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Flood inundation mapping based on land use and land cover change in Jatiroto Watershed, Lumajang, Indonesia

Nabilla Syafa*, Agus Suharyanto, Indradi Wijatmiko

***Abstract*— Floods are one of the most frequent natural disasters and cause considerable economic, infrastructure, and social losses, especially in areas experiencing land use/land cover change (LULC). In this study, we use GeoHECRAS and GIS to model the flood risk due to historic land use changes in the Jatiroto watershed (DAS Jatiroto) in Lumajang (East Java, Indonesia). The study evaluates the consequences of land-cover conversion between 1995 and 2023 on flood processes, including the variations of flood extent, depth, and duration. Rainfall, land use, soil types, and topography data were used to construct the flood prediction model, and the model was validated with historical flooding events. The findings indicate that the flood area is found to have increased substantially from 12.22% in 1995 to 15.66% in 2023. Moreover, flood depth was also raised, particularly in areas with urban and agricultural expansion. The research emphasizes that land-use changes play a significant role in raising the flood risk and that GeoHECRAS can simulate the flood incidences. These results can be useful for the optimization of flood disaster management and prevention in the rapidly urbanizing areas. More robust flood risk management strategies could be developed if the effects of climate change were taken into account in future studies on flood risk modeling simulations.**

***Index Terms*— Flood, GIS (Geographic Information System), Hydrological Simulation, Land-Use Change.**

I. Introduction

FLOOD is a frequent natural disaster, especially in the tropics, causing significant damage to infrastructure, economies and social systems. One of the main drivers of increased flood risk is land use change, especially in areas where natural vegetation is converted to urban or agricultural land. Several studies [1] emphasize how land cover change increases flood risk by reducing water absorption and accelerating surface runoff. In Jatiroto, East Java, the incidence of flooding is increasing, exacerbated by land use change, with deforestation and conversion of agricultural land to settlements [2].

Despite frequent flooding, detailed flood prediction maps, including depth, area, and speed of floodwaters, for the Jatiroto watershed (DAS Jatiroto) are scarce. Previous studies have concentrated on hydrological modeling and flood control measures, but none have comprehensively mapped flood inundation dynamics due to land use changes, especially over a historical timeline (1995, 2014, 2023).

While GIS and hydraulic models like GeoHECRAS have been applied to flood mapping, they have not been extensively used for detailed flood prediction in the Jatiroto DAS, especially considering the dynamic land-use changes. This gap in flood risk mapping is a critical issue that this research aims to address.

The objective of this study is to model and visualize flood prediction in the Jatiroto watershed as a result of land-use changes. This is achieved by developing a flood prediction model using historical rainfall data, analyzing the impact of land-use changes between 1995, 2014, and 2023 on flood extent and depth, and validating the integration of GIS and GeoHECRAS for simulating flood scenarios under different land-use conditions. The study seeks to provide a comprehensive understanding of how land-use alterations influence flood risks and the effectiveness of GIS-based modeling tools in flood prediction.

Building upon these gaps, this study addresses the research question: How do land use and land cover (LULC) changes affect the extent and depth of flood inundation in the Jatiroto watershed? We hypothesize that the expansion of built-up areas significantly increases both flood extent and depth, while GeoHECRAS provides a reliable framework to simulate these impacts under varying land use scenarios.

II. Research Methods

A. Study Area

The study focuses on the Jatiroto watershed located in Lumajang, East Java, Indonesia (Fig.1).

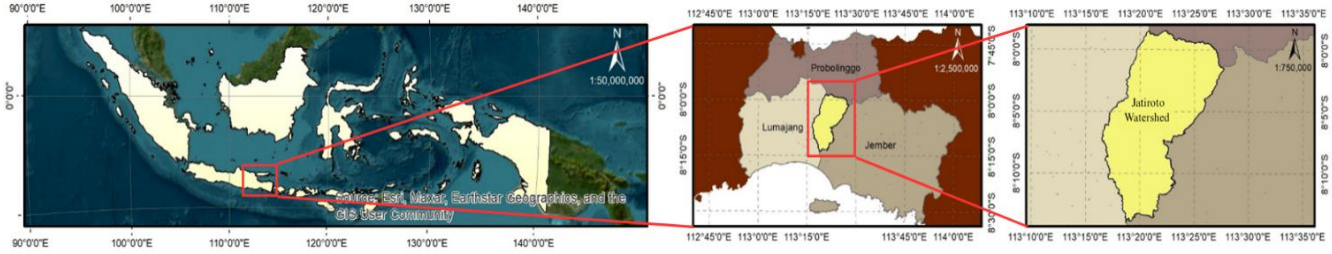


Fig. 1. Study Areas

This watershed spans 311.23 km² and includes diverse landscapes, such as agricultural fields, forests, and urban areas.

Nabilla Syafa, **Agus Suharyanto**, and **Indradi Wijatmiko** are with the Department of Civil Engineering Brawijaya University, Malang, Indonesia. Corresponding author email: nabillasfy@gmail.com

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The Jatiroto region is prone to flooding due to its topography, climate, and the rapid land-use changes over the past decades. The watershed boundary was delineated using a Digital Elevation Model (DEM) and hydrological analysis in GIS, as shown in Fig. 2 [3].



