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

Ref: nhess-2022-218

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 second 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

The authors address most of my comments and I am thankful to this. However, I feel acknowledging some lesson learnt about the applicability of the proposed methodology to a different city, and the limitation of the seemly overoptimistic assumption of "15-minutes arrival time" are necessary to have this contribution as realistic as possible. Details can be found below with reference to my "Original comment" followed by the "Authors' response" and then by the "New reviewer's comments" in relation to the "Authors' response".

Original comment: "2. Line 232: Is there any citation that you can use to justify the choice of the 15-minute arrival time?"

Authors' response: "[…] In previous study, considering various response time targets, three service zones lying within 8-, 12-, and 15-minute travel are specified for each individual EMS station. And the coverage areas all decreased under the impact of flood.

So, we chose 15-minute arrival time. In the revised manuscript, we added the reference:

Yin, J., Yu, D., and Liao, B.: A city-scale assessment of emergency response accessibility to vulnerable populations and facilities under normal and pluvial flood conditions for shanghai, china, ENVIRON PLAN B-URBAN, 48, 2239-2253, http://doi.org/10.1177/2399808320971304, 2021"

New reviewer's comments: In the "previous study" of Yin et al. (2021) – cited above – the investigators seem to have done a similar study but for Shanghai. On this, I have two comments:

(1) the author should discuss the findings of Yin et al. (2021) first in the introduction of this paper. Is the same method applied from a different city? If so, a reflection on what do learn from it as compared to the other city, Shanghai, would be useful – in the conclusions; and

Response: We thank for reviewer's comment. The method of quantifying the EMS accessibility is similar in our study and the paper of Yin et al. (2021): we both used the service area analysis based on ArcGIS Network Analysis. The main differences between our study and theirs is that we used the real recorded transportation data to analyze the influence of inclement weather on EMS accessibility, which is actually one of the important novelties of our study. In Yin's research, they used flood simulation model to build flood scenarios and set 4 drive speed limit level to build different transportation scenarios. We have added the findings of Yin et al. (2021) in the introduction part and further emphasize the research differences in Lines 94-98, 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, and the results show that EMS coverage could decrease up to 13% under 100-year surface water flooding;

In Yin's study, they found that "compared with normal operating condition, 5- and 20-year pluvial flooding both exerted very minor and even negligible impacts on the change of service area (less than 1%). The impact of 100-year surface water flooding is more pronounced (up to 13%)." Compared to our study, because the inclement weather days that we analyzed in 2019 didn't have quite high precipitation, so in our results, the most of the coverage area reductions were only around 0%-3%, which is consistent with their conclusions to some extent.

We also added some comparisons to the results in Lines 330-336, Page 16:

Consistent with the pattern of the traffic speed reduction, the worst loss of coverage rate also occurred on three rainy days: 1st July (Mon), 9th July (Tue), and 10th September (Tue), and one snowy day: 16th December (Mon), in which the 15-minute EMS coverage rate reduced by 4.6%, 5.6%, 4.2% and 13.3%. The rest days didn't have obvious coverage reduction. Combined with the spatial distribution of precipitation and traffic variation (Figure 4), the snowfall on December 16th caused a large traffic speed reduction of the suburban roads, which led to a significant reduction in overall EMS coverage. In previous studies, Yin et al. (2021) found that 5- and 20-year pluvial flooding both exerted less than 1% reduction in EMSs coverage rate of Shanghai, China; Coles et al. (2017) found that the coverage of Fire and

Rescue Stations services showed a 6% reduction overall under their modelled floods events in York, UK. In our study, the precipitation was less than 3mm/2h, and the corresponding coverage reduction was less than 3%, except for the special four days. The results are comparable to previous findings. In the following, we chose these four days as the worst weather scenario of the year and analyzed the spatial differences of medical accessibility in the whole city.

(2) the paper of Yin et al. (2021), which involves one of the co-authors, does not really justify the choice of the 15-minutes arrival time. Having looked at the NHS website for the UK, it seems like 8 to 19 minutes is an expected time window for an ambulance to arrive in normal weather conditions. Therefore, should the authors keep the choice of the "the 15-minute arrival time", this has to be discussed as part of a limitation sub-section or as part of the "assumptions" made. In fact, the 15-minutes travel time for an ambulance under flooding or snowfall conditions may be overly optimistic. If so, this should be acknowledged.

