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Integrating cellular automata model into 3D representation for enhancing flood risk communication

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Abstract:

“Floods are acts of God”, but flood disasters are a “people and space” issue (White, 1945). Thus, risk communication plays a vital role in flood risk management, which is an interactive process of information exchange among stakeholders with the aim of developing a shared understanding of disaster risks and characteristics, thereby enabling them to react better to an emergency (Dransch et al., 2010, Macchione et al., 2019, Santis et al., 2018). Since the spatiotemporal nature of floods, location-based risk communication makes it easier for the general public without direct experience with the flood to understand its occurrence and development.

Many studies have proved that flood risk maps are valuable in risk communication and knowledge sharing (Li et al., 2022). The general process of flood risk mapping includes two steps: numerical modelling and map generation. Flood modelling utilizes a mathematical approach to solve equations that can represent the physical behavior of water. Most one-dimensional (1D), two-dimensional (2D), and three-dimensional (3D) hydrodynamic models have been integrated into flood simulation tools (e.g., MIKE, HEC-RAS, and Delft 3D) for global users (Nkwunonwo et al., 2020), they can use the software to get the essential output of floods, such as depth, velocity, inundation extent, etc. Furthermore, the above-mentioned information can be overlaid with resource maps on geographic information system (GIS) platforms to present the spatial distribution and accessibility of affected infrastructures through map generation. However, the existing studies for flood modelling and representation have the following deficiencies which limit the efficiency of flood risk communication in the general community: (1) the modelling is difficult for stakeholders to use due to the cumbersome parameter settings; (2) the information representation cannot be easily understood by laypersons.

In this context, we adopt a numerical modelling approach based on cellular automata (CA) for floods since the advantages of low data requirements, high computational efficiency, and suitability for parallel computing (Li et al., 2013). The structure of the CA-based numerical model of floods is shown in Figure 1, where each cell has five attributes, namely water depth, roughness coefficient, surface elevation, and single-width fluxes in the X-direction and Y-direction. The basic idea of cell value update is to solve Saint-Venant equations (Li et al., 2013): (1) compute the single-width fluxes $M_{i,j}^{t+1}$, $N_{i,j}^{t+1}$ at the moment $t+1$ based on $M_{i,j}^{t}$, $N_{i,j}^{t}$, the water depth $d_{i,j}^{t}$ and the corresponding neighbourhoods $d_{i+1,j}^{t}$,

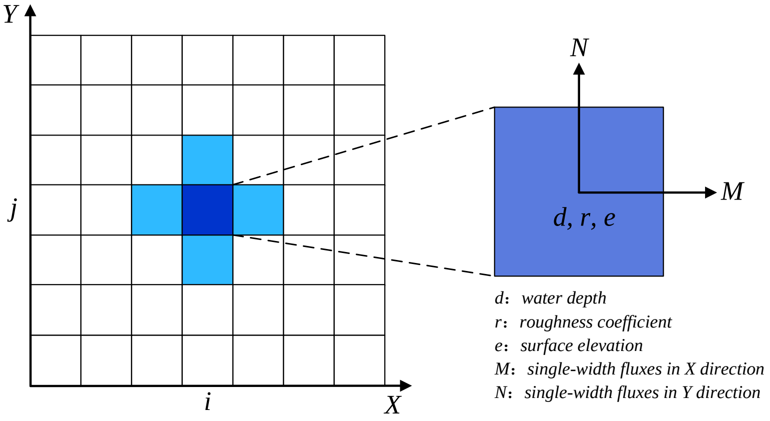

Figure 1. The structure of the CA-based numerical model of floods. The type of neighborhood is the Von Neumann neighbourhood, which is composed of a central cell and four adjacent cells.

