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Analysis of Multi-Factor Inundation Vulnerability in Palu City Using GIS-Based Weighted Overlay

Lusyana Eka Wardani[1], Nurhilal Fauziah Ramlan[2], Aisyah Protonia Tanjung[3], Maisarah[4], Qanitatul Isra Qamal[5]

[1,3,4,5]Civil Engineering Department, Universitas Malikussaleh, Lhokseumawe, Indonesia
[2]Urban and Regional Planning Department, Universitas Tadulako, Palu, Indonesia
*__Corresponding author__: lusyana@unimal.ac.id

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Abstract
Inundation recurs annually in Palu City despite its relatively low annual rainfall of 657 to 870 mm/year. This condition indicates that physical land characteristics strongly influence inundation vulnerability. This study assesses inundation vulnerability across the administrative area of Palu City using an expert-based GIS weighted overlay method. Six variables were analyzed: rainfall, soil texture, slope gradient, land use, topography, and river buffer zones. The assigned weights were rainfall 15%, soil texture 10%, slope gradient 10%, land use 25%, topography 20%, and river buffer zones 20%. Data were obtained from BPBD, BMKG, DEMNAS/BIG, SRTM/USGS, and DPUPR Palu City, then processed using ArcGIS 10.8. The final vulnerability index was classified into five classes using the equal interval method. The results show that 4.47 km² (1.13%) is very low, 138.07 km² (34.95%) low, 136.25 km² (34.49%) moderate, 103.45 km² (26.19%) high, and 12.82 km² (3.25%) very high. High and very high zones are concentrated in East Palu, South Palu, and West Palu. Mitigation priorities include river buffer control, drainage revitalization, and riparian revegetation.
Keywords: *palu city, gis, weighted overlay, land use, topography, river buffer zone*

Abstrak
Genangan terjadi berulang setiap tahun di Kota Palu meskipun curah hujan tahunannya relatif rendah, yaitu 657 hingga 870 mm/tahun. Kondisi ini menunjukkan bahwa karakteristik fisik lahan berpengaruh kuat terhadap kerawanan genangan. Penelitian ini menganalisis kerawanan genangan di wilayah administrasi Kota Palu menggunakan metode expert-based GIS weighted overlay. Enam variabel yang dianalisis meliputi curah hujan, tekstur tanah, kemiringan lereng, penggunaan lahan, topografi, dan buffer sungai. Bobot yang digunakan yaitu curah hujan 15%, tekstur tanah 10%, kemiringan lereng 10%, penggunaan lahan 25%, topografi 20%, dan buffer sungai 20%. Data bersumber dari BPBD, BMKG, DEMNAS/BIG, SRTM/USGS, dan DPUPR Kota Palu, kemudian diolah menggunakan ArcGIS 10.8. Indeks kerawanan akhir diklasifikasikan menjadi lima kelas menggunakan metode equal interval. Hasil penelitian menunjukkan bahwa 4,47 km² (1,13%) termasuk sangat rendah, 138,07 km² (34,95%) rendah, 136,25 km² (34,49%) sedang, 103,45 km² (26,19%) tinggi, dan 12,82 km² (3,25%) sangat tinggi. Zona tinggi dan sangat tinggi terkonsentrasi di Palu Timur, Palu Selatan, dan Palu Barat. Prioritas mitigasi meliputi pengendalian zona buffer sungai, revitalisasi drainase, dan revegetasi riparian.
Kata Kunci: *kota palu, sig, weighted overlay, penggunaan lahan, topografi, buffer sungai*

1. Introduction

Inundation is one of the most frequent hydrological disasters in urban areas, particularly in tropical regions characterized by high rainfall intensity and inadequate drainage systems [1], [2]. In the context of Palu City, the capital of Central Sulawesi Province, inundation is a recurring problem even though the city's average annual rainfall is relatively low, ranging from 657 to 870 mm/year [3], [4]. This indicates that factors other than rainfall especially the physical characteristics of the area play a more dominant role in triggering inundation [5]. From a management perspective, community participation is essential for effective disaster mitigation. Demonstrated that community readiness assessment is a critical step in formulating development actions, where leadership and problem-solving resources are the most influential dimensions [6].

