**Dear Reviewer,**

Thank you for your careful and constructive review for the manuscript: "Medical deserts induced by pluvial flood: emergency medical accessibility loss and population exposure". The comments from Reviewer improve the quality of the manuscript effectively.

We have responded to the comments from the Reviewers and revised the manuscript. The revised text is marked in blue. Thanks again to the reviewers and editors for their suggestions on this study.

**Responses**

**1. Abstract: Suggest adding a brief definition of medical desert within the abstract, for clarity.**

**Response:** Thank you for your helpful suggestion. We added a concise definition in the revised abstract. Medical deserts are defined as high-population-density areas located outside the EMS coverage.

**Revised text:**

This study evaluates EMS accessibility loss and flood-induced medical deserts, defined as high-population-density areas located outside the 8-min EMS coverage under pluvial flood in Mentougou New Town. (Abstract, Lines 10–11).

**2. Line 10: Extra "the".**

**Response:** Thank you for identifying this error. The duplicated "the" has been deleted.

**3. Line 32: What is meant by "increases detour costs"?**

**Response:** Thank you for your suggestion. The "increases detour costs" refers to the additional travel time incurred when road inundation prevents ambulances from using the shortest routes and forces them to take longer alternative routes. To eliminate this ambiguity, we have replaced the expression with the following more direct description.

**Revised text:**

During flood events, hospitals may remain operational but become less accessible because road inundation may force ambulances to take longer alternative routes, thereby increasing travel time. (Lines 41–43)

**4. Line 33: What are "network indicators"? Additionally, the sentence lists studies for "transport disruption", but the next sentence changes the scope to "road-level impacts". Suggest clarifying.**

**Response:** Thank you for your helpful suggestion. In this study, "network indicators" refers to quantitative measures used to characterize road network structure and system-wide performance, including connectivity, betweenness centrality, and global efficiency. We clarified this term in the manuscript. We have also revised the transition between road-level impacts and network-level transport disruption and added relevant references on road-network accessibility.

**Revised text:**

Previous studies have translated simulated inundation depths into road segment speed reductions or failures using depth-based thresholds and functions (Al-Qadami et al., 2024; Patro et al., 2009). And network metrics such as betweenness centrality and global efficiency have been used to identify critical links and evaluate connectivity loss. These metrics show how the degradation or failure of individual road segments affects connectivity across the road network (Dong et al., 2022; Wu et al., 2022). However, these impacts need to be further translated into changes in service areas and accessibility for EMS. (Lines 43–48)

**5. Line 35: Extra comma.**

**Response:** Thank you for your suggestion. We have deleted the extra comma.

**6. Line 43: The description of hazard, exposure, vulnerability paradigm does not seem to directly inform the last sentence highlighting why it's specifically applicable to EMS. Suggest clarifying.**

**Response:** Thank you for your helpful suggestion. The H-E-V framework is applicable to this study because flood-induced loss of EMS results from the interaction among flood hazard, exposed road infrastructure and populations. In particular, EMS may be disrupted even where hospitals or communities are not directly inundated if flood interrupts the road connecting them. We moved the interpretation of the H-E-V framework to the second paragraph of the Introduction. The subsequent literature review has also been reorganized around this framework, covering flood hazard simulation, the exposure of roads and populations, and the vulnerability and accessibility consequences for EMS. These revisions provide a clearer theoretical basis and improve the logical coherence of the Introduction section.

**Revised text:**

In this study, simulated inundation depth and extent characterize the hazard, affected roads and populations dependent on EMS constitute the exposed elements, and the depth-dependent loss of road functionality and limited availability of alternative routes and hospitals represent vulnerability (Rufat et al., 2015; Tate et al., 2021). Consequently, similar inundation conditions may produce different losses of 8-min EMS coverage depending on population distribution and the availability of viable routes and alternative hospitals.( Lines 32–37)

**7. Section 2.1: It will be helpful to introduce the total area of the study region and total population.**

**Response:** Thank you for your suggestion. We have added the total area and total population of the study area in the revised manuscript.

