AN INTERACTIVE EVACUATION TOOL TO IMPROVE THE PUBLIC FLOOD PERCEPTION

W. L. Li[1],*, N. Treff[1], F. Amann[1], J. Lehmen[1], Y. Dehbi[2], J.-H. Haunert[1]

[1] Institute of Geodesy and Geoinformation, University of Bonn, Germany, li@igg.uni-bonn.de
[2] Computational Methods Lab, HafenCity University Hamburg, Germany

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ABSTRACT:

The advancing climate change increases the danger of heavy rainfall events and devastating floods, which significantly threaten people's lives and properties. Geographic information system (GIS) has been a valuable tool for mapping flood risks and emergency management worldwide. In this paper, we develop an interactive evacuation tool to improve public flood perception. This work presents how to create an interactive and animated evacuation tool to strengthen the population's preparedness and action ability in case of a flood. We simulate water depths and flow velocities for a flood scenario in Bonn, Germany. Afterwards, we investigate the flood's impact on buildings and streets for different flood situations using geoinformation tools in the software QGIS. Based on thresholds from the literature, we identify endangered buildings where inhabitants have to evacuate and streets still ensuring safe locomotion options during the advancing flood. Taking possible shelter points for the population into account then allows for computing the shortest path to the nearest shelter at each flood situation. Our findings are summarized in evacuation maps that can be used together as interactive information tools for the public and can also serve rescue management and disaster education.

1. BACKGROUND

The latest report released by the Intergovernmental Panel on Climate Change (IPCC)[1] confirmed that extreme disasters induced by climate change had impacted human society more intensely and frequently than previously thought (Bhatt et al., 2015; Netzel et al., 2021). Particularly, catastrophic floods are one of the most widespread and frequent natural disasters on Earth (Li et al., 2013, 2015; Costabile et al., 2021; Li et al., 2022b; Mudashiru et al., 2021). In July 2021, several European countries experienced consecutive rainstorms and floods, devastatingly damaging many homes and businesses, causing almost 700 injuries, and 200 people died in the floods, where Germany and Belgium suffered the worst damage (Fekete and Sandholz, 2021; Bosseler et al., 2021; Serra-Llobet et al., 2022). In particular, more than 130 lives were lost in the Ahr Valley to the south of Bonn, Germany. Across Europe, the economic losses amounted to approximately 35.3 billion euros (Mohr et al., 2022). This flood hints that the frequency of such events may increase in a rapidly warming climate and global fashion, and there is much room to improve the initiatives for flood risk management (Tradowsky et al., 2023; Li et al., 2023; Kruczkiewicz et al., 2022).

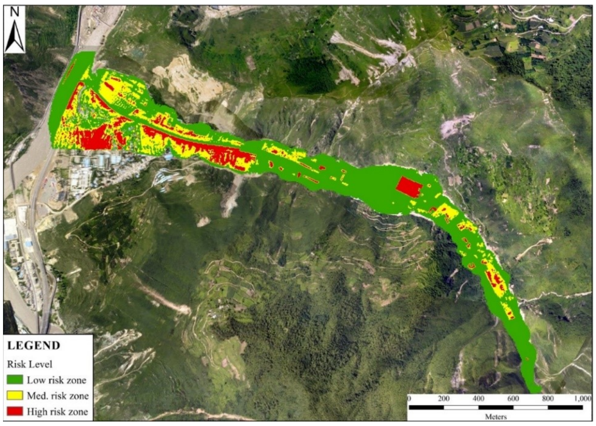
Apart from the structural measures for flood mitigation (Minea and Zaharia, 2011; Islam and Ryan, 2015; Meyer et al., 2012b), the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) states that the disaster agency should develop, periodically update and disseminate location-based disaster risk information, including disaster maps, to decision-makers, the general public and communities by using geospatial information technology (Center, 2015; Chisty et al., 2022; Aitsi-Selmi et al., 2016; Kelman, 2015), which the European Commission (EC) has also been working towards. For example, the European Union Floods Directive (FD) required the establishment of flood maps for high-risk cities in all member states by 2013 (Meyer et al., 2012a; Van Kerkvoorde et al., 2018). Roughly spoken, flood maps targeting the preparation for the public already exist, which are classified into frequent flood events (HQ10-20), mean flood events (HQ100), and extreme flood events (HQExtreme) (Viviroli et al., 2009; Barth and Döll, 2016). HQ values represent a statistically high, mean, and low probability of occurrence according to the flood's water runoff.

