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Effect of Land Use and Land Cover Change on Inundation and Flood Loss Value in Lumajang District

Regina Salsabila Athallah*, Agus Suharyanto, Indradi Wijatmiko

***Abstract*—This study examines the relationship between land cover change and the extent of inundation and the value of economic losses due to flooding in Lumajang district in 1995, 2014, and 2023. Using a spatial approach based on satellite imagery and hydraulic simulation, as well as the ECLAC method in calculating losses, this study shows that the loss of natural land cover, such as forests and wetlands, as well as the expansion of residential areas, contributed significantly to the increase in inundation intensity and economic losses. These findings are important for spatial planning that is adaptive to hydrometeorological disaster risks. In addition, this research also supports the implementation of mitigation policies based on spatial and hydrological data that are appropriate to the conditions of the Jatiroto watershed.**

***Index Terms*— Economic Loss, Flood, GIS, LULCC.**

I. INTRODUCTION

FLOODING is a hydrometeorological disaster that has a significant impact on social, economic and environmental life. One of the main factors influencing the magnitude of flood impacts is land cover change [1]. Land cover (LC) that is initially dominated by natural vegetation such as forests and wetlands tends to have a better ability to absorb and retain rainwater, thereby reducing the volume of runoff [2]. Conversely, land conversion to settlements, open land, or other impervious areas will increase runoff rates, increase peak discharges, and exacerbate flood inundation [3,4].

Runoff is the flow of rainwater that is not absorbed into the soil and flows directly on the surface [5,6]. The amount of runoff is influenced by various factors, including rainfall, land slope, soil type, and LC [7]. Densely vegetated LC tends to slow the flow of water and increase infiltration, thereby reducing the potential for flooding [8]. However, when vegetation is converted to open land or settlements, runoff potential increases significantly [3,9]. Flood losses include damage to buildings, infrastructure, agricultural land and other assets. The value of these losses generally depends on the depth of inundation, duration of flooding, and type of land affected [10]. To accurately estimate losses, an approach that considers physical and economic factors spatially and temporally is required.

The Jatiroto watershed is an important area that flows through Lumajang district and supports the community's water needs, both for domestic and agricultural purposes. With a large agricultural and plantation area, the existence of the river and the safety of the water flow are crucial. Several studies have shown that LC change in the Jatiroto watershed has a major impact on flood discharge and erosion [11], as well as decreasing river capacity due to sedimentation and utilization of the boundary as agricultural land [12].

In recent years, the Jatiroto watershed has experienced recurrent flooding events, including a major flood in 2018 that submerged hundreds of houses and agricultural land. The impact of flooding is not only physical but also triggers extensive economic losses, such as disruption of economic activities, infrastructure damage, and loss of community productivity. This is even more complex because the Jatiroto watershed has a combination of various types of land use-from settlements, agriculture, to forests and wetlands-each of which has different economic values and risks.

In this context, mapping flood inundation and estimating economic losses based on land use variation is important, because land use determines the type and value of exposed assets and the specific damage behaviour of each class to water depth. This study uses the SCS–Curve Number (SCS-CN) hydrological approach [13,14] due to its simplicity, seamless integration with hydraulic simulations, and direct relationship between soil, land cover, rainfall and surface runoff volume. CN values were taken directly from USDA–NRCS Technical Release 55 (1986) for the relevant land use–HSG combinations. This approach is combined with GeoHEC-RAS hydraulic modelling to obtain the spatial distribution of flood depth. Economic losses were then calculated using the Damage and Loss Assessment (DaLA) framework by ECLAC [15-18], which was chosen because it translates flood depth and area into comparable monetary losses through damage factors and unit values per land use class, allowing for village ranking based on losses using a common basis. In this application, the estimates explicitly consider the relationship between flood depth and the level/extent of damage to each land use class [10].

As an extension of this study, the estimation of economic losses by village administrative area was also analyzed. This analysis provides an overview of the spatial distribution of losses and enables the identification of villages with the highest levels of economic losses due to flooding. This information is very useful for setting disaster mitigation priorities more efficiently. Villages with the highest losses can be targeted in resource allocation, spatial planning and flood control infrastructure development. Thus, this approach supports a more targeted and data-driven mitigation strategy.

Regina Salsabila Athallah, **Agus Suharyanto,** and **Indradi Wijatmiko** are with the Department of Civil Engineering, Brawijaya University, Malang, Indonesia. Corresponding author email: ndollcaca@gmail.com.

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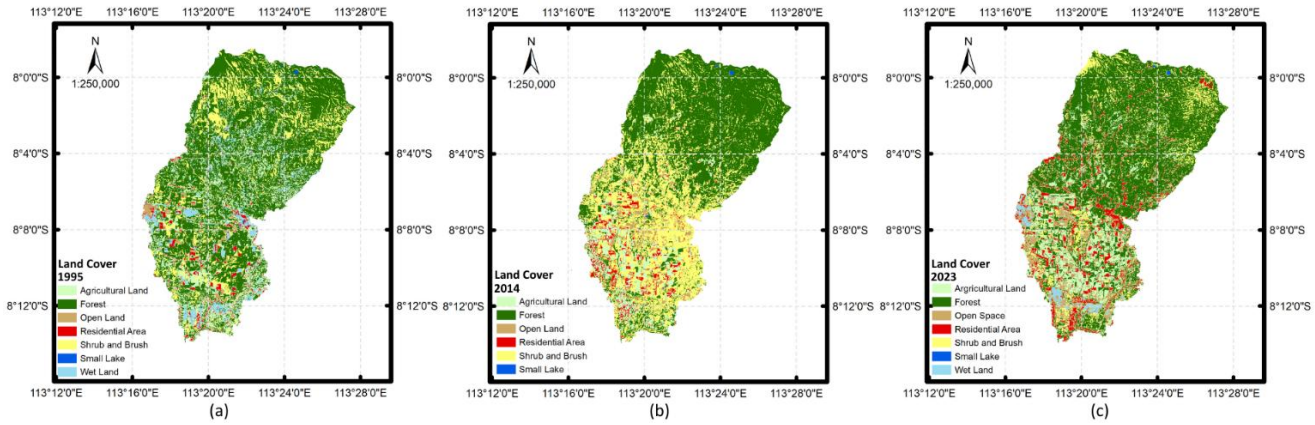


Fig. 1. Land cover map of (a) 1995, (b) 2014, and (c) 2023

The final result is expected to provide a spatial overview of risks and support data-driven flood mitigation strategies.

