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Increasing Urban Flood Challenges: Spatial Analysis of the 2024 Flood in Rajabasa, Bandar Lampung, Indonesia

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ABSTRACT

This study explores the spatial analysis of flood-prone areas in Rajabasa by utilizing Digital Elevation Model data from DEMNAS and high-resolution aerial photographs obtained via commercial drones. The research aims to understand the region's flood dynamics and watershed characteristics. The elongated shape of the Rajabasa basin, with a calculated circularity ratio (Rc) of 0.19, indicates that runoff follows the existing stream network, resulting in gradual and prolonged flood events. Field surveys were conducted to validate land cover data, revealing that the majority of the area was residential and classified under Hydrology Soil Group (HSG) D, leading to high Curve Number (CN) values between 88 and 93. These values suggest that nearly all rainfall converts to runoff, exacerbating flooding conditions. Effective flood management strategies were proposed by focusing on areas with the highest CN values and integrating long-term land improvement with short-term flood control infrastructure. The study also highlights the importance of preserving natural drainage lines, which are often overlooked, for enhancing flood mitigation, educating residents about floodplain management, and implementing proper land use regulations. The findings underscore the necessity of combining spatial analysis, high-resolution data, and targeted flood management strategies to mitigate flood risks in Rajabasa and similar flood-prone areas.

Keywords: Curve number; Spatial analysis; Urban flood

ABSTRAK

Penelitian ini mengeksplorasi analisis spasial daerah rawan banjir di Rajabasa dengan menggunakan data Digital Elevation Model (DEM) dari DEMNAS dan foto udara resolusi tinggi dari drone komersil guna memahami dinamika banjir dan karakteristik Daerah Aliran Sungai (DAS) di wilayah ini. Bentuk DAS Rajabasa yang memanjang, dengan rasio kebulatan (Rc) yang dihitung sebesar 0.19, menunjukkan bahwa limpasan air mengikuti jaringan aliran yang ada sehingga menimbulkan peristiwa banjir yang bertahap dan berkepanjangan. Survei lapangan terhadap data tutupan lahan menunjukkan bahwa mayoritas area merupakan pemukiman yang masuk dalam Kelompok Tanah Hidrologi (HSG) D dengan kecenderungan *Curve Number* (CN) tinggi antara 88 dan 93. Angka ini menunjukkan bahwa hampir semua curah hujan berubah menjadi limpasan dan memperparah kondisi banjir. Strategi manajemen banjir yang efektif perlu dilakukan terutama pada area dengan nilai CN tinggi dan mengintegrasikan perbaikan lahan jangka panjang dengan infrastruktur pengendalian banjir jangka pendek. Studi ini juga menyoroti pentingnya menjaga jalur drainase alami, yang seringkali diabaikan, untuk meningkatkan mitigasi banjir, edukasi pada penduduk tentang manajemen dataran banjir, dan penerapan regulasi penggunaan lahan. Temuan ini menggarisbawahi pentingnya analisis spasial, data resolusi tinggi, dan strategi manajemen banjir untuk mengurangi risiko banjir di Rajabasa dan daerah rawan banjir serupa.

Kata Kunci: Analisis spasial; Banjir perkotaan; *Curve Number* (CN)

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INTRODUCTION

In the past five years, flooding has been the most frequent disaster occurring in Indonesia (BNPB, 2024) as well as globally (UNDRR, 2020). In tropical regions like Indonesia, the most common type of flooding is river flooding due to the topographical conditions of extensive lowland areas (Hallegatte et al., 2013; Hanson et al., 2011).

In early 2024, the Province of Lampung experienced severe flooding. One of the worst-hit areas was Rajabasa, where floodwaters reached the rooftops of houses. Historically, this location has been prone to flooding, but it has never been as severe as the incident in 2024 (lampost.co, 2024). This situation was also observed in other areas of Bandar Lampung, such as Teluk (detik.com, 2024), Way Halim (mediaindonesia.com, 2024), and Urip Sumoharjo (radarlampung.disway.id, 2024).

