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MORALITY BEFORE KNOWLEDGE

Analyzing the impact of land use change on flood risk and social vulnerability using SCS-CN method and GIS

Yulaichah[1,*]
[1] *Department of Geography, Faculty of Geography, Universitas Gadjah Mada, Sleman, Special Region of Yogyakarta 55281, Indonesia.*
*Correspondence: yulaichah1996@mail.ugm.ac.id

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ABSTRACT

Background: Urban flooding has emerged as a chronic environmental challenge in Malang City, contradicting its geomorphological advantage as a highland region. This persistent phenomenon is fundamentally driven by rapid urbanization within the Bango Sub-watershed, where the massive conversion of permeable landscapes into impervious surfaces has severely disrupted the local hydrological balance. Understanding the complex interplay between physical landscape alterations and social demographic pressures is essential for formulating effective disaster mitigation strategies. **Methods:** This study employs a comprehensive quantitative spatial approach, integrating Geographic Information Systems (GIS) with the Soil Conservation Service Curve Number (SCS-CN) method to model surface runoff volumes and map flood hazards. Land use classification was conducted using Support Vector Machine algorithms on high-resolution satellite imagery to ensure precision. Uniquely, this research incorporates a social dimension through the calculation of the Settlement Carrying Capacity (DDPm) index to assess the sustainability of population density relative to the availability of safe land. **Findings:** The analysis demonstrates a significant positive correlation between the expansion of built-up areas and the magnitude of flood hazards. Areas dominated by commercial buildings and dense settlements exhibit extreme Curve Number values, identifying Blimbing and Lowokwaru Districts as critical runoff generators. The study reveals a severe carrying capacity deficit in the city center, where population pressure forces settlements to expand into disaster-prone river border zones, creating "hotspots" that combine high physical hazard with acute social vulnerability. **Conclusion:** It is concluded that the escalation of flood risk in the Bango Sub-watershed is an anthropogenic consequence of spatial planning mismanagement, rather than mere natural meteorological variability. Sustainable mitigation demands a paradigm shift from purely structural engineering to rigorous land use management, emphasizing the enforcement of river regulations and runoff retention policies. **Novelty/Originality of Article:** This article offers a novel methodological framework by synthesizing hydrological modeling with settlement carrying capacity assessment. Unlike traditional studies that isolate physical risks, this research explicitly links runoff dynamics with demographic pressures, providing a holistic perspective on how social demand for housing drives land conversion and amplifies disaster vulnerability in rapidly developing urban watersheds.

KEYWORDS: land use change; flood risk; social vulnerability; settlement carrying capacity; bango sub-watershed.

1. Introduction

Flooding in East Java represents a complex hydrometeorological phenomenon resulting from the interaction between climatic variability, watershed characteristics, and anthropogenic pressures. Increasing rainfall intensity, coupled with watershed degradation and inadequate drainage systems, has significantly exacerbated flood occurrences across

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the region. According to the Regional Disaster Management Agency of East Java, the province is exposed to numerous disaster types, the majority of which are natural hazards such as floods, landslides, droughts, and extreme weather events (Regional Disaster Management Agency of East Java, 2022). Within Southeast Asia more broadly, hydrometeorological disasters—particularly floods—are the most frequent and spatially widespread, affecting both urban and rural environments (Chen et al., 2023). At the global scale, flood risk is increasingly shaped by the interaction between land use dynamics and climate change. Studies show that urban expansion significantly increases exposure to flooding, particularly in rapidly developing regions (Jongman et al., 2012; Winsemius et al., 2018; Balaian et al., 2024). Furthermore, changes in land use and climate variability jointly amplify flood hazards by altering runoff generation processes and increasing the frequency of extreme hydrological events (Sun et al., 2022; White et al., 2025). This trend is particularly evident in urban catchments, where the transformation of natural landscapes into built environments fundamentally modifies hydrological responses (Endreny, 2006; Fletcher et al., 2015).

Spatially, flood-prone areas in East Java are distributed across multiple regencies and cities, including Malang, Batu, Kediri, Pasuruan, and Probolinggo. These flood events vary in typology, ranging from flash floods in mountainous regions to riverine and pluvial flooding in lowland and coastal areas. Such diversity highlights the importance of understanding local hydrological characteristics and transitional seasonal shifts when designing context-specific mitigation strategies (Zhou et al., 2017; Patel et al., 2022). Recent studies consistently demonstrate that land use change is a critical driver of increasing flood risk. The conversion of permeable surfaces into impervious urban areas reduces infiltration capacity and significantly increases surface runoff (Paul & Meyer, 2001; Feng et al., 2021; Kim & Lee, 2021; Młyński et al., 2024). In urban environments, these effects are further exacerbated by inadequate drainage infrastructure, which is often unable to accommodate increased runoff volumes (Suripin, 2004; Department of Public Works, 2014; Davis & Naumann, 2019).