There are two types of maps, hazard and risk maps (Dransch et al., 2010; Li et al., 2022b; Meyer et al., 2012a; Hagemeier-Klose and Wagner, 2009). Hazard maps, also called damage maps, highlight the affected areas, damaged buildings, causes and consequences of a specific disaster event. Risk maps are designed to illustrate the likelihood or frequency of a disaster event occurring. In many cases, these two types of maps are not clearly distinguished from each other, but they can serve a variety of purposes, e.g. flood impact assessment, spatial planning, early warning, emergency planning, and disaster education (Hammond et al., 2015; Bhola et al., 2020; Li et al., 2021b; Macchione et al., 2019; Huang et al., 2015; Rothkrantz and Fitrianie, 2018; Smith et al., 2016; Mudashiru et al., 2021). Figure 1(a) and (b) show an example of a risk map of a debris flow disaster and an example of a landslide susceptibility map, respectively.

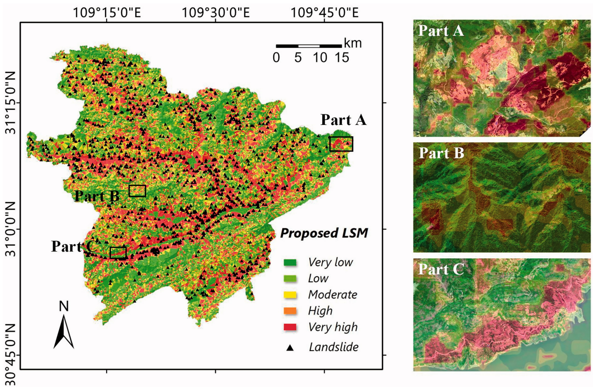
Disaster maps generally have wealth of information, and a professional design and representation (Peng et al., 2017). However, they are not entirely intuitive to the public (Li et al., 2022a; Kellens et al., 2009; Meyer et al., 2009; Liu et al., 2018; Hagemeier-Klose and Wagner, 2009), and they merely show general static information about floods and give no recommended individual action, which results in the general public without direct flood experience not being able to imagine what really happens. From the authors' point of view, the primary concern for the public is what to do when they face advancing floods.

* Corresponding author

[1] https://us.milliman.com/-/media/milliman/pdfs/2022-articles/3-28-22_europe-extreme-weather-report.ashx



(a) A risk map of a debris flow (Yin et al., 2017).



(b) a susceptibility map of a landslide (Zeng et al., 2022).

Figure 1. Examples of disaster maps.

Specifically, the flood maps for the general public should answer the following " $2W$ and $1H$ " questions:

1. When should they leave the house?
2. Where can they go?
3. How can they move to the shelter?

In this context, we develop an interactive evacuation tool for floods and achieve a particular form of appealing storytelling for the general public. The aim is to use this tool to recommend individual evacuation actions for the public and also serve rescue management.

The reminder of this paper is structured as follows: Section 2 gives insights into the introduced approach. Section 3 discusses the experimental results. Section 4 summarizes the paper and gives an outlook for future research.

2. METHODOLOGY

Figure 2 shows the roadmap for the implementation of interactive flood evacuation tool, which mainly includes endangered building detection, safe road detection, possible shelter selection, and the shortest route planning.

Based on the criteria proposed by Pistrika and Jonkman (2010), we adopt the equation (1) to detect the endangered buildings in the flooded area.

