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Hazard analysis and extreme weather mitigation in pontianak city based on Geographic Information System

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Abstract

The geographical location of Pontianak City, situated on the Equator, creates a high potential for hydrometeorological disasters, particularly extreme weather events such as whirlwinds. Based on the history of recurring events, it is essential to conduct this research to recommend disaster mitigation strategies based on hazard analysis and the Extreme Weather Disaster Class Index in Pontianak City. The data used are slope, land use, annual rainfall, and surface air temperature. These parameters are processed using the ArcGIS software. The results of the hazard analysis indicate that Pontianak City has a moderate level of hazard, covering an area of 5,191.46 ha, or 44.41% of the total area of Pontianak City. Sub-districts with medium-level potential areas are Pontianak Kota sub-district, with an area of 883.56 ha, West Pontianak sub-district, with an area of 836.97 ha, and South Pontianak sub-district, with an area of 761.59 ha. The non-structural disaster mitigation measures that need to be implemented to reduce the impact of extreme weather disasters include disaster risk assessment, enforcement of mitigation-based spatial plans, and community engagement. While structural mitigation can be achieved by strengthening building structures, these structures must utilize materials and construction techniques that are resistant to whirlwinds and enhance the strength of foundations, walls, and roofs. Making evacuation routes based on disaster mitigation and installing early warning equipment, such as Weather Information Display (WID), also needs to be done in an effort to minimize the impact of extreme whirlwind weather.

Introduction

West Kalimantan is geographically situated on the Equator, creating a high potential for hydrometeorological disasters, particularly extreme weather events (Pratama et al., 2023). Pontianak City is one of the areas affected by extreme weather. According to the Head Regulation of Meteorology, Climatology, and Geophysical Agency (BMKG) No. 09/2010, extreme weather refers to an abnormal, unusual weather event that can cause losses, particularly to the safety of life and property (BMKG, 2010). Additionally, extreme weather has a significant impact on the economic sector, causing damage to buildings and infrastructure facilities (Maulana & Andriansyah, 2024).

Data on extreme weather disaster events from the Central Bureau of Statistics and BPBD Pontianak City over the last seven years show that extreme weather is one of the threats to the community. In 2017, two extreme weather events occurred in the West Pontianak and East Pontianak sub-districts. In 2018, there were two times. Throughout 2019 and 2020, there was extreme weather that triggered whirlwinds, affecting the West, South, and North Pontianak sub-districts. Based on the analysis released by BMKG on July 14, 2021, extreme weather conditions were reported. In 2022, there were two whirlwind disasters due to extreme weather. According to BPBD Pontianak City incident data from October 2023, an extreme weather disaster occurred in the form of strong winds, resulting in damage to the building's roof.

The impact of extreme weather significantly affects various aspects of people's lives, including hindering socio-economic activities, and can also damage buildings located in areas affected by extreme weather disasters. The importance of a disaster risk analysis study is due to its high population density, very intensive use of infrastructure, and the development of industrial and business interests without being followed by control of space utilization and land use change, making Pontianak City more at risk of extreme weather disasters. Threats can be in the form of events that have the opportunity to cause losses, both natural and human-caused disasters (Wijaya et al., 2018). The impacts and losses caused by the disaster itself can be minimized by efforts to implement disaster management in the form of disaster mitigation. Disaster mitigation is an effort to reduce disaster risk, both structurally and non-structurally. Structurally or physically through natural and/or artificial physical development, while nonstructurally or non-physically through increasing the ability to face disaster threats Widodo & Manaf (2021), Mukhlisinpa & Gucci (2023).

Analysis of whirlwind extreme weather disaster hazard using ArcGIS software with spatial analysis and data overlay to obtain a disaster hazard class index. Disaster support technology will not be separated from geography: maps, GPS, GIS, and Geo-Information, where pre-disaster, during disaster, and post-disaster are determined by science related to Geo-Science (Sumantri et al., 2019). Disaster management with the initial stage of analyzing extreme weather disaster hazards in Pontianak City using the ArcGIS software system to process data to produce geographic and geospatial data (Putri et al., 2023)

Based on these problems, this research is important for analyzing the extreme weather disaster hazard of whirlwinds in Pontianak City and planning disaster management in the form of structural and non-structural mitigation. The results of the disaster hazard analysis assessment are also expected to serve as a technical basis for disaster management plans, making extreme weather disaster mitigation planning in Pontianak City more effective.

