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FLOOD RISK ANALYSIS: SPASIAL INTEGRATION OF LAND USE CHANGE, RTRW SUITABILITY, AND FLOOD VULNERABILITY IN THE JANG RIVER WATERSHED, TANJUNG PINANG CITY (2017-2015)

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ABSTRACT: This research explores the intensifying flood risks within the Jang River Watershed, Tanjung Pinang, by examining the critical intersection of rapid land-use shifts, regional spatial planning (RTRW), and escalating vulnerability levels. Utilizing a GIS-based quantitative spatial approach with weighted overlay techniques, the analysis reveals a compelling causal link between urban expansion and heightened flood exposure. Between 2017 and 2025, the watershed experienced a significant decline in hydrological function, driven by a 20.89% surge in built-up areas and a staggering 54% loss of wetland vegetation since 2021. These landscape alterations have resulted in 4,442.01 hectares being classified under moderate flood hazard, while 306.83 hectares are now designated as high-risk zones The 6,206.61 hectares of land-use mismatch with the official spatial plan (RTRW) shows a serious gap in local planning, which unfortunately allows new developments to expand into high-risk flood zones. The study identifies 426.34 hectares as highly vulnerable, particularly in zones where recent construction bypasses established spatial regulations.

Keywords: Land Change, The Jang River Watershed, Flood Hazards, Flood Vulnerability, RTRW

1. INTRODUCTION

Tanjung Pinang City faces escalating flood risks driven by rapid urbanization within the Jang River Watershed a critical hydrological unit where land-use transformation, spatial planning inconsistencies, and growing community vulnerability converge. Hydrometeorological disasters, particularly floods and flash floods, have become increasingly frequent [1][2] directly linked to the pace at which natural landscapes are converted into impervious surfaces. This heightened risk is no accident; the sheer pace of urbanization has fundamentally reshaped the local landscape. Past research confirms that such urban sprawl and land-use shifts do more than just spike surface runoff, effectively stifling the ground's natural ability to absorb water [1] [3].

As a regional hub for administration and culture, Tanjung Pinang attracts a steady stream of productive-age migrants, driving a demand for new land that often bypasses ecological logic [4], [5]. The consequences are particularly stark in the Jang River watershed, where reclamation and river backfilling have overhauled the area's original hydro-orology. This loss of infiltration capacity has, in turn, intensified the city's physical vulnerability to flooding, a reality now formally recognized in regional planning frameworks [6][7].

Assessing flood risk effectively requires us to look far beyond basic mapping, as it demands a deep integration of physical hazards and the complex social fabric of the community rightly argue, flood risk is never static [8][9]. Instead, it is something that evolves, shifting in tandem with a society's economic and spatial growth. This reality calls for a dynamic perspective, one that can account for how biophysical and social conditions change over time [10]. Within this framework, evaluating land-use consistency against the Regional Spatial Plan (RTRW) is not merely a planning exercise it is a diagnostic tool for identifying where unauthorized development directly amplifies flood hazard. In the Jang River Watershed, deviations from the RTRW have eroded hydrological buffers and accelerated

impervious surface expansion, demonstrating that spatial planning compliance is a core determinant of flood risk [11].

In rapidly expanding cities like Tanjung Pinang, we often see a dangerous mismatch between actual land use and official spatial plans. When this gap is paired with a surging population, social vulnerability intensifies almost immediately [12]. This trend is especially worrying in areas where infrastructure hasn't kept pace with hydrometeorological threats. In this study, we evaluate social vulnerability by looking closely at population density, age demographics, education, and economic status, all of which are critical factors that ultimately determine how much a community stands to lose [9][13].

To get a clear picture of these complexities, our research utilizes a GIS-based scoring method and weighted overlay techniques, both of which have a solid track record in vulnerability mapping [13-14]. However, there is a glaring gap in the current regional literature, as most studies only provide a 'frozen' or static snapshot of physical hazards. Our study moves past this limitation by offering a comparative, spatial-dynamic analysis. By tracing how physical shifts from land-use changes influence the spread of social vulnerability between two key milestones, 2017 and 2025, we aim to provide a more accurate and time-sensitive map of flood risk trends within the Jang River watershed [8-9]. Based on this gap, this study aims to identify and map land changes that occurred in Tanjung Pinang in 2017, 2021, 2025, analyze the suitability of RDTW land with the existing conditions of land use in Tanjung Pinang City and map the level of flood danger and vulnerability in the Jang watershed, Tanjung Pinang City which will be discussed in the formulation and objectives of the research. The results of this study are expected to provide a methodological contribution, as well as a useful reference for the adjustment of spatial planning policies and the determination of disaster mitigation in accordance with the goals of sustainable development in Tanjung Pinang City [16][17].