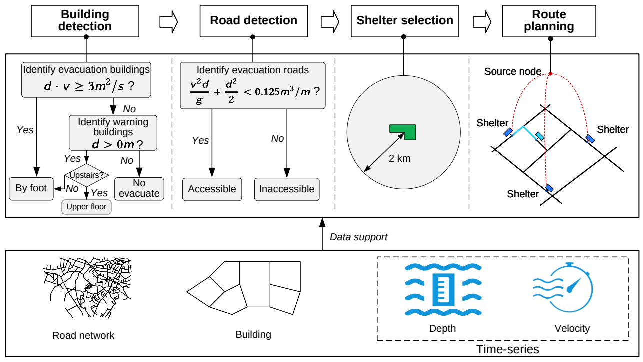


Figure 2. Roadmap for the implementation of interactive flood evacuation tool.

$$d \cdot v \geq 3 \tag{1}$$

In this equation, d indicates the water depth, and v represents the flow velocity. Suppose the product of d and v around the flooded building exceeds the threshold, the corresponding evacuation recommendation will be given. However, the risk status of buildings will change as the flood evolves, therefore a time series of simulation data is used to deal with this case.

Additionally, we use the equation (2) to detect flooded streets where safe evacuation by walking is still possible to reach the shelter points (Ishigaki, 2008).

$$\frac{v^2 d}{g} + \frac{d^2}{2} < 0.125 \tag{2}$$

Where g is the gravitational acceleration and d and v are as before.

Subsequently, the buffer analysis is used to identify the shelters within 2 km of the evacuation area. In our case, the school is mainly considered a shelter, and we concentrate on evacuation by foot because of the lack of parking places at the shelters.

Finally, the single source shortest path algorithm is used to compute the nearest reachable shelter for the building that needs to be evacuated. We introduce a dummy node (red node in Figure 2) and link it to each shelter, which connects to the building by the street graph. Subsequently, one call of the algorithm with the dummy node as the source could find the shortest path between every building and its nearest shelter, and the individuals can determine their optimal evacuation path by building ID.

3. EXPERIMENTAL RESULTS

3.1 Study area

In our study, we selected a section of the Rhine in Bonn, Germany, as the case area for the experiment analysis. Bonn covers an area of about $141km^2$ with an average altitude of about $60m$ above sea level. It is situated in a valley and is divided by the Rhine River. Figure 3 shows the location of Bonn. Bonn has been flooded many times in history, with the highest water level exceeding $10m$ in 1993. Figure 4 shows the tide gauge station in Bonn[2].

[2] https://undine.bafg.de/rhein/pegel/rhein_pegel_bonn.html?msclkid=c183e776cf7c11ecb033793457de2307

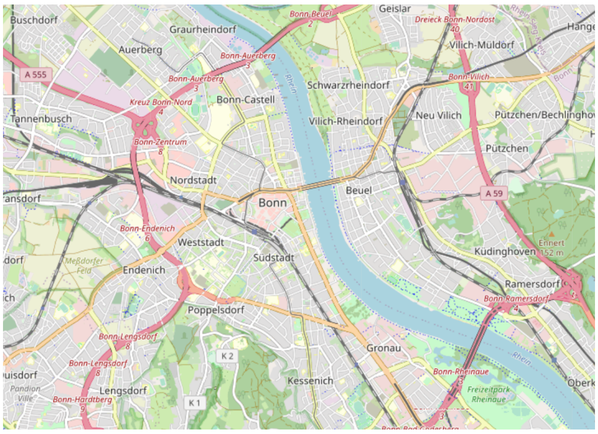


Figure 3. The location of Bonn, Germany.
Source: Openstreetmap

Figure 4. Tide gauge station in Bonn.

