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Spatial Analysis of Flood Vulnerability Levels in Makassar City Using Geographic Information Systems

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Abstract

This research aims to determine the flood intensity in Makassar City, which is influenced by several factors, including land use, slope gradient, land cover, and rainfall. The research method is a quantitative approach using spatial analysis to examine spatial phenomena. The spatial analysis was conducted using an overlay method with a scoring technique to map each variable that affects flood intensity. The analysis results indicate that the flood intensity in Makassar City is categorized into three levels: low, moderate, and high.. The analysis results suggest that in Makassar City, 37.4 km² or 21% of the total area falls into the low rainfall intensity category. In contrast, the moderate rainfall intensity category encompasses 73.3 km² or 41% of the city, while the high rainfall intensity category represents 68.1 km² or 38% of the total area. This research has implications for efforts to control the pace of regional development that influences and potentially exacerbates flooding, thereby enabling early mitigation of environmental issues.

Keywords*: Flood Vulnerability Levels, Geographic Information System, Makassar City, Overlay, Spatial Analysis*

INTRODUCTION

The continuous increase in urban population due to natural growth and urbanization creates an urgent need for cities to provide more supporting facilities, especially housing (Firsa, 2022; Aluman, 2024; Budiyanti *et al.*, 2024). With their crucial roles and functions in regional development, cities tend to transform natural environments into man-made environments to meet these needs (Indriastuti *et al.*, 2018; Iek, *et al*., 2014). This transformation, involving converting green spaces into buildings, roads, and other infrastructure, aims to accommodate the ever-growing population (Alszahabi, *et al.*, 2024).

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This situation proves that the intensity of changing natural environments into built environments is much higher in urban areas compared to rural areas, where development pressure is lower. The limited land available in cities exacerbates this situation, as the existing land must be optimized to meet various needs (Puspitasari & Suharyadi, 2016; Hidayati *et al*., 2018; Mawar *et al.*, 2021; Nuryadin *et al.*, 2024). In line with Masyhuri (2018), land use in major cities has undergone significant changes over the past five years. Residential or built-up land experienced the highest increase, reaching 96.55%. This increase reflects the substantial pressure on land in urban areas to fulfill the demand for housing and other public facilities. On the other hand, land use for services only increased by 3.45%, indicating a lower priority for land allocation in this sector. Meanwhile, several types of land use have decreased in area, such as mixed gardens, which have shrunk by up to 59.94%, rice fields by 5.23%, open land by 30.83%, and dry fields by 4.01%. This decline indicates a reduction in green spaces and productive land, which have traditionally functioned as water absorbers and microclimate regulators in cities (Halim, 2014; Nur *et al.*, 2024; Nurrizqi & Suyono, 2012; Nuryadin *et al.*, 2024; Suripin & Kurniani, 2016; Utami *et al.*, 2024).

The significant changes in land use, such as those occurring in Medan Denai District, trigger various environmental problems, one of which is the increased frequency and intensity of flooding (Rachmayanti, *et al.,* 2022; Rusdi, *et al.,* 2023). The conversion of open and green spaces into built-up areas reduces the land's ability to absorb rainwater, leading to an increase in surface water volume that the city's drainage system cannot adequately absorb. Reducing green and open spaces also eliminates other essential ecosystem functions, such as providing habitats for various flora and fauna and filtering pollutants from air and water. Therefore, cities face a major challenge in managing rapid growth while maintaining environmental balance and ecosystem sustainability (Pradipta *et al.*, 2018). Planned and sustainable mitigation efforts are urgently needed to address the negative impacts of massive land-use changes occurring in urban areas. The percentage of urban areas dominated by built-up zones, reaching 96.55%, does not necessarily positively impact the community and the environment. The expansion of built-up land can lead to various negative consequences. One of these is the increased occurrence of flooding, which has frequently affected the city of Makassar during the rainy season.

Flooding in urban areas occurs when rainwater cannot find a flow path to drain into rivers, as built-up areas make it difficult for rainwater to infiltrate the soil, compounded by the lack of vegetation that can absorb water. This situation can lead to flooding if built-up areas continue to expand and increase, with high rainfall each year that is not adequately anticipated with proper water absorption provisions in urban areas. The flooding problem in Makassar City has become a serious issue that needs to be anticipated as part of flood disaster mitigation efforts, due to the growing expanse of built-up areas, alongside other factors contributing to this phenomenon. Assessing flood vulnerability is crucial in addressing the potential disasters that may occur, serving as an initial and appropriate step to create effective solutions to this problem. This study will inform the government, policymakers, and the public about the impact of built-up areas, urban growth, and rainfall conditions that contribute to flooding. Furthermore, it will offer solutions for both the government and the community to deal with the recurring flooding in Makassar City.