Research Methods

The research location is the entire area of Pontianak City. This research uses quantitative methods with Geographic Information Systems and Remote Sensing approaches which are then subjected to descriptive analysis. The types of data used in this research are primary data in the form of literature studies, interviews with BPBD agencies and interviews with the community and documentation and secondary data from reference sources such as Climate Hazards Center InfraRed Precipitation With Station Data (CHIRPS), The Geospatial Information Agency (BIG), Meteorology, Climatology, and Geophysical Agency (BMKG) that provide data for this research presented in Table 1.

Table 1. Secondary Data Source

Num.	Data	Data Source
1	Adminitrative Boundary Map of Pontianak City	BIG
2	Slope Data	DEMNAS/NASA
3	Annual Rainfall Data	CHIRPS USGS
4	Land Use Data	BIG
5	Temperature Data	BMKG

The spatial analysis process utilizes ArcGIS Desktop software, with the data coordinate system being UTM (Universal Transverse Mercator). To conduct an assessment of the parameters used, scoring is carried out to determine the level of extreme weather threat. Spatial analysis of mapping with parameters using ArcGIS and the Overlay stage of the slope parameters (L), land use (KL), annual rainfall (CH), and surface air temperature (T) are obtained by the extreme weather hazard index with the following formula BNPB (2012), Destiana (2023).

$$Hazard\ Index = (0.351 \times KL) + (0.189 \times CH) + (0.351 \times L) + (0{,}109 \times T) \quad (1)$$

Based on the results of the hazard index overlay with the calculation score, the classification of extreme disaster hazard classes will be obtained to determine the area with classes formulated into 3 (three) levels, namely high, medium, and low, which are presented in Table 2 (Destiana, 2023).

Table 2. Extreme Weather Hazard Class

Disaster Class	Class	Value
I	Low	≤ 0.1566
II	Medium	$0.1567 > H < 0.2433$
III	High	≥ 0.2434

Based on the results of the hazard analysis study, a disaster mitigation analysis was subsequently conducted using descriptive analysis methods. The disaster mitigation analysis aims to obtain an appropriate mitigation study for areas with potential hazard levels at the research location, categorized into structural and non-structural disaster mitigation. This is done by identifying and comparative study of the success of extreme weather disaster mitigation programs in Pontianak City from the government and the BPBD strategic plan that has been implemented, conducting an analysis of interviews with the community and related agencies and historical documentation of events.

Results and Discussion

Extreme weather can be considered a disaster because it occurs every year. Based on Indonesian disaster information data. Extreme weather disasters occur in almost all sub-districts in Pontianak city in different periods each year (Nurlambang et al., 2013). Disaster hazard analysis is needed because the high population density, very intensive use of infrastructure, and the development of industrial and business interests without being followed by control of space utilization and land function change make Pontianak City more at risk of extreme weather disasters.

Table 3. Whirlwind Disaster History Data

Num.	Year Of Event	Total Occurrence
1	2017	2
2	2018	2
3	2019	4
4	2020	5
5	2021	1
6	2022	2
7	2023	1

Pontianak City has a relatively flat topographical contour with an average land elevation of 1-2 meters above sea level. Slope is the percentage ratio between vertical distance (land height) and horizontal distance (length of flat land), Land with a gentle slope has a higher potential to be exposed to strong winds (Putra & Karomah, 2022). These changes in wind speed and direction can create instability that favors the formation of a whirlwind.

The mapping of slopes in Pontianak City, classified by percentage of slope, is shown in Figure 1.

Table 4. Slope Classification in Pontianak City

Num.	Slope (%)	Informa-tion	Area (Ha)	Percentage (%)
1	0 - 8	Flat	8278.49	70.82
2	8 – 15	Ramps	2737.24	23.42
3	15 – 25	Somewh at Steep	597.85	5.11
4	25 – 45	Steep	72.40	0.62
5	> 45	Very steep	3.17	0.03

Table 5. Land Use in Pontianak City

Num.	*Reclassify*	Area (Ha)	Percentage (%)
1	Settlements	5132.45	43.41
2	Public/Industrial Facilities	47.86	0.40
3	Agriculture	5145.73	43.52
4	Water Body	653.53	5.53
5	Forest	843.81	7.14

The proportion of land use in Pontianak City is dominated by settlements and agriculture, which has a high percentage. Local governments have an important role to play in planning for sustainable land use and ensuring that the needs of the community are met without damaging the environment and considering disaster aspects. Therefore, disaster risk assessment-based local development planning is needed to reduce disaster risks in the region. Data on the extent of land use in Pontianak City is presented in Table 5.

