The Dynamics Effects of Land Use Change on the Flood Hazards in Juana Watershed

Yuli Astuti
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
yuli.astuti@indrakarya.co.id

Pitojo Tri Juwono
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
pitojo_tj@ub.ac.id

Lily Montarcih Limantara
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
lilymont@ub.ac.id (corresponding author)

Riyanto Haribowo
Department of Water Resources, Faculty of Engineering, University of Brawijaya, Indonesia
Riyanto_haribowo@ub.ac.id

Received: 25 April 2025 | Revised: 21 May 2025, 9 June 2025, and 1 July 2025 | Accepted: 3 July 2025

DOI: https://doi.org/10.48084/etasr.11715

ABSTRACT

This research aims to investigate the impact of land use changes on flood hazards. The study was carried out in the Juana River basin, specifically within the Juana watershed in Pati and Kudus Regencies. The methodology involves evaluating the flood hazards resulting from land use changes across various flood return periods, modeling flood hydrology, and flood hydraulics. Managing the flood disaster risk is especially critical in developing countries like Indonesia. The results show that the land use changes, primarily the expansion of residential areas, increase the risk of flooding across all return periods (Q5, Q25, and Q50). Notably, the high hazard class steadily increases from 2020 to 2070. This relationship is reflected in the correlation between the expanding residential zones and parameters, such as the Curve Number (CN) values, discharge, area, and flood hazard levels. The most substantial rise in flood hazard class, over 60%, occurs at the 5-year return period when comparing 2020 and 2070. Similarly, at the 25- and 50-year return periods, the increase in the high hazard flood risk reaches approximately 47% and 35.5%, respectively. To reduce the flood risk, future land use planning should prioritize rearranging the spatial and land use patterns in accordance with these findings.

Keywords-land use; flood hazard; hydrology modeling; hydraulics modeling

I. INTRODUCTION

Generally, spatial regulation is not primarily designed with flood risk management as the main goal [1]. Instead, it typically focuses on other social objectives, such as regulating the residential development to control where people live, choosing locations for industry and commerce, or safeguarding wildlife and agricultural areas from urban expansion. Consequently, spatial planning is typically decided at the administrative level and is rarely based on the water catchment area. The spatial design targeting flood disaster risk management [2, 3] is the most effective method to prevent rising flood risks by actively regulating the land and property development in the Juana River system area. According to disaster infographics from the National Disaster Management Agency (BNPB), floods are the most common natural disaster in Indonesia each year. Flooding has been caused by the river's limited capacity and land absorption [4]. The rapid urban growth and economic development have sped up urbanization, creating challenges, such as limited land for homes, businesses, green spaces, and water absorption. Typically, Indonesian cities are in river estuaries or deltas. The growing population in flood-prone areas, combined with low awareness and preparedness, has increased the flood risks, resulting in higher death tolls and greater property damage [4-7]. Flood disaster risk management is a key concern in developing countries. The need to address the flood risks and adapt to the climate change has led to a shift in policy approaches since the early 2000s. The focus has shifted from mainly hydrologic techniques to a comprehensive flood risk management approach that includes broader adaptation strategies [8-11]. One reason is that the conventional flood control infrastructure is considered inadequate and unable to face the ever-increasing risks [9-12].

Hydrology researchers have possessed an advanced understanding of flood risk management related to climate-driven changes in rainfall and increasing runoff from urbanization, both of which contribute to urban flooding. Effective flood risk strategies often depend on flood modeling, a tool that is also usable in developing countries [13]. Flood modeling involves creating algorithms to predict the flood depth, affected areas, and flow velocity [14].

II. MATERIALS AND METHODS

A. Study Location

This study was conducted in the river region of Juana, situated within the Juana Watershed in Pati and Kudus Regencies. The Juana Watershed comprises 11 sub-watersheds: Gembong, Juana 1a, Juana 1b, Juana 1c, Juana 1d, Juana 2a, Juana 2b, Juana 2c, Juana 3a, Juana 3b, and Logung (Figure 1).

