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Flood Vulnerability Analysis Using Multi-Criteria Spatial Assessment (MCSA): A Case Study in Makassar, Indonesia

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Abstract

Floods are among the most frequent and destructive natural hazards affecting urban areas, particularly in rapidly developing cities in Southeast Asia. This study aims to assess and map flood vulnerability in Makassar City, Indonesia, using a Geographic Information System (GIS)-based Multi-Criteria Spatial Assessment (MCSA) approach. Five parameters were selected based on their contribution to flood susceptibility: slope gradient, soil type, rainfall intensity, land use and cover, and distance to rivers. Each parameter was classified into five categories and scored from 1 to 5 according to hydrological relevance and literature support. The parameters were integrated through a weighted overlay analysis in a GIS environment to produce a composite flood vulnerability map. The results show that high- and very-high-vulnerability zones are concentrated in low-lying, densely populated districts, such as Tamalanrea, Biringkanaya, and Manggala, areas with flat topography, poor drainage, and extensive impervious surfaces. Meanwhile, the eastern and southeastern regions exhibit lower vulnerability due to better topographic conditions and less urban pressure. The generated map offers a practical tool for local authorities and urban planners to guide disaster mitigation strategies, optimize infrastructure development, and promote more resilient urban planning in flood-prone areas.

Keywords:

Flood vulnerability, Geographic Information System, Multi-Criteria Spatial Assessment, Makassar.

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1. Introduction

Indonesia is located between 6° 04' 50" N - 10° 32' 45" S and 95° 18' 30" E - 140° 59' 45" E, positioning the country within a tropical climate zone characterized by a humid environment with distinct dry and rainy seasons (Statistics of Indonesia, 2009). This strategic geographic and climatological positioning makes Indonesia highly vulnerable to various types of disasters, including geological, hydrological, and other natural hazards. One of the most frequently occurring natural disasters in the country is flooding (Faradiba, 2021). Floods occur when water overflows beyond the normal river level, inundating low-lying areas adjacent to the riverbanks (Al-Abbas et al., 2021). The high intensity of rainfall throughout the year, a characteristic of Indonesia's tropical climate, significantly contributes to the country's susceptibility to such hydrological disasters (Narulita and Ningrum, 2018; Alwi et al., 2021).

Flooding is a recurring phenomenon during the rainy season, affecting numerous river basins across most of Indonesia (Indrawan and Yusuf, 2020; Irfan et al., 2021; Narulita and Ningrum, 2018). In recent years, the frequency of flood events during the rainy seasons has shown a significant upward trend, along with an increasing number of human casualties and material losses, including damage to public infrastructure, transportation networks, and agricultural/irrigation systems (Kimutai et al., 2024; Zafar et al., 2024). Over the past four decades, rapid population growth has led to a reduction in water-infiltration areas (Rashid et al., 2021). This is primarily due to the conversion of open land into residential and industrial areas, whereas the remaining land has often been paved with asphalt roads or used as parking lots, reducing its ability to absorb rainwater (Banjara et al., 2024). Consequently, unabsorbed rainwater turns into surface runoff, which flows into rivers and eventually discharges into the sea, depending on the river's capacity to accommodate the water (Bastia et al., 2021; Francisco et al., 2022). Flooding occurs when the river exceeds its capacity or becomes obstructed, which is often exacerbated by the impermeability of urbanized surfaces and the displacement of natural water retention zones (Chathurani et al., 2022; Sugianto et al., 2022). This phenomenon is further compounded by the widespread issue of land subsidence, particularly in densely populated urban centers, where excessive groundwater extraction for consumption leads to the gradual sinking of the Earth's surface, exacerbating flood risks and sea-level rise projections (Sim et al., 2024).

Floods are among the most frequent and destructive natural hazards in tropical urban regions, causing severe disruptions to livelihoods, infrastructure, and local economies. Accurate flood prediction and vulnerability assessment are essential to support timely and effective disaster mitigation planning (Lessy et al., 2018; Yang and Chang, 2020; Zhu et al., 2025). Makassar City, Indonesia, a coastal lowland metropolis in South Sulawesi, is highly vulnerable to flooding due to its geographical location, rapid urbanization, and inadequate drainage infrastructure. This city plays a strategic role as an economic gateway to eastern Indonesia, making the impacts of flooding far-reaching for both local and regional development. Flood events in Makassar are most prevalent during the November–April rainy season, when heavy rainfall often exceeds the capacity of urban drainage systems, leading to river overflows and coastal inundation (Barkey et al., 2019; Halim et al., 2019; Mustari et al., 2022).

