish the scope of the future fluvial flood damage assessment from a comprehensive assessment of all flood types. Representative examples of the revisions are shown below; similar terminology changes were made throughout the manuscript where the future damage assessment is discussed.

Title

Original title	**Revised title**
Integrating flood-induced population movements into future flood damage estimates in Japan	Integrating flood-induced population movements into future fluvial flood damage estimates in Japan

Abstract

Original text	**Revised text**
This study evaluated the impacts of FIPMs on future flood damage costs in Japan, a country that faces flood risk and population decline. (p. 1, lines 14–15 in the original manuscript)	○ **p. 1, lines 14–15 in the revised manuscript** This study evaluated the impacts of FIPMs on future fluvial flood damage costs in Japan, a country that faces flood risk and population decline.

Introduction

Original text	Revised text
In Japan, many urban areas lie below river water levels, making them highly vulnerable to large-scale flood damage (Ministry of Land, Infrastructure and Transport of Japan [MLIT], 2006). (p. 2, lines 51–52 in the original manuscript)	○ **p. 2, lines 59–60 in the revised manuscript** In Japan, many urban areas lie below river water levels, making them highly vulnerable to large-scale fluvial flood damage (Ministry of Land, Infrastructure and Transport of Japan [MLIT], 2006).
These topographical and climatic conditions contribute to Japan's high susceptibility to flooding. Furthermore, Japan is projected to experience a significant population decline (Jarzebski et al., 2021). Given the dual challenges of flood damage and population decline, evaluating the impact of FIPMs on future flood damage costs in Japan is essential. (p. 2, lines 55–57 in the original manuscript)	○ **pp. 2–3, lines 63–66 in the revised manuscript** These topographical and climatic conditions contribute to Japan's high susceptibility to fluvial flooding. Furthermore, Japan is projected to experience a significant population decline (Jarzebski et al., 2021). Given the dual challenges of fluvial flood damage and population decline, evaluating the impact of FIPMs on future fluvial flood damage costs in Japan is essential.

Methods

Original text	Revised text
For grid cells in the treatment group, the maximum inundation depth was calculated based on values provided in the flood inundation maps. Details regarding the total population data at the 500 m grid-cell level, data on areas affected by water-related disasters, and flood inundation maps are provided in Sect. S2. (p. 4, lines 92–95 in the original manuscript)	○ **p. 5, lines 123–128 in the revised manuscript** For grid cells in the treatment group, the maximum inundation depth was calculated based on values provided in the flood inundation maps. The flood inundation maps provide estimates of inundated areas and inundation depths during the target heavy rainfall events and do not distinguish between fluvial and pluvial flooding. Therefore, the grid-cell-level analysis uses the estimated inundation without separating fluvial and pluvial components. Details regarding the total population data at the 500 m grid-cell level, data on areas affected by water-related disasters, and flood inundation maps are provided in Sect. S2.

To represent flood magnitude, we used the following municipality-level indicators: the proportion of households affected below floor level by flooding, the proportion of households affected above floor level by flooding, and the proportion of households that were completely destroyed (including washed away) by flooding. These indicators were expressed as percentages of the total households, following the method of Okamoto et al. (2023). (pp. 5–6, lines 134–138 in the original manuscript)	○ **p. 7, lines 165–170 in the revised manuscript** To represent flood magnitude, we used the following municipality-level indicators: the proportion of households affected below floor level by flooding, the proportion of households affected above floor level by flooding, and the proportion of households that were completely destroyed (including washed away) by flooding. These indicators were calculated to represent household damage associated with both fluvial and pluvial flooding. They were expressed as percentages of the total households, following the method of Okamoto et al. (2023).

Limitations

Added text
○ **p. 21, lines 478–488 in the revised manuscript** Third, the treatment of flood types requires careful interpretation. This study focuses primarily on future fluvial flood damage. As described by Yanagihara et al. (2024), the fluvial flood inundation model used for future projections partly includes the effect of pluvial flooding through basin-scale rainfall–runoff processes, but it does not explicitly account for inland water drainage facilities. To maintain consistency with this modeling framework, the flood data used in the DiD analyses were treated without separating fluvial and pluvial components. Thus, neither the observational data nor the predictive model fully separates fluvial and pluvial components, although their treatment of flood types is not identical. Coastal flooding is outside the scope of the predictive damage assessment. This limitation may introduce uncertainty in areas where drainage-related pluvial flooding or coastal flooding strongly influences population movements. Therefore, the results should be interpreted as an assessment of the impact of FIPMs on future fluvial flood damage, rather than as a comprehensive assessment of all flood types.

