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GIS-Based Mapping of Residential Water Ponding Vulnerability Using Weighted Overlay Analysis in Lamongan District, Indonesia

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ABSTRACT

Residential water ponding has become a recurring problem in Lamongan District, Indonesia, disrupting residential activities and increasing the risk of flooding. Accurate spatial identification of vulnerable areas is essential to support effective urban planning and drainage management. This study aims to map residential water ponding vulnerability using a Geographic Information System (GIS) and the Weighted Overlay Analysis. Five parameters, namely rainfall, slope, soil type, land use, and drainage conditions, were processed using ArcGIS through scoring, weighting, and spatial overlay techniques. A field questionnaire survey was also conducted to validate the spatial analysis results. The analysis classified the study area into four vulnerability levels: Low, Moderate, High, and Very High. The High vulnerability class dominated the study area, covering 37.14%, followed by Moderate (32.90%), Very High (25.41%), and Low (3.64%). Questionnaire results confirmed that water ponding frequently occurs in several residential areas, with respondents identifying high rainfall, inadequate drainage capacity, and blocked drainage channels as the primary contributing factors. The consistency between GIS analysis and field observations indicates that the proposed approach provides reliable spatial information for identifying priority areas for flood mitigation. The resulting vulnerability map can support evidence-based urban planning and sustainable drainage management in Lamongan District.

Contribution to Sustainable Development Goals (SDGs):

SDG 6: Clean Water and Sanitation

SDG 11: Sustainable Cities and Communities

SDG 13: Climate Action

SDG 15: Life on Land

1. INTRODUCTION

1.1. Research Background

Urban water ponding has become one of the most significant environmental challenges affecting rapidly growing cities worldwide. Rapid urbanization, land-use change, increasing impervious surfaces, and climate-induced changes in rainfall patterns have substantially altered the natural hydrological cycle, resulting in greater surface runoff and a higher frequency of water ponding and urban flooding. These conditions not only damage

infrastructure but also disrupt transportation systems, reduce economic productivity, threaten public health, and decrease the quality of urban environments. Recent studies have emphasized that rainfall intensity, urban development, and inadequate stormwater management are the primary factors accelerating urban water ponding in residential areas [1]–[4].

In Indonesia, urban water ponding has become an increasingly frequent problem due to high seasonal rainfall, rapid urban expansion, and inadequate drainage infrastructure. Residential areas are particularly vulnerable because urban development often exceeds the capacity of existing drainage



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systems, resulting in surface water accumulation during moderate-to-heavy rainfall events. Lamongan Regency, East Java Province, experiences similar conditions, with recurring inundation reported in several residential areas during the rainy season. These inundation events not only disrupt daily community activities and transportation but also damage residential infrastructure and degrade environmental quality. Therefore, understanding the spatial distribution of inundation-prone areas is essential for supporting evidence-based urban planning, drainage improvement, and disaster risk reduction strategies [5]–[8].

Geographic Information Systems (GIS) have become one of the most effective spatial decision-support tools for identifying, analyzing, and visualizing areas susceptible to water ponding and flooding. By integrating multiple spatial variables, GIS enables comprehensive analysis of interactions among environmental factors that influence inundation. Among various spatial analysis techniques, the Weighted Overlay approach combined with Multi-Criteria Decision Analysis (MCDA) has been widely adopted because it allows multiple conditioning factors to be evaluated simultaneously according to their relative importance. This method provides a systematic framework for integrating rainfall, slope, soil type, land use, and drainage conditions into a single spatial susceptibility map, thereby supporting more accurate identification of inundation-prone residential areas and facilitating evidence-based urban planning and disaster mitigation [9],[10].

Flood inundation is a complex phenomenon influenced by the interaction of multiple environmental and anthropogenic factors rather than by rainfall alone. Therefore, selecting appropriate conditioning factors is essential to improve the reliability of GIS-based inundation mapping. In this study, five key parameters were considered, namely rainfall, slope, soil type, land use, and drainage conditions. Rainfall directly determines the volume of water entering the watershed and is the primary driving force of surface runoff [1], [2]. Slope controls runoff velocity and water accumulation, where relatively flat areas generally have a greater tendency to experience prolonged inundation than steeper terrain [14]–[16]. Soil type influences infiltration capacity and permeability, thereby affecting how much rainfall infiltrates into the ground versus becomes surface runoff [14]–[16]. Land use determines the proportion of impervious surfaces, where urbanized and densely built-up areas typically generate higher runoff than vegetated land [17]–[19]. Furthermore, drainage conditions determine the efficiency of stormwater conveyance, and inadequate drainage systems substantially increase the likelihood of water accumulation in residential areas [5], [6]. The integration of these five parameters provides a comprehensive representation of the physical characteristics controlling water inundation and forms the basis for spatial susceptibility assessment using the Weighted Overlay method.