Palu City possesses a unique geomorphological setting, situated in a narrow valley flanked by the Gawalise Mountains to the west and the Palu-Tawaeli Mountains to the east, with the Palu River flowing through the city toward Palu Bay. This configuration creates an alluvial plain in the city center that naturally functions as a water accumulation basin [3]. Following the 2018 earthquake-triggered disaster and liquefaction, reconstruction and redevelopment have proceeded rapidly, expanding impervious surfaces and reducing natural infiltration areas.

Two of the most influential physical factors topography and proximity to river bodies (river buffer zones) have not yet been comprehensively studied in an integrated manner [7]. Topography determines the direction and accumulation of surface runoff, while river buffer zones reflect the areas most vulnerable to overbank flow and riverine flooding [8], [9]. A spatial understanding of these two factors is essential to support evidence-based land-use planning for disaster mitigation [10]

Based on BPBD Palu City data for 2018–2024, several inundation points have been repeatedly recorded, particularly in lowland areas near river channels. However, no study has specifically integrated historical inundation mapping with spatial analysis of topographic factors and river buffers as a basis for disaster mitigation. This research fills that gap through a comprehensive GIS-based analysis [11], [12].

The objectives of this study are: (1) to map the spatial distribution of inundation points in Palu City based on BPBD data from 2018-2024; (2) to analyze the influence of topography and river buffer zones on inundation vulnerability; and (3) to formulate GIS-based disaster mitigation policy recommendations that can be integrated into Palu City's spatial planning.

2. Material and Methods

2.1. Study Location

This research was conducted in Palu City, Central Sulawesi Province, which has an area of 395.06 km² and comprises eight districts: West Palu, East Palu, South Palu, North Palu, Ulujadi, Tatanga, Mantikolore, and Tawaeli. Geographically, the study area lies between 119°45.443′ E – 120°2.535′ E and 0°39.065′ S – 0°56.844′ S. The analysis focuses on identifying inundation distribution and examining topographic factors and river buffer zones across the entire administrative area.

2.2. Data Types and Sources

This study uses secondary data obtained from various official agencies. **Table 1** presents the data types and sources.

Table 1. Data types and sources

Data Type	Variable	Source
Secondary	Inundation points (2018–2024)	BPBD Palu City
Secondary	Topography (DEM)	DEMNAS, BIG
Secondary	River buffer (watershed)	SRTM DEM, USGS
Secondary	Rainfall (isohyet)	BMKG Palu City
Secondary	Soil texture	RTRW shapefile, DPUPR Palu City
Secondary	Slope gradient	DEMNAS, BIG (processed)
Secondary	Land use	RTRW 2021–2041, DPUPR Palu City
Secondary	Administrative boundaries	Bappeda Palu City
Secondary	Spatial plan (RTRW)	DPUPR Palu City 2021–2041

Source : BPBD Palu City, DEMNAS/BIG, SRTM DEM/USGS, and DPUPR Palu City; compiled by the author, 2026.

2.3. Variables and Scoring

Six variables were analyzed using the weighted overlay method [9], [13]. Each variable was classified into specific classes, assigned scores based on its contribution to inundation vulnerability, and weighted proportionally [2]. Variable weights reflect their relative contribution to inundation occurrence; higher weights indicate stronger influence. Each variable was classified into five classes, each receiving a score of 1 (lowest vulnerability) to 9 (highest vulnerability) [14], adapted to local conditions in Palu City.

Table 2 summarizes the weighting rationale for each variable. Variable weights were determined using an expert-based weighted overlay approach. The weighting process was conducted through consensus among the research team and domain experts in hydrology, spatial planning, and disaster management. The assessment was supported by comparable GIS-based flood vulnerability studies [9], [13], [15], empirical inundation records from BPBD Palu City, and local physical conditions of Palu City.

