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# Spatial modeling of tidal flooding in relation to land cover in the City of Banjarmasin

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## Abstract

This study aims to understand the tidal flood storage pattern in Banjarmasin City through spatial and land cover modeling and to produce detailed and accurate maps of the area of land cover inundated by tidal flooding and develop a spatial model to circle the impact of tidal flooding on various types of land cover. Modeling was carried out using the Ilwis Academic application analysis through the nearest neighbor (operational environment), considering air rise scenarios of 0.25 meters, 0.5 meters, and 1 meter, based on the average elevation of the Banjarmasin area. At an air rise of 0.25 meters, approximately 20.2% of agricultural land was inundated, increasing to 29.9% at an elevation of 0.5 meters. At an elevation of 1 meter, approximately 78% of the city area was inundated, with the agricultural sector being the most vulnerable to tidal flooding in all scenarios. These findings indicate the importance of effective mitigation strategies to reduce the negative impact of tidal flooding on the agricultural sector and daily activities in Banjarmasin City.

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## Introduction

The city of Banjarmasin, the most populous city in South Kalimantan Province, is located in the Barito River delta and is known as one of Indonesia's major cities. Situated in the Barito River delta, the city boasts a complex and extensive river network, making it a vital center for trade and transportation since ancient times (Nugroho et al., 2020). The rivers in Banjarmasin not only serve as the primary routes for the movement of goods and people but have also shaped the culture and social life of the local community (Subiyakto, 2020). However, the geographical characteristics that make Banjarmasin a center of prosperity also present significant challenges. Its location in a river delta makes it highly vulnerable to hydrometeorological disasters, particularly tidal flooding, which frequently occurs due to the rise and fall of sea levels (Wibawanto et al., 2023). Tidal flooding, a natural phenomenon where rising sea levels cause inundation in low-lying areas, often has significant impacts on the daily lives of the community (Nadya & Salim, 2023).

The average elevation of Banjarmasin City, which is only -0.16 meters above sea level (Central Statistics Agency, 2023), combined with ongoing land subsidence, exacerbates the impact of increasingly frequent tidal flooding (Kurniawan, 2003; Setiyono et al., 2023). One of the most striking impacts of tidal flooding is infrastructure damage. Major roads, bridges, and other public facilities are often submerged, causing damage that requires significant costs to repair (Yunida et al., 2017). Vital infrastructure such as drainage systems, clean water channels, and electrical installations are also disrupted, adding to the city government's burden in recovery and repair efforts (Salim, 2018).

Changes in land cover in Banjarmasin have further exacerbated the increasingly alarming situation of tidal flooding (Ariadi, 2023). The increasingly intensive conversion of open land into built-up areas has significantly reduced water infiltration areas, increased surface runoff, and added strain to the city's drainage system (Kusumadewi & Bisri, 2012; Pradana et al., 2022). When natural areas such as forests, swamps, and green open spaces are replaced by buildings, roads, and other infrastructure, the soil's ability to absorb rainwater is drastically reduced. As a result, rainwater that should seep into the ground now flows directly into drainage channels, rivers, and canals, which are often unable to accommodate this increased volume of water (Joga, 2013; Latief et al., 2021). This situation leads to an increase in the volume of water that must be managed by urban drainage systems, which are often not designed to handle such large water flows, especially during the rainy season or at high tide. Existing drainage systems frequently become clogged and overloaded, causing water to overflow and flood residential areas and major roads (Wasita & Sunarningsih, 2022). This situation is exacerbated by sediment and trash clogging waterways, reducing drainage effectiveness and increasing the risk of flooding.

One effective approach to understanding tidal flooding patterns is through spatial modeling (Bakti, 2010; Syafitri & Rochani, 2021). Spatial modeling allows for the visualization and analysis of the geographic distribution of tidal flooding, as well as the identification of factors contributing to the occurrence of flooding (Pratiwi & Santosa, 2021). Spatial modeling can also be used to predict potential future flooding based on scenarios of changing environmental conditions, such as sea-level rise and land-use changes (S. H. Nugroho, 2013; Pasaribu et al., 2021). Elevation data, obtained through topographic surveys or remote sensing technology, is crucial for determining which areas are at high risk of flooding. This modeling can estimate how water flow will change and where surface runoff will increase by accounting for changes in land cover, such as the transformation of open land into built-up areas (Marfai & King, 2008; Sejati et al., 2020).