Malang City presents a unique case in flood studies. Despite its relatively high elevation, which theoretically reduces flood susceptibility, the city has experienced persistent and increasing flood events over the past two decades. Records indicate hundreds of flood incidents occurring during transitional seasons, reflecting the inability of the urban hydrological system to adapt to rainfall variability and rapid urbanization (Central Statistics Agency of Malang City, 2023; National Institute of Technology Malang, 2024; Azwar et al., 2024). The spatial distribution of flooding in Malang City reveals systemic challenges related to land use planning and environmental management. Rapid urban expansion has reduced green open spaces and transformed natural catchment areas into built-up zones, while encroachment into river buffer zones has severely reduced channel capacity (Wong et al., 2024). This condition reflects a decline in environmental carrying capacity, where land resources can no longer sustainably support population pressures (Ministry of Environment, 2014). Similar spatial planning constraints have been identified globally as primary exacerbators of urban flood risk (Ku, 2024).

While structural measures such as dams and drainage systems have been implemented (Mayor of Malang City, 2024), these interventions alone are insufficient. Contemporary research emphasizes that effective flood mitigation requires integrating structural and non-structural approaches, including strict land use regulation and ecosystem-based adaptation solutions (Turner & Restrepo, 2019). The limited proportion of green open space in Malang—falling far below mandated national thresholds—further limits infiltration capacity (Republik Indonesia, 2007). From a theoretical perspective, flood risk is determined not only by physical hazards but also by social vulnerability. Vulnerability is shaped by the capacity of communities to anticipate, cope with, and recover from hazards (Cutter et al., 2003; Adger, 2006). In urban contexts, vulnerability is often spatially uneven, heavily influenced by socio-economic inequality, and closely linked to local infrastructure availability (Nguyen & Tran, 2020; Garcia & Lopez, 2022; Alshammari et al., 2023).

Despite extensive research on land use and hydrological processes, a significant gap remains in integrating flood hazard analysis with social vulnerability at detailed spatial scales. Moreover, the application of the Soil Conservation Service Curve Number (SCS-CN) method in urban watersheds remains a critical area of ongoing research, particularly given recent advancements in its calibration for tropical flood modeling (USDA-SCS, 1986; Mishra & Singh, 2003; Zhong et al., 2020; Miller et al., 2023; Ma et al., 2025; Oo & Humphries, 2025). Therefore, this study aims to analyze the impact of land use change on flood hazard and social vulnerability in the Bango Sub-watershed of Malang City. Specifically, the objectives are to: (1) map flood hazard using the SCS-CN method, (2) examine the relationship between land use change and runoff characteristics, and (3) assess the relationship between flood hazard, population density, and settlement carrying capacity. By integrating hydrological modeling with socio-spatial analysis, this study contributes to a more comprehensive framework for sustainable spatial planning and disaster risk reduction.

2. Methods

2.1 Research location and scope

The locus of this study is situated within the administrative boundaries of Malang City, East Java, with a specific focus on the hydrological system of the Bango Sub-watershed (Sub DAS Bango-Sari) and its interconnectivity with the broader Brantas Watershed. Geographically, the Bango-Sari Sub-watershed spans coordinates 7°40’28” - 7°49’57” South Latitude and 112°32’37” - 112°39’55” East Longitude. This area is an integral part of the Brantas Watershed system, covering an area of approximately 22,564.94 hectares. The research scope specifically targets the downstream segments of the sub-watershed located within Malang City, encompassing the districts (Kecamatan) of Kedungkandang, Blimbing, Klojen, and Lowokwaru. These districts are characterized by high population density and significant urban development, rendering them critical zones for analyzing the interface between urbanization, land use change, and flood vulnerability.

The selection of this location is predicated on its geomorphological characteristics as a highland urban area that paradoxically experiences frequent and intensifying flood events. The study area includes key riparian zones and settlement concentrations that have encroached upon river borders, particularly along the Bango and Sari rivers. By focusing on these specific administrative and hydrological boundaries, the research ensures a precise analysis of how local spatial planning policies interact with the physical realities of the watershed's drainage capacity. The scope further extends to the assessment of the environmental carrying capacity, specifically scrutinizing the balance between the available settlement area and the growing population pressures in flood-prone zones.

2.2 Research design and framework

This research employs a quantitative approach with a spatial perspective, utilizing a deductive logic that proceeds from general theories of hydrology and urban planning to specific empirical observations in Malang City. The research framework is structured systematically to integrate hydrological modeling with social vulnerability assessment. The design is operationalized through a multi-stage workflow, beginning with the identification of physical parameters and culminating in the formulation of spatial planning directives.

The core of the research design relies on the integration of Geographic Information Systems (GIS) with the Soil Conservation Service Curve Number (SCS-CN) method. This combination allows for the spatial modeling of surface runoff based on land use characteristics and soil properties. The framework is further bolstered by the application of the Support Vector Machine (SVM) algorithm for land use classification, ensuring high accuracy in interpreting satellite imagery. The research flow follows a logical sequence: (1) data acquisition and pre-processing, including atmospheric correction of satellite images; (2) extraction of thematic variables such as land use, slope, and soil types; (3) hydrological modeling using SCS-CN and Gumbel analysis for rainfall frequency; (4) calculation of settlement carrying capacity; and (5) validation of the flood hazard model using Receiver Operating Characteristic (ROC) curves and Area Under the Curve (AUC) analysis. This rigorous framework ensures that the resulting spatial planning recommendations are grounded in robust empirical evidence.