Each variable was assigned a relative weight according to its influence on inundation occurrence. Land use received the highest weight because built-up and impervious surfaces strongly increase surface runoff in urban areas. Topography and river buffer zones received high weights because low elevation and proximity to river channels directly affect water accumulation and overbank flooding. Rainfall, soil texture, and slope gradient received lower weights because they act as supporting factors in the local inundation process.

The final weights were rainfall 15%, soil texture 10%, slope gradient 10%, land use 25%, topography 20%, and river buffer zone 20%. The total weight equals 100%, indicating that all variables were proportionally normalized for weighted overlay analysis. This study did not apply a formal Analytical Hierarchy Process (AHP); therefore, no pairwise comparison matrix, consistency index, or consistency ratio was calculated.

The final inundation vulnerability index was calculated using the following formula:

$$\mathbf{FVI = [(15 \times R) + (10 \times ST) + (10 \times SG) + (25 \times LU) + (20 \times T) + (20 \times RB)] / 100}$$

where FVI is the final vulnerability index, R is rainfall, ST is soil texture, SG is slope gradient, LU is land use, T is topography, and RB is river buffer zone. Each variable was reclassified into five vulnerability scores ranging from 1 to 9, where higher scores indicate higher inundation vulnerability. This procedure follows the principle of GIS-based weighted overlay and weighted linear combination in multi-criteria spatial analysis, in which all input variables are reclassified into a common scale and combined using proportional weights [16], [17].

Table 2. Variables, weights, and scoring rationale

Variable	Weight	Score Range	Rationale for Weight
Rainfall (mm/year)	15	1–9	Moderate influence because Palu is classified as a dry area, but short-duration high-intensity rainfall can still trigger inundation.
Soil Texture	10	1–9	Moderate influence because soil texture affects infiltration capacity and surface runoff generation.
Slope Gradient (%)	10	1–9	Moderate influence because flat areas tend to accumulate water, while steep areas contribute runoff to downstream lowlands.
Land Use	25	1–9	Highest influence because built-up areas and impervious surfaces strongly increase surface runoff in urban areas.
Topography (masl)	20	1–9	High influence because low-elevation areas function as runoff accumulation zones.
River Buffer Zone (m)	20	1–9	High influence because areas close to river channels are more exposed to overbank flooding and river-related inundation.

2.4. Vulnerability Classification

The final vulnerability index was classified using the equal interval method, which divides the range between the minimum and maximum index values into equal class intervals [16]. Since each variable was reclassified into scores ranging from 1 to 9 and the total variable weight equals 100%, the minimum possible FVI value was 1.00 and the maximum possible FVI value was 9.00.
The class interval was calculated using the following formula:

$$\mathbf{Ki = (Xt - Xr) / k}$$

$$\mathbf{Ki = (9.00 - 1.00) / 5 = 1.60}$$

where Ki is the class interval, Xt is the maximum possible FVI value, Xr is the minimum possible FVI value, and k is the number of vulnerability classes. Based on this calculation, the inundation vulnerability classes were classified as follows: (1) Very Low: 1.00-2.60; (2) Low: 2.61-4.20; (3) Moderate: 4.21-5.80; (4) High: 5.81-7.40; and (5) Very High: 7.41-9.00.

2.5. Analysis Steps

The analysis proceeded through several stages. First, all spatial data were collected, checked, and prepared in ArcGIS 10.8. All datasets were projected into the same coordinate system and clipped using the official administrative boundary of Palu City to ensure consistency in area calculation. Second, inundation points from BPBD Palu City for 2018-2024 were mapped and overlaid with the physical variables to identify spatial patterns of inundation occurrence. Third, DEMNAS data were processed to generate topographic and slope gradient maps. Fourth, SRTM DEM data were processed using hydrological tools, including Fill, Flow Direction, Flow Accumulation, Stream Order, and Basin, to extract river networks and generate river buffer zones. Fifth, rainfall data from BMKG were interpolated using the isohyet method. Sixth, soil texture and land use data were extracted from RTRW spatial data and adjusted to the study area boundary. Seventh, all variables were reclassified into five vulnerability scores ranging

