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Regional Case Study

Spatial Characterization of Flood Intensity over the Drainage Condition of East Sempaja Village, Samarinda

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Abstract

The flood events frequently impacting Samarinda City have not yet been thoroughly examined based on their intensity, particularly in the most flood-prone village in the city, East Sempaja Village. This paper employed a rigorous methodology, including K-means cluster analysis and Getis-Ord G* statistics, to reveal spatial clustering patterns based on flood intensity and residential drainage conditions in East Sempaja. The Spearman correlation was determined to identify the relationship between both factors. The present study demonstrates that using community-derived data can enhance flood disaster mitigation strategies, particularly within regions with insufficient data availability. The analysis shows that most neighborhood areas in East Sempaja have moderate to high flood intensity levels. The areas with high flood intensity are spread across the North. This paper confirms that the condition of drainage channels has a positive, yet weak, significant relationship with the level of flood intensity. Thus, optimizing drainage channels is still relevant in managing flood disasters in East Sempaja, providing practical strategies for a pressing issue.

Keywords: Drainage; relationships; spatial characterization; flood intensity

1. Introduction

Flood disasters, commonly linked to urban areas, pose a significant threat that may challenge the economic activities of urban settlements, leading to financial setbacks, physical devastation, and, occasionally, loss of human life. Flood disasters occur when a large amount of surface water cannot be managed by existing water infrastructure, submerging the surrounding area (Olanrewaju & Reddy, 2022). Moreover, climate change exacerbates flood occurrences and reduces the available space for water absorption in urban environments (Huang et al., 2022; Owuor & Mwiturubani, 2022). Based on data from the National Agency for Disaster Countermeasures (BNPB), floods were identified as the most impactful disasters that seriously affected major cities in Indonesia from 2009 to 2021.

Samarinda City, situated in East Kalimantan Province, has been confronted annually with the issue of managing floods. Positioned at the estuary of the Mahakam River with a combination of sloping and flat land, the city faces a notable vulnerability to this disaster. Due to its natural characteristics, the city is susceptible to the rapid formation of inundations, particularly during rainfall (Sundari, 2018). This situation is further compounded by the prevalence of urbanized areas, suboptimal drainage conditions, insufficient green spaces, and inadequate flood mitigation systems (Bibi et al., 2023). The recurrence of floods appears to have become an unfavorable tradition, posing a primary development obstacle.

Data from the Central Statistics Agency of Samarinda City in 2022 reveal that floods rose between 2017 and 2021. Flood disasters were documented at 13 cases in 2017, climbed to 18 cases in 2020, and increased considerably to 30 cases in 2021. The number of affected communities has also grown significantly. According to the same data source, the villages damaged by the 2018 flood were divided into 18 villages, increasing to 32 by 2021. The most recent major flood occurred in 2019, inundating 10,000 homes and forcing 20,000 people to evacuate from four sub-districts, including North Samarinda (BPBD, 2019). Furthermore, the most recent data on the 2021 flood occurrence revealed flooding in six sub-districts across two sub-districts, North Samarinda and Sungai Pinang, causing damage in 80 neighborhood areas and affecting 11,994 people.

Sempaja Timur Village is one of Samarinda City's most prone to flooding. This village was the most severely hit by the flood in 2019 (Irawan et al., 2024), and it became the most frequently flooded community in North Samarinda Sub-district (Sundari, 2018). East Sempaja experienced a substantial increase in flood events between 2017 and 2019. In 2017, the Regional Agency for Disaster Countermeasures (BPBD) of Samarinda City documented two flood disasters in its initial report, affecting 19 residential areas (RTs). Conversely, the number had increased to five events by the end of 2019, which affected 41 RTs. Furthermore, a significant flood occurred in 2019, severely devastating East Sempaja and involving approximately 2,594 families and 8,791 individuals. This circumstance also makes Sempaja Timur Village a priority region for flood management in Samarinda City. According to the Medium-Term Development Plan of Samarinda City (RPJMD) for 2021-2026, the focus for dealing with floods in Sempaja Timur Village is along the Karang Mumus River's sub-watershed, as well as the Wahid Hasyim and P.M Noor Road corridors.

Currently, flood management in Samarinda City heavily relies on identifying flood disaster risk zones. Even though flood risk mapping has been extensively established to prepare an adequate response during a flood disaster, past studies have only assessed Samarinda City's flood catastrophe susceptibility, resilience, capability, or risk based on specific geographical units' physical, environmental, and social aspects. For instance, Sundari et al. (2023) discovered slope-based flood-prone zones in the Karang Asem River sub-watershed, whereas Matori et al. (2023) identified rainfall and physical characteristics-based flood risk clusters in the Mahakam River watershed. In addition, local embankments assessment in the Karang Mumus sub-watershed (Sukmara et al., 2015), drainage channel structures evaluation in East Sempaja village (Wijaya & Agustina, 2022), and community adaptation measurement (Asti & Mayasari, 2023; Fandri, 2020; Anwar et al., 2021) have also been examined by other scholars have not been able to provide flood control instruments at the neighborhoods level. Thus, highlighting the necessity of improving the database about high-risk flood zones at the local level is needed, enhancing public awareness and facilitating context-specific interventions (Majumder et al., 2019; Röthlisberger et al., 2017).

Apart from that, the primary concern regarding flood issues in Samarinda City has also been pinpointed to stem from the substandard condition of drainage systems. The lack of public awareness regarding the maintenance of drainage systems has a direct effect on the frequency of floods (Asti & Mayasari, 2023). The study conducted by Ali (2019) revealed that the community in North Samarinda urgently requires capacity development on proper waste management practices and the maintenance of drainage systems for flood prevention. An essential aspect of flood mitigation lies in the effective drainage systems capable of accommodating and efficiently discharging water runoff (Ndoma et al., 2020).

The drainage channel plays a crucial role in mitigating flood risks and requires comprehensive understanding and management strategies. Even though an effective flood control strategy frequently involves modifying drainage systems in previous studies' recommendations, which include increasing the capacity of channels (Ali, 2019; Ayari & Asyiawati, 2023), minimizing flow blockages caused by debris accumulation (Ayari & Asyiawati, 2023), upgrading structure design (Wijaya & Agustina, 2022), and enhancing the efficiency of water flow (Setiawan et al., 2020). However, prior studies have failed to establish a connection between the specific conditions of flood occurrences and the drainage conditions in the affected areas. Therefore, this study aims to explain the spatial pattern based on flood intensity on existing environmental drainage in neighborhood unit areas that previous studies have not revealed. The impact of flooding at the local level varies and is also influenced by drainage conditions, draining runoff optimally when in good conditions (Seyedashraf et al., 2021).

