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Flood Vulnerability Using Multi-Criteria Analysis in West Jakarta

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Abstract
The Special Capital Region of Jakarta, located on the north coast of Java Island, is a low-lying sedimentary area crossed by 13 rivers, making it highly vulnerable to flooding from river overflows and sea level rise intensified by climate change. Flooding has been a persistent issue since the Dutch colonial era, driven by rapid urban growth, inadequate development management, the emergence of slums, and poor water resource management. Major floods occurred in 2002 and 2007, and annual floods continued until 2020. Several key factors contribute to flooding, including slope, rainfall, and land cover, while in West Jakarta the problem is further exacerbated by land subsidence and sea level rise. To address this, a flood vulnerability analysis was carried out using a GIS-based multi-criteria analysis approach. Unlike the BNPB reference, which considers only slope, rainfall, and land cover, this study incorporated six parameters: land cover, rainfall, drainage density, slope, land subsidence, and sea level rise. Each parameter was weighted based on its contribution to flooding risk, and spatial data were processed through overlay and reclassification to produce a flood vulnerability map. The results categorize West Jakarta into four classes: Not Vulnerable, Slightly Vulnerable, Vulnerable, and Highly Vulnerable. The majority of the area falls into Not Vulnerable (39.62%) and Slightly Vulnerable (36.30%), while only Kembangan District is dominated by the Highly Vulnerable category. Validation was conducted by comparing the vulnerability map with historical flood data from 2016 to 2023. The comparison shows a strong positive correlation between mapped vulnerability levels and the frequency of actual flood events. This alignment confirms the validity of the method and highlights its value for improving flood risk management and mitigation planning in West Jakarta.

Keywords: Vulnerability, Flood, GIS, Multi-Criteria Analysis, West Jakarta

1. Introduction

Geographically, the Special Capital Region of Jakarta is situated on the northern coast of Java Island, an area predominantly consisting of alluvial deposits. Positioned in lowland areas adjacent to the Java Sea and traversed by 13 rivers, Jakarta is inherently prone to flooding, both from river overflows and sea-level rise. Moreover, Jakarta is highly vulnerable to climate change impacts, with flooding representing the most significant hazard due to heavy rainfall and coastal inundation. Flooding in Jakarta has been a persistent issue since the Dutch colonial era, as reflected in the construction of flood canals as an early flood control measure. However, in recent decades, the severity of flooding has increased, driven by rapid population growth, unregulated urban development, informal settlements, poor water resource management, and escalating disaster risks (Moerdianta & Stalker, 2007).

Since the early 2000s, Jakarta and its surrounding areas have experienced several major floods, notably in 2002 and 2007. Data from the “Pantau Banjir Jakarta” portal indicate that floods have been recorded almost annually, including in 2014, 2015, 2016, 2017, 2018, 2019, and 2020. As a low-lying area situated between upstream river basins and coastal zones, Jakarta is affected by three primary flood types: local rainfall, upstream floods, and tidal flooding. Contributing factors also include rapid land-use change, poorly designed urban drainage systems, and improper solid waste disposal, which obstruct river flows. Natural factors, such as high rainfall intensity exceeding 150 mm per day with prolonged duration, further exacerbate the problem. Approximately 40 percent (24,000 ha) of Jakarta lies below sea level, with much of this land traversed by river tributaries (Fajar, 2020). Rapid urban expansion has also converted water catchment areas into built-up zones, reducing infiltration and amplifying flood risks (Hung et al., 2007). Prior studies (Álvarez-Romero et al., 2015; Novitasari & Kurdi, 2022) confirm that land-use change significantly alters hydrological processes, thereby intensifying urban flood events.