**Revised text:**

The study area covers approximately 87.0 $km^2$ and has a population of 326,000 in 2025. (Lines 80)

**8. Fig. 1: The readers will be better oriented if the hospital locations and population density were also overlaid on the map (or a new map added).**

**Response:** Thank you for your suggestion. Figure 1 has therefore been expanded to include a new panel showing the eight hospital locations overlaid on the 2025 population-density raster. In addition, we have added a description of the spatial concentration of hospitals in the central part of the study area, providing the necessary spatial context for the "double jeopardy" finding reported in the discussion section.

**Revised text:**

The study area contains eight hospitals, including both secondary and tertiary facilities, which are mainly located in its central part and serve as the principal supply nodes in the EMS network. (Lines 86-87).

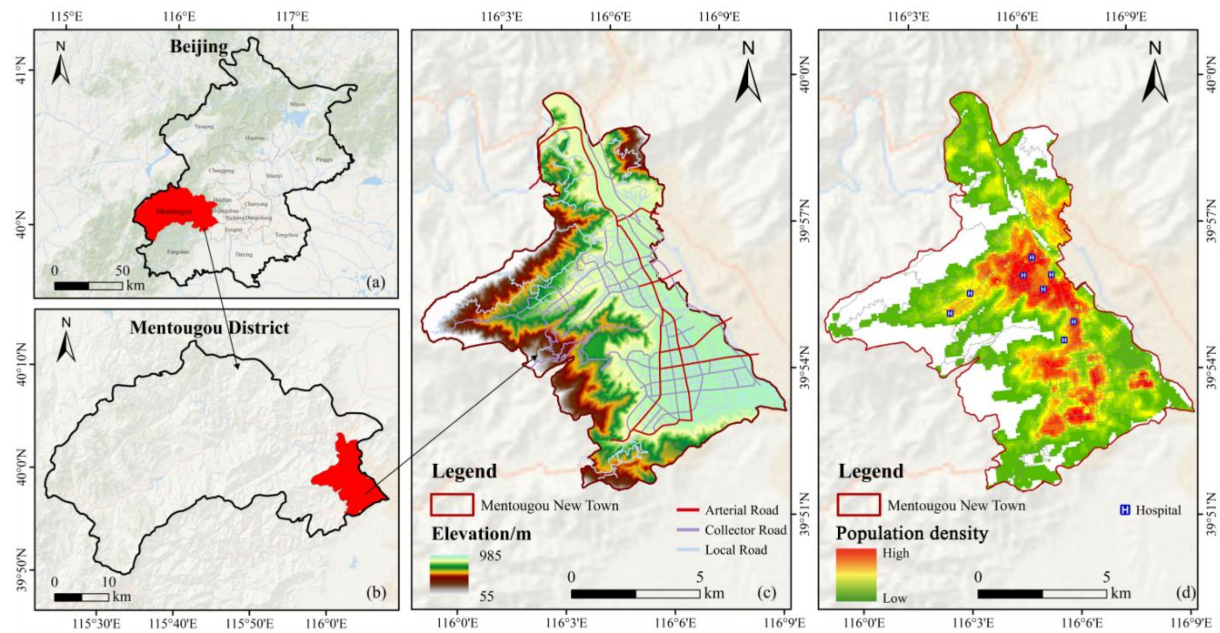


**Figure 1: Overview of the study area. (a) Location of Mentougou District in Beijing. (b) Location of Mentougou New Town in Mentougou District. (c) Topography and road network in Mentougou New Town. (d) Hospital locations and 2025 population density in Mentougou New Town. (Lines 90-92, Figure 1 and its caption).**

**9. Line 98: What is the resolution for the "high-resolution population distribution"? Broadly, it will be informative to include the spatiotemporal resolutions of all datasets in Table 1.**

**Response:** Thank you for your suggestion. The WorldPop population layer has a spatial resolution of 100 m and represents the residential population distribution in 2025. We have added a "Data Format" column to Table 1 to provide more detailed information on the datasets. (Lines 99 and Table 1)

