A decade of rainfall, one risk map: GIS-based flood susceptibility mapping in a rapidly urbanizing coastal regency

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Abstract
Flooding has become a major hydrometeorological hazard in rapidly developing urban areas, including Tangerang Regency, Banten Province, Indonesia. Increasing rainfall over recent years has intensified flood occurrences, highlighting the need for spatially informed flood-risk assessment. The study analyzed ten years (2015–2024) of rainfall observations obtained from the Budiarto Meteorological Station of the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG), complemented by Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) satellite rainfall data for GIS-based spatial analysis. Statistical analysis was applied to evaluate rainfall patterns and temporal variability, while GIS-based spatial analysis was employed to delineate flood-prone zones. The results indicate an increasing trend in rainfall during the observation period, with peak rainfall occurring in February and March and average monthly rainfall ranging from 70.86 to 249.90 mm. Spatial analysis identified Kresek, Gunung Kaler, Mekar Baru, Kronjo, Kemiri, Mauk, Sukadiri, Pakuhaji, Teluknaga, and Kosambi as areas with high flood susceptibility. Overall, approximately 34.48% of the study area was classified as as a zone with a high level of flood susceptibility. The integration of long-term rainfall analysis with GIS-based flood mapping provides a robust spatial framework for understanding flood susceptibility in Tangerang Regency. These findings provide a GIS-based framework that can support flood-risk assessment, disaster mitigation planning, and sustainable land-use management in flood-prone regions.

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1. Introduction

Flooding is one of the most destructive hydrometeorological disasters worldwide and has become increasingly frequent and severe under the influence of climate change. According to the Intergovernmental Panel on Climate Change (2023), recent climate variability has intensified extreme rainfall events, making floods more frequent in rapidly urbanizing regions where natural hydrological processes have been substantially altered. Extreme precipitation is recognized as one of the principal triggers of flooding because it increases surface runoff, exceeds drainage capacity, and accelerates river overflow, particularly in densely populated areas (Fura et al., 2020). In Indonesia, recurrent flood events have become an increasingly serious environmental challenge due to the combined effects of climate change, rapid urban expansion, and land-use conversion. Beyond causing substantial economic losses, flooding disrupts transportation networks, damages public infrastructure, degrades environmental quality, and threatens public health through water contamination and sanitation problems (Ruhiat, 2022). This condition highlights the need for a more comprehensive approach to environmental management in order to mitigate disaster risks (Fadhlina Mohd Anafi et al., 2023). The growing frequency of flood events serves as a warning signal that the need to plan and implement effective flood risk management systems is becoming increasingly urgent (Zevri, 2022).

Among rapidly developing regions in Indonesia, Tangerang Regency represents one of the most dynamic peri-urban areas within the Jakarta Metropolitan Region. Accelerated urban growth, expansion of residential and industrial areas, and the conversion of permeable land into impervious surfaces have substantially modified local hydrological responses. At the same time, increasing rainfall intensity has amplified flood occurrence in several parts of the regency despite the continuous development of drainage infrastructure (Wartalska et al., 2025). As a strategic economic corridor supporting the Jakarta metropolitan area, flood events in Tangerang Regency affect not only local communities but also industrial activities, transportation systems, and regional economic productivity. Previous studies have demonstrated that flood occurrence in rapidly urbanizing environments is controlled by the interaction of multiple factors, including rainfall characteristics, land-use change, topography, drainage conditions, and watershed characteristics (Murali & Srinivasan, 2025). Therefore,

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understanding the spatial distribution of rainfall and its relationship with flood-prone areas is becoming increasingly important for regional planning and climate adaptation.

Geographic Information Systems (GIS) have been widely recognized as an effective spatial analysis tool for flood susceptibility assessment because they enable the integration of hydrological, meteorological, topographical, and land-use information within a single analytical framework (Costache et al., 2022). Recent developments in GIS-based flood mapping have significantly improved the identification of vulnerable areas and supported evidence-based disaster mitigation planning (Husein et al., 2025). In addition to GIS, the availability of satellite-derived precipitation datasets has substantially enhanced rainfall analysis by providing continuous spatial coverage that complements conventional rain-gauge observations. Among the available satellite rainfall products, the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset has been extensively applied for hydrological and climatological studies because it provides gauge-adjusted rainfall estimates with relatively high spatial resolution and a long historical record (Funk et al., 2015). Furthermore, several validation studies have demonstrated that CHIRPS performs reliably in representing rainfall variability across tropical regions and can effectively complement ground-based observations for hydrological applications (Beck et al., 2019). The integration of long-term rainfall observations with GIS-based spatial analysis therefore offers considerable potential for improving flood susceptibility assessment and identifying priority areas for mitigation (Arifin et al., 2023).