The spatial boundaries of other natural hazards are difficult to measure, whirlwinds are relatively site-specific, and such precision helps in identifying affected places, as well as in mapping land use areas, which can be analyzed for extreme weather disaster hazards. Uncontrolled land use can cause environmental damage and increase disaster risk. At the level of potential environmental damage caused by extreme weather due to whirlwind, not damaging forests, shrubs, and other land cover in the environmental category, because damage or loss on land that tends to be open in the low category. Therefore, disaster risk assessment-based regional development planning is needed to reduce disaster risks in the region . Land use mapping in Pontianak City, which includes the classification of settlements, public and industrial facilities, plantations, water bodies, and forests, is presented in Figure 2.

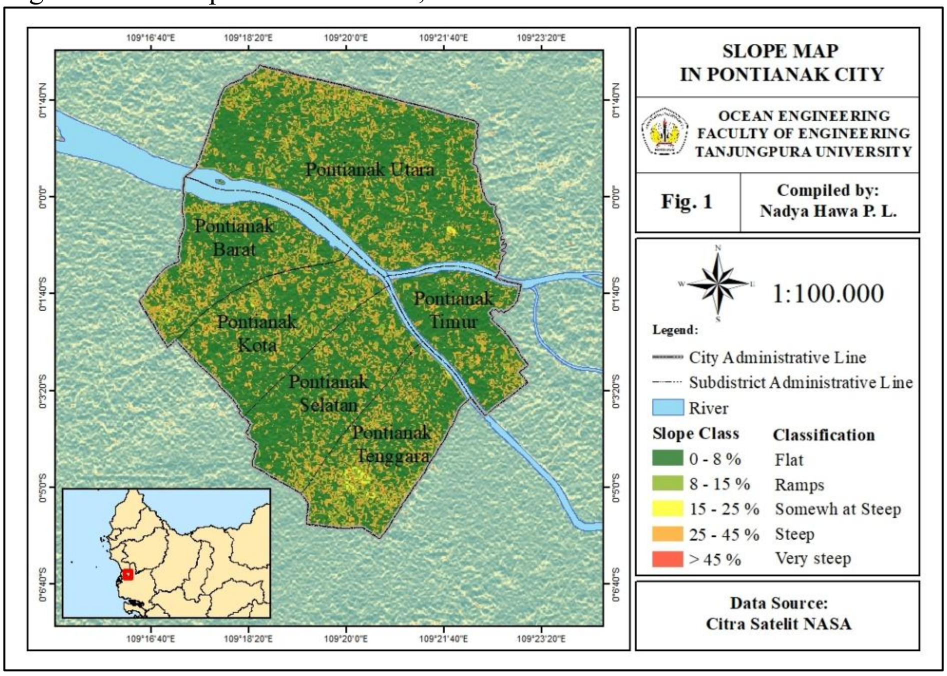

Figure 1. Slope Map

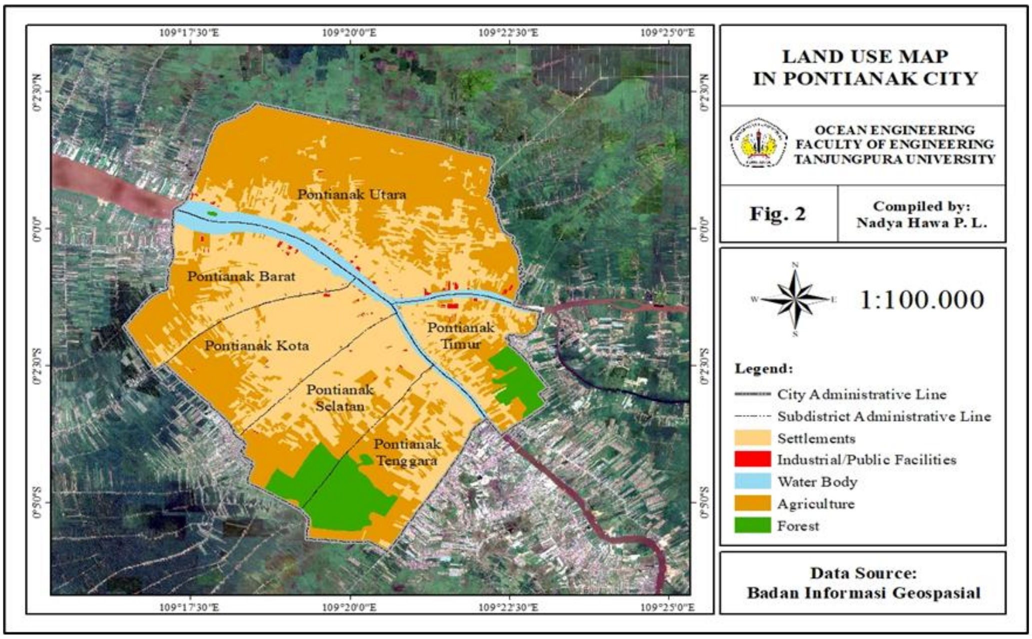

Figure 2. Land Use Map

Rainfall in Pontianak City tends to be evenly distributed throughout the region, and rainfall measurements are taken at the Pontianak Maritime Meteorological Station. Rainfall in Pontianak City falls within the high category, ranging from 3000 to 3500 mm per year. The higher the wind speed, the higher the effect of rainfall (Luthfiarta et al., 2020). The annual rainfall classification is presented in the following table 6.

Table 6. Annual Rainfall

No.	Rainfall (mm/year)	Description
1	>3500	Very High
2	2500 - 3500	High
3	1500 - 2500	Medium
4	<1500	Low

This evaporation supplies the moisture essential for cloud formation and rain. As evaporation rates increase, there is an increase in atmospheric humidity, resulting in conditions that are more likely to allow storms and extreme weather.