The association between flood intensity indicators and drainage conditions was investigated in this study using the Spearman correlation method. Prior to the correlation, this paper employed a spatial grouping approach based on clustering and hotspot analysis to identify areas with comparable characteristics in both indicators. The K-means clustering algorithm generates group regional units with similar characteristics, resulting in spatial concentration (Irwan et al., 2023). Hotspot analysis employing Getis Ord statistics helps to identify high-risk locations, allowing for more effective prioritization of flood catastrophe management and mitigation measures (Hassan et al., 2017). These approaches can signify distinct flood attributes and risk management approaches across the study area, shaping responses to flood threats according to local circumstances (de Moel et al., 2015).

2. Methods

2.1. Study Area

The research is focused on East Sempaja Village, situated in the North Samarinda Sub District, Samarinda City. The geographical coordinates of the research site lie within 0o 24' 39.86" - 0o 27' 40.35" South Latitude and 117o 09' 10.62" - 117o 09' 52.46" East Longitude. This village is centrally located inside the Mahakam River Branch sub-watershed, known as the Karang Mumus River. The Karang Mumus River flows through the study area to the west, making it one of Samarinda City's most flood-prone zones. The schematic representation in Figure 1 illustrates the spatial alignment of the study area to Samarinda City. East Sempaja has an area of 1,529 hectares and a population of 25,777 in 2019. Furthermore, this community is separated into 54 residential areas (referred to as "RT" henceforth), which will be used as the primary units for data analysis. Although East Sempaja is flood-prone, its landscape is not consistently flat. The topography of this area varies between 0 to 40 meters, with higher elevation primarily located in the central part of the village.

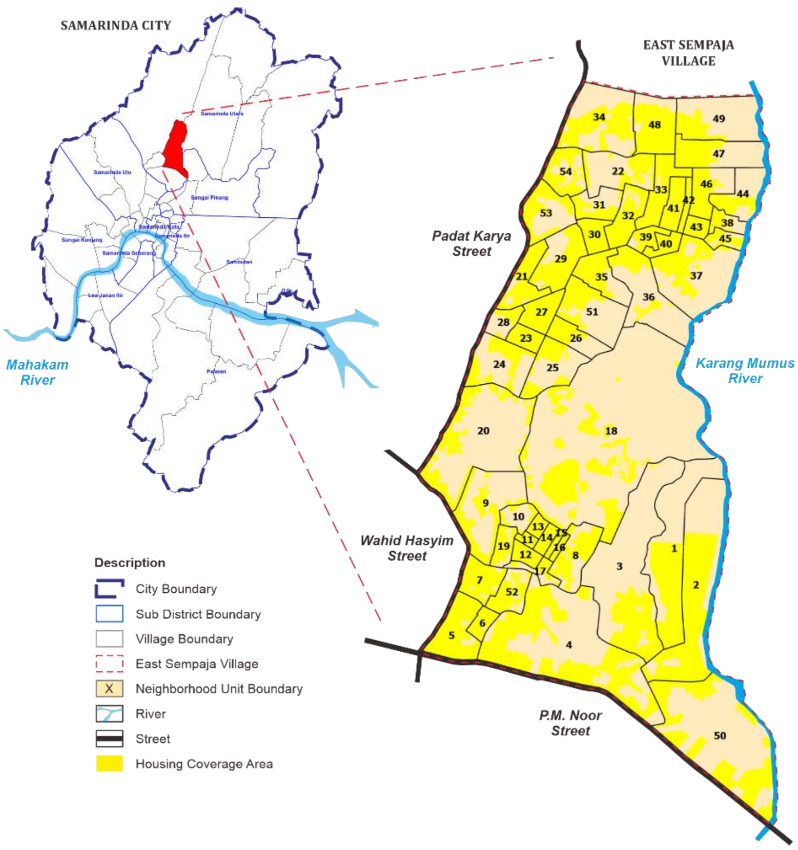

Figure 1. Orientation of the study area in the Samarinda City

2.2. Data Collections

The study employed two separate datasets, flood intensity and drainage channel condition, for each RT. Each data was collected separately. Firstly, Flood intensity data is obtained through the calculation of its parameters: the mean depth of inundation (TGB), the annual frequency of flooding (FRB), the length of inundation (DRB), and the approximate area affected by floods (PPT). This data represents the characteristics of flood intensity within specific area analysis units. A greater flood intensity in a particular area indicates a more significant flood risk disaster (Sahani et al., 2023; Vojtek & Vojteková, 2016). Currently, government data only shows flood-prone areas and flood events. Although reports on disaster conditions in Samarinda City are published annually, no precise data on floods at the sub-district level is reported. Due to the lack of relevant secondary data on flood intensity, it is necessary to conduct searches using public repositories. The active participation of communities in disaster response is essential for implementing flood control measures and represents the main recipients of disaster preparedness initiatives (Ali & George, 2022). Therefore, the knowledge obtained from community experiences can be crucial for assessing flood intensity at small-scale levels.

To be more practical, the number of respondents is determined by simple random sample procedures using Slovin's formula in Equation (1). The application of the equation in determining the number of samples needs to consider several assumptions: (1) the proportion of the population approaching 50%, (2) in a small population, (3) the sample is used to obtain precision from the estimate rather than statistical analysis power, and (4) the degree of confidence used is 95%. (Tejada and Punzalan, 2020; Santoso, 2023). In the context of this study, the high level of flooding exposure can be used to assume that the majority of residents in East Sempaja have had similar flood experiences. As a result, the majority of residents can provide accurate information on the flood intensity in the research area.

$$n = \frac{N}{1 + Ne^2} \tag{1}$$

Where *n* is the sample size, *N* denotes the population, and e is the margin of error (Santoso, 2023). According to the monograph data of East Sempaja Village in 2020, the area has 5371 populations. Thus, 371 respondents are required across the study area. RT boundaries can be considered subgroups of the population, with the sample distributed proportionally to its size relative to the total population in each RT region, ensuring that each subgroup is sufficiently represented. It is critical to draw correct conclusions about the population and assure confirmation (Marradi, 2022). Ultimately, the data for each parameter in every analysis unit is the average of responses collected from all respondents within each RT.

Secondly, data on drainage channel conditions were collected by measuring secondary and tertiary drainage channels in each RT. Although the primary channel, Karang Mumus River, is within the study area, the investigation only encompasses residential drainage channels across neighborhood areas. Subsequently, the condition of each channel was evaluated on site, considering factors such as sedimentation-induced shallowing (Gabr et al., 2023), blockage from debris or vegetation (Ayari & Asyiawati, 2023), and overall channel physicality (Setiawan et al., 2020). Favorable drainage conditions are channels without interference from the considered factors and are otherwise in poor condition. All channels were observed and traced on a segmented basis within each RT area. The findings from the survey were then quantified as a percentage (%) of the total channel length exhibiting favorable or poor conditions within each RT. The percentage of drainage channels in poor condition (PSB) utilized for further processing data.