**Table 1: List of basic data required for the study.**

| Data Category | Description | Source | **Data Format** |
|---|---|---|---|
| Hydrometeorological data | Historical daily rainfall | China Meteorological Data Network (https://data.cma.cn/) | Tabular time series; daily |
| Topographic data | Elevation | Geospatial Data Cloud (https://www.gscloud.cn/) | Raster DEM; 2 m (1:5,000) |
| River data | Water system distribution | National Geomatics Center of China (https://www.geodata.cn/) | Vector polyline; |
| Sewer system data | Design return period, elevations, etc. | Government water resources authority, field survey | Vector network (lines and nodes); |
| Road network data | Road name, length, classification, etc | Government transport authority, field survey | Vector polyline |

| Data Category | Description | Source | **Data Format** |
|---|---|---|---|
| Hospital data | Location, facility level | POI (Point of Interest) coordinates, field survey | Vector points |
| Population data | Population density distribution | WorldPop (https://hub.worldpop.org/) | Raster grid; 100 m (2025) |

**10. Line 101: What is meant by "spatial mismatch"?**

**Response:** Thank you for your suggestion. In this study, "spatial mismatch" refers to locations where relatively high potential medical demand falls outside the 8-min EMS coverage areas. We apologize that this term was not clearly explained in the original manuscript. Taking into account the reviewer' valuable suggestions, we have re-examined this section and revised the manuscript to better highlight the emergence of healthcare deserts resulting from spatial mismatch.

**Revised text:**

This section introduces the methods for assessing road-dependent EMS accessibility and identifying medical deserts defined as areas with relatively high potential medical demand that fall outside the 8-min EMS coverage. (Lines 101–102).

**11. Line 108: It will be helpful to add a reference for why 8 minutes is selected as the threshold.**

**Response:** Thank you for your suggestion. In the investigations and emergency-managements practice of countries such as China, the UK, and the US, an 8-min travel time has been widely used as a critical threshold for evaluating timely EMS accessibility. We have added the relevant references. And we also provided a more explicit justification for selecting the 8-min threshold in Section 3.3.

**Revised text:**

(3) Based on the traffic capacity and travel time matrix, a GIS-based service area analysis is conducted to quantify the area which patients can reach hospitals in the 8-min spatial extent within (Green et al., 2017; Coles et al., 2017; Yin et al., 2021; Yang et al., 2020). (Lines 109-110)

In flood accessibility studies, the 8-min threshold has been used to quantify changes in ambulance service coverage under pluvial, fluvial, and coastal flooding in the UK, the United States, and China (Green et al., 2017; Coles et al., 2017; Yin et al., 2021; Yang et al., 2020). It has also been applied in recent isochrone-based assessments of pre-hospital EMS accessibility in Beijing (Zhao and Zhou, 2024). Thus, this study adopts 8 min as the travel-time threshold for delineating EMS coverage. By integrating this threshold with the dynamic travel-time matrix and inundation data, a GIS-based service area model is used to delineate hospital service boundaries. (Lines 171–174)

**12. Line 124: Repeated sentence.**

**Response:** Thank you for identifying the duplication. We apologize for this oversight, and the repeated sentence has been deleted.

**13. Table 3: Do Shallow and Medium refer to two rows each? It will be helpful to draw horizontal lines in the table for clarification.**

**Response:** Thank you for your suggestion. "Shallow" refers to the <0.05 m and 0.05-0.15 m, whereas "Medium" refers to the 0.15-0.30 m and 0.30-0.50 m. We have reformatted Table 3 with clearly separated depth rows. (Lines 151-152, Table 3)

**14. Table 3: It is mentioned on Line 140 that depth > 0.5m assumes traffic interruption, but the table lists a non zero speed attenuation factor. Can the authors please clarify?**

**Response:** Thank you for your suggestion. Road segments with inundation depth greater than 0.50 m are treated as impassable: the attenuation factor is set to 0. We have revised Table 3 to ensure the description is accurate. (Lines 165, Table 3)

**15. Eqs 1, 2: The equations do not clarify how a range of speed attenuation factors is applied for modifying the road network. Did the authors use the center of the range?**

**Response:** Thank you for your suggestion. In this study, the speed attenuation factor is applied by multiplying it with the design speed to obtain the actual travel speed of a road segment under a given inundation depth. The speed attenuation factor ranges previously presented in Table 3 summarized values across each depth interval, which may have caused confusion. We have stated the operational rule explicitly in the revised manuscript. The center of a class range is not used.

