Spatial accessibility of emergency medical services under inclement weather: A case study in Beijing, China

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We would like to thank the editor and reviewers for the thorough reading of the manuscript and the valuable remarks that helped us to improve the manuscript. We have revised the manuscript carefully according to the reviewer's comments, and have incorporated the suggestions into the revised manuscript.

The notes below provide a point-by-point response to each comment from the referees. The texts with blue font are the reviewer's original comments, the texts with black font are authors' responses. We have incorporated most of the suggestions made by the reviewers. Those changes are highlighted within the manuscript. If there is any question addressed unclearly or unsatisfied, we are always willing to make a revision based on reviewer's comments. Thank you again for the opportunity to be considered for publication in *Natural Hazards and Earth System Sciences*.

Referee #1

I thank the authors for addressing my comments. I think that the scoping for this paper, in the introduction and the conclusion, should be improved:

Introduction (Line 103-105): "Due to insufficient recorded traffic data, relatively few studies have been performed to analyze the impact of road access capacity on EMSs accessibility according to actual traffic speed variation.".

This claim is used to prepare the reader to the key components of this paper. However, it is not backed up with key citations. What are these few studies, their limitations, etc., so that the proposed one here is the "a first attempt to analyze the spatial accessibility of EMSs under inclement weather based on city-scale ground truth traffic data and meteorological data, where the former is usually difficult to obtain" [Lines 471-479]?

Conclusion (Lines 471 to 479): "To the best of the authors' knowledge, this study provides a first attempt to analyze the spatial accessibility of EMSs under inclement weather based on city-scale ground truth traffic data and meteorological data, where the former is usually difficult to obtain. In previous literature, simulation methods were widely used on the research on EMSs accessibility or traffic capacity under inclement weather. The ground-truth traffic data that covers every road in the whole city, was hardly used in the previous studies of the impact of weather on traffic and accessibility. Our study could be a good empirical verification in this field of study. The reduction extent of EMSs accessibility was comparable to previous studies (Yin et al., 2021; Coles et al., 2017)."

This contribution should be crystal clear on the METHODOLOGICAL difference between the works of (Yin et al., 2021; Coles et al., 2017) and what is proposed here. While the case study sites/cities are different, the authors claim that this study is "… a first attempt to…" but then also claim that the results "…was comparable to previous studies (Yin et al., 2021; Coles et al., 2017)".
Overall, the specific METHODOLOGICAL added value should stand out for readers.

Response: We thank for reviewer's comment. We apologize for any misunderstandings that may have been caused by the comparison between our work and previous studies. We have provided additional explanations for this.
In the work of Yin et al., 2021, they simulated urban waterlogging scenarios under different rainfall intensities and the traffic speed was set based on recorded average traffic speed under normal conditions, the traffic speed variations induced by precipitation were not considered. While in our work, the traffic speeds were set based on the real-time traffic data under precipitation scenarios, the relationship between traffic speed and precipitation was further explored.
To the best of our knowledge, our work is the first attempt to analyze the spatial accessibility of EMSs under inclement weather based on city-scale ground truth traffic data and meteorological data. It is indeed inappropriate to compare our results with previous studies (Yin et al., 2021; Coles et al., 2017), since they did not consider traffic speed variations under precipitation. It is not to say that the results of our work should be exactly consistent with the results of similar studies by previous scholars, but in fact, they cannot be completely consistent because research areas and the methods are not the same.

We revised the description of Yin et al.'s work (2021) to better introduce their methods, please refer to Lines 94-99, page 5:
Yin et al. (2021) assessed the vulnerability of EMSs to surface water flooding in

Shanghai, China by quantifying accessibility in terms of service area, population coverage and response time. They simulated urban waterlogging scenarios under different rainfall intensities and set traffic speed based on recorded average traffic speed under normal conditions, which didn't consider the traffic speed variations induced by precipitation.