2.3 Data collection techniques

Data collection was conducted primarily through secondary sources and comprehensive literature reviews, adhering to the principles of data validity and reliability. The acquisition of data was stratified into spatial data and numerical/statistical data, obtained from authoritative government agencies to ensure official compliance and accuracy. Spatial data consisting of satellite imagery was utilized as the primary source for land use identification. Digital Elevation Models (DEM) were acquired to generate topographic data, including slope and elevation maps, which are critical for hydrological analysis. Spatial data regarding administrative boundaries, river networks, and existing drainage infrastructure were sourced from the Geospatial Information Agency (BIG) and local planning documents.

Hydrological and meteorological data in the form of time-series rainfall were obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) Class II Climatology Station of East Java. This data is essential for the Gumbel frequency analysis to determine design rainfall intensities for various return periods. Demographic and planning data in the form of population data disaggregated by district were sourced from the Central Statistics Agency and the Department of Population and Civil Registration. Additionally, documents related to the Detailed Spatial Plan and Regional Spatial Plan were collected from the Public Works, Spatial Planning, Housing, and Residential Areas Agency of Malang City. The literature review complemented the secondary data by providing the theoretical basis for the variables used, such as the Curve Number (CN) values for different land cover types and the formulas for carrying capacity. This triangulation of data sources—spatial, statistical, and theoretical—strengthens the integrity of the research inputs.

2.4 Data analysis methods

The data analysis strategy is divided into three primary components corresponding to the research objectives: flood hazard mapping, settlement carrying capacity analysis, and the formulation of spatial planning directives.

2.4.1 Flood hazard mapping using SCS-CN and GIS

The first stage of analysis focuses on mapping flood hazards. This is achieved using the Soil Conservation Service Curve Number (SCS-CN) method, a widely accepted empirical model for estimating direct runoff from rainfall events in ungauged watersheds. The SCS-CN method is particularly suitable for this study as it accounts for the complex relationship between land use, soil hydrologic groups, and antecedent moisture conditions. The process begins with the classification of land use using the Support Vector Machine (SVM) technique on satellite imagery. This supervised learning algorithm is chosen for its ability to handle high-dimensional data and produce accurate classification results. Simultaneously, soil data is categorized into Hydrologic Soil Groups (HSG) based on infiltration rates. The intersection of land use and soil groups yields the Curve Number (CN) grid, which represents the runoff potential of each spatial unit; a higher CN value indicates higher runoff and lower infiltration capacity. Rainfall data is analyzed using the Gumbel distribution method to predict rainfall intensity for specific return periods (e.g., 5-year, 10-year). The runoff depth (Q) is then calculated using the SCS-CN equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \qquad \text{(Eq. 1)}$$

P is rainfall, I_a is initial abstraction, and S is potential maximum retention.

These hydrological outputs are integrated into a GIS environment to generate Flood Hazard Maps. The hazard levels are classified into categories (e.g., Safe, Warning, Vulnerable, Critical) based on the depth and extent of inundation. To ensure the reliability of the hazard map, the model is validated using the Receiver Operating Characteristic (ROC) method. The Area Under the Curve (AUC) value is calculated to quantify the model's predictive accuracy; an AUC value closer to 1 indicates excellent model performance, thereby justifying the use of the hazard map for subsequent planning analysis.

2.4.2 Analysis of settlement carrying capacity

The second stage involves analyzing the environmental carrying capacity of settlements (DDPm) within the identified flood-prone areas. This analysis is critical for determining whether the current and projected population densities can be sustained by the available land without exacerbating disaster risks. The analysis adopts a quantitative formula to estimate the capacity of the land to support settlement functions. The carrying capacity is calculated using the following formula:

$$DDP_m = \frac{LP_m / JP}{\alpha} \qquad \text{(Eq. 2)}$$

DDPm is the settlement carrying capacity, *LPm* is the land area suitable for settlement. This is derived by subtracting the area of protected zones (L_{KL}) and the area of disaster-prone zones (L_{KRB}) from the total regional area (Lw), expressed as LPm = Lw - (L_{KL} + L_{KRB}). *JP* is the Total Population in the analysis unit, α is the standard land area requirement per capita (coefficient).

This calculation provides a ratio that indicates the pressure on land resources. A DDPm value of less than 1 suggests that the area has exceeded its carrying capacity (deficit), implying that the population density is too high for the available safe land. Conversely, a value greater than 1 indicates a surplus capacity. This quantitative index serves as a proxy for social vulnerability, highlighting areas where population pressure forces habitation in high-risk zones, thereby increasing the potential for social and economic loss during flood events.

2.4.3 Formulation of spatial planning directives

The final stage of analysis is the formulation of spatial planning directives, which is inductive in nature, synthesizing the findings from the hazard mapping and carrying capacity assessments. This stage involves an evaluative overlay of the generated Flood Hazard Maps and Carrying Capacity Maps against the existing Detailed Spatial Plan (RDTR) of Malang City. The analysis identifies spatial inconsistencies, such as areas designated for residential development in the RDTR that fall within high-risk flood zones or areas with a carrying capacity deficit. Based on these discrepancies, the study formulates corrective and preventive planning directives. These recommendations are categorized into structural measures (e.g., drainage improvements, retention basins) and non-structural measures (e.g., land use rezoning, green open space expansion, strict enforcement of river border setbacks). The output is a set of strategic recommendations aimed at aligning Malang City's spatial planning with the principles of disaster risk reduction (DRR) and sustainable development, ensuring that future growth does not compromise environmental safety or exceed the watershed's hydrological limits.

