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URBAN FLOOD MITIGATION STUDY BASED ON 3D SPATIAL MODELING FOR DETERMINING INFRASTRUCTURE RESILIENCE PRIORITIES IN WARA DISTRICT, PALOPO CITY

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Abstract

This study examines urban flood mitigation using three-dimensional (3D) spatial modeling to determine infrastructure resilience priorities in Wara District, Palopo City. The analysis integrates DEMNAS, field topographic survey data, land use, road networks, administrative boundaries, building distribution, and critical infrastructure into an integrated 3D geospatial database. Flood simulations were conducted for 25-year and 50-year return periods with a one-hour duration. The 25-year scenario used a river discharge of 377.52 m³/s, while the 50-year scenario used 566.28 m³/s. The modeling results identified 775 affected buildings, equivalent to 27.2% of 2,846 analyzed buildings, under the 25-year scenario; this increased to 845 buildings or 29.7% under the 50-year scenario. Risk patterns concentrate along the Wara River corridor and in relatively low-lying areas with high building density. Based on the integration of hazard, exposure, and vulnerability, Amasangan and Danmobilko were classified as high-priority areas, Tompotikka as medium-to-high priority, and Lagaligo as medium priority. The 3D modeling provides an intuitive visualization of the relationships among topography, river corridors, inundation, and buildings, supporting prioritization of drainage improvement, river corridor protection, infrastructure elevation, and flood preparedness measures.

Keywords: Urban Flood; 3D Spatial Modeling; Mitigation; Infrastructure Resilience; Wara District; Palopo City.

INTRODUCTION

Urban development increases the complexity of flood risks due to changes in land use, increased building density, limited infiltration space, and increased pressure on drainage systems. In urban areas developing around river corridors, risk is determined not only by the magnitude of discharge or inundation depth, but also by the distribution of buildings, road access, the presence of essential facilities, and the infrastructure's ability to remain functional during disruptions. Therefore, flood mitigation requires a spatial approach that connects the physical conditions of the area with the distribution of exposed assets and infrastructure. Wara District in Palopo City is an urban area with residential and infrastructure activities developing around the Wara River flow system. Variations in micro-elevation, the shape of the river cross-section, narrowings in some segments, and the proximity of buildings to the river corridor make inundation response difficult to understand adequately through two-dimensional maps alone. Information regarding the vertical relationship between land elevation, riverbed, buildings, and inundation is crucial for identifying locations at highest risk.

Three-dimensional spatial modeling offers the ability to represent surface shape, local depressions, slopes, built objects, and overflow directions in a single geospatial environment. This approach supports more comprehensive interpretations because simulation results not only show inundated areas but also show the relative position of affected objects to hazard sources. In the context of decision-making, this information can be translated into infrastructure resilience priorities based on a combination of hazard, exposure, and vulnerability levels. This study aims to: (1) build a 3D geospatial database for urban flood analysis in Wara District; (2) simulate Wara River inundation scenarios at 25- and 50-year return periods; (3) identify building exposure to inundation; and (4) determine infrastructure resilience priorities at the village level. The main contribution of this study is the development of an analytical framework that links inundation simulation outputs with infrastructure intervention priorities spatially.

METHOD

2.1 Research Location and Approach

The research was conducted in Wara District, Palopo City, focusing on the Wara River corridor and urban areas affected by the inundation simulation. The research approach utilized 3D geospatial modeling and risk analysis based on three main components: hazard, exposure, and vulnerability. The results of the integration of these three components were used to develop a priority classification of infrastructure resilience.

2.2 3D Geospatial Data and Processing

The primary data used consisted of DEMNAS and topographic survey results, land use maps, road networks, sub-district administrative boundaries, building distribution, and relevant infrastructure information. Elevation data was pre-processed through pit filling correction, surface smoothing, and coordinate system alignment and vertical datum. All data was then integrated into a Geographic Information System (GIS) environment using ArcGIS Pro to create a three-dimensional surface model and spatial database.

