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Integrating Flood Maps into Agent-Based Modeling for Participatory Management

Chainarong Kesamoon[1*], Prachya Boonprasurt[1]

[1]Thammasat University Research Unit in Strategic Science, Simulation and Decision Making, Pathumthani, 12121, Thailand

[*]Corresponding author. Email address: chainarong@mathstat.sci.tu.ac.th

Abstract

We illustrate the process of seamlessly integrating flood maps that have been derived from the Flood Modeller into agent-based simulation models. This demonstration highlights the smooth and effortless compatibility that exists with the Gama platform, underscoring the synergy between different technological tools in the realm of flood risk management. The utilization of this methodological approach not only showcases its efficacy but also presents a substantial potential for improvement across various dimensions. It offers a promising pathway for fostering a deep and comprehensive understanding of the complex dynamics involved in flood risk management, thereby facilitating the development of efficient mitigation strategies. This approach proves to be invaluable for a diverse array of stakeholders who have vested interests in the realm of flood risk management, providing a robust foundation for collaboration and informed decision-making.

Keywords: ABM, Gama platform, Flood Modeller, simulation, strategy

1. Introduction

Flooding serves as an environmental crisis that could result in substantial devastation and loss of life. The enactment of efficient flood control and mitigation measures is of paramount importance. One possible method to enhance flood control and mitigation strategies involves the integration of flood maps into agent-based modeling for participatory management. Agent-based modeling functions as a computational methodology that replicates the behaviors and interactions of individuals or entities (agents) within a specified system. Through the inclusion of flood maps within the architecture of Agent-Based Modeling, policymakers and stakeholders can achieve a more thorough understanding of the potential consequences of floods on diverse regions, infrastructure, and communities. This integration enables the analysis of various scenarios and the evaluation of different flood control strategies, like the placement of shelters, the implementation of early warning systems, and the distribution of resources for emergency response. In addition, the integration of flood maps in Agent-Based Modeling enables stakeholders to actively engage in the decision-making process. They are able to visualize and analyze the potential outcomes of various flood control strategies, thereby promoting more well-informed and collaborative decision-making. This approach also showcases the potential to reinforce community engagement and resilience by allowing individuals and communities to actively contribute their local knowledge and experience to the flood control process. Additionally, by combining flood maps with agent-based modeling, the model can be regularly updated with accurate and current data obtained from remote sensing technologies. Overall, the combination of flood maps with agent-based modeling for participatory management offers a powerful tool for understanding and optimizing flood control strategies. Essentially, the merging of flood maps with agent-based modeling presents a robust instrument for comprehending and refining flood control strategies.

2. State of the art

Flood modeling holds great importance in the comprehension and mitigation of flood impacts. There are multiple software tools and methodologies accessible for the simulation and analysis of flood events. Noteworthy examples include Flood Modeller, HEC-RAS, INFOWORKS, MIKE FLOOD, and LISFLOOD-FP, which are commonly utilized for flood simulation and risk assessment (Mark et al., 2015). Flood Modeller presents several benefits that establish it as a valuable instrument for flood modeling and risk assessment. A significant advantage is its capacity to offer a detailed and precise depiction of flood events. This software permits the simulation of intricate flood scenarios, encompassing two-dimensional modeling of urban surface topography, a crucial element for hydrodynamic simulations of surface floodwater (Mark et al., 2015). Such functionality empowers users to accurately map the actual flooding process with a high degree of accuracy, thereby enhancing the effectiveness of flood risk evaluations. In addition, Flood Modeller provides robust capabilities for delineating water processes and flooded areas based on hydrological models. This particular feature is essential for precisely delineating flood extents and grasping the dynamics of inundation, both of which are crucial for efficient floodplain and flood risk management.

Agent-based simulation software plays a crucial role in the representation of intricate systems composed of autonomous agents engaging in interactions with one another (Macal & North, 2010). The utilization of such simulations spans across various domains, such as manufacturing systems, where they are employed to assess agent-based controllers and improve system flexibility (Kovalenko et al., 2023). Notably, the GAMA platform has emerged as a significant instrument for agent-based modeling and simulation, offering benefits like user-friendly interfaces for modelers with limited programming skills (Taillandier et al., 2019). Scholars have underscored the advantages of integrating agent architectures into the GAMA platform to leverage its modeling language, which streamlines the process of model development (Bourgais et al., 2018).