2.3. Analysis Techniques

This study comprises three distinct analysis stages: cluster analysis, hotspot analysis, and Spearman correlation analysis, which examine the relationship between flood intensity and drainage channel conditions. Clustering analysis for both K-means and hotspots was conducted with ArcGIS 10.8 software, while correlation analysis was carried out with IBM SPSS 26 software. All data obtained from the surveys was inserted in the spatial boundary of each RT. For more practically:

1. K-means cluster analysis divides all spatial feature data into categories or clusters according to similarity or distance (Li et al., 2023). In the process, K-means calculates the distance between individual data using the squared Euclidean distance metric as a similarity measure, then minimizes the sum of squares in one cluster to maximize the distance between groups (Peeters et al., 2015).

$$S = \arg\min_{S} \sum_{i=1}^{k} \sum_{x_j \in S_j}^{n} \left\| x_j - \mu_i \right\|^2 \tag{2}$$

Equation (2) is an iterative method for dividing a collection of n data observations ($x_1, x_2, ..., x_n$) into homogenous k clusters *($k \leq n$), with* $S=\{S_1, S_2, ..., S_n\}$. The x_j denotes the attribute value of the target feature, and π_j is the centroid of cluster S_i. The K-means algorithm iteratively assigns data points to the cluster with the nearest mean, continuing the process until convergence, typically when cluster assignments no longer change significantly (Nie et al., 2023). Although determining the number of groups formed is a challenge (Xu et al., 2018), the higher the similarity (minimal variance) within a class and the greater the differences between classes (maximizing variance), the better the grouping effect (Fernandez et al., 2016). Notably, the analysis utilized three cluster groups - representing areas with high, medium, and low flood intensity, with regions of high flood intensity exhibiting higher FRB, DRB, PPT, and TGB conditions than others. A clustering process was also conducted based on PSB conditions, indicating that areas with more drainage in poor conditions are more susceptible to floods.

2. Hotspot analysis focuses on identifying local spatial autocorrelation to effectively distinguish locations with high and low risk (Shariati et al., 2022). Each specific location is assigned values based on various parameters for assessing flood intensity and channel conditions. Even though the analysis is similar to the K-means cluster, the basis of autocorrelation means that the resulting grouping can distinguish areas with positive spatial autocorrelation as similar values that are located close to each other, thus forming significant groups of the highest values (hot spots) and the lowest values (cold spots). Determining these hot spots can support flood management strategies focusing on the most vulnerable areas (Röthlisberger et al., 2017). The methodology employs Getis-Ord G* (G-star) statistics to compute autocorrelation within regional units based on variable values and neighboring units, as in Eq. (3).

$$G_i^*(d) = \frac{\sum_j w_{ij}(d) x_j}{\sum_j x_j} \tag{3}$$

Where G_i^*(d) represents the local G-statistic for a feature i located within a distance d, while x_j denotes the attribute value of each neighbor, and w_{ij} represents the spatial weight associated with the target-neighbor pair of i and j (Peeters et al., 2015). The assessment is then determined by calculating the z-score test and critical p-values. A higher z-score indicates a greater likelihood of hotspot clustering, whereas a lower z-score signifies minimal impact from flooding or intense cold spots (Majumder et al., 2019). A z-score falling within the range of -1.65 to 1.65 reflects a random, which is considered statistically insignificant (Qiang, 2019). Z-score < -2.58 or > 2.58 is always followed by p-value < 0.01, while z-score <-1.96 or > 1.96 obtains p-value < 0.05, and z-score < -1.65 or > 1.65 produces p-value < 0.10, assuring statistical confidence level (Hassan et al., 2017; Qiang, 2019; Shariati et al., 2022)

3. Correlation analysis is a methodology employed to investigate the relationship between the categorization of drainage conditions and flood intensity levels within each RT. This approach allows for evaluating the effectiveness of drainage systems in flood mitigation within specific regions (Sohn et al., 2020). The dataset for this examination comprises the scoring derived from the cluster analysis outputs related to flood intensity and drainage conditions, as outlined in Table 1. Due to the scoring value, the Spearman correlation method was used to analyze non-parametric ordinal data, emphasizing the data hierarchy rather than assuming a normal distribution (Eden et al., 2022). The characteristic of correlation between variables can be illustrated by an r-value that leans towards 1, meaning a directly proportional relationship, or -1, meaning an inversely proportional relationship (Schechtman & Shelef, 2018).

Table 1. Scoring Terms for K-Means Cluster Analysis Output

Score	Condition	Parameters
1	Cluster of low value in flood intensity	FSB, DRB, PPT, TGB
	Cluster of low percentage of poor drainage conditions	PSB
2	Cluster of moderate value in flood intensity	FSB, DRB, PPT, TGB
	Cluster of moderate percentage of poor drainage conditions	PSB
3	Cluster of high value in flood intensity	FSB, DRB, PPT, TGB
	Cluster of high percentage of poor drainage conditions	PSB

3. Result and Discussion

3.1. Flood incident Conditions

Between 2017 and 2019, there was a notable increase in flood events observed in East Sempaja. An initial report from the Regional Agency for Disaster Countermeasures (BPBD) of Samarinda City recorded two flood events in 2017. In contrast, by the end of 2019, the number had escalated to five. The affected areas by the flood have also grown considerably. In 2017, the flood impacted 19 RTs, followed by 26 RTs in 2018 and a further increase to 41 RTs in 2019. In addition, a major flood occurred in 2019, inflicting severe damage on East Sempaja and affecting approximately 2,594 families and 8,791 people. The inundation in East Sempaja poses an impediment to the community's daily activities and results in substantial losses. BPBD (2019) also recorded that the financial toll of this flood event amounted to Rp. 60.56 billion.

The outcomes of on-site observations were based on data provided by the communities, indicating that the inundation impacted 41 RTs. Observational evidence discovered that the flood-free zone is located at an elevation of 40 meters above sea level. This particular zone, which comprises RT 7, RT 11-18, RT 23-25, and RT 28, is primarily defined by vacant or marshy areas, notably along the Karang Mumus River. The southern portion of East Sempaja is the central location for commercial activities, services, and administrative tasks, particularly along the Wahid Hasyim Street axis in Figure 2. In contrast, the northern region is acknowledged as the central hub of the residential areas even though the government office of East Sempaja is located in RT 51. The floods in the southern region had a negative impact on the main economic activities in East Sempaja, while such disasters in the northern part could potentially disturb the everyday routines of the local communities.