Over the past decade, the frequency and severity of these floods have increased, resulting in significant socio-economic losses and environmental degradation. To address this challenge, Multi-Criteria Spatial Assessment (MCSA) provides an integrated geospatial framework for mapping and quantifying flood vulnerability by incorporating physical, hydrological, and socio-economic indicators (Roy et al., 2017; Sambah and Miura, 2019). This study applies MCSA to Makassar to produce a detailed vulnerability map, enabling the identification of high-risk zones, prioritization of mitigation strategies, and informed decision-making for disaster risk reduction.

2. Description of the Study Area

Geographically, Makassar features low-lying coastal terrain in the west that gradually rises towards the east, with elevations ranging from 0 to 25 meters above sea level. According to Indrayani et al. (2023) and Surya et al. (2020), its proximity to the Makassar Strait, as well as the presence of multiple river systems, makes it vulnerable to both tidal and fluvial flooding, particularly amid rapid urbanization and limited drainage infrastructure.

Based on the Regional Geological Map of Ujung Pandang, Benteng, and Sinjai, South Sulawesi (Sukamto and Supriatna, 1982), the geological structure of Makassar City comprises three main formations: the Camba Formation (Tmc), Basalt and Basalt Dykes (b), and Alluvial and Coastal Deposits (Qac) (Figure 2). The Camba Formation, which unconformably overlies older rocks, consists of marine sedimentary rocks interbedded with volcanic rocks and extends from north to south along the eastern part of the city. It includes fine to coarse tuff, lapilli, volcanic breccia, and occasional limestone fragments. The Baturape-Cindako Formation, of Quaternary (Pleistocene) age, is composed of volcanic rocks resulting from both effusive and explosive eruptions.

It is predominantly found in the southern part of Makassar and consists of lava flows interbedded with fine- to coarse-grained tuff and volcanic breccia, with a general orientation from northeast to southwest.