Despite these advances, several important research gaps remain. Existing flood studies in Tangerang Regency have primarily focused on watershed-scale assessments or GIS-based flood vulnerability mapping without explicitly integrating long-term rainfall variability into regional flood susceptibility analysis (Ikhwali et al., 2022). Moreover, many flood hazard assessments continue to emphasize drainage systems or static environmental variables while overlooking temporal rainfall dynamics under changing hydroclimatic conditions (Sandiwarno, 2024). In addition, previous GIS-based studies frequently rely on either ground-based rainfall observations or satellite precipitation products independently, which limits their ability to simultaneously capture temporal consistency and spatial heterogeneity of rainfall distribution. Although CHIRPS has been widely utilized for rainfall monitoring, its integration with long-term rainfall observations from the Indonesian Meteorological, Climatological, and Geophysical Agency (BMKG) within a GIS framework has rarely been implemented for flood susceptibility assessment at the regency scale in Tangerang. Addressing these limitations is expected to improve the spatial representation of rainfall characteristics and provide more reliable information for regional flood-risk assessment and sustainable land-use planning (Sunarti et al., 2024)

Therefore, this study aims to integrate ten years (2015–2024) of BMKG rainfall observations with CHIRPS satellite precipitation data within a Geographic Information Systems framework to analyze temporal rainfall variability and produce a spatially explicit flood susceptibility map for Tangerang Regency that can support evidence-based disaster mitigation, flood-risk assessment, and sustainable regional spatial planning.

2. Method

Tangerang Regency is one of the regencies located in Banten Province, with a land area of 1.027.76 km^2. To the east, it borders Tangerang City and the Special Capital Region of Jakarta (DKI Jakarta). To the west, it borders Serang Regency. To the south, it is adjacent to South Tangerang City and Bogor Regency, while to the north it borders the Java Sea. Tangerang Regency consists of 29 administrative districts. The region is characterized by diverse topographic conditions, ranging from low-lying coastal plains in the northern part to relatively higher terrain in the south. Rapid urban expansion combined with seasonal monsoonal rainfall has increased flood susceptibility, particularly in densely populated northern districts. However, despite being designed with modern drainage systems, these areas are still unable to fully mitigate flooding caused by extreme rainfall (Wartalska et al., 2025).

Tangerang Regency, as one of the buffer regions of the Jakarta metropolitan area, is experiencing rapid urbanization pressure, which has significantly influenced its hydrological dynamics. In recent years, several areas within Tangerang Regency have faced challenges related to climate change, particularly its impact on rainfall patterns and flood potential. Increased rainfall intensity has led to a higher frequency and severity of flood events. This escalation in flooding is driven by three main factors: climate change, land-use change, and deforestation (Murali & Srinivasan, 2025) Consequently, Tangerang Regency was selected as the study area because it frequently experiences hydrometeorological flooding associated with intense rainfall events.

The overall research framework consisted of four stages: (1) rainfall data collection, (2) statistical rainfall analysis, (3) rainfall frequency and intensity analysis using the Gumbel distribution and Mononobe equation, and (4) GIS-based spatial flood hazard mapping through the integration of rainfall and topographic data. This study was conducted in Tangerang Regency. Secondary rainfall observations were collected from the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG), specifically from the Budiarto Meteorological Station, covering the period from January 2015 to December 2024. To improve the spatial representation of rainfall, satellite-derived precipitation data were obtained from the Climate Hazards Group InfraRed

Precipitation with Station Data (CHIRPS), (https://data.chc.ucsb.edu/products/CHIRPS-2.0) for the same period (2015–2024).

2.1. Temporal Distribution

The temporal distribution of rainfall was analyzed using the following Equation (1).

$$CH_b = \sum_{i=1}^{n} \frac{CH_i}{n} \quad (1)$$

Where,
CH_b : Average monthly/annual rainfall (mm) (mm)
CH_i : Rainfall in a particular month/year in one-unit i and n is the number of years observed.