Global climate change can affect rainfall patterns in Pontianak and increase the intensity and frequency of extreme events suchas heavy rainfall. High rainfall intensity can indicate extreme weather events, with numerous cases of such events occurring. This analysis provides an overview of the annual rainfall characteristics in Pontianak City. Annual rainfall analysis can also serve as a reference for effective and regular drainage system management, which is essential to reduce the risk of flooding due to extreme weather. Monthly rainfall data is presented in Table 7.

The surface air temperature in Pontianak City has been observed by the BMKG agency's Pontianak Maritime Meteorological Station. Air temperature data for 2019-2023 was analyzed by mapping in centigrade units. The increase in air temperature will lead to an increase in disaster risk. Increased air temperature, resulting from the rise in greenhouse gases, is followed by a reduction in land cover, leading to an increase in extreme temperature events. Based on the results of data processing, the average surface air temperature in Pontianak city is 27.9°C, according to BMKG, this figure shows that the air temperature in Pontianak City is in the normal category Wicaksono (2023), Meiwandari et al. (2024), and Hidayat & Farihah (2020). Surface air temperature data are presented in Table 8.

Table 7. Annual Rainfall

Mon	Annual Rainfall (mm/month)					
	2023	2022	2021	2020	2019	Avg
Jan	176.1	130.3	306.4	439.6	198.5	250.2
Feb	140.6	156.4	11.9	421.6	247.7	195.6
Mar	149.5	150.3	226.1	212.5	107	169.1
Apr	220.1	382.3	261.4	237	299.2	280.0
May	231.5	228.9	381	282.3	246.7	274.1
Jun	238.9	470.2	294.5	278.2	515.8	359.5
Jul	300	179.6	205.8	408.6	227.9	264.4
Aug	95.3	318.5	633.5	164.9	73	257.0
Sep	259.2	355.4	439.5	281.5	39.2	275.0
Oct	293.2	349.4	281.6	281.5	582.3	357.6
Nov	337.8	212.9	211.9	585	387.5	347.0
Dec	348.9	314.7	159.8	179.7	584.1	317.4
Sum	2791.1	3248.9	3413.4	3772.4	3508.9	3346.9