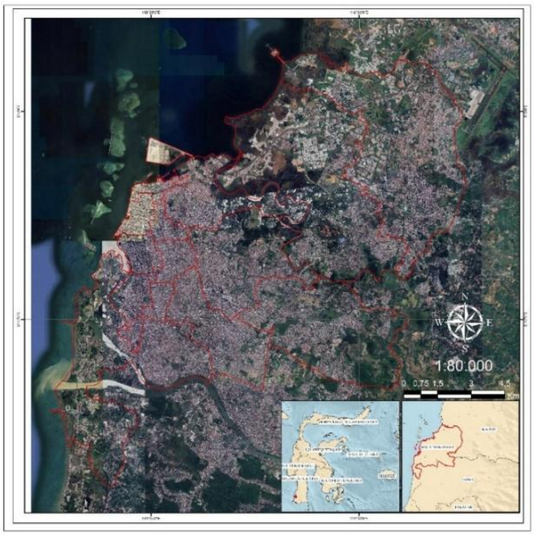

Fig. 1: The study area

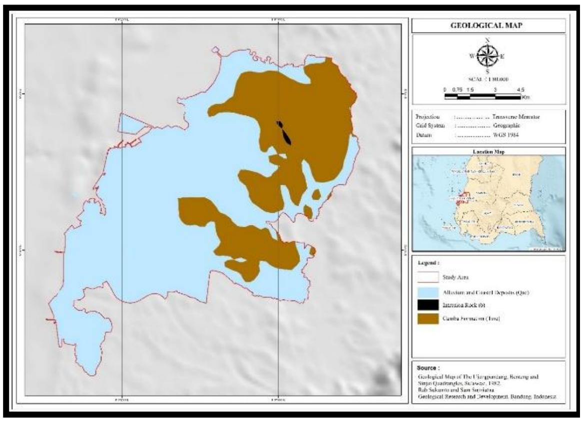

Fig. 2: Geological map of the study area

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4. Materials and Methods

This study employed a survey and mapping approach utilizing Geographic Information System (GIS) analysis to evaluate flood vulnerability in Andoolo District, South Konawe Regency. The research was conducted between December 2023 and January 2024. GIS was selected for its ability to effectively integrate spatial and attribute data, thereby enabling comprehensive multi-criteria assessment in disaster risk analysis. The data used in this study consisted of both primary and secondary sources. Primary data were obtained through direct field observation and documentation of flood-affected locations to validate the spatial classification results. Secondary data were collected from the Geospatial Information Agency (GIA) and the Climate Hazards Group InfraRed Precipitation with Station (CHGIRPS), including slope maps, soil type maps, rainfall data, land use and cover maps, river networks, and administrative boundaries. The data were analyzed using a GIS-based overlay technique, integrating multiple spatial data layers to produce a composite flood vulnerability map. Five key parameters, such as slope gradient, soil type, rainfall intensity, land use, and distance from the river, were selected for their relevance for flood risk assessment (Darmawan and Suprayogi, 2017; Batu and Fibriani, 2017). Each parameter was classified into defined categories and assigned a susceptibility score ranging from 1 to 5, with higher scores indicating greater vulnerability. Weighting factors were then applied to represent the relative influence of each parameter on flood occurrence.

A. Slope

Slope gradient significantly affects surface runoff velocity and risks for flooding. Gentle slopes slow down water flow, increasing the risk of water accumulation and flooding. In this study, slope gradient data were obtained from the Indonesian Geospatial Information Agency in 2024, using topographic maps at a scale of 1:50.000 (Table 1).

Table 1: Distribution of Slope Parameters.

No.	Slope (%)	Description	Score	Weight
1	0-8	Flat	5	
2	>8-15	Gentle	4	
3	>15-25	Slightly Steep	3	0,25
4	>25-40	Steep	2	
5	>45	Very Steep	1	

B. Rainfall/Precipitation Level

Precipitation level is a primary climatic factor that directly contributes to flood events, particularly when it occurs at high intensity over a sustained period. Precipitation data for this study were sourced from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS), which provides globally recognized precipitation datasets with a spatial resolution of 0.05°. Rainfall was classified into four categories—low, moderate, high, and very high—following guidelines from the National Disaster Management Authority of Indonesia, 2013 (Table 2).

Table 2: Distribution of Precipitation Level Parameters.

No.	Class	Precipitation Level (mm/years)	Score	Weight
1	Low	2001-2500	1	0,15
2	Moderate	2501-3000	2	
3	High	3001-3500	3	
4	Very High	>3500	4	

C. Soil Type

Soil type significantly affects infiltration capacity and thus plays a key role in flood vulnerability. Soils with low permeability, such as Regosol and Organosol, exhibit poor water absorption, thereby increasing the likelihood of surface runoff and flooding. Soil data were derived from the FAO/UNESCO Soil Map of the World. The classification and sensitivity levels of the soil types were based on Darmawan and Suprayogi (2017), who categorized soil into five infiltration sensitivity classes, from very low to very high, and assigned corresponding scores and weights for spatial analysis (Table 3).

Table 3: Distribution of Soil Parameters.

No.	Soil Type	Infiltration	Score	Weight
1	Alluvial, Palnosol, Hydromorph, Lateric	Very Low	5	0,1
2	Latosol	Low	4	
3	Forest Soil, Mediterranean Soil	Moderate	3	
4	Andosol, Lateric Grumosol, Podsol, Podsolic	High	2	
5	Regosol, Litosol, Organosol, Renzina	Very High	1	

D. Land Use and Cover

Land use and cover reflect the extent of human intervention in the natural environment and significantly influence hydrological processes. Urbanized and intensively farmed lands typically increase surface runoff, while natural vegetation, such as forests, can effectively absorb rainfall and reduce flood risk. Land use data were obtained from BIG (2024) with a map scale of 1:50.000. Classification and scoring of land use types followed the method of Darmawan and Suprayogi (2017), who identified five major categories: forest, shrubs, mixed cultivation, rice fields/fish ponds, and settlements (Table 4). Settlements/Water Body received the highest scores due to their strong association with flood hazard potential.

Table 4: Distribution of Land Use Parameters.

