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ANALYSIS OF THE CYCLONE WIND HAZARD LEVEL BASED ON REMOTE SENSING AND GIS IN PONTIANAK CITY

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ABSTRACT

Over the past century, numerous cyclones have affected several countries, resulting in significant economic losses. This study uses GIS to determine the Danger Level of Tornadoes and the distribution of areas affected by tornadoes in Pontianak City in 2024. The method used is secondary data analysis. The data analysis technique used is a weighted, tiered quantitative analysis employing the Analytical Hierarchy Process (AHP) approach and the Overlay function in ArcGIS 10.8, utilising the Weighted Overlay spatial analysis tool. The data were rainfall, ground surface temperature, slope, and land cover. The four parameters were made into a map, each weighted using the AHP method. The results showed that the level of danger of tornadoes in Pontianak City in 2024, using GIS and Remote Sensing, has four classes: very low, low, medium, and high. Very low class has an area of 223.86 ha (2%), low class 3510.52 ha (35%), medium class 6262.04 ha (62%) and high class (151.71 ha (1%). Most of the classes of tornado hazard levels are medium. The distribution of this class is mostly in West Pontianak, Pontianak Kota, and South Pontianak sub-districts. The lower class is mostly located in Southeast and North Pontianak.

Keywords: *Analysis; Cyclone Disaster; GIS; Level Denger; Remote Sensing*

INTRODUCTION

Over the past century, many Tornadoes have struck several countries, causing significant economic losses. For example, between 1949 and 2006, 793 Tornadoes caused more than USD 1 million in losses for each Tornado (Changnon, 2009; Kaya et al., 2024). In addition to monetary losses, these disasters also caused 71 fatalities annually between 1993 and 2022 (Service, 2022).

Apart from tornadoes causing death, injury, and damage to property and the economy, they can also have long-term impacts on the psychological condition of the community (First et al., 2021). The problem, as we advance, is the increasing risk of tornadoes and the increasing extent of higher exposure due to factors triggered by climate change (Strader et al., 2017). When all these issues arise, it is essential to develop methodologies that can help reduce the impact of disasters and address related issues.

As with any disaster, it is important to investigate the tornado phenomenon. The goal is understanding individual risk, preparedness, response, protective measures, and recovery techniques. In the literature, several factors have been found that cause tornadoes. The first step is to measure the causal factors to reduce vulnerability due to disasters. Tornadoes can cause disruptions such as power outages, house damage, fallen trees, and even threaten life safety. Therefore, literature on tornadoes is necessary for disaster mitigation efforts.

For example, the power outages caused by Hurricane Hermine in the Tallahassee community and infrastructure can be analysed through spatial and statistical analysis (Ulak et al., 2018). Spatial analysis was used to detect heavily affected areas based on the criterion of a percentage of affected customers. In contrast, Bayesian spatial autoregressive models were used to associate those customers with demographics, socioeconomic status, access to transportation infrastructure, and storm-related activities.

Evaluating tornado exposure variables can help authorities determine tornado problem locations. In the study, Dixon and Moore used tornado factors between 1950 and 2008 and several sociodemographic variables in Texas counties to assess tornado vulnerability at the county level and its spatial distribution (Dixon & Moore, 2012). Other researchers use several other techniques, where an area's vulnerability to a particular hazard is influenced by the community's exposure to the area and the occurrence of that hazard (Kaya et al., 2024; Pielke Jr & Pielke Sr, 1997). These three different assessment methods were used to map the vulnerability of the Cyclone.

Although the spatial distribution varied based on the method used, some districts were classified as highly vulnerable based on all three methods. In contrast to the technique proposed by Pielke and Pielke, Leon-Cruz and Castillo-Aja conceptualised the risk of a Cyclone in an area as a combination of hazard, vulnerability, and exposure (León-Cruz & Castillo-Aja, 2022). In their investigation, they assessed the hazard, vulnerability, and exposure of Cyclone at the municipal level in Mexico using a GIS-based approach.

The resulting values were weighted based on their explanatory power to create a vulnerability index. Tornado exposure was measured using municipal population density. Next, a tornado risk index was calculated by multiplying the vulnerability, hazard and exposure indices. The spatial distribution of these risk components and the tornado risk index are presented separately, classified from very low to very high using natural classification methods. Finally, this study shows the percentage of cities categorised by state, with varying levels of calculated risk ranging from very low to very high.