Table 8. Surface Air Temperature

Mon	Annual Rainfall (°C)					
	2023	2022	2021	2020	2019	Avg
Jan	26.9	27.1	27.8	27.1	27.2	27.3
Feb	27.3	27.2	27.2	27.3	27.3	27.2
Mar	27.8	27.8	27.3	27.9	28.1	27.8
Apr	28.0	27.7	27.7	28.1	28.2	27.9
Mei	28.9	28.2	28.2	28.4	28.9	28.5
Jun	28.4	27.2	27.8	28.1	28.0	27.9
Jul	28.5	27.9	28.2	27.2	28.4	28.0
Ags	28.5	27.3	27.1	27.6	28.4	27.8
Sep	28.4	26.8	27.9	27.8	27.9	27.7
Okt	27.9	27.7	27.9	27.5	27.9	27.8
Nov	28.6	27.4	27.9	28.1	28.4	28.1
Des	28.4	27.9	27.4	28.3	28.9	28.2
Avg	28.1	27.5	27.7	27.8	28.1	27.9

Based on the overlay results of these parameters, extreme weather disaster hazard mapping is obtained to identify hazard zoning and establish zones based on disaster risk levels to assist in spatial planning and safer infrastructure development. The potential hazard areas and extreme weather hazard classes are presented in Table 9

Table 9. Extreme Weather Hazard Class

No	Legend	Class	Extensive	Percentage (%)
1		Low	5014.02	42.90
2		Medium	5191.46	44.41
3		High	1483.49	12.69
		Total	11688.97	100

Based on the results of the hazard analysis mapping of extreme weather disasters, it is evident that Pontianak City falls into the category with moderate potential for extreme weather disasters, covering an area of 5,191.46 ha, or 44.90% of the total area of Pontianak City. The extent of the hazard level by sub-district is presented in Table 10. The extent of the hazard indicates the size of the affected area, while the hazard index indicates the high probability of occurrence and intensity of the hazard (Guswanto, 2024). The hazard mapping of extreme weather disasters in Pontianak City is presented in Figure 3.

Table 10. Class of Hazard per Sub-district

Sub-district	Area (Ha)				Class
	Low	Medium	High	Sum	
Pontianak Barat	504.8	836.9	264.7	1606.5	Medium
Pontianak Kota	373.7	883.5	339.3	1596.7	Medium
Pontianak Selatan	632.3	761.5	245.0	1638.9	Medium
Pontianak Tenggara	786.6	638.7	172.6	1597.9	Low
Pontianak Timur	577.7	485.1	110.6	1173.5	Low
Pontianak Utara	2138.7	1585.3	351.1	4075.2	Low
Sum	5014.0	5191.4	1483.4	11688.9	Medium