The recurring floods have resulted in substantial social and economic consequences. Despite various government interventions employing structural approaches, flood risks remain unresolved. According to Undang-Undang Nomor 24 Tahun 2007, disasters are defined as events threatening human life and livelihoods, triggered by natural, non-natural, or human factors, resulting in casualties, environmental damage, economic losses, and psychological impacts (BNPB, 2019). Within this context, systematic flood vulnerability assessment emerges as a critical requirement for guiding disaster risk reduction efforts, land-use planning, and sustainable urban development. Therefore, identifying and analyzing Jakarta's most flood-prone areas is essential in order to inform more localized, context-specific strategies—particularly in regions such as West Jakarta, which face compounding urban and environmental pressures.

Administratively, West Jakarta occupies an area of 12,615.44 hectares at an average elevation of +7 meters above sea level, with a population of 2,589,933 people distributed across 8 districts and 56 subdistricts. Within this administrative boundary, Cengkareng and Kembangan are recognized as the most flood-prone areas due to their low-lying alluvial plains and inadequate drainage capacity. For example, in 2017, Rawabuaya in Cengkareng experienced flood depths of 250–300 cm that persisted for eight days (Narani, 2009). The floods of 2007 were particularly devastating, with Cengkareng alone reporting over 6,500 displaced residents and three fatalities when floodwaters exceeded two meters (Sitepu & Sugiyanto, 2007).

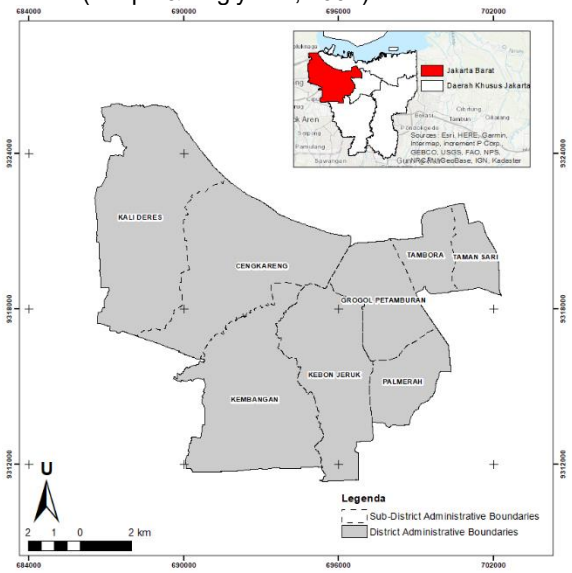

Fig 1. Administrative boundaries of study area

Despite being highly exposed to flood hazards, local residents have developed various adaptive strategies, including elevating house floors, constructing drainage channels, and building makeshift embankments. However, these community-level efforts remain insufficient in mitigating large-scale flood events. Consequently, West Jakarta represents a highly relevant study area for urban flood vulnerability research, not only due to its historical flood records and recurring impacts but also because of its demographic and spatial characteristics that amplify disaster risk.

To address these challenges, Geographic Information Systems (GIS) and Remote Sensing (RS) provide robust analytical tools for spatially assessing flood-prone zones. Through the integration of topographic, hydrological, land-use, and socio-economic parameters, GIS-based multi-criteria analysis enables comprehensive vulnerability mapping and predictive modeling of flood scenarios. Several studies, such as Wang (2015), Nasr et al. (2022), and Ouma & Tateishi (2014), have demonstrated the utility of GIS-based approaches in urban flood risk assessment. In line with these methodological advancements, the present research applies an integrated spatial and descriptive analysis to assess river flood vulnerability in West Jakarta. Unlike existing national flood mapping standards, which primarily emphasize rainfall and land cover, this study incorporates additional parameters such as land subsidence and sea-level rise, both of which are critical in Jakarta's context. By focusing on West Jakarta as a case study, this research aims to generate a comprehensive vulnerability assessment that can serve as a model for localized disaster risk management and broader urban resilience planning across Jakarta.

2. Materials and Methods

2.1 Data Collection

In conducting spatial and descriptive analyses of flood vulnerability in West Jakarta, this study utilizes a combination of geospatial, hydrological, climatological, and socio-environmental datasets. The selection of datasets was guided by their relevance to multi-criteria flood vulnerability assessment summarized in Table 1.