2.2. Frequency Distribution

The Gumbel distribution was selected because it is one of the most widely used probability distributions for modeling annual maximum rainfall and estimating design rainfall associated with extreme hydrological events. Compared with the Normal and Log-Normal distributions, the Gumbel distribution provides a better representation of the upper tail of extreme rainfall events and has been extensively applied in flood frequency analysis where annual maximum rainfall data are available (Papalexiou & Koutsoyiannis, 2013). Although the Generalized Extreme Value (GEV) distribution offers greater flexibility through an additional shape parameter, using the Gumbel distribution to analyze rainfall frequency in order to identify extreme rainfall and estimate the return period. The cumulative distribution function of the Gumbel distribution is expressed as (Equation 2):

$$p = e^{-(\frac{x-\mu}{\beta})} \quad (2)$$

Where,
x : rainfall,
μ : parameter location,
β : parameter scale

2.3. Rainfall Intensity

The Mononobe equation was employed to convert daily rainfall into shorter-duration rainfall intensities because sub-daily rainfall observations were not consistently available throughout the study period. Compared with empirical relationships such as the Talbot and Sherman equations, which require local intensity–duration–frequency (IDF) calibration, the Mononobe equation has been widely adopted in Indonesia and other tropical regions due to its simplicity and satisfactory performance under limited rainfall data conditions. Consequently, the Mononobe equation is considered appropriate for estimating rainfall intensity in this study. Rainfall intensity was estimated using the Mononobe empirical equation. This equation relates the maximum 24-hour rainfall to rainfall duration and has been widely applied in tropical regions due to its simplicity and satisfactory performance. The rainfall intensity is calculated using Equation (3):

$$I = \frac{R24}{24} \left(\frac{24}{t}\right)^{2/3} \quad (3)$$

Where,
R_{24}: Maximum 24-hour rainfall (mm)
t : Rainfall duration (hours)
I : Rainfall intensity (mm/hour)

The design rainfall for a specified return period was estimated using the Gumbel frequency distribution. The maximum 24-hour rainfall is calculated using Equation (4):

$$R_t = R + KS_x \quad (4)$$

R_t :Rainfall for a given time period (mm)
t : Time (hours)
R : Average rainfall

The mean annual rainfall was first determined because it is required in the Gumbel frequency analysis. The average rainfall is computed using Equation (5).

$$\bar{R} = \frac{\sum R_i}{n} \quad (5)$$

The frequency factor (K) was then determined to estimate rainfall corresponding to different return periods. The calculation follows Equation (6).

$$K = \frac{Y_t - Y_n}{S_n} \quad (6)$$

where the reduced variate Y_t is obtained from Equation (7).

$$Y_t = -L_n\left[-L_n\frac{T-1}{T}\right] \quad (7)$$

Formula description:
K : Gumbel frequency factor
Y_t : Reduced variate
S_n : Reduced standard deviasi
Y_n : Reduced mean
L_n : Logaritma Normal
n : total data

The standard deviation of the rainfall dataset was calculated to quantify the variability of annual rainfall values. The standard deviation is determined using Equation (8).

$$S_d = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \bar{X})^2}{n-1}} \quad (8)$$

Subsequently, to examine the spatial distribution of rainfall, data from the CHIRPS dataset (https://data.chc.ucsb.edu/products/CHIRPS-2.0) covering the period from 2015 to 2024 were utilized. The data and the resulting analytical maps were used to identify potential flood-prone areas in Tangerang Regency (Ruhiat et al., 2025).

2.4. Overlay GIS

Spatial analysis was performed using Geographic Information Systems (GIS) to integrate long-term rainfall data with administrative boundary layers and generate rainfall-based flood susceptibility maps for Tangerang Regency. The analysis was intentionally limited to rainfall as the primary hydrometeorological driver of flooding, while other flood-conditioning factors such as topography, land use, drainage capacity, and soil characteristics were excluded because the objective was to evaluate the spatial variability of rainfall rather than to develop a comprehensive multi-factor flood susceptibility model. Consequently, the resulting maps should be interpreted as rainfall-based flood susceptibility indicators. Administrative boundary shapefiles at the village level were obtained from Indonesia Geospatial (Anastasya & Wilantika, 2023) and overlaid with interpolated rainfall surfaces within the GIS environment. Potential sources of uncertainty include the spatial bias of satellite-derived rainfall estimates, the limited spatial representativeness of rain-gauge observations, and uncertainties associated with GIS interpolation and spatial overlay procedures. These limitations should be considered when interpreting the results and provide opportunities for future studies to incorporate additional environmental variables into flood susceptibility assessments.