Comment 2

The concluding statement about "importance for flood risk management frameworks" is not convincingly supported by 1–2% national-level effects. Either soften the claim to focus on local relevance (>10% in some municipalities), or strengthen it with additional argumentation.

Response:

We thank the reviewer for this important suggestion. We agree that the original concluding statements were too broad, given the limited national-level effects of FIPMs. Accordingly, we have revised the relevant statements to focus on implications at the municipal level, where some municipalities showed reductions in estimated fluvial flood damage costs exceeding 10 %.

Original text	Revised text
These findings highlight the importance of accounting for FIPMs in flood risk management frameworks and policy evaluations. (p. 1, lines 21–22 in the original manuscript)	○ **p. 1, lines 24–26 in the revised manuscript** These findings highlight the importance of accounting for FIPMs in municipal-level fluvial flood risk management frameworks and policy evaluations.
These findings highlight the importance of incorporating FIPMs into future flood risk assessments and policy evaluations, particularly at the local level. (p. 18, lines 421–423 in the original manuscript)	○ **p. 20, lines 463–465 in the revised manuscript** These findings suggest that incorporating FIPMs may be important for municipal-level fluvial flood risk assessments and policy evaluations, despite their limited influence at the national level.
Thus, future assessments and policy evaluations at the local scale should explicitly consider the effects of FIPMs. (p. 19, lines 454–455 in the original manuscript)	○ **p. 22, lines 523–524 in the revised manuscript** Thus, municipal-level fluvial flood risk assessments and policy evaluations should consider the effects of FIPMs.

Comment 3

Clarify the distinction between planned relocation (policy-driven resettlement) and spontaneous migration (individual household decisions) early in the introduction.

Response:

We thank the reviewer for this helpful comment. We agree that the distinction between planned relocation and spontaneous migration should be clarified early in the Introduction. We have therefore added text explaining that FIPMs can take different forms of population movement, including planned relocation or policy-driven resettlement and spontaneous migration by households or individuals. We also added references to support this conceptual distinction.

Original text	Revised text
In contrast, recent studies have highlighted the importance of FIPMs (Del Rio Amador et al., 2025; Kakinuma et al., 2020; Kam et al., 2021). FIPMs can alter patterns of exposure to flood hazards, thereby influencing the extent of flood damage. (p. 2, lines 38–40 in the original manuscript)	○ **p. 2, lines 42–47 in the revised manuscript** In contrast, recent studies have highlighted the importance of FIPMs (Del Rio Amador et al., 2025; Kakinuma et al., 2020; Kam et al., 2021). FIPMs can take different forms, including planned relocation or policy-driven resettlement and spontaneous migration by households or individuals. Planned relocation involves organized efforts to move residents away from hazardous areas (McAdam and Ferris, 2015), whereas spontaneous migration reflects household- or individual-level decisions to move (Black et al., 2011). FIPMs can alter patterns of exposure to flood hazards, thereby influencing the extent of flood damage.

Added references
Black, R., Adger, W. N., Arnell, N. W., Dercon, S., Geddes, A., and Thomas, D.: The effect of environmental change on human migration, Glob. Environ. Change, 21, S3–S11, https://doi.org/10.1016/j.gloenvcha.2011.10.001, 2011.
McAdam, J. and Ferris, E.: Planned relocations in the context of climate change: unpacking the legal and conceptual issues, Camb. Int. Law J., 4, 137–166, https://doi.org/10.7574/cjicl.04.01.137, 2015.

Comment 4

I suggest that Sections 3 onwards should be structured as subsections of the Methods section (Section 2) for consistency and clarity.

Response:

We thank the reviewer for this helpful suggestion. In response, we have reorganized the manuscript by integrating the methodological framework, the quantification of flood-induced population movements (FIPMs), and the procedures for projecting future population, land use, and fluvial flood damage costs into a single unified "Methods" section. The revised structure is shown below, and the relevant section and subsection numbers have been updated accordingly throughout the manuscript.