Previous studies have demonstrated that Geographic Information Systems (GIS) integrated with Multi-Criteria Decision Analysis (MCDA) and Weighted Overlay techniques are effective tools for flood susceptibility and inundation mapping. Amiri et al. [20] applied a GIS-based machine learning approach to improve flood susceptibility prediction by integrating multiple environmental variables and remote sensing data. Similarly, Faizan et al. [21] employed the Analytical Hierarchy Process (AHP) combined with GIS to classify flood-prone areas using rainfall, slope, land use, and soil characteristics. Bokhari et

al. [22] further demonstrated that integrating Fuzzy-AHP with GIS enhances the reliability of flood susceptibility mapping by reducing subjectivity in parameter weighting. In addition, Das and Gupta [23] successfully applied Multi-Criteria Decision Analysis (MCDA) to evaluate flood susceptibility and hydro-geomorphic changes, while Vashist and Singh [24] confirmed that GIS-based AHP provides reliable spatial information for identifying flood-prone areas and supporting disaster mitigation planning. Collectively, these studies confirm that integrating multiple environmental parameters within a GIS framework is an effective approach for flood hazard assessment and spatial decision-making.

Although previous studies have demonstrated the effectiveness of GIS-based flood susceptibility mapping using Multi-Criteria Decision Analysis (MCDA), Analytical Hierarchy Process (AHP), and machine learning approaches, several limitations remain. Most existing studies focus on regional flood susceptibility at the watershed or city scale rather than on residential water ponding at the district level [20]–[24]. In addition, drainage conditions are often treated as secondary variables, despite their significant influence on ponding of water in urban residential areas. Furthermore, many studies rely primarily on physical environmental parameters and do not incorporate community perceptions to validate the results of spatial analyses, thereby limiting the practical applicability of the generated susceptibility maps for local planning and decision-making [17], [19]. These limitations indicate the need for a more comprehensive GIS-based assessment that integrates both physical environmental factors and field-based community information to better represent residential water ponding conditions.

To address these research gaps, this study proposes a GIS-based spatial assessment specifically designed for residential water ponding in Lamongan District, East Java, Indonesia. Unlike previous studies that mainly emphasize flood susceptibility at broader regional scales, this research focuses on water ponding in residential areas at the district level by integrating five key conditioning factors, namely rainfall, slope, soil type, land use, and drainage conditions, through the Weighted Overlay Analysis approach [5], [9], [17], [29]. In addition, community perceptions obtained through questionnaire surveys are incorporated to complement and validate the spatial analysis results, thereby providing a more comprehensive understanding of residential water-ponding conditions. The resulting inundation susceptibility map is expected to support local governments in identifying priority areas for drainage improvement, disaster mitigation, and sustainable urban planning based on spatial evidence.

Based on the identified research gaps and the proposed research framework, this study aims to assess the spatial vulnerability of residential water ponding in Lamongan District, East Java, Indonesia, by integrating rainfall, slope, soil type, land use, and drainage conditions within a Geographic Information System (GIS)-based Weighted Overlay Analysis. Specifically, this study seeks to (1) evaluate the spatial influence of the five conditioning factors on residential water ponding vulnerability, (2) produce a vulnerability map that classifies residential areas into different susceptibility levels, and (3) validate the spatial analysis results using community-based questionnaire data. The findings are expected to provide scientific evidence and practical spatial information that can support local governments in prioritizing drainage improvement, reducing residential water

ponding risk, and promoting sustainable urban planning and disaster mitigation [5], [7], [8], [20], [25].

1.2. Literature Review

1.2.1. Geographic Information Systems

Geographic Information Systems (GIS) are computer-based systems designed to capture, store, manage, analyze, and visualize geographically referenced data. By integrating spatial and attribute information within a unified analytical framework, GIS enables researchers to investigate spatial relationships, identify patterns, and support evidence-based decision-making across fields such as environmental management, hydrology, and urban planning. The capability of GIS to combine multiple thematic datasets into a single spatial database has made it one of the most widely adopted tools for flood susceptibility assessment and water ponding analysis [1], [2].

Recent studies have demonstrated that GIS significantly improves the accuracy of environmental vulnerability mapping by integrating multiple flood-conditioning factors, such as rainfall, slope, soil type, land use, and drainage conditions, into a comprehensive spatial model. Compared with conventional mapping approaches, GIS facilitates spatial processing techniques including overlay analysis, reclassification, buffering, and spatial interpolation, enabling more objective identification of vulnerable locations. Consequently, GIS has become a fundamental platform for developing flood susceptibility maps and supporting disaster mitigation planning at local and regional scales [5], [7], [17].

Beyond its capability for spatial visualization, GIS also serves as an effective decision-support system by integrating Multi-Criteria Decision Analysis (MCDA) techniques. The combination of GIS and MCDA enables environmental parameters to be weighted by their relative influence on flood occurrence, thereby improving the reliability of spatial assessments. This integration has been widely applied in flood hazard and water ponding studies because it enables the systematic evaluation of complex environmental interactions and produces practical outputs for infrastructure planning and disaster risk reduction [18], [19], [20].