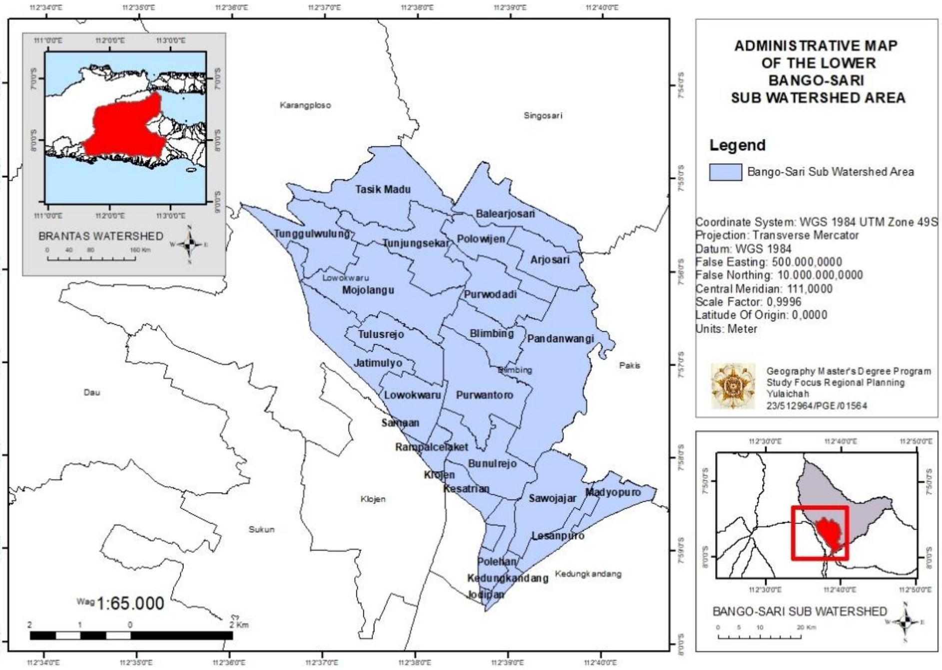

Fig. 1. Research location on bango sub-watershed

3. Result and Discussion

This chapter elucidates the findings derived from the spatial and hydrological analysis conducted in the Bango Sub-watershed, Malang City. The exposition is structured systematically, commencing with the analysis of land use dynamics as the primary variable, followed by the hydrological modeling of flood hazards using the SCS-CN method, and culminating in the assessment of settlement carrying capacity. The discussion integrates these physical parameters with social vulnerability factors to provide a comprehensive evaluation of the current spatial planning regime.

3.1 Analysis of land use characteristics and classification

The fundamental premise of this study, supported by Shrestha et al. (2021), is that land use configuration acts as the determinant variable in the hydrological response of a watershed. utilizing the Support Vector Machine (SVM) algorithm on high-resolution satellite imagery, the land use within the Bango Sub-watershed was categorized into six distinct classes. These classes were analyzed not merely for their spatial extent but for their hydrological implications regarding surface roughness and infiltration capability.

Table 1. Land use classification and areal distribution in bango sub-watershed

No	Land use class	Characteristics	Hydrological implication
1	Buildings/Built-up	High-density commercial/institutional structures; >85% impervious.	Very Critical: Generates immediate peak runoff.
2	Settlements	Residential zones mixed with minimal vegetation; 60-80% impervious.	Critical/Moderately Critical: High runoff contribution.
3	Paddy Fields	Seasonal cultivation; saturated soil conditions during irrigation.	Critical: Low infiltration when saturated.
4	Grassland	Open areas with herbaceous cover.	Vulnerable: Moderate infiltration depending on slope.
5	Plantations	Tree cover mixed with undergrowth.	Potentially Vulnerable: Better interception than crops.
6	Shrubs/Dry Fields	Mixed vegetation; seasonal changes.	Potentially Vulnerable: Variable infiltration rates.

The classification results reveal a landscape undergoing intense anthropogenic alteration. The six identified classes are: Buildings/Built-up Areas, Settlements, Paddy Fields, Plantations/Gardens, Dry Fields/Moorlands (Tegalan), and Grasslands/Shrubs. The spatial distribution indicates a significant dominance of impermeable surfaces in the downstream areas, particularly within the administrative districts of Blimbing and Lowokwaru.

The analysis highlights a critical transition where areas historically functioning as natural retention zones—such as "Shrubs" and "Plantations"—have been converted into "Buildings" and "Settlements." This conversion is most pronounced in the riparian zones of the Bango and Sari rivers. The "Buildings" class, characterized by extensive concrete coverage (shopping centers, office complexes, and academic institutions), exhibits the highest runoff coefficient. Conversely, the "Settlements" class, while slightly more permeable due to the presence of yard spaces, still represents a major contributor to total discharge. The data suggests that the reduction in "Paddy Fields" and "Plantations" correlates directly with the loss of the watershed's time of concentration (Tc), leading to flashier flood peaks.