The increasing urban flooding highlights the need for a change in approach to flood management. Traditionally, the construction of flood control infrastructure has been the primary solution. However, it may now be necessary to also consider environmental conditions and land use changes in both the flood-prone areas and their upstream catchment areas. Sayers et al (2015) describe the evolution of flood management processes over time through the following stages: (i) relocation from flood areas; (ii) utilization of floodplains, (iii) flood control; (iv) reduction of flood damage; and (v) implementation of flood risk management. It appears that Indonesia's flood management process is stalled at the flood control stage.

The changes in flood management have been driven by the increasingly limited availability of land. When land was abundant, residents could relocate to new areas when floods occurred, abandoning the old flooded areas. Flood control typically involves flood infrastructure such as dams, levees, drainage systems, and pumps, which are feasible when there is space for these structures. When flood discharge increases and the infrastructure cannot prevent flooding, the management approach shifts to reducing flood impacts. Currently, as flooding becomes inevitable and land becomes densely populated, risk management becomes the primary focus of flood management.

This article aims to provide a comprehensive analysis of the challenges faced in future urban flood management through a spatial approach, with a focus on the 2024 Rajabasa flood as a case study. The study integrates multiple spatial analysis techniques to better understand the dynamics and contributing factors of flooding in urban settings. By employing field measurement tools such as GPS and drones, a detailed 3D model of the flood-affected area is created to offer a high-resolution perspective on the terrain. This model is supplemented by secondary data sources, including Digital Elevation Models (DEMs) obtained from global datasets, ensuring that the analysis is both data-rich and contextually accurate.

The spatial hydrological analysis conducted in this study identifies critical factors such as catchment areas, stream networks, and land cover types, which are derived from both field survey data and advanced spatial techniques. Additionally, the study delves into the application of the Curve Number method as a key indicator for evaluating surface runoff potential, providing insights into how various land uses and surface conditions contribute to flood risks. By bridging the gap in detailed flood location analysis, this research aims to pinpoint the specific sources and processes leading to surface runoff formation, thereby offering practical recommendations for improving urban flood management strategies.

THEORETICAL FRAMEWORK

The continuous increase in urban flooding due to population growth (Areu-Rangel et al., 2019), both in terms of intensity and the extent of the affected areas, requires more intensive management. Addressing disasters with attention to local characteristics is one approach agreed upon within the global disaster management framework (Wahlström, 2015). In the context of flood management, it is essential to examine flood issues in detail. One effort to achieve it is through spatial analysis of the relationship between flood locations and the characteristics of their catchments.

Conducting a detailed spatial analysis needs detailed data support. Currently, the rapid development of drones offers a boon for mapping processes with the advent of close-range photogrammetry, which can map large areas quickly with high resolution (Feng et al., 2015; Rohman & Prasetya, 2019). The drones are no longer limited to specialized mapping drones but may also include commercially available drones that are affordable.

Spatial Analysis of Flooding

Spatial analysis for disaster management has been conducted for a long time through the use of maps. As map technology has advanced, the process of spatial analysis has become faster and easier. In the case of flood analysis, current spatial analysis can be used for flood inundation modeling for different return periods (Kusratmoko et al., 2016), examining patterns and distribution of land use (Carver et al., 2012), and combining with other methodologies such as the Analytical Hierarchy Process (AHP) and multi-criteria decision analysis (MCDA) for urban area mapping (Gigović et al., 2017).

For extracting information on the characteristics of river basins or catchment areas, spatial analysis is commonly used as a tool for conducting morphometry (El Alfy, 2016). Morphometry is a quantitative analysis to obtain watershed characteristics such as watershed area (A), watershed length (Lb), main river length (Ln), watershed width (W), drainage density (Dd), bifurcation ratio (Rb), and circularity ratio (Rc) (Tutur et al., 2022). By understanding these characteristics, appropriate flood management approaches can be developed for the affected locations.