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from 1 to 9, where higher scores indicate higher inundation vulnerability. Eighth, an expert-based weighted overlay was applied using the assigned variable weights: rainfall 15%, soil texture 10%, slope gradient 10%, land use 25%, topography 20%, and river buffer zone 20%. The final vulnerability index was then calculated using the FVI formula. Ninth, the final FVI map was classified into five vulnerability classes using the equal interval method. Finally, the spatial distribution of vulnerability classes was analyzed and used to formulate GIS-based inundation mitigation recommendations for Palu City.

3. Results and Discussion

3.1. Inundation Distribution in Palu City (2018–2024)

Based on BPBD data, 37 inundation events were recorded across 2018–2024 (**Table 3**). Events are unevenly distributed, concentrating in areas with flat topography, residential land use, and proximity to rivers.

Table 3. Summary of inundation events by year, Palu City 2018–2024

Year	Events	Main Locations	Largest Impact	Sub-districts
2018	5	Jl. Karoya, Tavanjuka, Tombolotutu	Traffic disruption; 5 houses at risk	W. Palu, Tatanga
2019	1	Kampung Lere, Kampung Baru	Houses on riverbank inundated	West Palu
2020	4	Jl. Bulili, Jl. KH Wahid Hasyim, Huntara Mamboro	20 houses + kos inundated	South Palu
2021	9	Jl. Maluku, Jl. Bayam, Jembatan 3	24 houses (Jembatan 3)	E. Palu, S. Palu
2022	11	Jl. Bayam, Jl. RE Martadinata, Jl. Maluku	52 houses inundated	South Palu
2023	5	Jl. Malonda, Jl. Basuki Rahmat	Bridge collapse (Donggala–Palu link)	East Palu
2024	2	Jl. Jamur, Jl. Imam Bonjol, Pasar Inpres, Jl. WR Supratman	Most of West Palu submerged	West Palu

Source: BPBD Palu City; Processed by the author, 2026.

In 2018, inundation occurred at several points, including Jl. Tanjung Karang (12 January), Jl. Karoya (14 January), Jl. Tavanjuka Mas (18 January), Jl. Tombolotutu (30 May), and Kelurahan Pantoloan Boya (25 May). In 2019, inundation was recorded in Kampung Lere, Jl. Lorong Bakso, and Kampung Baru on 29 April, affecting houses along the Palu River.

In 2020, four significant events occurred: Huntara Terminal Mamboro (28 September, 6 families displaced); Huntap Budha Tzu Chi (16 August); Jl. KH. Wahid Hasyim (6 July, 20 houses and boarding houses inundated); and Jl. Bulili (12 July, 10 houses inundated). In 2021, nine events were recorded from March to October, with the greatest impact at Jembatan 3 on 3 July (24 houses inundated). 2022 had the highest frequency (11 events), including Jl. Bayam on 25 September (52 houses inundated). In 2023, an event at Jl. Malonda on 7 April caused the connecting bridge between Donggala Regency and Palu City to collapse. In 2024, a mass inundation event occurred on 23 August, affecting much of West Palu, including Jl. Jamur, Jl. Imam Bonjol, Pasar Inpres, and Jl. WR. Supratman.

The spatial pattern is consistent over seven years: East Palu and South Palu dominate inundation frequency, followed by West Palu and Tatanga. The highest event count was in 2022 (11 events), and 2019 recorded the lowest (1 event). Sub-districts such as Palu Selatan and Palu Timur, characterized by flat alluvial plains (5-15 masl) traversed by tributaries of the Palu River, are exposed to a double-exposure mechanism: simultaneous accumulation of runoff from surrounding highland areas and risk of overbank flooding from the river.

