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3D Modeling Application for Predicting Flood-Prone Areas: A Case Study of Universitas Indonesia Depok Campus

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Abstract

A 3D Modelling is a process of generating three-dimensional objects that can be presented in visual form. Geographic Information Systems (GIS) play a crucial role in modelling hydrological phenomena, including floods. Flooding can significantly impact infrastructure and community activities, including those at the Universitas Indonesia (UI) Depok Campus. GIS-based 3D modelling serves as an effective method for analyzing and predicting potential flood risk areas. This study aims to create a 3D model to visualize flood-prone areas within the UI Depok Campus. It processes Digital Elevation Model (DEM) and Triangulated Irregular Network (TIN) data as the foundation for 3D flood inundation. The model simulates water overflow based on extreme rainfall scenarios and drainage capacity. Results indicate that certain areas within the UI Depok Campus, particularly in the north, are highly prone to flooding during heavy rainfall. These impacts can be mitigated through the design of effective mitigation strategies, the development of adaptive infrastructure, and the formulation of responsive, data-driven policies.

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Abstrak

Pemodelan 3D merupakan suatu proses dalam menghasilkan objek tiga dimensi yang dapat dipresentasikan dalam bentuk visual. Sistem Informasi Geografi (SIG) memiliki peran dalam memodelkan fenomena hidrologi, seperti kejadian banjir. Banjir dapat menimbulkan dampak signifikan terhadap infrastruktur dan aktivitas masyarakat, termasuk di Kampus Universitas Indonesia (UI) Depok. Pemodelan 3D berbasis SIG menjadi metode yang efektif dalam menganalisis dan memprediksi wilayah dengan potensi banjir. Penelitian ini bertujuan untuk mengembangkan pemodelan 3D guna memvisualisasikan daerah yang berisiko terendam banjir di area Kampus UI Depok. Metode yang digunakan adalah pengolahan data Digital Elevation Modelling (DEM) dan Triangulated Irregular Network (TIN) sebagai dasar pemodelan genangan banjir tiga dimensi. Proses pemodelan ini mensimulasikan luapan air berdasarkan skenario curah hujan ekstrem dan kapasitas drainase yang tersedia. Hasil penelitian ini menunjukkan bahwa beberapa area di Kampus UI Depok, terutama sisi utara memiliki potensi terendam banjir saat curah hujan tinggi. Dampak tersebut dapat diminimalisir melalui perancangan strategi mitigasi yang efektif, pengembangan infrastruktur adaptif dan penyusunan kebijakan yang responsif dan berbasis data.

INTRODUCTION

Floods represent one of the most destructive natural disasters worldwide, substantially impacting social, economic, and ecological systems across multiple regions (Shahiri Tabarestani & Afzalimehr, 2022). Driven by global warming and human activities, the frequency and intensity of floods have increased significantly. A flood is defined as the overflow of water beyond its normal confines, typically the riverbanks, resulting in the inundation of adjacent low-lying land areas (Cabrera & Lee, 2020). Natural factors, including hydrological conditions, environmental characteristics, and topographic features, primarily influence flood disasters. Key contributors include prolonged precipitation, climate change, and alterations in land use patterns (Zhang et al., 2025).

According to data from the Regional Disaster Management Agency (BPBD) of East Java Province, the rising frequency of flood events and their increasingly widespread impacts in Indonesia are primarily attributed to high rainfall intensity, climate change, and additional contributing factors such as illegal logging, development in water catchment areas, and improper waste disposal (BPBD Jawa Timur, 2023). In several cities in Indonesia, flooding has become a routine annual occurrence. Most flood events are primarily attributed to high rainfall and extensive urbanization, compounded by land use changes that reduce the availability of vacant areas serving as water catchment zones, thereby causing surface runoff to exceed the capacities of rivers and existing drainage channels.

Flooding in urban areas, including university campuses, represents a specific form of urban flooding that significantly disrupts the core functions of campuses as centers of education and public activity (Munsaka & Mutasa, 2020). Its impacts include the interruption of academic operations, restricted access to educational facilities, and damage to essential infrastructure such as halls, laboratories, IT Systems, and utilities like electricity and clean water networks (Kabir et al., 2020).

Several areas within the Universitas Indonesia (UI) Campus in Depok are not exempt from flooding. The campus, located in Depok City, covers an area of 320 hectares, with approximately 25% of the land developed and the remaining 75% consisting of green space in the form of urban forest. The UI Depok campus has a drainage system designed to sustainably manage stormwater runoff by utilizing a combination of natural and engineered systems.