For each road segment, the maximum inundation depth is extracted from the raster, and the attenuation factor is obtained by piecewise-linear interpolation between the breakpoint pairs (h, α) = (0, 1.0), (0.05, 0.9), (0.15, 0.6), (0.30, 0.3), and (0.50, 0.0). For h ≥ 0.50 m, α = 0 and the road is treated as closed.

**Revised text:**

For road segments with an inundation depth below 0.5m, the speed attenuation factor is calculated by linear interpolation between two adjacent depth factor breakpoints, as shown in Eq. (1):

$$\alpha(h_i^t)=\alpha_i+\frac{\alpha_{i+1}-\alpha_i}{h_{i+1}-h_i}(h-h_i); \quad h_i \leqslant h \leqslant h_{i+1} \tag{1}$$

where h is the inundation depth, $h_i$ and $h_{i+1}$ are the lower and upper depth breakpoints, and $\alpha_i$and $\alpha_{i+1}$ are their corresponding speed attenuation factors. (Lines 153–157)

**16. Line 151: $v_i^0$ and $C_i^0$ appear to indicate the same value. Can the authors clarify?**

**Response:** Thank you for your suggestion. Both symbols were used for the baseline/design speed, creating unnecessary duplication. We sincerely apologize for this oversight. We have removed $C_i^0$ and use $v_i^0$ consistently. Equations (2) and (3) and all variable definitions have been rewritten accordingly.

**Revised text:**

$$C_i^t=v_i^0\times\alpha(h_i^t) \tag{2}$$

$$T_i^t=\frac{60L_i}{C_i^t} \tag{3}$$

where $C_i^t$ is the actual travel speed of road segment i at time t, $v_i^0$ is the design speed of the road segment (km/h), $\alpha(h_i^t)$ denotes the speed attenuation factor corresponding to the inundation depth of road segment i at time t. $T_i^t$ is the travel time of the road segment i at time t (min); $L_i$ is the length of road segment i (km). The values assigned to $v_i^0$ follow the design speed specifications in the Code for Design of Urban Road Engineering (CJJ 37-2012) and are listed in Table 4. (Lines 160–165).

**17. Line 199: What inundation depth is used to calculate the inundation area?**

**Response:** Thank you for your suggestion. For each return-period event, inundated area is calculated from cells whose maximum simulated water depth is at least 0.05 m. Cells below 0.05 m are excluded from the inundated-area total.

**Revised text:**

The total area with an inundation depth of 0.05 m or greater is calculated. (Lines 212)

**18. Line 234: Can the three-stage attenuation pattern, and its associated terms be further described? This is their first mention and it will be helpful to include both the definitions and their consequences.**

**Response:** Thank you for this helpful advice. The three-stage attenuation pattern refers to the progressive spatial changes in the 8-min EMS coverage across increasingly severe flood scenarios. The three stages are: (1) loss at the edges, (2) fragmentation of the main coverage area, and (3) separation into isolated service areas. We have added explicit definitions and descriptions of their consequences in the revised manuscript.