No.	Land Use	Score	Weight
1	Forest	1	0,25
2	Shrub/Bushland	2	
3	Dry Field/Mixed Dryland Farming	3	
4	Paddy Field/Fish Pond	4	
5	Build-up Area/Settlement	5	

E. River Proximity

The proximity of an area to river bodies significantly determines its exposure to flooding, especially during river overflows. River network data were obtained from BIG (2024) and analyzed in GIS software with buffer techniques (Khalil et al., 2024). The buffer zone classification was based on the method suggested by Batu and Fibriani (2017), who categorized flood risk into four zones: very high risk (0–50 m), high risk, moderate risk, and safe zone (>250 m) (Table 5). Each buffer zone was assigned a score related to its distance from the river, with closer areas receiving higher scores due to increased flood exposure.

Table 5: Distribution of River Proximity Parameters

No.	Class	Distance From River (m)	Score	Weight
1	Safe	250 - 500	1	0,25
2	Moderate Risk	150-250	2	
3	High Risk	50-150	3	
4	Very High Risk	0-50	4	

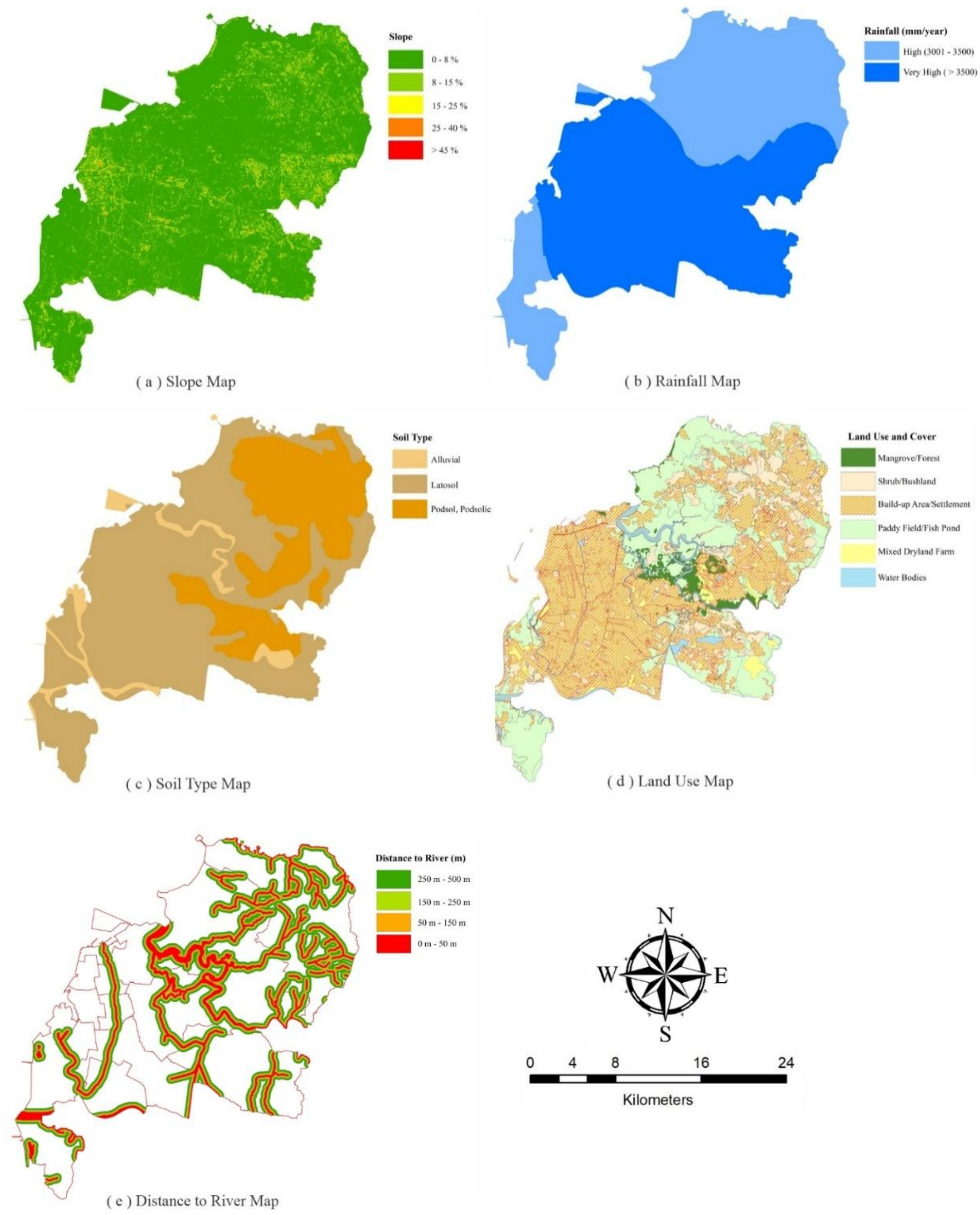

Fig. 3: Distribution of All Criteria in Makassar City

5. Results and Discussion

A. Flood Vulnerability Index

The classification of flood vulnerability levels in this study was based on composite scores derived from the weighted overlay analysis of five parameters: slope gradient, soil type, rainfall intensity, land use, and distance from the river. These scores were grouped into five categories: not vulnerable, slightly vulnerable, moderately vulnerable, vulnerable, and highly vulnerable. The classification applied the equal interval method, which is widely adopted in hazard mapping for its simplicity and consistency in generating evenly spaced classes, as demonstrated by Santosa et al. (2015) and Maliki and Saputra (2021). The class interval was calculated using the following formula: $I = \frac{R}{n}$

Where I is the interval width, R is the range between the maximum and minimum vulnerability scores, and n is the number of desired classes (in this case, five).

The overall vulnerability score (K) for each spatial unit was calculated using the weighted linear combination method, which is a standard approach in multi-criteria decision analysis (MCDA) within GIS environments (Darmawan and Suprayogi, 2017). The formula is:

$$K=\sum_{i=1}^{n}(Wi\ x\ Xi)$$

Where K is the composite flood vulnerability index, Wi is the weight assigned to the parameter, and Xi is the score corresponding to the class of that parameter. The parameter weights used in this study were determined based on previous empirical studies and expert judgment: slope gradient (0.25), land use (0.25), distance from river (0.25), rainfall (0.15), and soil type (0.10). Each parameter was classified into five classes and assigned scores from 1 to 5, with higher scores indicating greater flood susceptibility.