Table 1. Data type, years, and source

Data	Years	Source
Administrative boundary of West Jakarta	2024	Badan Informasi Geospasial
Slope, derived from DSM	2021	JAXA ALOS Digital Surface Model (DSM) 30m v3.2
Rainfall	2022	Badan Meteorologi, Klimatologi, dan Geofisika (BMKG)
Land cover	2022	dari ESA Sentinel-2 WorldCover 10m v200
Drainage channel length	2022	Dinas Sumber Daya Air (DSDA) Daerah Khusus Jakarta
Land subsidence	2022	Kementerian Energi dan Sumber Daya Mineral (ESDM
Sea level rise projection	2020 – 2030	NASA IPCC Sea Level Rises Projection
Historical flood events in West Jakarta	2016 – 2023	Pemerintah Daerah Provinsi DKI Jakarta

2.2 Pre-Processing Data

The pre-processing stage involved integrating multiple datasets representing environmental and anthropogenic factors influencing flood vulnerability in West Jakarta. Topographic conditions were assessed using slope data derived from the JAXA ALOS DSM 30m v3.2, accessed via Google Earth Engine (GEE). The dataset was clipped to the study area, exported in raster format, and subsequently processed in ArcGIS, where it was projected to the Universal Transverse Mercator (UTM) Zone 49S and converted into slope values using the *Spatial Analyst* toolbox. This provided an accurate depiction of the predominantly flat to gently sloping terrain characteristic of West Jakarta.

Rainfall data were obtained from four meteorological stations managed by the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG), namely Soekarno-Hatta, Banten, Kemayoran, and Tanjung Priok. Daily records for 2022 were compiled and averaged to generate annual rainfall estimates for each station. To represent the spatial variability of rainfall across the city, the values were interpolated using the Inverse Distance Weighting (IDW) method in ArcGIS, producing a continuous raster surface.

Land-cover information was sourced from the ESA WorldCover 10m v200 dataset (2022) through GEE. Following data retrieval and export, the classification results were refined in ArcGIS to identify key land-cover categories such as built-up areas, agriculture, and water bodies. These classes are essential in understanding infiltration capacity and runoff dynamics across the urban landscape.

Drainage density was derived from spatial data provided by the Jakarta Water Resources Agency (DSDA), which included drainage network maps and total channel lengths per subdistrict. Drainage density values were calculated by dividing drainage length by the corresponding subdistrict area and subsequently joined to administrative boundaries in ArcGIS. This produced a spatial representation of drainage capacity that highlights areas with limited stormwater conveyance infrastructure.

Land subsidence was incorporated using secondary data from the Ministry of Energy and Mineral Resources (ESDM), covering the period 2015–2022. The original maps, provided in image format, were georeferenced and digitized through on-screen delineation to capture subsidence categories. These digitized layers were then integrated into the GIS database, enabling spatial analysis of subsidence patterns that exacerbate flood risk in densely populated districts.

Sea-level rise projections were obtained from the Intergovernmental Panel on Climate Change (IPCC) datasets hosted by NASA. Regional estimates for 2020–2030 were analyzed, showing an average increase of 0.067 m per year. The projected values were converted into raster format and spatially assigned to West Jakarta's administrative boundaries, ensuring consistency with the other variables.

Through this comprehensive pre-processing workflow, all datasets were standardized, spatially aligned, and prepared for subsequent multi-criteria analysis to evaluate flood vulnerability across West Jakarta.

2.3 Multi-Criteria Analysis

The core analysis of this study focuses on mapping flood-prone zones in West Jakarta through the integration of multiple vulnerability parameters. Each parameter was reclassified into classes and assigned a weight reflecting its relative contribution to flood risk, with reference to Table 2. Parameter ranking followed the approach of Purnama (2008), in which classification values were adjusted to their level of influence, using a uniform scale from 1 to 10 across all parameters. Table 2 presents the final weights and rankings applied to each parameter class.