3.2. Rainfall Conditions

Palu City's annual rainfall ranges from 657 to 870 mm/year across five isohyet classes, all classified as 'dry' (500-1000 mm/year). The entire city receives a score of 1 (lowest vulnerability class) for rainfall, with a weight of 15. Despite this, inundation occurs regularly indicating that rainfall volume per se is less important than the physical land conditions that determine how that rainfall becomes surface runoff. High-intensity short-duration events - even with limited total annual accumulation - overwhelm drainage systems in impervious urban areas, particularly on flat terrain.

3.3. Soil Texture Conditions

Soil texture significantly affects infiltration capacity, which in turn governs the proportion of rainfall converted to surface runoff (**Table 4**). Palu City's soils range from fine-textured Gleisol Eutrik to moderately coarse Podsolik Haplik.

Table 4. Soil texture classification, Palu City

Soil Type	Texture Class	Area (km²)	Percentage (%)	Weight	Score
Gleisol Eutrik	Fine	0.19	0.05	10	9
Gleisol Fluvik	Moderately Fine	37.66	9.53	10	7
Molisol Haplik	Moderately Fine	-	-	10	7
Gleisol District	Medium	231.71	58.65	10	5
Kambisol Eutrik	Moderately Coarse	125.50	31.77	10	3
Podsolik Haplik	Moderately Coarse	-	-	10	3
Total		395.06	100		

Source: Rakuasa et al, modified for Palu City, 2025.

Medium-textured soils dominate Palu City, covering 231.71 km² or 58.65% of the total area, primarily in Mantikolore and Ulujadi Districts. While medium texture offers moderate infiltration under natural conditions, urban construction activities such as soil compaction and surface sealing can reduce infiltration capacity. Moderately coarse soils cover 125.50 km² or 31.77%, while moderately fine soils cover 37.66 km² or 9.53%. Fine-textured Gleisol Eutrik, the most vulnerable class, covers only 0.19 km² or 0.05%, concentrated in Tatanga District.

3.4. Slope Gradient Conditions

Slope gradient controls the velocity of surface flow and thus the duration water remains at any location (**Table 5**). Flat and gentle slope areas are retention zones; steep areas generate high runoff volumes that accumulate in downstream lowlands.

Table 5. Slope gradient classification, Palu City

Class	Slope (%)	Area (km²)	Percentage (%)	Weight	Score	Vulnerability
Flat	0–8	103.28	26.14	10	9	Very High
Gentle	8–15	49.39	12.50	10	7	High
Moderately Steep	15–25	45.27	11.46	10	5	Moderate
Steep	25–45	86.54	21.90	10	3	Low
Very Steep	>45	110.58	27.99	10	1	Very Low
Total		395.06	100			

Source: Rakuasa et al, modified for Palu City, 2025.

Flat terrain with a slope of 0-8% covers 103.28 km² or 26.14% of Palu City and is concentrated in central sub-districts such as East Palu, West Palu, and South Palu, where impervious settlement surfaces dominate. Flat and gentle slopes together cover 152.67 km² or 38.64% of the city and function as the main inundation retention zones. Very steep terrain (>45%) covers the largest single area, reaching 110.58 km² or 27.99%, and acts as an upstream runoff source that channels water toward downstream lowlands during rainfall events.

3.5. Land Use Conditions

Land use had the highest assigned weight at 25%, as it directly controls the proportion of rainfall converted to surface runoff through surface imperviousness (**Table 6**).

Table 6. Land use classification, Palu City

Land Use	Area (km²)	Percentage (%)	Weight	Score	Vulnerability
Water body / Open land	2.62	0.66	25	9	Very High
Settlement	58.63	14.84	25	7	High
Paddy field	12.04	3.05	25	7	High
Mixed garden	65.11	16.48	25	5	Moderate
Shrubland	92.98	23.54	25	3	Low
Forest	163.68	41.43	25	1	Very Low
Total	395.06	100			

Source: Rakuasa et al, modified for Palu City, 2025.