Some regions on the Earth's surface may be particularly vulnerable to tornadoes (Blinn, 2012). To consider these spatial variations, spatial statistical techniques such as geographically weighted regression (GWR) can be used. GWR is used to investigate the spatially explicit relationship between inundation frequency and spatial explanatory variables (Wang et al., 2017). They indicated that GWR models help investigate spatially varying causes of flooding. Similarly, GWR can also be used to measure the heterogeneity of local flood risk indicators for flood-prone areas in Seoul city (Chun et al., 2017).

This study uses GWR to develop a social resilience assessment model. Similar to previous studies, the local GWR model showed results that, as described above, GWR can be more successful than global models in explaining spatial relationships. However, it has some limitations, such as assuming each explanatory variable has the same spatial variability. Multiscale geographically weighted regression (MGWR) can be used instead of GWR to relax this assumption.

While the literature provides valuable insights into community vulnerability and resilience to Tornadoes, there is still a gap in providing risk assessment using sophisticated GIS models. Therefore, this paper makes a meaningful contribution to the research literature by introducing several key innovations in the GIS-based Tornado risk assessment field. First, a finer spatial unit is used compared to other studies, which offers a higher spatial resolution for understanding the relationship of the selected variables with the impact of the Tornado. Second, this study focuses on the region's vulnerability by focusing on each variable, contrary to existing studies

(Dixon & Moore, 2012; León-Cruz & Castillo-Aja, 2022) that create a composite index while measuring vulnerability using multiple variables. Therefore, each impact and its associated exposure can be analysed more comprehensively.

Given the importance of analysis and evaluation to reduce such disasters, estimating the level of wind hazard in the Pontianak area is necessary. The purpose of this research is to determine the level of danger of tornado disasters in Pontianak city by calculating hazard parameters such as rainfall, surface temperature, slope, and land cover, and to determine the distribution of tornado-affected areas in Pontianak city. This research uses GIS to determine the level of danger of cyclones and the distribution of areas affected by cyclones in Pontianak city in 2024.

MATERIALS AND METHODS

1. Study Area

The research location is in Pontianak city with an area of 107.82 Km². Pontianak city is at 0^0 02' 24” North latitude - 0^0 05′ 37” South latitude and 109^0 16' 25” - 109^0 23′ 01” East Longitude. The elevation of Pontianak City ranges from 0.10 meters to 1.50 meters above sea level. Administratively, Pontianak City is divided into six sub-districts, namely South Pontianak Sub-district, North Pontianak Sub-district, West Pontianak Sub-district, East Pontianak Sub-district, City Pontianak Sub-district, and Southeast Pontianak Sub-district, with boundaries: The northern part is bordered by Siantan District, the southern part is bordered by Sungai Raya District, Sungai Kakap District and Siantan District, the western part is bordered by Sungai Kakap District and the eastern part is bordered by Sungai Raya District and Sungai Ambawang District.

2. Method

The data used in this study are surface temperature, land cover, slope, and rainfall. Data collection techniques used in this study included three techniques: literature study techniques, field survey techniques, and documentation. The data analysis technique used is quantitative analysis by weighting using the Analytical Hierarchy Process (AHP) (Pasaribu et al., 2023) approach and the overlay function of each hazard parameter. The AHP questionnaire respondents are selected based on technical expertise or field experience, strategic roles in policy making or disaster management and diverse perspectives so that the AHP results reflect multi-stakeholder views. Four parameters were used when creating the map: rainfall, surface temperature, slope, and land cover type; each was mapped.

Rainfall, hefty rainfall accompanied by lightning, can create atmospheric conditions that support the formation of cumulonimbus (CB) clouds that have the potential to produce cyclones (Sari, 2025). High surface temperatures, especially during the transitional season, can increase the potential for thunderstorms and cyclones. This increase in temperature can also increase the water vapour content in the atmosphere, which can form cumulonimbus clouds, the main source of extreme weather, including cyclones (Sari, 2025). The flatter or smaller the slope, the greater the possibility of cyclones (Syafitri et al., 2021). Changes in land cover, such as converting agricultural Land to buildings, can increase the Earth's surface temperature and accelerate the growth of cumulonimbus clouds, favourable conditions for cyclone formation (Syafitri et al., 2021). Each factor was weighted using the AHP process.