One of the main components is the existence of six artificial lakes with a total capacity of approximately 259,306 m^3, serving as retention ponds to capture stormwater runoff from both on-campus and off-campus areas (Universitas Indonesia, 2023). UI regularly carries out maintenance of its drainage infrastructure, including repairs of retaining walls around the campus lakes. In 2018, for instance, a restoration project was undertaken on the retaining structure of Lake Puspa to ensure its optimal performance in channeling and retaining stormwater (Universitas Indonesia, 2018).

Although the majority of the campus comprises forested green areas, in 2007, the UI campus experienced flooding with water levels reaching up to 40 centimeters. The flood was caused by prolonged heavy rainfall lasting approximately five hours, which exceeded the capacity of one of the campus's lakes to contain the water. As a result, the overflow spread onto the roadside, causing traffic congestion that extended for up to two kilometers. This indicates that, despite the ecologically greener characteristics of campus environments, there remains a potential vulnerability to hydrometeorological disasters if drainage systems are not well-integrated and properly managed.

A comprehensive assessment of flood potential within campus environments warrants greater attention due to the limited number of studies that specifically examine flood risks within the framework of spatial planning and the functional roles of university areas. Most urban flood studies have yet to address the unique spatial and functional complexities of higher education institutions as distinct operational entities. The assessment of flood-prone areas is inseparable from the role of Geographic Information Systems (GIS) as a supporting tool. Moreover, GIS is capable of providing modeling functionalities to represent the phenomenon of urban flood inundation (Rajabifard & Williamson, 2000).

Based on 3D Modeling techniques, three-dimensional building models can be generated using existing remote sensing imagery and GIS data in a fast and batch-processing manner. This holds significant importance for 3D GIS. The 3D GIS technology offers robust three-dimensional visualization and spatial analysis capabilities, making it an effective technical approach. The expertise and complexity inherent in 3D technology are primarily applied in urban modeling, visual representation, and the extraction of relevant information through 3D GIS tools (Zhang et al., 2014).

A 3D Modeling in areas with potential flood hazards is essential for conducting thorough assessments and informing appropriate policy decisions to mitigate future flood-prone areas and to develop three-dimensional visualizations to provide an objective and accurate representation of flood distribution within the UI campus to protect the UI campus from flooding.

METHOD

Study Area

The study area is the main campus of the UI, situated in the northern region of Depok City, West Java Province, which is directly bordering South Jakarta. The UI is located at coordinates 6°21’44” S - 106°49’36” E. The northern part of the UI is covered by forested land, while the southern area is predominantly occupied by built-up land. Within the campus, there are six lakes that have quite important hydrological functions. The six lakes function as water retention areas, helping to mitigate the impacts of both flooding and drought by storing large volumes of water and releasing it during periods of water scarcity (Kristyanto, 2023). These six lakes are Kenanga, Aghatis, Mahoni, Puspa, Ulin, and Salam. The research location is visualized in Figure 1 below.