3.2 Hydrological modeling and flood hazard mapping

Building upon the land use classification, the flood hazard potential was modeled using the Soil Conservation Service Curve Number (SCS-CN) method. This approach synthesizes the land use data with Hydrologic Soil Groups (HSG) and rainfall intensity to generate a composite Curve Number (CN) for each spatial unit. The CN value serves as a proxy for runoff potential, ranging from 0 to 100, where a higher value indicates higher runoff and lower infiltration.

3.2.1 Curve number (CN) analysis and runoff estimation

The analysis demonstrates that the Bango Sub-watershed possesses a high aggregate CN value, indicative of a system with low retention capacity. Areas classified as "Buildings" and "Settlements" exhibited CN values exceeding 85 (for HSG C and D typical in Malang), meaning that over 85% of rainfall is converted directly into surface runoff. The modeling results categorized the flood hazard levels into distinct classes based on the specific runoff depth generated during design rainfall events (e.g., 10-year return period). The classification of hazard influence based on land use is detailed as follows:

Table 2. Flood hazard level distribution based on land use and runoff

Hazard level	Dominant land use	Estimated runoff coefficient (C)	Spatial focus
Very Critical	Buildings	> 0.90	CBD, Trade Centers
Critical	Paddy Fields, Grassland	0.70 - 0.85	Peri-urban fringes
Moderately Critical	Settlements	0.60 - 0.75	High-density housing
Potentially Vulnerable	Plantations, Shrubs	< 0.60	Riverbanks (upstream)

Very Critical: Coincides with the "Buildings" land use class. These areas, particularly around Jalan Soekarno Hatta and commercial zones in Klojen, act as primary runoff generators. The lack of infiltration causes water to accumulate rapidly in the drainage system, exceeding its capacity. Critical (Rawan): Encompasses "Paddy Fields" and "Grasslands." While counter-intuitive, paddy fields in this specific sub-watershed context are classified as critical due to their saturation levels during the monsoon season, which prevents further absorption of extreme rainfall. Moderately Critical (Cukup Rawan): Associated with "Settlements." Although residential areas have some green spaces, the density of housing in Malang City (e.g., in densely populated kampung areas) renders them significant contributors to flood volume. Potentially Vulnerable: Includes "Plantations" and "Dry Fields/Shrubs." These areas offer the best relative protection against flooding, yet their diminishing area makes their mitigating impact negligible on a watershed scale.

3.2.2 Spatial distribution of flood hazard

The spatial overlay of these hazard levels reveals that the highest risk is not merely a function of elevation but is strongly dictated by land use intensity. The "Very Critical" zones are concentrated in the urban core and along major transportation arteries where drainage sealing is maximum. Specifically, the analysis corroborates historical data cited in the introduction, identifying the districts of Blimbing and Lowokwaru as hotspots.

In Blimbing District, the conversion of catchment areas into residential complexes has created a "bathtub effect" where runoff from higher impervious grounds accumulates in low-lying roads such as Jalan Sulfat. Similarly, in Lowokwaru, the massive development of educational infrastructure and student housing has drastically altered the flow regime of the local tributaries feeding into the Bango River. The map indicates that approximately 60% of the study area falls within the "Critical" to "Very Critical" hazard categories, necessitating urgent intervention.

3.2.3 Analysis of settlement carrying capacity (DDPm)

The third component of the results addresses the Social Vulnerability aspect through the lens of Settlement Carrying Capacity (DDPm). This metric evaluates whether the land resource is sufficient to support the population without encroaching into hazardous or protected zones. The calculation of DDPm for the Bango Sub-watershed reveals a concerning deficit. With the formula $DDPm = (L_{suitable} / Population) / \alpha$, the results indicate that the value of DDPm in the majority of the analyzed districts is less than 1 ($DDPm < 1$). This signifies an "overshoot" condition, where the population pressure exceeds the environmental capacity.

Table 3. Settlement carrying capacity status by district

District	Population density	Available land for settlement (Lm)	DDPm value	Status
Klojen	Very High	Low	< 0.5	Deficit (Critical)
Lowokwaru	High	Moderate	0.6 - 0.8	Deficit
Blimbing	High	Moderate	0.7 - 0.9	Deficit
Kedungkandang	Moderate	Moderate/High	0.9 - 1.1	Threshold/Surplus

The deficit in carrying capacity is intrinsically linked to the flood hazard. As the safe land ($L_{suitable}$) is fully utilized, the population is forced to settle in L_{KRB} (Disaster-Prone Areas), specifically the river border zones (sempadan sungai). The analysis identified distinct clusters of informal settlements encroaching upon the banks of the Bango River. These settlements are "doubly vulnerable": they are physically located in high-velocity flood paths (Physical Hazard) and are socially vulnerable due to high population density and limited evacuation infrastructure (Social Vulnerability). The district of Klojen exhibits the most severe deficit. As the city center, it leaves almost no room for natural infiltration. The high population density implies that a single flood event affects a disproportionately large number of people compared to less dense areas. This validates the hypothesis that flood risk in Malang is as much a social demographic issue as it is a hydrological one.