**Revised text:**

Regarding spatial distribution, the 8-min EMS coverage shows a three-stage attenuation sequence as the rainfall return period increases, characterized by loss at the edges, fragmentation of the main coverage area, and separation into isolated service areas. In the first stage, coverage loss is concentrated along the edges, reducing timely access in peripheral communities while the main service area remains connected. In the second stage, as rainfall intensity increases, the main service area is divided into multiple disconnected areas, creating gaps in EMS coverage. In the third stage, the remaining EMS coverage becomes separated into isolated service areas, accompanied by substantial coverage loss and the expansion of medical deserts. Overall, EMS coverage changes only slightly under more frequent, lower-intensity flood scenarios but contracts substantially under the 50- and 100-year events.(Lines 246-252)

**19. Line 240: Table 7 lists the proportion of covered area as ~60%, so the conclusion that almost all built-up area is covered is unclear. Applies to all related conclusions from Table 7 in this paragraph.**

**Response:** Thank you for your careful suggestion. First, the percentage values reported in Table 7 are calculated using the total area of the study region as the denominator. The total area of Mentougou New Town includes woodland, farmland, and other non-built-up land without permanent residential settlements. Consequently, the 8-min EMS area under the 10-year event accounts for 59.84% of the total study area, although it is concentrated in the inhabited built-up areas. We have revised the manuscript and carefully reviewed the related conclusions in the paragraph. The revised text now reports the values that can be directly derived from Table 7.

**Revised text:**

As summarized in Table 7, under the 10-year event, the 8-min EMS coverage area is 52.06 km², accounting for 59.84% of the total study area. (Lines 256-257)

**20. Line 254: Repeated sentence.**

**Response:** Thank you for your careful suggestion. We apologize for the oversight and the repeated sentence has been removed in the revised manuscript. We have also carefully checked the entire manuscript to avoid similar issues.

**21. Line 294: The sentence mentions "many studies", yet only one reference is provided.**

**Response:** Thank you for your suggestion. We have replaced the phrase "many studies" with "previous studies" and added directly relevant studies of flood-related travel-time and critical-facility accessibility losses.

**Revised text:**

Previous studies have quantified flood-induced increases in travel time and losses of critical-facility accessibility (Green et al., 2017;  Papilloud et al., 2024; He et al., 2026a). (Lines 302-304)

**22. Line 296: The sentence is unclear, e.g., what is meant by targeted disruption?**

**Response:** Thank you for your suggestion. In this study, "targeted disruption" refers to the selective failure or removal of the most critical road segments in a network. This interpretation follows the vulnerability of road networks to targeted attacks on high-importance links. We have revised the manuscript and the original phrase "targeted disruption" has been replaced with the clearer expression "targeted attacks on the most critical road segments," so that the intended network-related meaning is directly stated.

**Revised text:**

This pattern is consistent with evidence that road networks are particularly vulnerable to the selective disruption of high-importance links. (Lines 305-306)

**23. Line 297: Can the authors cite the corresponding Fig. to support the critical conclusion about secondary roads? This conclusion was not previously stated in the results.**

**Response:** Thank you for this helpful suggestion. Figure 1c presents the road classification, and Figure 6 illustrates the failure or performance degradation of roads under flooding. By combining these two figures, the differential impact on secondary roads can be observed. In the revised manuscript, we have explicitly referred to Figure 1c and 6 and added a corresponding explanation in the Results section to support this conclusion.

**Revised text:**

A comparison of the road hierarchy in Fig. 1c with the flood-induced road degradation in Fig. 6 shows that moderate inundation (0.3-0.5 m) of several secondary roads was not accompanied by system-wide effects, indicating that the impact of road failure depends more on the importance of the affected roads within the network than on road class or inundated road length alone. Thus, the protection of critical roads should be a priority in resilience measures. (Lines 306-309)

**24. Line 303: Can the authors further clarify their double jeopardy conclusion? There was no previous analysis of areas that are already disadvantaged.**

**Response:** Thank you for this important suggestion. We have clarified that double jeopardy refers to the combination of this pre-existing spatial disadvantage resulting from the uneven distribution of medical facilities and the additional loss of EMS accessibility caused by flood-induced road disruption. We have added further spatial context in the study area section showing that hospitals are concentrated in the central area, while high-population-density communities in the south have relatively limited medical provision and fewer alternative facilities.