Concerning the flood occurrence frequency, Figure 2 shows that floods occur between one and four times annually. In the northern region, only seven RTs experience floods once a year, whereas ten RTs experience four events per year. Depending on the flood severity, the inundation depth within the examination area ranges between 20 and 150 cm. RTs around the Karang Mumus River in the west and Wahid Hasyim Street in the south are the most exposed to floods. Moving on to the duration parameter, most inundations in the study area last more than a day. Specifically, the inundation in RT 35 and 37 persisted for a whole week. The most severe flood-affected areas were located in RT 50 and its vicinity, flooding all settlements.

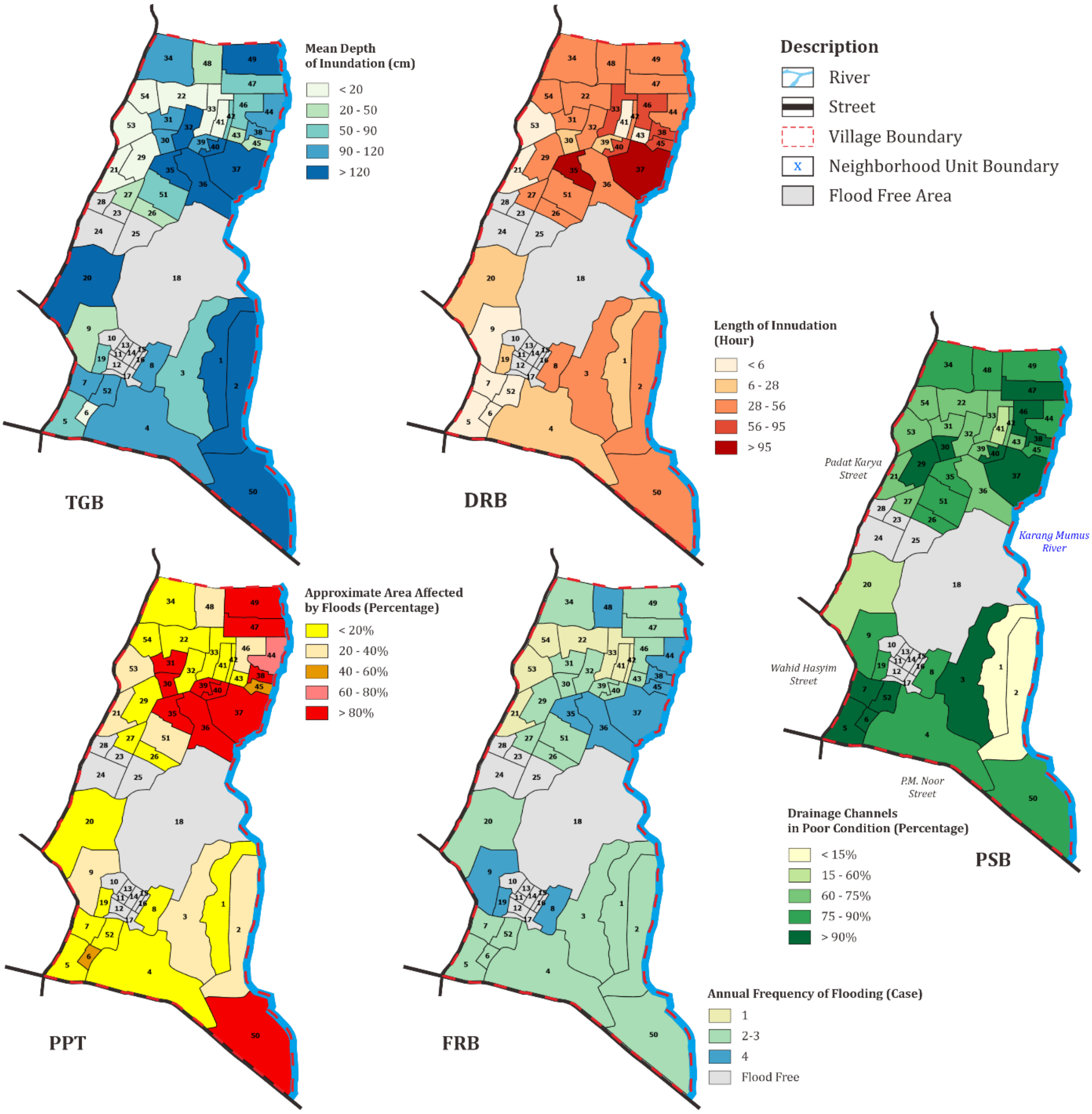

Figure 2. Data distribution in each parameter

These data confirm that the flood intensity varies among the different RTs within the study area, with each RT exhibiting the highest intensity on the specific parameter. The survey results are consistent with local news reports about flood conditions in East Sempaja in 2019, as reported by Sucipto (2019) and Kaltim Prima Multi-Media (2019), flood event in 2020, according to Sucipto (2020) and Pranita & Sumarningtyas (2020), and flood event in 2021 published by Klik Samarinda (2021) and Zakaria & Indra (2021), as well as flood record from the Samarinda City Government's flood management website (Samarinda City Government, 2021b). Although these media can only provide incomplete information about numerous inundated RTs and their estimated depth, they are sufficient to corroborate the survey results within the constraints of secondary data.

Examination of the drainage conditions showed that nearly 90% of residential territories exhibit poor situations. A majority exceeding 60% of the waterways within the study area are obstructed by debris, overgrown vegetation, sediment accumulation, or other factors that hinder their optimal functionality. Specifically, two residential territories in the southern segment, RT 1 and RT 2 demonstrate favorable drainage conditions due to adherence to the drainage provisions outlined in the housing development plan. Additionally, it is understood that several RT areas also have residential zones that are still under development, with currently only apparent bare land available for construction. These areas without residential structures are not supplied with drainage systems, reducing infiltration capacity due to soil compaction and lack of vegetative cover, increasing surface runoff, and exacerbating the risk of flooding in these regions (Sanches Brito et al., 2020).