Curve Number as an Indicator of Land Cover Health

In hydrological modeling, one method used for the rainfall-runoff approach is the SCS-Curve Number method. The Curve Number (CN) is reflected with a value ranging from

0 to 100, which represents a composite value combining land cover/land use with Hydrological Soil Group (HSG) conditions (Satheeshkumar et al., 2017). A lower CN value indicates less runoff formation, and vice versa. This information allows for the assessment of land health within the watershed system.

CN information can also be used for land improvement processes aimed at flood mitigation by altering existing land use to reduce CN values (Rohman et al., 2019).

METHODOLOGY

Research Design

The study was conducted towards one of the flood-affected areas in 2024 in Rajabasa, near the river outlet that crosses the railway tracks, as shown in Figure 1.

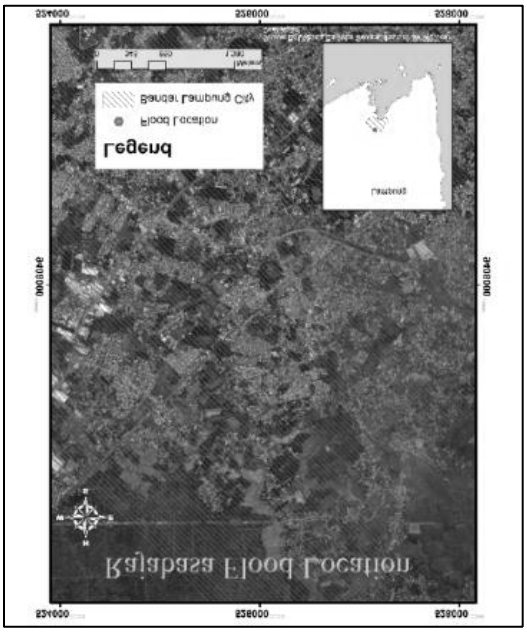

Figure 1. Rajabasa flood location

The research process was carried out in the following stages: (i) data collection; (ii) basin processing; (iii) analysis of CN values to identify potential flood-causing locations. The methodology flowchart can be seen in Figure 2.

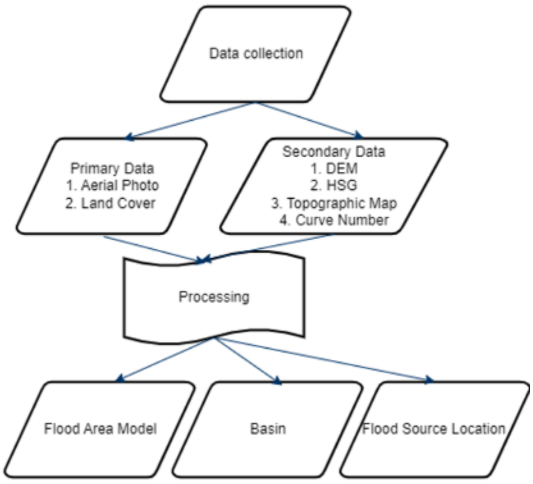

Figure 2. Flowchart of the research method

In this study, most of the elevation data (DEM) used came from the Geospatial Information Agency, with a resolution of approximately 8.1 meters (Geospatial Information Agency, 2018). Aerial photo data were focused on the flood-affected area and did not yet cover the entire catchment area. The aerial photos were used to model and reconstruct the distribution of the flood-affected area. This process was conducted one day after the flood. The mapping was completed in less than a day, from data collection to processing, making it a rapid mapping process commonly used for fast flood modeling (Rohman & Prasetya, 2019).

For watershed processing, the method used involved dividing the area based on elevation from the DEM to determine regions with the same flow endpoints. This delineation process is simply defined as setting boundaries around areas where, if it rains, the runoff will flow to a single location known as the main river. This processing can be carried out using Geographic Information System (GIS) software such as QGIS and HEC-HMS.