B. Hydrology Modeling by Using HEC-HMS

The Hydrologic Engineering Center - Hydrologic Modeling System (HEC-HMS) is a hydrology software that analyzes the rainfall transformation and routing within a watershed system. The generated unit hydrograph can be used on its own or combined with other software for applications, like water availability, urban drainage, forecasting urbanization impacts, spillway design, flood damage mitigation, flood regulation, and hydrological operation systems [15]. Some analytical methods for runoff analysis are: 1) The initial and constant-rate loss model; 2) The deficit and constant-rate loss model; 3) The SCS Curve Number (SCN) loss model, which can be composite or gridded; and 4) The Green and Ampt loss model. Since this research aims to analyze the land use related to the flood discharge, the SCN is selected to estimate the runoff volume, and the SCS-Unit Hydrograph (SUH) is employed to analyze the direct runoff through routing, which includes the time lag.

C. Land Use

Land use planning involves organizing the land resources. In land use, it is not only focused on the use of the earth's surface, but also on how it relates to the use of the earth's surface in the ocean [16]. According to Indonesian basic laws on agriculture, the land use is a planned as well as unplanned pattern of land utilization that includes land preparation, land provision, land usage, and maintenance. In flood risk management discussions, an essential aspect for reducing the disaster risk is the application of risk-based approaches in land use planning and the establishment of rules to address the primary causes of disasters and associated losses. According to the definition, land use planning is a non-structural measure that involves managing, utilizing, and conserving land and natural resources to promote sustainable development and lower risk [17]. Furthermore, land use planning plays a direct role in safeguarding the infrastructure and assets. It also helps boost resilience and lower vulnerability and risk by regulating the land cover expansion into hazard-prone zones [18]. Consequently, the land use planning promotes the societal progress by designating safe land and supporting the development of more hazard-resistant structures, thereby decreasing the core risk factors [19, 20].

Authors in [21, 22] emphasized the direct connection between the flood intensity or frequency and the land use changes. In this context, zonation serves as an effective approach for floodplain management via land use planning. This includes: 1) establishing the flood water surface boundary, and 2) creating and enforcing land use and construction regulations to promote development resilient to floods [22]. Beyond the natural factors, such as floodplain position, land use changes, and new infrastructure, including businesses and residences, it is also crucial to assess the vulnerability of assets and populations [23, 24]. Consequently, the land use zoning serves as a key tool to mitigate the flood risk [25]. Nevertheless, its implementation is complex, requiring long-term, systematic planning and collaboration among various scientific disciplines, stakeholders, and decision-makers [26]. In this framework, the land use planning involves proposing or regulating suitable land uses by intensifying the restrictions in high-flood risk zones and redesigning low-risk areas [27]. However, the effectiveness of these measures depends on hazard maps, which often specify risk thresholds [28], raising debates about the spatial extent of such restrictions. The SCN method considers that the runoff caused by rainfall depends on the cumulative rainfall, land cover, land use, soil type, and moisture levels. Its CNs span from 100, representing a water-covered surface, to 30, indicating an unsaturated surface with high infiltration. This study employs the Soil Conservation Service (SCS) unit hydrograph, assuming that rainfall is uniformly distributed across the watershed and maintains a constant intensity at each interval.