The classification system differentiates flood-prone areas based on the interaction of biophysical and environmental factors. Areas with flat terrain (0–8% slope), impermeable soils, intense land development, and proximity to river channels were generally categorized as "highly vulnerable", which is consistent with findings from other flood risk mapping studies by Liu et al. (2021) and Rakuasa et al. (2022). The resulting flood vulnerability map serves as a critical tool for disaster preparedness, spatial planning, and community risk reduction. These spatial patterns are also consistent with previous empirical studies, which have similarly highlighted the combined effects of natural terrain and human-induced modifications on flood susceptibility (Kurniawan et al., 2020; Sarker et al., 2025). For instance, the analytical hierarchy process has been widely utilized to determine the weights of various parameters, such as flow accumulation, soil type, rainfall, elevation, and land use, for developing comprehensive flood hazard indices (Ouma and Tateishi, 2014; Ahmed et al., 2023). This multi-criteria approach allows for a nuanced assessment of flood risk, integrating both physical susceptibility and socioeconomic factors to provide a holistic vulnerability index (Burke et al., 2011; Kashyap and Mahanta, 2020). Furthermore, the integration of this approach with modeling such as hydrodynamic can validate the hazard component of such indices, thereby enhancing the accuracy and reliability of inundation risk assessments (Pereira et al., 2020).

B. Spatial Characterization of Flood Hazard in Makassar City

This study employed a Geographic Information Systems (GIS)-based multi-criteria analysis (MCA) to develop a flood hazard zonation map of Makassar City, Indonesia. The integration of biophysical and anthropogenic parameters enables a comprehensive assessment of flood vulnerability across diverse urban landscapes. The five primary criteria selected for the model slope gradient, soil type, rainfall intensity, land use/land cover, and proximity to river systems represent the critical physical and socio-environmental variables influencing hydrological behavior in the city. Each parameter was systematically classified into vulnerability categories and assigned a score on a scale from 1 (very low vulnerability) to 5 (very high vulnerability). These scores were subsequently combined using a weighted overlay method to generate a composite flood hazard index. The weightings were derived using previous literature and expert judgment, ensuring an accurate representation of each parameter's relative influence.