Response: We thank for reviewer's comment. In China, there is no national legislative requirements for emergency response time. However, in Beijing, according to the data from the report of Beijing Municipal Health Commission, the average response time of pre-hospital emergency treatment is about 15 minutes in 2022. Therefore, we chose 15-min as the boundary in our study. We have added the news report to the references.

Beijing Youth Daily. Available at: https://t.ynet.cn/baijia/33458913.html (lase access: 11 February 2023),2022.

Indeed, the circumstance would be different in other cities like London, UK. We admit that we were overoptimistic to the applicability of the proposed methodology to a different city. Therefore, we added the following explanation to the discussion in Lines 504-508, Pages 25-26, and the assumption in Lines 195-199, Page 9:

Fourth, we used the "15-minutes arrival time" as a main boundary in this study, however, the proper response time would vary in different countries or cities. So, the setting of response time boundary should be adjusted considering the actual situation of the city when the method in this paper is applied to other cities.

In this study, we made the following assumptions: …… (5) According to the report by Beijing Municipal Health Commission, the average response time of pre-hospital emergency treatment in Beijing is about 15 minutes for the year of 2022. We therefore chose 15-min as the boundary of EMSs response time in our study. (Beijing Youth, 2022).

Referee #2

The authors implemented valuable amendments and clarifications, which greatly improved the manuscript. Limitations of the study are also explained better and put into context.
Altogether, the study provides an interesting first proof of concept on how to integrate various forms of empirical data into the research question of EMS accessibility under adverse weather conditions, and conveniently summarises a range of concepts, that can be more refined in the future.

A few technical (and grammar-related) comments remain, together with some minor content-related questions:

Grammar and style: The following points are only anecdotally collected instances where amendments should be made, please consider proof-reading by a native speaker for a smoother reading flow.

L28: the word "citywide" does not fit here.
L 61: 1.5 to 2 hours; wouldn't --> would not (please check the manuscript for similar informally-sounding instances)
L62: on usual --> usually
L82 - 85: people are more concerned about (...) than about.
L155: the moderate rain is defined as the rainfall is 5.0~14.9 mm within 12 hours. --> moderate rain (without "the") is defined as rainfall between 5.0 and 14.9 mm within 12 hours (?)

Response: We thank for reviewer's comment. They all have been revised in the revised manuscript.

Lines 28-29: *the area in the city that could get EMSs within 15 minutes would decrease by 13% compared to normal scenario.*
Lines 62-63: *Usually, the transfer time would not be more than 1 hour.*
Lines 84-86: *people are more concerned about the transportation situation, instead of the interaction between supply and demand.*
Lines 156-157: *moderate rain is defined as the rainfall is 5.0~14.9 mm per 12 hours.*

To Section 3.3:
True, interpreting the centroid of the aggregated 1x1km population grid as a "sample" seems a valid interpretation - especially for such a large city as Beijing, where this still results in >16k population nodes on the graph.
As a thought for future studies, though: looking at the topology of the studied network, health facilities, roads and population density in the inner city are much denser than in the suburbs. Hence a varying resolution could have been applied with a finer grid in the

heavily populated center, and a more coarse grid towards the outskirts. This could still keep the number of OD nodes equally reduced, while capturing more of the dynamics in a metropolis with varying population and infrastructure densities.

Response: We thank for reviewer's comment. A varying resolution, with a finer grid in the heavily populated center and a coarser grid towards the outskirts, would help to capture more of the dynamics in a metropolis. We are willing to try this method in future research. We added this in the discussion part in Lines 508-511, Page 26:

Fifth, we aggregated the population grid evenly in the city. If a varying resolution could have been applied with a finer grid in the heavily populated center, and a coarser grid towards the outskirts, it may capture more of the dynamics in a metropolis with varying population and infrastructure densities.

Results 4.2.1 - Figure 8

In lines 372-374 you write that "the results reveal that the population of the towns with low baseline EMS coverage rate would lose more EMS coverage under inclement weather, especially on snowy day." While the one hypothesis which you discuss to explain this, namely the lower redundancy of possible access roads in rural areas, makes sense, there is a second point to this: the plots in figure 8 show relative (!) changes in EMS coverage rates. Hence, if base accessibility was already low, it is only natural that relative changes for low numbers are very big (for instance, if in a suburban zone, base coverage rate of EMS was around 20%, and it dropped to 15% during inclement weather, this would show up as a 25% relative reduction in your plot), whereas if in an inner-city zone coverage drops by the same percentage (say, from 100% to 95%), this would show up in your plot only as a 5% decrease. This has hence nothing to do with road topology and physical accessibility, but is an artefact of the display method.