METHODS

1. Type And Location Research

The type of research employed in this study is quantitative research, which is conducted by processing spatial data using Geographic Information Systems (GIS). Spatial analysis is intended as a research approach that enables the examination of phenomena in a spatial context within a specific area, providing a framework for understanding how various factors interact across different locations (Fauzi, 2022). This approach makes it highly suitable for studying more complex spatial issues, as it allows for

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a detailed exploration of patterns, relationships, and trends that are influenced by the geographical characteristics of a region.

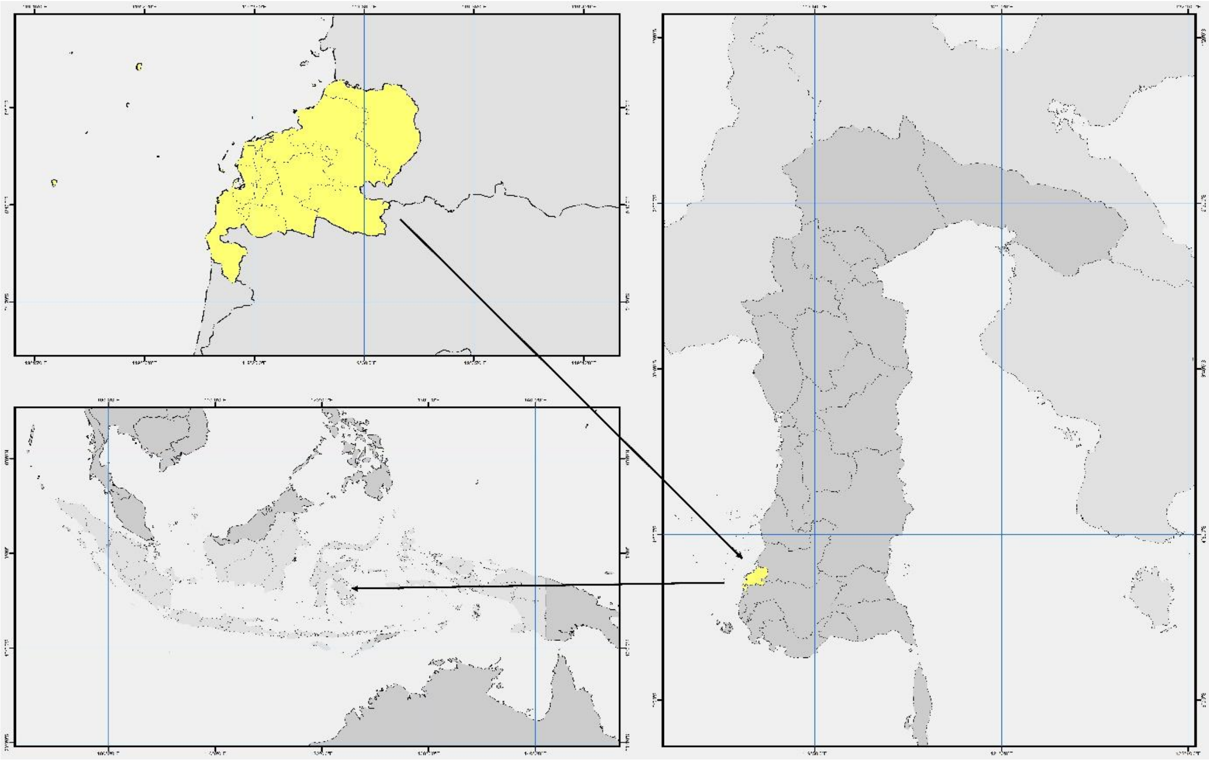

Figure 1. Location Research Map.

2. Data Source

The data used in this research consists of secondary data processed using ArcGIS software, a spatial data analysis platform that enables mapping of the areas under study. The sources of data for this research are outlined as follows.

a. DEM SRTM 30m Data sourced from the USGS website
b. Makassar City Administrative Map sourced from the Makassar City Spatial Planning Office, 2023
c. Land Cover Data of Makassar City sourced from the Makassar City Spatial Planning Office, 2023
d. Daily Rainfall Data for the Year 2023 sourced from the BMKG Makassar City (Paotere Station) and BMKG Maros Regency (South Sulawesi Climatology Station)
e. Landsat 8 OLI Satellite Image Map captured on August 29, 2023, sourced from the USGS website.