3.3 The correlation between land use, flood hazard, and social vulnerability

The findings of this study confirm that land use change is the dominant driver of hydrological alteration in the Bango Sub-watershed. The expansion of built-up areas has significantly increased surface runoff while reducing infiltration capacity, consistent with previous studies on both global and regional scales (Feng et al., 2021; Kim & Lee, 2021; Młyński et al., 2024). Urbanization transforms natural hydrological systems into rapid runoff systems characterized by shorter lag times and higher peak discharges (Endreny, 2006; Fletcher et al., 2015; Paul & Meyer, 2001). This transformation is particularly evident in rapidly growing urban districts, reflecting patterns documented in emerging cities across East Java and Southeast Asia (Azwar et al., 2024; Shrestha et al., 2021).

From a hydrological standpoint, high Curve Number (CN) values observed in built-up areas indicate a limited capacity for water retention. According to the SCS-CN method, areas with CN values exceeding 85 convert most rainfall into direct runoff (Mishra & Singh, 2003; USDA-SCS, 1986). Recent advancements in SCS-CN applications further validate its effectiveness in urban flood modeling and hazard mapping (Ma et al., 2025; Oo & Humphries, 2025; Zhong et al., 2020), even when applied to highly modified tropical urban environments (Miller et al., 2023). To ensure spatial accuracy in mapping these complex areas, modern machine learning approaches like Support Vector Machines (SVM) have become invaluable for watershed delineation (Williams et al., 2024). These findings align with broader hydrological theory, emphasizing the profound influence of land cover, soil properties, and rainfall intensity on watershed response (Asdak, 2010; Chow et al., 1988; Limantara, 2010), a dynamic previously confirmed in nearby regions such as the upstream Brantas sub-watershed (Priyantoro & Limantara, 2017).

Interestingly, this study also identifies paddy fields as contributors to flood risk under saturated conditions. Although generally considered permeable, irrigated agricultural lands can exhibit reduced infiltration capacity during prolonged rainfall events, effectively functioning as runoff sources (Hardjowigeno, 2007; Kumar & Singh, 2021). Sustainable drainage concepts caution that disregarding these temporarily saturated agricultural zones can skew hazard estimations (Suripin, 2004). This finding underscores the importance of considering temporal dynamics in land use functionality when assessing flood hazards. Beyond physical processes, the study highlights a strong interaction between flood hazard and social vulnerability. High hazard zones frequently coincide with areas of high population density and low environmental carrying capacity. This supports established frameworks that conceptualize disaster risk as the intersection of hazard exposure and social vulnerability (Adger, 2006; Cutter et al., 2003). Spatial inequality often dictates that socio-economically marginalized populations reside in the most flood-prone regions (Garcia & Lopez, 2022). Consequently, localized vulnerability indices are essential for rapid-onset disasters in urban environments (Nguyen & Tran, 2020). Urban flood vulnerability is further intensified by limited infrastructure capacity and socio-economic constraints (Alshammari et al., 2023), requiring complex machine learning classifications to accurately assess overlapping socio-spatial patterns (Smith & Brown, 2020).

The carrying capacity analysis reveals that most urban areas are in a deficit condition, indicating that available safe land is insufficient to support the existing population (Ministry of Environment, 2014). As a result, settlements rapidly expand beyond safe urbanization limits into high-risk areas such as riverbanks (Oudin et al., 2018). This encroachment severely degrades channel capacity, a phenomenon widely observed in emerging megacities across Asia (Wong et al., 2024). Such unmanaged expansion not only increases exposure to traditional flooding but also exacerbates flash floods during transitional seasons (Patel et al., 2022). Ultimately, these spatial planning challenges demonstrate how uncontrolled development amplifies flood risk in critical catchments (Ku, 2024). This situation creates a destructive hydrological–social feedback loop. Population growth drives land conversion, which increases runoff and flood hazard; in turn, repeated flooding degrades environmental quality, thereby increasing vulnerability. This dynamic reflects global patterns in which land use change and localized extreme rainfall, accelerated by climate change scenarios, jointly intensify flood risk (Sun et al., 2022; White et al., 2025). Furthermore, comprehensive models and regional studies confirm that future river flooding will be heavily driven by these dual pressures (Chen et al., 2023; Hirabayashi et al., 2013; Winsemius et al., 2018). Consequently, populations residing near these heavily altered catchments face unprecedented exposure to extreme events (Jongman et al., 2012).

From a spatial planning perspective, the results indicate a severe misalignment between existing land use patterns and watershed ecological functions. Local demographic pressures and recorded disaster occurrences clearly necessitate stricter zoning (Regional Disaster Management Agency of East Java, 2022; Central Statistics Agency of Malang City, 2023). However, despite the presence of detailed regulatory frameworks and evaluated local drainage systems (National Institute of Technology Malang, 2024; Mayor of Malang City, 2024), implementation remains weak, particularly regarding the enforcement of river buffer zones and the maintenance of green spaces. This localized finding resonates with broader research emphasizing the critical need to align spatial planning with actual flood exposure mapping (Balaian et al., 2024).