GAMA's support for spatial data and spatial analysis, coupled with its componential architecture that allows for the concurrent use of multiple formalisms within a model, has made it a preferred choice for co-modeling environmental, social, and economic dynamics (Drogoul et al., 2016). This capability to handle diverse types of data and modeling approaches within a unified framework showcases the platform's robustness and flexibility in addressing complex interdisciplinary challenges

Moreover, the GAMA platform has garnered praise for its adaptability, sophisticated features for crafting agent-based models, and smooth integration of geospatial data, positioning it as a favored option for constructing agent-based models (Chambers, 2023). The platform has played a pivotal role in developing spatially explicit multi-agent simulations, demonstrating its efficacy in modeling abstract robots and extensive swarms of simple robots (Molins et al., 2019). Furthermore, GAMA has found application in participatory modeling and simulation, underscoring its importance in investigating complex systems and social phenomena (Taillandier et al., 2019; Davidsson & Verhagen, 2020).

Integrating flood maps into agent-based modeling for participatory management involves a comprehensive approach that combines various strategies to enhance flood risk management. The conventional flood protection paradigm typically relies on centrally implemented structural measures, but a more effective approach involves an integrated combination of structural and non-structural measures implemented by multiple actors in a participatory manner (Wagner et al., 2021). This integrated approach emphasizes utilizing all available data sources, flood models, and inundation maps for response, recovery, and mitigation activities during and after flood events.

The aim of this study is to offer a concise illustration of the smooth incorporation of flood maps, particularly those generated by Flood Modeller, into the sophisticated Gama platform for the purpose of conducting agent-based simulations. These simulations are intended to be utilized in the context of participatory management, a method that involves active engagement of stakeholders in decision-making processes related to flood risk management.

3. Materials and Methods

3.1. Study area

The study area encompasses the urban district within Wiang Sa, Nan province, Thailand, spanning approximately 4.6 square kilometers. Due to its geographical characteristics, this specific area is notably prone to flooding. Situated in a low-lying terrain, it frequently encounters substantial water retention from neighboring areas during periods of intense rainfall. The district's topography plays a crucial role in exacerbating its susceptibility to floods, as water from higher altitudes converges and accumulates in the valley where it is located. Recent assessments underscore the impact of heavy precipitation in Wiang Sa, resulting in severe flooding and subsequent mudslides that disrupt transportation networks by obstructing roads and toppling trees and electricity poles. In some instances, residents are compelled to seek refuge on rooftops as their residences are inundated by floodwaters.

The Nan River, a primary watercourse in the region, originates in the Luang Prabang Range. Particularly during the monsoon season, this river can significantly contribute to flooding events when water levels surge rapidly. An additional noteworthy river in Wiang Sa is the Sa River, which also emanates from elevated terrains. Converging with the Nan River near Wiang Sa town, this river plays a pivotal role in augmenting the water capacity of the vicinity. Serving as a tributary to the Nan River, the Sa River's influence on flood dynamics within the district is substantial, especially when both rivers concurrently experience elevated water levels. The study area encompasses a total of 2,236 structures, which were meticulously documented using QGIS and Google Satellite imagery.

Figure 1. Wiang Sa district and the study area

3.2. Flood modeling

The Flood Modeller software was utilized in the present investigation to analyze flood occurrences and evaluate their potential impacts. It facilitated the simulation of various flood scenarios, the estimation of flood depths and velocities, and the assessment of flood management strategies' efficacy. River modeling encompasses the interplay between the channel and both external and internal constraints, with consideration given to the necessity of conserving the mass and momentum of the water body. By incorporating referenced river lines and synthesis cross sections, the 1D river modeling method was employed to replicate the flow and dynamics of the river system within the research area. Subsequently, it was integrated with a 2D model of shallow water hydraulics to replicate the inundation and water flow across the terrain (Nguyen et al., 2022). The 2D solver (FAST) computational engine of Flood Modeller relies on a straightforward set of principles to model the spread of floodwater across a designated floodplain. It forecasts the reaction of a region to a given water volume input, utilizing information derived from an elaborate digital terrain map (DTM). The fundamental sequence of processes is depicted in *Figure 1*.