3. Data Analysis

The data analysis technique used in this research is the overlay technique. The overlay technique is a process of spatial data processing by overlapping maps that are relevant to the research being conducted (Darmawan *et al.*, 2017a). The principle of overlay analysis involves using a scoring system to determine the intensity of each boundary within the mapped areas (Fauzi, 2022; Septian *et al.*, 2020). In this study, the overlay method is applied to determine flood intensity by using a combination of maps, including rainfall maps, slope maps, built-up land maps, and land use maps. The scoring system applied to each variable influencing flood intensity is detailed as follows.

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Table 1. Scoring of Variables Influencing Flood Intensity

Classification	Scoring	Weight	Point
Slope			
0-2	1	0,35	1,05
2-5	2	0,35	0,7
>5	3	0,35	0,35
Land Cover			
Rice fields/forest	1	0,35	1,05
Bush/agriculture	2	0,35	0,7
Settlement	3	0,35	0,35
Rainfall			
<90	1	0,3	1,05
90-100	2	0,3	0,7
>100	3	0,3	0,3
Built-up land			
Built-up land	1	0,35	0,35
Land is not developed	3	0,35	1,05

Source: Research by Ujung *et al.*, (2019)

The scoring value above overlays the map to obtain a flood intensity map, which will also identify the intensity type. There are 3 types used to analyze flood intensity spatially, namely low, medium, and high, with intervals that can be seen as follows.

Table 2. Class Intervals for Determining Flood Intensity

Scoring	Class Interval	Classification
1,05 + 1,05 + 1,05 + 0,35 = 3,5	2,4 – 3,00	Low
0,7 + 0,7 + 0,7 + 0,35 = 2,45	2,25 – 2,4	Currently
0,35 + 0,35 + 0,3 + 1,05 = 2,05	2,05 – 2,24	Hight

Source: Research by Ujung *et al.*, (2019)

RESULT AND DISCUSSION

1. Slope

Based on the data obtained, the required data to determine slope gradients is the DEM data sourced from the USGS website. This data is then processed using ArcGIS, resulting in a classification of slope gradients across different areas in Makassar City. Most of the city has a slope gradient of 0-2%, covering an area of 127.9 km², while slope gradients of 2-5% cover an area of 46.6 km², representing 26% of the total area. Meanwhile, slope gradients of 5-8% occupy only 4.4 km² or about 2% of the total area of Makassar City.

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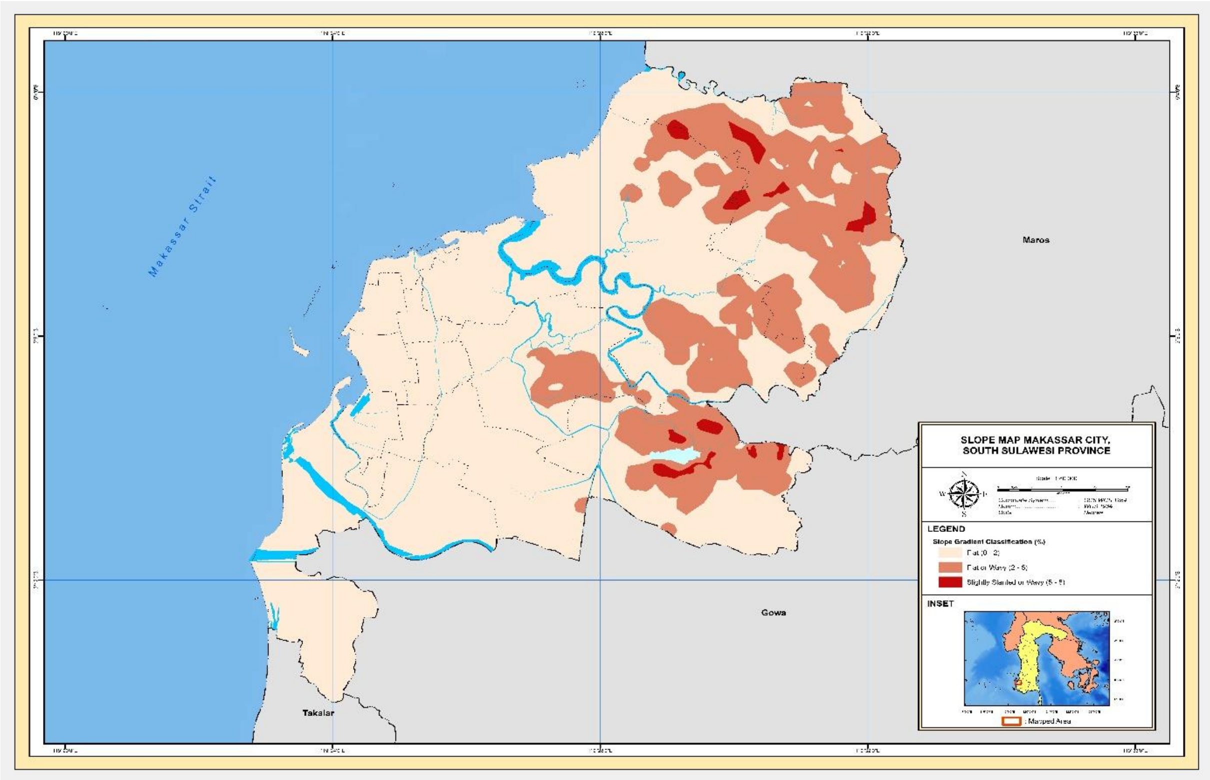