The objectives of this research include (1) mapping the distribution of inundation in Jatiroto watershed based on LC changes; (2) calculating and analyzing the level of flood losses from LC changes that occur in the Jatiroto watershed; and (3) ranking each village based on the results of inundation losses in the Jatiroto watershed, thereby providing an operational basis for mitigation planning and budgeting.

II. METHOD

This research combines remote sensing, hydrological and hydraulic modeling, and economic loss analysis methods as follows:

A. Study Area

This research was conducted in Jatiroto Watershed, which is administratively located in Lumajang Regency, Jember Regency, and Probolinggo Regency, East Java. This watershed has a total area of 316.09 km^2. Jatiroto is one of the important watersheds that has a vital role in supporting people's lives, especially in terms of water supply for households, agriculture, and plantations. In this study, the watershed is divided into 7 land covers, namely agricultural area, forest, residential area, shrubs, wetland, and small lake. This watershed location also frequently experiences seasonal flooding events, especially during the rainy season, with significant impacts on the socio-economy of the local community.

B. Data Collection

This study uses satellite imagery from 1995, 2014, and 2023, DEM data from DEMNAS (≈8×8 m), rainfall data from BMKG stations, and economic data based on land use types with unit values referring to Budiyono et al. (2016). The three analysis years were selected based on the availability of suitable, cloud-acceptable datasets and are intended to represent approximately three decades of land cover change in the study area. Administrative boundaries were sourced from the Geospatial Information Agency (BIG), and LULC mapping was derived from satellite imagery with reference to BIG base maps for positional consistency. Model calibration used BPBD flood reports to spatially match simulated inundation with reported flooded villages.

In this study, no separate validation of the dataset was performed; all data were used as available for hydrological-hydraulic modeling and loss calculations.

C. Land Cover Processing

The LULC maps reached 87.5% overall accuracy, with an expected agreement of 0.21 and a Kappa of 83.5%, so they're reliable as inputs for hydraulic simulations and flood exposure analysis. We generated the maps using supervised classification and used them to track land-use/land-cover changes (Fig. 1).

D. Hydraulic Simulation

Inundation simulations were conducted using GeoHEC-RAS software by integrating DEM, river network and runoff discharge. The variables that were kept constant for all scenarios (1995, 2014, and 2023) were rainfall, DEM, and river structure-the only variable that differed was LC. This is applied to suppress independent variables so that the effect of LC on flooding can be clearly seen.

Since there is no measured discharge data (no gauging stations) available for the rivers under study, GeoHEC-RAS calibration was performed based on inundation area: matching villages reported as flooded in BPBD flood reports with simulation results. This approach is adequate for spatial matching at the village scale, but does not assess the accuracy of peak discharge or temporal dynamics.

E. Reclassification and Raster Conversion

The flood raster was reclassified into 17 depth bands with an interval of 0.125 m (Table I). The 0.125 m step, half of the 0.25 m increment used in the depth-damage curve by Budiyono et al. (2016) (Fig. 2), was chosen to sharpen the area-depth integration, as each depth band occupies a different spatial area.

TABLE I. DEPTH INTERVAL FOR RECLASSIFICATION VALUES

Class	Depth (m)	Class	Depth (m)
1	0 – 0.125	**10**	1.125 – 1.25
2	0.125 – 0.25	**11**	1.25 – 1.375
3	0.25 – 0.375	**12**	1.375 – 1.5
4	0.375 – 0.5	**13**	1.5 – 1.625
5	0.5 – 0.625	**14**	1.625 – 1.75
6	0.625 – 0.75	**15**	1.75 – 1.875
7	0.75 – 0.875	**16**	1.875 – 2
8	0.875 – 1	**17**	2 – 5
9	1 – 1.125		

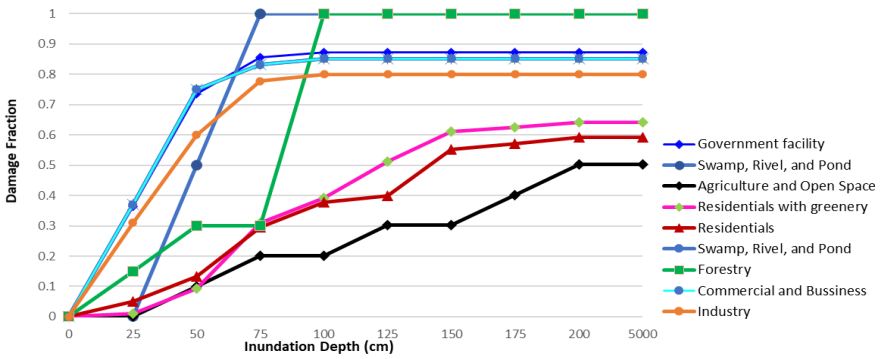


Fig. 2. Damage-Fraction by Budiyono [10]