Comparable approaches have been applied in other urban contexts, demonstrating the validity of this methodology. For example, Darmawan and Suprayogi (2017) applied a similar GIS–MCA framework in urban areas, highlighting the dominant influence of land use and river proximity on flood susceptibility. Batu and Fibriani (2017) conducted a spatial vulnerability assessment in Central Java and similarly emphasized the combined role of slope and land cover in shaping flood risk. More recently, Liu et al. (2021), Chen et al. (2022), and Rakuasa et al. (2022) demonstrated the resilience of weighted overlay techniques for delineating hazard-prone zones in densely populated regions of China and Southeast Asia. Furthermore, studies have shown that similar methodologies can be employed for urban coastal flood-prone mapping, considering the combined impact of tidal waves and heavy rainfall, as exemplified in Mataram City, Indonesia (Sutrisno et al., 2020). These advancements in spatial analysis, particularly with Geographic Information

Systems, enable the assimilation of extensive spatial datasets for flood risk assessment, enhancing the precision and reliability of vulnerability mapping (Ying et al., 2023). The consistency of these findings across diverse geographic contexts highlights the broader applicability of the weighted overlay approach while also highlighting the originality of its implementation in Makassar, where unique patterns of coastal urbanization and rapid land-use change intensify the city's flood vulnerability.

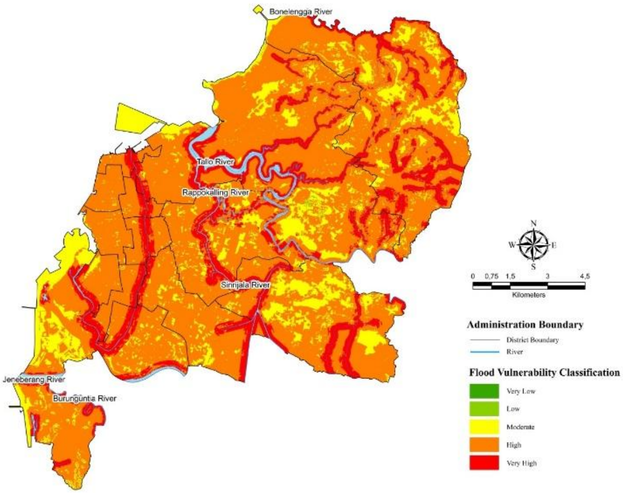

Fig. 4: Flood Vulnerability Map in Makassar City

The spatial analysis yielded a stratified map delineating five distinct flood hazard zones: Very Low (Very Safe), Low (Safe), Moderate, High, and Very High. The spatial distribution of these zones reveals significant spatial heterogeneity in flood risk levels, largely correlated with geomorphological and urban development characteristics (Figure 4).

The Very High-Risk Zones, predominantly situated around river areas in Makassar, exhibit the most unfavorable combination of flood-related factors. These areas are situated on flat or concave terrain with a minimal elevation gradient, possess clayey soils with poor infiltration capacity, and are close to the primary drainage corridors, the Jeneberang and Tallo Rivers. These zones are highly urbanized, with dense residential neighbourhoods, commercial districts, and industrial facilities. Such land uses reduce vegetative cover and increase impervious surfaces, thereby exacerbating surface runoff. Furthermore, the drainage systems in these areas are often under-dimensioned or poorly maintained, leading to frequent localized flooding during periods of high precipitation.

The crucial zones include Perumnas Antang (Manggala), BTP and Kodam III (Biringkanaya), BTN Bung Permai (Tamalanrea), and Monginsidi Baru Street (Makassar). These zones are frequently affected by seasonal and event-based floods, which pose significant dangers to infrastructure, public assets, and human well-being. The convergence of natural susceptibility and anthropogenic stressors underscores the urgent need for prioritized intervention in these zones.