3. Results and Discussion

3.1. Rainfall analysis and flood susceptibility mapping in Tangerang Regency

Observational data from the Budiarto Meteorological Station in Tangerang Regency were used to predict temporal rainfall patterns. The results of rainfall observations over a ten-year period (2015–2024) are presented in Table 1.

Table 1. Rainfall data for Tangerang Regency

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	137.5	0.00	0.00	0.00	6.2	9	0.00	0.00	0.00	5.2	225.5	93.7
2016	112.5	114.3	150.7	200.9	137.2	109.3	185.4	156.6	105.3	272.1	382.6	120
2017	242.8	247.3	191.8	277.7	187.9	158.3	252.8	65.6	198.5	202.7	134	160.1
2018	123.1	231.8	283.7	300.6	173.9	148	0.00	7	25.2	63.3	244	239
2019	279.9	279.3	129.2	127.9	337.9	72.8	20.2	37	0.00	9.6	93.4	195.7
2020	241.8	635.2	399.7	120	136.6	76.1	56.1	112.3	230.8	358.8	272.6	197.6
2021	326.4	548	104.4	203.3	279.1	236.8	98.1	251.4	259.8	278.1	116.9	328.5
2022	157.2	240.6	361.9	131.6	179.6	278	150.8	0.00	80.2	69	55.2	62.8
2023	32.7	52	1.7	59.7	85.1	223.9	0.8	78.7	0.00	12.9	308.6	156.3

Table 1 shows substantial temporal variability in monthly rainfall during the 2015–2024 observation period, with monthly rainfall ranging from 0.00 to 635.20 mm. Peak rainfall generally occurred during February and March, coinciding with the peak of the Northwest Monsoon that dominates rainfall over western Java. This seasonal pattern is consistent with the regional climatology reported by the Indonesian Agency for Meteorology, Climatology, and Geophysics (BMKG) and previous studies conducted in western Indonesia (Mulsandi et al., 2024). Conversely, rainfall declined markedly during the dry season (July–September), reflecting the influence of the Southeast Monsoon.

Interannual rainfall variability was also evident throughout the study period. Years such as 2020 and 2021 exhibited substantially higher rainfall totals than other years, indicating stronger hydrometeorological conditions favorable for flood occurrence. This variability may be associated with large-scale climate oscillations, including the El Nino–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD), which are known to influence rainfall distribution across Indonesia (Mulsandi et al., 2024). Although these climate drivers were not explicitly analyzed in this study, they provide a plausible explanation for the observed temporal fluctuations in rainfall. From a hydrological perspective, prolonged periods of high rainfall increase soil saturation and surface runoff, thereby elevating flood susceptibility, particularly in low-lying urban areas with limited drainage capacity. Nevertheless, rainfall alone does not fully explain flood occurrence because land use, drainage infrastructure, topography, and soil characteristics also influence flood generation. The results of this analysis are presented in Figure 1.