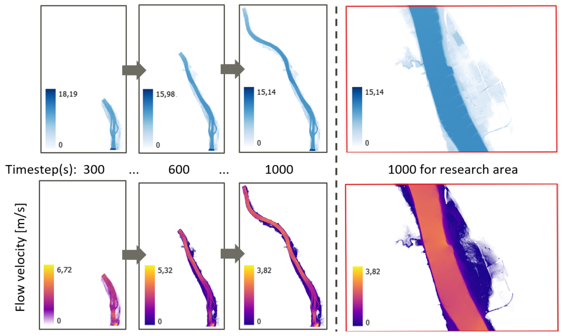
3.2 Data description

Figure 5 shows the geodata required for flood simulation and evacuation analysis. The flood simulation data was provided by Li et al. (2021a), which refers to a system that integrates a numerical model of flood based on the cellular automata (CA) and the virtual geographic environment (VGE) framework. To realize the simulation and visualization of a flood process, this system develops a workflow that includes data acquisition, model calculation and dynamic visualization functions. In addition, the whole process of a flood can be visualized in a virtual 3D view through a user-friendly operation interface and flexible parameter configuration. Digital elevation model (DEM), building, and road network data were obtained from Open North-Rhine-Westphalia (NRW)[3].

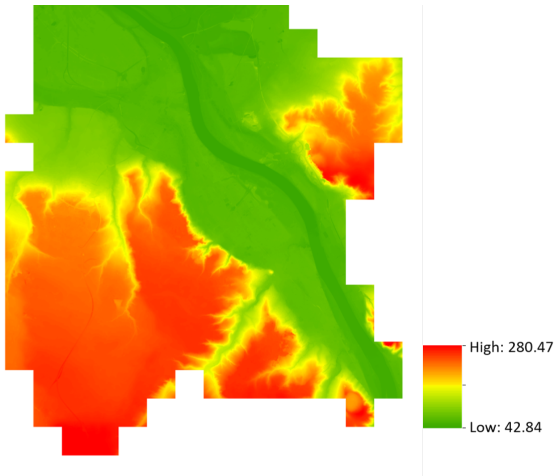
3.3 Results analysis

The interactive evacuation tool, designed to recommend evacuation actions during a flood, has been implemented using Java. Figure 6(a) shows the recommended action in 1 hour and 24 minutes after the flood started, while Figure 6(b) illustrates the subsequent time step, which occurred 2 hours and 6 minutes later. Although the building selected by the user was classified as safe in both time steps, its assigned shelter and path were determined based on the state of flood propagation. The simulation can foresee that the building will soon be classified as endangered and thus has to be evacuated. Therefore the tool depicts the assignment and the path to a shelter at a point of time

[3] https://open.nrw/



(a) Water depth and flow velocity.

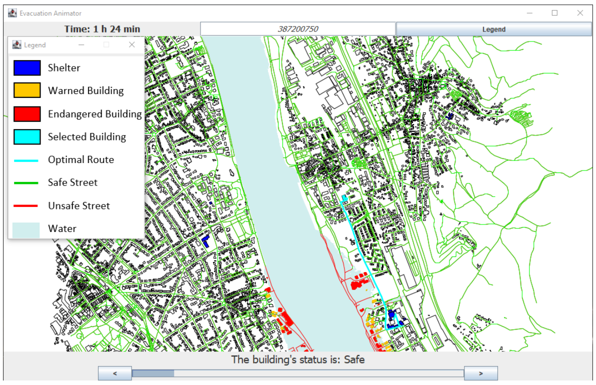


(b) Digital elevation model.

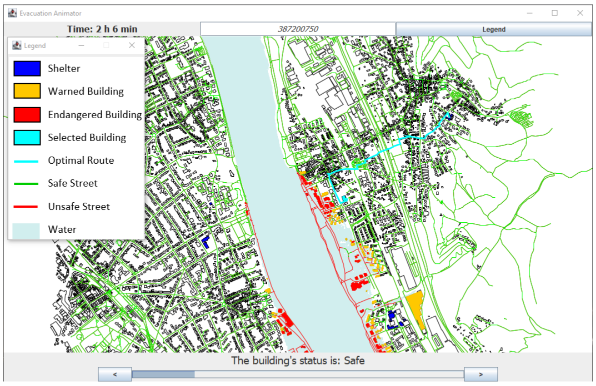
(c) Building and road data.