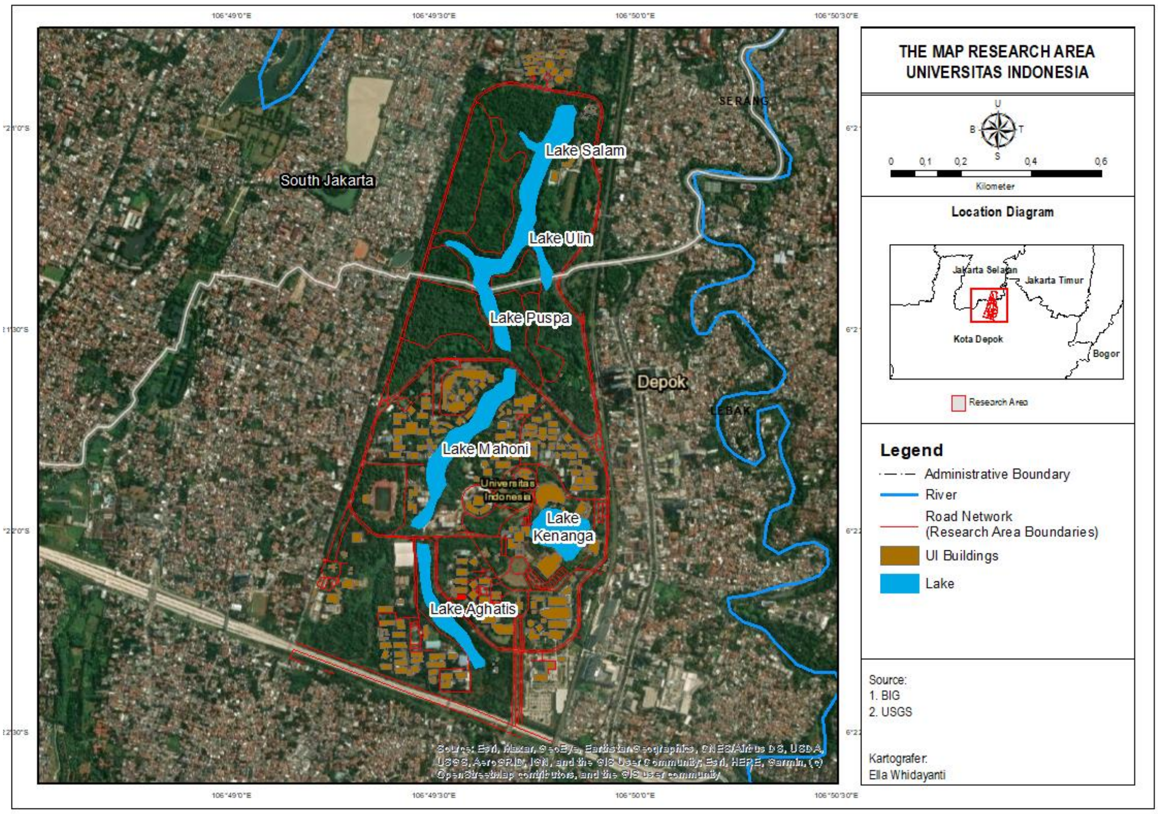


Figure 1. The Map Research Area of Universitas Indonesia

Data Collection

The data used in this study include High-Resolution Satellite Imagery (HRSI) data, Digital Elevation Models (DEM), and supporting vector data obtained in 2024, serving as the basis for 3D model information (Table 1). Digital Elevation Model systematically provides point-based elevation data, enabling the modeling of land contours and slopes, which are critical for predicting the direction and velocity of water flow. In this research, the utilization of DEM plays a key role in determining the spatial accuracy of flood flow and inundation extent, thereby significantly influencing the reliability and precision of the flood simulation outcomes (Xu et al., 2021).

Table 1. Research Spatial Data

Spatial Data	Source	Utility
HRSI	Geospatial Information Agency	The Map Research Area
SRTM DEM	Geospatial Information Agency	The 3D Model of the UI Area
Road Network	Departement of Geography, UI	Visualization of UI Buildings
Universitas Indonesia Buildings	Departement of Geography, UI	Visualization of UI Buildings

Data Analysis Techniques

Flood simulation was performed using software to assist in processing spatial data within a GIS, specifically ArcGIS Desktop 10.6. The tools used in ArcGIS were ArcMap and ArcScene. ArcScene is a feature within ArcGIS Desktop designed for processing data and generating three-dimensional data results. The resulting visualizations were then spatially analyzed and verified by comparing the model's output with descriptive information from online media and data obtained through interviews with local communities around the UI campus in Depok City. The interview method employed was a semi-structured approach. A semi-structured interview method was employed to collect relevant information, while allowing sufficient flexibility for respondents to freely provide additional insights related to the phenomenon being studied (Cope, 2016).

Processing of DEM and TIN Data

The data processing procedure for generating the DEM involved converting contour data in shapefile (.shp) format. The DEM served as the basis for creating a TIN used in three-dimensional flood inundation modeling. Prior to conversion into DEM data, contour lines must undergo topological error correction and elevation value consistency verification.

The DEM generation process primarily consisted of integrating river elevation points and contour lines. This process utilized the Topo to Raster tool in ArcGIS, which was subsequently processed using the Raster to TIN tool available in the 3D analyst extension (Figure 2). The TIN approach was employed in this research due to its ability to represent topographic surfaces more accurately and efficiently, particularly in areas with complex terrain contours (Li et al., 2005).