Fig. 2. Sub-watershed boundary

B. Data Collection

The data used in this study consist of spatial and meteorological datasets. Topographic data were obtained from the DEM provided by BIG, with an additional sensitivity test using an 8×8 m DEM resolution. Land cover maps for 1995, 2014, and 2023 were derived from Landsat imagery using supervised classification, validated with an overall accuracy of 87.5%, random accuracy of 0.21, and a Kappa coefficient of 83.5%. The years were selected based on data availability: 1995 as the baseline, 2014 as a period of rapid land conversion, and 2023 as the most recent status.

Rainfall records from 12 BMKG stations (2013–2022) were used for hydrological simulations. Although limited to 10 years, these official data were applied without further validation. Design storms (2–25 years return periods) were estimated using the Log-Pearson Type III distribution; the short record is acknowledged as a limitation, and future studies should apply longer series or regional frequency analysis to reduce uncertainty.

Soil data from the FAO Harmonized World Soil Database supported Curve Number (CN) estimation. The 2018 flood event was used for model validation, providing a representative benchmark despite limited historical records. All datasets were integrated into GeoHECRAS for flood risk modeling.

C. Hydrological Modeling

In this study, hydrological modeling is conducted using the Nakayasu method [4] for surface runoff estimation and the Soil Conservation Service Curve Number (SCS-CN) method for infiltration estimation [5]. The Nakayasu method, which is particularly suitable for regions like Java, Indonesia, is employed to calculate surface runoff by considering rainfall intensity, duration, and land use characteristics. This method is effective in tropical environments, where rainfall patterns and land use significantly influence runoff.

For infiltration estimation, we chose the SCS-CN method because it is particularly useful in analyzing the impact of land-use/land-cover (LULC) changes on the hydrological behavior of a watershed. The SCS-CN method estimates the watershed's infiltration capacity, which is crucial in understanding how changes in land use (e.g., deforestation, urbanization, or agricultural expansion) alter the watershed's ability to absorb rainfall. The method assigns Curve Number (CN) values based on land-use types, soil properties, and hydrological conditions, making it ideal for studying the effects of LULC changes on runoff and infiltration.

To determine the representative storm duration for rainfall-runoff modeling, the time of concentration (Tc) of the Jatiroto watershed was calculated using the Kirpich formula, resulting in 5.2 hours. Accordingly, the design storm duration was set to 6 hours, which closely matches the watershed's hydrological response time.

By using this method, we can analyze how different land-use scenarios (1995, 2014, and 2023) affect infiltration rates and runoff, and thus assess the role of LULC in influencing flood risks. The CN values, which are integrated into the runoff model, provide a detailed representation of the watershed's changing infiltration capacity, helping to highlight the direct impact of land-use changes on flood dynamics.

D. GeoHECRAS Hydraulic Modeling

In this study, GeoHECRAS 2021 is employed for hydraulic modeling, which is an essential tool for simulating water flow and flood inundation in the Jatiroto watershed. GeoHECRAS is a GIS-based extension of the widely used HEC-RAS 6.1 software, which allows for the integration of spatial data with hydraulic modeling using QGIS to produce accurate flood simulations. The hydraulic model used here simulates the flow of water across the watershed, focusing on flood depth, extent, and velocity under different land-use scenarios (1995, 2014, and 2023). Below is a step-by-step explanation of how the model is developed and implemented, based on information sourced from the GeoHECRAS official website [6].

1) **Defining the 2D Flow Areas**

The first step in GeoHECRAS modeling is to define the 2D Flow Areas in the watershed. These areas represent the regions where water will flow during a flood event. For the Jatiroto watershed, the study area is divided into multiple Sub-watersheds, each represented as a 2D flow area. The boundaries of these flow areas are carefully delineated based on topographical features, land-use classification, and hydrological properties of each sub-watershed. This step is essential because the flow areas define the computational domain where the water flow and flood inundation will be modeled.

2) **Mesh Generation**

After defining the 2D flow areas, a computational grid (mesh) is created, dividing the study area into smaller cells for numerical calculations. In this study, the mesh resolution is set to 10 meters, balancing accuracy and efficiency. For areas with complex topography or urban

environments, the mesh is refined to capture detailed flow dynamics, particularly in regions with rapid water flow or high flood risks. This ensures precise simulation of water movement.