The main basin characteristics to be extracted are the area (A) and the perimeter (P) to determine the circularity ratio (Rc) using the general formula: $Rc = 4\pi A/\rho^2$ (Gregory & Walling, 1973). The Rc indicates the roundness of the watershed. If $Rc > 0.5$, the basin is circular; if $Rc < 0.5$, it is elongated. The difference in shape determines the type of flooding that will occur. A circular shape indicates that the flood discharge will be large and occur over a short period, while an elongated shape suggests that flooding in the basin will last longer.

After determining the watershed area of the flood location, the next step is analyzing the CN values in the basin area based on CN values from TR-55 (Dang & Kumar, 2017; USDA, 1986). The CN values for each land cover type in built-up areas with specific Hydrology Soil Groups (HSG), assuming fair conditions, can be seen in Table 1.

Table 1. CN for urban area from TR-55

No	Cover Type in urban Area	HSG			
		A	B	C	D
1	Open space with grass cover 50% to 75%	49	69	79	84
2	Commercial and business area	89	92	94	95
3	Industrial	81	88	91	93
4	Residential $500m^2$ or less	77	85	90	92
5	Newly graded areas	77	86	91	94

Using the reference CN values, spatial analysis can then be conducted to extract the CN values for the watershed conditions. These values serve as a basis for identifying areas that are likely generating high runoff. The results of this analysis then provide materials for discussions on which flood management strategies are suitable for implementation.

Data and Data Source

The data used in this study are as follows.

1. Digital Elevation Model (DEM) from DEMNAS, Geospatial Information Agency, accessible at https://tanahair.indonesia.go.id/demnas/#/demnas.
2. Field measurements and field photos obtained from field surveys.
3. Aerial photos acquired from direct field measurements using a DJI Mavic Pro 3 drone.
4. Administrative boundary data from the Indonesian Topographic Map *(Peta Rupa Bumi Indonesia)*.
5. River data from the Indonesian Topographic Map *(Peta Rupa Bumi Indonesia)*.
6. Reference Curve Number (CN) values from TR-55 (USDA, 1986).
7. Land cover data from digitization, validated with field surveys.
8. Hydrology Soil Group (HSG) data with a 250-meter resolution from a global model, accessible at https://daac.ornl.gov/SOILS/guides/Global_Hydrologic_Soil_Group.html

RESULTS/FINDINGS

Aerial Photo and Land Cover Survey

The data collection process using drones was conducted in the area around the river that experienced approximately 3 meters of flood inundation. The data obtained using the drone consists of photo maps and a Digital Surface Model (DSM). The positioning of the aerial photos relies solely on the embedded GPS navigation, resulting in data accuracy that is not highly precise but sufficient to show the flood-affected areas. Figure 3 shows the inundation conditions derived from the spatial analysis of the aerial photos, with floodwaters reaching 3 meters at the surveyed house locations (darkened dot).