2. RESEARCH METHODS

2.1 Research Design and Setting

The research location is focused on the Jang River Watershed, Tanjung Pinang City, Riau Islands Province. The study area includes Bukit Bestari District, Tanjung Pinang City which is spatially within the watershed boundary.

Table 1. Research Materials

No	Data	Source	Function
1	Rainfall in 2017 and 2025	BMKG Tanjung Pinang City	Rainfall of the research area
2	RBI Map	Ina-Geoportal	Regional Administration
3	Shapefile Soil Type	Government of Tanjung Pinang City	Soil Type Research Area
4	Population in 2017 – 2025	BPS Tanjung Pinang City	Social Conditions
5	Slope Map	USGS	Slope of the research area

Source: Processed by author, 2025

This study employs a spatial quantitative approach within the Jang River Watershed as the primary analytical unit. The research integrates three interconnected analyses (1) multi temporal land-use change detection across 2017, 2021, and 2025. (2) spatial consistency assessment of existing land use against the Tanjung Pinang City Regional Spatial Plan (RTRW) and (3) GIS based flood hazard and vulnerability mapping. This integrated framework enables a dynamic assessment of how land-use transformations and planning inconsistencies collectively drive flood risk evolution within the watershed.

2.2 Data Analysis Techniques

2.2.1 Land Use Change in Tanjung Pinang City (2017 – 2025)

Land-use dynamics within the Jang River watershed across the 2017, 2021, and 2025 periods were analyzed through a comparative spatial approach in a GIS environment. This process involved synthesizing multi-temporal datasets to calculate area fluctuations, followed by a map overlay technique to quantify and visualize land-use transitions for each period [18].

2.2.2 Suitability of Existing Land Use with the Tanjung Pinang City RTRW

The suitability of the use of existing land to the Regional Spatial Plan (RTRW) of Tanjung Pinang City was carried out by overlay analysis. Overlays are carried out using land use maps and RTRW maps that generate new polygons or areas with specific information. Each sliced polygon is evaluated and classified into 2 appropriate and non-appropriate categories. The category is appropriate if the change in land use is in accordance with the RTRW designation, the category is not suitable if the land use has not

reached the planned cultivation function and has not been in accordance with the conditions of the area [3][11][19].

Table 2. Parameter Weighting

No	Criteria	Sub Criteria	Rank	Weight (%)	Score
1	Rainfall	2.500 – 3.000 mm/year	2	15	0,30
		301-399 mm/year	3		0,45
2	Slope	0-8%	5	25	1,25
		8.1-15%	4		1,00
		15.1-25%	3		0,75
		25.1-45%	2		0,50
		>45%	1		0,25
3	Land Use	Water bodies	5	25	1,25
		Vegetation/ Forest	1		0,25
		Wetland Vegetation	2		0,50
		Agriculture/ Plantation	3		0,75
		Woke Areas	4		1,00
		Vacant Land	5		1,25
		Cloud	1		0,25
		Grasslands	3		0,75
4	Soil Type	Red Yellow Podzolic	2	10	2,00
5	Distance from the River	>500 m	1	25	0,25
		250 - 500 m	2		0,50
		150 - 250 m	3		0,75
		50 -100 m	4		1,00
		0 - 50 m	5		1,25

2.2.3 Flood Hazard in Tanjung Pinang City

This study operationalizes the Risk = Hazard x Vulnerability framework by integrating physical environmental data with socio-economic indicators [12]. Validated by empirical modeling literature [20], this approach allows for a dynamic assessment of how land-use changes directly influence flood risk evolution. Specifically for the Jang River watershed, we employ a GIS-based weighted overlay analysis. We decompose flood hazard into five key physical parameters: rainfall intensity, soil infiltration capacity, slope steepness, existing land use, and proximity to river systems. Each parameter is scored on a 1–5 scale based on its relative contribution to flood susceptibility. By assigning specific weights to these layers, we generate a spatial-dynamic map that classifies the watershed into low, moderate, and high hazard zones [16-17]. This method ensures the resulting risk trends accurately reflect the temporal shifts between the 2017 and 2025 planning periods.

