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IDENTIFICATION OF FLOOD-PRONE AREAS IN THE LOWER CILIWUNG WATERSHED BASED ON GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

Given the geographical reality of, a significant contributor to the city's recurrent flooding is the inherent presence of rivers within the region, including the Ciliwung River. This study aims to map areas vulnerable to flooding in the Ciliwung Hilir Watershed. The flood-prone area map produced from Composite Mapping Analysis and overlay through a Geographic Information System’s based on parameters such as soil type, land elevation, slope gradient, land use, rainfall, and river density. From the processed data, the flood-prone areas in the Ciliwung Hilir Watershed are classified into three levels of vulnerability: low 296.83 Ha (3.13%), moderate 2,610.03 Ha (27.5%), and high 6,585.21 Ha (69.37%). The map has a very high accuracy of 88.8%, based on validation data from flood occurrences in DKI Jakarta from 2010 to 2020. The generated flood vulnerability map will provide predictive insights, supporting the implementation of mitigation strategies designed to minimize potential adverse impacts.

A. INTRODUCTION

Indonesia experiences high rainfall with variable weather conditions and climatic changes. This situation makes Indonesia susceptible to hydrometeorological disasters, including floods (Setiawan et al., 2021). Floods exceeding normal water levels can cause flooding from river overflow onto lower land areas adjacent to rivers (Cabrera and Lee, 2020). In general, floods in Indonesia are caused by high rainfall causing in the river drainage system, natural tributaries and artificial canal systems being unable to accommodate the accumulation of rainwater and overflowing, causing flooding (Islam et al., 2016; Rakuasa et al., 2022). Apart from that, development that continues to be carried out without paying attention to environmental conservation can also be the cause of flooding (Sulaiman et al., 2020; Sholihah et al., 2020).

According to Musfida et al. (2021), flood issues have increased in intensity, frequency, and spatial distribution, reaching up to 40% compared to other natural events over a one-year period. Climate change projections show that the frequency and magnitude of floods will increase in many parts of the world over the next few decades (Ishtiaque et al., 2022). This aligns with disaster data in Indonesia showing that floods were the

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most frequent occurrence in 2021, with 1,794 incidents occurring across various regions due to diverse geomorphological, hydrological, and meteorological conditions (National Disaster Mitigation Agency, 2022).

Flooding occurs almost every year during the monsoon season in numerous major cities across Indonesia, including Jakarta. The recorded frequency of flooding in 2021 revealed 22 instances, with Southern Jakarta experiencing seven episodes, Eastern Jakarta nine episodes, Western Jakarta five episodes, and Northern Jakarta one episode (Statistics Center of DKI Jakarta Province, 2022). Additionally, other factors such as the passage of several principal rivers through Jakarta contribute to the likelihood of flooding, particularly the Ciliwung River.

The Ciliwung River, which possesses a sufficiently high water discharge, particularly during the rainy season, results in a lack of water absorpp/tion into the soil, thereby generating surface runoff that may overflow (Ariyani, 2017). The flooding issues attributed to the Ciliwung River, according to data from FORDA (2016), contribute to 24% of the total flooding incidents.

The impact of floods is felt socially and economically because they cause loss of life, damage to facilities and infrastructure and can even cause economic inflation (Regar et al., 2020; Ginting, 2020), so flood disaster mitigation efforts are very necessary to minimize the impacts that occur (Monger et al., 2022). The densely populated areas are vulnerable to flooding, and the impacts will be more severe than in other regions (Bajracharya et al., 2021). Therefore, the risk of flooding in the Lower Ciliwung watershed must be comprehensively assessed to generate reliable data for effective mitigation strategies. This is particularly important as the watershed functions as the smallest administrative unit in water resource management, including flood overflow control (Amri et al., 2016).

Although flood vulnerability mapping in the Ciliwung watershed has been explored in previous studies, most have concentrated on upstream or broader watershed regions, often lacking detailed spatial analysis and empirical validation for the lower basin. For instance, Pramono (2016) investigated the spatial distribution of groundwater infiltration using weighted multi-parameter analysis, but did not explicitly classify flood-prone areas nor validate findings with historical flood events.