3D models are used to interpret micro-elevation variations, surface slopes, flow corridors, local basins, and the relationship of structures to the river body. The integration of raster and vector data allows inundation simulations to be displayed in two-dimensional maps and three-dimensional perspectives.

2.3 Flood Scenario Simulation

Simulations were conducted on two return period scenarios: 25 years and 50 years, with a simulation duration of one hour. Discharge and precipitation parameters followed the data in the modeling report that served as the basis for the study. Analysis of surface flow direction, river cross-section capacity, and inundation distribution was used to assess differences in spatial response across the two scenarios.

Parameter	25th Birthday	50th Birthday
Simulation duration	1 hour	1 hour
Precipitation	674.81 mm/hour	1,012 mm/hour
Wara River Discharge	377.52 m^3/second	566.28 m^3/second
Topographic sources	DEMNAS and survey results	DEMNAS and survey results
Software	ArcGIS Pro	ArcGIS Pro

Table 1. Simulation parameters of Wara River flood inundation.

2.4 Risk Assessment and Infrastructure Resilience Priorities

Hazard is determined based on indications of inundation depth and distribution, as well as interpretation of flow dynamics in critical areas. Exposure is assessed based on the presence of buildings, settlements, roads, and infrastructure within the inundation area. Vulnerability is assessed indicatively through settlement density and patterns, as well as the condition of drainage capacity to reduce inundation duration. The three components are then integrated semi-quantitatively to determine high, medium-high, medium, and low priority categories.

Conceptually, risk can be written as $R = f(H, E, V)$, where R is risk, H is hazard, E is exposure, and V is vulnerability. In this study, this equation is used as a conceptual integration framework; the final classification still takes into account spatial interpretation and the limitations of the available data.

RESULTS AND DISCUSSION

3.1 3D Spatial Database and Topographic Characteristics

The processing of DEMNAS and survey results produces a three-dimensional surface that serves as the basis for interpreting the relationship between land elevation, the Wara River flow, and building distribution. This database allows for the identification of micro-topographic variations not always visible on conventional contour maps, particularly in local basins and riparian zones.

The reliability of the elevation database is crucial because errors in the underlying surface can affect flow direction and the interpretation of inundation extent. Therefore, data correction and alignment processes are performed before being used in simulations. In the context of mitigation, 3D models also serve as a risk communication tool because they can display vertical relationships between objects in a way that is more easily understood by stakeholders.

3.2 Simulation of Inundation at 25-Year Return

In the 25-year return period scenario, the Wara River discharge of 377.52 m^3/s was used as input for a one-hour simulation. The results show that inundation was concentrated along the river corridor and extended to several areas with relatively low bank elevations. The map in Figure 1 shows the spatial pattern of inundation as well as the classification of affected and unaffected buildings.