1.2.2. Weighted Overlay Analysis

Weighted Overlay Analysis (WOA) is one of the most widely used Multi-Criteria Decision Analysis (MCDA) techniques in Geographic Information Systems (GIS) for evaluating spatial suitability and environmental vulnerability. The method integrates multiple thematic layers by assigning relative weights and scores to each parameter based on its contribution to a specific phenomenon. Through this process, different environmental variables can be standardized and combined into a single spatial index that represents the degree of susceptibility or suitability of each location. Because of its simplicity, flexibility, and ability to incorporate expert knowledge, Weighted Overlay Analysis has been extensively applied in flood susceptibility mapping, land suitability assessment, and environmental hazard evaluation [5], [11], [17].

The effectiveness of Weighted Overlay Analysis depends on the appropriate selection of conditioning factors and the assignment of representative weights to each parameter. Previous studies have successfully integrated variables such as rainfall, slope, soil type, land use, and drainage conditions to produce

reliable flood susceptibility maps using GIS-based Weighted Overlay techniques. Compared with single-factor analyses, integrating multiple parameters provides a more comprehensive representation of hydrological processes and environmental characteristics that influence water accumulation. Consequently, the Weighted Overlay approach has become one of the most practical and transparent methods for supporting flood risk assessment and spatial planning [12]–[15], [18].

In this study, the Weighted Overlay Analysis method was selected because it enables the integration of five major flood-conditioning factors, namely rainfall, slope, soil type, land use, and drainage conditions, into a unified spatial assessment framework. Each parameter was classified, assigned a suitability score, and weighted according to its relative contribution to residential water ponding. The resulting weighted spatial model provides a systematic basis for identifying inundation-prone areas and supports evidence-based decision-making for drainage improvement, land-use planning, and disaster risk reduction at the district level [17], [18], [35], [39].

1.2.3. Rainfall

Rainfall is a primary factor influencing residential water ponding, as it directly controls the volume and intensity of surface runoff during precipitation events. Higher rainfall intensity and longer rainfall duration generally increase the likelihood of inundation, particularly in areas with limited infiltration capacity and inadequate drainage systems. Previous studies have consistently identified rainfall as a dominant parameter in flood susceptibility mapping, emphasizing its critical role in determining the spatial distribution of flood-prone areas. Therefore, rainfall is incorporated as one of the principal conditioning factors in GIS-based Weighted Overlay Analysis [23]–[26], [43].

1.2.4. Slope

Slope significantly influences the movement and accumulation of surface runoff by controlling flow velocity and drainage efficiency. Areas with gentle or nearly flat slopes generally experience slower runoff, allowing water to accumulate longer and increasing the potential for residential water ponding. Conversely, steeper slopes facilitate faster runoff and reduce the likelihood of prolonged inundation. Due to its strong influence on hydrological processes, slope has been widely recognized as one of the essential parameters in GIS-based flood susceptibility assessments [27]–[30], [45].

1.2.5. Soil Type

Soil type affects residential water ponding by influencing infiltration capacity, permeability, and water retention characteristics. Fine-textured soils with high clay content generally exhibit lower infiltration rates, resulting in greater surface runoff and increased inundation potential, whereas coarse-textured soils promote faster infiltration and reduce water accumulation. Consequently, soil characteristics are frequently incorporated into flood susceptibility studies to improve the representation of hydrological responses within GIS-based spatial analyses [31]–[34], [46].

1.2.6. Land Use

Land use plays a significant role in controlling runoff generation because different land cover types exhibit varying infiltration

capacities and surface characteristics. Urban and residential areas, which are dominated by impervious surfaces such as roads and buildings, generally generate higher runoff than vegetated or agricultural land. Changes in land use associated with urbanization have therefore been recognized as major contributors to increased flood susceptibility and residential water ponding. Accordingly, land use is commonly included as a key parameter in GIS-based flood vulnerability mapping [17]–[19], [30].

1.2.7. Drainage

Drainage systems determine the efficiency of stormwater conveyance and are therefore essential in reducing the occurrence and duration of residential water ponding. Well-developed drainage networks facilitate rapid runoff discharge, whereas inadequate drainage capacity or poorly maintained drainage channels increase the likelihood of water accumulation during rainfall events. Recent studies have highlighted that integrating drainage conditions with other environmental parameters significantly improves the accuracy of flood susceptibility assessments and supports more effective urban drainage planning and flood mitigation strategies [3]–[5].