Settlement areas cover 58.63 km² or 14.84% of Palu City, while water bodies and open land cover 2.62 km² or 0.66%. These land use classes are important inundation contributors because impervious and exposed surfaces increase surface runoff. Forest covers the largest area, reaching 163.68 km² or 41.43%, followed by shrubland with 92.98 km² or 23.54%. Together, forest and shrubland cover 256.66 km² or

64.97% of the city and function as the main runoff-buffering land cover, although ongoing land conversion may reduce this hydrological function.

3.6. Analysis of Topographic Conditions

Topography is one of the most influential physical factors determining surface flow distribution and water accumulation [9], [13]. Low-lying, flat areas tend to become accumulation zones for water draining from surrounding higher elevations, resulting in higher inundation vulnerability [7]. Conversely, sloping terrain allows faster water flow, although it increases runoff volume that eventually reaches lowlands. Processing of DEMNAS data using ArcGIS 10.8 shows that Palu City has highly varied topography, from coastal lowlands to mountains. Based on elevation, the city was divided into five classes (**Table 7**).

Table 7. Topographic classification of Palu City

Class	Elevation (masl)	Area (km²)	Percentage (%)	Weight	Score
Lowland	0-200	187.99	47.59	20	9
Upland	200-500	70.40	17.82	20	7
Hilly	500-1000	84.07	21.28	20	5
Moderate Mountain	1000-1500	51.59	13.06	20	3
High Mountain	>1500	1.01	0.26	20	1
Total	-	395.06	**100**	-	-

Source: Rakuasa et al., 2022; author modification, 2026

Lowland areas of 0-200 masl constitute the largest elevation class, covering 187.99 km² or 47.59% of Palu City. This zone is the primary accumulation area for rainfall runoff from surrounding hilly and mountainous areas. Most residential, commercial, and office activities are concentrated in this lowland zone, making inundation impacts directly felt by the community. Hilly areas of 500-1000 masl cover 84.07 km² or 21.28%, while uplands of 200-500 masl cover 70.40 km² or 17.82%. Moderate mountains cover 51.59 km² or 13.06%, and high mountains cover only 1.01 km² or 0.26%.

3.7. Analysis of River Buffer Zones

Rivers and their buffer zones play a dual role in urban inundation dynamics: they act as natural drainage pathways but can also become sources of inundation when their capacity is exceeded during peak flows [8], [18], [19]. River buffer zones-the riparian areas along riverbanks-help attenuate surface runoff, provide extra space for rivers during floods, and support water infiltration.

River network and buffer zone maps were derived from SRTM DEM processing using ArcGIS 10.8 hydrological tools (Fill, Flow Direction, Flow Accumulation, Stream Order, Basin) [5], [20]. After extracting the river network, buffer zones were generated using two distance thresholds: 25 meters for tributaries and 100 meters for the main river. These buffer zones were then used to assess inundation vulnerability (**Table 8**).

Table 8. Classification of river buffer zones in Palu City

Buffer Zone (m)	Area (km²)	Percentage (%)	Vulnerability Level	Weight	Score
0–25	17.10	4.33	Very High	20	9
25–50	9.13	2.31	High	20	7
50–75	3.15	0.80	Moderate	20	5
75–100	3.15	0.80	Low	20	3
>100	362.53	91.77	Very Low	20	1
Total	395.06	100	-	-	-

Source: Rakuasa et al., 2022; author modification, 2026

The >100 m buffer zone covers the largest area, reaching 362.53 km² or 91.77% of Palu City, and is classified as very low vulnerability because it is farther from river channels. However, the highest vulnerability is found in the 0-25 m buffer zone, which covers 17.10 km² or 4.33% of the city. This area lies directly along riverbanks and is the first zone exposed to increased river discharge and overbank flooding. The 25-50 m buffer zone covers 9.13 km² or 2.31% and is classified as high vulnerability. Together, the 0-50 m buffer zones cover 26.23 km² or 6.64% of Palu City and should become the main priority area for river buffer control and inundation mitigation.