Modeling tidal flooding is a highly useful method for understanding and predicting the distribution and impacts of tidal flooding (Sagala et al., 2021). This modeling process requires an accurate digital elevation model to capture the topography and physical characteristics of the area to be analyzed. These digital elevation models can be obtained from various sources, such as topographic maps, Light Detection and Ranging (LiDAR), and AdvantEdge imagery (Fewtrell et al., 2008; Kasbullah & Marfai, 2014; Shodiq, Sobatnu, & Inayah, 2022). ILWIS (Integrated Land and Water Information System) is both GIS software and an image data processor that enables users to perform spatial analysis and hydrological modeling. ILWIS can be used for various environmental and natural resource applications, including flood modeling, due to its ability to integrate raster and vector data (Hengl et al., 2003; Marfai & King, 2008). In addition, the use of ILWIS in modeling tidal flooding allows for the comprehensive integration of topographic, hydrological, and land-use data, resulting in more accurate tidal flood risk maps that can serve as a basis for sustainable coastal mitigation and adaptation planning. Thus, the modeling results are not only utilized as a tool for scientific analysis but can also be used by decision-makers in spatial planning. Research on the spatial modeling of tidal flooding using GIS has been conducted in various coastal areas of Indonesia. Azhari et al. (2022) conducted spatial modeling of tidal flooding along the northern coast of Banten to identify vulnerable areas and formulate appropriate mitigation strategies.

Although previous studies have modeled tidal flooding in various coastal areas, most of them have focused on mapping inundation without integrating quantitative land-cover analysis across different water-level scenarios. Furthermore, the use of the neighborhood operation method in modeling tidal flooding inundation in Banjarmasin City remains limited. Therefore, this study offers a novel approach by integrating neighborhood operation-based spatial modeling with land cover analysis across several sea-level rise scenarios. The resulting model will take into account factors such as land elevation and land cover types, thereby providing more accurate predictions of high-risk areas. The results of this modeling will be highly useful for urban spatial planning, the development of flood control infrastructure, and long-term adaptation strategies to reduce vulnerability to tidal flooding. See Fig 1.

Fig 1. Research Location Banjarmasin City

## Method

### *Location and Research Data*

The Methods This study was conducted in the city of Banjarmasin, South Kalimantan (Fig. 1), which is located at the geographical coordinates 3° 16’ 46” to 3° 22’54” South Latitude and 114° 31’ 40” to 114°39’ 55” East Longitude (Central Bureau of Statistics, 2023). See Table 1. A Digital Elevation Model (DEM) serves as the fundamental basis for creating flood inundation maps (Fig 1). This is emphasized by Parizi et al. (2022), who state that a DEM plays a crucial role in visualizing elevation data at the study site. This capability makes it a crucial element in understanding and analyzing the potential risks of tidal flooding. A DEM functions as a three-dimensional elevation map that depicts the Earth’s surface in detail. This elevation information is obtained from various methods, such as laser-based remote sensing (LiDAR), stereo aerial photography, and radar interferometry (InSAR) (Dowman, 2004; Muhadi et al., 2020).

Table 1. Types of Data Used

| Data Type | Daya Collection | Data Sources |
|---|---|---|
| Demographic Data | n/a | Geospatial Information Agency |
| Land Cover | 2021 | City Planning and Development Agency |
| Administrative Boundaries | 2019 | City Planning and Development Agenc |

### *DEMNAS*

Modeling flood inundation in the city of Banjarmasin requires precise surface data. DEMNAS (National Digital Elevation Model) provides surface data with high spatial resolution, specifically 0.27 arc-seconds, which is equivalent to 8.3 meters (Geospatial Information Agency, 2018). As a database, the DEM data must be made more consistent with the actual site conditions by adding information such as the contours of the study area. The goal is to produce a good model and values that are nearly accurate (Kasbullah & Marfai, 2014).