III. RESULTS AND DISCUSSION

A. Simulation Result of Land Use Change

In 2020, the land use was primarily agricultural (45.92%), followed by vegetation (20.81%), residential (16.57%), and forests (14.86%). Ponds and water made up the rest. By 2025, residential is forecasted to have risen to 17.68%, agricultural to have dropped to 45.14%, and vegetation to have slightly declined to 20.49%. By 2045, residential areas are expected to have reached 22.10%, agricultural areas will have decreased to 41.9%, and vegetation will have accounted for 19.32%. In 2070, residential areas will have increased to 27.62%, agricultural areas will have decreased to 37.86%, and vegetation areas will have decreased to 17.87%. Ponds will have slightly decreased. Water, forests, and industry will have stayed the same (Table I, source: own study, 2020, and Figure 1). The Sankey diagram in Figure 2 illustrates the land use changes and the specific land types that have been transformed into residential areas. Residential growth primarily stems from the conversion of agricultural land, vegetation, and pond areas within the Juwana Watershed. By 2070, this growth is expected to have increased by 15,583 Ha, representing a 66.67% rise from the 23,377 Ha recorded in 2020. The primary cause of this increase is the conversion of agricultural land, which accounts for approximately 65.9%, followed by vegetation at 23.7%, and ponds at 1.03%. Residential development will have covered about 11.05% of the Juwana Watershed. The watershed encompasses forested northern areas, such as the Muria Mountains, which should be protected from further expansion. To the south, the Kapur Utara Mountains are mainly forests with some residences, but less than the Muria Mountains. It is, thus, crucial to maintain its protected status by limiting the development.

TABLE I. DEVELOPMENT MODELING RESULT OF LAND USE IN JUANA WATERSHED

No	Landuse	2020		2025		2040		2070	
		Area (Ha)	%	Area (Ha)	%	Area (Ha)	%	Area (Ha)	%
1	Waterbodies	744.32	0.53%	744.32	0.53%	744.32	0.53%	744.32	0.53%
2	Forest	20,961.48	14.86%	20,961.48	14.86%	20,961.48	14.86%	20,961.48	14.86%
3	Industry	289.80	0.21%	289.80	0.21%	289.80	0.21%	289.80	0.21%
4	Settlements	23,377.40	16.57%	24,935.68	17.68%	31,168.80	22.10%	38,960.20	27.62%
5	Agriculture	64,767.92	45.92%	63,669.44	45.14%	59,098.88	41.90%	53,394.36	37.86%
6	Fishponds	1,549.32	1.10%	1,545.56	1.10%	1,534.36	1.09%	1,493.04	1.06%
7	Vegetation	29,351.00	20.81%	28,894.96	20.49%	27,243.60	19.32%	25,198.04	17.87%
	Total	**141,041.24**	100.00%	**141,041.24**	100.00%	**141,041.24**	100.00%	**141,041.24**	100.00%

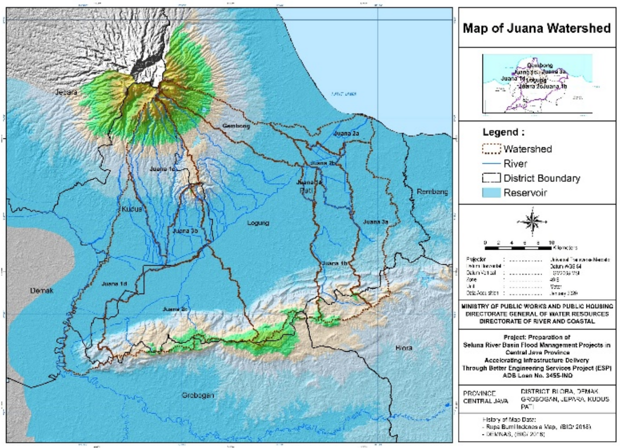


Fig. 1. Location of the study area.

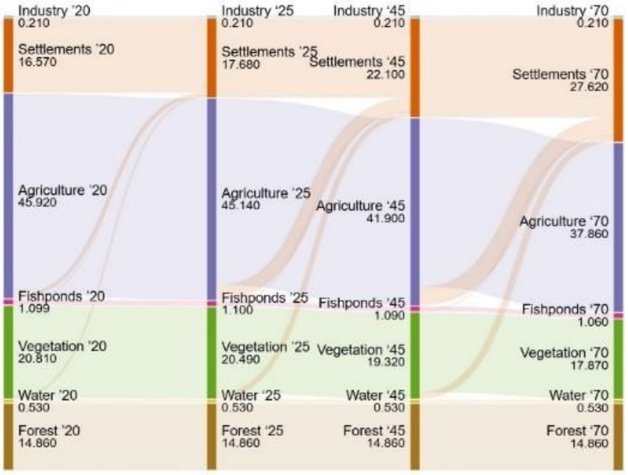


Fig. 2. Land use changes in Juana watershed from 2020 to 2070.