The conventional algorithm embedded in Flood Modeller's 2D solver (FAST) generates a tabulation of water levels for each depression, with the volumes computed and aggregated to verify model mass equilibrium. The water level results are merged with a grid structure, where each cell is assigned the identifier of the associated depression. This operation yields a grid layout of water levels (for specific cells, levels may dip below ground level within unfilled depressions). Subtracting the DTM data from the water levels produces depths, with negative values being disregarded. Both the depth and water level grids are saved as ASCII grid raster files, constituting a distinct phase of post-processing.

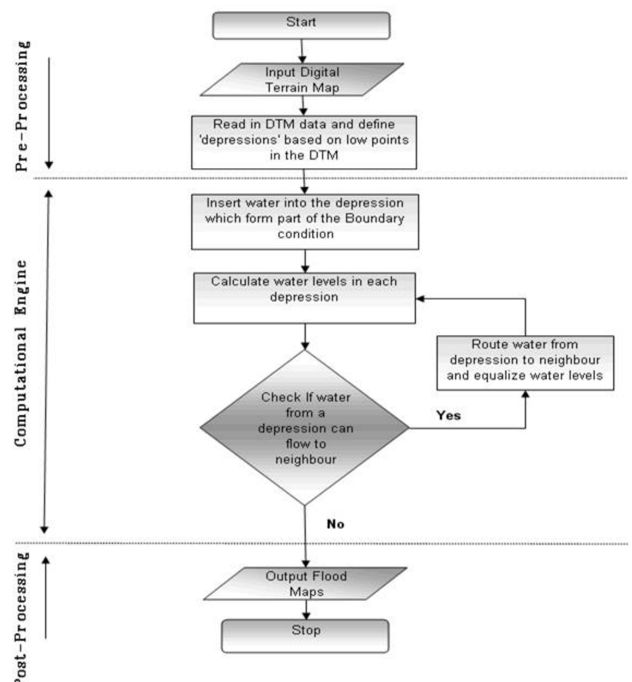


Figure 1 The fundamental sequence of flood modeling processes

3.3. Agent-based modeling

The case study focused on the simulation of the evacuation process in the event of a flood, with an emphasis on utilizing agent-based modeling to depict human behavior and decision-making dynamics in response to the flood. Various factors were taken into consideration in the simulation, such as the availability of evacuation routes, population distribution, and transportation infrastructure.

Within this study, the agents comprised individuals, households, and emergency response teams as people, while roads and buildings were classified as objects. Valuable insights were acquired concerning the efficacy of diverse evacuation strategies through the simulation. The agent-based model facilitated the assessment of the effects of different interventions, including the establishment of evacuation shelters, the implementation of traffic management measures, and the dissemination of real-time flood information. To create and execute the agent-based model, the Gama platform was utilized, with the incorporation of GIS data to accurately portray the physical environment and spatial relationships.

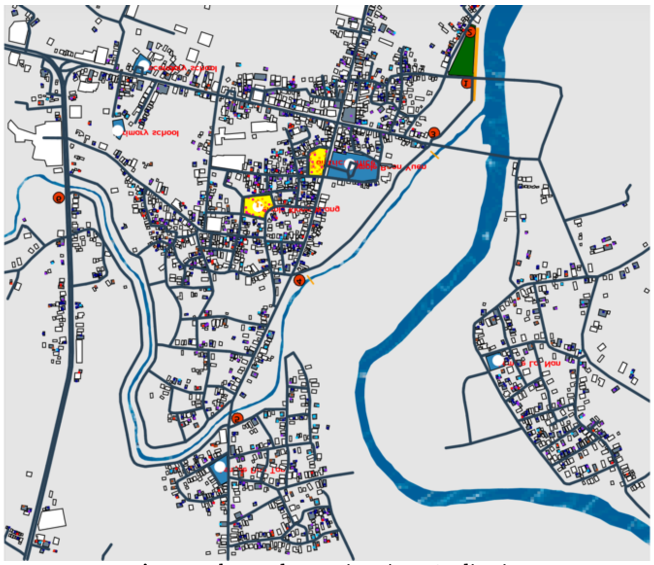


Figure 2 the study area in Wiang Sa district

3.4. Integrated model

The case study focused on the simulation of the evacuation process in the event of a flood, with an emphasis on utilizing agent-based modeling to depict human behavior and decision-making dynamics in response to the flood. Various factors were taken into consideration in the simulation, such as the availability of evacuation routes, population distribution, and transportation infrastructure.