### *Land Cover*

The Indonesian government, through the Ministry of Environment and Forestry (KLHK), defines land cover as the physical condition of materials covering the Earth’s surface, whether in the form of vegetation (such as forests, shrubs, and grass) or non-vegetation (such as water bodies, built-up areas, and open land). This definition encompasses various land-use types, such as agriculture, settlements, industry, and conservation. The land cover data used in this study were obtained from the relevant government agency, namely the Regional Development Planning Agency (BAPPEDA) of Banjarmasin City. In this study, adjustments will be made to the land cover classification (Table 2) to ensure the modeling process runs smoothly.

Table 2. Types of Land Cover Classification

| No. | Land Cover Classification |
|---|---|
| 1 | Built-up Land |
| 2 | Undeveloped Land |
| 3 | Roads |
| 4 | Agricultural Land |
| 5 | Water Bodies |

### *Data Analysis Methods and Research Flowcharts*

Mapping of tidal flood inundation in Banjarmasin City was conducted through an iterative process utilizing neighborhood operations or nearest-neighbor analysis. Iteration, which is part of map calculations, involves the sequential repetition of mathematical operations. In each iteration step, the results of the previous calculation are used as input for the subsequent calculation. This approach allows for the gradual adjustment and refinement of data until accurate and comprehensive results are achieved. This iterative method is highly effective in mapping tidal flood inundation because it enables more detailed modeling and responsiveness to changes in conditions occurring in the region (Arief et al., 2014; Utami et al., 2021). By using a neighborhood analysis, this process is able to identify and account for the spatial relationships between data points, thereby producing more realistic and informative flood maps.The formula used to perform the iteration according to (Marfai & King, 2008) is as follows:

Result = MapIterProp (Gs, iff(DEM > n, Gs, nbmax (GS#)))

Description:

| | |
|---|---|
| Result | : Output of the iteration process in the form of a raster |
| MapIterProp | : iteration expression that determines the calculations to be performed |
| GS | : River lines, the starting point of the iteration |
| DEM | : Data for which pixel values will be calculated |
| n | : The highest value in the specified model (meters) |
| nbmax(GS#) | : function to return to the starting pixel (value 1) |

The iterative process in this study was carried out using the ILWIS 3.3 Academic version software. This software was selected due to its strong capabilities in handling spatial analysis and geospatial data modeling. The modeling performed in this study utilized raster data as the basis for analysis, in accordance with the methodology proposed by (Marfai & King, 2008; Sejati et al., 2020). Modeling of tidal flooding in the city of Banjarmasin was conducted by considering various possible water levels: 0.25 meters, 0.5 meters, and 1 meter. These scenarios were selected based on the average elevation of the Banjarmasin area, thereby providing a realistic picture of the potential for tidal flooding in the region. Flood inundation analysis can provide a more comprehensive picture of the potential impacts in Banjarmasin by utilizing various water level scenarios. This method enables the identification of which areas are most vulnerable to flooding under each scenario and aids in planning appropriate mitigation solutions. Furthermore, the application of various water level scenarios provides a more comprehensive understanding of the impact of changes in water elevation on the infrastructure and environmental conditions of Banjarmasin. This information is crucial for developing better flood management plans by considering the scenarios that best align with the city's actual conditions.

### *Research Flowchart*

This process begins with identifying specific issues related to tidal flooding. Next, relevant data both primary and secondary is collected, such as regional administrative data, DEMs, and river lines. After the data is collected, data processing is performed, which includes cropping the DEM data, modifying land cover classifications, and converting vector data into raster format. This data is then used to create a tidal flooding model, which will show how flooding occurs and spreads across the study area. The area inundated by tidal flooding is calculated after the model is run. The modeling results report, which includes the inundated areas, flood depth levels, and other information, is crucial for understanding the impacts of flooding and planning mitigation measures. See Fig 2.