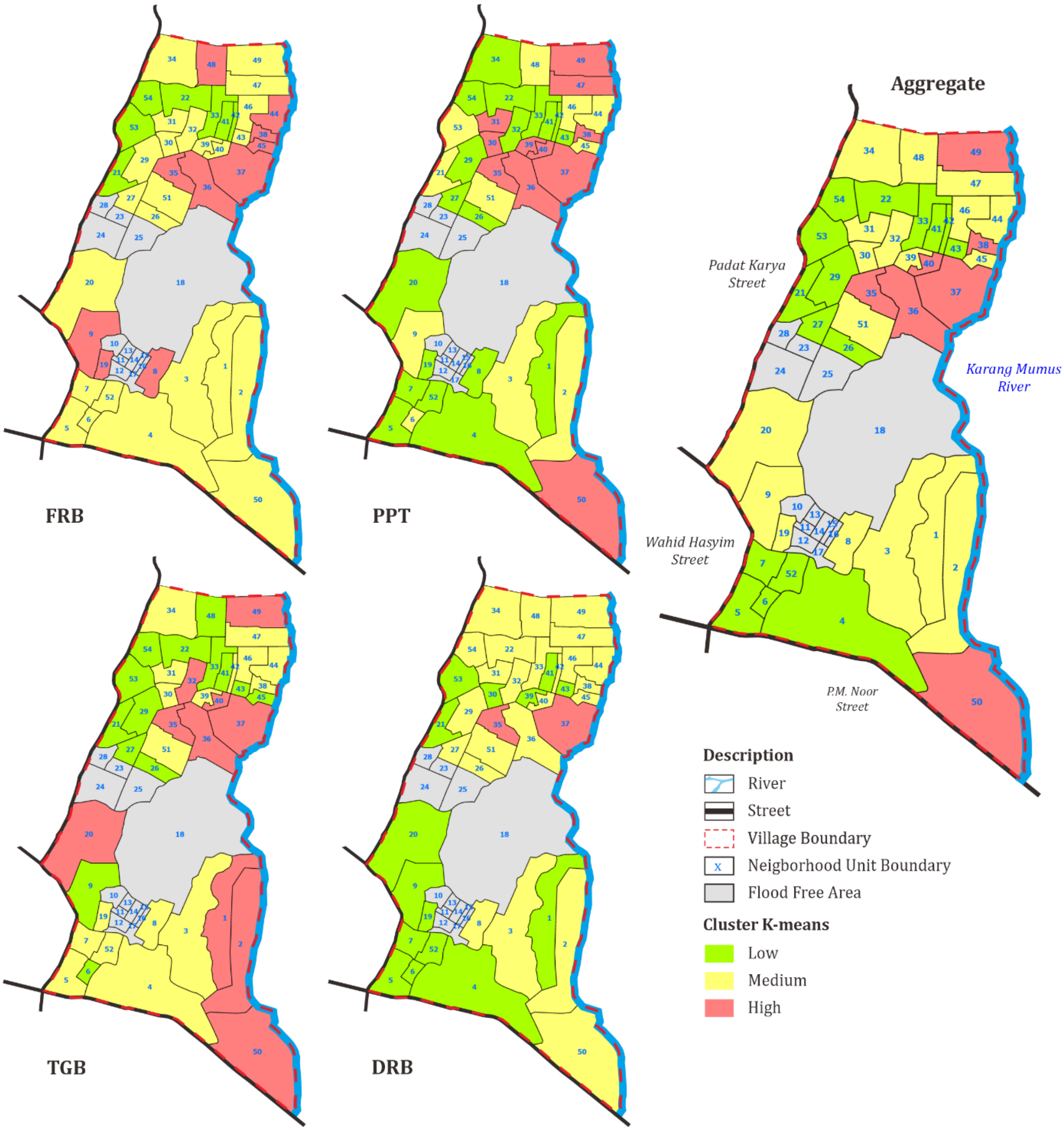

Figure 3. Spatial pattern based on flood intensity parameters using K-Means

3.2. Flood Intensity Grouping Pattern

Flood intensity indeed pertains to the magnitude of the flood risk within impacted areas, encompassing various dimensions such as the scale of the flood, the resultant damage, and the underlying factors contributing to the flood's severity (Wang et al., 2018). The categorization of flood occurrences in East Sempaja depends on the characteristics contributing to flood severity. The degree of flooding in a given area is influenced by various factors, including precipitation patterns, geography, and different physical and environmental characteristics (Sahani et al., 2023). The empirical findings from East Sempaja show that a yearly inundation affects only 43 of 54 residential zones. Figure 3 depicts the clustering of residential areas depending on flood intensity, with K-means applied across all parameters.

The spatial clusters based on flood frequency show that RTs along the Karang Mumus River experienced different amounts of events. The cluster with higher frequencies was mainly located in the northern region, including RT 37 and 44. In contrast, almost all RTs outside this high-frequency cluster experienced twice yearly. An example can be observed in RT 53, 54, and 22, where disasters happened only once. The distribution of affected communities follows a similar pattern, particularly in the high-frequency clusters of RT 35 and RT 40, where settlements were affected entirely. RT 50 in the southern region joins the high-frequency cluster but remains spatially separated from its counterparts. Aside from that, the moderate cluster has a percentage of affected settlements ranging from 5% to 12%.