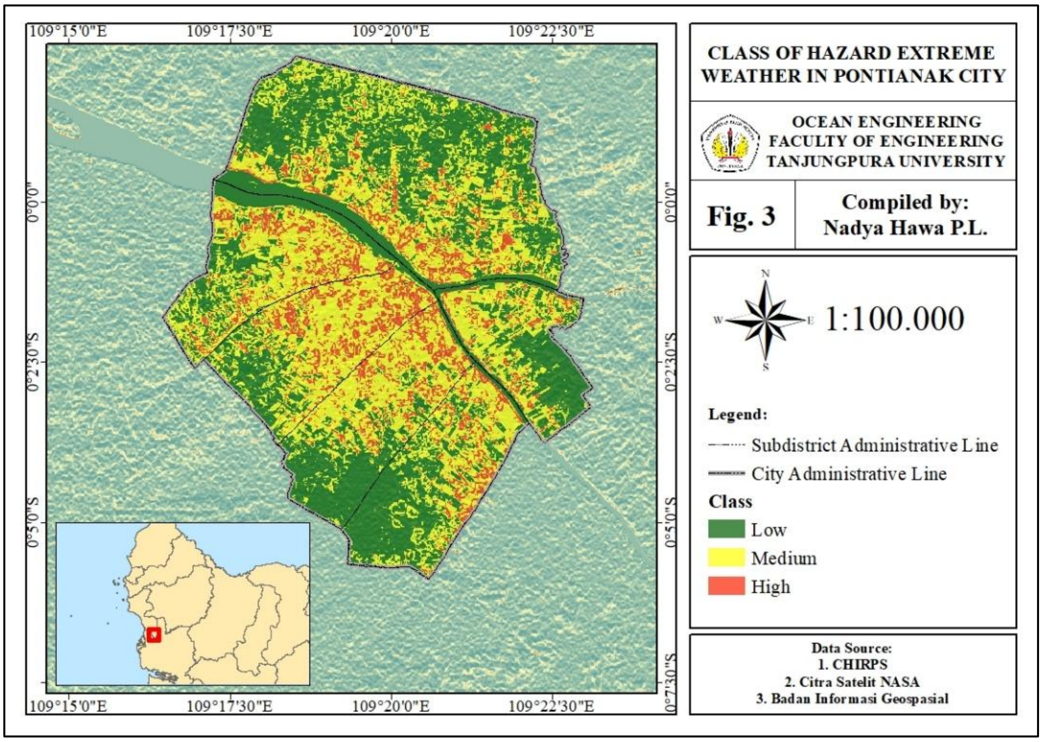

Figure 3. Class of Hazard

The results of the analysis of the extreme weather disaster hazard map, based on disaster hazard mapping, show that Pontianak City has a moderate potential for the impact of whirlwind extreme weather disasters. Sub-districts with medium-level potential areas are Pontianak Kota sub-district (883.56 ha), West Pontianak sub-district (836.97 ha), and South Pontianak sub-district (761.59 ha). This is due to dense land use with steep slopes. Natural factors such as high annual rainfall and air temperature also affect the potential for disaster and the impact of extreme disasters. Interactions between the atmosphere and ocean also play a crucial role in the formation of extreme weather phenomena, such as tropical storms, typhoons, and cyclones. La Nina events are an example of the strong interactions between the ocean and atmosphere that influence global weather patterns (Safitri, 2015). While La Niña can influence atmospheric conditions that favor whirlwind formation, it is essential to remember that local factors, such as topography, land use, and local wind flow patterns, also play a significant role in the formation and intensity of whirlwinds in a region.

Hazard analysis is the first step in disaster assessment to formulate disaster mitigation to minimize impacts and losses due to extreme weather disasters. Hazard mapping also helps in developing emergency plans and specific disaster mitigation strategies to reduce disaster risks and impacts. Disaster analysis was also conducted at the research location to identify the disaster history and potential at the site. Areas with dense settlements and less robust building structures tend to be more vulnerable to the impact of the whirlwind. Meanwhile, locations with moderate and low categories tend to have no history of whirlwind events. Based on the analysis of interviews with communities around areas affected by whirlwinds in Pontianak City, they tend to occur more frequently during the rainy season. This shows that the history of whirlwind disaster events tends to have occurred in areas with high hazard class categories, as presented in Figure 4.