*3) **Boundary Conditions***

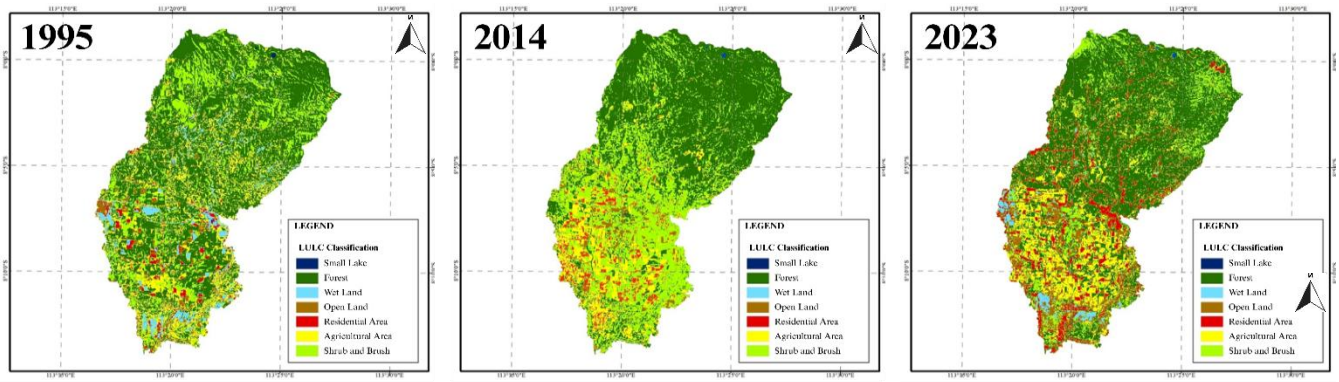


Fig. 3. LULC Classification of Jatiroto Watershed.

In GeoHECRAS hydraulic modeling, the boundary conditions defined how water enters and exits the model. The inflow boundary condition uses rainfall data (from 12 stations) applied as rain-on-grid, simulating varying rainfall intensities for recurrence intervals of 2, 5, 10, and 25 years. The outflow boundary condition is set using a normal depth condition, assuming water exits at a constant depth and slope, typical for areas draining into larger bodies of water. These boundary conditions enable accurate simulation of water flow and flood dynamics within the watershed.

4) **Assigning Manning's Roughness Coefficients (n)**

Manning's n is a key parameter in hydraulic modeling that represents the surface roughness or resistance to flow. It affects water flow, with rougher surfaces (e.g., urban areas, agricultural fields) slowing flow, while smoother surfaces (e.g., rivers, forests) allow water to flow more easily. In this study, Manning's n values were assigned based on land-use data for 1995, 2014, and 2023, as shown in Table I. Urban areas received higher n values due to paved roads and buildings, while forested areas were assigned lower n values. These values were applied to each grid cell in the mesh, ensuring the model accurately simulates flow resistance and predicts flood behavior. The assigned Manning's n values follow standard recommendations from Van Te Chow (1959), providing a validated basis for roughness coefficients in different land-use categories.

TABLE I. MANNING'S N, HSG, AND CN VALUE FOR EACH LAND USE

LULC	Manning	HSG	CN
Forest	0.3	C	70
Open Land	0.15	C	91
Residential	0.012	C	90
Shrub and Brush	0.2	C	65
Small Lake	0.035	C	100
Wet Land	0.3	C	100
Agricultural Land	0.2	C	82

5) **Hydraulic Simulation**

After defining the computational grid, boundary conditions, and roughness coefficients, the model runs a hydraulic simulation to simulate the movement of floodwaters across the watershed. GeoHECRAS solves the Shallow Water Equations (SWE) [6] to model the flow of water in the 2D flow areas. The simulation calculates the depth, velocity, and extent of floodwaters for different rainfall scenarios (1995, 2014, and 2023). The Diffusion Wave model was used for this study because it is well-suited for floodplain areas with relatively flat topography, where flow velocities are moderate. The Diffusion Wave model simplifies the full Saint-Venant equations by assuming negligible local inertia and acceleration, making it computationally efficient while still capturing the essential dynamics of flooding in low-gradient areas.

6) **Simulation Outputs and Analysis**

The primary outputs of the GeoHECRAS model include flood depth, extent, and velocity maps, produced for different land-use scenarios (1995, 2014, and 2023) and recurrence intervals (2, 5, 10, and 25 years). The flood extent map shows the affected areas, the flood depth map indicates the severity of flooding, and the flood velocity map shows how quickly floodwaters spread. These results help assess the impact of land-use changes, with areas of increased urbanization or deforestation showing larger and deeper flood extents. This analysis identifies vulnerable regions and aids in flood risk management.

7) **Model Calibration and Validation**

The model was calibrated by adjusting parameters, such as Manning's n and inflow data, to align with real-world flood event data, particularly from the December 2018 flood [7]. This calibration process allowed for the refinement of the model's predictive accuracy. For validation, the simulation results, including flood depth and flood extent, were compared to observed field data from the same event. This step ensured the model's reliability in predicting flood behavior by confirming that the simulated flooding matched the observed conditions.

8) **Model Sensitivity**

The sensitivity analysis indicates that flood inundation extent is strongly affected by changes in Curve Number (CN). Increasing CN from 69.7 to 87.49 resulted in a 21.3% increase in inundated area (from 0.199 km² to 0.242 km²), highlighting the importance of land use and soil

conditions in controlling runoff generation. In contrast, variations in Manning's roughness coefficient (0.03–0.06) produced negligible effects on inundation extent, with the flooded area remaining almost unchanged (0.199 km²). These results suggest that the model outputs are more sensitive to LULC-related hydrological parameters than to hydraulic roughness.

III. Result and Discussion

A. Land Use Change

This study analyzed land cover change in the Jatiroto watershed in 1995, 2014, and 2023 to understand land use dynamics and their relationship with flood inundation risk. Land cover data was obtained through the interpretation of Landsat 5 satellite imagery and processed with supervised classification techniques.