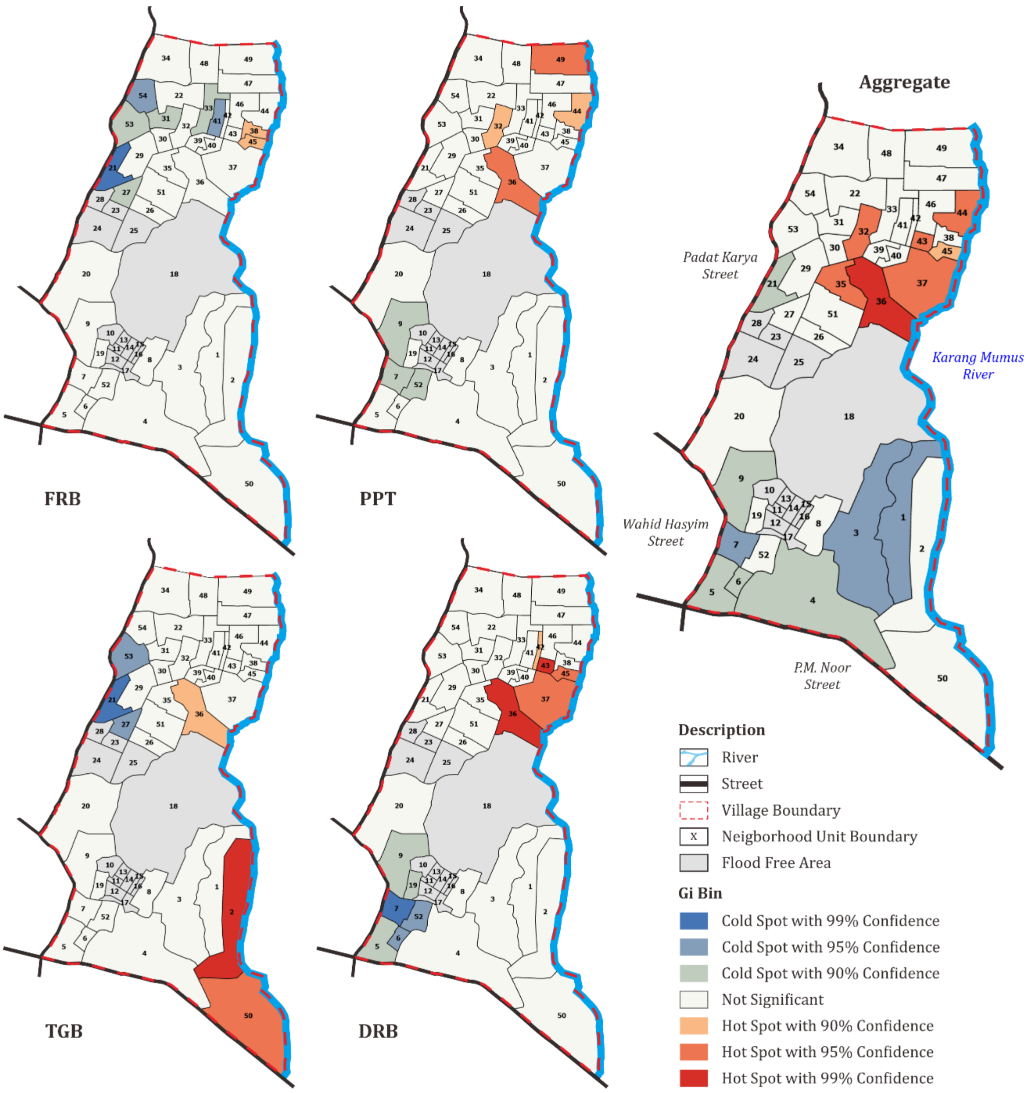

Figure 4. Spatial pattern based on flood intensity parameters using hotspot analysis

Concerning the inundation parameter, high clusters were formed by RTs with high inundation above 100 cm. These high clusters are primarily concentrated around RT 1, 2, and 50 in the southern region and five RTs adjacent to RT 35 in the northern. Conversely, areas characterized by low inundation heights, less than 50 cm, tend to coalesce in proximity to unaffected RT areas, spanning from RT 48 in the northern to RT 17 in the central village. The areas with high topography, particularly in the RT 18 area along the Karang Mumus River to the west, have a very concentrated distribution of the lowest inundation height groups. Meanwhile, an anomaly was discovered in the conditions of RT 20, which is situated a considerable distance from the river border. However, it exhibited a flood height exceeding 100 cm, making it the most severely affected location in this parameter.

When examining the distribution of clusters based on the length of inundation, it becomes evident that merely two RTs, specifically RT 37 and RT 35, were categorized under the cluster with the most prolonged inundated time, which amounted to seven days. Despite not being directly adjacent, these RTs are situated in lower-elevation areas. In addition, the cluster of moderate inundations was located in the northern region around RT 3, where a flood event typically persisted for 2 to 4 days. The ultimate cluster experiences an extended period of submergence lasting less than 48 hours in the western. Consequently, these clustering results confirmed that floods along the Karang Mumus River and lower elevations take longer to subside.

Figure 4 depicts the grouping results based on hotspot analysis, indicating that the northern region has a higher overall flood intensity. By applying a 90% confidence threshold, 7 RT zones were included in the hotspot group, indicating a significant level of flood intensity. The northern region constantly produces hotspot areas for every parameter. In particular, there are hotspots in RT 36, 37, 42, 43, and 45 for DRB and hotspots in RT 32, 36, 44, and 49 for PPT. In contrast, the FRB and TBG parameters result in a reduced number of hotspot areas. The FRB hotspots are located explicitly at RT 38 and 45 in the North, while the TGB hotspots are found at RT 2 and 50 in the South. The results of this investigation strongly correspond with the cluster analysis output, emphasizing the increased levels of flood risk in the northern section. The hotspot analysis highlights the presence of local spatial autocorrelation, revealing the clustering of high values and the concentration of statistically significant locations. The identified hotspot zones display increased flood intensity conditions and are surrounded by neighboring areas with elevated values (Majumder et al., 2019). The flood intensity hotspot zone in East Sempaja is mainly located around RT 36 in the northern region.

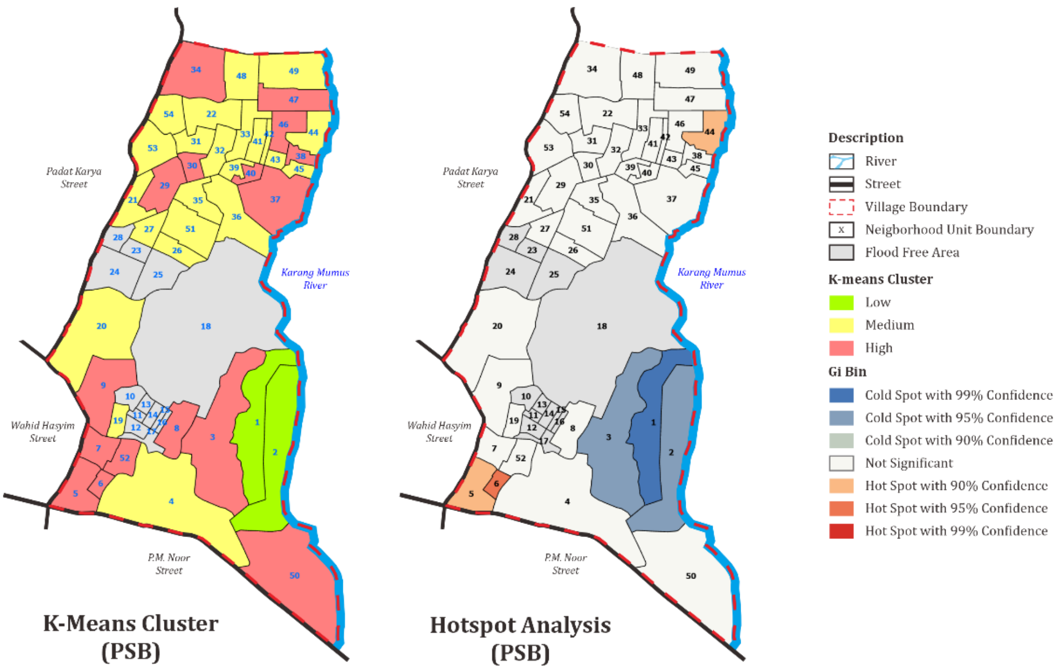

Figure 5. Spatial pattern based on drainage condition using (left) k-means and (right) hotspot analysis.

3.3. Drainage Conditions Grouping Pattern

Following the comprehensive previous depiction, the evaluation of the PSB parameter is determined based on the percentage of poor channel lengths in each RT. The illustration provided in Figure 5 delineates that the spatial grouping according to PSB exhibits a distinct dispersion compared to the distribution of flood intensity. Notably, areas with high PSB conditions are identified in the north and south regions, with poor channel conditions above 90%. In the northern, clusters formed in 3 separate parts, specifically RT 40 and 37, RT 29 and 30, and RT 46 and 47, while others were observed in the southern region, such as RT 3, RT 8-9, and RT 50.