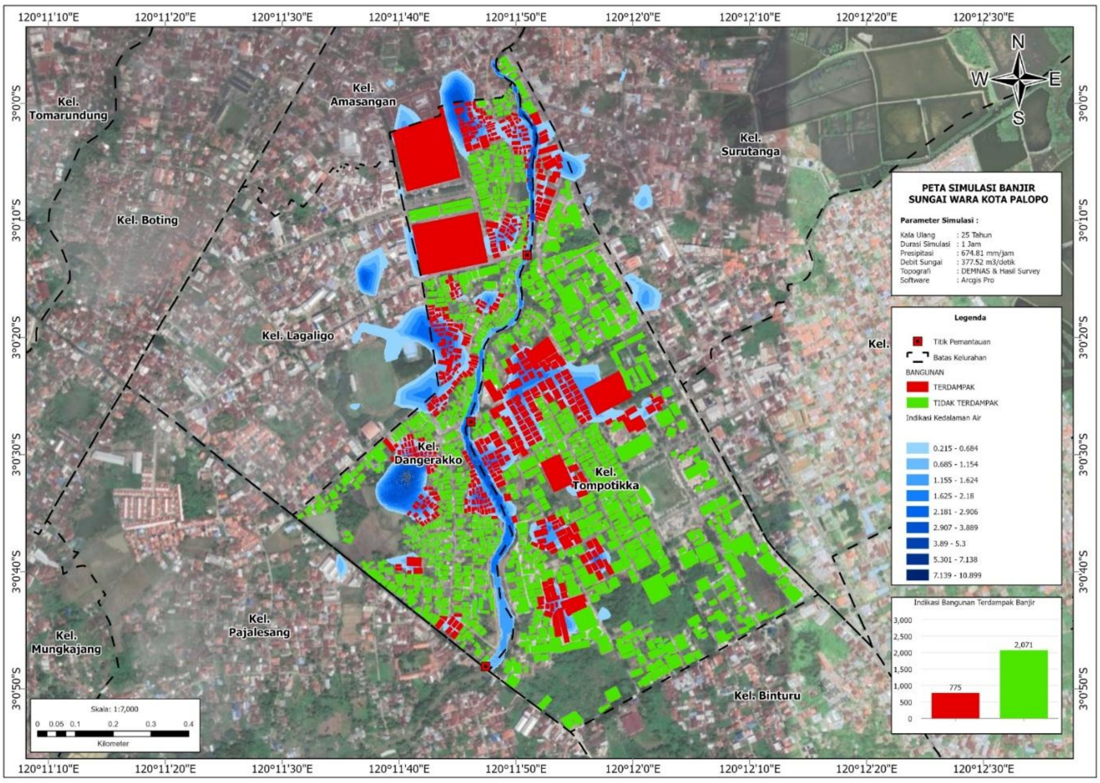

Figure 1. Simulation map of the Wara River flood at 25-year return period.

In this scenario, 775 buildings out of a total of 2,846 were identified as being affected by inundation, or 27.2%. The affected buildings were concentrated in river corridors and several residential zones in the Amasangan, Dangerakko, and Tompotikka sub-districts. This pattern indicates that proximity to the river and local elevation conditions influence exposure levels.

3.3 Simulation of Inundation at 50-Year Return

At the 50-year return period, the simulated discharge increased to 566.28 m^3/s. This increased discharge resulted in an expansion of inundation in the transition zone between the river and the built-up area. The map in Figure 2 shows the increased impact area compared to the 25-year scenario.