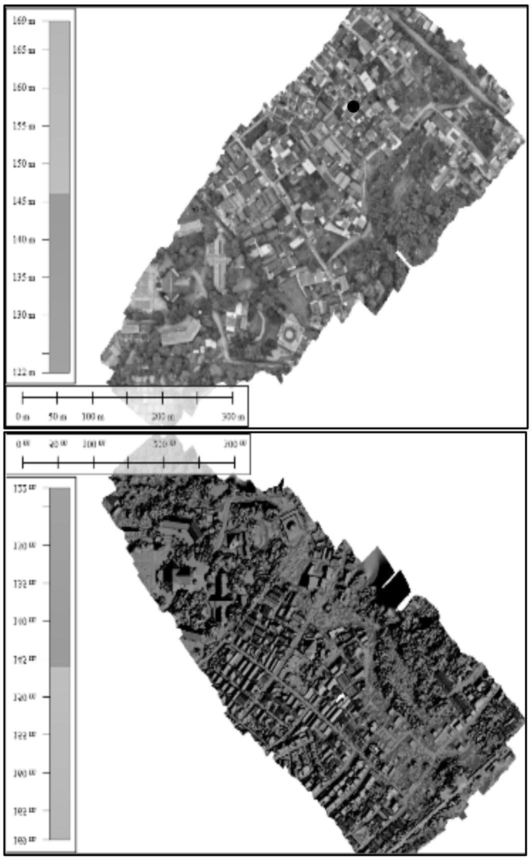

Figure 3. Flood area model from aerial photo

To assess the land cover and land use conditions around the riverbanks, a series of photographs were taken along the main river channel. The identification results indicated that many buildings were constructed very close to the river, encroaching on the natural floodplain. This proximity increased the vulnerability of these structures to flood damage. Additionally, numerous levees have been constructed, which prevent the river from widening naturally during high flow events. These levees, while intended to protect adjacent land, can exacerbate flooding upstream and downstream by restricting the river's ability to disperse excess water. The combined effect of close building proximity and levee construction highlights significant challenges in managing flood risks. An example of the field survey results illustrating these conditions can be seen in Figure 4.

Location Number	4
Latitude	-5.3706
Longitude	105.2324
Water Depth	±1.5 metres
River width	± 2 metres

Figure 4. Example of river and land cover condition

Basin Area and Characteristic

The processing of Digital Elevation Model (DEM) data from DEMNAS reveals that the streamline of the flood-affected area in Rajabasa is connected to an upstream region around the TVRI Transmitter on Jalan Wan Abdurrahman. The watershed area spans 2,368 hectares with a perimeter of 39 kilometers, resulting in a circularity ratio (Rc) of 0.19. This low Rc value indicates an elongated basin, suggesting that runoff will not peak immediately but will follow the existing stream network, leading to a more gradual and prolonged flow of water.

Understanding this elongated shape is crucial for effective flood management. The gradual runoff allows for early warning systems upstream, providing downstream communities with more time to prepare. Regular maintenance of stream channels and the creation of flood storage areas can help manage water volumes during heavy rainfall. Additionally, land use planning can minimize flood impacts on urban areas. The elongated nature of the basin and its implications for flood dynamics are visualized in Figure 5, aiding in the planning of flood mitigation measures.

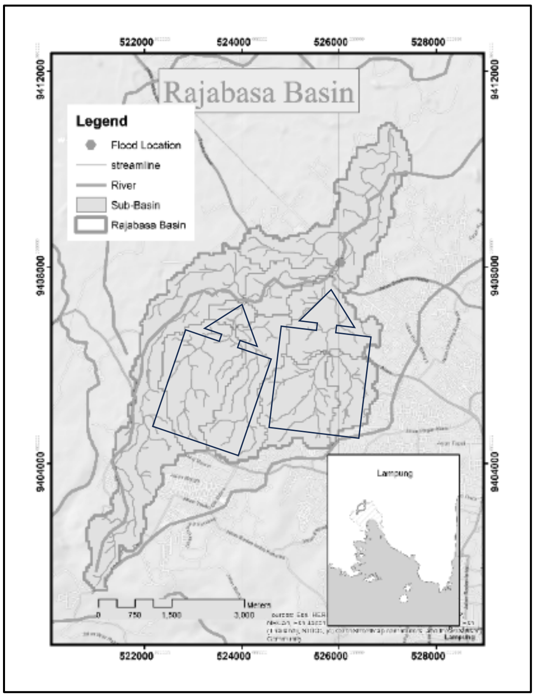

Figure 5. Rajabasa basin

As can be seen in Figure 5, the basin shape is elongated. If the basin is divided into sub-basins, it is evident that the main river flows along the western side of the basin, through two very elongated major sub-basins. The remaining sub-basins are divided into two large sub-basins that capture rainfall and channel runoff from the streams to the river in the direction indicated by the arrows.