Similarly, Tiyas and Sutjiningsih (2018) simulated flood hydrographs in the middle to lower Ciliwung sub-watershed using HEC-GeoHMS, emphasizing discharge prediction rather than spatial vulnerability mapping. These approaches, while valuable, do not provide a comprehensive spatial classification of flood risk areas that can directly inform mitigation planning. Therefore, this study aims to fill this gap by identifying and validating flood-prone zones in the lower Ciliwung watershed using a Composite Mapping Analysis (CMA) approach based on six key parameters, and by verifying the output against actual flood occurrences from 2010 to 2020. These methodological gaps highlight the absence of a spatially detailed, empirically validated flood vulnerability map specifically for the Lower Ciliwung watershed.

The application of Geographic Information Systems (GIS) plays a vital role in identifying and mapping flood-prone areas, thereby supporting spatially informed disaster management strategies (Tomaszewski, 2015). GIS enables the analysis of key factors contributing to flood vulnerability and facilitates the generation of spatial maps that illustrate the extent and distribution of flood risk in the Lower Ciliwung watershed through the overlay of multiple flood-related parameters. These maps are essential for developing early warning systems and guiding mitigation efforts. The outcomes produced can also be utilized by local communities and government authorities in flood disaster management.

B. METHOD

The lower Ciliwung watershed serves as a sub-watershed of the Ciliwung River, located in the northern part of the Ciliwung watershed and situated in DKI Jakarta, covering an area of 9,492.07 hectares. Overall, the lower Ciliwung watershed is further divided into three sub-watersheds: Ciliwung Hilir, Kali Baru 1, and Kali Condet. Administratively, the lower Ciliwung watershed falls within the DKI Jakarta region, which is subdivided into five municipalities encompassing 20 districts. This study employs a quantitative approach to interpret the levels of flood vulnerability in the lower Ciliwung watershed. The quantitative methodology involves examining the impact of each flood parameter to establish classifications for areas susceptible to flooding within the lower Ciliwung watershed. The data collected comprises secondary data, including spatial data in both raster and vector formats, as detailed in Table 1.

The collected secondary data will be analyzed using scoring and overlay techniques to produce a flood vulnerability map for the lower Ciliwung watershed. Mapping flood vulnerability requires scores and weights for each parameter along with their respective criterion classes (Sitorus et al., 2021).

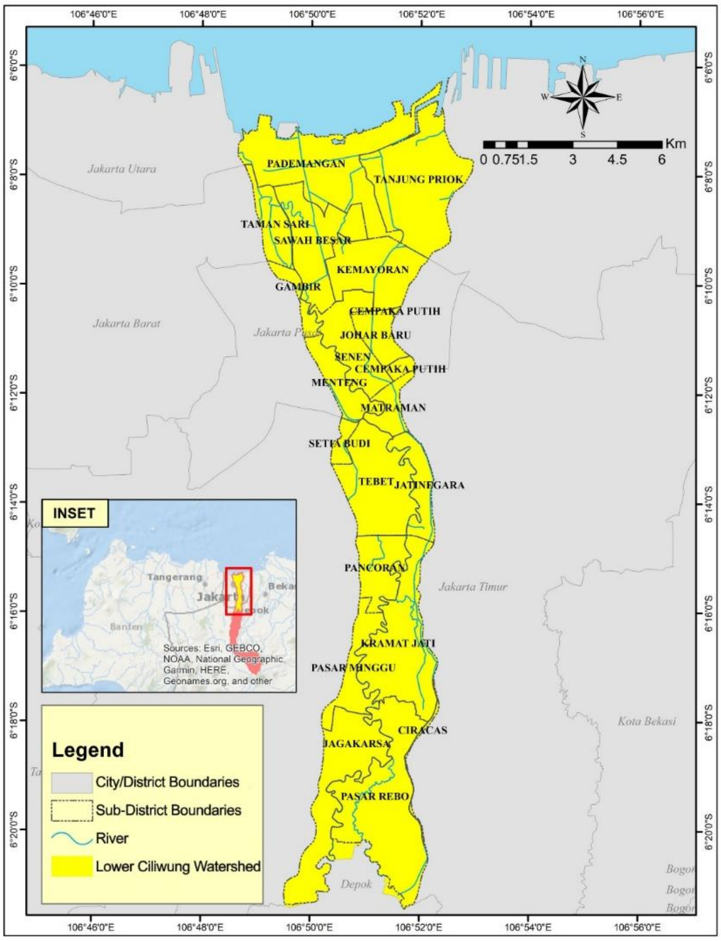

Figure 1. Location Map of the Lower Ciliwung Watershed
(Source: author, 2025)