In contrast, only two areas, RT 1 and RT 2, are classified as low category, with a PSB rate below 30%. The PSB rate of the remaining RTs ranges from 30% to 80%, placing them in the moderate category. Their clustering indicates the dispersion of PSB values throughout the study area. This inference is supported by the results of the hotspot mapping, which indicates that only two RTs are classified as hotspots with a confidence level of 90% to 95%. These RTs are RT 4 to 6 in the South and RT 44 in the North. This outcome is particularly noteworthy because it contradicts the clustering pattern based on flood intensity, as it fails to verify the areas that PSB identifies as constituents of flood intensity hotspots. Nonetheless, these findings are relevant as a representation of actual flood conditions in the study area.

3.4. Validation of Grouping Results

Several validation processes are utilized to evaluate the grouping outcomes of both approaches. First, cluster outputs can be evaluated effectively when the level of difference between clusters and similarity within clusters is highest (Fernandez et al., 2016; Hassan et al., 2017). The goodness of variance fit (GVT), as defined in Equation (4), assesses the validity of cluster partitioning (Peeters et al., 2015). SST represents differences across groups, whereas SSW reflects group commonalities. SST is calculated as the sum of the squared deviations from the global average of the entire data set. SSW is calculated by summing the squared differences between each value and the average value of the class to which it belongs. The closer the GVF index is to one, the more homogeneous the cluster, indicating more effective data partitioning (Peeters et al., 2015).

$$GVT = \frac{SST - SSW}{SST} \tag{4}$$

Table 2 shows the GVT values of clustering in each parameter. All clustering results in each parameter of the flood intensity and drainage condition indicators exceed 0.85. This indicates that the definition of 3 partitioning data (low, medium, and high cluster) successfully maximized the distance between groups and the similarities among group members in all variables.

Table 2. The GVT values on clustering results in each variable

Parameters	SST	SSW	GVT
FRB	19.610	0.900	0.954
DRB	54633.610	7586.933	0.861
PPT	66710.292	4858.227	0.927
TGB	108390.244	10783.193	0.901
Aggregate (Flood Intensity)	159.951	21.929	0.863
PSB	17292.572	1958.194	0.887

Second, the z-score test and crucial p-value can be used to directly assess the validity of the hotspot analysis results. However, to investigate how the spatial structure of hotspots and cold spots is reflected in the cluster output, the spatial patterns of clusters and hotspots of the analysis were compared and evaluated. The distribution of clusters in Figure 3 and hotspots in Figure 4 reveals that the hotspot area is linear, with sufficient high clusters with neighbors in high and medium clusters. One example is observed in RT 49. According to the cluster analysis results, this area is part of the high cluster, and a hotspot is generated with 95% confidence because it is surrounded by RT 48 (medium) and RT 47 (high). In contrast, in the TGB and Aggregate variables, a high cluster in the same area does not generate hotspots because the surrounding areas are only in the low and medium groups. Thus, the spatial structure of the two approaches is linear and non-contradictory.

3.5. Relationship between Drainage Conditions and Flood Intensity

From the results obtained in the previous section, it can be concluded that only a limited number of RTs classified under the high flood intensity also align with its high PSB conditions. Most high flood intensity areas showcase moderate PSB conditions, showing that 30-80% of their channels are in poor condition. This pattern enhances the weak correlation between flood intensity parameters and PSB, as illustrated in Table 2, indicated by a value lower than 0,5. The PSB column displays the correlation coefficient between PSB (initial value) and flood Intensity parameters. Meanwhile, the scored PSB cluster column represents a relationship to the scoring of spatial cluster output based on PSB.

Based on the r-value and p-value (Eden et al., 2022), the overall flood intensity within the study area illustrates a weak correlation with coefficient ranging from 0.31 to 0.34 at the 95% confidence interval. PPT and PRB exhibit a coefficient exceeding 0.3 and are deemed statistically significant at the 95% confidence level. In contrast, the DRB and TGB attributes differ slightly, with a coefficient below 0.25 and considered statistically insignificant. Even though the correlation results show a weak value, the coefficient in the PPT, FRB, and aggregate parameters confirm that both factor's relationships are statistically significant. Therefore, it can be concluded that channel conditions in the study area still contribute to the flood situations.

Table 3. Correlation Value Between Flood Intensity and Drainage Condition

Correlation		PPT	FRB	DRB	TGB	Aggregate
PSB	r-spearman	0.283*	0.348**	0.207	0.163	0.311*
	p-value (2-tailed)	0.038	0.010	0.133	0.238	0.022
Scored PSB Cluster	r-spearman	0.303*	0.366**	0.197	0.206	0.345*
	p-value (2-tailed)	0.026	0.006	0.153	0.135	0.011

. **Correlation is significant at the 0.01 level (2-tailed).
*. **Correlation is significant at the 0.05 level (2-tailed).**

3.6. Discussion

The lack of a comprehensive flood database in Samarinda City hinders the ability to make well-informed decisions regarding flood management and response. Current records of flood events primarily focus on the number of occurrences, with limited reports at the sub-district level. Enhanced data availability, particularly at the local level, enables more targeted flood management strategies based on specific vulnerability assessments in an actual condition (Majumder et al., 2019). A complete flood database is crucial in enhancing preparedness, mitigation, and adaptation efforts. Detailed information, such as predictions of inundation areas and volumes, can inform strategies for mitigating impacts on affected communities (Abdel-Mooty et al., 2021; Sundari, 2018), assessing vulnerability (De Risi et al., 2020), and estimating physical losses to critical infrastructure (Qiang, 2019; Zhang et al., 2021).

Furthermore, a database on flood intensity can provide insights into the severity of disasters, thereby facilitating the development of context-specific mitigation measures tailored to local flood conditions (Majumder et al., 2019; Vojtek & Vojteková, 2016).

Previous research findings concerning flood disaster management have not adequately supported the limited data availability in Samarinda City. Existing studies primarily focus on predicting flood vulnerability through hydrological and hydraulic calculations (Pratiwi & Ndraha, 2018; Sukmara et al., 2015), assessing the environmental conditions to determine vulnerability and risk (Ayari & Asyiawati, 2023; Matori et al., 2023; Setiawan et al., 2020), and conducting general qualitative evaluations of government and community capabilities (Ali, 2019; Asti & Mayasari, 2023; Fandri, 2020). These previous studies suggested strategies for optimizing, providing, and enhancing water infrastructure capacity. For instance, a study by Wijaya and Agustina (2022) examining channel capacities in the Wahid Hasyim Street corridor revealed safe dimensions for flood drainage, yet practical observations indicate otherwise. However, historical data on flood intensity remains incomplete, leaving unanswered questions concerning how poor drainage conditions affect floods. While channel capacity is crucial for flood control, there is a lack of research in Samarinda City investigating the relationship between flood events and channel conditions. This study asserts that the hypothesis linking effective channels with reduced flood occurrences warrants further exploration in critical areas. Overall, the lack of detailed local data poses a significant challenge for identification purposes in answering such questions.