RESULTS AND DISCUSSION

The data analysis technique used is a weighted tiered quantitative analysis using the Analytical Hierarchy Process (AHP) approach and the Overlay function using ArcGIS 10.8, utilising the spatial analysis tool Weighted Overlay. Four parameters were used to prepare the cyclone disaster hazard distribution map. The four parameters are rainfall, land surface temperature, slope, and land cover. The four parameters were made into a map, each weighted using the AHP method. The Analytical Hierarchy Process (AHP) is an approach developed by Thomas L. Saaty, a mathematician from the University of Pittsburgh in the United States, in 1970 (Pasaribu et al., 2023). As for determining the score for each sub-parameter shown in **Tables 1** and **2**.

Table 1. Value of Each Parameter

Parameter	Slope	Rainfall	Land Cover	Temperature
Slope	1	0,333333	0,2	0,142857
Rainfall	3	1	0,6	0,428571
Land Cover	5	0,6	1	0,714286
Temperature	7	0,428571	1,4	1
Sum	16	2,361905	3,2	2,285714

Source: Research Analysis, 2024

Table 2. Igen Value

Parameter	a	b	c	d	S	Average	Weight
a	0,0625	0,1411	0,0625	0,0625	0,3287	0,082157	8
b	0,1875	0,4234	0,1875	0,1875	0,9859	0,246472	25
c	0,3125	0,2540	0,3125	0,3125	1,1915	0,297883	30
d	0,4375	0,1815	0,4375	0,4375	1,4940	0,373488	37
Sum	1	1	1	1		1	100

a: Slope, b: Rainfall, c: Land Cover, d: Temperature

CI = (Lamda Max-n)/(n-1)

Lamda Max 3,703571

CI -0,09881

CR=CI/CR -0,10979

Based on the calculation of the CI value below 0, this value is consistent and considered correct when giving weights and values. The results of classification, scoring and weighting of each parameter can be seen in **Table 3**.

Table 3. Classification, Scaling, and Weighting of Cyclone Wind Parameters

Parameter	Clasification	Scor	Weight
	416, 00 - 422,69	1	
	422,69 - 429,62	2	
Rainfall (mm)	429,62 - 434,84	3	25
	343,84 - 439,95	4	
	> 439,95	5	
	6,14 – 15,35	1	
	15,35 – 20,81	2	
Temperatur (°C)	20,81 – 24,33	3	37
	24,33 - 26,78	4	
	27,78 – 31, 08	5	
Slope (%)	0 -3	1	8
	3 - 8	2	
	Paddy Field	5	
	Shrubs	4	
Land Cover	Farmland	3	30
	Settlement	2	
	Plantation	1	

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1. Rainfall

Rainfall is calculated from the CHRS data portal, the PERSIAN cloud classification system for 2024. The amount of rainfall ranges from 416.00 to 447 mm/year. The rainfall map of Pontianak City for the year 2024 is shown in **Figure 1**.