The High-Risk Zones form a buffer zone around the very high-risk areas, representing transitional landscapes where elevation varies slightly, and land use is less intense but still problematic. These areas are often adjacent to riverbanks and characterized by mixed soil types, predominantly loamy or sandy clay, which yet have limited permeability. Notably, these zones face systemic issues with stormwater management, including sedimentation in drainage channels and encroachment on natural retention areas due to rapid urban sprawl. Examples include parts of Panakkukang, Tamalanrea, and eastern Biringkanaya. The zoning typology identified in Makassar shows parallels with flood-risk analyses in other rapidly urbanizing cities across Southeast Asia. For instance, studies in Jakarta demonstrate that transitional buffer areas along riverbanks, including the High-Risk Zones in Panakkukang, Tamalanrea, and Biringkanaya, are highly vulnerable due to poor drainage capacity, informal settlements, and sediment-laden waterways (Marfai and King, 2008; Firman et al., 2011). Comparable findings have also been reported in Manila, where peri-urban flood-prone landscapes face compounded pressures from land encroachment and ineffective stormwater management (Siringan and Rodolfo, 2003).

The Moderate-Risk Zones encompass interior urban areas with mixed-use land patterns and gently undulating terrain. Although not currently at critical risk levels, these zones are vulnerable to escalated flood hazards in the future due to ongoing land conversion, loss of green space, and infrastructure expansion. Such areas should be viewed as "at-risk" zones, requiring careful land use regulation, green infrastructure preservation, and improvement to micro-drainage systems. The Moderate-Risk Zones in Makassar likewise reflect patterns observed in Bangkok's inner districts, where mixed-use urban expansion and the loss of permeable green spaces accelerate localized flood risk over time (Marks and Lebel, 2016). These studies collectively highlight the transitional fragility of such areas, which, although not yet catastrophic, are nonetheless highly sensitive to shifts in land use policy controls and infrastructure growth.

In contrast, the Safe and Very Safe Zones are primarily located in the eastern and southeastern peripheries of Makassar. These areas benefit from favorable topography, with moderate to steep slopes and permeable soils such as sandy loam or gravel-rich profiles. Natural vegetation. Urban forests and rain-fed agricultural lands are frequently the dominant land cover in these zones. Given their ecological value as infiltration and runoff control zones, these regions should be preserved through stringent spatial planning regulations. Comparable conditions have been documented in the highland peripheries of Kuala Lumpur, where preserved forested slopes and permeable soil layers reduce runoff and serve as natural flood buffers (Chan, 2012). Similarly, studies in Vietnam and Singapore demonstrate that maintaining green cover and forested terrain in peripheral districts significantly enhances infiltration capacity and contributes to urban flood resilience (Ngoc, 2024; Liu et al., 2025). These findings reinforce the importance of safeguarding Makassar's Safe and Very Safe Zones through strict spatial planning policies and conservation-oriented zoning regulations, ensuring that ecological advantages are preserved and not undermined by unchecked development.

C. Integrative Approaches to Urban Flood Risk Management

Urban flood risk in Makassar is increasingly shaped by both environmental and anthropogenic factors, with climate change emerging as a critical driver through more frequent and intense rainfall events. Recent studies confirm that Southeast Asian coastal cities are particularly vulnerable to compound flooding events caused by extreme precipitation, sea-level rise, and urbanization (Jongman, 2018; Rogers et al., 2025). To address this complexity, nature-based solutions (NBS) have gained recognition as effective alternatives to hard infrastructure. NBS enhance infiltration, regulate surface runoff, and provide multiple co-benefits for biodiversity and urban liveability. For instance, Griffiths et al. (2024) demonstrated that integrating NBS into catchment planning reduces flood peaks, while McQueen (2025) emphasized the role of nature-based and nature-neutral flood barriers (NNBF) in strengthening the resilience of coastal cities. These approaches are increasingly being mainstreamed into climate-adaptive planning frameworks across Asia. Simultaneously, big data analytics and artificial intelligence (AI) are transforming flood forecasting. Chitwatkulsiri and Miyamoto (2023) reviewed AI-based urban flood forecasting in Southeast Asia, showing improvements in both accuracy and lead time compared to traditional models. More recently, Chang (2025) implemented an AI-driven intelligent flood control decision support system in Taipei that optimized pump operations and reduced flood damage by nearly half. Similarly, Ikram (2025) developed evolutionary AI models that adaptively predict riverine flood risk, offering more robust decision-making under uncertainty. Equally important is community-based disaster risk reduction (CBDRR), which ensures that flood governance is not limited to technical solutions but also engages local capacity. Wolff et al. (2021) illustrated how citizen science initiatives in informal settlements improved real-time flood monitoring and strengthened trust between communities and government. Martelo et al. (2024) extended this idea by developing a GPT-4-enabled AI assistant to democratize flood risk communication, making complex flood forecasts more accessible to decision-makers and vulnerable populations. Collectively, these findings highlight that adopting a multi-dimensional approach can transform flood governance from a reactive crisis response into a proactive, climate-resilient urban planning framework.