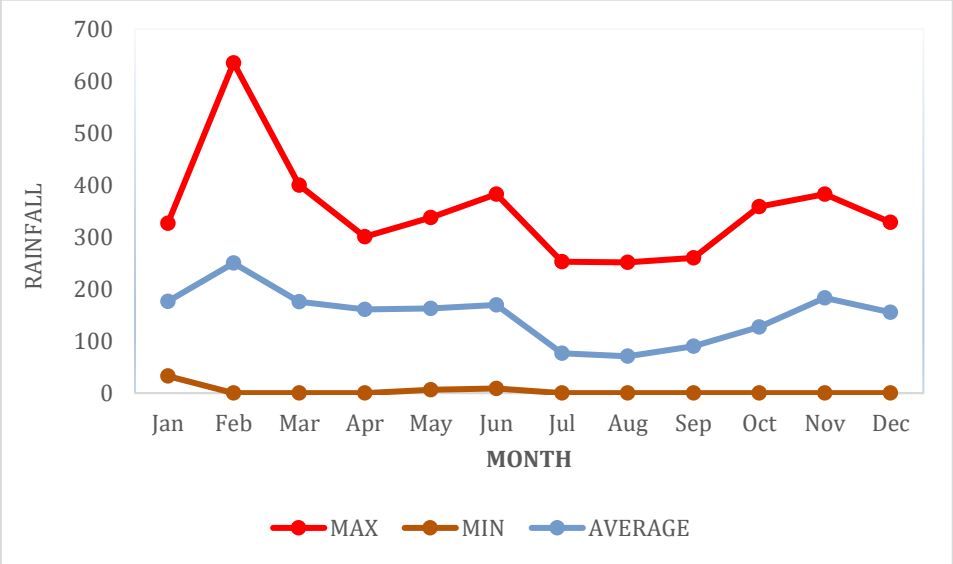

Figure 1. Graph of monthly rainfall for the last 10 years in Tangerang Regency

Figure 1 illustrates the temporal variability of monthly rainfall in Tangerang Regency during the 2015–2024 observation period. The average monthly rainfall ranged from 70.86 mm in August to 249.90 mm in February, indicating pronounced seasonal variability. Maximum monthly rainfall reached approximately 635.20 mm in February, whereas minimum rainfall approached 0 mm during several months of the dry season. This pattern reflects the monsoonal climate of western Java, characterized by a wet season from November to March and a dry season from June to September . The highest rainfall observed in February and March corresponds to the peak of the Northwest Monsoon, when moisture transport from the equatorial Indian Ocean and surrounding seas intensifies precipitation across western Indonesia. Conversely, the substantial decline in rainfall between July and September is associated with the Southeast Monsoon, which transports relatively dry air masses from the Australian continent. Similar seasonal rainfall characteristics have been reported for western Java and other regions of Indonesia (Supari et al., 2017).

The rainfall pattern in Tangerang Regency exhibits a wave-like (fluctuating) behavior, indicating the possibility of recurrence following certain return periods. By applying the Gumbel distribution, it is possible to estimate the expected monthly rainfall in Tangerang Regency. This distribution provides rainfall projections for various return periods, such as 2, 5, and 10 years, and beyond.Furthermore, rainfall intensity is estimated using the Mononobe equation. Equation (3) is employed to calculate rainfall intensity for each return period, and the results are presented in

Table 2.

Table 2. Result of analysis of return periode and rainfall intensity

Periode	Xav	Yt	S/Sn	Yt-Yn	(S/Sn). (Yt-Yn)	Estimate (R)	Time		I=Period (year)			
							(T) Minute	(T) hours	2	5	10	15
2	376.06	0.37	131.82	-0.13	-16.97	359.09	5.00	0.08	652.51	924.00	1.103.75	1.205.16
5	376.06	1.50	131.82	1.00	132.44	508.50	10.00	0.17	411.06	582.08	695.32	759.21
10	376.06	2.25	131.82	1.76	231.36	607.42	30.00	0.50	197.62	279.84	334.27	364.99
15	376.06	2.67	131.82	2.18	287.17	663.23	60.00	1.00	124.49	176.29	210.58	229.93

Table 2 presents the design rainfall estimated using the Gumbel frequency distribution for return periods of 2, 5, 10, and 15 years. The estimated design rainfall increased from 359.09 mm for the 2-year return period to 663.23 mm for the 15-year return period, reflecting the increasing probability of more extreme rainfall events associated with longer recurrence intervals. This trend is consistent with the theoretical basis of extreme value analysis, whereby rainfall magnitude increases as the probability of exceedance decreases (Ruhiat et al., 2025).

Rainfall intensity estimated using the Mononobe equation also exhibited a strong dependence on rainfall duration. For a 10-minute duration, rainfall intensity ranged from 411.06 mmh for the 2-year return period to 759.21 mm/h for the 15-year return period. As rainfall duration increased, the corresponding rainfall intensity decreased substantially, reflecting the inverse relationship between rainfall duration and rainfall intensity that is commonly observed in intensity–duration–frequency (IDF) analyses(Costache et al., 2022).

From a hydrological perspective, the estimated high rainfall intensities during short-duration storm events indicate a greater potential for rapid surface runoff generation, particularly in highly urbanized areas where infiltration capacity is limited. Such conditions may exceed the capacity of existing drainage systems, thereby increasing the likelihood of pluvial flooding. Consequently, the design rainfall estimates derived in this study provide valuable information for hydraulic infrastructure design and flood hazard assessment in Tangerang Regency.

It should be noted, however, that these estimates are based on historical rainfall observations and assume stationarity in rainfall characteristics. Potential future changes in rainfall extremes associated with climate change were not considered in the present analysis and therefore represent an important direction for future research.