1.3. Research Objective

Based on the research background, literature review, and identified research gaps, this study aims to assess the spatial vulnerability of residential water ponding in Lamongan District, East Java, Indonesia, using a Geographic Information System (GIS)-based Weighted Overlay Analysis. The assessment integrates five key conditioning factors, namely rainfall, slope, soil type, land use, and drainage conditions, to produce a residential water ponding vulnerability map. Furthermore, this study aims to validate the spatial analysis results using community-based questionnaire data and to provide scientific information to support local governments in identifying priority areas for drainage improvement, urban planning, and mitigation of residential water ponding.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in Lamongan District, Lamongan Regency, East Java Province, Indonesia. The district covers an area of approximately 40.9441 km² and comprises 20 villages/urban villages, making it one of the most densely populated administrative areas in the regency. As the administrative and economic center of Lamongan Regency, the district has experienced rapid urban development, resulting in increased impervious surfaces and greater pressure on the existing drainage system. During the rainy season, several residential areas frequently experience water ponding due to the combined effects of high rainfall, relatively flat topography, land-use changes, and insufficient drainage capacity. These characteristics make Lamongan District an appropriate study area for assessing residential water ponding vulnerability using Geographic Information System (GIS)-based spatial analysis. The geographical location of the study area is shown in Figure 1. Spatial datasets used in this study include administrative boundaries, the Digital Elevation Model Nasional (DEMNAS), rainfall data from the Indonesian Agency for Meteorology,

Climatology, and Geophysics (BMKG), land-use data, soil-type maps, and drainage network data collected from relevant government agencies. These datasets were integrated into a GIS environment to support spatial analysis and mapping of residential water-ponding vulnerability .

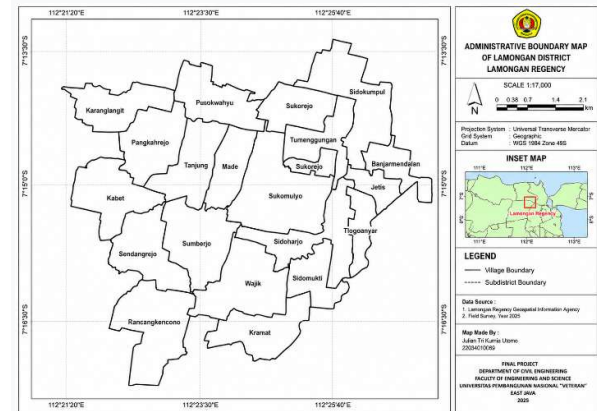


Figure 1. Study Area Map of Lamongan District

2.2. Research Data

Table 1.Research Data Used in the Study

Data	Source	Purpose
Administrative Boundary	BPS / BIG	Study area boundary
Rainfall	BMKG	Rainfall parameter
DEM	DEMNAS	Slope analysis
Soil Type	FAO Soil	Soil parameter
Land Use	RBI / Digitizing	Land use parameter
Drainage Network	Dinas PRKPCK Kabupaten Lamongan	Drainage parameter
Questionnaire	Field Survey	Validation

2.3. Research Method

This research employed a quantitative spatial analysis using Geographic Information Systems (GIS) and the Weighted Overlay Analysis method to assess residential water-ponding vulnerability in Lamongan District. The research consisted of several sequential stages, including data collection, spatial data preprocessing, thematic map preparation, parameter classification and scoring, weighted overlay analysis, and validation using community-based questionnaire data. Spatial datasets, including rainfall, slope, soil type, land use, and drainage conditions, were processed and converted into thematic layers within the GIS environment. Each parameter was subsequently classified according to its criteria, then assigned a score and weight based on its relative contribution to residential water ponding. Finally, all weighted thematic layers were integrated through the Weighted Overlay Analysis to generate a residential water ponding vulnerability map, which was then validated using field questionnaire data to evaluate the

consistency between spatial analysis results and community observations [5], [9], [25], [29].