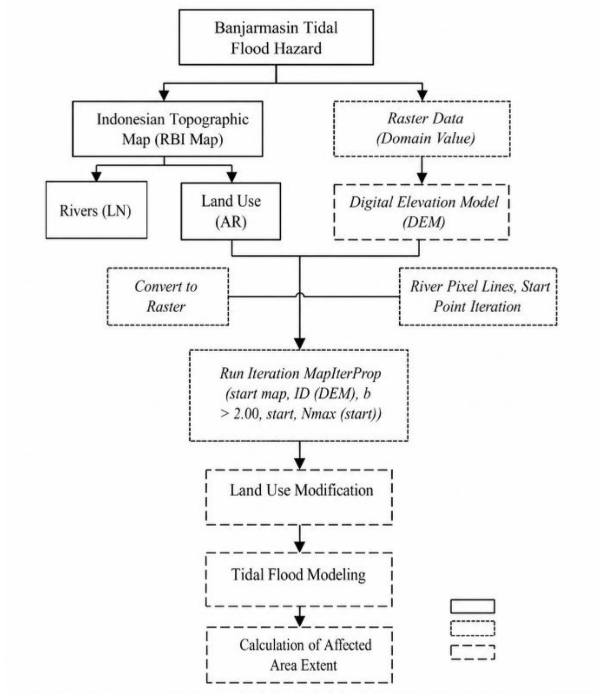

Fig. 2 Research Flowchart

## Result

### 0.25-Meter Sea-Level Rise Scenario

Modeling of the first scenario, which accounts for a 0.25-meter rise in sea level, indicates that flooding is limited to specific areas in South Banjarmasin and North Banjarmasin subdistricts (Table 3). These areas are generally undeveloped, such as swamps, scrubland, open land, and agricultural areas. Flooding in this scenario does not spread widely to residential areas or major infrastructure, but remains localized in areas that are naturally more vulnerable to flooding (Fig 3).

These conditions indicate that at a sea-level rise of 0.25 meters, the impacts of tidal flooding remain manageable and are limited to areas that are geographically and ecologically more prone to flooding. Swamps and open lands tend to have low elevations and limited drainage capacity, causing water to accumulate easily and result in flooding. In open areas, low infiltration can also increase surface runoff, which ultimately expands the flooded area in the surrounding region. Shrublands and agricultural areas typically have vegetation that can help absorb water, though they remain at risk of flooding when sea levels rise.

Table 3. Area of Land Cover Types Affected by Tidal Flooding at a 0.25-meter Rise

| Land Cover | Area (Ha) | (%) |
|---|---|---|
| Flooded Roads | 36,79 | 0,41% |
| Flooded Undeveloped Land | 392,38 | 4,39% |
| Flooded Developed Land | 353,47 | 3,96% |
| Flooded Agricultural Land | 1801,52 | 20,18% |
| Non-flooded Roads | 220,45 | 2,47% |
| Non-flooded Undeveloped Land | 920,03 | 10,30% |
| Non-flooded Developed Land | 3602,86 | 40,35% |
| Non-flooded Agricultural Land | 1601,88 | 17,94% |
| Total Area | 8929,38 | 100% |