Figure 5. Geodata required for flood simulation and evacuation analysis.

where evacuation via a path is still possible. In summary, the finding of our work could provide a flood evacuation recommendation to individuals, which could be further applied to the popularization of disaster science for the general public, thus enhancing flood risk perception in the community.



(a) Assignment to nearest shelter.



(b) Assignment to eastern shelter due to evolving flood.

Figure 6. Different recommendations from the interactive evacuation tool.

4. CONCLUSION

In this paper, we developed an evacuation tool that considers time series simulation data to generate evacuation actions for the inhabitants in a flooded area. The advantage of the temporal evolution of flood allows us to deduce the current and future status of the building. In the case of an endangered building, an optimal evacuation route to the nearest shelter will be generated, even at an earlier time step. With this proceeding, we can clearly state for each inhabitant what to do in the case of a flood.

The present interactive tool shows the evacuation for inhabitants in endangered buildings by foot. An open point for future work might be incorporating other evacuation methods, such as by bus or car.

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References

Aitsi-Selmi, A., Murray, V., Wannous, C., Dickinson, C., Johnston, D., Kawasaki, A., Stevance, A.-S., Yeung, T., 2016. Reflections on a science and technology agenda for 21st century disaster risk reduction: Based on the scientific content of the 2016 UNISDR science and technology conference on the implementation of the Sendai framework for disaster risk reduction 2015–2030. *International Journal of Disaster Risk Science*, 7, 1–29.

Barth, N.-C., Döll, P., 2016. Assessing the ecosystem service flood protection of a riparian forest by applying a cascade approach. *Ecosystem Services*, 21, 39–52.

Bhatt, D., Mall, R., Banerjee, T., 2015. Climate change, climate extremes and disaster risk reduction: Stéphane hallegatte: Natural disasters and climate change: an economic perspective. springer international publishing, doi: 10.1007/978-3-319-08933-1, isbn: 978-3-319-08932-4.

Bhola, P. K., Leandro, J., Disse, M., 2020. Building hazard maps with differentiated risk perception for flood impact assessment. *Natural Hazards and Earth System Sciences*, 20(10), 2647–2663.

Bosseler, B., Salomon, M., Schlüter, M., Rubinato, M., 2021. Living with urban flooding: A continuous learning process for local municipalities and lessons learnt from the 2021 events in Germany. *Water*, 13(19), 2769.

Center, A. D. R., 2015. Sendai framework for disaster risk reduction 2015–2030. *United Nations Office for Disaster Risk Reduction: Geneva, Switzerland*.

Chisty, M. A., Muhtasim, M., Biva, F. J., Dola, S. E. A., Khan, N. A., 2022. Sendai Framework for Disaster Risk Reduction (SFDRR) and disaster management policies in Bangladesh: How far we have come to make communities resilient? *International Journal of Disaster Risk Reduction*, 76, 103039.

Costabile, P., Costanzo, C., De Lorenzo, G., De Santis, R., Penna, N., Macchione, F., 2021. Terrestrial and airborne laser scanning and 2-D modelling for 3-D flood hazard maps in urban areas: New opportunities and perspectives. *Environmental Modelling & Software*, 135, 104889.

Dransch, D., Rotzoll, H., Poser, K., 2010. The contribution of maps to the challenges of risk communication to the public. *International Journal of Digital Earth*, 3(3), 292–311.

Fekete, A., Sandholz, S., 2021. Here comes the flood, but not failure? Lessons to learn after the heavy rain and pluvial floods in Germany 2021. *Water*, 13(21), 3016.

Hagemeier-Klose, M., Wagner, K., 2009. Evaluation of flood hazard maps in print and web mapping services as information tools in flood risk communication. *Natural hazards and earth system sciences*, 9(2), 563–574.

Hammond, M. J., Chen, A. S., Djordjević, S., Butler, D., Mark, O., 2015. Urban flood impact assessment: A state-of-the-art review. *Urban Water Journal*, 12(1), 14–29.