Figure 2. Slope Map Makassar City, South Sulawesi.

Table 3. Results of Analysis of Slope Data for the City of Makassar

No	Classification	Area (Km^2)	Percentage
1	0-2	127,9	72%
2	2-5	46,6	26%
3	5-8	4,4	2%
	Total	**178,8**	**100%**

Source: Data Analysis, 2024.

Slope or land gradient is the percentage ratio between the vertical distance (elevation) and the horizontal distance (length of the flat land). Flat slopes have a higher risk of flooding compared to steep slopes (Darmawan *et al.,* 2017b). Slope gradient affects the amount and speed of surface runoff, surface drainage, land use, and erosion. If the land has a gentle slope, the surface runoff becomes faster, allowing rainwater to flow away quickly without pooling in that area, thereby reducing the risk of flooding. (Anggraini *et al.*, 2021).

2. Land Cover

Makassar City comprises several types of land use, including rice fields/forests, shrubs/agriculture, and residential areas. However, the predominant type of land use in Makassar is residential, which covers an area of 87.0 km^2 (49%). Land used for rice fields/forests occupies 63.3 km^2 or 35%, while land for shrubs/agriculture accounts for only 28.5 km^2, representing just 16% of the total area of Makassar. The land use type significantly affects the intensity and frequency of flooding in a given area.