6. Conclusion

This study successfully developed a flood hazard zonation map for Makassar City using a multi-criteria GIS-based approach, integrating five key factors: slope gradient, soil type, rainfall intensity, land use/land cover, and proximity to rivers. The weighted overlay method provided a robust analytical framework for quantifying and visualizing spatial flood vulnerability in an urban context.

These findings underscore the importance of integrating both natural and anthropogenic parameters in urban flood risk assessment.

Moreover, the flood hazard map produced is not only scientifically rigorous but also highly applicable in guiding urban planning, infrastructure development, and disaster risk reduction strategies.

To enhance urban resilience, very high-risk zones should be prioritized for mitigation interventions such as development restrictions, drainage improvements, and potential relocation programs. High-and moderate-risk zones require adaptive land use management and investment in sustainable drainage infrastructure. Safe zones must be preserved and used as ecological buffers to support flood regulation functions.

Ultimately, this research contributes to a more nuanced and spatially explicit understanding of flood dynamics in tropical urban environments. It provides an evidence-based tool for policymakers and urban managers to make informed decisions that balance development with sustainability and disaster preparedness.

7. Acknowledgements

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تحليل قابلية التأثر بالفيضانات باستخدام التقييم المكاني متعدد المعايير (MCSA): دراسة حالة في ماكاسار، إندونيسيا

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الملخص

تُعد الفيضانات من بين أكثر المخاطر الطبيعية تكراراً وتدميراً وتأثيراً على المناطق الحضرية، لا سيما في المدن سريعة التطور في جنوب شرق آسيا. تهدف هذه الدراسة إلى تقييم ورسم خرائط الهشاشة (الضعف) تجاه الفيضانات في مدينة ماكاسار بإندونيسيا، باستخدام نهج التقييم المكاني متعدد المعايير (MCSA) القائم على نظم المعلومات الجغرافية (GIS). تم اختيار خمسة عوامل (برامترات) بناءً على مدى مساهمتها في قابليتها للتأثر بالفيضانات، وهي: درجة الانحدار (الميل)، ونوع التربة، وكثافة الأمطار، واستخدامات الأراضي والغطاء الأرضي، والمسافة إلى الأنهار. صُنّف كل عامل إلى خمس فئات وأعطيت درجات تراوحت من 1 إلى 5 وفقاً للأهمية الهيدرولوجية والدراسات السابقة. دُمجت هذه العوامل من خلال تحليل التراكب الموزون (Weighted Overlay Analysis) في بيئة نظم المعلومات الجغرافية لإنتاج خريطة مركبة للهشاشة تجاه الفيضانات. تظهر النتائج أن نطاقات الهشاشة "العالية" و"العالية جداً" تتركز في المناطق المنخفضة والمكتظة بالسكان، مثل مديريات (تامالانريا، وبيرينغكانيا، ومانغالا)، وهي مناطق تتميز بطبوغرافية منبسطة، وتصريف مياه رديء، ومساحات شاسعة من الأسطح غير المنفذة للمياه. وفي المقابل، تُظهر المناطق الشرقية والجنوبية الشرقية هشاشة أقل نظراً لظروفها الطبوغرافية الأفضل وضغوطها الحضرية الأقل. وتقدم الخريطة الناتجة أداة عملية للسلطات المحلية ومخططي المدن لتوجيه استراتيجيات التخفيف من آثار الكوارث، وتحسين تطوير البنية التحتية، وتعزيز تخطيط حضري أكثر مرونة في المناطق المعرضة للفيضانات.

الكلمات المفتاحية:

الهشاشة تجاه الفيضانات، نظم المعلومات الجغرافية (GIS)، التقييم المكاني متعدد المعايير (MCSA)، ماكاسار.

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