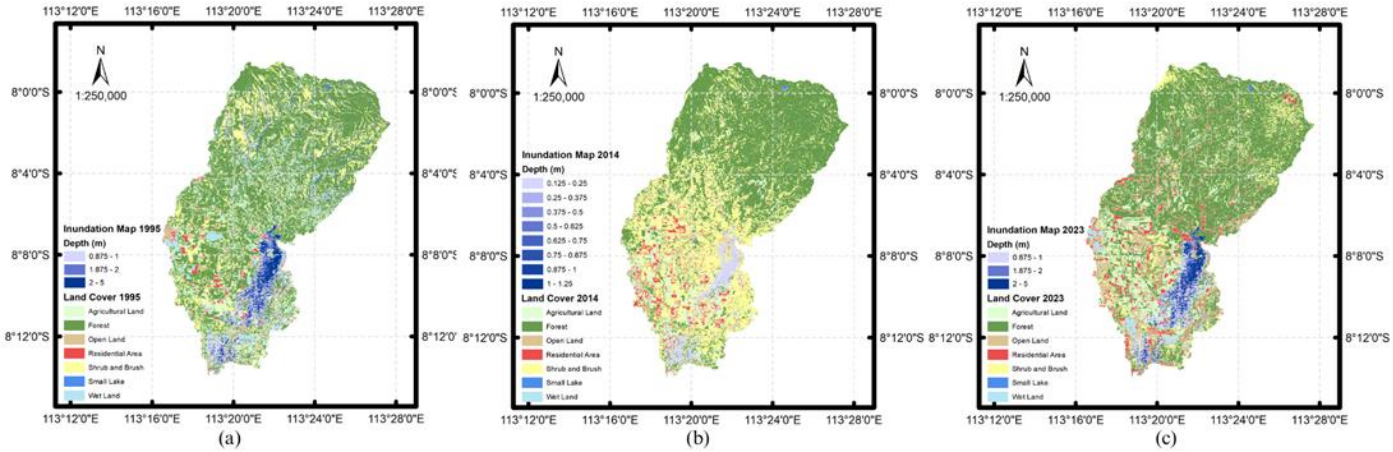


Fig. 3. Inundation map based on land cover of (a) 1995, (b) 2014, and (c) 2023

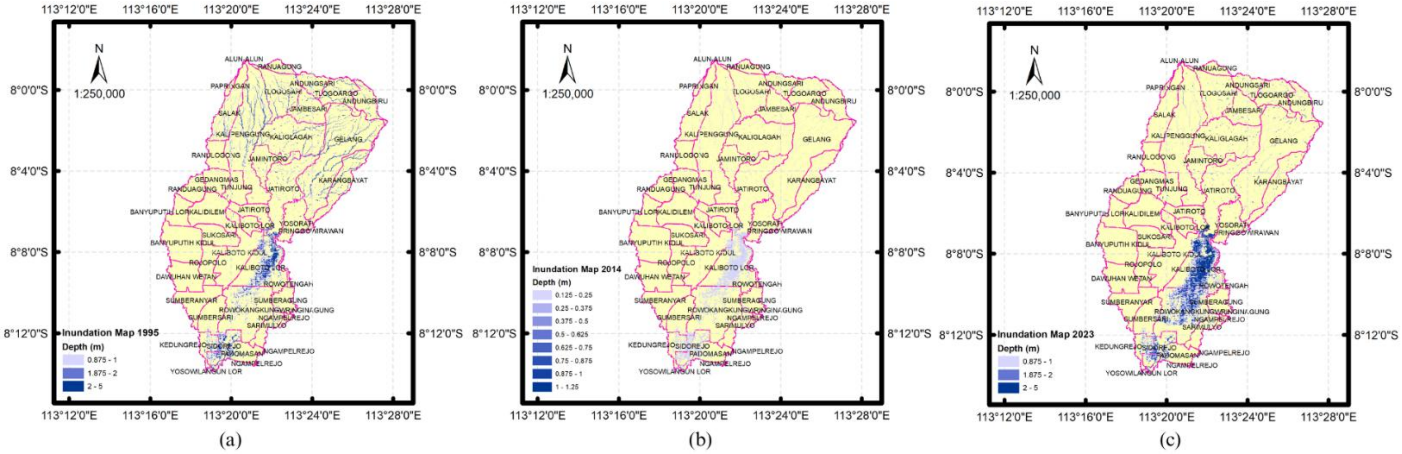


Fig. 4. Inundation map based on administrative boundaries of (a) 1995, (b) 2014, and (c) 2023

For each band, the damage factor was obtained through linear interpolation of the curve with 0.25 m intervals. The reclassified map was then converted into polygons (ArcGIS Raster to Polygon) to summarize the area based on depth and overlaid with land use classes for loss estimation. This classification directly affects the visualization of the depth map in Fig. 4 and the estimation of damage factors used in loss calculations.

F. Loss Calculation

The converted inundation polygons were then intersected with the land cover map, resulting in the combined attributes of information: depth (value), land type and village name. The area of each polygon was calculated using Calculate Geometry, and all attributes were exported to Microsoft Excel for loss calculation.

Using the Damage and Loss Analysis by ECLAC (1) method by multiplying the inundated area, economic exposure value per land, and damage factor based on the depth-damage curve. This method has been widely used in various flood-affected areas, such as in Krueng Kluet Aceh [15], Bandung Regency [16], Jember District [17], Cikapundung watershed [18], and in Jakarta area [10]. The use of this method allows for systematic estimation of economic losses, especially for comparing land use change scenarios. The damage factor and economic exposure value used was taken from research by Budiyono [10] (Fig. 2 and Table II), with the highest unit value is residential in this case. The loss value in USD was then converted to IDR using the 2009 exchange rate of 9654 according to Budiyono et al (2016), and adjusted for 2023 for all three years (2).

$$\text{Loss}_{\text{USD 2009}} = \sum(L_i \times D_i \times V_{\text{USD}i}) \quad (1)$$

$$\text{Loss}_{\text{IDR 2023}} = \text{Loss}_{\text{USD 2009}} \times 9{,}654 \times \frac{\text{CPI}_{\text{ID 2023}}}{\text{CPI}_{\text{ID 2009}}} \quad (2)$$

where:

L_i: Area of submerged land in the i-th LC class (hectares)
D_i: Damage factor according to inundation depth (0-1)
V_{USDi}: Economic value per unit area of the i-th LC (USD/hectare)
9,654: The USD/IDR exchange rate used in Budiyono et al. (2016) corresponds to 2009 rate (USD 1 = IDR 9,654)
$CPI_{ID\ 2023}$ & $CPI_{ID\ 2009}$: Cosumer Price Index Indonesia in 2023 & 2009

TABLE II. ECONOMIC EXPOSURE VALUE BASED ON LAND COVER

Land Cover	Economic Exposure Value (USD per hectare)
Government facility	301.0
Forestry	10.4
Industry and warehouse	517.9
Commercial and business	517.9
Residential	150.6
Residential with greenery	341.8
Agriculture	1.6
Swamp, river and pond	3.8
Agricultural and open land	3.1