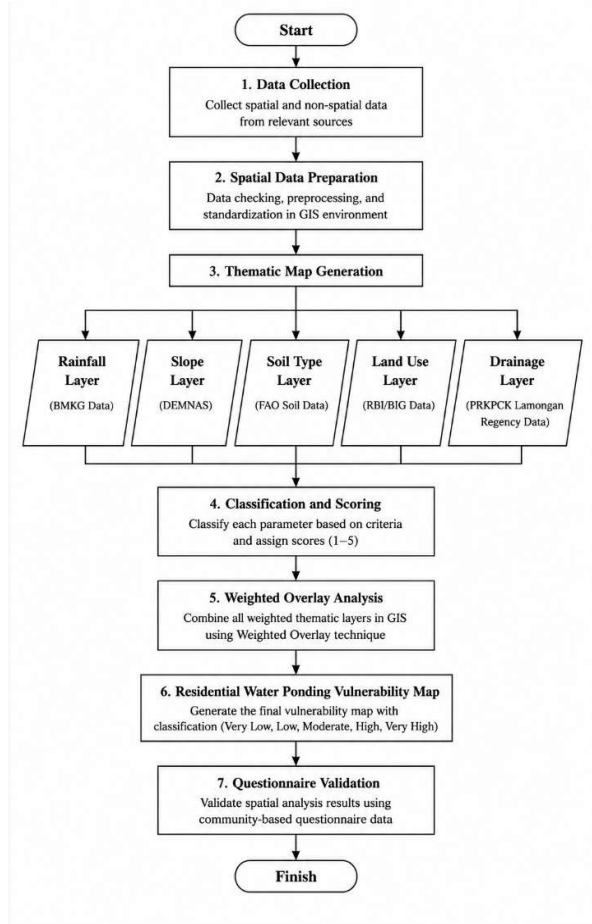


Figure 2. Research Methodology Flowchart

2.4. GIS Spatial Analysis

Geographic Information System (GIS) spatial analysis was performed in ArcGIS to evaluate the spatial distribution of residential water-ponding vulnerability in Lamongan District. All spatial datasets, including rainfall, slope, soil type, land use, and drainage, were first converted into raster format with a uniform coordinate system and spatial resolution to ensure data consistency. Each thematic layer was then processed through clipping, reclassification, and spatial standardization based on the predefined classification criteria. These preprocessing steps ensured that all parameters were represented in a comparable format before the weighted overlay analysis was conducted [9], [25], [29].

The resulting thematic layers were subsequently integrated within the GIS environment to produce a spatial database representing the environmental conditions of the study area. GIS tools were utilized to manage, visualize, and analyze the spatial relationships among the five conditioning factors. This spatial analysis provided the basis for identifying areas potentially susceptible to residential water ponding and served as the primary input for the Weighted Overlay Analysis described in the subsequent section [20], [29].

2.5. Scoring Criteria

Table 2. Scoring Criteria

Parameter	Classification	Score
Rainfall (mm/year)	>3000	5
	2501–3000	4
	2001–2500	3
	1501–2000	2
	<1500	1
Slope (%)	15–30 (Hilly)	4
	8–15 (Rolling)	3
	3–8 (Undulating)	2
	0–3 (Flat)	1
Soil Type	Alluvial, Planosol, Gray Hydromorphic	5
	Latosol	4
	Brown Forest, Mediterranean	3
	Andosol, Lateritic, Grumosol, Podsol, Podsollic	2
	Regosol, Litosol, Organosol, Renzina	1
Land Use	Residential / Built-up	5
	Rice Field / Fish Pond	4
	Dry Land / Moor / Plantation	3
	Shrubland	2
	Forest	1
Drainage	Poor	4
	Moderate	3
	Good	2
	Very Good	1

2.6. Spatial Overlay Analysis

Following the scoring process, each thematic layer was reclassified into standardized scores ranging from **1 to 5** according to the established scoring criteria. The reclassified raster layers representing rainfall, slope, soil type, land use, and drainage were subsequently integrated using the Raster Calculator tool in ArcGIS to generate the residential water ponding vulnerability map. This spatial overlay approach enables multiple environmental parameters to be combined into a single thematic map for vulnerability assessment [20], [29].

The resulting raster values represent the cumulative scores across the five thematic parameters and were subsequently classified into four levels of residential water-ponding vulnerability: Low, Moderate, High, and Very High. The classification results were then visualized as a vulnerability map to identify areas with different levels of residential water ponding susceptibility in Lamongan District.

3. RESULT AND DISCUSSION

3.1. Rainfall Analysis

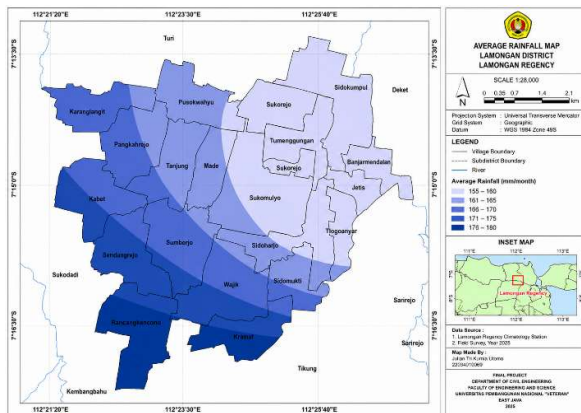


Figure 3. Rainfall Distribution Map of Lamongan District

The annual rainfall distribution in Lamongan District was generated using BMKG rainfall data and classified according to the scoring criteria presented in Table 2. The results indicate that most of the study area falls within the Moderately Low (1,501–2,000 mm/year) and Moderate (2,001–2,500 mm/year) rainfall categories. Areas with higher annual rainfall received higher scores because they generate greater surface runoff, thereby increasing the potential for residential water ponding [1], [2], [7].

The spatial distribution indicates that rainfall varies across the study area, resulting in different runoff potentials among locations. Areas receiving relatively high annual rainfall tend to accumulate more water, particularly during periods of intense precipitation. This observation is consistent with previous studies, which reported that increasing rainfall intensity contributes to higher runoff generation and flood susceptibility [1], [9].