Huang, J., Huang, R., Ju, N., Xu, Q., He, C., 2015. 3D WebGIS-based platform for debris flow early warning: A case study. *Engineering Geology*, 197, 57–66.

Ishigaki, T., 2008. Evacuation criteria during urban flooding in underground space. *Proc. of 11th ICUD, Scotland, UK, 2008*.

Islam, T., Ryan, J., 2015. *Hazard mitigation in emergency management*. Butterworth-Heinemann.

Kellens, W., Vanneuville, W., Ooms, K., De Maeyer, P., 2009. Communicating flood risk to the public by cartography. *Proceedings of the 24th International Cartographic Conference, Santiago de Chili*.

Kelman, I., 2015. Climate change and the Sendai framework for disaster risk reduction. *International Journal of Disaster Risk Science*, 6, 117–127.

Kruczkiewicz, A., Cian, F., Monasterolo, I., Di Baldassarre, G., Caldas, A., Royz, M., Glasscoe, M., Ranger, N., van Aalst, M., 2022. Multiform flood risk in a rapidly changing world: what we do not do, what we should and why it matters. *Environmental Research Letters*, 17(8), 081001.

Li, W., Haunert, J.-H., Knechtel, J., Zhu, J., Zhu, Q., Dehbi, Y., 2023. Social media insights on public perception and sentiment during and after disasters: The European floods in 2021 as a case study. *Transactions in GIS*, 27(6), 1766-1793.

Li, W., Zhu, J., Fu, L., Zhu, Q., Guo, Y., Gong, Y., 2021a. A rapid 3D reproduction system of dam-break floods constrained by post-disaster information. *Environmental Modelling & Software*, 139, 104994.

Li, W., Zhu, J., Fu, L., Zhu, Q., Xie, Y., Hu, Y., 2021b. An augmented representation method of debris flow scenes to improve public perception. *International Journal of Geographical Information Science*, 35(8), 1521–1544.

Li, W., Zhu, J., Haunert, J.-H., Fu, L., Zhu, Q., Dehbi, Y., 2022a. Three-dimensional virtual representation for the whole process of dam-break floods from a geospatial storytelling perspective. *International Journal of Digital Earth*, 15(1), 1637–1656.

Li, W., Zhu, J., Pirasteh, S., Zhu, Q., Fu, L., Wu, J., Hu, Y., Dehbi, Y., 2022b. Investigations of disaster information representation from a geospatial perspective: Progress, challenges and recommendations. *Transactions in GIS*, 26(3), 1376–1398.

Li, Y., Gong, J., Liu, H., Zhu, J., Song, Y., Liang, J., 2015. Real-time flood simulations using CA model driven by dynamic observation data. *International Journal of Geographical Information Science*, 29(4), 523–535.

Li, Y., Gong, J., Zhu, J., Song, Y., Hu, Y., Ye, L., 2013. Spatiotemporal simulation and risk analysis of dam-break flooding based on cellular automata. *International Journal of Geographical Information Science*, 27(10), 2043–2059.

Liu, W., Dugar, S., McCallum, I., Thapa, G., See, L., Khadka, P., Budhathoki, N., Brown, S., Mechler, R., Fritz, S. et al., 2018. Integrated participatory and collaborative risk mapping for enhancing disaster resilience. *ISPRS International Journal of Geo-Information*, 7(2), 68.

Macchione, F., Costabile, P., Costanzo, C., De Santis, R., 2019. Moving to 3-D flood hazard maps for enhancing risk communication. *Environmental modelling & software*, 111, 510–522.

Meyer, V., Kuhlicke, C., Luther, J., Fuchs, S., Priest, S., Dorner, W., Serrhini, K., Pardoe, J., McCarthy, S., Seidel, J. et al., 2012a. Recommendations for the user-specific enhancement of flood maps. *Natural Hazards and Earth System Sciences*, 12(5), 1701–1716.

Meyer, V., Priest, S., Kuhlicke, C., 2012b. Economic evaluation of structural and non-structural flood risk management measures: examples from the Mulde River. *Natural Hazards*, 62, 301–324.