3.8. Composite Vulnerability Analysis and Spatial Pattern

The weighted overlay produced a composite vulnerability map classified into five levels. **Table 9** presents the final vulnerability distribution.

Table 9. Final inundation vulnerability classification, Palu City

Vulnerability Class	Score Range	Area (km²)	Percentage (%)	Dominant Characteristics
Very Low	1.00-2.60	4.47	1.13	Very steep slopes (>45%), forest cover, high infiltration
Low	2.61-4.20	138.07	34.95	Hilly-upland terrain, forest/shrub cover, low urban density
Moderate	4.21-5.80	136.25	34.49	Mixed land use, moderate slopes, 50–100 m from river
High	5.81-7.40	103.45	26.19	Settlement on flat terrain, 25–50 m from river, medium-fine soil
Very High	7.41-9.00	12.82	3.25	Dense settlement on lowland (<200 masl), within 0–25 m of river
Total		395.06	100	

Source: Processed by authors using weighted overlay analysis, ArcGIS 10.8, 2026.

The composite analysis shows that the low vulnerability class covers the largest area, accounting for 138.07 km² or 34.95% of Palu City. The moderate vulnerability class covers 136.25 km² or 34.49%, while the high and very high vulnerability classes cover 116.27 km² or 29.44% of the study area. These high and very high zones indicate areas that require priority attention because they are associated with flat terrain, residential land use, low elevation, and proximity to river channels.

Of the 37 inundation events documented by BPBD during 2018-2024, more than 80% were located in areas classified as high or very high vulnerability. This pattern confirms that inundation in Palu City is strongly influenced by the combination of physical land characteristics and river proximity.

Land use had the highest assigned weight at 25%, indicating that built-up areas and impervious surfaces play the strongest role in increasing inundation vulnerability. Topography and river buffer zones followed with weights of 20% each, confirming the important role of low elevation and proximity to river channels in shaping the spatial distribution of inundation risk. Rainfall, soil texture, and slope gradient had lower assigned weights because they function as supporting factors in the local inundation process.

3.9. Vulnerability by Sub-district

Spatial analysis shows a strong correlation between BPBD recorded inundation points and the distribution of lowland topography and river buffer zones[21]. Of the 37 inundation events that could be spatially located during 2018-2024, more than 80% occurred in areas with elevations of 0-200 masl and within 0-50 m of the nearest river.

East Palu and South Palu Districts, which topographically constitute the lowest alluvial plains in Palu City, recorded the highest inundation frequencies. Both districts have average elevations of 5-15 masl and are traversed by tributaries flowing into the Palu River. Consequently, they receive not only local rainfall runoff but also runoff from upstream areas.

This phenomenon illustrates a *double exposure* mechanism: areas that are simultaneously accumulation zones for runoff from higher terrain (due to flat topography) and prone to overbank flooding (due to river proximity). This combination significantly increases flood risk and frequency, consistent with BPBD data showing that low-lying areas near the river experienced inundation almost every year during the study period.

From a management perspective, the situation is worsened by the number of buildings constructed within river buffer zones, especially in the 0-25 m zone. These structures narrow the river channel, reduce flood storage capacity, and eliminate the natural buffer that should serve as the first line of defense against overbank flow. Field observations indicate that this condition is prevalent along the Palu River in West Palu and East Palu Districts.

Table 10. Correlation of inundation frequency with topography and river buffer by district

District	Inundation Frequency (2018-2024)	Dominant Land Use	Dominant Topography	Buffer 0–50 m Area (km²)	Risk Category
East Palu	Very High	Settlement	0-100 masl	High	Very Vulnerable
South Palu	Very High	Settlement	0-200 masl	High	Very Vulnerable
Tatanga	High	Settlement/Commerce	0-300 masl	Moderate	Vulnerable
West Palu	High	Settlement/Agriculture	0-200 masl	High	Vulnerable
North Palu	Moderate	Mixed	0-300 masl	Moderate	Moderately Vulnerable
Mantikolore	Low	Mixed/Agriculture	200-1000 masl	Low	Relatively Safe
Ulujadi	Low	Forest/Shrub	200-1000 masl	Low	Relatively Safe
Tawaeli	Low	Forest/Agriculture	0-500 masl	Moderate	Moderately Vulnerable

Source: Processed by the author, 2026.