The weighting of each parameter was applied to calculate flood vulnerability in West Jakarta. A multi-criteria analysis using a GIS-based approach was employed in this model. The weighting stage involves assigning values to each parameter according to its overall influence on flood vulnerability. Parameters with stronger influence were given higher weights, with references drawn from previous studies.

Literature indicates that land use is the most influential factor in flood vulnerability (Islam et al., 2020; Talukdar et al., 2020), as it directly affects surface runoff. In West Jakarta, where built-up areas dominate and infiltration capacity is low, hydrological functions are impaired (Rahayu et al., 2023). Accordingly, land use was assigned the highest weight of 40% (0.4).

Topography, particularly slope, also plays a key role. With gradients of only 0–2%, West Jakarta is predominantly flat, resulting in high runoff and heightened flood risk during the rainy season (Alawiyah & Harintaka, 2021). Extreme rainfall further increases discharge; therefore, slope and rainfall were each weighted at 20% (0.2).

Drainage density was included as a supporting factor. While effective drainage can reduce flood risk, it may be overwhelmed under extreme rainfall conditions (Budiyono et al., 2014). As its effect is less direct, drainage density was assigned a weight of 10% (0.1).

Then, land subsidence and sea-level rise were considered based on projections indicating worsening flood risk in West Jakarta in the future (Nicholls, 2002; Abidin, 2011; Muis, 2015; IPCC, 2021). Although their current impact is limited, both parameters are expected to significantly increase vulnerability over time. Each was therefore assigned a weight of 5% (0.05). The complete parameter weighting scheme is presented in Table 2.

Table 2. Weight and ranking flood vulnerability management parameter classes for West Jakarta

Parameters	Relative Weight	Parameter Reclassification	Ranking
Land Cover (Modified Anderson et.al, 1976)	40%	Waters Bare Land Mangroves Fishponds Agriculture Industry and Residential Areas	1 2 4 6 8 10
Rainfall (mm/day) (Modified BMKG, 2010)	20%	<5 5-20 20-50 50-100 >100	1 3 5 7 10
Slope (%) (Modified Haynes, 1998)	20%	> 30 15-30 10-15 5-10 1-5 < 1	1 2 4 6 8 10
Drainage Density (m/m^2) (Modified Rimba dkk., 2017)	10%	<0,00143 0,00143-0,00287 0,00288-0,00430 0,00430-0,00574 >0,00574	1 3 5 7 10
Land Subsidence (cm/year) (Modified Abidin et.al, 2001)	5%	< 2 2-4 4-6 6-8 8-10 > 10	1 2 4 6 8 10
Sea Level Rise (mm/year) (Modified Gornitz, 1991)	5%	< 1 1-2 2-3 3-4 4-5 > 5	1 2 4 6 8 10

3. Results and Discussion

3.1 Analysis of Flood Vulnerability Parameters in West Jakarta

The analysis in this study demonstrates that flood events in West Jakarta are influenced by six key parameters: slope, rainfall, land use, drainage density, sea-level rise, and land subsidence. Each parameter contributes differently to flood vulnerability, as determined through a multi-criteria evaluation. The results highlight that the relative significance of these parameters varies spatially, shaping the overall pattern of flood-prone areas across the city.

The dominant slope class in West Jakarta ranges between 0.5%–5%, covering 104.635 km², with Cengkareng, Kalideres, and Kembangan as the most representative subdistricts. In contrast, the steepest slope class (>30%) is concentrated in Grogol Petamburan. Overall, West Jakarta is characterized by very flat terrain, consistent with its coastal and densely populated setting. These findings confirm that the city's flat topography significantly contributes to high surface runoff and, consequently, flood susceptibility.

Then, analysis of rainfall data from four stations shows monthly averages ranging between 1.853 and 32.940 mm/day. Kemayoran, Soekarno-Hatta, and Tanjung Priok stations exhibit similar patterns, with rainfall increasing from October to January, while Banten records the highest values between June and December. Spatial interpolation of rainfall for 2022 indicates that West Jakarta is largely categorized as *very light rainfall* (<10 mm/day), with only parts of Kembangan (17.935 km²), Kebon Jeruk (7.306 km²), and Palmerah (0.964 km²) falling into the *light rainfall* category (10–15 mm/day). These findings highlight the relatively low rainfall intensity across the city, though local variations remain significant.