The spatial analysis indicates that the residential development (Figure 3) is primarily concentrated in three key areas: Kudus, Pati, and Juana. Additionally, the government center and local economic activities promote the residential growth in the district and city centers of Pati Regency. The area's role is evident, as government and economic hubs drive residential expansion in their surrounding regions. The residential area has expanded along the main road network on the National Road connecting Demak, Kudus, Pati, Juana, and Rembang. Additionally, development is also occurring along Province Road. In the Juana Watershed, there are three provincial roads: Jalan Pati-Purwodadi and Jalan Juana-Blora, which run south, and Jalan Juana-Jepara to the north. The residential growth closely correlates with the population increase. Figure 4 shows a linear relationship between the population growth and the expansion of agriculture, which tends to grow exponentially. The residential growth is approximately 1.33% annually, and the projected population growth in the Juana Watershed from 2010 to 2070 is about 1.31% per year. A review was also conducted to examine the relationship between the residential development and the rising CN values, an important parameter indicating the flow conditions in the watershed. The correlation suggests a tendency towards a reverse exponential relationship, meaning that the CN values tend to increase more rapidly during the early stages of residential expansion.

B. *Flood Hydrology Modeling*

Flood modeling is performed using the HEC-HMS software, which employs a semi-distributed approach. However, the flood discharge analysis relies on the SCS and Snyder methods. Calibration is done by comparing the recorded discharge data at Klambu Weir, though the data in the Juana Watershed are limited. Both sites are part of the Seluna River system, including Serang, Lusi, and Juana. The calibration effectiveness is assessed through objective functions, like Root Mean Square Error (RMSE) and Nash-Sutcliffe Efficiency (NSE). The calibration is considered successful if the NS value is close to 1 and the RMSE is near 0. In this calibration, the NSE value is 0.68, indicating a very good model performance. Based on these results, the flood discharge simulations were conducted using the SCS and Snyder methods. When comparing the two, it is observed that the hydrographs are quite similar in shape. However, the hydrograph from the SCS method is higher than that from the Snyder method, so the SCS method will be used for further analysis. The 2025 design flood prediction is based on rainfall data generated by BMKG. For projections extending to 2045 and 2070, the flood discharge modeling relies on the projected CN values, with the results shown in Table II.

TABLE II. DESIGN FLOOD IN JUANA WATERSHED

No	Location	Return period (years)	Flood design year of 2020	Flood design year of 2025	Flood design year of 2045	Flood design year of 2070	No	Location	Return period (years)	Flood design year of 2020	Flood design year of 2025	Flood design year of 2045	Flood design year of 2070
1	Juana 1d	5	574.33	577.84	604.37	625.55	7	Gembong	5	37.44	40.39	46.69	55.70
		25	761.34	767.59	792.86	812.00			25	85.52	104.91	121.85	141.63
		50	892.70	902.00	926.24	944.10			50	86.99	112.64	130.37	150.74
2	Juana 1c	5	334.54	347.29	372.07	393.24	8	Juana 1b	5	458.53	482.86	513.22	539.12
		25	657.59	701.64	724.05	740.46			25	894.48	967.19	998.02	1023.44
		50	803.81	873.14	893.93	908.70			50	1037.37	1131.99	1163.79	1187.62
3	Juana 2c	5	589.06	608.07	669.41	728.53	9	Juana 2b	5	66.65	70.35	77.36	84.44
		25	1054.62	1091.16	1157.83	1214.28			25	79.90	91.81	99.55	106.82
		50	1296.91	1345.91	1412.09	1465.78			50	84.73	101.06	108.97	116.27
4	Juana 3b	5	253.76	266.92	284.61	299.46	10	Juana 3a	5	333.31	357.25	392.64	426.09
		25	576.96	642.98	657.64	668.16			25	678.34	774.80	811.29	840.09
		50	747.07	858.68	871.55	882.01			50	799.65	943.02	978.24	1004.94
5	Logung	5	598.13	634.25	634.43	901.22	11	Juana 2a	5	400.56	409.37	420.78	428.94
		25	815.25	806.25	853.21	1220.92			25	786.82	818.88	827.12	832.96
		50	921.43	880.91	959.74	1376.21			50	948.28	1002.58	1009.88	1015.63
6	Juana 1a	5	20.50	21.72	23.90	25.99	12	Outlet	5	346.12	387.80	373.64	393.23
		25	24.73	28.61	30.92	33.02			25	554.88	638.08	619.47	617.33
		50	26.26	31.60	33.94	36.08			50	650.70	758.78	736.39	722.92