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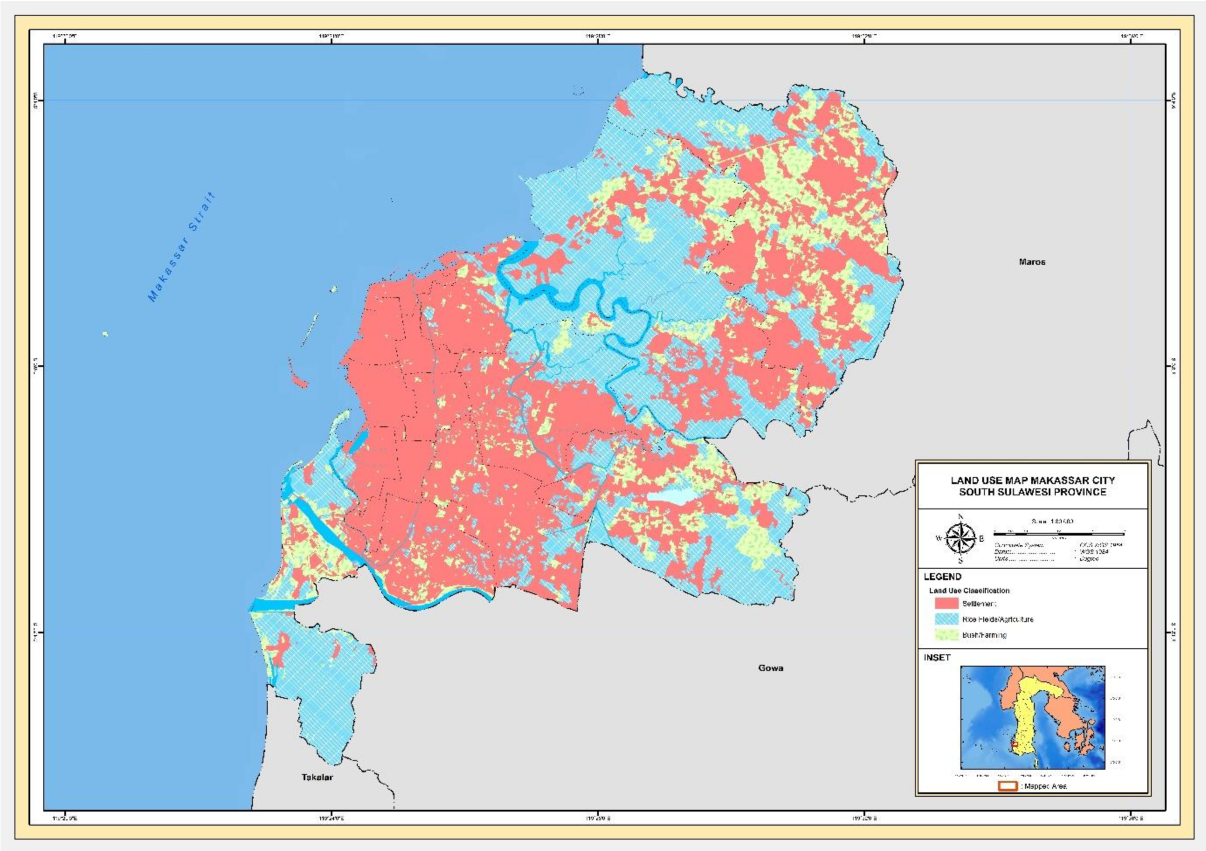

Figure 3. Land Use Map Makassar City South Sulawesi.

Table 4. Results of Analysis of Land Cover Data for the City of Makassar

No	Classification	Area (Km^2)	Percentage
1	Rice fields/forest	63,3	35%
2	Bush/agriculture	28,5	16%
3	Settlement	87,0	49%
	Total	**178,8**	**100%**

Source: Data Analysis, 2024.

Land use will affect the flood vulnerability of an area (Darmawan *et al.*, 2017b). The land use pattern of Makassar City consists of land use for built-up areas and undeveloped areas. Land use for built-up areas includes residential and residential areas as well as trade and service areas. Meanwhile, undeveloped land consists of green open space areas, rice fields, and open land areas. If there is inappropriate land development, it will have fatal and detrimental consequences and potentially cause flooding. Land use will play a role in the amount of runoff resulting from rain that exceeds the infiltration rate (Scorecard, 2016). Floods in Makassar City hit areas adjacent to rivers/beaches.

3. Rainfall

The daily rainfall data for 2023 sourced from BMKG Makassar City shows that rainfall in Makassar varies across different locations, ranging from low rainfall levels (<90 mm) to moderate levels (90–100 mm), and high rainfall levels (>100 mm). These rainfall levels were determined after interpolating rainfall data from several rainfall stations within Makassar City. The city's rainfall is predominantly characterized by low levels, covering about 70% of the total area.