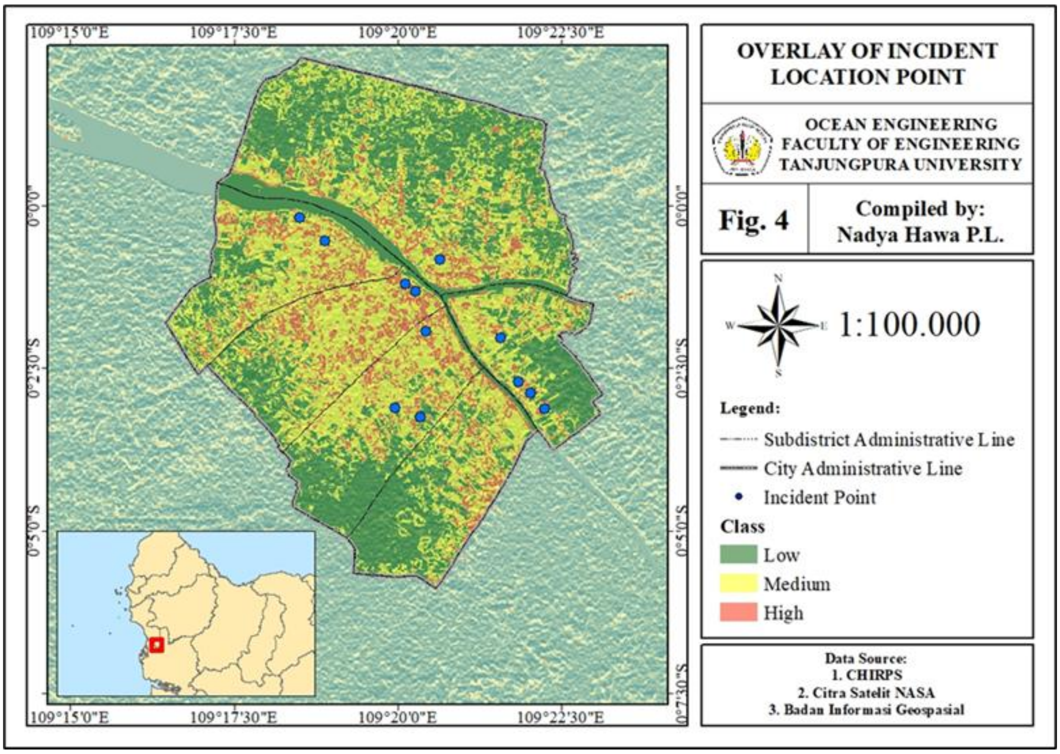

Figure 4. Overlay of Incident Location Point

Non-structural disaster mitigation is in the form of enforcement of spatial plans based on disaster mitigation through increasing the effectiveness of spatial utilization control instruments in areas that have high hazard classes and early warning systems, namely weather information that can be accessed easily by the community and make updates in the dissemination of socialization information to the community to create a community that is responsive to extreme weather disasters that utilize social media, the role of the community in terms of mitigation and extreme weather disaster mitigation efforts is also very influential. Establishment of disaster awareness community organizations or communities in Pontianak City (Kurniawati, 2018). The level of community preparedness needs to be increased so that people are ready when a disaster occurs. In reality in the field, people still do not have an understanding of disaster emergency response, which is an important factor in the level of disaster preparedness. Therefore, disaster hazard mapping can be the first step in formulating disaster mitigation strategies and socializing extreme weather disaster emergency responses in areas with high potential levels and among vulnerable groups. Extreme weather disaster hazard mapping allows the government, related institutions, and communities to be better prepared for potential disasters, reduce vulnerability, and protect human resources and critical assets from the impacts that may occur by carrying out environmental maintenance such as pruning large trees that have the potential to fall in the event of an extreme weather disaster and rehabilitation.

The structural disaster mitigation efforts that can be carried out are by building or strengthening buildings using materials and construction techniques that are resistant to whirlwind, such as the use of reinforced concrete, steel, or strong composite materials and strengthening the structure of foundations, walls, roofs, and other structures to increase resistance to high wind pressure. Building construction should pay attention to the selection of the quality of materials and the strength of construction in ace of extreme weather to reduce the risk of damage (Prabowo, 2020). Reconstructing buildings damaged by extreme weather disasters, as well as creating evacuation routes, in addition to good visual finishing results, it is necessary to pay attention to the elements of the building walls and foundations. Structural extreme weather disaster mitigation planning can also be done by installing early warning equipment such as Weather Information Display (WID) includes weather parameters such as temperature, air pressure, wind speed and direction, rainfall, and cloud conditions is a system designed to collect, process, store, analyze, and disseminate weather and climate information at locations affected by extreme weather. Ground Generators, in the context of extreme weather disaster mitigation, refer to a variety of technologies or systems designed to enhance safety and response to extreme weather disasters that often threaten infrastructure and human life.

Conclusions

Pontianak City has a moderate level of risk from extreme weather disasters, covering an area of 5,191.46 ha, or 44.41% of the total area of Pontianak City. Sub-districts with a medium level of potential area include Pontianak Kota sub-district, with an area of 883.56 ha, West Pontianak sub-district, with an area of 836.97 ha, and South Pontianak sub-district, with an area of 761.59 ha. The potential for extreme weather hazards is influenced by dense land use on steep slopes, and high rainfall and low air temperatures can affect the level of potential disaster hazards. interactions between the atmosphere and the sea, such as La Niña and MJO, also trigger extreme weather disaster events (Rahmaniar et al., 2020). Due to the location of Pontianak City, which is within a radius of 30 km from the coast. Some actions that can be taken in disaster management include prevention, mitigation, preparedness, and emergency management (Handoko et al., 2017). One of the most important actions is disaster mitigation. Disaster mitigation recommendations that can be done non-structurally, based on the whirlwind extreme weather disaster hazard analysis and disaster mitigation analysis, are updates in the dissemination of socialization information to the community, enforcement of spatial plans based on disaster mitigation and environmental maintenance, and establishment of disaster awareness community organizations or communities in Pontianak City. Structural disaster mitigation is building or strengthening buildings by using wind-resistant construction materials and techniques, building Ground Generator Vehicles in the context of extreme weather disaster mitigation to improve security and response to extreme weather disasters, and installing early warning equipment such as Weather Information Display (WID) (Pratama et al., 2023). Weather Modification Technology (WMT) is also employed to achieve the desired weather conditions, as well as to utilize Ground Generator and Flare Tree vehicles for static systems.

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