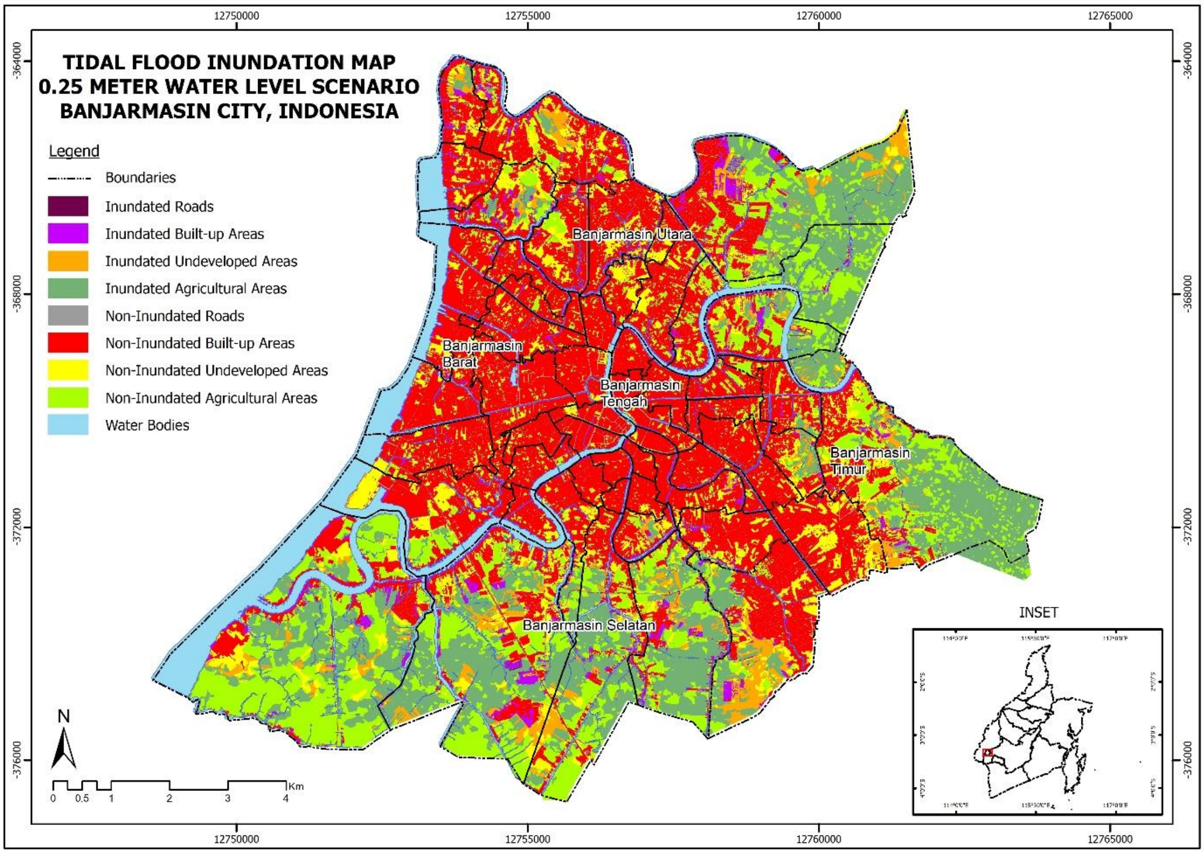

Fig. 3 Map of Tidal Flood Distribution for the 0.25 m Scenario

### 0.5-meter Elevation Scenario

Scenario modeling with a sea-level rise of 0.5 meters shows more significant impacts compared to the previous scenario (Table 4). At this level of rise, tidal flooding not only inundates undeveloped areas such as swamps, scrubland, open land, and agricultural areas, but also begins to encroach on developed areas (Fig4). The affected developed areas include residential areas, social and public facilities, and industrial zones. This flooding poses a greater risk to people's lives, economic activities, and critical infrastructure in the three main districts of North Banjarmasin, West Banjarmasin, and South Banjarmasin. Flooded residential areas can cause damage to homes, disrupt daily activities, and increase health risks due to contaminated water. Flooded educational facilities can disrupt the teaching and learning process, while submerged industrial zones can hinder the production and distribution of goods, as well as cause significant economic losses. Additionally, widespread flooding in undeveloped areas such as swamps, thickets, open land, and agricultural areas will certainly also has a negative impact on natural ecosystems and agricultural productivity. Flooded swamps and scrublands are at risk of ecosystem changes, which can affect biodiversity and ecological functions. Flooded open lands and agricultural areas can cause crop damage, reduce crop yields, and disrupt local food security.

### 1-Meter Height Scenario

Scenario modeling with a 1-meter rise in sea level indicates very significant and alarming impacts for the city of Banjarmasin (Table 5). At this level of rise, all subdistricts in the city would be inundated by storm surges, including most built-up areas. Residential areas, public facilities, transportation infrastructure, and various economic activities are massively disrupted (Fig 5). Tidal flooding on this scale can paralyze most of the city's functions and cause massive economic losses. However, office areas such as the Mayor's Office, Sudimampir Market, and their surroundings remain relatively safe from flooding. Additionally, most of Ahmad Yani Street remains dry, particularly the section from kilometer 1 to kilometer 7. This indicates that areas with higher elevations or those supported by flood-protective infrastructure tend to be more resilient to sea-level rise. Conversely, this scenario illustrates how the city of Banjarmasin could be impacted by sea-level rise. A 1-meter rise in sea level could alter the city's landscape and threaten the lives of surrounding communities if no significant preventive measures are taken.