G. Recapitulation and Comparative Analysis

After the loss values were calculated for each polygon, a recapitulation of the total loss by year (1995, 2014, 2023) and by village was conducted. Village-level loss rankings were visualized as choropleth "ranking maps" for each study year (1995, 2014, 2023). Ranks (1 = highest loss) were computed from the ECLAC-based village loss estimates and mapped with a single-hue sequential ramp (darker = higher rank) to enhance ordinal readability. These results were used to:

- Analyze changes in total losses between years
- Identify villages with the highest economic losses
- Assess the relationship between LC, inundation area and economic loss

H. Statistical Analysis

Statistical analysis was conducted for each year, namely 1995, 2014, and 2023. Flood damage values were compared with three groups of factors: inundation area, inundation depth (average and maximum), and land cover area (agricultural, forest, open land, settlements, shrubs, wetland, and lakes). The strength of the relationship was measured using Pearson (r) and Spearman (ρ) correlations, then reported for each year along with the inter-year average to identify recurring patterns. As an additional check, Pearson correlations between inundation area and losses were calculated for five sample villages in all years.

In addition, as an external comparison, village rankings based on losses were compared with the BNPB Flood Vulnerability Index compiled based on BNPB Regulation No. 12/2012, a vulnerability value that considers social, economic, environmental, and infrastructure aspects. A Spearman's correlation analysis (ρ) was conducted, calculated between village priority rankings and Top-10 overlaps (the percentage of villages that simultaneously ranked in the top 10 according to both frameworks).

III. RESULT

Overall, across 1995–2014–2023, changes in land cover are associated with shifts in inundation extent/depth and losses; 2014 shows the shallowest and smallest footprint amid wider secondary vegetation, while 2023 exhibits higher losses as flood footprints intersect more residential areas (see Table III and Fig. 3).

To identify the economic impact of flooding on different types of land use, losses were estimated based on LC classification. Table III shows the total estimated losses by LC type in each year. It shows that residential areas dominate total losses, followed by forest and agricultur, while open land, wetland, shrubs, and lake contribute relatively less (Table III). This reflects the much higher unit values assigned to residential land compared with others.

In addition to the LC classification, the distribution of inundation was also analyzed based on village administrative areas to obtain spatial information that is more applicable for policy making. This mapping on Fig. 4 shows that villages such as Kaliboto Lor, Rowokangkung, Kedungrejo, Sidorejo, and Padomasan are the areas with the widest distribution of inundation. The following map displays the distribution of flood inundation by village for 1995, 2014 and 2023.

Regarding economic loss estimation, the depth–damage factors and unit values from Budiyono et al. (2016) are applied as Indonesia-based proxies. In the absence of local claims data, their transferability to the Jatiroto context is treated as indicative rather than fully localised; loss estimates should therefore be read as first-order approximations, with future work aimed at calibrating these curves using post-event surveys or administrative claims. To deepen understanding of the relationship between flood inundation area and the amounts of economic losses caused by flooding, five villages were deliberately selected based on patterns of change identified from data from 1995, 2014, and 2023 (Table IV). These case villages correspond to the top five settlements with the highest estimated economic losses in 2023.

TABLE III. TOTAL AREA AND ECONOMIC LOSSES CAUSED BY INUNDATION BASED ON LAND COVER

Land Cover	Total Area (Ha)			Inundation Area (Ha)			Economic Losses (Thousand Rupiahs)		
	1995	2014	2023	1995	2014	2023	1995	2014	2023
Forest	17744.1	15335.9	16660.2	1392.0	540.2	927.9	196,206,011.2	7,452,645.7	132,341,465.3
Wetland	1728.8	0.0	566.0	285.3	0.0	50.6	18,612,529.4	0.0	3,302,030.2
Agricultural	5600.5	3343.4	5041.7	508.0	293.3	846.2	8,096,606.3	3.9	15,285,468.7
Residential	818.2	1210.1	1952.9	127.6	92.4	336.3	144,465,731.3	6,038,704.0	412,185,923.8
Open Land	505.6	998.3	3625.2	60.9	88.2	402.9	1,005,195.9	11.9	7,016,838.3
Shrubs	5147.0	10648.8	3710.2	555.7	825.3	226.0	4,729,401.1	7.9	1,953,014.2
Small Lake	28.2	36.5	17.5	4.5	4.7	3.3	292,455.4	0.0	217,007.8
			Total	2934.0	1844.0	2793.4	373,407,930.6	13,491,373.3	572,301,748.2

TABLE IV. PEARSON AND SPEARMAN CORRELATION RESULTS BETWEEN VARIABLES AND ECONOMIC LOSSES

Variable	Pearson				Spearman			
	1995	2014	2023	Average	1995	2014	2023	Average
Agricultural Land	0.5732	0.5012	0.7091	0.5945	0.6606	0.5623	0.5856	0.6028
Forest	0.4802	0.2718	0.0705	0.2742	0.1303	0.6875	0.6905	0.5027
Open Land	0.3616	0.3821	0.5401	0.4279	0.3471	0.3262	0.6092	0.4275
Shrubs	0.6206	0.4631	0.8121	0.6319	0.4432	0.5287	0.6490	0.5403
Small Lake	0.3586	0.6444	0.0452	0.3494	0.6895	0.5555	0.6476	0.6308
Wetland	0.1940	0.0376	-0.0435	0.0627	0.3886	0.3440	-0.7889	-0.0187
Flood Area	0.7014	0.0000	0.1532	0.2849	0.6700	-0.8491	0.5138	0.1116
Maximum Flood Depth	0.9445	0.8319	0.9470	0.9078	0.9904	0.9381	0.9718	0.9668
Average Flood Depth	0.2564	0.3421	0.1862	0.2615	0.3105	0.5971	0.3860	0.4312

TABLE V. PEARSON CORRELATION RESULTS BETWEEN INUNDATION AREA AND ECONOMIC LOSSES ON FIVE VILLAGES

Village	Inundation Area (ha)				Economic Losses (Thousand Rupiahs)			
	1995	2014	2023	Graph	1995	2014	2023	Graph
Kaliboto Lor	550.985	549.631	844.773		100,960,275.09	1,845,648.49	226,596,975.60	
Rowokangkung	269.296	262.065	814.179		35,149,147.11	2,636,078.71	124,812,100.14	
Sidorejo	196.495	200.056	172.701		41,140,056.78	1,145,604.68	79,603,786.33	
Padomasan	85.489	87.525	64.393		17,522,528.34	620,233.73	20,813,137.65	
Kaliboto Kidul	53.089	43.575	69.376		7,874,998.07	91,926.25	12,574,589.05	
Pearson's value					0.920	0.688	0.939	

After running statistical analysis, the results show a consistent outcomes. Flood areas are most closely related to the increase in flood damage values (see Table IV). Additional analysis of five sample villages reinforced the main results, namely the Pearson correlation between inundation area and high losses in Table V.