In 1995, the watershed was dominated by forest (175.02 km²) and shrubs (106.56 km²), with only small areas of settlements (7.88 km²), open land (5.06 km²), and wetlands (16.54 km²). By 2014, forest cover had declined to 151.67 km², agriculture had emerged at 32.85 km², and settlements and open land increased, while wetlands disappeared. In 2023, agriculture expanded to 47.90 km², open land to 33.10 km², and settlements to 18.33 km², while shrubs declined and forests slightly recovered to 160.39 km². These trends are summarized in Table II and Fig. 3.

Table II. Land Cover Area Of Jatiroto Watershed

LULC	Area (km²)		
	1995	*2014*	*2023*
Forest	175.02	151.67	160.39
Open Land	5.06	9.90	33.10
Residential Area	7.88	11.95	18.33
Shrub and Brush	106.56	104.49	35.03
Small Lake	0.15	0.36	0.18
Wet Land	16.54	0.00	6.02
Agricultural Land	0.00	32.85	47.90

Table III. Area Of Change Of Built And Non-Built Land In Jatiroto Watershed

Year	Developed Area (km²)	Non-Developed Area (km²)	% Developed	% Non-Developed
1995	12.94	310.44	4%	96%
2014	21.85	301.53	7%	93%
2023	51.43	271.95	16%	84%

Land cover change in the Jatiroto watershed showed a significant increase in the category of built-up land (settlements and open land) between 1995 and 2014, and 2023. Based on Table III, the area of built-up land in 1995 was recorded at 12.94 km² (4.0%), increased to 21.85 km² (6.8%) in 2014, and jumped to 51.43 km² (15.9%) in 2023. In contrast, non-developed land decreased from 310.44 km² (96%) in 1995 to 271.95 km² (84%) in 2023. These changes have a direct impact on the hydrological response of the watershed, increasing Curve Number (CN) values, reducing infiltration capacity, and increasing surface runoff volumes, which are important in flood risk mitigation planning in the region.

B. Soil Type

Soil types in the Jatiroto watershed are dominated by sandy-clay soils belonging to HSG C, which have a moderate infiltration capacity. Soils with HSG C allow slower infiltration compared to HSG A (sandy) and HSG B (sandy-silty), but better than HSG D (dense clay). These soils are found in agricultural areas and some urban areas, as identified based on the FAO Soil Map [8].

Table IV and Fig. 4 show the distribution of soil types in the Jatiroto watershed, all of which belong to HSG C. This indicates that this area has moderate infiltration ability, which affects surface runoff and water infiltration capacity.

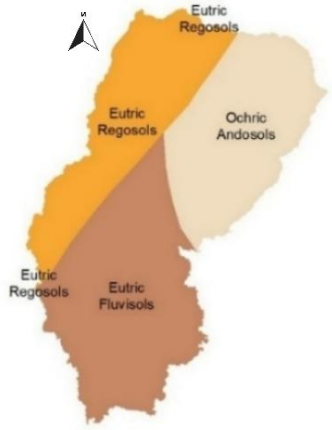


Fig. 4. Soil Type of Jatiroto Watershed

Table IV. Soil Type of Jatiroto Watershed

Soil Type	Area (km²)	%
Ochric Andosols	96.75	31%
Eutric Regosols	87.51	28%
Eutric Fluvisols	126.98	41%
Total	323.3	100%

Table V. Average Annual Rainfall (Mm)

Rain Station	Rainfall (mm)
Tekung	89.7
Nogosari	100.7
Meleman	117.3
Sukodono	88.4
Rojopolo	88.1
Banyu Putih Kidul	80.4
Kali Penggung	83.5
Blimbing	107.7
Tiris	164
Pladingan	95.9
Watu Urip	110.7
Wringin Agung	71

C. Rainfall Characteristics and Trends

Rainfall analysis was conducted based on data from 12 rainfall stations during the period 2013–2022, which were evenly distributed across the upstream, middle, and downstream areas of the Jatiroto Watershed, as shown in Table V. The rainfall data were obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG) of Indonesia [9]. This spatial and temporal pattern supports runoff analysis and flood modeling under various return period scenarios.

Average annual rainfall varies between stations, with the highest value at Tiris Station (164 mm) and the lowest at Wringin Agung (71 mm), reflecting the influence of

topography on rainfall intensity as shown in Table VI. The monthly analysis results show that the Jatiroto watershed has a strong monsoon rainfall pattern, with peak rainfall occurring in December, January, and February (average > 60 mm), while the dry season lasts from July to September with very low rainfall (< 20 mm). The highest monthly maximum rainfall value was recorded in December (>220 mm). On an annual basis, the highest maximum rainfall occurred in 2018 (>230 mm), followed by fluctuations that show no significant upward or downward trend until 2022.

The rainfall plan was calculated based on annual maximum rainfall data using the Log Pearson Type III distribution. The results of the analysis show that the design rainfall for the 2, 5, 10, and 25 years return periods are: 102.88 mm, 114.73 mm, 121.27 mm, and 128.51 mm for Subbasin 1. Similar values were found for the other Subbasins. These values were converted to 6-hour durations using the Mononobe method to represent high-intensity rainfall events prevalent in the tropics.