Based on ESA Sentinel WorldCover (2022), four land-cover classes were identified, while aquaculture, mangrove, and bare land were not classified due to algorithmic limitations. Land cover in West Jakarta is dominated by industrial and residential areas, totaling 94.552 km², whereas water bodies cover the smallest area at 1.032 km². Tambora has the highest proportion of industrial and residential land (95.1%), while Kembangan records the largest share of agricultural land (52.4%). Water bodies, assigned the lowest weight in the flood vulnerability analysis, are most prominent in Grogol Petamburan, accounting for 2% of its area.

Cengkareng has the longest drainage network (54.025 km), while Tambora has the shortest (14.122 km). In terms of drainage density, Tamansari records the highest value (0.00387 m/m²), whereas Kembangan has the lowest (0.00154 m/m²). These

variations reflect differences in drainage capacity across subdistricts, which directly influence local flood vulnerability.

Land subsidence in West Jakarta is predominantly within the 2.5–4.0 cm/year range, covering 77.624 km². The fastest subsidence (4.0–5.5 cm/year) occurs in Grogol Petamburan, Kalideres, Kebon Jeruk, and Tamansari. This phenomenon is primarily driven by excessive groundwater extraction and natural consolidation of alluvial soils, exacerbated by high population density. Additional factors, including building loads and geotechnical conditions, further accelerate subsidence rates (Handika et al., 2024).

Sea-level rise data for West Jakarta, obtained from the NASA IPCC Project, projects an increase from 0.050 m in 2020 to 0.084 m in 2030, averaging 0.067 m per year. According to Gornitz (1991), this rate (>4 mm/year) falls into the *highly vulnerable* category, indicating significant long-term risks for coastal flooding.