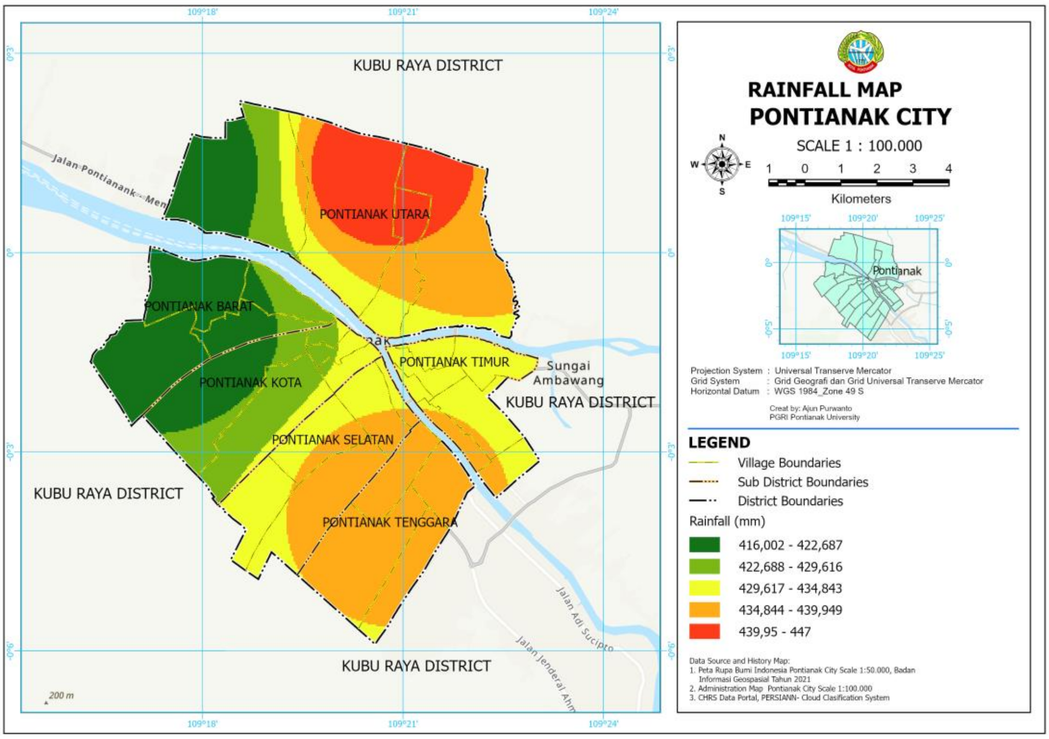

Figure 1. Rainfall Map of Pontianak City Year 2024

Cyclone Winds usually occur in conjunction with heavy rainfall and severe weather (Forbis et al., 2024; Mateo et al., 2009). Rain, previously marked by cumulonimbus clouds, from morning to afternoon, will quickly change colour to dark in the afternoon and evening. Strong winds will appear, accompanied by rainfall with high intensity or heavy and cold air. Therefore, if the Comulunimbus cloud phenomenon appears, you need to be careful because it will trigger heavy rainfall and the appearance of cyclones. However, not all Comulunimbu cloud growth will cause cyclones. Cumulus clouds take various forms and sizes, ranging from non-precipitating fair-weather cumuli to heavily precipitating thunderstorms (Chen et al., 2023). Its presence is unpredictable and usually occurs suddenly (5-10 minutes) in a very local scale area.

When viewed from the rainfall map above, the area that has very high rainfall is the North Pontianak sub-district, while high rainfall is scattered in parts of Southeast Pontianak, South Pontianak, and also North Pontianak.

2. Surface Temperature

Surface temperature was measured using Landsat 9 imagery in 2023, using bands 10, 11, and 4.5. Landsat 9 image processing uses the Map Algebra spatial analysis tool to obtain surface temperature. Based on the Landsat image analysis results, the surface temperature in Pontianak city ranges from 6.15 to 31.08 °C (see **Figure 2**).