Spatial Analysis with CN to Determine Flood Source Location

The results from the field survey were used to validate land cover and to classify it into different categories. The land cover processing results showed that the majority of the land cover was residential. According to the global Hydrology Soil Group (HSG) model data, the entire basin area falls into HSG class D which represents soils with very low infiltration rates and the highest runoff potential. Thus, the Curve Number (CN) values used correspond to this class. Combining these conditions with the lookup table for CN values in Table 1, the CN distribution for the sub-basins was obtained, as shown in Figure 6. It can be observed that almost the entire basin area that channels water to the main river has high CN values, which indicate that nearly all rainfall will convert to runoff.

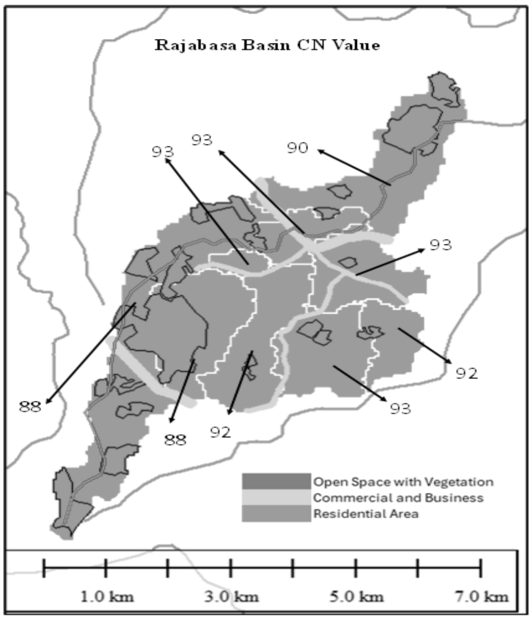

Figure 6. CN value for each subbasin

The calculations show that the CN values range from a minimum of 88 to a maximum of 93. With such similar CN values, it can be interpreted that nearly all areas within the Rajabasa basin contribute to the formation of runoff water, leading to flooding. If we consider these CN values in terms of the percentage of runoff formation, it means that approximately 90% of rainfall will become runoff flowing into the river.

For flood management, efforts should start with areas having the highest CN values. Long-term solutions include land improvement to reduce CN values, while short-term solutions involve constructing flood control infrastructure. By addressing the highest CN areas first, it is possible to effectively mitigate runoff and reduce flooding risks.

DISCUSSION/ANALYSIS

The Need for Accurate Elevation Models

Spatial analysis with GIS for examining flood-prone areas, especially in smaller basins like Rajabasa, requires high-resolution data, particularly topographic or elevation models. This is crucial because hydrological analysis relies heavily on accurate elevation data, as water flows from higher to lower areas.

In the initial reconstruction of the flood location, the DSM data from aerial photos proved to be highly beneficial for determining the affected areas as mentioned in urban mapping process by Feng et al (2015). This effectiveness arises because, as previously mentioned, flooding in Indonesia typically occurs in expansive, flat lowland areas (Hallegatte et al., 2013; Hanson et al., 2011). Global DEM data often lacks the necessary resolution to detect these subtle elevation changes.

Therefore, there is a need for methods to quickly and cost-effectively obtain elevation data. Currently, this gap can be filled by mapping with commercial drones. Rohman and Prasetya (2019) showed in their research the commercial drones with the price around 10 million Rupiah could be utilised to obtain the high elevation model to model the flood. However, it is essential that the data collection and processing follow proper mapping guidelines to ensure the resulting data is accurate and reliable.

Proximity of Upstream and Downstream Areas

In flood management, one of the most effective methods to address flooding is by focusing on the upstream sections of the river basin. The devastating flood in Rajabasa reveals that the source of the floodwaters is still within close proximity to the flood site. The distance from the flood location to the upstream area is approximately 10 kilometers. Given this relatively short distance and the minimal difference in elevation, it is crucial to examine the sub-basins closely. Figure 7 shows a longitudinal section of the river from the upstream area to the flood location. To understand this shape of the river, is part of the simple morphometry analysis (El Alfy, 2016).