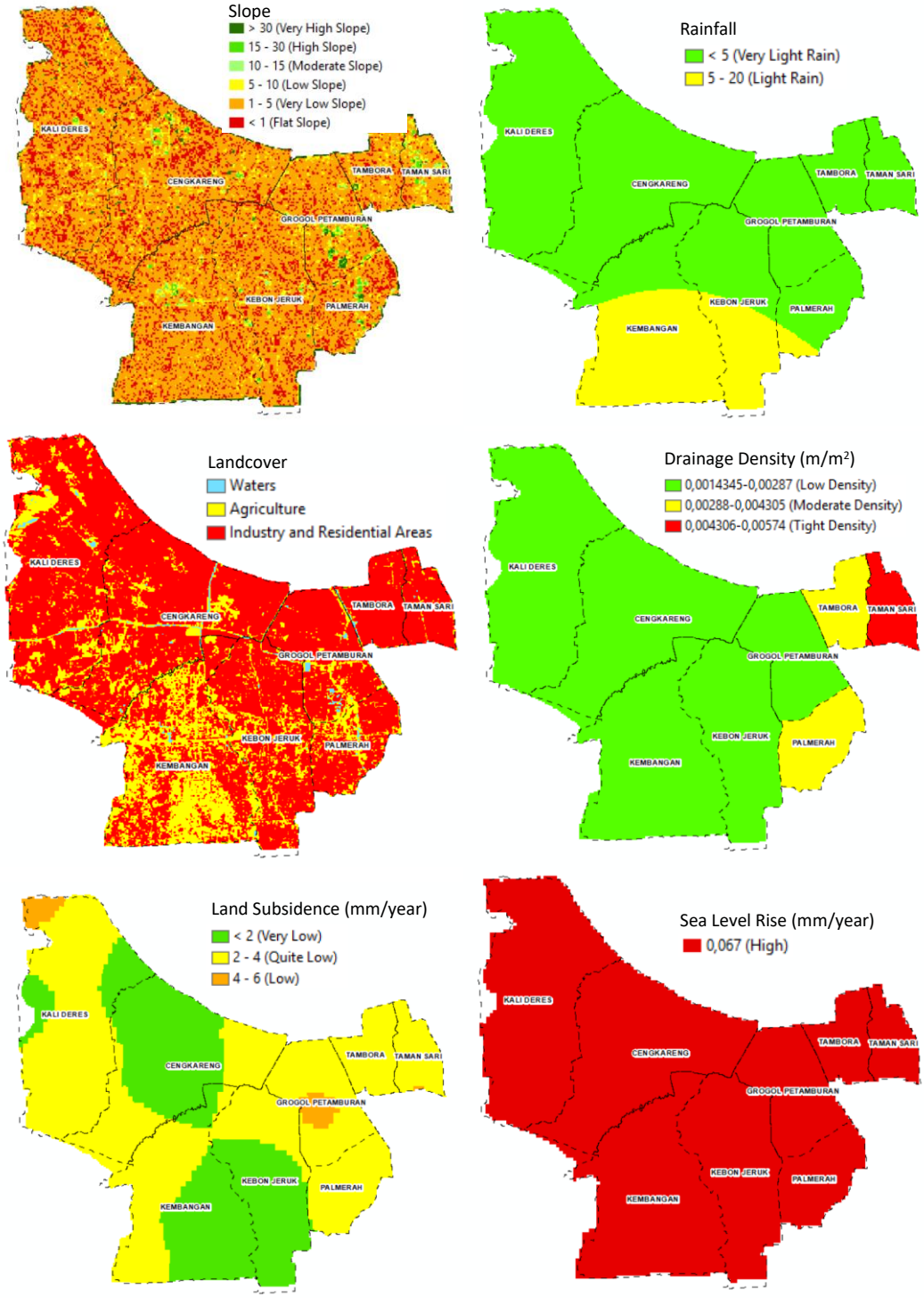

Fig 2. Classification map of flood vulnerability management parameter classes for West Jakarta

3.2 Flood Vulnerability Analysis

The final flood vulnerability results were classified into four categories: *Not Vulnerable*, *Slightly Vulnerable*, *Vulnerable*, and *Highly Vulnerable*. West Jakarta is predominantly classified as *Not Vulnerable* (48.76 km²), followed by *Slightly Vulnerable* (44.675 km²), *Highly Vulnerable* (18.661 km²), and *Vulnerable* (10.969 km²). The percentage distribution of these categories is presented in Table 3, with a graphical visualization shown in Fig 3.

Based on the spatial distribution of flood-prone areas, the characteristics of flood vulnerability in each subdistrict of West Jakarta can be summarized as follows:

a) **Cengkareng** – The largest proportion falls under *Slightly Vulnerable* (14.828 km²; 58.18%), followed by *Not Vulnerable* (6.687 km²), *Vulnerable* (2.418 km²), and *Highly Vulnerable* (1.552 km²).
b) **Grogol Petamburan** – Predominantly *Not Vulnerable* (7.086 km²; 63.42%), with smaller areas of *Slightly Vulnerable* (2.115 km²) and equal extents of *Vulnerable* and *Highly Vulnerable* (0.986 km² each).
c) **Kalideres** – Mostly *Not Vulnerable* (14.207 km²; 51.2%), followed by *Slightly Vulnerable* (8.817 km²), *Highly Vulnerable* (3.35 km²), and *Vulnerable* (1.369 km²).
d) **Kebon Jeruk** – Dominated by *Slightly Vulnerable* (9.186 km²; 53.41%), with additional areas classified as *Not Vulnerable* (4.212 km²), *Vulnerable* (3.191 km²), and *Highly Vulnerable* (0.61 km²).
e) **Kembangan** – The most flood-prone, with *Highly Vulnerable* areas covering 10.639 km² (43.09%), followed by *Slightly Vulnerable* (9.414 km²), *Vulnerable* (2.488 km²), and *Not Vulnerable* (2.149 km²).
f) **Palmerah** – Largely *Not Vulnerable* (5.291 km²; 73.62%), with smaller portions of *Highly Vulnerable* (1.563 km²), *Slightly Vulnerable* (0.303 km²), and *Vulnerable* (0.029 km²).
g) **Tamansari** – Predominantly *Not Vulnerable* (4.078 km²; 94.48%), with minor extents of *Highly Vulnerable* (0.226 km²) and *Slightly Vulnerable* (0.012 km²). No areas fall into the *Vulnerable* category.
h) **Tambora** – Almost entirely *Not Vulnerable* (5.05 km²; 95.77%), with limited areas of *Highly Vulnerable* (0.194 km²) and *Vulnerable* (0.029 km²). No areas are classified as *Slightly Vulnerable*.