I would suggest having a look at a modified version of the plots in figure 8, plotting base rate EMS coverage against daily EMS coverage rate (i.e. in absolute % numbers, not in relative reduction), to see if this over-proportional affectedness persists in such a plot.

Response: We thank for reviewer's comment. We fully understand the concerns of the reviewer.

The absolute reduction and the relative reduction are two different aspects reflecting the inequity of town's EMSs accessibility. As the reviewer pointed out, we first evaluated the absolute change in our study. In Figure 7, we used the spatial distribution map to present the absolute reduction of each town. We can see that lots of areas in suburban did experience severe decrease in population coverage under inclement weather conditions.

Meanwhile, we also pay attention to the relative reduction, which is also a very important indicator. Comparing to the absolute reduction, this could better reflect town's changes relative to themselves. For example, if in a suburban town, base coverage rate was about 10% and it dropped to 0% during inclement weather, this town would be almost completely unavailable to EMSs. And these towns should be the key areas in the planning of infrastructure construction. However, if in an urban town, the coverage rate dropped from 100% to 90% during inclement weather, it still can obtain relatively high of EMSs coverage. So, we still keep the display of the relative reduction of the EMSs coverage.

Lastly, both figures 8 and 10 are not extremely insightful, but take quite a bit of space. I would consider either merging the multi-panels, or moving them to the appendix.

Response: We thank for reviewer's comment. We have moved both figure 8 and 10 to the appendix.

Referee #3

Specific comments:
L. 27/ 80: The definition of "normal": Can you provide an explanation to the reader to facilitate their understanding?

• L. 27: "Under inclement weather scenario, the area in the citywide that could get EMSs within 15 minutes would decrease by 13% compared to normal scenario, while in some suburban townships, the population that could get 15-min EMSs would decrease by 40%."
• L. 80: "The 2SFCAmethod considers accessibility to be mediated by not only the distance decay but also the interactions between supply and demand (Chen and Jia, 2019), which is more suitable for normal scenarios"

Response: We thank for reviewer's comment. "Normal" refers to "the average state of weekdays without precipitation" in this paper. We have added the explanation where the word first appeared in Lines 28-30, Page 2:

the area in the city that could get EMSs within 15 minutes would decrease by 13% compared to normal scenario (the average state of weekdays without precipitation)

Further explanation required:
• L. 51: "Because inclement weather conditions would reduce road capacity, increase transfer time, and sometimes block roads completely (Agarwal et al., 2006; Chang et al., 2013; Cools et al., 2010; Suarez et al., 2005; Zhang and Chen, 2019), resulting in

reduced spatial accessibility and delayed the response time of EMSs." --> This sentence seems to be somewhat incomplete. In the previous version, this was part of the previous sentence.

Response: We thank for reviewer's comment. The sentence in the previous version was split into two sentences because the sentence was considered too long to be readable. We tried to revise it again in Line 49-55, Page 3:

The efficiency of emergency services is highly vulnerable to inclement weather conditions such as rain, snow, frog, etc. The reason why inclement weather conditions would reduce the efficiency of emergency services is that inclement weather conditions would reduce road capacity, increase transfer time, and sometimes block roads completely, which leads to the reduction of spatial accessibility and delay of response time.

• L. 82: "While for studies focusing on the influence of inclement weather on EMSs, people concern more about the transportation situation, instead of the interaction between supply and demand." --> What is meant by "for"?

Response: We thank for reviewer's comment. We have revised the sentences in Lines 83-85, Page 4:

While in the studies focusing on the influence of inclement weather on EMSs, people are more concerned about the transportation situation

• L. 321: "Combined with the spatial distribution of precipitation and traffic variation (Figure 4) to analyse, …" --> "to analyse" does not fit in the sentence. Can you leave that out?

Response: We thank for reviewer's comment. We have removed "to analyze" in this sentence in Lines 327-330, Page16.

Combined with the spatial distribution of precipitation and traffic variation (Figure 4), the snowfall on December 16th caused a large traffic speed reduction of the suburban roads, which led to a significant reduction in overall EMS coverage.

• L. 324: "Therefore, we chose these four days as the worst weather scenario of the year and analysis the…" --> Do you mean "and analysed the…"?

Response: We thank for reviewer's comment. Yes, it should be "analyzed" and we corrected the mistake in Lines 336-338, Page16.

In the following, we chose these four days as the worst weather scenario of the year and analyzed the spatial differences of medical accessibility in the whole city.