To gauge robustness, a simple sensitivity test was conducted under the controlled-scenario design. Curve Number (CN) was varied from 69.7 to 87.49 and Manning's roughness from 0.03 to 0.06, while rainfall, the DEM (DEMNAS ≈ 8 × 8 m), and channel geometry were held constant. Inundation area increased by 21.3% as CN rose (0.199 to 0.242 km²), whereas changes in roughness produced negligible differences (≈0.199 km²). Within these bounds, the model indicates greater sensitivity to LULC-related hydrologic parameters than to hydraulic roughness.

On the other hand, a comparison of village rankings with the BNPB regulation-based index shows a moderate correlation between the two village priority orders, with a Spearman ρ value of 0.436 from 44 villages and a Top-10 overlap value of 50% from the 10 villages with the highest rankings.

IV. DISCUSSION

A. Inundation Result and Economic Loss Based on LC

Based on the Table II and Fig. 3 presented, it can be seen that there are significant changes in LC, inundation area, flood depth distribution, and total economic losses during 1995, 2014, and 2023 in Lumajang District. These changes have a complex impact on the characteristics of inundation and losses caused by flooding.

In 1995, the LC was dominated by forest (17,744.1 hectares) and agricultural land (5,600.5 hectares), with 1,728.8 hectares of wetlands that played an important role as hydrological absorption and buffer areas. However, the region also has a distribution of open land (505.6 hectares) and residential area (818.2 hectares) that tend to be scattered in the downstream and central parts. Inundation mapping indicates extensive flooding with predominantly higher depths (locally >5 m; Fig. 3a), with a total inundated area of 2,934 ha and estimated losses of IDR 373,407,930,600, a large share of which occurred where the flood footprint intersected forested zones due to their areal extent. Forest cover appears to be associated with lower inundation severity in some upstream areas, but this pattern is interpreted as a spatial association rather than a proven hydrodynamic mechanism. Because processes such as interception, infiltration, and roughness were not explicitly modeled, the role of forests in flood moderation is treated as indicative rather than conclusive. This indicates that forest area alone does not guarantee a reduction in flood risk if the spatial distribution is uneven or not strategically positioned as a buffer against runoff.

Entering 2014, there were major changes in the LC configuration. Forest area decreased to 15,335.9 hectares, and wetland even disappeared completely (0 hectares). However, there was a sharp increase in the area of shrubs to 10,648.8 hectares, which was spread fairly evenly in the middle and downstream of the study area. This type of vegetation is able to provide a hydrological function that is quite effective in slowing down surface flow, reducing runoff velocity, and increasing infiltration, thus reducing the volume of water that reaches the inundation area. During this period, agricultural land shrank to 3,343.4 hectares, while residential land increased to 1,210.1 hectares. Despite the increase in impermeable area, the 2014 inundation map shows the dominance of inundation with a very shallow depth (range 0.125-1.25 m), and a decrease in inundation area to 1,844 hectares. The value of losses incurred was also very low, at only IDR 13,491,373,300, dominated by impacts on residential land. This shows that although the total forest area is smaller than in 1995, the presence of spatially distributed secondary vegetation (shrubs and agriculture) can significantly reduce hydrological impacts.

In 2023, there were new dynamics in LC change. The area of forest experienced a slight increase to 16,660.2 hectares, and wetlands began to reappear covering an area of 566 hectares. However, buffer vegetation such as shrubs decreased sharply to only 3,710.2 hectares, while open

land increased dramatically to 3,625.2 hectares, and residential land expanded to 1,952.9 hectares. These changes led to another rapid increase in surface flow that was not retained by absorbent vegetation. Based on the 2023 inundation map, it is clear that the depth of inundation has increased again (to >5 m), and the distribution of inundation has expanded, especially in the southern region. The inundation area rises to 2,793.4 hectares, and the value of economic losses increases sharply to IDR 572,301,748,200, with the largest contribution of damage coming from residential land (IDR 388 billion) and forests (IDR 124 billion). This reinforces the finding that the increase in impermeable land and loss of buffer vegetation has a significant impact on increasing flood risk and losses.

These LC–flood relationships are interpreted as associations based on spatial patterns, not definitive hydrodynamic causality, because processes such as storage, roughness, and infiltration were not explicitly modeled. Visually and spatially, changes in land characteristics from natural or secondary vegetation to settlements and open land with no absorption capacity have been shown to have a significant impact on increasing the extent and depth of inundation and the value of economic losses. Conversely, an evenly distributed and well-connected vegetation configuration between areas can help control surface flow and reduce the risk of inundation.

B. Inundation Results Based on Village Administrative Boundaries

From Fig. 1, it can be seen that in 1995, LC in the Jatiroto watershed was dominated by forest and agricultural land, which were widely distributed, especially in the central and northern parts of the region. Residential areas were still scattered in a limited manner, centered around Kaliboto, Rowotengah, and several downstream parts such as Ngampelrejo and Sumbergading.

Based on the 1995 inundation map (Fig. 4), inundation areas are concentrated in the downstream areas of the watershed, particularly in villages such as Kaliboto Kidul, Kaliboto Lor, Rowokangkung and Sumbergading. Inundation depths are dominated by the 0.875-2 meters class, with some areas reaching more than 2 meters, indicating moderate to high flood potential in the area.