TABLE VI. RAINFALL INTENSITY BY STATION IN JATIROTO WATERSHED 23 DECEMBER 2018

Rain Station	Rainfall (mm)
Sukodono	57
Rojopolo	97
Banyupatih Kidul	60
Kali Penggung	103
Tekung	88
Nogosari	98
Meleman	25
Blimbing	108
Pladungan	0
Watu Urip	141
Wringin Agung	45
Tiris	48

TABLE VII. AVERAGE CURVE NUMBER

Subbasin	Average Curve Number		
	1995	2014	2023
1	69.38	69.55	71.18
2	70.60	69.50	76.93
3	69.72	69.56	72.72
4	71.63	69.99	87.49
5	80.58	69.70	87.49
6	69.38	69.55	71.18

D. *Curve Number*

Curve Number (CN) is an important parameter in the estimation of direct runoff from rainfall, which is determined based on a combination of land cover and soil type. In this study, CN values were calculated for the years 1995, 2014, and 2023, and used as the main input in effective rainfall calculation and flood modeling [10].

The average CN per Subbasin is presented in Table VII. In 1995, most of the watershed area was still dominated by forests and shrubs with low CN values (CN 70 and 65), reflecting natural and infiltrative hydrological conditions. In 2014, CN values began to increase due to the expansion of residential and agricultural land with higher CN (CN 90 and 82). For example, in Subbasin 1, the CN value increased from 69.38 to 69.55. A sharper increase in CN occurs in 2023, as the area of built-up land increases and vegetation cover decreases. In Subbasin 1, CN increased to 71.18, while Subbasins 4 and 5 reached 87.49, signaling a major change in the infiltration capacity of the area.

Overall, the upward trend in CN indicates an increase in runoff potential and flood risk, especially in downstream areas where the topography is flat and natural infiltration zones are increasingly lost.

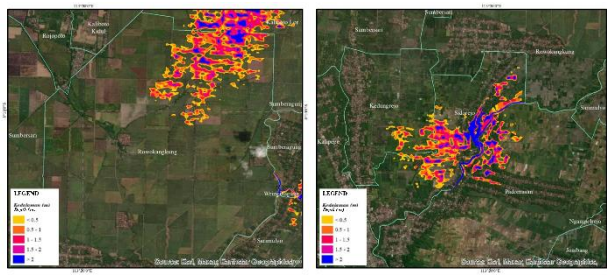
E. *Computation and Validation Process*

The flood prediction model was run to produce a map of flood inundation depth and distribution based on rainfall and the physical characteristics of the Jatiroto watershed. The model was validated using actual rainfall data from December 23, 2018, and inundation data from the December 24, 2018 flood event. The rainfall distribution showed significant variation, with Watu Urip receiving the highest rainfall (141 mm) and Pladingan the lowest (0 mm). This data was incorporated into the model and validated with field observations, as presented in Table I.

The majority of inundation depths ranged from 0.1 to 1.5 meters, consistent with field observations [7]. Simulation results also showed that the affected areas in Rowokangkung and Sidorejo Villages were predominantly inundated within this depth range. The agreement between simulated and observed depths confirms that the GeoHECRAS model using the Diffusion Wave approach is reliable and accurate for flood analysis and decision-making in flood risk management. Detailed spatial information on inundated areas is presented in Fig. 5, while quantitative comparisons are summarized in Table VIII. The simulation results showed a consistent pattern of inundation depth, with Rowokangkung Village experiencing 1.45 km² of inundation and Sidorejo Village 0.99 km².

TABLE VIII. INUNDATION AREA IN JATIROTO WATERSHED 24 DECEMBER 2018

Village		Rowokangkung	Sidorejo
Depth	*< 0.5 m*	0.52	0.25
	0.5–1 m	0.42	0.25
	1–1.5 m	0.29	0.19
	1.5–2 m	0.14	0.11
	>2 m	0.08	0.19
Total Inundation Area (km²)		1.45	0.99



(a) (b)

Fig. 5. Flood Depth Map: (a) Rowokangkung Village (b) Sidorejo Village.

F. *Flood Mapping*

This section presents flood inundation maps for each return period (2, 5, 10, and 25 years) and land cover scenario in 1995, 2014, and 2023, visualized in Fig. 7 (a-l). These maps show the changes in inundation area and flood depth for each land cover scenario and return period. Analysis of the different inundation patterns that occur due to land use change will be discussed further to provide a

clearer picture of the impact of land cover change on flood risk. These maps provide an important basis for flood mitigation planning and more informed policy decision-making.

G. Flood Inundation Area Comparison

For instance, at the 2-year return period, the inundated area increased from 12.88% in 1995 to 15.66% in 2023. Larger return periods display even greater expansions, confirming that extreme rainfall events exacerbate flooding in landscapes with reduced infiltration capacity.