3.2. Slope Analysis

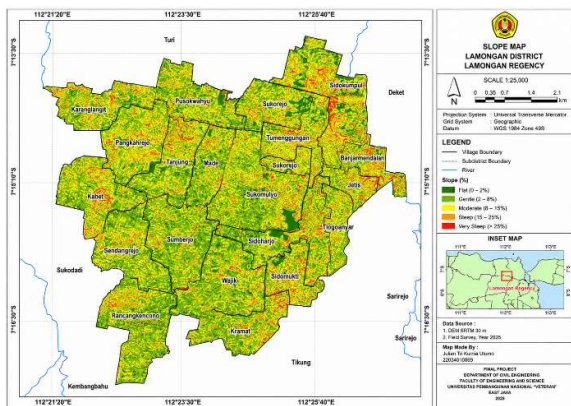


Figure 4. Slope Map of Lamongan District

The slope map of Lamongan District was generated from the Digital Elevation Model Nasional (DEMNAS) and classified according to the scoring criteria presented in Table 2. The analysis shows that the study area is predominantly characterized by flat (0–3%) and undulating (3–8%) terrain. These topographic conditions received lower to moderate scores because gentle slopes reduce runoff velocity and increase the potential for

temporary water accumulation, particularly in residential areas with limited drainage capacity [27], [28], [45].

The spatial distribution of slope indicates that relatively flat areas are more susceptible to residential water ponding due to slower surface runoff. This finding is consistent with previous studies, which reported that low-gradient terrain promotes water accumulation and increases flood susceptibility, whereas steeper slopes facilitate rapid runoff and reduce inundation potential [1], [11], [12].

Table 3. Slope Gradient

Slope Class	Area (ha)	Percentage (%)
Flat	454.92	11.20
Gentle	1,878.06	46.26
Moderate	1,113.57	27.43
Steep	467.00	11.50
Very Steep	146.65	3.61
Total	4,060.20	100.00

3.3. Soil Type Analysis

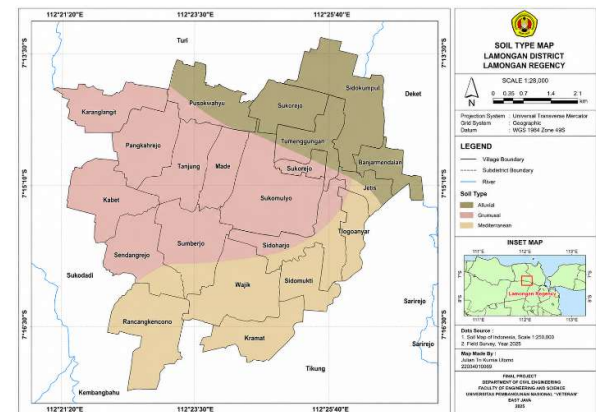


Figure 5. Soil Type Map of Lamongan District

Table 4. Soil Type Classification in Lamongan District

Soil Type	Area (ha)	Percentage (%)
Grumosol	1,689.13	41.26
Mediteran	1,280.86	31.29
Aluvial	1,123.54	27.45
Total	4,094.41	100.00

The soil type map of Lamongan District was classified according to the scoring criteria presented in Table 2, while the spatial distribution and area of each soil type are summarized in Table 4. The results indicate that the study area comprises several soil types with varying infiltration capacities, leading to varying levels of residential water-ponding susceptibility. Soil types assigned higher scores generally exhibit lower infiltration capacity, allowing a greater proportion of rainfall to become surface runoff and increasing the potential for water accumulation [14], [15], [27].

The spatial variation in soil characteristics influences the hydrological response of the study area. Areas dominated by low-permeability soils tend to retain surface water for longer periods,

thereby increasing the likelihood of residential water ponding. This finding is consistent with previous studies, which reported that soil infiltration characteristics play an important role in controlling runoff generation and flood susceptibility [9], [14], [15].

3.4. Land Use Analysis

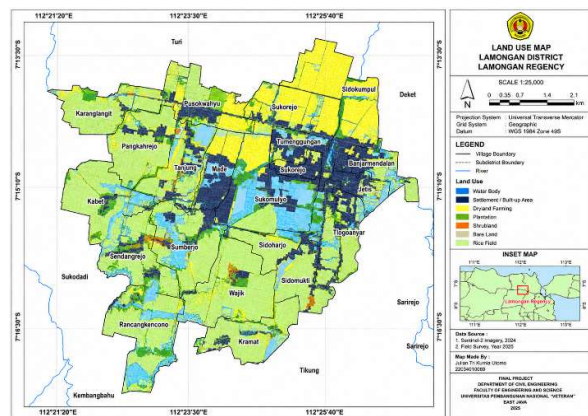


Figure 6. Land Use Map of Lamongan District

Table 5. Land Use Classification in Lamongan District

Land Use	Area (ha)	Percentage (%)
Residential Area	804.97	19.66
Rice Field	1,685.13	41.16
Dry Agricultural Land	829.71	20.28
Plantation	246.96	6.03
Shrubland	17.97	0.44
River	8.66	0.21
Lake/Pond	501.02	12.24
Total	4,094.41	100.00