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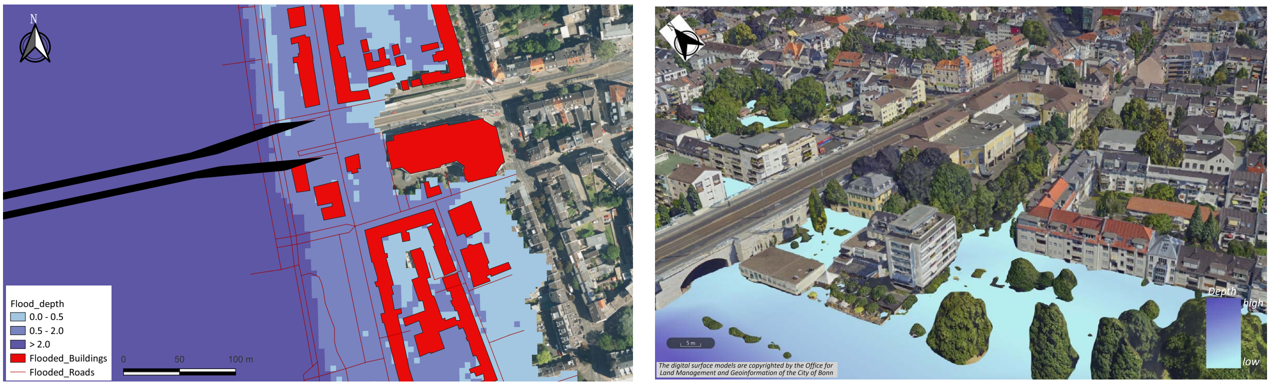

(a) A classic flood map based on satellite imagery.

(b) Our flood representation in a 3D virtual environment.

Figure 2. The flood representation in 2D and 3D views.

$d^t_{i,j+1}$ at the moment t, roughness coefficient $r_{i,j}$, surface elevation $e_{i,j}$, flow velocity $u^t_{i,j}$ and $v^t_{i,j}$; (2) update the water depth $d^{t+1}_{i,j}$ at the moment $t+1$ based on the single-width fluxes $M^{t+1}_{i,j}$ and $N^{t+1}_{i,j}$; (3) iterate the above process and output the water depth values of all cells within the flood range. Subsequently, we convert the cells with water depth from 2D projection coordinates to 3D geographical coordinates, and then we take the four adjacent cells as the basic unit to construct the triangular model in 3D. The water depth at each moment is one-to-one mapped according to a continuous blue ribbon, which is consistent with the general public perception of floods. The main contribution is that we adopt a simple CA model compared with hydrodynamic models for flood modelling, the modelling results are transformed from 2D to 3D, from abstract to realistic, which allows flood modelling to move away from specialized outputs to intuitive 3D scenes.

In addition, we selected a section of the Rhine in Bonn, Germany, as the case area for the experiment analysis. The digital elevation model (DEM), digital surface model (DSM), and satellite images were collected for flood numerical modelling and 3D representation. The 3D open-source library CesiumJS was used to present the results and the experiment was tested on Google Chrome. Figure 2(a) and (b) show the representation of flood information in 2D and 3D views, respectively. It is clear that the flood representation in 3D is more helpful for participants from different backgrounds to understand the flooding process efficiently. The finding of our work could apply to the popularization of disaster science for the general public, thus enhancing flood risk communication in the community. In the future, one of our main tasks will be to integrate the hydrodynamic mechanism with the simplified CA model to improve accuracy while reducing model complexity.

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References

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

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

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

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

Nkwunonwo, U., Whitworth, M. and Baily, B., 2020. A review of the current status of flood modelling for urban flood risk management in the developing countries. *Scientific African* 7, pp. e00269.

Santis, R. D., Macchione, F., Costabile, P. and Costanzo, C., 2018. Visual risk communication of urban flooding in 3d environments based on terrestrial laser scanning. In: *International Conference on Urban Drainage Modelling*, Springer, pp. 783–787.

White, G. F., 1945. Human adjustment to floods: Department of geography research paper no. 29. *Chicago, IL: University of Chicago*.

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