TABLE IX. INUNDATION AREA BY DEPTH

Flood Depth (m)	Inundation Area by Depth (km²)											
	TR 2			*TR 5*			*TR 10*			*TR 25*		
	1995	*2014*	*2023*	*1995*	*2014*	*2023*	*1995*	*2014*	*2023*	*1995*	*2014*	*2023*
< 0.5	11.7	13.9	10.5	13.9	14.1	14.1	14.0	14.2	14.5	13.9	14.1	14.8
0.5 - 1	11.5	14.7	17.7	16.4	15.0	19.1	17.0	16.1	19.8	17.3	15.7	20.3
1 - 1.5	6.0	6.3	8.7	7.6	6.6	8.9	8.1	7.5	9.4	8.6	6.4	9.9
1.5 - 2	4.3	4.0	7.7	4.9	4.3	6.5	5.4	4.8	7.1	5.8	3.8	7.9
> 2	6.7	5.3	4.2	7.4	6.6	5.6	8.3	7.2	6.6	9.0	4.0	7.6
Total	40.1	44.2	48.8	50.3	46.7	54.1	52.7	49.8	57.4	54.8	44.1	60.6

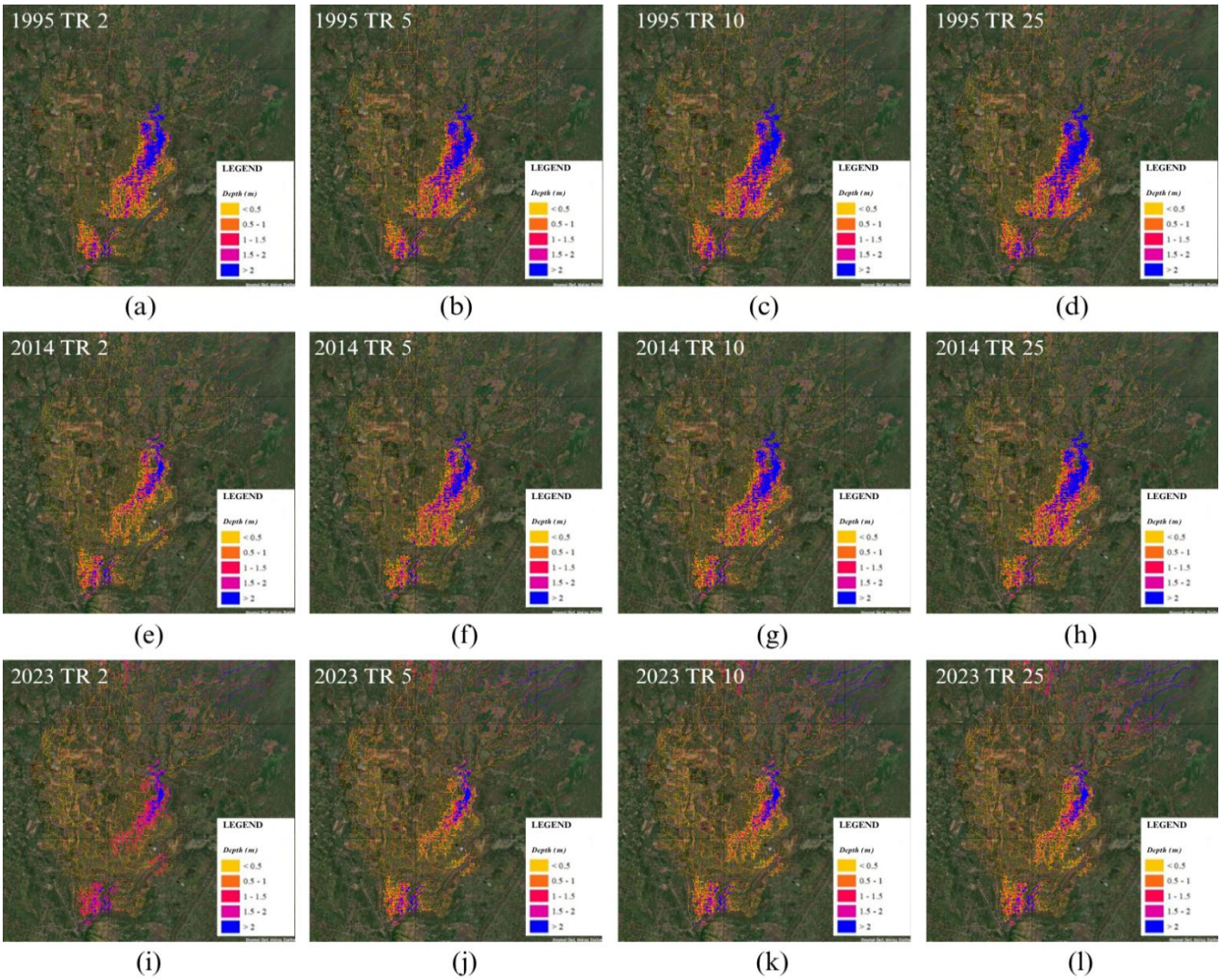


Fig. 6. Flood inundation maps based on land cover year and rainfall return period scenarios in the Jatiroto watershed: (a) 1995 with 2-year return period; (b) 1995 with 5-year return period; (c) 1995 with 10-year return period; (d) 1995 with 25-year return period

The comparison of inundation areas across the 1995, 2014, and 2023 scenarios (Fig.6, Table IX, and Table X) shows a consistent expansion of flood extent, primarily driven by the conversion of natural vegetation into settlements and open land. In 1995, inundation was largely confined to the river channel and adjacent lowlands, but by 2014 it had spread into agricultural and residential zones. The 2023 scenario records the most extensive flooding, with inundation reaching densely populated built-up areas.