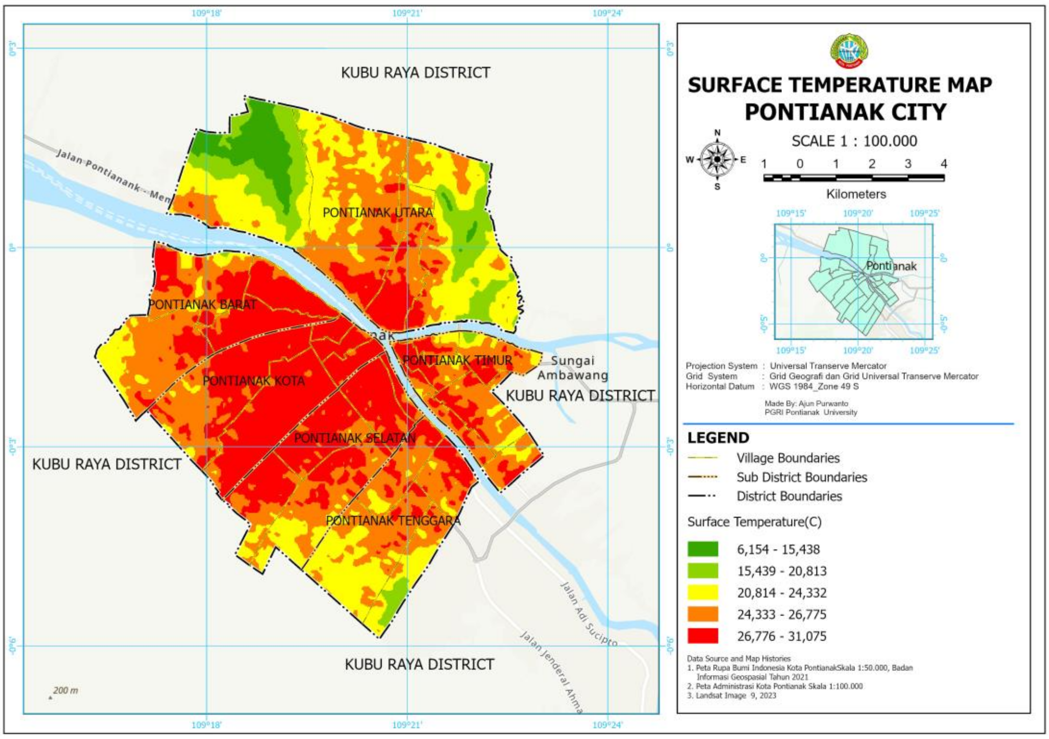

Figure 2. Surface Temperature Map of Pontianak City in 2024

The conditions for the occurrence of cyclones are met based on the above temperatures. The average Cyclone occurs at a temperature of 65 to 84 °F and, if converted to °C, is 18.33-28.89 °C or when the air stability index ranges from 27-29 °C (Fernanda et al., 2024). The figure above shows that the distribution of surface heat with a very high class is spread across 70% of the Pontianak city area. Pontianak City and South Pontianak are the most extensive areas with very high-temperature distribution.

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3. Slope

Slope and aspect are derivatives of elevation and were computed directly from the DEM using the spatial analysis tools in ArcGIS. The slope measurement results using the Digital Elevation Model (DEM) image of Pontianak City have two slope classes, namely slopes with a slope of 0 - 3% and 3 - 8%. In a homogeneous slope, it will have little effect on the occurrence of cyclones. This is because the slope is only homogeneous, namely flat (Frazier et al., 2019; Kellner & Niyogi, 2014). The slope class of Pontianak City can be seen in **Figure 3**.

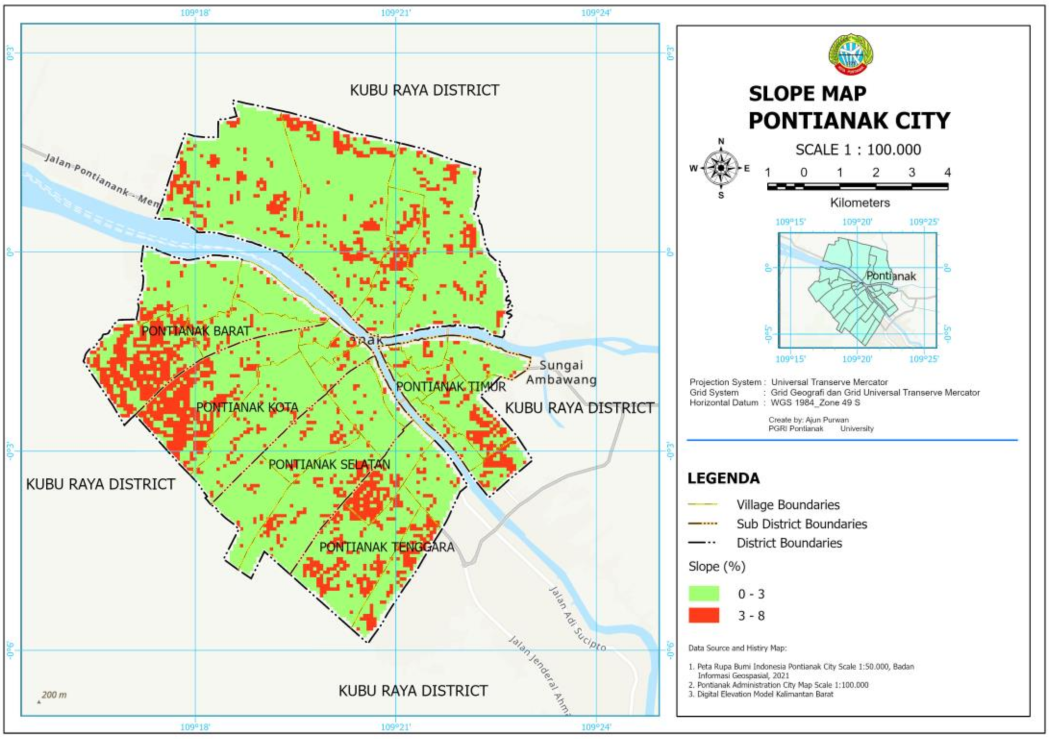

Figure 3. Map of the Slope of Pontianak City in 2024

Areas with flat slopes will usually get more radiant temperatures. As a result, the surface temperature increases, and convection temperature often occurs. Hot temperatures will rise and be replaced by cold temperatures. If this condition continues, surface temperature will increase, which can trigger a cyclone. Pontianak city has almost 95% flat slopes with 0 - 3% slope. This means that, in general, Pontianak does not have the potential for cyclones.