**Revised text:**

Medical deserts under pluvial floods arise not merely from road failures or high population density alone, but from their spatial mismatch. As shown in Fig. 1d, hospitals are concentrated in the central area, while high-population-density communities in the south have fewer nearby medical facilities and alternatives under normal conditions. Flooding compounds the pre-existing disadvantage by disrupting the critical roads connecting these communities to centrally located hospitals. The three medical deserts identified under the 100-year scenario (100-1, 100-2, and 100-3) therefore illustrate a spatial form of double jeopardy, whereby communities with relatively weak baseline provision experience an additional loss of EMS accessibility during flooding (Gotham, 2010; Rozhkov et al., 2025). Their spatial correspondence with disrupted critical road segments further indicates that infrastructure–resource mismatches contribute substantially to EMS accessibility loss during extreme events. (Lines 312-318)

**25. Line 314: It is not clear how the conclusion that central facilities can be maintained to lower standards is supported.**

**Response:** Thank you for your suggestion. This conclusion was based on the preceding results concerning road inundation and the resulting changes in EMS coverage. Compared with peripheral areas, the central area retained comparatively greater 8-min EMS coverage, a pattern consistent with the concentration of hospitals and the availability of alternative routes. Our intention is not to suggest that facilities in the central area should be maintained to lower safety standards, but to distinguish the resilience priorities of different areas. We apologize that the original wording did not make this distinction clearly. As part of the overall revision of the manuscript, we have revised this conclusion to focus on area-specific measures: maintaining route redundancy and protecting critical access corridors in the central area, while strengthening alternative access and supplementary emergency medical provision in peripheral high-density areas.

**Revised text:**

The results indicate spatially differentiated priorities for EMS resilience. In the central area, where hospitals are concentrated and alternative routes are relatively abundant, planning should prioritize maintaining the stability of existing facilities and preserving network redundancy, rather than automatically requiring higher flood-protection standards; in high-population-density peripheral areas, priority should be given to strengthening flood-protection standards for critical roads and providing necessary supplementary emergency medical facilities. (Lines 325-330)

**26. Line 316: The sentence is unclear, including the terminology: dual-use for normal and emergency.**

**Response:** Thank you for your suggestion. In the original manuscript, “dual-use for normal and emergency” referred to facilities that provide routine healthcare services under normal conditions and can be rapidly adapted to support emergency medical services during disasters. We recognize that this expression was unclear. We have therefore explicitly described the proposed routine and emergency functions. The revised text also clarifies that community health centers are intended to supplement, rather than replace, general hospitals during emergencies.

**Revised text:**

Selected community health centers in potential medical deserts could be equipped with appropriate emergency medical equipment, staffing, and response capacity, enabling them to provide routine healthcare under normal conditions and function as emergency medical response points during flood events. These facilities would supplement, rather than replace, general hospitals. (Lines 330-333)

**27. Line 376: Item (4) is unclear, and I am unsure which results are used to arrive at this conclusion.**

**Response:** Thank you for your suggestion. As part of the overall revision of the manuscript, we have revised former Item (4). It has been replaced with a conclusion that directly synthesizes the spatial-overlay findings presented in Section 4.4.

**Revised text:**

(4) Flood-induced medical deserts arise from the overlap of high population density, loss of 8-min road-based access, and limited alternative medical nodes. Their marked expansion from the 50-year to the 100-year scenario indicates that corridor protection and supplementary emergency medical nodes should be targeted to the identified service gaps. (Lines 404-406)

**28. I would suggest to the authors to add some limitations and motivations for future research in Discussion/Conclusions. For example, some key limitations of their study are:**
**1. The inundation model has not been validated. The authors determined the parameters and then tested the model on the same 3 sites and a single event.**
**2. Only single scenarios are considered for each hazard level. Multiple hyetographs are possible for the same hazard level.**
**3. Hospital inundation/downtime was not considered.**
**4. All the impacts were estimated deterministically without accounting for any probabilities.**

**Response:** Thank you for this comprehensive and constructive comment. It has helped us more clearly define the scope of the present analysis and identify important directions for future research. We supplied each of these four limitations below.