[Original structure]

2 Methodological framework
3 Quantifying FIPMs
  3.1 Estimating changes in the total population at the 500 m grid-cell level due to flooding
    3.1.1 Analysis target and period
    3.1.2 Covariates
    3.1.3 Analytical method
  3.2 Estimating changes in the net migration rate at the municipality level due to flooding
    3.2.1 Analysis target and period
    3.2.2 Covariates
    3.2.3 Analytical method
4 Projecting future population and land use and estimating flood damage costs
  4.1 Projecting future population incorporating FIPMs
    4.1.1 Population changes due to FIPMs at the municipality level
    4.1.2 Population changes due to FIPMs at the 500 m grid-cell level
  4.2 Projecting land use based on future population
  4.3 Estimating future flood damage costs considering changes in rainfall and land use

[Revised structure]

2 Methods
  2.1 Methodological framework
  2.2 Estimating changes in the total population at the 500 m grid-cell level due to flooding
    2.2.1 Analysis target and period
    2.2.2 Covariates
    2.2.3 Analytical method
  2.3 Estimating changes in the net migration rate at the municipality level due to flooding
    2.3.1 Analysis target and period

Comment 5

At l. 84, clarify whether the analysis is based on only two specific extreme events: if so, this is a significant scope limitation that should be stated clearly in both abstract and introduction. Alternatively, clarify whether the two events serve as empirical anchors for estimating movement assumptions used in the broader modelling.

Response:

We thank the reviewer for this important comment. We agree that the role of the two observed flood events was not sufficiently clear in the original manuscript. We revised the Abstract, Introduction, and Methods to clarify that the two events are used in the grid-cell-level analysis to estimate empirical relationships between flood magnitude and FIPMs, and that these observed events themselves are not directly extrapolated. We also clarified that the municipality-level analysis is not based only on these two events, but uses municipality-level data from flood-affected municipalities during 2015–2020. The estimated empirical relationships are then applied to future population projections using flood magnitude indicators derived from future fluvial flood inundation analyses.

Original text	Revised text
We develop a methodological framework that uses statistical causal inference to quantify FIPMs, integrates these estimates into future population and land-use projections, and evaluates future flood damage costs under scenarios of climate and land-use change. The results indicate that incorporating FIPMs leads to only modest changes in estimated flood damage costs at the national level (generally below 1 %), and similarly modest impacts at the prefectural level, except for a few prefectures with changes of approximately 2 %. (p. 1, lines 15–19 in the original manuscript)	○ **p. 1, lines 15–22 in the revised manuscript** We developed a methodological framework that uses statistical causal inference to quantify FIPMs, integrates these estimates into future population and land-use projections, and evaluates future fluvial flood damage costs under scenarios of climate and land-use change. Empirical relationships between flood magnitude and FIPMs were estimated using grid-cell-level data from two flood events in 2019 and 2020 and municipality-level data from municipalities affected by flood disasters during 2015–2020, and then applied to future population projections using flood magnitude indicators derived from future fluvial flood inundation analyses. The results indicate that incorporating FIPMs leads to only modest changes in estimated fluvial flood damage costs at the national level (generally below 1 %), and similarly modest impacts at the prefectural level, except for a few prefectures with changes of

	approximately 2 %.
Against this background, this study aims to evaluate the impacts of FIPMs on future flood damage costs in Japan. To achieve this, we propose a methodological framework for projecting future population and estimating flood damage costs that accounts for FIPMs. To quantify population movements between and within municipalities in response to varying flood magnitudes, this study employs the difference-in-differences (DiD) method – a statistical causal inference technique developed in the fields of econometrics and sociology. (p. 3, lines 66–70 in the original manuscript)	○ **p. 3, lines 86–93 in the revised manuscript** Against this background, this study aims to evaluate the impacts of FIPMs on future fluvial flood damage costs in Japan. To achieve this, we propose a methodological framework for projecting future population and estimating fluvial flood damage costs that accounts for FIPMs. Specifically, we use the DiD method to quantify FIPMs between and within municipalities in response to varying flood magnitudes and incorporate the estimated relationships into future population and land-use projections. These empirical relationships are estimated using grid-cell-level data from two flood events in 2019 and 2020 and municipality-level data from flood-affected municipalities during 2015–2020. They are then applied to future population projections using flood magnitude indicators derived from future fluvial flood inundation analyses, rather than by directly extrapolating the observed events themselves.
FIPMs were quantified at both the grid-cell and municipality levels utilizing available demographic data to capture population movements occurring within and between municipalities in response to varying flood magnitudes. Detailed methodologies for quantifying FIPMs are presented in Sect. 3, while methodologies for the subsequent processes of the framework are described in Sect. 4. (p. 4, lines 77–80 in the original manuscript)	○ **pp. 4–5, lines 101–112 in the revised manuscript** FIPMs were quantified at both the grid-cell and municipality levels using available demographic data to capture population movements occurring within and between municipalities in response to varying flood magnitudes. Specifically, FIPMs were quantified using two types of observed datasets that combine flood-related and demographic information. Within-municipality population changes were estimated using flood inundation maps for areas affected by Typhoon Hagibis (2019) and the heavy rainfall event of July 2020, together with 500 m grid-cell population data. Inter-municipality population movements were estimated using municipality-