2.2.4 Flood Vulnerability of Tanjung Pinang City

To capture the complexities of flood vulnerability in Tanjung Pinang City, this study weaves together socio-spatial dynamics and physical landscape variables. Our mapping process integrated CHIRPS rainfall records with the city's 2025 Land-Use Map and RBI topographic data, while extracting critical elevation and slope gradients directly from DEMNAS [18]. By analyzing these layers, we categorized the city's terrain into five vulnerability tiers, moving from non-vulnerable to highly vulnerable zones. This focus on vulnerability is further sharpened by looking at how rainfall intensity and river network density intersect with urban growth. Instead of a generic assessment, our approach utilizes a weighted framework cross-referenced with actual historical flood footprints [21][22]. By prioritizing these socio-spatial factors, the resulting analysis provides a realistic, dynamic picture of how vulnerability is shifting across Tanjung Pinang, specifically where human activity meets high-risk environmental conditions [23].

3. RESULTS AND DISCUSSION

3.1 Land Use Changes in Tanjung Pinang City in 2017 – 2025

Land use identification within the jang River Watershed, encompassing the administrative area of tanjung Pinang City, was condusted for the periods of 2027, 2021, and 2025 through systematic satellite amge interpretation. The classification includes water bodies, forest vegetation, wetland vegetation, agriculture, built-up areas, vacant land, and grasslands. Notably, from 2017 to 2021, the most dominant transition was a 165.57% surge in agricultural and plantation areas. During the same period, built-up areas expanded by 16.54%. This trend of rapid urban expansion and land cover alteration mirrors global patterns where the conversion of natural landscapes into impervious surfaces significantly heightens regional flood risks [24]. Further details regarding these shifts are presented in the following table.

Table 3. Trends of Land Use Change in Tanjung Pinang City in 2017, 2021, 2025

No	Criteria	Land Area in 2017(Ha)	Land Area in 2021 (Ha)	% Change 2017 -2021	Land Area in 2025 (Ha	% Change 2021 -2025
1	Water bodies	9653,0	888,94	-7,05	842,47	-5,23
2	Vegetation/ Forest	5.242,08	4.770,97	-8,97	5.561,03	+16,54
3	Wetland Vegetation	221,57	152,40	-31,22	148,55	-54
4	Agriculture/ Plantation	310,96	825,70	+165,57	724,36	-12,27
5	Woke Areas	3.996,60	4.579,14	+14,56	4.778,58	+4,35
6	Vacant Land	882,18	474,62	-46,20	313,68	-33,90
7	Cloud	130,45	79,72	-38,91	56,89	-28,62
8	Grasslands	3.286.34	3.254,65	-0,96	2.600,68	-20,08

Source: Results of data analysis, 2025

Land use in 2025 has changed where there is an increase in vegetation/forest area of 16.54% from 2021, there is also an increase in built-up area of 4.35% from 2021 while other land uses have decreased in area. The percentage reduction from agricultural areas is 12.27%, wetland vegetation is reduced by 54% from 2021.