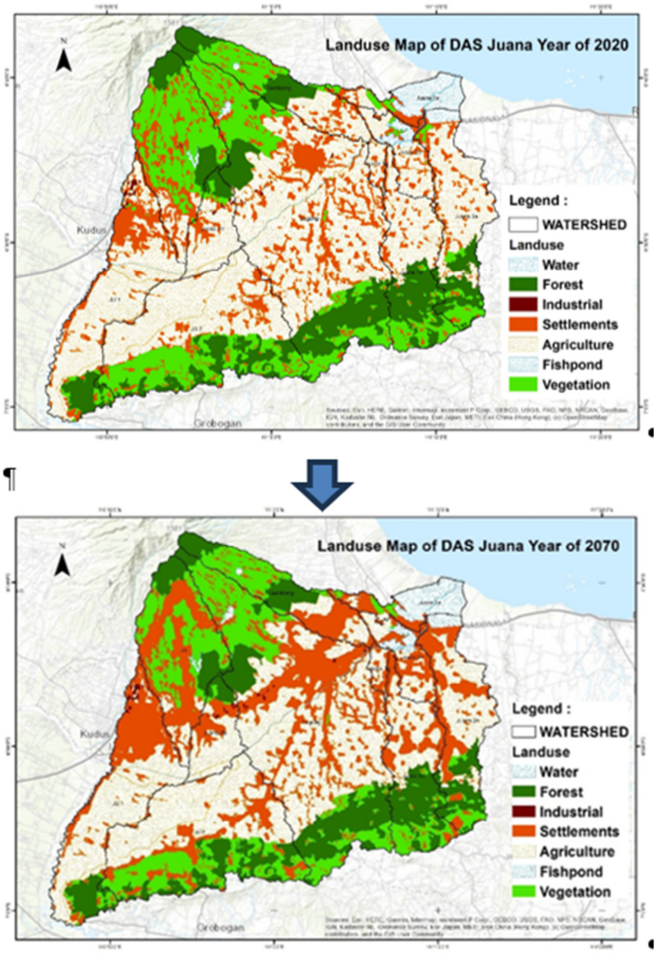


Fig. 3. Simulation results of residential development from 2020 to 2070.

TABLE III. FLOODED AREA IN JUANA WATERSHED FOR RETURN PERIODS OF 5, 25, AND 50 YEARS IN 2020, 2025, 2045, AND 2070

Year	Flooded area (Ha)		
	Q5	Q25	Q50
2020	23,339.70	30,800.10	37,282.80
2025	25,410.40	34,995.50	39,195.50
2045	29,062.70	37,502.20	40,147.00
2070	30,626.60	39,182.60	41,452.80

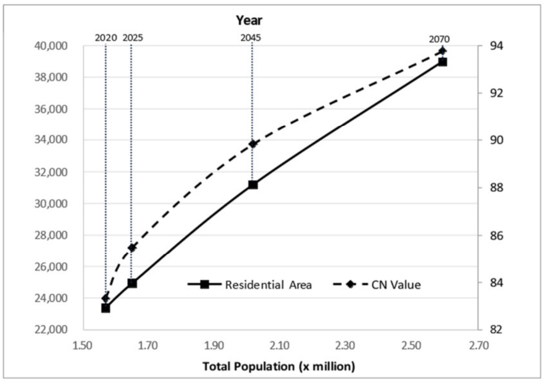


Fig. 4. The relationship between the population growth, housing development, and the increase of CN in the Juana watershed.