The implications of this study highlight the absolute necessity of adopting integrated flood management strategies. Structural measures alone—such as traditional drainage improvements and retention basins—are insufficient without addressing underlying urban runoff variability and drainage infrastructure limitations (Davis & Naumann, 2019). Sustainable flood mitigation requires a harmonious combination of structural and non-structural approaches, particularly prioritizing ecosystem-based adaptation and green infrastructure (Turner & Restrepo, 2019; Zhou et al., 2017). Comprehensive planning, supported by robust geoinformation systems, is vital to guide these complex mitigation efforts effectively (Billa et al., 2006).

Furthermore, the adoption of carrying capacity-based zoning represents an important innovation in spatial planning. By strictly aligning development intensity with environmental capacity, policymakers can successfully reduce land overexploitation and minimize disaster risk. This approach is not only essential for achieving long-term urban sustainability and hydrological balance (Rahman et al., 2023) but is also firmly mandated by national spatial planning laws (Republik Indonesia, 2007). In conclusion, the study demonstrates that flood risk in the Bango Sub-watershed is predominantly driven by anthropogenic factors, particularly land use change and population pressure. Effective mitigation requires restoring the balance between urban development and watershed capacity through integrated spatial planning, improved governance, and community-based resilience approaches.

3.4 Implications for spatial planning and policy recommendations

The findings necessitate a rigorous re-evaluation of the Regional Spatial Plan and Detailed Spatial Plan of Malang City. The current spatial patterns show a deviation from the ideal "ecological function" of a highland watershed. Strict Enforcement of River Borders: The analysis identifies the encroachment of settlements into river borders as a primary driver of risk. It is imperative to enforce the regulations regarding river setbacks, restoring these zones to "Plantations" or "Green Open Spaces" (RTH). This aligns with the finding that "Plantations" are only 'Potentially Vulnerable' and serve as effective buffers. Implementation of Zero Runoff Policy: For the "Buildings" and "Very Critical" zones, structural interventions are non-negotiable. New developments in commercial zones (Lowokwaru/Klojen) must be mandated to implement Zero Delta Q principles, utilizing infiltration wells and retention ponds to neutralize the runoff surplus generated by their impervious surfaces.

Carrying Capacity-Based Zoning: Future development permits must be tied to the DDPm index. Districts with a deficit (Klojen, Blimbing) should be subject to a moratorium on new high-density residential developments until drainage capacity is upgraded or green space ratios are improved. Social Engineering in Flood Prone Areas: Recognizing the social vulnerability in high-density settlements, non-structural measures such as community-based early warning systems and flood-resilient housing designs are crucial for areas where relocation is socially or economically unfeasible. In response to these findings, a spatial planning matrix analysis was formulated specifically for the Bango Sub-watershed, as summarized in Table 4. This matrix strategically combines all analysis results—Hazard Level, Vulnerability Level (Risk), and Settlement Carrying Capacity—with a primary focus on existing settlement areas. This matrix serves as a decision-making tool for formulating specific mitigation and adaptation directions.

Table 4. Matrix of risk-based and carrying capacity-based spatial planning guidelines in the bango sub-DAS settlements

Residential area classification (Combined analysis results)	Non-structural mitigation directives (Spatial planning & policy)	Structural mitigation directives (Physical)
HIGH Vulnerability (High Hazard, High Vulnerability, Low Carrying Capacity)	Priority 1: Tightening/moratorium on new development permits. Directive: Land use conversion of riparian zones into Green Open Space (RTH)/Green Belts. Policy: Programmed relocation for settlements in the most critical zones.	Priority 1: Construction of protective infrastructure (e.g., embankments/dikes, check dams). Directive: Massive increase in primary drainage capacity.
MEDIUM Vulnerability (Medium Hazard, Medium Vulnerability, Medium Carrying Capacity)	Priority 2: Control of land utilization (incentives & disincentives). Directive: Community education and strengthening of early warning systems. Policy: Strict implementation of the Green Base Coefficient (KDH - Koefisien Dasar Hijau).	Priority 2: Optimization and normalization of secondary & tertiary drainage networks. Directive: Construction of communal infiltration wells and biopores.
LOW Vulnerability (Low Hazard, Low Vulnerability, High Carrying Capacity)	Priority 3: Conservation of remaining infiltration areas. Directive: Maintenance of existing Green Open Space (RTH). Policy: Enforcement of river border regulations (riparian rules).	Priority 3: Routine maintenance of existing drainage infrastructure. Directive: Development of green infrastructure (e.g., rain gardens).

The most significant finding of the risk analysis is that risk is not just about physical hazards. The highest risk in the Bango Sub-watershed was identified in areas where high flood hazards intersect with communities with high socio-economic vulnerability (e.g., dense, informal settlements with low adaptive capacity). This confirms that disasters are the product of the interaction between natural (or human-induced) phenomena and social conditions. The resulting risk map, therefore, is not a purely physical map, but rather a socio-spatial map that shows where disaster impacts will be most severe. The matrix in Table 4 represents a strategic response to these risk findings. Its primary purpose is to provide differentiated guidance, not a one-size-fits-all solution. For "HIGH Vulnerability" zones, guidance such as "Programmed Relocation" and "Land Conversion" is explicit, recognizing that in some locations, the risk is already too high and technical (structural) solutions alone will be insufficient or no longer feasible. In contrast, for the "MEDIUM Vulnerability" zone, balanced guidance between infrastructure improvements (e.g., drainage normalization) and social capacity building (education) suggests that an adaptation or "living with floods" approach is still feasible. This tiered approach is more pragmatic and can be implemented within a spatial planning framework.