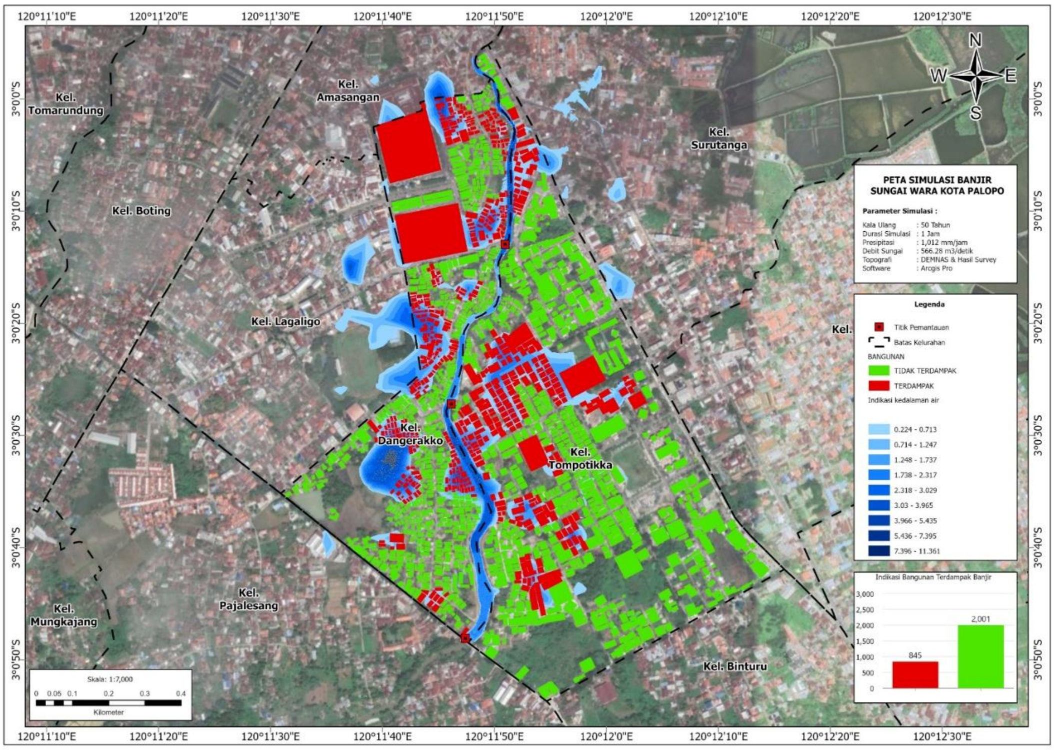

Figure 2. Simulation map of the Wara River flood at 50-year return period.

The number of affected buildings increased to 845, or 29.7% of the total analyzed. This represents an additional 70 buildings affected compared to the 25-year scenario. This increase demonstrates the area's sensitivity to increased discharge and indicates the need for infrastructure resilience design that responds not only to routine flooding events but also to higher-intensity scenarios.

3.4 Building and Infrastructure Exposure Analysis

A comparison of the two scenarios shows that increased hazard results in increased exposure. The distribution of affected buildings is uneven due to local topography, location relative to the river channel, and development patterns. Amasangan sub-district exhibits the presence of large buildings with the potential for significant economic impacts. Dangerakko exhibits denser settlements, so the increase in the number of affected buildings directly impacts the potential for increased population and exposed assets. Tompotikka also exhibits significant exposure, particularly in areas directly connected to the inundation corridor.

Scenario	Affected buildings	Total building	Percentage
25th birthday	775	2,846	27.2%
50th birthday	845	2,846	29.7%
Change	+70	-	+2.5 percentage points

Table 2. Comparison of building exposure in two flood scenarios.

3.5 3D Visualization as a Basis for Infrastructure Resilience Interpretation

3D visualizations enhance spatial interpretation by showing the relationships between topography, river corridor shape, inundation surface, and building mass. The perspective views in Figures 3 and 4 help identify concentrations of impacted objects that are not always easily read on flat maps. From a mitigation perspective, these visualizations can be used to communicate priority zones to local governments, communities, and infrastructure managers.