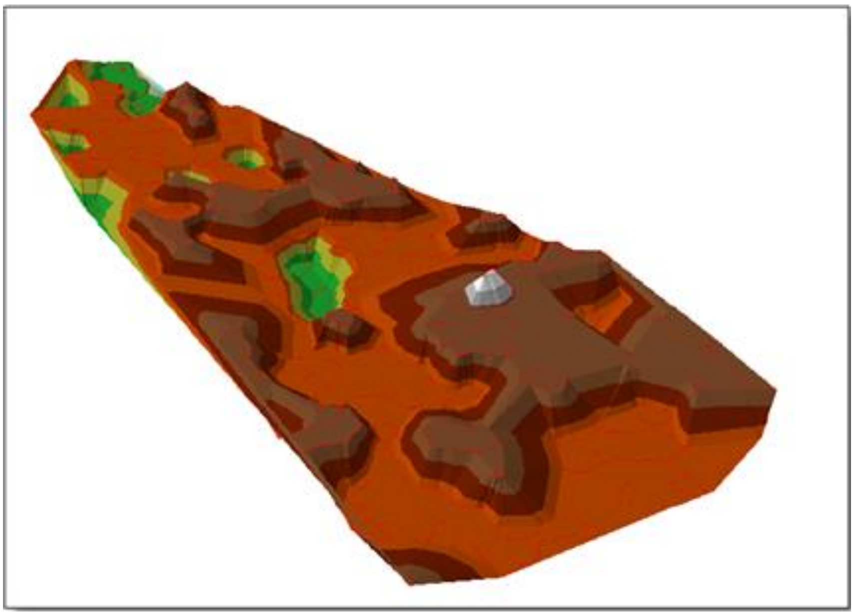


Figure 2. The 3D Model of the Universitas Indonesia Area

Building Visualization

To visualize buildings in three dimensions, the attribute table of the building shapefile must contain a z-value representing building height. Next, the extrusion features should be activated, and the building height defined. Building height is determined by calculating the number of floors. In this study, each floor is assumed to be four meters high (Eastman et al., 2011). In the extrusion value setting, the z-value is multiplied by the height of each floor, and the option "adding it to features minimum height" is selected to set the building base according to the lowest topographic point (Figure 3).

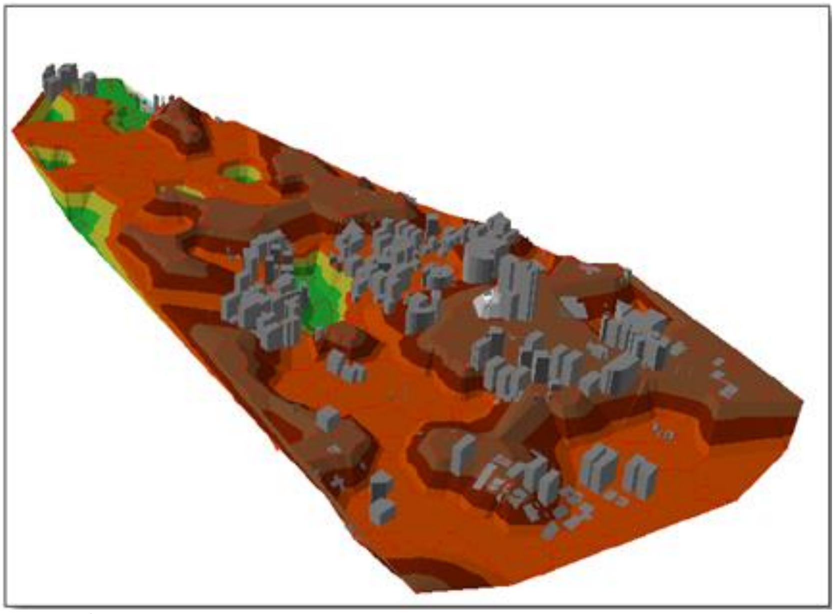


Figure 3. Visualization of Universitas Indonesia Buildings

Flood Inundation Modeling

The stages of constructing the three-dimensional model were carried out using processed spatial data, which were then aligned with the visualization plan in ArcScene 10.6. The flood inundation modeling produced a spatial representation of affected areas within specific zones. The visualization of flood-affected areas was performed by utilizing footprints and the flood extent polygons generated during the modeling process.

Flood modeling was conducted under three scenarios with predicted water levels of 5 meters, 7.5 meters, and 12.5 meters. This approach aims to simulate varying degrees of flood severity based on the potential peak discharge from extreme rainfall events and runoff from the catchment area. The use of tiered scenarios allows for the identification of regional vulnerability thresholds and supports the development of more adaptive flood risk mitigation strategies in response to potential climate change scenarios (Maidment, 2002).