It is important to note, as mentioned in the study's limitations, that this matrix provides clear qualitative guidance on what to do. However, this study has not yet quantified the effectiveness of each of these directives. For example, this study did not calculate the extent of flood discharge reduction resulting from land conversion in zone A, or the effectiveness of infiltration well construction in zone B. This limitation is an important finding in itself, highlighting the need for further research to conduct more detailed hydrological modeling and cost-benefit analyses to validate and quantify the impact of each recommended intervention. Spatial risk analysis was conducted by overlaying flood hazard and social vulnerability maps. The results show a varied distribution of risk. In conclusion, the results unequivocally demonstrate that flood risk in the Bango Sub-watershed is an anthropogenic product of land use mismanagement. The solution lies not merely in channelizing rivers (structural) but in restoring the balance between settlement growth (social) and the watershed's hydrological limits (environmental).

4. Conclusions

The research conducted in the Bango Sub-watershed, Malang City, confirms that the escalating flood risk is not merely a consequence of natural meteorological variability but is fundamentally driven by anthropogenic land use alterations and spatial planning inconsistencies. By integrating the Soil Conservation Service Curve Number (SCS-CN) method with social vulnerability analysis, this study provides a multi-dimensional assessment of how urbanization creates a feedback loop of hydrological instability and social exposure. The findings unequivocally demonstrate a direct and critical correlation between land conversion and flood hazard magnitude. The transformation of permeable landscapes—specifically plantations and open spaces—into high-density built-up areas and settlements has drastically altered the watershed's hydrological response. The analysis reveals that the dominant land use classes, specifically "Buildings" and "Settlements," exhibit Curve Number (CN) values indicative of a system with minimal retention capacity. Consequently, districts such as Blimbing and Lowokwaru have become primary runoff generators, where surface discharge exceeds the design capacity of existing drainage infrastructure.

Furthermore, the study highlights a severe deficit in the Settlement Carrying Capacity (DDPm) within the urban core, particularly in Klojen and parts of Blimbing. The results indicate that the population density in these areas has overshot the environmental limits, forcing residential expansion into disaster-prone zones (L_{KRB}), most notably along the riparian corridors of the Bango River. This intersection of high physical hazard and high population density identifies specific "Risk Hotspots" where social vulnerability is exacerbated by the lack of safe, habitable land. These findings carry profound implications for urban policy and disaster management in Malang City. The study challenges the traditional reliance on structural flood control measures (such as canalization) by proving that without controlling the source of runoff through land use management, such infrastructure will remain perpetually insufficient. The research contributes to the existing body of knowledge by empirically quantifying the "cost" of spatial planning violations—specifically the encroachment on river borders—in terms of increased runoff volume and social risk. It bridges the gap between hydrological engineering and urban planning, offering a methodological framework that treats social carrying capacity as a critical variable in flood risk assessment.

Based on these conclusions, it is imperative that the Regional Spatial Plan (RTRW) and Detailed Spatial Plan (RDTR) of Malang City undergo a rigorous revision to align development targets with the watershed's hydrological carrying capacity. Future urban development must enforce a "Zero Delta Q" policy for new commercial zones, mandating on-site retention to neutralize runoff. Additionally, the restoration of river border setbacks must be prioritized, not only as green open spaces but as essential buffer zones to decouple social settlements from physical hazards. While this study provides a robust snapshot of current risks, future research should expand to include temporal simulations of climate change scenarios to predict how changing rainfall intensities might further amplify these risks. Additionally, more granular studies on community resilience and adaptive capacity in informal riverbank settlements would provide valuable insights for designing socially inclusive mitigation strategies. Ultimately, this study asserts that sustainable flood mitigation in Malang City depends on restoring the ecological function of land and respecting the physical limits of the watershed.

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Author Contribution

YY has collected and drafted the manuscript, formatted it, and approved the final manuscript.

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The study used publicly available spatial and demographic data without human or animal subjects.

Informed Consent Statement

This research did not involve human participants or identifiable personal data.

Conflicts of Interest

The author declares no conflict of interest.

Declaration of Generative AI Use

During the preparation of this work, the author used ChatGPT (OpenAI, GPT-5 model) to assist in improving the academic tone, English structure, and clarity of the manuscript. After using this tool, the author thoroughly reviewed and edited the content as needed and takes full responsibility for the final version of the publication.

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Biographies of Author

Yulaichah, is a geographer and disaster risk specialist focusing on urban flood risk assessment, spatial planning, and environmental carrying capacity. She earned her Bachelor's degree in Geography from Universitas Negeri Malang and a Master's degree in Geography from Universitas Gadjah Mada, Indonesia, as a recipient of the LPDP Scholarship. Her research integrates GIS, remote sensing, and hydrological modeling (SCS-CN) for sustainable urban development and disaster mitigation.

- Email: yuli.yulaichah96@gmail.com
- ORCID: 0000-0002-3784-3322
- Web of Science ResearcherID: OLR-1596-2025
- Scopus Author ID: N/A
- Homepage: N/A