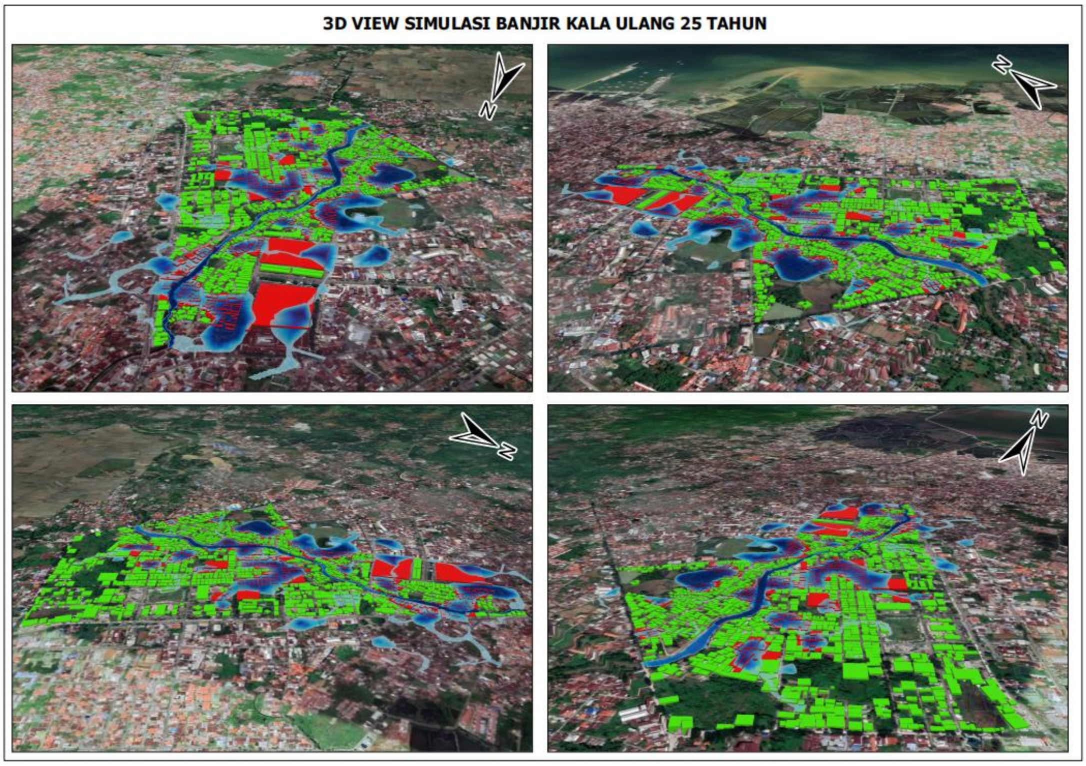

Figure 3. Three-dimensional view (3D view) of flood inundation simulation at 25-year return period.

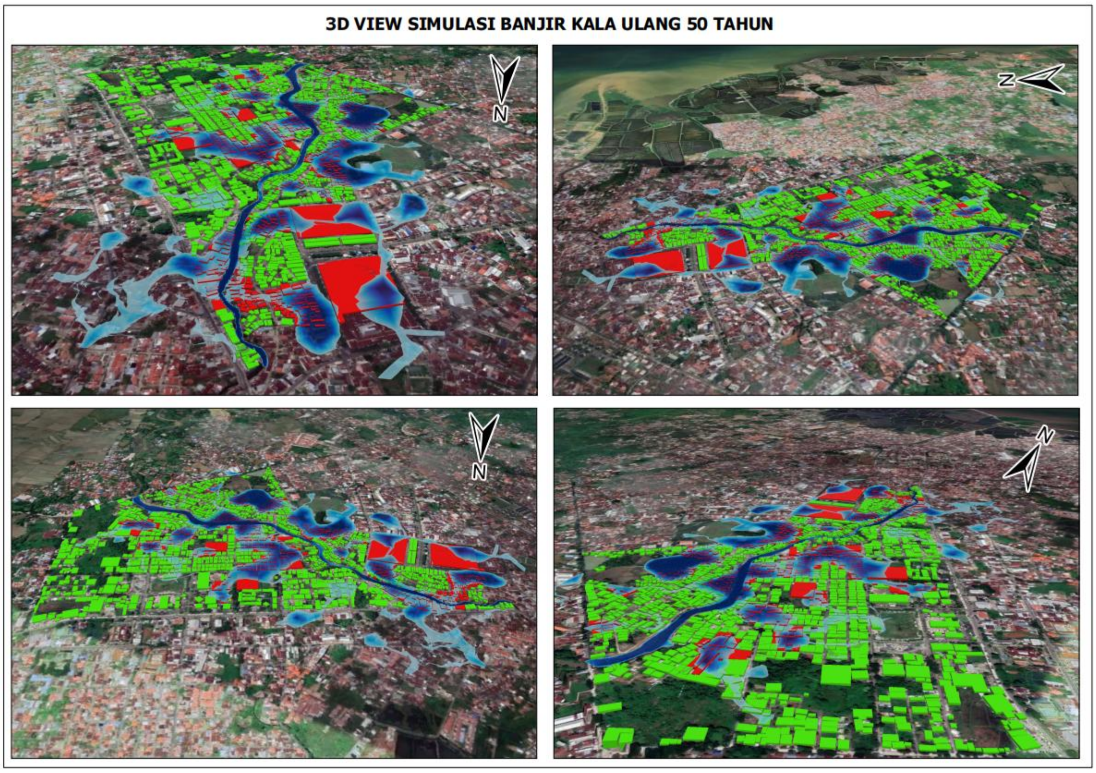

Figure 4. Three-dimensional view (3D view) of flood inundation simulation at 50-year return period.