Spatial analysis shows that villages with predominantly agricultural LC located near the river are more vulnerable to inundation. This is because open land without dense vegetation accelerates surface flow towards the river. In addition, residential areas located in lowland zones such as Kaliboto Lor and Rowokangkung show significant levels of inundation. This indicates that the presence of settlements in flood-prone areas has increased the risk of localized flooding. And villages that retain forest cover such as Kaliglagah and Gelang appear relatively safer from inundation, as dense vegetation functions as a water retainer and surface runoff inhibitor. In conclusion, the 1995 LC condition, which was still dominated by forest and traditional agriculture, limited the extent of inundation, but villages downstream with more open LC showed marked vulnerability. This finding provides an important baseline for comparing the impact of LC change in subsequent years.

The 2014 results show significant changes in LC composition compared to 1995. Forest areas are still quite extensive in the northern and eastern parts of the watershed, but there has been a conversion to agricultural land and settlements in the central and southern parts. Some areas that were previously covered by shrubs also turned into open areas and settlements, especially around Kaliboto, Sukosari and Rowokangkung.

From the 2014 inundation map, there was a decrease in inundation intensity compared to 1995. Most of the affected areas only experienced inundation with a depth of <1 meter, and only a few areas were inundated more than 1 meter. The distribution of inundation was also more spread out but relatively shallow.

Spatially, it was found that there was a decrease in the depth of inundation in the Kaliboto Lor, Rowokangkung and Kedungrejo, Siderejo, and Padomasan areas, although these villages still showed quite high inundation areas. This can be attributed to the more even distribution of LC: there is no dominance of wetlands as in 2023, and most areas are covered by agricultural vegetation with relatively moderate infiltration capacity. The presence or absence of wetlands appears to be associated with changes in inundation patterns across years. In 2014, when wetlands were absent, inundation was more extensive but relatively shallow, while in 2023, the reappearance of wetlands coincided with stagnant water in some downstream areas. These observations suggest a possible relationship, although we recognize that detailed hydrodynamic processes (e.g., water storage and drainage functions) were not explicitly modeled in this study. Therefore, the role of wetlands is interpreted as indicative rather than conclusive. Some villages with forest cover change to agriculture, such as Kalidilem and Sukosari, show new shallow inundations that were not present in 1995. This indicates that the conversion of forest to agriculture caused an increase in surface flow, but not enough to create deep inundation.

When compared to 1995, the inundation in 2014 was wider in distribution but shallower, indicating that even and non-extreme LC changes such as 2023 are still able to drain runoff in a more balanced manner without the accumulation of large volumes of water in one spot.

Overall, 2014 can be considered a transition period. Although forests began to degrade and settlements developed, there were no extreme pressures like in 2023. The water flow system is still relatively under control, and there has not been an alarming concentration of deep inundation.

In 2023, the most extreme condition in the dynamics of LC change and inundation in the Jatiroto watershed is reflected when compared to 1995 and 2014. Spatially, the middle and downstream areas of the watershed experienced a significant increase in inundation intensity, especially in the villages of Kaliboto Lor, Kaliboto Kidul, Rowokangkung, Sidorejo, Kedungrejo, and Padomasan. Inundation depths this year reached more than 2 meters in some spots, indicating a serious increase in risk to local communities and infrastructure. LC change shows a massive expansion of residential areas, especially along road networks and low-lying areas. On the other hand, forest areas are degrading, especially in the central part of the watershed, reducing the land's ability to absorb rainwater.

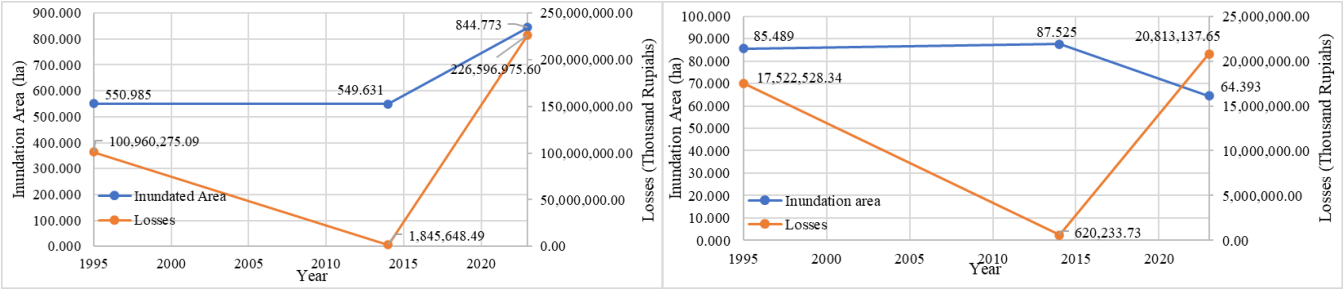


Fig. 5. Inundation area and losses of (a) Kaliboto Lor for pattern 1 example and (b) Padomasan for pattern 2 example

Wetland data that had disappeared in 2014 reappeared in 2023. However, the ecological function of the wetland is not optimized, and actually exacerbates the stagnant water conditions in the downstream area.

This condition is exacerbated by the fact that many rapidly growing residential areas are located in inundation-prone zones. Accumulated runoff from the upper and middle reaches of the watershed, which is no longer retained by natural vegetation, empties into the relatively flat and densely populated lower reaches. Villages such as Padomasan, Kaliboto Lor and Rowokangkung are priority risk areas, given the high inundation depths and loss values recorded. When compared to 1995, when inundation was deeper but did not touch many residential areas, and 2014, when inundation tended to be shallow and scattered, 2023 is the peak of accumulated impacts from ecological degradation and uncontrolled spatial growth. Thus, 2023 represents a critical stage in Jatiroto watershed management that must be followed up immediately through vegetation restoration efforts, spatial control, and improvement of area-based drainage infrastructure.

C. Loss Calculation Result Based on Village Administrative Boundaries

Based on the results of the calculation of flood economic losses in the Jatiroto watershed in 2023, the distribution of loss values varied greatly between villages. Village loss rankings are presented as choropleth maps in Fig. 6a–c (1995, 2014, 2023), with 1 indicating the highest-loss village in each year.