The land use map of Lamongan District was classified according to the scoring criteria presented in Table 2, while the spatial distribution and area of each land use class are summarized in Table 5. The results show that the study area comprises residential areas, rice fields, ponds, dry land, plantations, shrubland, and forest, each with distinct spatial distributions. Residential and built-up areas received the highest score due to their high proportion of impervious surfaces, whereas forest areas received the lowest score because of their greater infiltration capacity [17], [18], [27].

The dominance of built-up land use in urban areas increases surface runoff by reducing water infiltration into the soil. Consequently, residential areas are more susceptible to water ponding, particularly during heavy rainfall events. These findings are consistent with previous studies, which reported that urbanization and land use changes significantly increase runoff generation and flood susceptibility by decreasing natural infiltration capacity [9], [17], [18].

3.5. Drainage Analysis

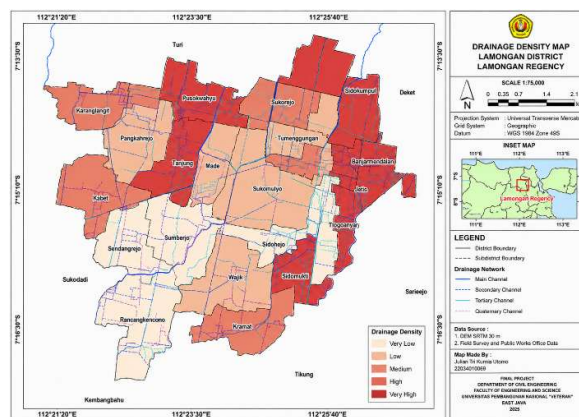


Figure 7. Drainage Network Map of Lamongan District

Table 6. Drainage Classification

Drainage Classification	Score	Description
Very Good	1	Very high drainage network density
Good	2	High drainage network density
Moderate	3	Moderate drainage network density
Poor	4	Low drainage network density

The drainage condition map of Lamongan District is presented in Figure 7, while the classification results are summarized in Table 6. The analysis indicates that the study area is predominantly classified as having good drainage conditions, whereas **very** good, moderate, and poor drainage conditions are distributed in several locations. This spatial variation reflects differences in the capacity of drainage networks to convey surface runoff, which may influence the occurrence of residential water ponding [5], [6].

Areas with poor or moderate drainage are more likely to experience temporary water accumulation due to their limited capacity to discharge runoff during rainfall events. In contrast, areas with good and very good drainage generally have more effective drainage networks, allowing stormwater to be conveyed more efficiently and reducing the potential for prolonged water ponding. The spatial differences observed in this study indicate that drainage performance varies across the study area and should be considered in urban drainage management.

These findings are consistent with previous studies, which reported that drainage capacity is a key factor influencing urban water ponding. Regular maintenance of drainage channels, removal of sediment and solid waste, and improvements to drainage infrastructure can enhance runoff conveyance and reduce residential water ponding [5], [6].

3.6. Water Ponding Vulnerability Mapping

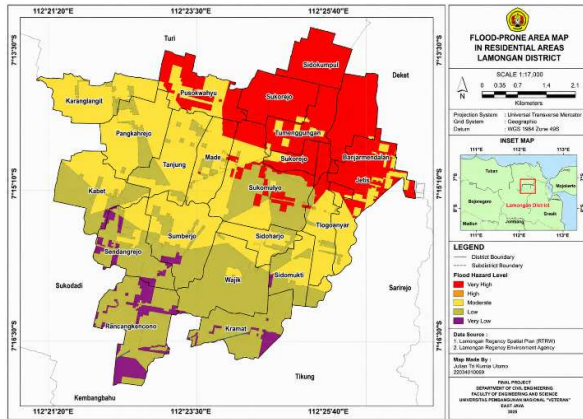


Figure 8. Water Ponding Vulnerability Map of Lamongan District

Table 7. Water Ponding Vulnerability Classification

Vulnerability Level	Area (ha)	Percentage (%)
Low	149.04	3.64
Moderate	1,346.97	32.90
High	1,520.64	37.14
Very High	1,040.59	25.41
Total	4,094.41	100.00

The residential water ponding vulnerability map generated using the Weighted Overlay Analysis is presented in Figure 8, while the classification results are summarized in Table 7. The analysis shows that the High vulnerability class dominates the study area, covering 1,520.64 ha (37.14%), followed by the Moderate class with 1,346.97 ha (32.90%). The Very High vulnerability class occupies 1,040.59 ha (25.41%), whereas the Low vulnerability class represents only 149.04 ha (3.64%). These results indicate that approximately 95% of the study area falls within the Moderate to Very High vulnerability categories, suggesting that residential water ponding is a widespread environmental issue in Lamongan District.