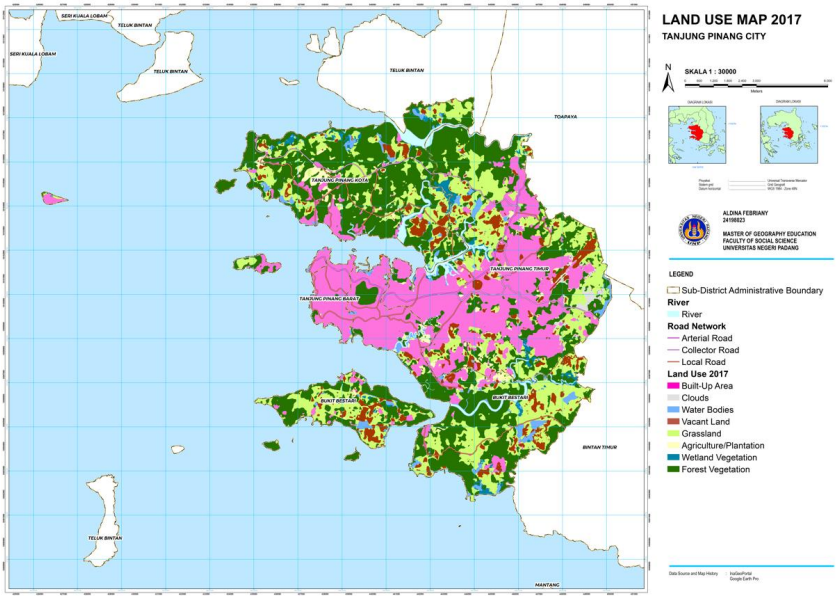

Fig. 1 Land Use Map,2017 in Tanjung Pinang City

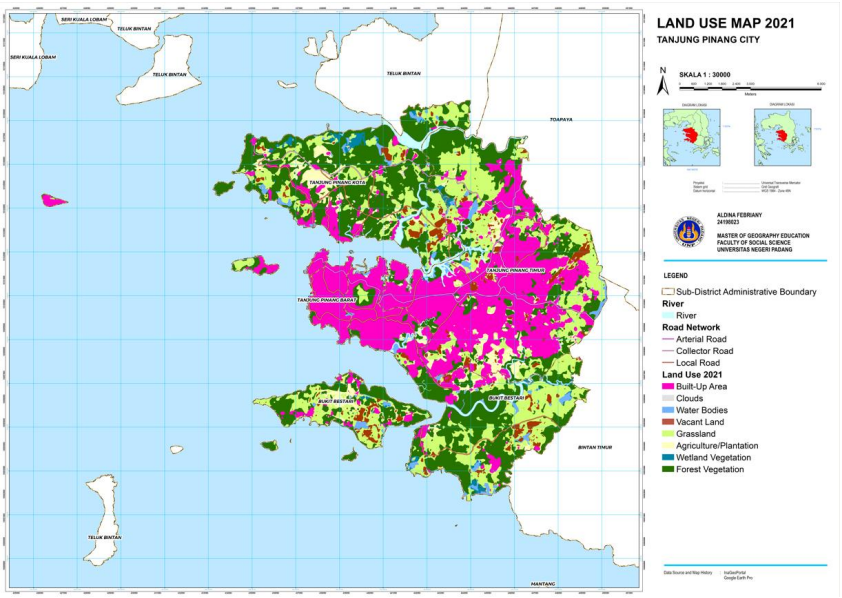

Fig. 2 Land Use Map,2021 in Tanjung Pinang City

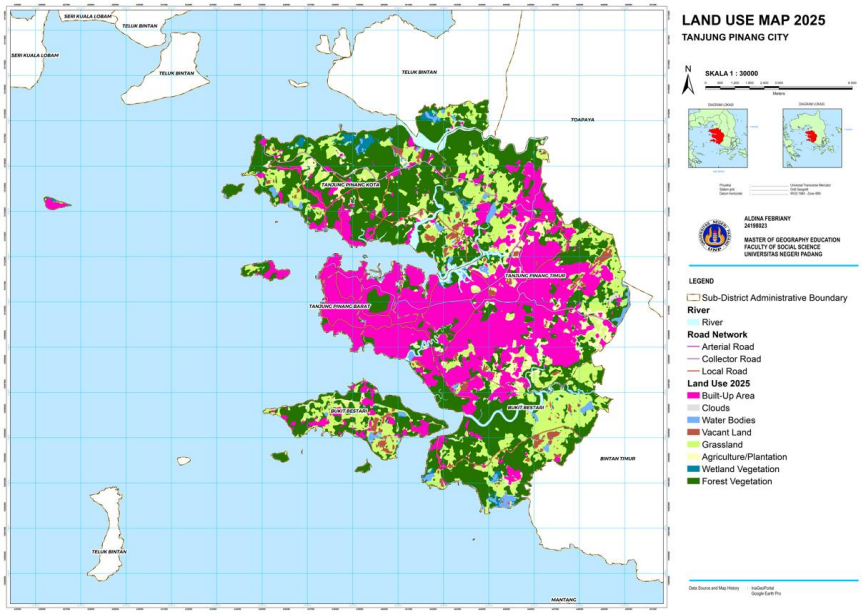

Fig. 3 Land Use Map, 2025 in Tanjung Pinang City

3.2 Level of Land Use Suitability with Suitable Land for RTRW in 2025 in Tanjung Pinang City

The projection of land use Tanjung Pinang City in 2025 shows that there are spatial dynamics, especially in the increase in built-up areas and changes in other regional functions. This phenomenon occurs because it is caused by population growth and the need for land to meet residential areas and residents' activities so that it can reduce other productive areas. The gap between land use and RTRW is based on land conversion that exceeds the carrying capacity of the area and has the potential to cause new environmental problems and even disasters [25].

The existing area of Tanjung Pinang City is analyzed based on several aspects of land use obtained from the overlay of RTRW data with the land use of Tanjung Pinang City. The suitability of land for the Tanjung Pinang City RTRW consists of suitable and inappropriate areas. The area that complies with the RTRW covers an area of 8.691,63 hectares while the area that does not comply with the area is 6.206,61 hectares. From the analysis using imagery, there is an area of 56,89 hectares that is not identified because the area is covered by clouds. Critically, when the 6.206,61 hectares of non compliant land are spatially cross referenced with flood hazard zones in the Jang River Watershed, a significant proportion falls within medium to high hazard

areas. This overlap demonstrates that RTRW non compliance is not merely a regulatory concern but a direct amplifier of flood risk, validating the integration of suitability analysis as a diagnostic layer within the overall flood risk framework.