Overall, the subdistricts of Grogol Petamburan, Kalideres, Palmerah, Tamansari, and Tambora are predominantly *Not Vulnerable*. Cengkareng and Kebon Jeruk are mainly *Slightly Vulnerable*, while Kembangan exhibits the highest extent of *Highly Vulnerable* areas in West Jakarta.

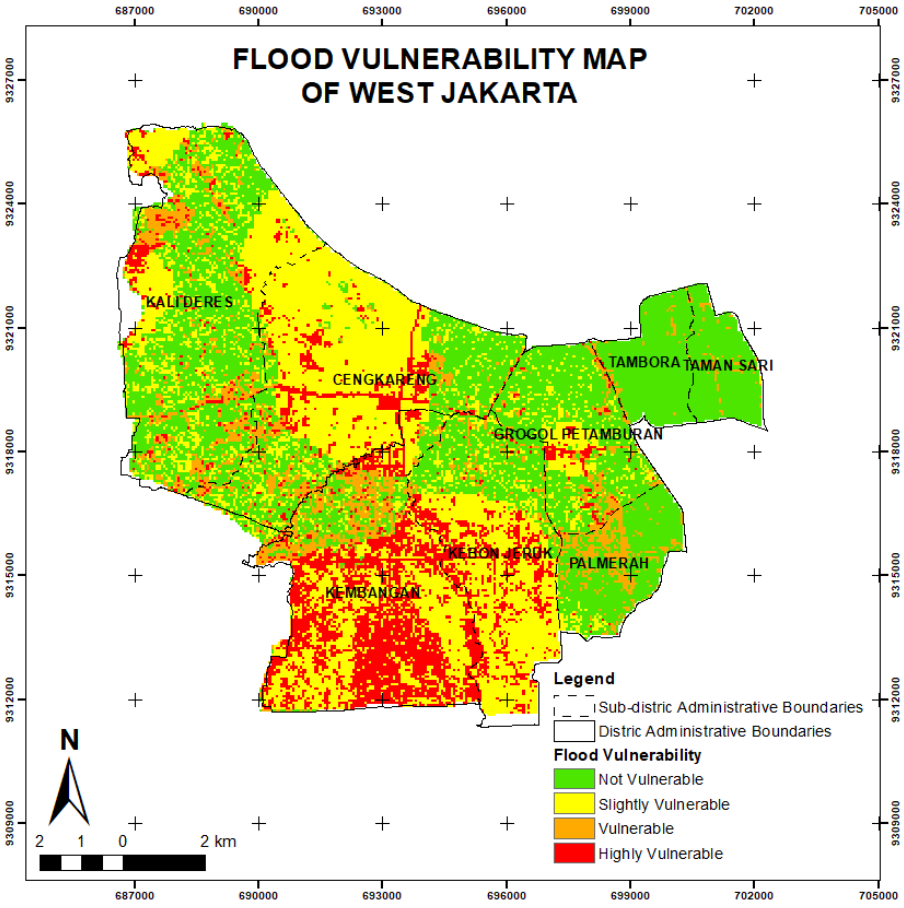

Fig 3. Flood Vulnerability Map of Wes Jakarta

Table 3. Area of each vulnerability class per sub-district

Vulnerability Area (km²)				
Subdistrict	**Not Vulnerable**	**Slightly Vulnerable**	**Vulnerable**	**Highly Vulnerable**
Cengkareng	6,687	14,828	2,418	1,552
Grogol Petamburan	7,086	2,115	0,986	0,986
Kalideres	14,207	8,817	1,369	3,350
Kebon Jeruk	4,212	9,186	0,610	3,191
Kembangan	2,149	9,414	2,488	10,639
Palmerah	5,291	0,303	0,029	1,563
Tamansari	4,078	0,012	0	0,226
Tambora	5,050	0	0,029	0,194
Total	**48,76**	**44,675**	**18,661**	**10,969**

3.3 Historical Flood Incident Analysis

To validate the flood vulnerability map of West Jakarta produced in this study, a comparative analysis was conducted against actual flood events. This validation involved comparing the vulnerability map with historical flood records obtained from the Provincial Government of DKI Jakarta via the *Satu Data Indonesia* platform. The dataset includes flood events recorded between 2016 and 2023, as summarized in Table 4.

Based on the comparative analysis between the flood vulnerability map and historical flood events in West Jakarta (2016–2023), the applied methodology demonstrates a positive correlation with actual flood occurrences. Subdistricts classified as having low vulnerability, such as Grogol Petamburan, Kalideres, Palmerah, Tamansari, and Tambora, experienced fewer flood events over time, consistent with their dominant classification as *Not Vulnerable*.

Conversely, Cengkareng, Kebon Jeruk, and Kembangan recorded higher flood frequencies, aligning with their dominant classifications of *Slightly Vulnerable*, *Vulnerable*, and *Highly Vulnerable*. This consistency indicates that the parameters employed in this study effectively capture the spatial characteristics of flood vulnerability in West Jakarta. The alignment between the vulnerability map and historical data reinforces the map's validity as a tool for identifying flood-prone areas and provides a robust basis for future disaster mitigation and risk management planning.