Based on Figure 2, the annual rainfall in Tangerang Regency in 2017 ranged from 1.500 to 5.000 mm per year. During this period, rainfall categories varied from low to very high. Extremely high rainfall levels (>3.000 mm per year) were observed in the districts of Solear, Jambe, Legok, and Cisauk. As shown in Figure 3, the annual rainfall in Tangerang Regency in 2019 ranged from 1.200 to 2.500 mm per year. During this year, rainfall categories varied from very low to moderate. Moderate rainfall levels (2.001–2.500 mm per year) were observed in Jambe and Cisauk districts. In Figure 4, the annual rainfall in Tangerang Regency in 2021 ranged from 1.500 to 3.500 mm per year. During this period, rainfall categories ranged from low to very high. Extremely high rainfall levels (>3.000 mm per year) occurred in Solear, Jambe, and Cisauk districts. As illustrated in Figure 5, the annual rainfall in Tangerang Regency in 2023 ranged from 1.200 to 2.500 mm per year. During this year, rainfall categories varied from very low to moderate. Moderate rainfall levels (2.001–2.500 mm per year) were observed in Solear, Jambe, Legok, Pagedangan, and Cisauk districts.

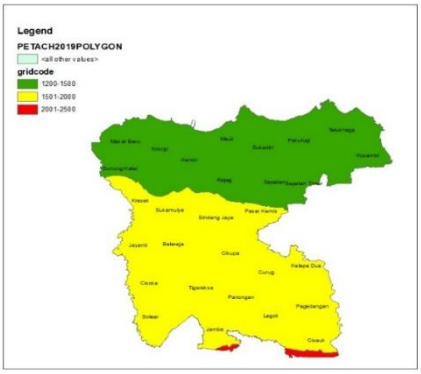

Figure 2. Rainfall areas in Tangerang Regency on 2017

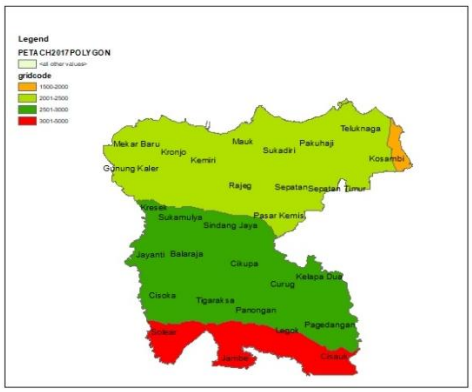

Figure 3. Rainfall areas in Tangerang Regency on 2019

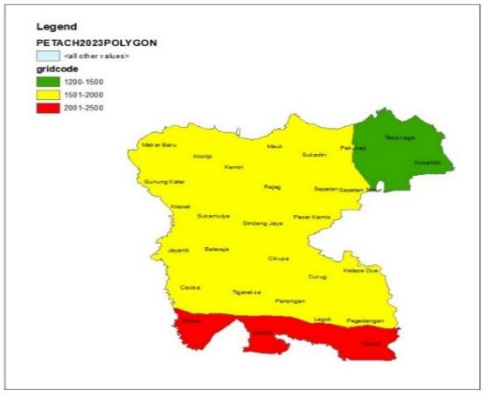

Figure 4. Rainfall areas in Tangerang Regency on 2021

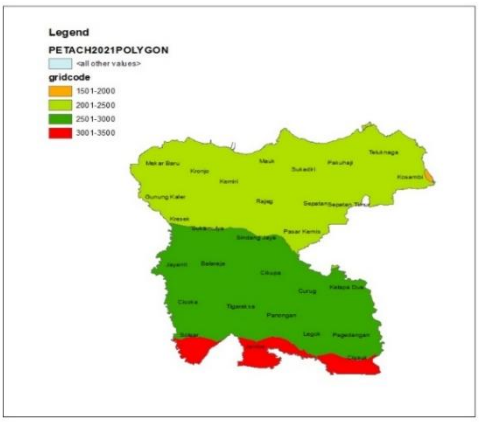

Figure 5. Rainfall areas in Tangerang Regency on 2023

Based on the rainfall data, a biennial (two-year) pattern of rainfall variability is evident in Tangerang Regency. Rainfall categories range from low to very high in the districts of Solear, Jambe, Legok, and Cisauk. Meanwhile, rainfall categories from very low to moderate occur in Solear, Jambe, Legok, Pagedangan, and Cisauk districts. Over a two-year cycle, the rainfall pattern consistently alternates as follows: low to very high, very low to moderate, low to very high, and very low to moderate.