4. Land Cover

Based on the selected RBI map data of Pontianak city, the land cover of

Pontianak city consists of Settlements, Plantations, Paddy Fields, Shrubs, and Fields. Settlements dominate overall land cover in Pontianak city. For details of the Pontianak city land cover, see **Figure 4.**

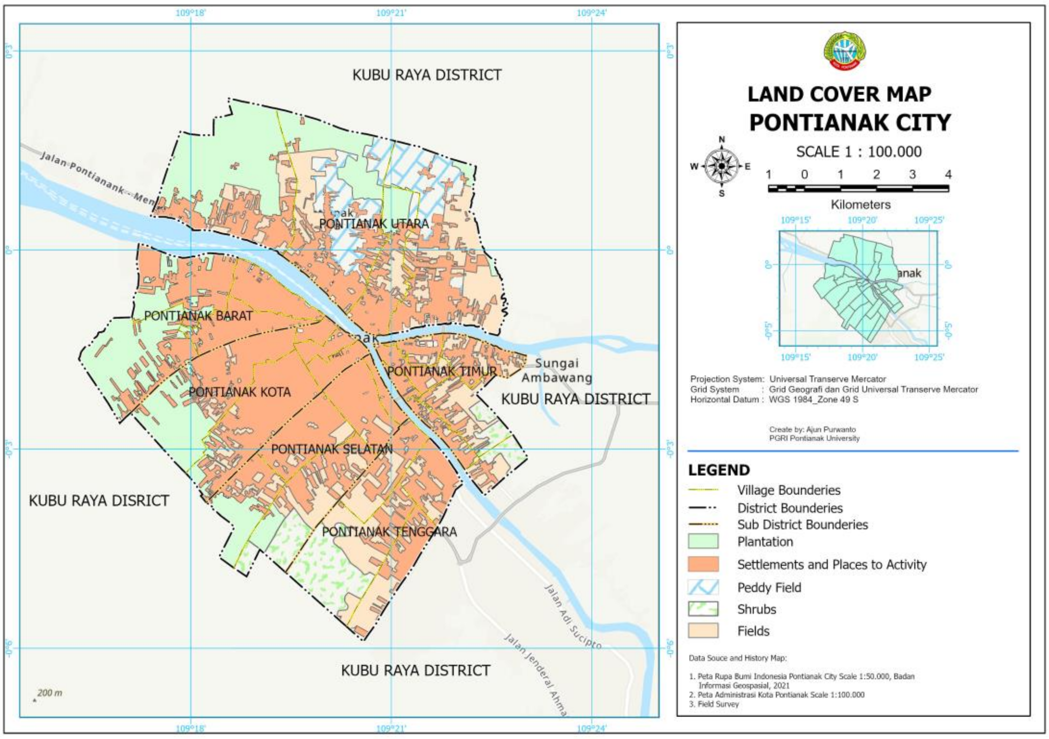

Figure 4. Land Cover Map of Pontianak City in 2024

Based on the map above, if it is related to the potential for cyclones, areas with sparse vegetation, such as rice fields, are more prone to cyclones. This is because the land surface receives much sunlight, which causes the surface temperature to rise. Conversely, plantation and residential areas receive less heat. Research results show that Land with forest land cover is less likely to experience tornadoes than Land with non-forest land cover (Payne, 2020).

5. Cyclones Hazard Level

After classification, scoring, and weighting, the overlay process is carried out using ArcGIS and the Spatial Analysis tool as an overlay, in order to utilise the Weighted Overlay tool and obtain results as shown in **Figure 5**.

Based on **Table 4**, it can be seen that the level of danger of cyclones in Pontianak city is in 4 classes: very low, low, medium, and high. Most of the classes of cyclone hazard levels are medium. The distribution of this class is mostly in West Pontianak,

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Pontianak Kota and South Pontianak sub-districts. The lower class is mostly located in Southeast and North Pontianak. Briefly, concisely, and clearly. Future research exploration may be suggested for further research to be developed by other researchers, and can be conveyed briefly and clearly in a new paragraph of the conclusion.