The assignment of scores and weights is conducted using the CMA method. The scores and weights generated are based on the frequency of flooding events occurring at the locations, utilizing various parameters to be applied (Haryani et al., 2012). Mathematically, the CMA model for mapping flood vulnerability employs the following equation.

$$\text{TRB} = \sum_{i=1}^{n}(Wi.Xi)\text{..............}(1)$$

Information:

TRB : Flood Prone Level

Wi : Weight of parameters that cause flooding

Xi : Flood parameter criteria score

i and n : Number of parameters

The Wi and Xi equations can be formulated as follows.

$$\text{Wi} = \frac{Mi}{\sum Mi}\text{......................}(2)$$

$$\text{Xi} = \left(\frac{Oi}{Ei}\right).\frac{100}{\sum(\frac{Oi}{Ei})}\text{..............}(3)$$

Information:

Mi : Average area of observations

Oi : Number of observations of flood events

Ei : Expected number of flood events

Subsequently, interval values are calculated, and vulnerability classes are established. The classification of vulnerability levels is divided into three categories using the equation proposed by Setiawan et al. (2021) as follows.

$$I = \frac{R}{k} \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Information:

I : Interval width

R : Range of highest data values minus lowest data

k : Number of class intervals

Table 1. Secondary Data Collection

Objective	Data Type	Source	Method	Output
Watershed Boundaries	Shapefile	Ministry of Environment and Forestry	-	Research Location Map
Soil Type	Shapefile	FAO Digital Soil Map of the World	-	Soil Type Map
Land Height	TIFF	National DEM	-	Land Elevation Map
Slope	TIFF	National DEM	-	Slope Map
Land Use	Shapefile	Geospatial Information Agency	-	Land Use Map
Rainfall	CHIRPS	Climate Hazards Center	Inverse Distance Weighting	Rainfall Map
Drainage	Shapefile	Geospatial Information Agency	Spatial Analysis	River Density Map

(Source: author, 2025)

Subsequently, validation can be conducted to assess the accuracy of the flood vulnerability map created in relation to actual events observed in the field (Gunadi et al., 2015). This validation is performed by overlaying data or maps of flood disaster occurrences from 2010 to 2020, obtained from the Regional Disaster Management Agency (BPBD) of DKI Jakarta, with the generated flood vulnerability map.

C. RESULT AND DISCUSSION

C.1. RESULT

a) Soil Type

Soil type is related to the infiltration mechanisms, specifically when rainwater is absorbed into the soil due to capillary forces (lateral water flow) and gravity (vertical flow). Once the upper soil layer becomes saturated, excess water will be absorbed deeper into the soil due to gravitational forces or percolation mechanisms.

Based on the soil type parameter, the lower Ciliwung watershed is characterized by two dominant soil types: Nitosol and Fluvisol. Nitosol predominantly occupies the central to southern parts of the watershed. This soil type is generally associated with relatively low water infiltration capacity, which may contribute to increased surface runoff. In contrast, Fluvisol is known for its favorable drainage properties and high nutrient content. It is typically found in flat topographical areas that are periodically subject to flooding, including certain sections of the lower Ciliwung watershed.

Results derived from the Composite Mapping Analysis (CMA) indicate that the highest flood potential is associated with the Nitosol soil type, which has recorded a total of 216 flood events and a flood potential score of 0.44. However, spatial comparison reveals that the Fluvisol type yields a higher composite score of 0.56, suggesting a greater overall susceptibility when multiple spatial factors are considered.

b) Land Height

The elevation of the land significantly influences the occurrence of flooding. This is attributed to the characteristics of water, which flows in accordance with gravitational forces, moving from higher areas to lower ones. Consequently, regions situated at lower elevations are highly susceptible to flooding (Setiawan et al., 2021).