Given the significant impact of a 1-meter rise in sea level on the city of Banjarmasin, prompt and comprehensive adaptation and mitigation measures are of the utmost importance. The government and the public need to collaborate to build robust flood protection infrastructure, such as seawalls, floodgates, and efficient drainage systems. Additionally, sustainable land-use planning must be implemented by restricting development in flood-prone areas and designating green zones as water absorption areas. It is also important to raise public awareness about the dangers of tidal flooding through intensive education and outreach. This includes understanding the risks, causes, and mitigation measures that can be taken. The implementation of an effective early warning system is also crucial for providing timely and accurate information regarding potential tidal flooding, enabling the public to take timely evacuation and preparedness actions.

Table 4. Area of Land Cover Types Affected by Tidal Flooding at a Height of 0.5 Meters

| Land Cover | Area (Ha) | (%) |
|---|---|---|
| Flooded Roads | 118,02 | 1,32% |
| Flooded Undeveloped Land | 877,32 | 9,82% |
| Flooded Developed Land | 1568,72 | 17,56% |
| Flooded Agricultural Land | 2669,21 | 29,89% |
| Non-flooded Roads | 147,97 | 1,66% |
| Non-flooded Undeveloped Land | 435,97 | 4,88% |
| Non-flooded Developed Land | 2376,88 | 26,61% |
| Non-flooded Agricultural Land | 737,23 | 8,25% |
| Total Area | 8931,31 | 100% |

Table 5. Area of Land Cover Types Affected by Tidal Flooding at a Height of 1 Meter

| Land Cover | Area (Ha) | (%) |
|---|---|---|
| Flooded Roads | 118,02 | 1,32% |
| Flooded Undeveloped Land | 877,32 | 9,82% |
| Flooded Developed Land | 1568,72 | 17,56% |
| Flooded Agricultural Land | 2669,21 | 29,89% |
| Non-flooded Roads | 147,97 | 1,66% |
| Non-flooded Undeveloped Land | 435,97 | 4,88% |
| Non-flooded Developed Land | 2376,88 | 26,61% |
| Non-flooded Agricultural Land | 737,23 | 8,25% |
| Total Area | 8931,31 | 100% |