1. Thank you for drawing attention to this important issue. Our team was primarily involved in post-disaster reconstruction planning for Mentougou District. The flood-inundation model used in this study was originally developed as part of the technical investigations supporting post-disaster reconstruction planning in Mentougou District following the “23.7” event. The model simulation results served as one of the bases for determining flood-protection standards for roads and other critical infrastructure in the post-disaster reconstruction plan. Its development was supported by a systematic post-event flood survey covering 105 communities across Mentougou District. We used GPS equipment, rangefinders, and measuring rods to delineate inundation boundaries based on water marks, sediment traces, and damage boundaries and to measure high-water-mark elevations and representative cross-sections.

To make the empirical evaluation of the model more explicit , we have supplemented the model-development background, clarified the post-event survey procedure. We regret that comparable inundation-depth observations were unavailable for other historical flood events in Mentougou New Town, which prevented an independent-event validation using a separate rainfall event. We have explicitly acknowledged this constraint in the revised manuscript. Nevertheless, the comparison with the post-event field survey provides direct empirical evidence that the model can reasonably reproduce the observed inundation conditions during the “23.7” event and supports its application to the subsequent design-rainfall scenarios.

2. The design rainfall depths for the 10-, 20-, 50-, and 100-year return periods are estimated using the Pearson Type III probability distribution, and the corresponding hyetographs are constructed according to the Region II design storm pattern specified in the Beijing Hydrological Manual. The rainfall scenarios are therefore based on a standardized local hydrological method. This approach provides a consistent basis for comparing inundation and EMS accessibility across return periods and facilitates the interpretation of the results in relation to local flood-defence and planning standards.

Nevertheless, a given return period does not correspond to a unique rainfall temporal pattern. We are grateful to the reviewer for highlighting this important source of uncertainty. We clarify that the present results are conditional on the standardized design hyetograph adopted in this study and include this issue in the study limitations. This valuable suggestion provides clear direction for extending the research. In future research, we plan to examine multiple plausible hyetographs for each return period to evaluate the sensitivity and uncertainty of flood-induced EMS accessibility loss.

3. This study focuses on the loss of EMS accessibility caused by road-network disruption. The present analysis therefore assumes that these hospitals remain operational. Moreover, because the study is conducted at the city scale, and neither historical disasters nor simulations suggested that hospitals were exposed to inundation risk, we do not incorporate differences in resource availability among individual hospitals. We are grateful to the reviewer for highlighting this important limitation. In future research, we plan to incorporate hospital-level flood exposure, functional fragility, operational downtime, and resource constraints to provide a more comprehensive assessment of EMS performance.

4. Finally, this study adopts fixed design-hazard scenarios because local flood-defence standards and post-disaster reconstruction planning are formulated using specified rainfall return periods. The 10-, 20-, 50-, and 100-year scenarios therefore provide common planning benchmarks, allowing the estimated accessibility losses to be directly related to existing protection standards and helping identify roads and EMS areas that require priority intervention. Within each scenario, fixed model parameters and road-performance thresholds provide a consistent basis for comparison.

We thank the reviewer for drawing attention to this methodological limitation. In future research, we plan to supplement our research with multiple rainfall temporal patterns, probabilistic parameter distributions, hospital fragility to quantify the uncertainty and probability distribution of EMS accessibility loss.

**Revised text:**

5.3 Limitations and future research:

This study is developed within a planning-oriented framework intended to support post-disaster reconstruction and the evaluation of flood-protection standards. The study incorporated detailed field observations collected after the “23.7” flood event and supported the determination of flood-protection standards for critical infrastructure. Standardized return-period rainfall scenarios, a locally prescribed design hyetograph, and fixed road-performance thresholds are adopted to ensure consistency with existing flood-defence and reconstruction-planning practices. The results should consequently be interpreted as scenario-specific estimates rather than probabilistic predictions. Future research could move beyond the requirements of planning assessment by incorporating multiple rainfall temporal patterns, probabilistic parameter distributions, and ensemble simulations to examine the uncertainty of flood-induced medical-desert formation. In addition, future extensions should incorporate hospital fragility, operational downtime, and resource availability to provide a more comprehensive representation of EMS performance. (Lines 378-388)