Compared to two-dimensional representations, 3D models provide additional context regarding the relative position of buildings relative to surface elevations and the direction of flooding corridors. This information is relevant for determining locations for building or road elevations, drainage system improvements, river corridor security, and evacuation facility placement.

3.6 Infrastructure Resilience Priorities per Sub-district

Prioritization was carried out through an integration of hazard, exposure, and vulnerability levels. Amasangan and Dangerakko were assigned high priority because they consistently demonstrated a concentration of impacts across both scenarios. Amasangan has exposure to large building assets, while Dangerakko is characterized by dense settlements and higher vulnerability. Tompotikka was categorized as medium-high because parts of its area showed a significant concentration of affected buildings. Lagaligo was assigned medium priority. Other villages within a more limited simulation scope were provisionally categorized as low and require expansion of the simulation scope before being used as the basis for definitive policy.

Ward	Danger	Exposure	Vulnerability	Priority
Couple	Tall	High (large assets)	Currently	Tall
Dangerakko	Tall	High (dense settlement)	Tall	Tall
Tompotikka	Medium–High	Medium–High	Currently	Medium–High
Lagaligo	Currently	Currently	Currently	Currently
Boting/Tomarundung/Surutanga	Low*	Low*	Low*	Low
Pajalesang/Mungkajang/Binturu	Low*	Low*	Low*	Low

Table 3. Infrastructure resilience priority matrix based on flood risk level per sub-district.

**The classification is temporary because the simulation area coverage in the sub-district is relatively limited and needs to be verified through model expansion and field surveys.*

3.7 Implications of Mitigation Strategies

Modeling results guide mitigation strategies toward location-based actions. In high-priority zones, interventions should focus on increasing drainage capacity and maintenance, protecting river corridors, reducing flow obstructions, and strengthening critical buildings or facilities. In areas with densely populated buildings, preparedness strategies and evacuation access should be developed in conjunction with physical interventions.

For Amasangan, primary attention can be directed to protecting exposed assets and large buildings. For Dangerakko, increasing resilience requires considering settlement density and emergency access capacity. In Tompotikka, adaptation measures can be prioritized in zones with increasing inundation expansion under the 50-year scenario. This approach uses modeling results as a basis for more targeted resource allocation.

The main limitation of this study lies in the indicative nature of the building vulnerability assessment, which lacks detailed data on construction materials, construction year, ground floor elevation, and structural capacity. Furthermore, scenario discharge parameters need to be continuously verified against hydrological data and field measurements. Future studies should include building surveys, more detailed drainage network data, and validation of actual inundation levels.

CONCLUSION

3D spatial modeling is able to integrate topography, the Wara River corridor, building distribution, and inundation simulation results, thus providing a more comprehensive basis for urban flood mitigation in Wara District.

In the 25-year return period scenario, 775 buildings, or 27.2% of the 2,846 buildings, were affected. In the 50-year return period scenario, this number increased to 845 buildings, or 29.7%. The increase of 70 buildings affected indicates the area's sensitivity to increased discharge and expansion of inundation.

The highest priority for infrastructure resilience is in the Amasangan and Dangerakko sub-districts. Tompotikka is at medium-high priority, while Lagaligo is at medium priority. Sub-districts with limited simulation coverage require additional analysis before establishing definitive policies.

3D visualization can be used as a decision-support tool to determine the location of drainage interventions, protect river corridors, improve infrastructure elevations, and strengthen preparedness. Further research is needed to strengthen model validation with actual inundation data, updated hydrological data, and detailed surveys of building vulnerability.

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