Table 4. Comparison of vulnerable status and historical data on flood events in West Jakarta per sub-district from 2016 to 2023

Subdistrict	**Vulnerable Status**	**Frequency**								**Total**
		2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	
Cengkareng	Slightly Vulnerable	10	12	9	12	36	1	6	7	93
Grogol Petamburan	Not Vulnerable	3	4	2	4	14	1	0	1	29
Kalideres	Not Vulnerable	4	4	5	7	21	3	2	4	50
Kebon Jeruk	Slightly Vulnerable	8	10	1	8	50	14	4	16	111
Kembangan	Highly Vulnerable	10	11	2	7	35	6	5	7	83
Palmerah	Not Vulnerable	0	1	1	4	16	0	0	1	23
Tamansari	Not Vulnerable	2	1	0	0	3	6	0	0	12
Tambora	Not Vulnerable	0	0	0	1	2	0	0	0	3

4. Conclusion

The results of this study indicate that the spatial distribution of flood vulnerability in West Jakarta is predominantly classified as "Not Vulnerable," accounting for 39.62% of the total area (48.76 km²), concentrated in the districts of Grogol Petamburan, Kalideres, Palmerah, Tamansari, and Tambora. The second largest category is "Slightly Vulnerable," representing 36.30% of the total area (44.68 km²), primarily located in Cengkareng and Kebon Jeruk, while Kembangan emerges as the only district categorized as "Highly Vulnerable." Validation using historical flood event data from 2016 to 2023 demonstrates a strong positive correlation between the vulnerability map and observed flood occurrences. These findings confirm that the application of multi-criteria analysis, incorporating six parameters—land cover, rainfall, drainage density, slope, land subsidence, and sea level rise—provides an accurate and robust framework for assessing flood vulnerability. Consequently, the study underscores the methodological reliability of this approach while offering a valuable basis for flood risk management and urban planning in West Jakarta.

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