Having personally witnessed the effects of floods, communities play a crucial role as a significant data source and actively contribute to addressing data gaps about floods (Salami et al., 2017). The involvement of communities is also essential for collaborative knowledge production through integrative flood risk governance management (Williams et al., 2018). Using this approach, the study shows that the community's involvement in flood management can be enhanced, even at the grassroots level, particularly regarding information provision and data sharing. The study utilized community-based information to unveil the various aspects of flood severity in each specific geographic area. Despite the data accuracy issues, employing random sampling of participants in different regions can enhance the reliability of the information and ensure a representative sample, reducing the possibility of false or misleading information (Howell et al., 2020). Conclusions are drawn from data provided by various community members rather than a single individual. Individuals with direct exposure to flooding can offer intricate details, enabling the identification of flood severity levels within each community setting.

Nevertheless, the challenge lies in the communities' capacity to recollect past flood occurrences, with a tendency among individuals to recount recent experiences. In this research area, a significant flood disaster occurred in 2019, marking it as a notable event compared to previous years. Communities tend to generalize flood severity based on their experiences during the 2019 flood disaster. As a result, the study suggests that a more robust and reliable database be established in the future by meticulously observing and documenting all elements of flood data during every flood event, including community involvement. Furthermore, the flood management database can be combined by utilizing satellite imagery to identify flood-prone areas (Wang et al., 2021; Xu et al., 2018) or flood inundations (Wakabayashi et al., 2021; Yulianto et al., 2015), increasing accuracy data.

The flood intensity observed at the neighborhood level, as depicted in Figure 5, can effectively delineate the degree of flood risk related to actual conditions. By employing K-means and hotspot clustering methodologies, areas exhibiting heightened vulnerability can be pinpointed through the analysis of past flood events as reported by local inhabitants. The application of the K-means technique yields insights into the disparate distribution of high flood-intensity regions across various intensity levels, as presented in Figure 5 (left). Moreover, hotspot analysis serves to refine the identification of at-risk areas within the research site based on the statistical significance of local autocorrelation, as shown in Figure 5 (right). These approaches facilitate the cartographic representation of areas in alignment with cluster characteristics and flood intensity hotspots, thereby enabling the customization of flood mitigation strategies to suit the specific attributes of flood-induced impacts.

Maintaining effective flood management, the findings validate the presence of a substantial correlation between flood severity and drainage conditions, as presented in Table 3, particularly in terms of the extent and frequency of inundation, allowing those parameters to play a significant role in flood mitigation. Poor drainage conditions significantly inhibit surface water flow, leading to increased areas of water stagnation and prolonged recession times. Consequently, the greater area of inundation (PPT) leads to the increased potential for economic losses due to damage in residential areas, trades, urban facilities, and infrastructures (Ahmad et al., 2011; Zhang et al., 2021). Furthermore, the increasing frequency of flooding (FRB) significantly heightens the potential for disease among local communities, primarily due to the lack of access to clean water and the subsequent contamination of water sources (Manzoor et al., 2022). The selection of appropriate flood management strategies necessitates a comprehensive understanding of the risk levels and flood characteristics in specific catchment areas and channels (Tariq et al., 2020). This study illustrates that understanding and leveraging differences in cluster patterns based on flood characteristics and intensity can significantly enhance flood hazard assessment and management, ensuring that interventions are appropriately tailored to each region's specific vulnerabilities and needs.

The research findings indicate that the flood intensity in East Sempaja is more pronounced in the northern region, which is characterized by lower elevation and serves as a residential hub with a dense population. Figure 4 shows that identified flood hotspots are notably clustered around RT 36 in the northern region, enabling the prioritization of flood management strategies. These identified hotspots effectively delineate the distribution of areas at higher risk of flooding, underscoring the necessity for targeted disaster management and mitigation efforts in these specific locations. It is essential to note that the absence of a hotspot designation does not negate the need for intervention; rather, hotspot presence signifies a notable aggregation of high values due to neighboring regions experiencing similarly high flood intensities. Hence, cluster and hotspot analyses are essential spatial clustering techniques mutually reinforcing one another. Cluster analysis facilitates the identification of regional groupings based on variable values, whereas hotspots pinpoint concentrations of these variable values.

Finally, drainage conditions are crucial in flood disaster management for controlling water flow and stormwater to mitigate potential flooding risks (Ndoma et al., 2020; Sohn et al., 2020). Adequate drainage systems have the capacity to effectively manage and direct surface runoff during rainfall. Even though the analysis outcomes revealed a weak correlation between flood severity and drainage conditions in all parameters, this correlation is positive and statistically significant, especially in the extent of inundation and the frequency of annual floods. The limited correlation between these variables suggests the presence of additional factors beyond drainage conditions that must be considered in flood management within the study area, allowing further investigation in the future. Therefore, the optimization strategy for drainage channels remains pertinent in managing flood disasters in East Sempaja, particularly in mitigating more severe impacts. Future strategies must continue to evaluate the capacity and quality of primary and secondary channels, including the Karang Mumus River, and land use assessment. Evidence shows that more vulnerable residential areas near the Karang Mumus River have inadequate drainage, and land use changes generate higher rainwater runoff. Collectively, this study underscores the importance of an interrelated approach to drainage management, combining network distribution, appropriate structure dimension, community involvement, and regular maintenance to effectively reduce the impact of flooding in urban settlement areas, especially in flood-prone zones.

4. Conclusions

Flood occurrences in East Sempaja should be understood as more than just predicting inundation or identifying risk, susceptibility, and community capacity in flood disasters. Even though data on flood disasters in Samarinda City is limited, using flood disaster information from the communities may be a viable option due to the direct experiences of those affected by such disasters. Local flood data can provide valuable insights into the size of the disaster area, allowing for improvements in flood management and mitigation techniques suited to the individual characteristics of the affected region. This study demonstrates the importance of community-derived information as critical data for evaluating flood intensity and predicting the severity of flood occurrences in East Sempaja. This study's findings reveal that most RT areas in East Sempaja exhibit moderate to high flood intensity levels, mainly concentrated in the northern region, with RT 36 identified as a focal point. Categorizing flood intensity levels in East Sempaja can help identify crucial locations for prioritizing flood management and mitigation measures based on the particular characteristics of the impacted zones. Furthermore, this study emphasizes a previously unexplored association between local flood conditions and drainage systems in flood-prone areas. The study's findings show that residential drainage channel conditions are not strongly correlated with flood intensity levels; however, the correlation is still positive and statistically significant. Despite a weak correlation between the two factors, the importance of drainage systems in the effective management of flood disasters in East Sempaja cannot be neglected.

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