	level flood damage records and annual migration data. These data were used to estimate empirical relationships between flood magnitude and FIPMs, rather than to directly extrapolate the observed events themselves. The areas covered by the flood inundation maps used in the 500 m grid-cell-level analysis and the treated municipalities used in the municipality-level DiD analysis are shown in Figs. S1 and S2, respectively. Detailed methodologies for quantifying FIPMs are presented in Sects. 2.2 and 2.3, while methodologies for the subsequent processes of the framework are described in Sects. 2.4–2.6.

Comment 6

l. 333 / Figure 4: Specify the unit clearly – "persons per [what]?" needs to be defined (per km², per municipality, per 1,000 inhabitants, etc.).

Response:

We thank the reviewer for this helpful comment. The aggregation procedure was described in the original manuscript (pp. 13–14, lines 330–332): municipality-level population changes were summed across all municipalities in Japan, whereas grid-cell-level differences in population with and without FIPMs were aggregated nationwide. However, we agree that the unit in Fig. 4 could be made clearer. Figure 4 shows aggregated national-level population changes due to FIPMs, rather than rates or densities. These values represent absolute population changes and are not normalized by area, municipality, grid cell, or population. For readability, the 500 m grid-cell-level values are divided by 100 and expressed in hundreds of persons, whereas the municipality-level values are expressed in persons. This scaling is used only for display and does not indicate normalization. We have revised the main text and figure caption to clarify this point.

Original text	Revised text
Figure 4 presents the aggregated national-level population changes due to FIPMs at the municipality and the 500 m grid-cell levels. At the municipality level, absolute population changes due to FIPMs were obtained using Eq. (4) and summed across all municipalities in Japan. (p. 13, lines 329–331 in the original manuscript)	○ **p. 15, lines 350–354 in the revised manuscript** Figure 4 presents the aggregated national-level population changes due to FIPMs at the municipality and the 500 m grid-cell levels. The values shown in Fig. 4 represent absolute population changes and are not normalized by area, municipality, grid cell, or population. For readability, the 500 m grid-cell-level values are shown in hundreds of persons, whereas the municipality-level values are shown in persons. At the municipality level, absolute population changes due to FIPMs were obtained using Eq. (4) and summed across all municipalities in Japan.
Figure 4: Aggregated national-level population changes due to FIPMs at the municipality and the 500 m grid-cell levels. Population changes are shown at five-year intervals from 2020 to 2100, with each value representing the cumulative population change over the preceding five-year	○ **Caption for Figure 4 in the revised manuscript** Figure 4: Aggregated national-level population changes due to FIPMs at the municipality and the 500 m grid-cell levels. Values represent absolute population changes and are not normalized by

period. The changes were calculated based on the average values estimated from five GCMs. Error bands indicate the range between the maximum and minimum population changes derived from the five GCMs. (Caption for Figure 4 in the original manuscript)	area, municipality, grid cell, or population. For readability, values for the 500 m grid-cell-level analysis are divided by 100 and expressed in hundreds of persons, whereas values for the municipality-level analysis are expressed in persons. Population changes are shown at five-year intervals from 2020 to 2100, with each value representing the cumulative population change over the preceding five-year period. The changes were calculated based on the average values estimated from five GCMs. Error bands indicate the range between the maximum and minimum population changes derived from the five GCMs.

Comment 7

l. 345: Explain why flood damages are initially reduced under higher climate change scenarios – this is counterintuitive and needs explicit reasoning. Is it due to outmigration from high-risk zones reducing exposed population? Or overall population increase?

Response:

We thank the reviewer for this helpful comment. We revised the text to clarify how the sign of the percentage change should be interpreted and to explain why the percentage changes in estimated fluvial flood damage costs were negative in the near future. Specifically, the initial reduction can be interpreted as a reduction in population exposure in flood-exposed areas due to FIPMs, rather than as a result of overall population increase. We further clarified that the percentage changes can shift from negative to positive toward the end of the 21st century when increases in population exposure in other areas that remain flood-exposed exceed reductions in exposure elsewhere.