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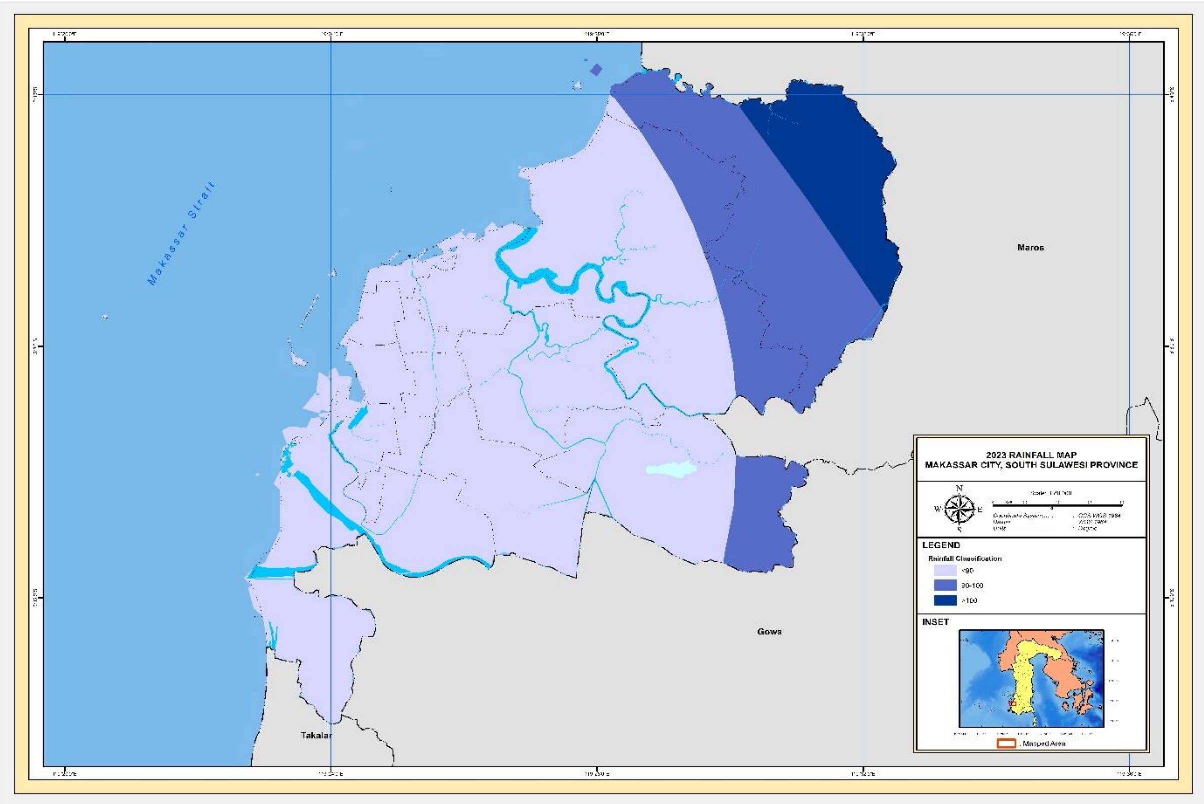

Figure 4. Rainfall Map Makassar City South Sulawesi.

Table 5. Results of Analysis of Rainfall data for the City of Makassar

No	Classification	Area (Km^2)	Percentage
1	<90	124,9	70%
2	90-100	38,9	22%
3	>100	14,9	8%
	Total	**178,8**	**100%**

Source: Data Analysis, 2024.

Rainfall is the average volume of rainwater that falls over a specific area. Regions with high rainfall are more likely to experience flooding, as the higher the rainfall in a particular area, the greater the potential for flooding. This is because high rainfall increases the volume of water, and when the capacity of rivers is exceeded, it results in flooding (Aisyah, 2021). Based on the analysis, it is evident that the highest rainfall in Makassar City is predominantly in the eastern to northern regions, exhibiting a pattern of moderate rain. Meanwhile, low rainfall is mainly found in the southern and western regions, which are located near the coastal areas of Makassar City.

4. Built-up Land

Makassar City is predominantly covered by built-up areas, with a total area of 154.9 km², accounting for 87% of the city's total land. These areas consist of residential zones and other facilities for businesses, industry, and services. In contrast, non-built-up land, such as vacant land and rice fields, is minimal, covering only 24.0 km² or just 13% of the total area of Makassar City. The analysis results indicate that Makassar is largely composed of built-up land, which significantly contributes to flooding, particularly local flooding, due to the limited areas available for water infiltration.