To avoid possible misunderstandings, we deleted the comparisons and elaborated the description of existing studies, please refer to Lines 484-494, page 24:

To the best of our knowledge, there was no studies have been performed to analyze the impact of road access capacity on EMSs accessibility under inclement weather according to actual traffic speed variation. Our study provides an attempt to analyze the spatial accessibility of EMSs under inclement weather based on city-scale ground truth traffic data and meteorological data, where the former is usually difficult to obtain. In previous literatures (Yin et al., 2021; Coles et al., 2017; Albano et al., 2014), simulation methods were widely used on the research on EMSs accessibility or traffic capacity under inclement weather; however, the ground-truth traffic data that covers every road in the whole city under precipitation scenarios, was hardly used in the previous studies of the impact of weather on traffic and accessibility. Our study could be a good empirical verification in this field of study.

Referee #2

The manuscript is investigating the impact of rainfall events on EMS, which is an interesting topic to study.

The authors have compared the traffic speed reduction during rainy days and calculated average speed reduction, which is used for further analysis. However, there are a number of assumptions or details not properly explained in the manuscripts.

1. The methodology uses the precipitation as the criteria for defining the wet days, the rainfall-runoff process is not directly reflected in the assumption. How are the influences of soil infiltration, natural and urban drainage in the process? Would 3 mm/2h exceed the design capacity of the sewer network in Beijing?

Response: We thank for reviewer's comment. We have checked the drainage design standards in Beijing (DB11/ 685—2021, DB 11/T 1575—2018), which stipulate that the rainwater drainage design standard should not be less than a 2-year return period (about 55mm/2h). And a 3 mm/2h clearly would not exceed the design capacity of the sewer network in Beijing. However, even if precipitation of this intensity cannot cause road waterlogging, it can still lead to wet and slippery road surface and affect the drive speed. So, in our study, we used the actual recorded speed changes, which indeed showed that precipitation had an impact on traffic speed.

And we added some references to support this point:

Chu L J, Fwa T F. Pavement skid resistance consideration in rain-related wet-weather speed limits determination[J]. Road materials and pavement design, 2018, 19(2): 334-352.

Katz, Bryan, et al. Guidelines for the use of variable speed limit systems in wet weather. No. FHWA-SA-12-022. United States. Federal Highway Administration. Office of Safety, 2012.

To make it clear, we have revised the expression in Lines 159-166, pages 7-8:

In this study, we set a rule that if the precipitation of more than 10 grids (over 5% area of the city) in Beijing is greater than 1.5 mm in 2 hours, it is considered a precipitation event. This amount of precipitation may not high enough to cause the rainfall-runoff exceed the drainage capacity of the sewer network in Beijing (DB11/ 685—2021, DB 11/T 1575—2018). But the precipitation would cause slippery roads and decrease in drivers' visibility, which would lead to a reduction of traffic efficiency and accessibility (Chu and Fwa, 2018; Katz et al., 2012).

2. It is unclear if the calculations were done by only comparing the reductions during the 2h window or by the selected wet days. If it is done by every 2h window, how to reflect the delayed responses of runoff? If it is done by daily average, for the periods without rainfall during the day, were the traffic conditions the same to normal days? Should those periods be included?
   Should the temporal changes of rainfall affect the traffic condition? How is such a situation reflected in the methodology?

Response: We thank for reviewer's comment. Yes, we did the calculations by the 2h window of morning rush period. The precipitation is calculated as the cumulative precipitation within 2 hours of the morning rush period, and traffic speed is averaged by the speed during 2 hours of the morning rush period. Both are not daily averages. We apologize for the unclear definition of traffic speed in equation (1), we added more explanation in Lines 220-233, pages 10-11. The original equation (1) was split into two equations, to make it clearer.

The original equation (1):

$$r_c = \frac{v_p - \frac{\sum_{j=0}^{m} v_{d_j}}{m}}{\frac{\sum_{j=0}^{m} v_{d_j}}{m}} \quad (1)$$

The new equations and their descriptions:

$$r_c = \frac{v_p - v_b}{v_b} \quad \textit{(1)}$$

where r_c *is the traffic speed reduction rate in the selected period of the precipitation day to its corresponding baseline day;* v_p *is the traffic speed in the selected period of the given precipitation day, and it is the average of the real-time traffic speed in every 2 minutes during the selected time period in that day;* v_b *is the traffic speed in the selected period of the baseline precipitation days, which is calculated by eq.(2):*

$$v_b = \frac{\sum_{j=0}^{m} v_{d_j}}{m} \quad \textit{(2)}$$

where v_{d_j} *is the traffic speed in the selected period of a baseline day, and it is the average of the real-time traffic speed in every 2 minutes during the selected time period in that day; m is the number of baseline days. In this case, m equals 4. The average traffic speed reduction rate is obtained by averaging the reduction rates of all roads with reduced speed in the city.*