This close proximity necessitates a thorough analysis of the sub-basins to understand their contribution to the flood. The minimal elevation difference means that water can quickly travel from the upstream areas to the flood site, exacerbating flooding conditions. By focusing on the sub-basins, targeted flood management strategies can be developed, which could include both structural and non-structural measures. Structural measures might involve constructing levees or retention basins, while non-structural measures could include improving land use practices and increasing vegetation cover to reduce runoff.

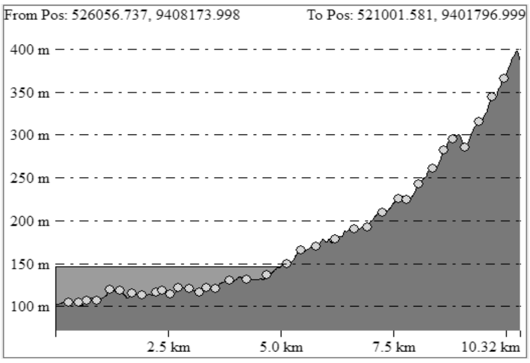

Figure 7. River profile

Figure 7 shows that the distance from the highest point to the nearest flood location is 5 kilometers, which highlights a significant spatial relationship between elevation and flood risk. The field survey results indicate that the river's condition from upstream to downstream reveals a critical insight: while the upstream section of the river still maintains a relatively wide floodplain, this natural asset is not being utilized for its intended ecological purpose. Unfortunately, due to a lack of awareness among local residents about the importance of preserving floodplains, much of this area has been converted into farmland. Farming activities in floodplain areas can increase surface runoff and exacerbate flood risks due to reduced water infiltration into the soil.

This floodplain, if properly managed, could act as a crucial buffer zone during flood events. Planting trees and vegetation in this area would not only help stabilize the soil but also enhance its water-holding capacity, slowing down the movement of floodwaters and providing natural water storage. Trees and other deep-rooted plants can act as a "green infrastructure" solution, reducing peak flows during floods and mitigating the overall impact on downstream areas. In addition, such vegetation could help recharge groundwater reserves, further contributing to long-term water management strategies in the region.

Alternatively, this floodplain could be utilized for other land uses that have a lower Curve Number (CN) than farming (Satheeshkumar et al., 2017). The Curve Number is an empirical parameter used in hydrology for predicting runoff based on land use, soil type, and hydrologic condition. Farming typically results in higher CN values, leading to increased runoff during heavy rainfall. By shifting the land use to something with a lower CN, such as reforestation, grasslands, or even certain types of low-impact recreational spaces, the area could better absorb and slow down floodwaters. This approach not only reduces immediate flood risks but also enhances the overall resilience of the landscape to future extreme weather events. Educating the community about the risks of inappropriate land use in floodplain areas, coupled with incentives for adopting more sustainable practices, can transform these zones into effective natural flood management systems. This proactive land use planning would ultimately contribute to the long-term health of the river ecosystem while simultaneously providing greater protection for residents living downstream.

This situation highlights the need for targeted flood management strategies. In the upstream areas where the river has a wide floodplain, raise awareness among the locals about the risks of utilizing these areas for agriculture is very crucial. Educating residents about floodplain management and implementing land use regulations can help preserve the natural floodplain's ability to absorb floodwaters, reducing the volume and speed of runoff traveling downstream.

Additionally, integrating structural measures such as levees or retention basins in strategic locations can help manage floodwaters more effectively. Non-structural measures (e.g., reforestation and the creation of buffer zones along the river) also play a significant role in mitigating flood risks. By combining these approaches, the development of a comprehensive flood management plan that addresses both immediate and long-term needs might be successfully achieved.

Drainage System

Spatial analysis for flood management aims to facilitate the identification of flood-prone areas and their basin systems. For example, the analysis has shown that the Rajabasa flood basin has an elongated shape. Therefore, a primary mitigation strategy can involve engineering the drainage paths. This does not only refer to residential drainage systems but also to natural drainage lines identified through hydrological analysis.