• L. 151: “The meteorological data utilized in this paper are TRMM precipitation” --> Could you write out the full term in case readers are not familiar with the abbreviation?

Response: We thank for reviewer’s comment. TRMM refers to Tropical Rainfall Measuring Mission. We added this in Lines 152-153, Page 7:

The meteorological data utilized in this paper are TRMM (Tropical Rainfall Measuring Mission) precipitation data obtained from NASA.

• L. 263: "population medical accessibility index..." --> You have previously introduced the “total transfer time”, but use "population medical accessibility index" here.

Response: We thank for reviewer’s comment. The mistake has been revised in Lines 266-267, Page 13:

For each population grid centroid i, its total transfer time (T) is calculated by eq.(4)

• L. 500: “Third, due to the lack of high-resolution DSM data…” --? Could you write out the full term in case readers are not familiar with the abbreviation?

Response: We thank for reviewer’s comment. DSM refers to Digital Surface Model. We added this in Lines 500-502, Page 25:

due to the lack of high-resolution DSM (Digital Surface Model) data, we didn’t run a hydrological flood simulation in Beijing

• L. 478: “The reduction extent of EMSs accessibility was close to previous studies.” --> Can you briefly mention the other studies?

Response: We thank for reviewer’s comment. We have added the reference for this sentence in Lines 478-479, Page 24, and we have added brief comparison in our results in Lines 330-334, Pages 16:

The reduction extent of EMSs accessibility was close to previous studies (Yin et al., 2021; Coles et al., 2017).

In previous studies, Yin et al. (2021) found that 5- and 20-year pluvial flooding both exerted less than 1% reduction in EMSs coverage rate of Shanghai, China; Coles et al. (2017) found that the coverage of Fire and Rescue Stations services showed a 6% reduction overall under their modelled floods events in York, UK.

Figures:

• Could you indicate the software used to produce each figure, such as figures 3, 5, 8, 10?

• Could you also indicate the name of the GIS software used to produce the figures 1, 4, 6, 7, 9, and 11? Can this information be included in the caption and/or appendix?

Response: We thank for reviewer's comment. Figures 3, 5, 8, 10 were made in Excel 2016. Figures 1, 4, 6, 7, 9, and 11 were made in ArcGIS 10.8. And we have added the descriptions after each figure title.

Technical corrections:

• L. 28: "… the area in the citywide that could get EMs" --> Do you mean "the area in the city" or "the area in the citywide network"?

• L. 33: "Furthermore, towns with lower baseline EMSs accessibility is more vulnerable to inclement weather." --> "towns… are".

• L. 185: "Both service area analysis and OD Cost Matrix analysis are GIS-based, and was done in ArcGIS 10.8" --> "Both the service area analysis and the OD cost matrix analysis are GIS-based and were done in ArcGIS 10.8."?

• L. 269: "the diurnal variation in traffic can be divided into fourperiods" --> "four periods"?

• L. 483: "The relevant methods mentioned in this paper is also suitable for both holidays and workdays" --> "are suitable"?

• L. 494: "If with longer time series precipitation and traffic data, we could analyze the impact of precipitation magnitude to the traffic and accessibility,…" --> The sentence is somewhat cumbersome. Do you mean "If we had longer time series…"?

• L. 501: "we didn't run a hydrological" --> Could you write "did not"?

• L. 61: "1.5~2 hours for each evacuation during the rainstorm, while the transfer time wouldn't" --> Could you write "would not" ?

Response: We thank for reviewer's comment. We have corrected these technical mistakes based on reviewers' comments.

There are inconsistencies in line quotes. Sometimes a space is inserted between the end of the sentence and the reference, sometimes not. Could you please be consistent. Examples include:

• L. 46: "survival(Blackwell and Kaufman, 2002)."

• L. 68: "cities more frequently(Huber and Gulledge, 2011; ….)"

• L. 69: "problem of urban rainstorms and waterlogging(the…)"

• L. 86: “shortest path analysis method(Albano…”
• L. 201: “holiday effects(Cools et al., 2007), season….”
• L. 227: “area analysis of the 15-minute(Yin et al.,...”
Response: We thank for reviewer’s comment. We have inserted spaces between the end of the sentence and the reference throughout the paper.

There are inconsistencies in the spacing between numbers and units. Could you please be consistent. Examples include:
• L. 65: “190.6mm”, but line 58 mentions: “170 mm”
Response: We thank for reviewer’s comment. We have unified the spacing between numbers and nits throughout the paper. For example, the “190.6mm” has been changed into “190.6 mm”, and the number “170 mm” has been changed into “170.0 mm”.