The animation feature can be used to initiate the flood animation, and in the source object option, the z-value is selected to represent elevation. The z translation can then be adjusted according to the desired flood level changes. The research flow diagram in this research are presented in Figure 4.

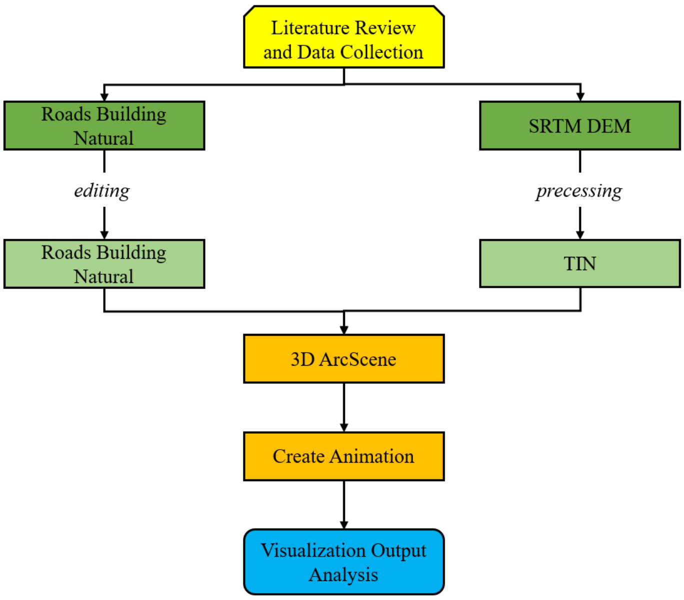
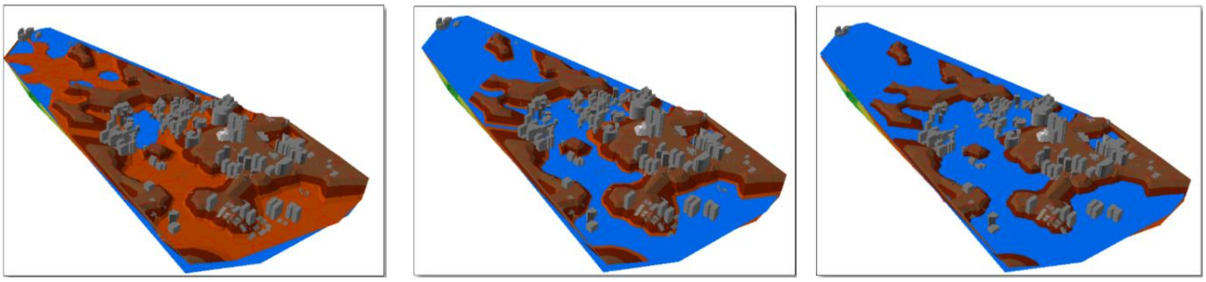


Figure 4. Research Framework Diagram

RESULT AND DISCUSSION

Based on the flood modeling that has been conducted, it was found that the flooding was caused by the overflow of six lakes located within the UI Depok Campus area, namely Lake Kenanga, Lake Aghatis, Lake Mahoni, Lake Puspa, Lake Ulin, and Lake Salam. The flood model was developed using varying predicted water levels. This flood modeling was animated over a duration of ten seconds to visualize areas with potential flood risk, as illustrated in the Figure 5 below.



a b c

Figure 5. Flood inundation modeling scenarios at varying water levels: a) 5 meters; b) 7,5 meters; and c) 12,5 meters

Model at a water level of 5 meters (Figure 5a), only a small number of buildings appear to be affected by flooding. The inundation does not submerge the entire structure but only impacts certain areas, particularly in the northern part near the UI Dormitory in Depok. Model at a water level of 7.5 meters (Figure 5b), a greater number of buildings are inundated, including those located in the northern, central, and southern zones of the campus. While model at a water level of 12.5 meters (Figure 5c), nearly the entire area of the UI Depok Campus is submerged. The varying levels of flood impact on buildings are likely due to differences in topographic characteristics across the campus area.

Based on the simulation results, the initial flooding originated from the northern area, specifically from Lake Salam. This phenomenon can be attributed to the undulating topography of the UI Depok Campus, where the northern part lies at a lower elevation compared to the southern area. However, the presence of urban forest areas functioning as water catchment zones has prevented some northern regions from becoming inundated, despite their relatively low elevation. This is consistent with the role of urban forests and green spaces in facilitating rainwater absorption and reducing flood risk in urban areas, including those with low-lying topography (Gills et al., 2007).