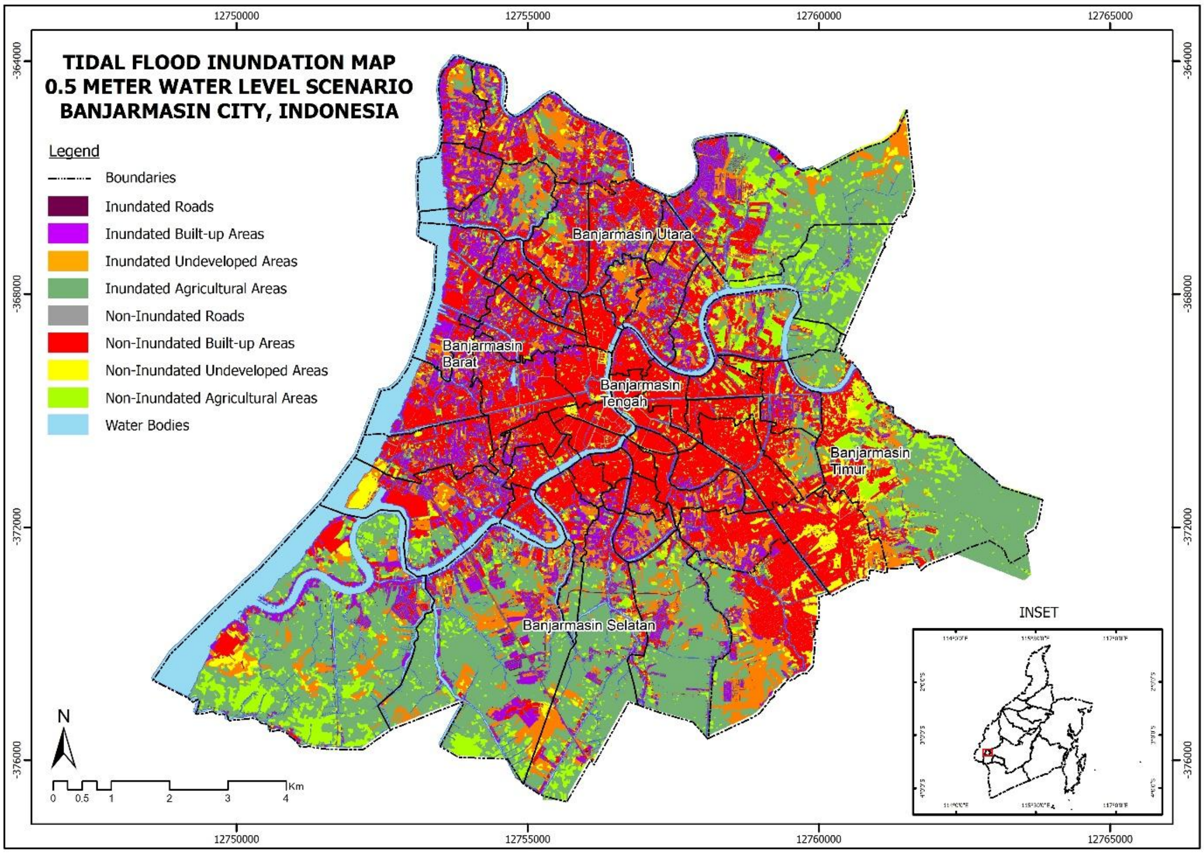

Fig 4. Map of Tidal Flood Distribution for the 0.5 m Scenario

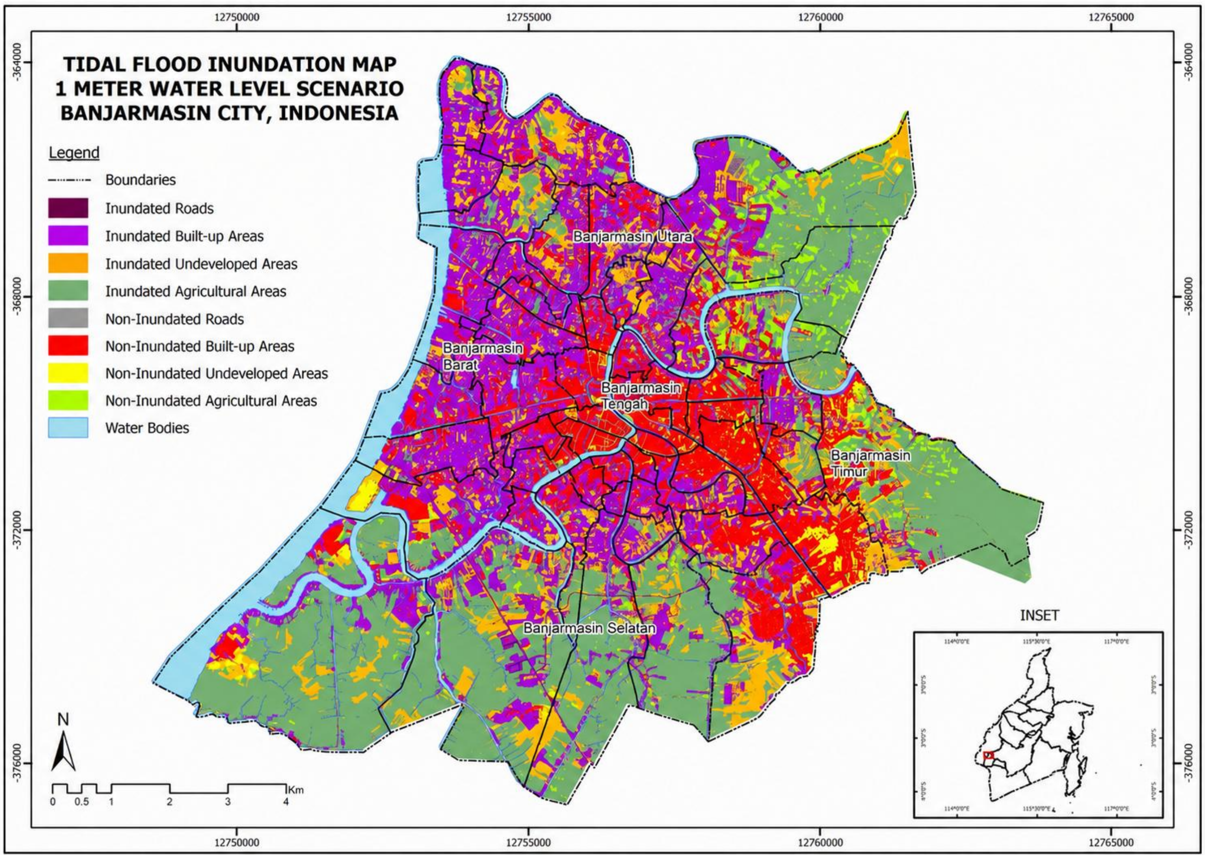

Fig. 5 Map of Tidal Flooding Distribution for the 1-Meter Scenario

## Discussion

The results of the study indicate that rising sea levels significantly affect the extent of tidal flooding in the city of Banjarmasin. In the 0.25-meter scenario, flooding remains relatively limited and is predominantly confined to agricultural land, accounting for approximately 20.3% of the total area. However, in the 0.5-meter scenario, the extent of flooding increases significantly, particularly in agricultural areas (approximately 29.90%) and begins to spread into built-up areas (approximately 17.56%). In the 1-meter scenario, the flood area becomes even more extensive, with agricultural land accounting for ±35.12% and built-up areas for ±27.78%. This indicates that sea-level rise not only expands the inundation area but also progressively increases the vulnerability of urban areas.

This finding is consistent with the research by Robert J. Nicholls (2004), who states that low lying coastal areas are highly vulnerable to the impacts of sea level rise, particularly in delta and swamp cities such as Banjarmasin. Additionally, research by Doni Marfai (2008) indicates that tidal flooding in Indonesia’s coastal regions is influenced by a combination of low topography, land use, and tidal dynamics.

Physically, the flooding patterns observed in this study are influenced by land cover characteristics and topographic conditions. Agricultural land and swamps are generally located at low elevations with limited drainage capacity, so water easily accumulates and causes flooding that lasts for longer periods. Meanwhile, on developed land, impervious surfaces such as concrete and asphalt reduce infiltration and increase surface runoff, thereby accelerating the spread of flooding to surrounding areas. These conditions explain why, under higher elevation scenarios, flooding begins to spread significantly into urban areas.

When comparing the scenarios, there is a consistent increase in the extent of flooding across all land cover types. This increase is nonlinear, meaning that even a small rise in sea level can lead to a significant expansion of flooding, particularly in areas with flat topography. This indicates that the city of Banjarmasin is highly sensitive to changes in sea level. Thus, this study contributes to understanding the relationship between sea level rise and the distribution of tidal flooding based on land cover characteristics through a spatial modeling approach based on the neighborhood operation.