4. Results and Discussion

Figure 3 shows the time-based flood maps are derived from Flood Modeller in the form of grid ASCII files, serving as crucial datasets for comprehending the scope and intensity of possible inundation in a designated region. These intricate flood maps encompass detailed information regarding water levels at individual locations within the area, enabling a nuanced understanding of the spatial distribution of potential flooding events. Through the incorporation of these flood maps into agent-based modeling frameworks, it becomes feasible to conduct simulations and assessments on the projected repercussions of floods on a multitude of variables, including but not limited to the dynamics of road traffic flow. As the duration of the flooding event progresses from a minimum of 1 hour to a maximum of 24 hours, the extent of the flooded area widens, resulting in further constraints on transportation accessibility. This escalation in flood coverage underscores the necessity for alternative modes of transport to mitigate the effects of the inundation.

This outcome specifically highlights the repercussions of flooding on road traffic patterns; however, the implications can be extrapolated to encompass a broader spectrum of infrastructure, ranging from buildings to the surrounding environment. Through an analysis of the broader impact of floods on various infrastructure components, a more comprehensive understanding of the challenges presented by these natural disasters can be achieved.

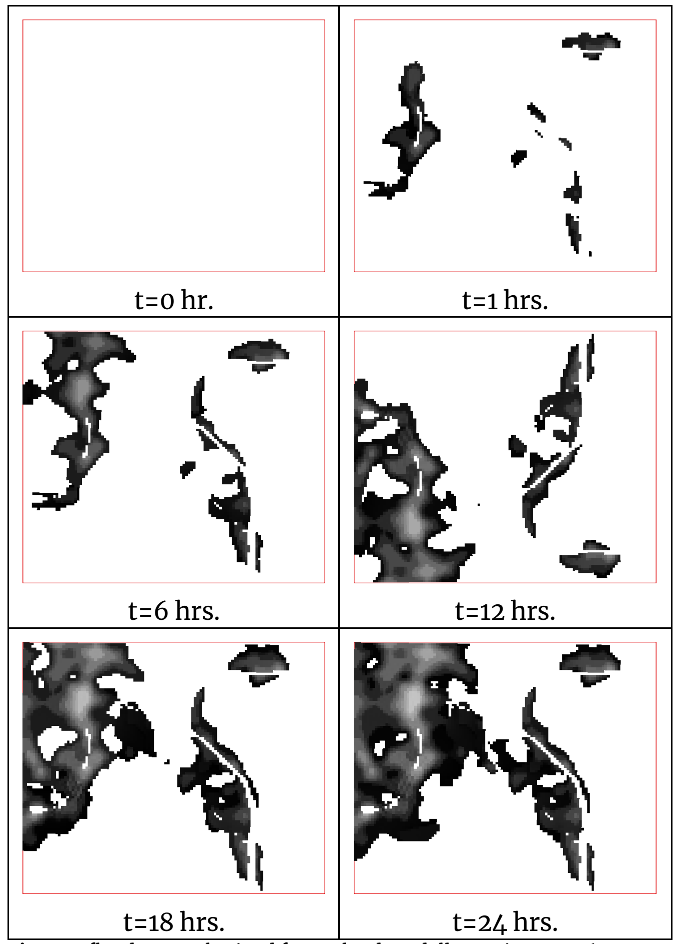


Figure 3 flood maps obtained from Flood Modeller at time 0, 1, 6, 12, 18 and 24 hours

At every individual increment of time within the simulation framework, we possess the capability to replicate and analyze the intricate interplay between the varying levels of flooding and their consequential impact on the infrastructure of road networks.