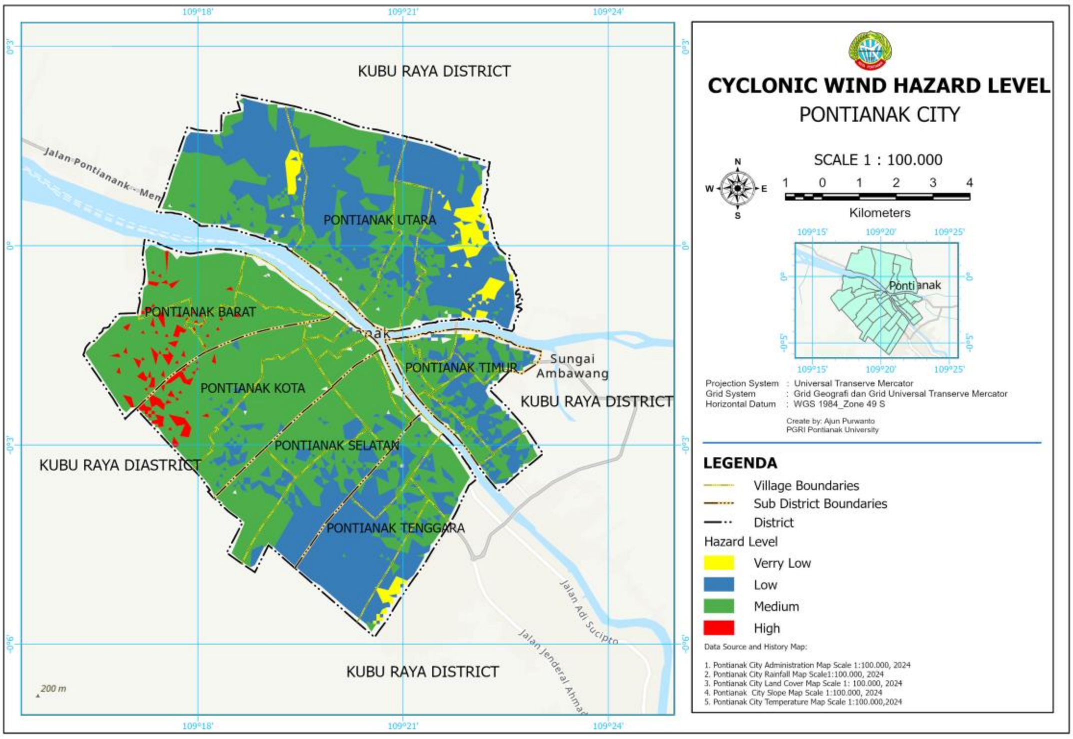

Figure 5. Level of Danger of Cyclone Hazard in Pontianak City

Table 4. The extent of the Danger Level of Cyclone Wind in Pontianak City

Level	Area (Ha)	%
Very Low	223,86	2
Low	3510,52	35
Medium	6262,04	62
High	151,71	1

In general, the class of cyclone hazard level in Pontianak City mostly has a medium level with an area of 6262.04 ha (62%), while the smallest is the high level of only 151.71 ha (1%). Compared to previous cyclone disaster events, the spatial distribution of cyclone hazard classes is generally centred on the cyclone core track, with an elongated distribution following the direction of wind movement and topographic features. The discrepancy becomes an evaluation point to adjust the weight of the criteria in the AHP, or add important variables such as wind speed, soil moisture, or regional response capacity.

CONCLUSIONS

The results showed that the level of danger of cyclones in Pontianak city in 2024, using GIS and Remote Sensing, has four classes: very low, low, medium, and high. Very low class has an area of 223.86 ha (2%), low class 3510.52 ha (35%), medium class 6262.04 ha (62%), and high class (151.71ha (1%). Most of the classes of cyclone hazard level are medium. The distribution of this class is mostly in West Pontianak, Pontianak Kota, and South Pontianak sub-districts. The lower class is mostly located in Southeast and North Pontianak.

Cyclone data is often poorly documented, especially in rural areas or with minimal reporting. This results in reduced accuracy of spatial analysis and makes predictions difficult to validate historically. AHP or GIS models often only consider physical variables, but do not include social aspects (vulnerability, preparedness). This reduces the power of holistic risk analysis. This research can be improved by integrating real-time data from weather radar, AWS (automatic weather station), or high-resolution satellite imagery for local wind detection. A multi-criteria approach with social aspects (level of education, access to information, and community preparedness in vulnerability analysis) is needed. For stakeholders, it is necessary to strengthen local early warning systems, mitigation and adaptation training, and adaptive spatial planning.

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