The implementation of an effective early warning system is also crucial for providing rapid and accurate information about potential tidal flooding, enabling the public to take timely evacuation and preparedness measures. Collaboration between the government and the public in these efforts will be critical to successfully addressing the challenges posed by rising sea levels, protecting lives, and maintaining the stability and sustainability of the city of Banjarmasin.

## Conclusion

This study shows that rising sea levels have significantly increased the extent of tidal flooding in the city of Banjarmasin, with agricultural land being the most vulnerable land cover. In the 0.25-meter scenario, flooding remains limited (±20.2%), but increases in the 0.5 meter scenario (±29.9%) and becomes extensive in the 1-meter scenario, with approximately 78% of the city’s area flooded. This indicates that the city of Banjarmasin has a high level of vulnerability to sealevel rise, particularly in low lying areas with limited drainage systems. The contribution of this study lies in the application of neighborhood based spatial modeling integrated with land cover analysis under various sea level rise scenarios. This approach enables the identification of vulnerable areas in greater detail, thereby supporting spatially based tidal flood mitigation planning.

However, this study has limitations because it uses only Digital Elevation Model (DEM) and land cover data, without considering hydrodynamic factors such as tides, rainfall, and land subsidence. Therefore, future research is recommended to incorporate more complex hydrodynamic data and employ a wider range of sea level rise scenarios to improve modeling accuracy. In practical terms, the results of this study can serve as a basis for developing mitigation strategies, such as strengthening flood-control infrastructure, implementing risk-based spatial planning, and implementing nature-based solutions to enhance the resilience of coastal areas to storm surges.

## Author Contribution

All authors contributed equally to this work. All authors participated in the conception and design of the study, data collection, data analysis and interpretation, manuscript writing, revision of the manuscript, and approval of the final version.

## Data Availability Statement

All data generated or analyzed during this study are presented in the tables and figures within this article.

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## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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