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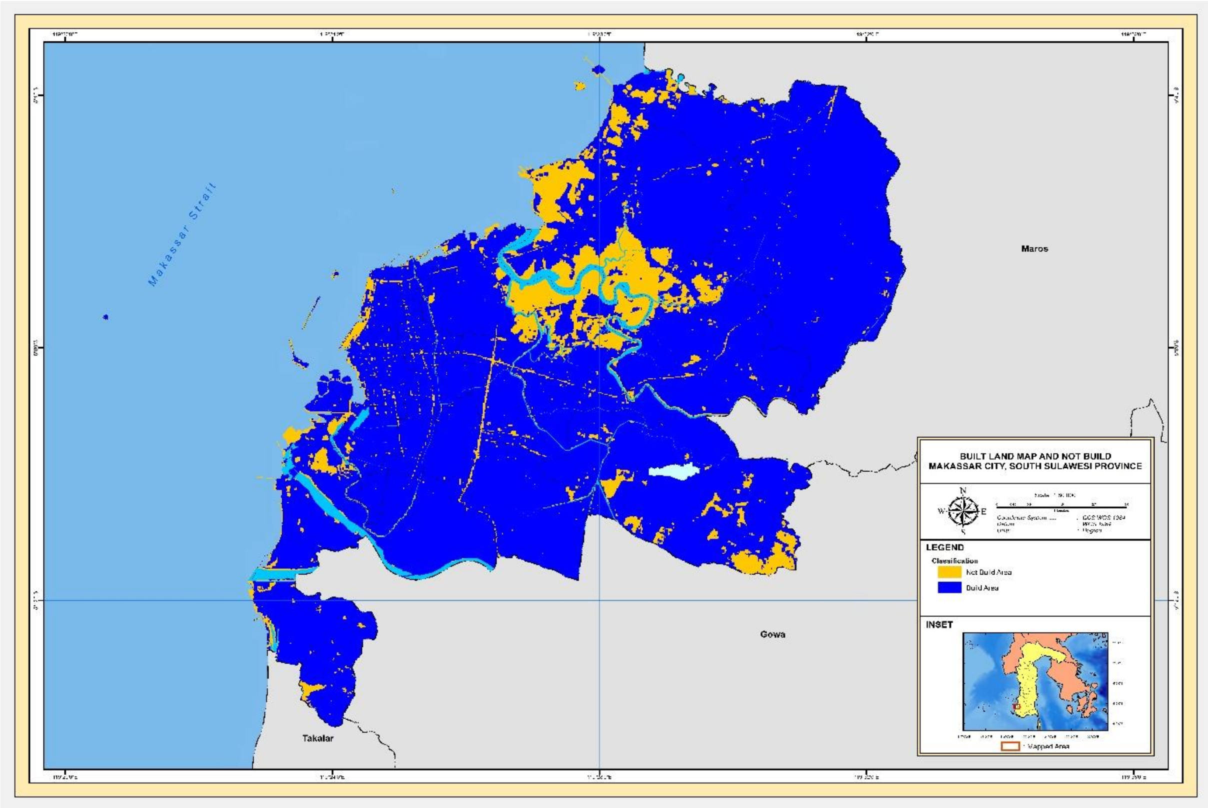

Figure 5. Built Land Map Makassar City South Sulawesi.

Table 6. Results of Analysis of Built Land Data for the City of Makassar

No	Classification	Area (Km^2)	Percentage
1	Undeveloped land	24,0	13%
2	Built-up land	154,9	87%
	Total	**178,8**	**100%**

Source: Data Analysis, 2024.

Urban problems are becoming increasingly complex each year in line with the pace of development due to the growing population. Population growth also affects the demand for land. Land that should be designated for water catchment areas and generally used for green space conservation is often converted into built-up areas, triggering changes in land use functions. Converting green spaces into built-up areas affects the land's water absorption capacity and the water quality along the river basins, leading to increased flooding. (Hoirisky *et al.*, 2018).

5. Flood Intensity

The vulnerability to flood disasters in Makassar City is classified into three categories: low, moderate, and high. Most of Makassar City has a moderate level of flood vulnerability, covering an area of 73.3 km^2, accounting for 41% of the city's total area. Areas with low flood vulnerability cover 37.4 km^2, or just 21%. In contrast, high flood vulnerability areas almost dominate the city, covering 68.1 km^2, which represents 38% of the total area of Makassar.