Original text	Revised text
Here, the percentage change in flood damage costs due to FIPMs is defined as the relative difference from estimates without considering FIPMs. At the national level, under JSSP1–RCP2.6, the percentage change due to FIPMs across Japan was −0.2 % in the near future and +0.3 % at the end of the 21st century, based on flood damage costs averaged across five GCMs. (p. 14, lines 343–346 in the original manuscript)	○ **p. 16, lines 366–372 in the revised manuscript** Here, the percentage change in fluvial flood damage costs due to FIPMs is defined as the relative difference from estimates without considering FIPMs. Negative values indicate that incorporating FIPMs reduces estimated fluvial flood damage costs relative to the corresponding estimates without FIPMs. Conversely, positive values indicate that incorporating FIPMs increases estimated fluvial flood damage costs relative to the corresponding estimates without FIPMs. At the national level, under JSSP1–RCP2.6, the percentage change due to FIPMs across Japan was −0.2 % in the near future and +0.3 % at the end of the 21st century, based on fluvial flood damage costs averaged across five GCMs.
National-level impacts of FIPMs on future flood damage costs are minimal, with absolute percentage changes consistently below 1 %. (p. 17, lines 406–407 in the original manuscript)	○ **p. 20, lines 440–445 in the revised manuscript** As shown in Sect. 3.3, in the national-level estimates, the percentage changes in estimated fluvial flood damage costs due to FIPMs were

	negative in the near future. This indicates that FIPMs may reduce population exposure in flood-exposed areas, thereby lowering these costs. Toward the end of the 21st century, however, the percentage changes shifted from negative to positive values. This shift can occur when increases in population exposure in other areas that remain flood-exposed exceed reductions in exposure in areas where exposure decreases. Nevertheless, national-level impacts of FIPMs on future fluvial flood damage costs are minimal, with absolute percentage changes consistently below 1 %.

Comment 8

Figure 5: Add a brief explanatory note in the text clarifying what it means when flood damages increase due to population movement – presumably this reflects in-migration into higher-risk areas, but this should be stated directly.

Response:

We thank the reviewer for this helpful suggestion. We added explanatory text referring to Figs. 5 and 6. In the revised text, we explain that positive percentage changes at the prefectural and municipal levels may occur when greater population exposure in areas that remain flood-exposed exceeds reductions in exposure elsewhere. We did not state that these changes directly reflect in-migration into the highest-risk areas, because the present framework does not explicitly identify the destinations of population movements. Instead, we described the interpretation in terms of changes in population exposure within flood-exposed areas.

Original text	Revised text
Our findings extend this understanding, showing that reductions in population growth can translate into lower future flood damage costs. From a practical perspective, although only a limited number of municipalities experienced notable cost reductions due to FIPMs, overlooking these effects could lead to an overestimation of the effectiveness of flood mitigation measures. (pp. 17–18, lines 418–421 in the original manuscript)	○ **p. 20, lines 457–463 in the revised manuscript** Our findings extend this understanding, showing that reductions in population growth can translate into lower future fluvial flood damage costs. At the prefectural and municipal levels, Figs. 5 and 6 show that some prefectures and municipalities exhibited positive percentage changes, although their magnitudes were generally smaller than the largest reductions. As discussed above, such increases may occur when greater population exposure in some areas that remain flood-exposed exceeds reductions in exposure elsewhere. From a practical perspective, although only a limited number of municipalities experienced notable cost reductions due to FIPMs, overlooking these effects could lead to an overestimation of the effectiveness of flood mitigation measures.

Comment 9

l. 422: The strong general claim is not well-supported given the small national-level numbers and the nuanced discussion preceding it. Consider limiting the claim to the local/municipal scale, where the evidence is stronger.

Response:

We thank the reviewer for this important comment. This point has been addressed in our response to Comment 2. Specifically, we revised the relevant statements to avoid broad generalization and to focus on implications at the municipal level, where the evidence is stronger.

Original text	Revised text
These findings highlight the importance of incorporating FIPMs into future flood risk assessments and policy evaluations, particularly at the local level. (p. 18, lines 421–423 in the original manuscript)	○ **p. 20, lines 463–465 in the revised manuscript** These findings suggest that incorporating FIPMs may be important for municipal-level fluvial flood risk assessments and policy evaluations, despite their limited influence at the national level.