There are inconsistent spellings of the term hotspot. Examples include:
• L. 358: “the hot spots…”, but lines 24/ 90 mention: “hotspots”
Response: We thank for reviewer’s comment. We have corrected the inconsistencies in the revised manuscript.

There are inconsistencies in the use of words or numerals for numbers:
• L. 206: “…we would continue to look forward or backward until 4 baseline days are found. The average speed data of the four baseline days…” --> Use “four” consistently.
• L. 203: “For a given precipitation day, we search for the same day of week in the 2 weeks forward and backward to obtain the corresponding baseline days without precipitation.” --> Use “two”
Response: We thank for reviewer’s comment. We have corrected the inconsistencies in the revised manuscript.

Repetitions and very long sentence that affect readability.
• L. 57: “For example, on July 21, 2012, Beijing was hit by a rainstorm, with the average cumulative rainfall reaching 170 mm, caused 63 roads to be seriously flooded, and led to a one-third increase in the number of calls to the emergency center, and the transfer time of ambulances was significantly prolonged, taking approximately 1.5~2 hours for each evacuation during the rainstorm, while the transfer time wouldn’t be more than 1 hour on usual (Wang et al., 2013; Beijing Evening,2012).”
• L. 359: “Compared with other districts in inner suburbs, such as Shunyi,Daxing, and Tongzhou, these areas are farther away from the city center and have less distribution of medical facilities and sparser road networks and more vulnerable to inclement weather, and these areas are also regions with a relatively higher proportion of the elderly population over the age of 80 in the total population.” --> Also, the word "and" is used too often, which affects readability.

Response: We thank for reviewer's comment. We revised the sentences in Lines 58-64, Page3 and Lines 372-375, Pages 18-19:

For example, on July 21, 2012, Beijing was hit by a rainstorm, with the average cumulative rainfall reaching 170.0 mm, caused 63 roads to be seriously flooded. This rainfall event led to a one-third increase in the number of calls to the emergency center, and the transfer time of ambulances was significantly prolonged, taking approximately 1.5~2 hours for each evacuation during the rainstorm. Usually, the transfer time would not be more than 1 hour. (Wang et al., 2013; Beijing Evening,2012)

The suburb areas, such as Shunyi, Daxing, and Tongzhou, are more vulnerable to inclement weather as they have less distribution of medical facilities and sparser road networks, as well have a relatively higher proportion of the elderly population over the age of 80.

Could you paraphrase sentences that currently begin with "And"?
• L. 30: "And we found that snowfall has a greater impact on the accessibility of EMSs than rainfall."
• L. 383: "And on snowy days"
• L. 503: "And this could be improved"
Response: We thank for reviewer's comment. We removed the meaningless "and" in these sentences.

Citation style:
• L. 118: "According to the seventh national census (http://www.stats.gov.cn/tjsj/tjgb/rkpcgb/)" --> Could you please adhere to the citation style and do not include the web link in-line?
• L. 155: "According to the China Meteorological Administration" --> Could you please provide a reference for this source?
• L. 165: "The locations of these first-aid stations were obtained from the distribution map of first-aid stations published on the official website of the Beijing Emergency Center," --> Could you please provide a reference for this source?
• L. 168: "The hospital point data were extracted from the online map point of interest (POI) data of Beijing in 2019." --> Could you please provide a reference for this source?
• L. 175: "The demographic data of 2019 were obtained from WorldPop..." --> Could you please provide a reference for this source?

Response: We thank for reviewer's comment. We have added references in the revised manuscript as given below.

National Bureau of Statistics. Bulletin of the National Population Census. Available at: http://www.stats.gov.cn/tjsj/tjgb/rkpcgb/ (last access: 11 February 2023), 2021.

China Meteorological Administration. Classification of precipitation. Available at: https://www.cma.gov.cn/2011xzt/2012zhuant/20120928_1_1_1_1/2010052703/20121212/t20121212_195616.html (last access: 11 February 2023), 2012.
Beijing Emergency Medical Center. Available at: https://beijing120.com/channel/184 (last access: 30 August 2021).
Gaode Maps. Available at: https://lbs.amap.com/api/webservice/guide/api/search (lase access: 30 August 2021).
WorldPop (www.worldpop.org - School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Departement de Geographie, Universite de Namur) and Center for International Earth Science Information Network (CIESIN), Columbia University (2018). Global High Resolution Population Denominators Project - Funded by The Bill and Melinda Gates Foundation (OPP1134076).