The elevation parameter is classified into five categories: <10, 10–50, 50–100, 100–200, and >200 meters above sea level (masl). The largest area falls within the 10–50 masl range, covering approximately 4,587.37 hectares, and is generally located in the central region of the Lower Ciliwung watershed. In contrast, the smallest area is found in the 50–100 masl category, with a total of 739.14 hectares. Further analysis reveals that the highest flood potential occurs in areas situated below 10 masl, with a maximum flood potential score of 0.5 and a total area of 4,165.56 hectares. These results are consistent with the theoretical assumption that lower elevation zones are more susceptible to flooding compared to higher elevation classes.

c) Slope

According to Kusumo et al. (2016), slope gradient is related to the direction, velocity, and concentration of rainfall. A flatter slope results in a slower runoff, which increases the potential for the formation of standing water or significant flooding. Slope gradients in the Lower Ciliwung watershed are classified into five categories: 0–2%, 2–5%, 5–15%, 15–40%, and >40%. The watershed is predominantly composed of slopes with gradients ranging from 5–15%, covering an area of 5,321.31 hectares, which are categorized as relatively gentle slopes.

The analysis indicates that the 0–2% slope class exhibits the highest flood potential score, recorded at 0.34. This is followed by the 2–5% and 5–15% slope classes, each with a score of 0.26. The lowest score is found in the 15–40% slope class, with a value of 0.14.

d) Land Use

Land use contributes to the increase in runoff or flooding (Nurrochman et al., 2018). Areas dominated by vegetation can facilitate the infiltration of rainfall and provide a longer travel time for water to reach rivers, thereby resulting in a lower incidence of flooding compared to areas devoid of vegetation (Darmawan et al., 2017).

Land use within the Lower Ciliwung watershed is categorized into nine classes: lake, building/industry, plantation, settlement, rice field, shrubs, river, vacant land, and moorland/field. The area is predominantly covered by settlements, occupying approximately 6,694.58 hectares. This extensive residential coverage suggests a high potential for flooding in the region. The analytical results indicate that the settlement class recorded the highest flood potential score, at 0.40, and accounted for a total of 351 flood events. Flood-prone areas were also identified in industrial which scored 0.27, followed by plantation areas with a score of 0.06, and vacant land with a score of 0.12.

e) Rainfall

Precipitation is a dynamic factor influencing flood occurrences in a given area. Increased rainfall intensity may exceed the capacity of rivers to contain the water, leading to surface runoff that inundates surrounding regions (Nugroho, 2002).

The rainfall parameter in the Lower Ciliwung watershed is classified into five categories: <1,500 mm, 1,501–2,000 mm, 2,001–2,500 mm, 2,501–3,000 mm, and >3,000 mm per year. Generally, the watershed experiences moderate to humid precipitation, with annual averages ranging from 2,001 to 2,500 mm. The southern region receives higher rainfall, averaging between 2,501 and 3,000 mm per year, which falls under the high rainfall category. According to the analysis results, the 2,001–2,500 mm category was assigned a score of 0.36. The highest score, 0.49, was recorded in the 1,501–2,000 mm category, while the 2,501–3,000 mm category received a lower score of 0.14.

f) River Density

River density is an index value that reflects the quantity of tributaries within a watershed. As the consistency of the drainage area increases, the velocity of water flow also rises. Areas with high river density will generate greater volume in a shorter duration (Matondang, 2013; Darmawan et al., 2017). Conversely, a lower drainage density indicates a deteriorating system, which may lead to an increased incidence of flooding (Utama et al., 2016).

The analysis of the data yielded reveals that the length of the Lower Ciliwung watershed's main stream is approximately 123.748 kilometers, whereas its total area measures about 9,492.07 square kilometers. According to Lynsley’s classification (1975), these findings suggest that the Ciliwung Hilir watershed possesses low drainage density, leading to instances of ponding and potentially causing floods.

g) Determination of Flood Parameter Weights

The results obtained from the calculations of the observed values for all flood vulnerability parameters are utilized to compute the weights of each indicator contributing to flooding. The weights derived from the calculations using the CMA method are presented in Table 2.