Based on the Gumbel and Mononobe analysis results (Table 2), rainfall patterns in Tangerang Regency for a 2-year return period are predicted to range from low to very high in 2025 and from very low to moderate in 2027. Given these rainfall categories, flooding is predicted to occur in several areas. An overlay analysis was performed using the flood-prone area map from https://inarisk.bnpb.go.id. For this overlay, the flood-prone assessment relied solely on rainfall data, as the BNPB map is national in scope. The analysis of flood-prone areas utilized only monthly rainfall data from Tangerang Regency. The results of the overlay analysis between flood-prone areas and monthly rainfall in Tangerang Regency are presented in Figure 6.

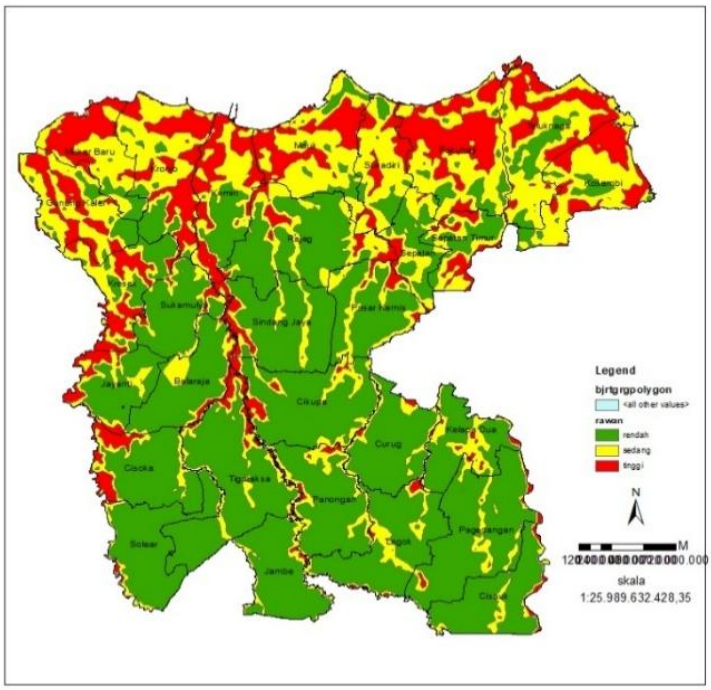

Figure 6. Potential flood areas in Tangerang Regency.

Figure 6 presents the spatial distribution of rainfall-based flood hazard in Tangerang Regency derived from GIS overlay analysis. The results indicate that approximately 1 of the 29 districts exhibit moderate to high flood hazard levels, representing nearly 34.48% of the study area. High flood susceptibility is primarily concentrated in the northern part of Tangerang Regency, including Kresek, Gunung Kaler, Mekar Baru, Kronjo, Kemiri, Mauk, Sukadiri, Pakuhaji, Teluknaga, and Kosambi, whereas the southern districts generally exhibit lower flood susceptibility. The observed spatial pattern reflects the interaction between rainfall distribution and regional topographic characteristics. Northern Tangerang is predominantly characterized by low-lying coastal plains with relatively gentle slopes, which reduce natural drainage efficiency and promote water accumulation during periods of intense rainfall. In contrast, the southern region generally has slightly higher elevations and better natural drainage conditions, contributing to lower flood susceptibility. Similar spatial flood patterns have been reported in other lowland coastal regions of Indonesia, where topography substantially influences flood inundation following heavy rainfall (Costache et al., 2022).

The spatial distribution of flood hazard is consistent with the rainfall analysis presented in the previous section, which identified February and March as the months with the highest rainfall intensity. Although rainfall acts as the primary hydrometeorological trigger, the severity and spatial extent of flooding are further influenced by local environmental conditions, including land use, drainage infrastructure, river capacity, and soil characteristics. Consequently, the flood hazard maps generated in this study should be interpreted as rainfall-based susceptibility maps rather than comprehensive flood-risk assessments. The resulting flood hazard maps provide spatial information that may support regional flood-risk assessment and assist local authorities in identifying priority areas for monitoring, infrastructure planning, and future disaster risk reduction initiatives. However, the present study does not evaluate the operational performance of flood mitigation measures or early warning systems. Therefore, additional hydrological modeling, hydraulic simulations, and validation using historical flood inundation data are required before these maps can be directly applied for operational flood forecasting or early warning purposes.