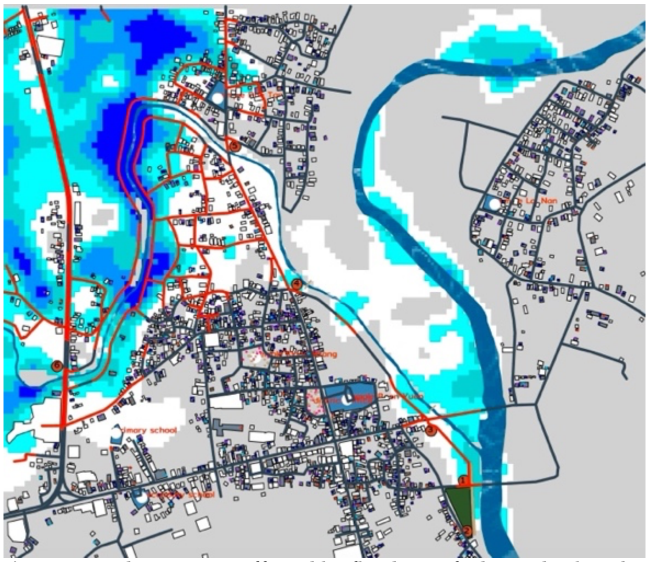
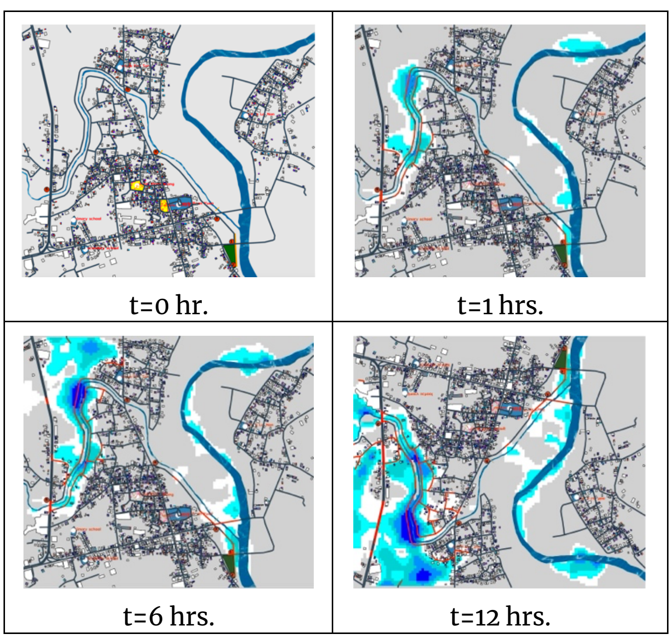


Figure 4 Road agents are affected by flood specified in red color, this lead to reduced speed in transportation

It is imperative to analyze the extent to which the flood field affects the transportation network and housing units. Moreover, the roads that are impacted by flooding experience constraints in terms of speed limits and overall accessibility, posing challenges for both commuters and residents alike. As the duration of flooding ranges from 1 hour to 24 hours, the extent of inundation progressively expands, encompassing larger areas over time. This phenomenon leads to a reduction in available transportation alternatives, thereby exacerbating the challenges posed by the flood event.



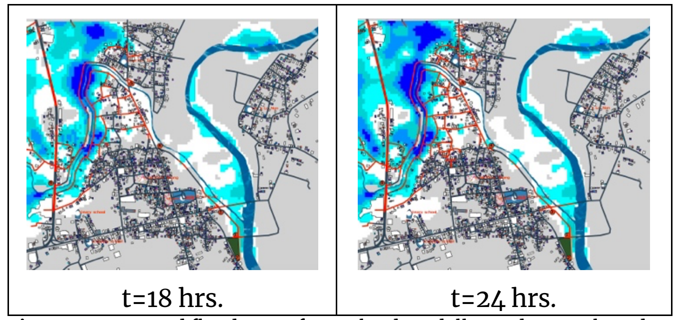


Figure 5 Integrated flood maps from Flood Modeller and agent-based model in Gama platform

5. Conclusions

In the concluding remarks of this study, we illustrate the seamless integration process of flood maps derived from the Flood Modeller into agent-based simulation models, showcasing the effortless compatibility with the Gama platform. This methodological approach holds significant potential for enhancement across various dimensions, offering a promising avenue for fostering comprehensive comprehension and efficient mitigation strategies in flood risk management for diverse stakeholders.

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