The calculations obtained using the CMA model indicate that the slope gradient parameter carries the highest weight, signifying a strong correlation with occurrence of flooding in the Lower Ciliwung watershed, with a weight value of 0.27. This is attributed to the flood disaster occurrences from 2010 to 2020, during which the affected areas exhibited gradients ranging from flat to undulating. Other parameters that present significant values include land use and precipitation, with weights of 0.20 and 0.18, respectively.

Table 2. Flood Parameter Weight Values

Parameters	Flood Observation	Weight of Parameters
Soil Type	0.085	0.13
Land Height	0.103	0.16
Slope	0.173	0.27
Land Use	0.089	0.2
Rainfall	0.119	0.18
River Density	0.041	0.06

(Source: author, 2025)

Each type of land use demonstrates varying responses in terms of water retention and absorption of rainfall on the surface. The volume of inundation and the time required for receding are common occurrences during flooding events (Kodoatie, 2021). Furthermore, when precipitation intensity is high, its impact on flooding also increases (Osei et al., 2021).

h) Flood Vulnerability

The flood vulnerability analysis yielded three classes of risk levels: low, moderate, and high. The calculations with weighting and scoring resulted in a range of vulnerability values from 0.2 to 0.44, with intervals of 0.08.

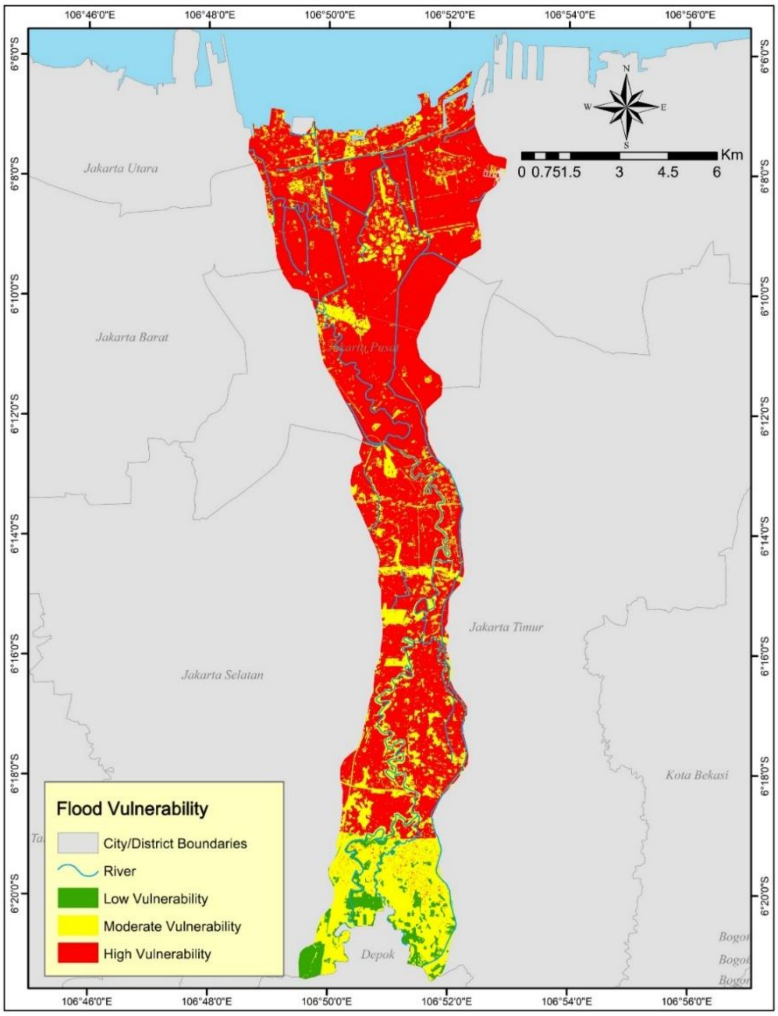

Figure 2. Flood Hazard Map of the Lower Ciliwung Watershed
(Source: author, 2025)

The flood vulnerability analysis identified three classes of risk: low, moderate, and high. Areas classified as having high vulnerability constitute the largest portion, encompassing 69.37% of the total area, while regions with low vulnerability represent the smallest portion, accounting for 3.13% of the entire Ciliwung Hilir watershed. Meanwhile, areas with moderate vulnerability cover 27.5% of the overall watershed.