Previous studies have identified rainfall and elevation as important flood-conditioning factors (Handika et al., 2023; Ruhiat et al., 2025) In the present study, rainfall was analyzed as the primary hydrometeorological variable for rainfall-based flood hazard mapping. Compared with previous GIS-based flood mapping studies in Indonesia, which generally combine multiple environmental variables such as land use, soil type, drainage density, slope, and river proximity (Beck et al., 2019), the present study specifically emphasizes the integration of long-term rainfall observations from BMKG with CHIRPS satellite precipitation data to improve the spatial representation of rainfall variability. This approach provides a more detailed characterization of the hydrometeorological component of flood hazard at the regency level while maintaining a relatively simple and reproducible analytical framework.

Nevertheless, several limitations should be acknowledged. First, the flood hazard maps represent rainfall-based susceptibility and do not explicitly incorporate other important flood-conditioning factors, including

drainage capacity, land use and land cover change, soil properties, river geometry, or hydraulic processes. Second, uncertainties associated with satellite-derived rainfall estimates and spatial interpolation may affect the accuracy of the resulting flood hazard maps, particularly in areas exhibiting high local rainfall variability. Consequently, the generated maps should be interpreted as indicative flood hazard information rather than definitive flood-risk assessments. Future studies should integrate hydrological and hydraulic modeling together with multi-factor GIS analysis to improve prediction accuracy and operational applicability.

The principal contribution of this study lies in integrating long-term ground-based rainfall observations with CHIRPS satellite precipitation data within a GIS framework to characterize rainfall variability and flood hazard at the district scale. Unlike previous studies focusing primarily on static environmental variables, this approach incorporates temporal rainfall variability, thereby providing additional insight into the hydrometeorological drivers of flood susceptibility in Tangerang Regency.

4. Conclusion

This study demonstrated that integrating long-term rainfall observations from the Budiarto Meteorological Station with CHIRPS satellite precipitation data within a Geographic Information Systems (GIS) framework provides an effective approach for assessing rainfall variability and rainfall-based flood hazard in Tangerang Regency. The results revealed pronounced seasonal rainfall variability, with peak rainfall occurring during February and March, while GIS-based spatial analysis identified approximately 34.48% of the study area, including ten districts, as having moderate to high flood hazard. Furthermore, the Gumbel frequency analysis indicated that the estimated design rainfall increased from 359.09 mm for the 2-year return period to 663.23 mm for the 15-year return period, reflecting the increasing likelihood of extreme rainfall events. Beyond these findings, the principal scientific contribution of this study lies in integrating long-term ground-based rainfall observations with satellite-derived precipitation data to improve the spatial representation of rainfall variability for district-scale flood hazard assessment. Unlike many previous GIS-based flood mapping studies that primarily emphasize static environmental variables, this study explicitly incorporates temporal rainfall characteristics as the principal hydrometeorological component of flood hazard. This approach provides a reproducible framework for rainfall-based flood susceptibility assessment in regions where hydrological observations remain limited.

The resulting flood hazard maps provide spatial information that may support flood-risk assessment, regional spatial planning, and the prioritization of disaster risk reduction measures. However, the findings should be interpreted within the scope of rainfall-based flood hazard assessment because additional flood-conditioning factors, such as land use, drainage capacity, river hydraulics, and soil characteristics, were not incorporated. Future research should integrate hydrological and hydraulic modeling together with multi-factor GIS analysis and historical flood inundation records to improve prediction accuracy and operational applicability.From a practical perspective, the identified high-hazard districts should be prioritized for periodic drainage capacity assessment, maintenance of urban drainage networks, flood retention infrastructure, and routine monitoring during the peak rainy season (February–March). In addition, the resulting flood hazard maps can be incorporated into regional spatial planning (RTRW), land-use management, and infrastructure development to reduce future exposure of settlements and public facilities to flood hazards. These applications are expected to support evidence-based decision-making rather than replace detailed hydrological or hydraulic investigations required for engineering design.

Future research should integrate additional flood-conditioning factors, including land use and land cover dynamics, drainage system capacity, soil characteristics, river network attributes, and high-resolution topographic data. Furthermore, coupling GIS-based spatial analysis with hydrological and hydraulic modeling and validating the results using historical flood inundation records would improve the accuracy and operational applicability of flood hazard assessments in Tangerang Regency.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Data Availability

The datasets generated during and/ or analyzed during the current study are available from the corresponding author on reasonable request.

Declaration on AI Use

The authors declare that no artificial intelligence (AI) or AI-assisted tools were used in the preparation of this manuscript.

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