The reviewer's proposal of "the delayed effect of rainfall on runoff formation" is indeed worth considering and analyzing. In our study, more attention is paid to the immediate effects of rainfall, such as causing slippery roads and reduced visibility, without considering the cumulative effects of rainfall runoff. In further research in the future, maybe we can explore the difference in the impact of accumulated rainfall before the selected time window and within the time window on traffic speed.

Besides, we agree that the temporal variation of rainfall may affect traffic conditions. In this study, the problem was simplified and analyzed without considering the impact of changes within the 2-hour time window, as the selected 2-hour time window was not quite long, and the time resolution of the original precipitation data was only half an hour. If precipitation data with higher spatiotemporal resolution can be obtained in the future, the relationship between rainfall variation and traffic changes can be further refined

In response to these points, we supplemented them in the discussion in Lines 502-504, page 25:

First, we averaged the traffic speed reduction rate of all the roads in the city, as well as the precipitation data, which could conceal congestion hotspots. Besides, all the calculation was done by the 2-hour selected period, which may neglect the delayed responses of rainfall runoff and temporal variation of rainfall. In further studies, with higher resolution precipitation, along with corresponding traffic data, we could narrow the scale to blocks, pay more attention to local congestions, and analyze the correlation of precipitation and traffic speed on a finer scale.

3. According to Figure 4, the reductions are very different from road to road for different rainfall conditions. Should the main roads and minor roads use the same average reduction in the analysis? Same question goes to roads in city center and rural areas. The single average value will underestimate the reductions in those areas that were impacted most.

Response: We thank for reviewer's comment. We agree that there are significant differences in the variation of traffic speed between roads. However, because the spatial resolution of precipitation data is relatively coarse, it is difficult to further refine the scale when analyzing the correlation between precipitation and traffic speed reduction. So, we average the speed reduction of all roads when comparing the overall speed reduction rate of the city.

But we did not do any average calculation of traffic when we build the road network and set speed for every road to analysis the accessibility. We did not put the average speed reduction into the analysis of accessibility, instead, the traffic speed of every road was set by the real traffic speed of the chosen date and chosen period.

To better illustrate this point, we have added the following explanation in Lines 241-243, page 11:

In this study, the time needed to pass through the road is calculated by the length of each road divided by its corresponding traffic speed, and the service area analysis is carried out with time as the impedance. In different scenarios, the time impedance varies, since the traffic speed of each road is set according to the real-time traffic speed record of the chosen date and chosen period.

4. In Figure 9, the delay of EMS is multiplied by the population, this is probably over exaggerating the information. It is unlikely all populations in the area require EMS

simultaneously. On the other hand, the capacity of EMS in different areas should also be considered. What if a hospital is exceeding its capacity, will the delay be further extended?

Response: We thank for reviewer's comment. We agree that not all populations in the area require EMS simultaneously. However, the busyness of emergency services in one region is roughly proportional to its population. We only use population as a weight coefficient, and the numerical value has no practical significance.

To better illustrate this point, we have added the following explanation in the methods section in Lines 280-283, page 13:

The total transfer time is introduced to quantify the cumulative transfer time for each population grid based on its population size, which is the number of potential users of EMSs. The total transfer time is defined in this study by the shortest transfer time of each population grid to the nearest hospital multiplied by its population. The numerical value has no practical significance, and is only used for comparing the spatial differences among regions.

Besides, we agree that the capacity of hospitals should be considered, unfortunately we are unable to obtain data like the number of beds, number of medical staffs, and medical material reserves of each hospital. If detailed public hospital data can be obtained in the future, this analysis can be further improved. Therefore, in our study, we assumed that the EMSs needs would not exceed the hospitals' carrying capacity. And we added this assumption in Lines 203-205, page 9:

(6) The hospitals' carrying capacity is not been considered in this study, and we assume that the demand of EMSs would not exceed the first aid stations' and hospitals' carrying capacity.