Inundation depth analysis further indicates that medium depths (0.5–1.5 m) have become increasingly dominant, while the deepest class (>2 m) slightly decreased after 2014 but remains higher than in 1995. By the 25-year return period, inundation depths exceeding 1 m cover more than 37.8 km² in 2023. These findings highlight that urban expansion and the loss of natural infiltration zones have intensified flood hazards. Although forest cover showed a slight recovery in 2023, this increase

occurred mainly in downstream areas outside major flood zones, limiting its contribution to flood mitigation.

Overall, the results confirm that land use and land cover (LULC) change have a strong influence on flood hazard in the Jatiroto watershed, reinforcing the urgency of implementing watershed-based land management strategies to mitigate future risks.

TABLE X. FLOOD INUNDATION AREA BY LAND COVER SCENARIO AND RETURN PERIOD

Rainfall Return Time (Years)	Inundation Area (km^2)			Percentage (%)		
	1995	*2014*	*2023*	*1995*	*2014*	*2023*
2	40.1	44.2	48.8	12.88%	14.19%	15.66%
5	50.3	46.7	54.1	16.16%	14.99%	17.38%
10	52.7	49.8	57.4	16.94%	16.01%	18.45%
25	54.8	44.1	60.6	17.59%	14.16%	19.46%

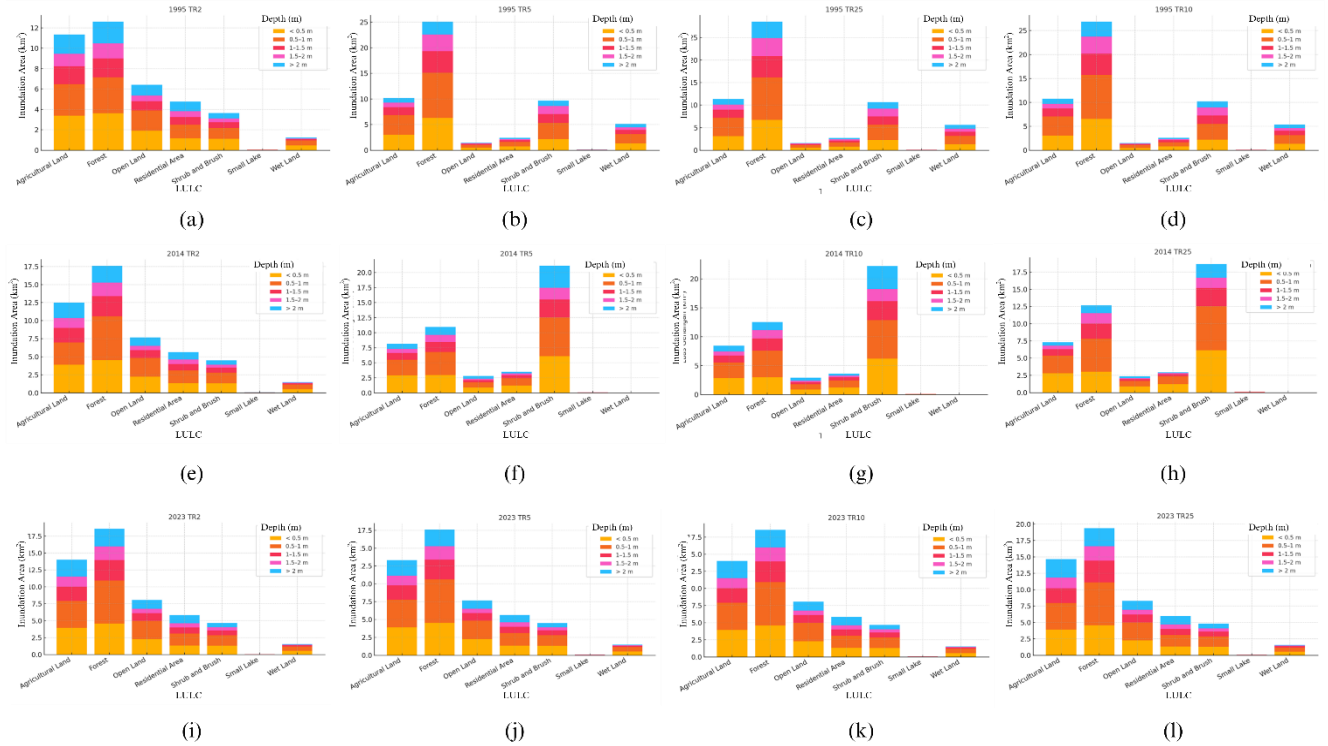


Fig. 7. Distribution of Inundation Depth by Land Cover (a) 1995 TR 2; (b)1995 TR 5; (c) 1995 TR 10; (d) 1995 TR 25; (e) 2014 TR 2; (f) 2014 TR 5; (g) 2014 TR 10; (h) 2014TR 25; (i) 2023 TR 2; (j) 2023 TR 5; (k) 2023 TR 10;(l) 2023 TR 25

H. Correlation of Inundation Depth with Land Cover

The distribution of inundation depth across land cover types shows clear temporal changes between 1995, 2014, and 2023, as shown in Fig.7. In 1995, forests and agricultural areas dominated the inundated zones, with deep inundation (>2 m) primarily affecting forests (up to 3.65 km² at TR 25). By 2014, inundation began to shift toward built-up areas, with settlements and open land showing increasing inundation depths, while agricultural land showed a decrease in inundated area. In 2023, this trend intensified: settlements and open land consistently experienced deeper inundation, reaching 1.28 km² and 1.37 km² (>2 m) at TR 25, respectively.