In Figure 8, a zoomed-in view of an area marked with an arrow in Figure 5 clearly shows that the analysis indicates a streamline or drainage line that forms when it rains. However, this is often not recognized because these streamlines disappear when raining stops, unlike rivers, which are continuously filled with water.

To address this issue, field marking can be done to identify these areas and ensure they are preserved for water absorption rather than other uses. By recognizing and preserving these natural drainage lines, effective flood mitigation can be achieved. Figure 8 shows the location of the drainage line in question. This marking can prevent the area from being used for purposes that would impede its function as a natural drainage path, such as construction or farming, and instead promote its use as a water absorption zone.

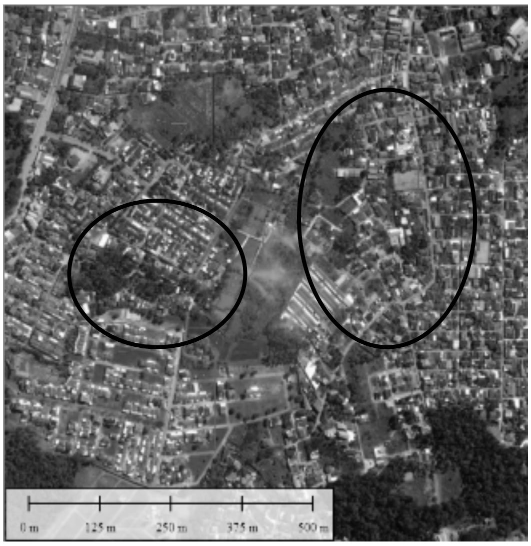

Figure 8. Drainage line in the residential area

CONCLUSION

Addressing urban flooding, which is exacerbated by population growth (Areu-Rangel et al., 2019) in terms of both intensity and area affected, requires a more detailed and localised approach. The spatial analysis of flood-prone areas in Rajabasa, using Digital Elevation Model (DEM) data from DEMNAS and aerial photos, has provided significant insights into the flood dynamics and watershed characteristics. The Rajabasa basin, with its elongated shape and proximity of upstream and downstream areas, highlights the need for accurate and high-resolution topographic data for effective flood management. The calculated circularity ratio (Rc) of 0.19 indicates that runoff will follow the existing stream network, which results in gradual and prolonged flood events.

The land cover data reveal that the majority of the area is residential, with the entire basin classified under Hydrology Soil Group (HSG) D. This classification resulted in high Curve Number (CN) values ranging from 88 to 93, which indicate that nearly all rainfall will convert to runoff and exacerbate flooding conditions.

The analysis also emphasized the importance of natural drainage lines, which are often overlooked due to their temporary or seasonal nature. These drainage paths, although not always visible year-round, play a vital role in controlling the flow of water during heavy rainfall or flood events. Their preservation can help reduce surface water runoff, minimize erosion, and ensure water is redirected away from vulnerable areas. Identifying and protecting these natural drainage paths can significantly enhance flood mitigation efforts by providing a natural means of water management, complementing engineered solutions like storm drains or levees.

Moreover, public awareness is key. Educating residents about the function of floodplains and natural drainage systems is essential to help communities understand their role in flood prevention. By teaching local populations about the importance of floodplain management and natural waterways, they can become active agents in flood risk reduction efforts. This education can be supported by implementing proper land use regulations that prevent construction in flood-prone areas and promote the preservation of natural landscapes.

Practical actions may also be taken to enhance the visibility and effectiveness of the drainage paths. Local governments or community organizations, for instance, can establish zoning areas specifically designed for natural drainage purposes. These areas could include the planting of small trees and shrubs, which not only help with water absorption but also prevent soil erosion. Signage could be installed to clearly mark these paths, indicating the direction of water flow during flood events. Such measures would serve both as practical solutions and as visual reminders to the community of the critical importance of natural drainage systems in managing flood risks.

Overall, the combination of spatial analysis, high-resolution data, and targeted flood management strategies can provide a comprehensive approach for the government and stakeholders to mitigate flood risks in Rajabasa and similar flood-prone areas.

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