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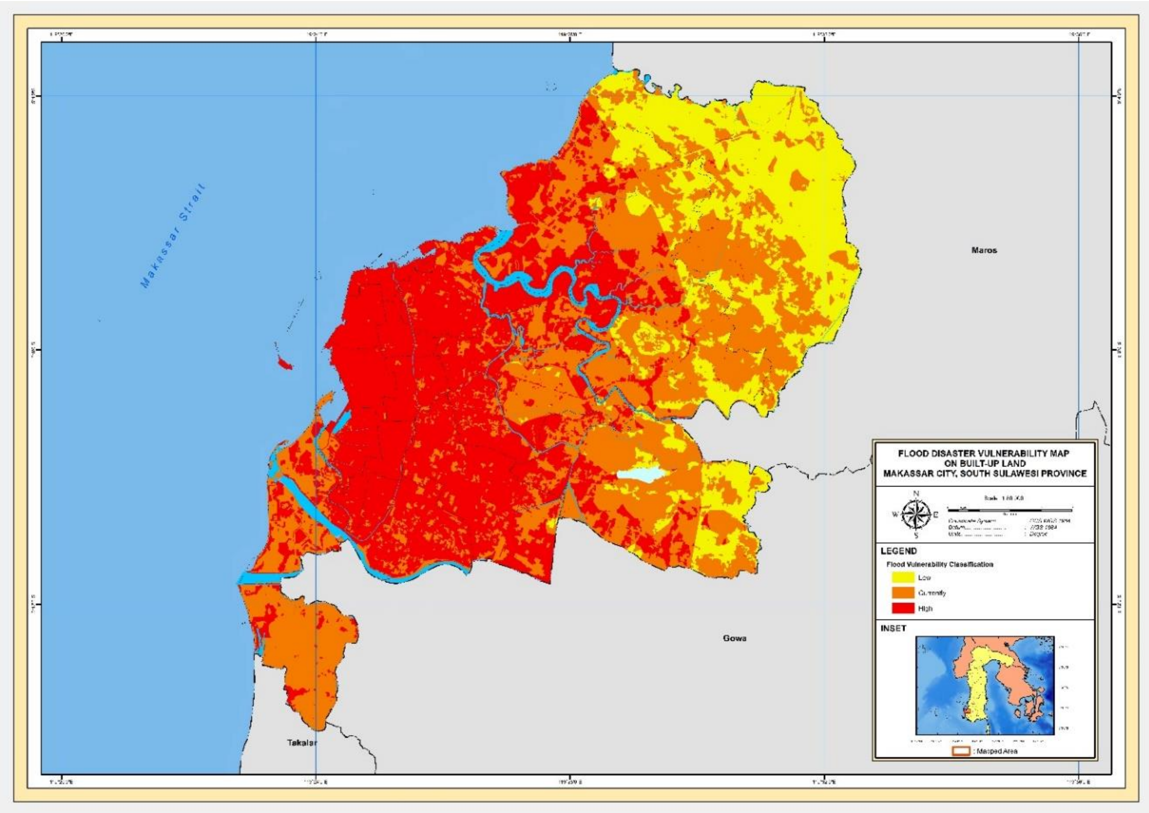

Figure 6. Flood Disaster Vulnerability Map on Built-up Land Makassar.

Table 6. Results of Analysis of Flood Disaster Vulnerability data for the City of Makassar

No	Classification	Area (Km^2)	Percentage
1	Low	37,4	21%
2	Currently	73,3	41%
3	Hight	68,1	38%
	Total	**178,8**	**100%**

Source: Data Analysis, 2024.

Vulnerability is a condition or state of a community or society that leads to or results in an inability to cope with disaster threats (Hadini *et al.,* 2023). The analysis of flood vulnerability in Makassar City was conducted using spatial analysis. This approach utilized indicators such as built-up and non-built-up areas, land use, rainfall, and slope gradients. Based on classification, The analysis reveals that flood intensity in Makassar City shows that 37.4 km² or 21% of the total area falls under the low rainfall intensity category. Meanwhile, the moderate rainfall intensity category covers 73.3 km² or 41% of the city. The high rainfall intensity category accounts for 68.1 km² or 38% of the area. This indicates that rainfall variability in Makassar City is highly diverse and influenced by several factors, including year-round rainfall in different areas, land use, and land cover, which significantly contribute to increased flood intensity. Additionally, slope gradients considerably impact rainfall intensity patterns in Makassar City.

CONCLUSION

Vulnerability is a condition within a community or society that reduces its capacity to effectively manage disaster threats, which is essential in understanding the impact of natural hazards, such as floods, on urban areas. In Makassar City, flood vulnerability has been assessed using spatial methods

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incorporating multiple indicators, including the distribution of built-up and non-built-up areas, land use patterns, rainfall levels, and slope gradients, each contributing to the city's overall flood risk profile. The analysis shows significant variations in flood intensity across the city, with 21% of the area experiencing low rainfall intensity and a lower flood likelihood, 41% facing moderate rainfall intensity and a higher risk of moderate flooding, and 38% subject to high rainfall intensity, indicating a substantial risk of severe flooding. These variations are shaped by factors such as varying rainfall amounts throughout the year, changes in land use, and extensive built-up areas that limit the land's capacity to absorb water, along with slope gradients that influence rainfall distribution and absorption, adding complexity to the city's flood risk patterns.

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