3.10. GIS-Based Mitigation Recommendations

Based on the inundation distribution mapping and analysis factors, the following evidence based spatial policy recommendations are formulated, grouped into three intervention dimensions: physical infrastructure, land use planning, and institutional measures [21], [22].

First, regarding physical infrastructure: the Palu City government should prioritize embankment construction along the Palu River in the segments crossing East Palu and West Palu, which exhibit the highest vulnerability scores and fall within the 0-25 m buffer zone. Infiltration wells and retention ponds should be constructed in lowland areas (0-200 masl) to reduce surface water accumulation. Drainage channel revitalization connecting lowland areas to the main river is urgently needed, particularly in South Palu where settlement density is highest.

Second, regarding land-use planning: the RTRW 2021–2041 should be revised to incorporate the multi-factor vulnerability map as a mandatory overlay layer. The 0–50 m river buffer zone must be designated as a conservation area with no permanent structures. Lowland areas classified as high and very high vulnerability zones should be subject to strict building coverage ratio (BCR) regulations maintaining minimum 40% open land. Detailed Spatial Plans (RDTR) for East Palu and South Palu must be explicitly calibrated to hydrological risk.

Third, regarding institutional measures: a real-time monitoring system integrating water-level sensors with GIS should be implemented, particularly for the 0–25 m buffer zone [12]. Community-based riparian vegetation programs have proven effective in improving hydrological resilience. and should be scaled in West Palu and East Palu where riverbank encroachment is most severe. Land use enforcement, especially against conversion of riparian shrubland and paddy fields to settlement, must be strengthened.

4. Conclusion

This study integrated six physical factors into an expert-based GIS weighted overlay framework to assess inundation vulnerability across Palu City using BPBD inundation data from 2018 to 2024. The analysis used rainfall, soil texture, slope gradient, land use, topography, and river buffer zones as the main variables.

First, inundation events during 2018 to 2024 were concentrated in East Palu, South Palu, and West Palu. These areas are characterized by flat terrain, residential land use, low elevation, and proximity to river channels. This pattern indicates that inundation in Palu City is influenced more by local physical conditions than by annual rainfall alone.

Second, land use had the highest assigned weight at 25%, indicating that built-up areas and impervious surfaces play the strongest role in increasing inundation vulnerability. Topography and river buffer zones followed with weights of 20% each, confirming that low elevation and river proximity are important controls of inundation distribution.

Third, the final vulnerability map shows that 4.47 km² (1.13%) of Palu City is classified as very low vulnerability, 138.07 km² (34.95%) as low, 136.25 km² (34.49%) as moderate, 103.45 km² (26.19%) as high, and 12.82 km² (3.25%) as very high. The high and very high classes cover 116.27 km² or 29.44% of the study area.

Fourth, mitigation priorities should focus on high and very high vulnerability zones, particularly in lowland settlements and areas located within 0 to 50 m of river channels. Recommended actions include strict development control in river buffer zones, drainage revitalization, riparian revegetation, and integration of the vulnerability map into RTRW and RDTR planning.

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6. Abbreviations

BIG	Geospatial Information Agency (Badan Informasi Geospasial)
BMKG	Meteorology, Climatology and Geophysics Agency (Badan Meteorologi Klimatologi Geofisika)
BPBD	Regional Disaster Management Agency (Badan Penanggulangan Bencana Daerah)
DEM	Digital Elevation Model
DEMNAS	National Digital Elevation Model (DEM Nasional)
DPUPR	Agency for Public Works and Spatial Planning
GIS	Geographic Information System
masl	meters above sea level
RDTR	Detailed Spatial Plan (Rencana Detail Tata Ruang)
RTRW	Spatial Plan (Rencana Tata Ruang Wilayah)
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey

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