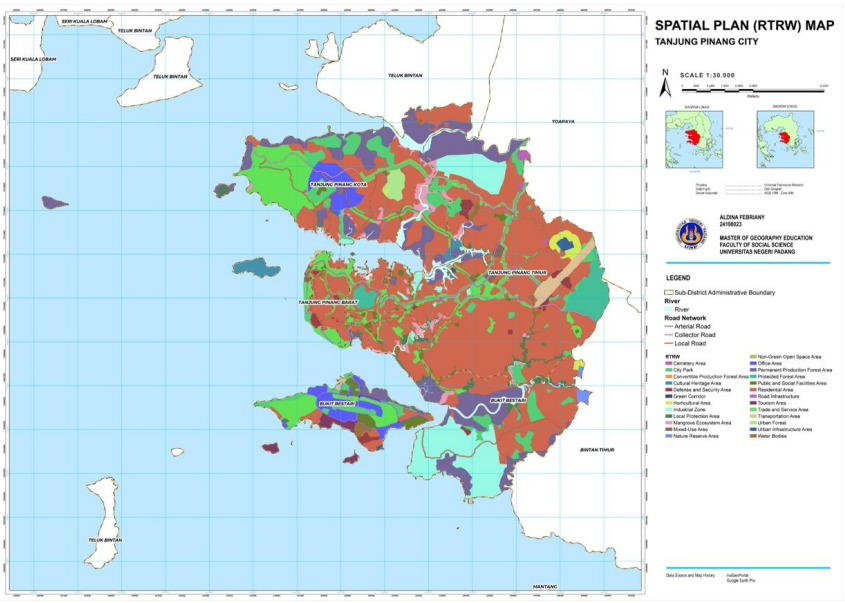

Fig. 4 The Spatial Plan (RTRW) Map, Tanjung Pinang City

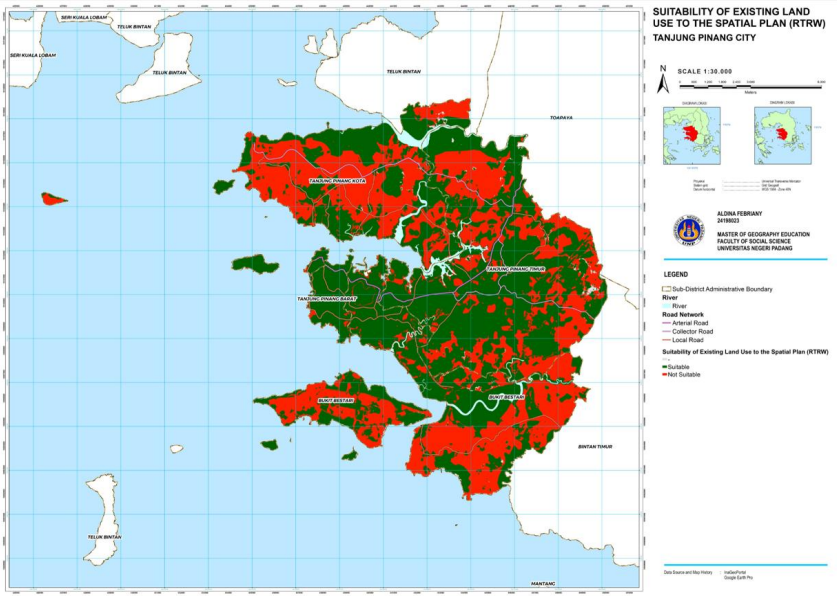

Fig. 5 The Suitability of Existing Land Use the Spatial Plan (RTRW) in Tanjung Pinang City

3.3 Flood Hazard Level in The Jang River Watershed, Tanjung Pinang City

Mapping the level of flood danger in Tanjung Pinang City was carried out by scoring method by overlaying land use, rainfall, soil type and slope. Areas with low-level flood hazard classes with an area of 1,226.83 hectares, medium-level flood hazard areas with an area of 4,442.01 hectares and high-level flood hazard areas with an area of 306.83 hectares. Mapping of areas with flood danger levels can be seen on the following map.

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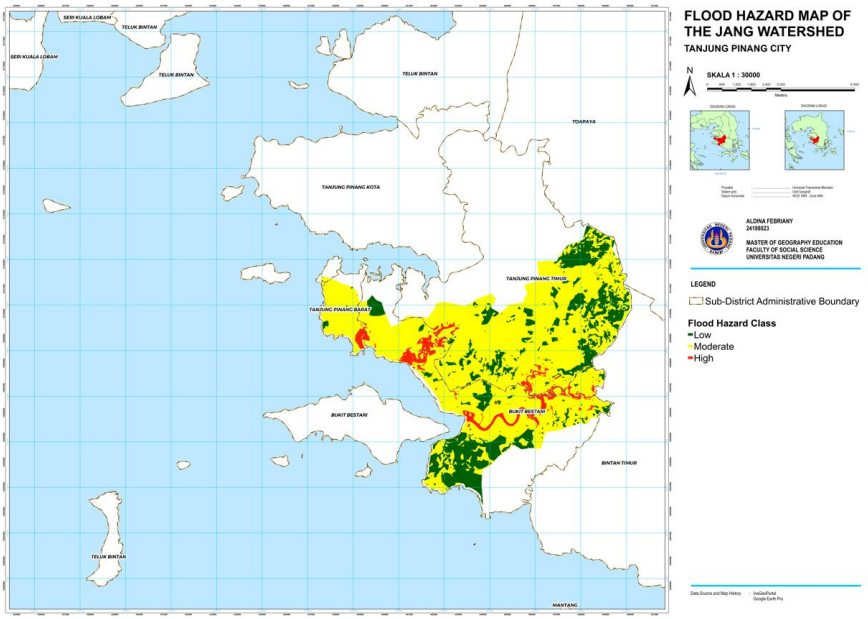

Fig. 6 The Flood Hazard Level of The Jang River Watershed Map, Tanjung Pinang City

3.4 Flood Vulnerability Level in The Jang River Watershed, Tanjung Pinang City

The level of flood vulnerability in Tanjung Pinang City was analyzed by a combination of biophysical and hydrometeorological parameters, namely rainfall, slope, soil type, distance to the river and land use.

Based on the overlay analysis, the area of flood vulnerability around the Jang River watershed, Tanjung Pinang City was obtained. Areas with a relatively flood-prone area with an area of 1,615 hectares, sufficient treatment area of 3,451.36 hectares, flood-prone area of 426.34 hectares, very vulnerable areas with an area of 165.73 hectares and non-vulnerable areas with an area of 317.23 hectares.