Kaliboto Lor village ranks first as the village with the highest loss, amounting to IDR 213.8 billion, followed by Rowokangkung with IDR 117.8 billion, and Sidorejo with IDR 75.1 billion. These three villages consistently had high inundation depths and wide coverage of affected areas, with land use dominated by settlements and productive agricultural land. This reinforces the role of these areas as centers of economic impact that need to be given high priority in disaster mitigation and adaptation.

Other villages that also experienced large losses above IDR 10 billion were Padomasan, Kaliboto Kidul, Gelang, and Jatiroto, which show similar regional characteristics with high vulnerability, both from the aspect of land use change. Meanwhile, villages such as Kaliglagah, Kalipenggung, and Yosorati, although not in the top three, still show significant loss values between IDR 3 to 9 billion, so they fall into the middle to upper category in the priority scale of handling.

Conversely, there are also villages with very low losses, even close to zero rupiah, such as Alun-Alun, Yosowilangun Lor, Pedagangan, and Ranugedang. This very small loss value could be because these areas did not experience inundation or have LC that is not a high economic asset such as buildings or production land. On the other hand, villages such as Papringan, Wringinagung, and Ngampelrejo show loss values below IDR 100 million, indicating that the economic impact of flooding in these areas is almost insignificant.

To deepen the relationship between inundation, especially in terms of area, and loss value, the five villages with the highest loss values in 2023 (Fig. 6c) were selected as examples for calculation and further analysis of the mechanisms underlying these losses.

Two main patterns emerged:

1) **Increased flooding area → increased losses (Area-driven villages)**

This pattern occurred in Kaliboto Lor, Rowokangkung, and Kaliboto Kidul. In addition to the increase in total flooding area (Kaliboto Lor 550.9 → 844.8 ha; Rowokangkung 269.3 → 814.2 ha; Kaliboto Kidul 53.1 → 69.4 ha), the proportion of inundation affecting residential areas also surged (Kaliboto Lor 46.4 → 138.7 ha; Rowokangkung 17.9 → 75.3 ha; Kaliboto Kidul 4.0 → 7.5 ha). Because the unit value of residential areas far exceeds that of other classes, the expansion of the flood footprint into this zone has led to an increase in losses that is proportional to—even greater than—the increase in area alone. This is visualized in Fig. 5a (example of Kaliboto Lor).

2) **Decreased flooding area → increased losses (Value-shift-driven villages)**

This pattern can be seen in Sidorejo and Padomasan. Although the total inundation area decreased (Sidorejo 200.1 → 172.7 ha; Padomasan 87.5 → 64.4 ha), losses actually increased (Sidorejo 41.1 million → 79.6 million thousand IDR; Padomasan 0.62 million → 20.8 million thousand IDR). The trigger was a shift in flooding to high-value areas: the area of residential flooding in Sidorejo increased from 4.81 to 61.72 ha, and in Padomasan from 3.94 to 14.34 ha. With a very large unit value, a slight increase in flooding in residential areas was able to offset—and even exceed—the decrease in flooding in low-value classes, so that the total losses continued to increase. This pattern is shown in Fig. 5b (Padomasan example).

From these two patterns, it can be seen that changes in losses are not determined solely by the extent of flooding, but also by the "economic location" of the flooding or the type of land on which it occurs.

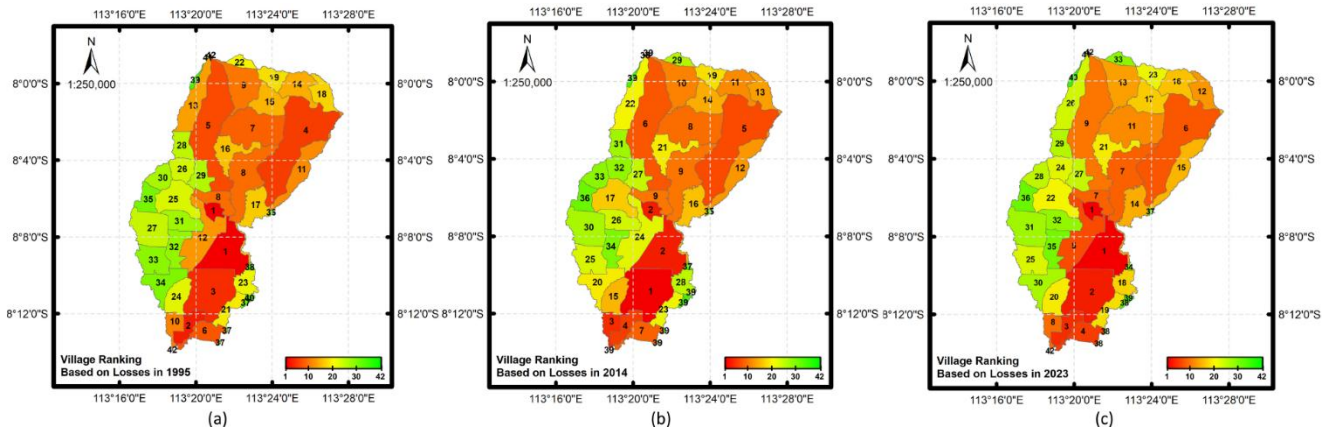


Fig. 6. Village-level loss ranking (1 = highest) for (a) 1995, (b) 2014, and (c) 2023

An increase in the proportion of flooding in residential areas will sharply increase losses per hectare, while an increase in low-value areas will result in a slower increase in losses. The practical implication is that villages with the first pattern need to prioritize reducing the extent of inundation (e.g., through retention, floodplain restoration, and normalization of narrow points), while villages with the second pattern should focus on protecting high-value assets (elevation/flood-proofing of buildings and critical facilities, as well as micro-zoning) because of their high value per hectare.