The spatial distribution demonstrates that areas classified as High and Very High vulnerability are generally associated with the combined influence of relatively high rainfall, gentle topography, low-permeability soils, built-up land use, and less effective drainage conditions. These environmental characteristics reduce infiltration and increase surface runoff, leading to a greater tendency for water accumulation during rainfall events. In contrast, areas classified as Low vulnerability generally possess more favorable physical conditions, including better drainage performance and land characteristics that facilitate runoff and infiltration. These findings confirm that residential water ponding is controlled by the interaction of multiple environmental factors rather than by a single parameter alone [9], [17].

The resulting vulnerability map provides practical spatial information to identify priority areas requiring drainage improvements and flood mitigation. Areas classified as High and Very High should receive greater attention through drainage rehabilitation, routine maintenance, and sustainable land-use management to reduce residential water ponding risk. Therefore, the generated map can support evidence-based decision-making

for urban planning and disaster mitigation in Lamongan District [5], [6].

3.7. Questionnaire Validation

Figure 9. Summary of Questionnaire Results

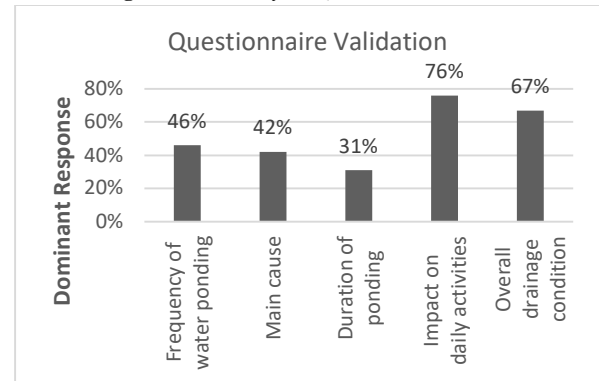


Table 8. Summary of Questionnaire Responses

Indicator	Dominant Response
Frequency of water ponding	Rarely (46%)
Main cause	High rainfall (42%)
Duration of ponding	Less than 1 hour (31%)
Impact on daily activities	Very disturbing (76%)
Overall drainage condition	Good (67%)

The questionnaire survey was conducted to validate the spatial analysis results obtained from the GIS-based weighted overlay. The survey collected community perceptions of residential water ponding, including its frequency, duration, primary causes, impacts on daily activities, and the condition of the existing drainage system. These responses provide field-based information that complements the spatial analysis and strengthens the interpretation of the resulting vulnerability map.

The survey results indicate that 46% of respondents reported that water ponding occurs rarely, while 42% identified high rainfall as the primary cause of ponding. Most respondents (31%) stated that water ponding generally lasts less than one hour, although 76% considered it very disruptive to their daily activities. Furthermore, 67% of respondents assessed the existing drainage condition as good, indicating that drainage infrastructure is generally available but may not always be sufficient to accommodate intense rainfall events. These findings suggest that localized drainage limitations and environmental conditions still contribute to the occurrence of temporary water ponding.

Overall, the questionnaire findings are consistent with the GIS analysis, which identified a predominance of moderate-to-high water-ponding vulnerability across Lamongan District. The agreement between community observations and spatial analysis indicates that the weighted overlay method effectively represents field conditions. Therefore, integrating GIS-based spatial analysis with questionnaire data provides a more reliable basis for identifying priority areas for drainage improvement and supporting sustainable urban water ponding management [24], [28].

4. CONCLUSION

This study applied a Geographic Information System (GIS) and Weighted Overlay Analysis to map residential water-ponding vulnerability in Lamongan District, Indonesia. The integration of rainfall, slope, soil type, land use, and drainage conditions resulted in the classification of the study area into four vulnerability levels. The High vulnerability class occupied the largest area (37.14%), followed by the Moderate (32.90%) and Very High (25.41%) classes, while the Low vulnerability class accounted for only 3.64% of the study area. These results indicate that most residential areas have moderate to very high vulnerability to water ponding. The questionnaire survey supports the spatial analysis results, indicating that residential water ponding remains a common issue in several parts of Lamongan District. Community responses generally identified high rainfall, inadequate drainage capacity, and drainage blockage as the main factors contributing to water ponding. This agreement between the GIS analysis and field observations increases the reliability of the vulnerability assessment. The resulting vulnerability map provides useful spatial information for prioritizing drainage improvement and flood mitigation planning. Therefore, the GIS-based approach can support evidence-based urban planning and sustainable water management in Lamongan District. Future studies are recommended to incorporate additional hydrological parameters and higher-resolution spatial data to improve mapping accuracy.

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