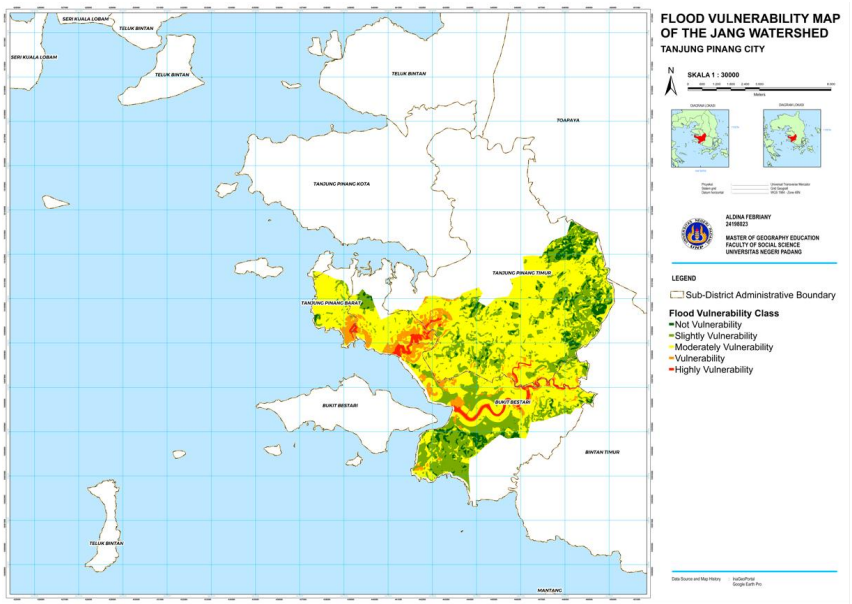

Fig. 7 The Flood Vulnerability Map of The Jang River Watershed, Tanjung Pinang City

3.5 Relationship between Land Use Change, Land Suitability Level with RTRW, Flood Hazard Level and Flood Vulnerability Level in The Jang River Watershed, Tanjung Pinang City

The integrated spatial analysis reveals a clear causal chain operating within the Jang River Watershed. First, the conversion of vegetated and wetland areas into built up and agricultural land (2017–2025) reduced natural infiltration capacity, directly intensifying flood hazard levels. Second, the 6.206,61 hectares of RTRW-non-compliant development concentrated disproportionately in areas classified as medium to high hazard zones, confirming that spatial planning violations accelerate hydrological degradation [3]. Third, the combination of physical hazard intensification and planning non compliance has expanded the spatial footprint of flood vulnerability, with 426,34 and 165,73 hectares of built up areas now falling within flood prone and highly vulnerable zones, respectively.

This three component integration land use change, RTRW suitability, flood hazard and vulnerability provides a more complete explanatory framework than single factor analyses, capturing both the drivers and the spatial distribution of flood risk. The findings underscore that effective flood risk management in Tanjung Pinang City requires simultaneous attention to land-use dynamics, spatial planning compliance, and community vulnerability, as each component compounds the others in ways that static or isolated assessments cannot reveal [22] [26] [27].

4. CONCLUSION

The escalating flood risk in the Jang River watershed stems from a sharp conflict between rapid urban growth and stalled spatial planning. Between 2017 and 2025, hydrological functions declined significantly, marked by a staggering 54% loss of wetlands and productive areas since 2021. This shift has directly expanded flood-prone zones. The crisis is worsened by 6,206.31 hectares of land-use mismatches with the official RTRW, placing critical built-up areas, specifically 426.34 and 165.73 hectares, within high-vulnerability zones. These findings confirm that a truly comprehensive risk assessment must integrate land-use changes, spatial planning consistency, and socio-physical vulnerability. The use of dynamic modeling is essential to track how risks evolve alongside urbanization, as the nature of flood threats is inherently transformative [19]. To mitigate these impacts, the Tanjung Pinang government must move beyond passive oversight to firm RTRW enforcement and protected area preservation. By adopting risk-based planning that balances social and ecological needs, the city can effectively curb flood threats while securing sustainable urban growth. The integrated analysis of land-use change, RTRW suitability, and flood vulnerability within the Jang River Watershed demonstrates that these three dimensions are not independent phenomena but mutually reinforcing drivers of flood risk. This study's primary contribution lies in demonstrating how their spatial integration rather than isolated assessment produces a more accurate and actionable risk map for urban watershed management.

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