D. Correlation Between Physical Variables and Losses

The results of the correlation analysis in Table IV show a clear pattern, namely that losses are determined more by the extent of the flooded area than by the average depth, while high-value exposures, particularly settlements and agriculture, increase losses over the same area. According to ECLAC's calculations, this makes sense because losses result from a combination of area × depth × damage factor per class × asset value; so when flooding spreads to high-value zones, the spike in losses is not always captured by looking only at depth metrics. This is also confirmed by a correlation analysis of the five villages with the highest losses, which can be seen in Table V. The Pearson correlation coefficient between inundation area and losses reached 0.920 (1995), dropped to 0.688 (2014), and then rose again to 0.939 (2023), in line with the analysis of all villages. From this, in terms of policy, the most effective flood mitigation based on losses is focused on reducing inundation area, for example through retention ponds, riparian/floodplain restoration, and normalization of bottlenecks, especially in villages with a large percentage of settlements or agriculture.

E. Cross-Framework Validation with the BNPB Index

On the other hand, village rankings derived from the ranking maps (Fig. 6a–c) were compared with the BNPB Flood Vulnerability Index (Reg. No. 12/2012), which considers social, economic, environmental, and infrastructure aspects. The 50% overlap in the top 10 villages in the ECLAC loss and BNPB vulnerability methods shows a moderate correlation in village rankings. This provides some support for the loss-based approach. The observed differences, namely that 5 of the top 10 are different, are due to the two frameworks focusing on different things. The BNPB index considers vulnerability in social, economic, environmental, and infrastructure aspects simultaneously, while ECLAC converts flood exposure into monetary losses for specific scenarios based on land cover values. In practical practice, these two approaches should be used together: loss-based rankings to guide budget allocation (with avoided losses as a metric), and the BNPB index to address asset protection issues. When there are different rankings, a gap review can help target actions. For example, villages with high losses but moderate vulnerability indices may require hazard-oriented measures, while villages with high vulnerability values but moderate losses may be better served by low-cost, multi-hazard interventions or social protection.

F. Policy Implications

Guided by the two village archetypes (Figs. 5–6) and an A, B, C priority scheme that combines the ECLAC loss ranking with the BNPB vulnerability index (Fig. 7), interventions should be targeted accordingly. Area driven villages should prioritise footprint reduction through retention or detention storage, floodplain reconnection and river setbacks, removal of hydraulic bottlenecks, permeable pavements, and routine drainage operations and maintenance. Value shift driven villages should focus on asset protection and growth steering, including finished floor elevation with freeboard, flood proofing of critical facilities, micro zoning to avoid high depth bands, permeable surfaces and household rain tanks, and, where necessary, targeted relocation or land swaps. Implementation can be staged over short, medium, and long terms, with tradeoffs explicitly assessed, and progress tracked using storage volume created, kilometres of floodplain reconnected, percent impervious cover, elevated or flood proofed units, loss per hectare in settlements, and operations and maintenance compliance. Framed in this way, the two pathways offer a portable lens for data limited watersheds and are transferable to rapidly urbanising basins with similar constraints, subject to local validation.

V. CONCLUSION

This study examined how land cover change relates to flood footprints and economic loss in the Jatiroto watershed using a controlled-scenario design in which rainfall, the DEM, and river structure were held constant across 1995, 2014, and 2023. Under this scope, results are interpreted as associations rather than proof of causality, allowing a clear view of the marginal effect of land cover trajectories on inundation patterns and losses.

Across the three snapshots, land cover dynamics align with marked shifts in flood extent and depth as well as in economic loss. The 2023 condition shows wider and

locally deeper inundation where open land and settlements expanded and secondary vegetation contracted, particularly in downstream areas such as Kaliboto Lor and its surroundings. Losses concentrate where flood footprints intersect higher-value land uses, notably settlements and intensive rice fields. Two recurrent pathways summarise these dynamics: losses that rise with expanding flood area (area-driven), and losses that rise despite smaller flood area when inundation shifts toward higher-value land cover (value-shift). Correlation tests indicate that inundation area is a more consistent predictor of loss than mean depth, and a simple sensitivity check shows greater model sensitivity to Curve Number than to plausible variations in hydraulic roughness within the tested range.

Village-level analysis identifies current hotspots such as Kaliboto Lor, Rowokangkung, and Sidorejo, providing a practical basis for prioritisation. The policy framing developed from these results maps the two pathways to distinct intervention logics. Area-driven locations benefit most from footprint-reduction measures, including retention or detention storage, floodplain reconnection and river setbacks, removal of hydraulic bottlenecks, permeable pavements, and routine drainage operations and maintenance. Value-shift locations call for asset-protection and growth-steering measures, including finished-floor elevation with freeboard, flood-proofing of critical facilities, micro-zoning to avoid higher-depth bands, expansion of permeable surfaces and household rain tanks, and targeted relocation or land swaps where necessary. An A, B, C priority scheme that combines the ECLAC loss ranking with the BNPB vulnerability index can guide sequencing, and progress can be tracked using measurable indicators such as storage volume created, kilometres of floodplain reconnected, percent impervious cover, numbers of elevated or flood-proofed units, loss per hectare in settlements, and compliance with operations and maintenance.

Several caveats shape interpretation. Inundation was checked against BPBD reports at village scale in the absence of discharge or water-level gauges. Economic loss estimates follow the ECLAC framework with depth–damage factors and unit values adapted from Budiyono et al., adjusted for inflation, and treated as Indonesia-based proxies rather than site-specific calibrations. Land cover accuracy was assessed, yet classification and co-registration errors are possible, and the DEMNAS grid does not resolve micro-topography or channel bathymetry. The three analysis years were chosen for data availability and to represent roughly three decades of change, so intermediate variability is not captured.

Within these bounds, the study contributes an interpretable and decision-oriented view of how land cover trajectories shape flood exposure and economic loss. The two loss pathways offer a portable lens for data-limited watersheds and can inform regional planning and landscape-based disaster risk reduction, with transferability to other rapidly urbanising basins plausible subject to local validation. Future work could incorporate event-based rainfall ensembles and channel surveys for calibration, localisation of damage curves using post-event claims or surveys, multi-parameter sensitivity and formal uncertainty propagation, and explicit treatment of socio-economic change and cost–benefit trade-offs for the proposed interventions.

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Regina S. Athallah is currently pursuing her Master's degree in Civil Engineering at Brawijaya University, Malang. Her academic interests include flood risk analysis, hydraulic modeling, and spatial analysis using GIS. (email: ndollcaca@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).