Table 3. Flood Vulnerability Class of the Lower Ciliwung Watershed

No	Level of Vulnerability	Area (Ha)	Area (%)
1	Low (0.2-0.28)	296.83	3.13
2	Moderate (0.28-0.36)	2,610.03	27.5
3	High (0.36-0.44)	6,585.21	69.37
Total		9,492.07	100

(Source: author, 2025)

Figure 2 illustrates that regions with high flood vulnerability are located in the northern part, extending along the Ciliwung River to the boundary with the Java Sea. Conversely, areas with low vulnerability are found in the southern part of the Ciliwung Hilir watershed, encompassing two sub-districts: Jagakarsa (South Jakarta) and Pasar Rebo (East Jakarta).

i) Validation

Validation was conducted to assess the accuracy of the flood vulnerability map developed in relation to the actual conditions at the site (Gunadi et al., 2015). Therefore, to ascertain the validity of the flood vulnerability findings obtained through the CMA method, a validation test was performed. In this study, the validation involved comparing the flood vulnerability map generated by the CMA method with the flood occurrence map from 2010 to 2020, obtained from the Regional Disaster Management Agency (BPBD) of DKI Jakarta.

The distribution results of the flood occurrence map reveal 393 incident points utilized for validation testing. Furthermore, the low vulnerability level has 2 flood incident points, the moderate vulnerability level has 42 flood incident points, and the high vulnerability level contains 349 flood incident points. The percentage of conformity in the distribution of flood incident points is assumed to be predominantly located within the high flood vulnerability level, as determined through calculations, yielding an accuracy of 89%.

The results from the validation calculations in this study indicate a correspondence between the actual flood incident locations, which are predominantly situated in areas of high vulnerability, thereby elucidating a correlation between flood occurrences and the generated vulnerability map. Furthermore, the relatively high accuracy observed in the map suggests that regions classified as having high flood vulnerability within the Ciliwung Hilir watershed have a significant likelihood or potential for experiencing future flood disasters, similar to past flooding phenomena.

C.2. DISCUSSION

In the study, the resulting level of flood vulnerability is similar to research by Rakuasa et al. (2023), where areas classified as having high vulnerability are located in settlements dispersed along coastal regions and adjacent to river flows, characterized by flat topography. However, the results of weighting using the CMA method are different, where the land use parameter has the highest weight value, followed by the land height parameter with a significant weight value. Research by Teng et al. (2017) said that land use is also an important parameter for mapping flood vulnerability.

Furthermore, research analyzing flood-prone areas used the same method, namely CMA in Padang City by Darmawan et al. (2023), produced similar results where in areas with high rainfall, flat slopes, land cover dominated by residential areas, indicating that vegetation is very sparse, resulting in these areas being highly vulnerable to flood disasters. The volume of water increases in each unit of land obtained based on the flood vulnerability value (Kusomo and Nursari, 2016), high rainfall collects in places with a flat slope, then the water cannot be absorbed by the plains because the soil type has low porosity and the vegetation is less dense so the water will pool when there is heavy rain (Darmawan et al., 2023).

D. CONCLUSION

The analysis of flood vulnerability in the Lower Ciliwung watershed has identified three classes of risk, with high vulnerability dominating an area of 6,585.21 hectares. Meanwhile, regions classified as having low vulnerability are located in the southern part of the Ciliwung Hilir watershed, covering an area of 296.83 hectares, which includes two sub-districts: Jagakarsa (South Jakarta) and Pasar Rebo (East Jakarta). Based on validation tests, the accuracy of the flood vulnerability map generated using the CMA method is determined to be 89%.

The findings indicate that the primary causes of flooding in the Lower Ciliwung Hilir watershed are slopes ranging from flat to undulating, exacerbated by land use predominantly characterized by residential areas and relatively high rainfall. These factors contribute to a heightened level of flood vulnerability, particularly in areas adjacent to river flows.

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