Correlation analysis further supports these findings. As shown in Table XI. Spearman's rho indicates strong positive correlations between inundation area and open land (ρ = 0.819), settlements (ρ = 0.757), and wetlands (ρ = 0.743), suggesting that expansion of these land cover types significantly increases flood risk. In contrast, forest cover shows a strong negative correlation (ρ = –0.819), confirming its critical role in reducing flood inundation. Agriculture has a moderate positive correlation (ρ = 0.576), while shrubs/grass (ρ = –0.238) and lakes (ρ = 0.129) show weaker relationships.

Overall, the results reveal a growing extent and depth of inundation over time, strongly associated with the expansion of built-up areas and the reduction of natural infiltration zones. The statistical evidence highlights that urban expansion and loss of forest cover are the primary drivers of flood risk intensification in the Jatiroto watershed. These findings underscore the urgency of regulating land use change and implementing watershed-based flood mitigation strategies, especially in rapidly developing areas.

TABLE XI. SPEARMAN CORRELATION BETWEEN LULC AND FLOOD INUNDATION

Land Use / Land Cover (LULC)	Spearman's ρ	Interpretation
Open Land	0.819	Strong positive correlation
Residential	0.757	Strong positive correlation
Wetland	0.743	Strong positive correlation
Agriculture	0.576	Moderate positive correlation
Lake	0.129	Weak positive correlation
Shrubs and Brush	-0.238	Weak negative correlation
Forest	-0.819	Strong negative correlation

I. Implications for Flood Management and Policy

Based on the findings of this study, several adaptation and mitigation strategies are recommended to reduce flood risk in the Jatiroto watershed. Land use management measures such as stricter zoning regulations to limit settlement expansion in flood-prone areas and

conservation of natural land, particularly in upstream regions, can help maintain infiltration and reduce runoff. Watershed-based interventions, including rehabilitation of upstream forests, construction or improvement of drainage channels, retention ponds, and infiltration wells in critical midstream and downstream areas, can mitigate flood extent and depth. Additionally, the results can inform scenario-based planning, allowing policymakers to simulate future urban expansion or climate change impacts and to develop flood risk maps as decision-support tools. Finally, promoting community awareness and preparedness, such as early warning systems and local-scale mitigation practices, ensures that residents in high-risk areas are better equipped to respond to flooding events.

IV. Conclusion

This study demonstrates that land use and land cover (LULC) changes in the Jatiroto watershed between 1995 and 2023 significantly influenced flood inundation dynamics. The expansion of settlements and open land led to higher Curve Numbers, reduced infiltration, and ultimately increased inundation extent and depth across most scenarios. Flooded areas rose from 12.88% in 1995 to 15.66% in 2023, with depths of 0.5–1.5 m becoming increasingly dominant in residential and agricultural zones.

Although forest cover slightly increased in 2023, this recovery mainly occurred in the upstream region, which is not exposed to major inundation. Therefore, its positive hydrological effect did not substantially reduce flood risks in critical upstream and midstream areas.

These findings confirm that urban expansion and conversion of natural land are the primary drivers of flood risk escalation in the watershed. Integrating spatial analysis with hydrologic–hydraulic modeling provides a reliable framework for assessing future flood risks and emphasizes the need for stricter land use regulation and watershed-based flood mitigation planning.

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Nabilla Syafa was born in Malang, Indonesia. She is a master’s student at Brawijaya University, Malang, Indonesia, in 2025. Her research interests include hydrology, flood modeling, and land use change. She has participated in international engineering competitions and is active in youth and community development initiatives. (email: nabillasfy@gmail.com).



Prof. Ir. Agus Suharyanto, M.Eng., Ph.D., is a professor in the Department of Civil Engineering, Brawijaya University. He currently serves as the Head of the Functional Position Group in Water Resources Engineering. His research focuses on hydrology, flood modeling, and sustainable water resources management. He holds a professional engineering title (Ir.) and is actively involved in academic and applied research in the water sector. (email: agus_ceub@yahoo.com).



Dr. Eng. Ir. Indradi Wijatmiko, S.T., M.Eng. (Prac.), IPU., ASEAN Eng. is a lecturer in the Department of Civil Engineering, Brawijaya University, and currently serves as the Vice Dean for Academic Affairs at the Faculty of Engineering. His research interests include structural engineering, earthquake-resistant design, and engineering education. He holds the title of Professional Engineer (IPU) and is certified as a Practicing Engineer (M.Eng. Prac.). (email: indradi@ub.ac.id).