Meyer, V., Scheuer, S., Haase, D., 2009. A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. *Natural hazards*, 48, 17–39.

Minea, G., Zaharia, L., 2011. Structural and non-structural measures for flood risk mitigation in the bâsca river catchment (romania. *Forum geografic*, 10number 1.

Mohr, S., Ehret, U., Kunz, M., Ludwig, P., Caldas-Alvarez, A., Daniell, J. E., Ehmele, F., Feldmann, H., Franca, M. J., Gattke, C. et al., 2022. A multi-disciplinary analysis of the exceptional flood event of July 2021 in central Europe. Part 1: Event description and analysis. *Natural Hazards and Earth System Sciences Discussions*, 1–44.

Mudashiru, R. B., Sabtu, N., Abustan, I., Balogun, W., 2021. Flood hazard mapping methods: A review. *Journal of hydrology*, 603, 126846.

Netzel, L. M., Heldt, S., Engler, S., Denecke, M., 2021. The importance of public risk perception for the effective management of pluvial floods in urban areas: A case study from Germany. *Journal of Flood Risk Management*, 14(2), e12688.

Peng, G., Yue, S., Li, Y., Song, Z., Wen, Y., 2017. A procedural construction method for interactive map symbols used for disasters and emergency response. *ISPRS International Journal of Geo-Information*, 6(4), 95.

Pistrika, A. K., Jonkman, S. N., 2010. Damage to residential buildings due to flooding of New Orleans after hurricane Katrina. *Natural Hazards*, 54, 413–434.

Rothkrantz, L. J., Fitrianie, S., 2018. Public awareness and education for flooding disasters. *Crisis management-theory and practice*, IntechOpen.

Serra-Llobet, A., Jähnig, S. C., Geist, J., Kondolf, G. M., Damm, C., Scholz, M., Lund, J., Opperman, J. J., Yarnell, S. M., Pawley, A. et al., 2022. Restoring rivers and floodplains for habitat and flood risk reduction: experiences in multi-benefit floodplain management from California and Germany. *Frontiers in Environmental Science*, 9, 778568.

Smith, P., Pappenberger, F., Wetterhall, F., Del Pozo, J. T., Krzeminski, B., Salamon, P., Muraro, D., Kalas, M., Baugh, C., 2016. On the operational implementation of the european flood awareness system (efas). *Flood forecasting*, Elsevier, 313–348.

Tradowsky, J. S., Philip, S. Y., Kreienkamp, F., Kew, S. F., Lorenz, P., Arrighi, J., Bettmann, T., Caluwaerts, S., Chan, S. C., De Cruz, L. et al., 2023. Attribution of the heavy rainfall events leading to severe flooding in Western Europe during July 2021. *Climatic Change*, 176(7), 90.

Van Kerkvoorde, M., Kellens, W., Verfaillie, E., Ooms, K., 2018. Evaluation of web maps for the communication of flood risks to the public in Europe. *International Journal of Cartography*, 4(1), 49–64.

Viviroli, D., Mittelbach, H., Gurtz, J., Weingartner, R., 2009. Continuous simulation for flood estimation in ungauged mesoscale catchments of Switzerland–Part II: Parameter regionalisation and flood estimation results. *Journal of Hydrology*, 377(1-2), 208–225.

Yin, L., Zhu, J., Li, Y., Zeng, C., Zhu, Q., Qi, H., Liu, M., Li, W., Cao, Z., Yang, W. et al., 2017. A virtual geographic environment for debris flow risk analysis in residential areas. *ISPRS International Journal of Geo-Information*, 6(11), 377.

Zeng, H., Zhu, Q., Ding, Y., Hu, H., Chen, L., Xie, X., Chen, M., Yao, Y., 2022. Graph neural networks with constraints of environmental consistency for landslide susceptibility evaluation. *International Journal of Geographical Information Science*, 36(11), 2270–2295.

https://doi.org/10.5194/isprs-archives-XLVIII-1-W2-2023-437-2023