Reflecting on the flood event that occurred at the UI Depok Campus in 2007, the Ministry of Public Works and Housing (PUPR), the Ministry of Environment and Forestry, the Ministry of Agriculture, and the Provincial Government of DKI Jakarta initiated the planting of 1,000 tree seedlings in the campus urban forest as a flood mitigation effort (Kemeterian PU, 2007). Based on previous literature, urban trees can reduce peak stormwater runoff by up to 27% and absorb an average of 0.14 liters per second per tree, playing a significant role in urban flood mitigation (Medina Camarena et al., 2022). The study emphasizes the need to integrate vegetation into urban spatial planning as a strategy to address flooding caused by intense rainfall events.

The first area affected by flooding is the UI Student Dormitory, located near Lake Salam. Another lake with a similar overflow potential is Lake Kenanga, situated adjacent to the UI Rectorate. Overflow from this lake may impact surrounding structures such as the UI Mosque, the main library, the floating hall (*Aula Terapung*), and the Balairung building, due to the relatively low elevation difference between the water surface and the adjacent land. Furthermore, land-use changes in the vicinity of Lake Kenanga have reduced the capacity of natural water catchment areas, thereby increasing the risk of flood expansion into nearby roads.

The water flow among the lakes within the UI Depok campus is interlinked, with water transfer occurring between them, with the exception of Lake Kenanga. These lakes are fed by three main inlets, located respectively at Lake Kenanga, Lake Aghatis, and Lake Mahoni. The inflowing water originates from local residential drainage systems and tributaries of the Ciliwung River. The sole outlet is situated at Lake Salam, which eventually discharges into the Kali Baru Barat River (Sudinda, 2014).

The lakes within the UI Depok Campus area play a significant role in mitigating flood and drought hazards from a hydrological perspective (Suwartha & Pramadin, 2012). They serve as important components for water resource conservation, functioning both as flood retarding basins and as groundwater recharge zones.

The main limitation in this study lies in the limited resolution and accuracy of the elevation data used, namely SRTM DEM. This data has a relatively coarse spatial resolution, which is around 30 meters, so it is less able to capture micro-topographic details that are important in local-scale flood modeling such as in the Universitas Indonesia campus area. This can have an impact on the accuracy of the TIN model produced and the prediction of flood inundation distribution, especially in low elevation scenarios such as 5 meters. Therefore, the accuracy of the simulation results is still indicative and cannot be used as a basis for precise decision making.

Another limitation lies in the static assumptions used in the simulation of three elevation scenarios (5 m, 7.5 m, and 12.5 m), which do not take into account comprehensive hydrological dynamics such as actual rainfall, drainage channel capacity, and soil permeability. This model only considers elevation as the main determinant of flood-prone areas, so it is not yet able to describe real conditions during heavy rain or water runoff. The implication of this approach is that the 3D model results are more appropriate as an initial visualization tool to increase risk awareness, rather than as an operational prediction tool.

To overcome these limitations, future research can integrate high-resolution elevation data such as LiDAR, and add a hydrologic-hydraulic simulation component based on actual weather data. A similar case study at the University of California, Berkeley campus, showed that the use of LiDAR and SWMM (Storm Water Management Model) modeling can provide a more realistic picture of flood risk in the campus environment (Dong, 2018). With this approach, the 3D model will not only serve as a spatial representation tool, but also as a data-driven decision-making platform for more effective flood mitigation in the campus environment.

In addition, the scope of the study, which is limited to the Universitas Indonesia campus area, also limits the generalization of findings. The topography, land use, and drainage system of this campus are unique and cannot be directly compared or applied to other areas without adjustment. Therefore, further studies are needed on other campuses with different geographical characteristics, such as the Nanyang Technological University (NTU) campus in Singapore, which is located in a hilly area and has an integrated water management system (Ying, 2016). This cross-case study comparison can enrich the understanding of the effectiveness of 3D models in predicting flood-prone areas and increase the flexibility of model application for various campus area conditions.

CONCLUSION

Based on the preceding discussion, the area most likely to experience flooding first are located in the northern part of the UI Depok Campus, with floodwaters progressing southward. Consequently, flood hazard potential can be effectively visualized through 3D modeling based on GIS, which provides clear and relevant spatial information. This spatial analysis supports the UI in anticipating flood impacts, informing adaptive infrastructure planning, and developing effective mitigation strategies and policy responses aligned with the geographic and hydrological characteristics of the campus environment.

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