C. Flood Hydraulics Modeling

The flood simulation results indicate that the flooded area in the Juana Watershed is almost evenly distributed, ranging from southwest to upstream, and then from southeast to downstream along the Juana River (Figure 5). Morphologically, the southwest upstream area of the Juana River is a valley region near the Serang River. This zone includes several affluent areas along the Serang River, which are also part of the Juana River system. Under certain conditions, the flooding from the Serang River can overflow into the Juana River, worsening the flooding within the Juana Watershed. Conversely, the slopes of the Muria Mountains in northern Juana Watershed and the Kapur Utara Mountains in the south are relatively safe from flooding due to their higher elevations. The review of the entire flooded area across different return periods shows an increase in the flooded regions caused by the land use changes in 2020, 2025, 2045, and 2070, as depicted in Table III (source: own study, 2020). During the 5-year return period, the flooding in 2070 caused a 26.9% increase in the flooded area compared to 2020. However, for the 25- and 50-year return periods, the increases are 7.7% and 8.2%, respectively.

The flooded area in the Juana watershed expands due to increased discharge caused by the land use changes. Figures 7 - 10 illustrate the variation in the relationship between the discharge and flooded areas in 2020, 2025, 2045, and 2070. For a 5-year return period, there is a clear correlation: a 5% increase in discharges results in about a 10% rise in flooded areas. In contrast, for 25- and 50-year return periods, the changes in discharge have minimal effects on the flooded areas, around 5% for the 25-year and roughly 2% for the 50-year return period. This difference occurs because, in the 5-year return period, flooding occurs in relatively flat regions, so even small increases in the flood levels significantly expand the flood zone. Meanwhile, in the 25- and 50-year periods, flooding occurs in steeper or higher-elevation areas, making the increases in discharge less impactful on the flooded area. Additionally, the connection between the rising flood discharge and the expanding flood-inundation area shows a linear pattern (Figure 6). As the discharge increases, the flood-affected area also grows. For lower return periods, the increases in discharge lead to a more significant expansion of the flood-inundated zones compared to higher return periods. This is likely because lands inundated at smaller discharges tend to be flatter, causing faster increases in flooded areas (Table III). Conversely, at higher discharges, the extent of inundation is more influenced by the steeper terrain, meaning that the increases in discharge do not cause the flood area to expand proportionally (Figures 7 -10).

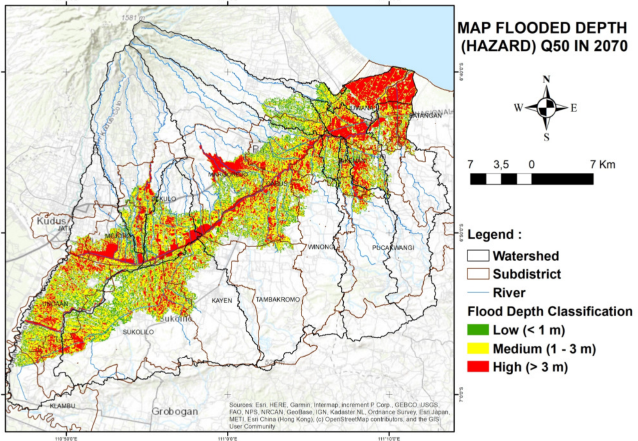


Fig. 5. Flood simulation results for Q50 on the land in 2070.

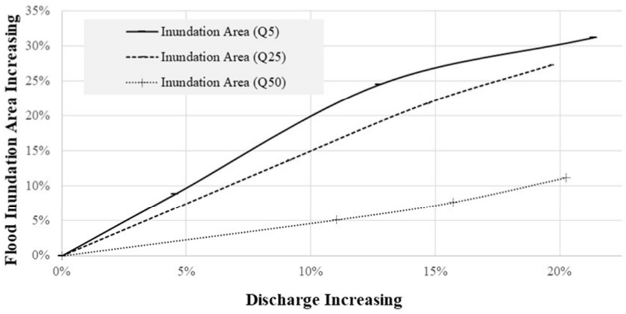
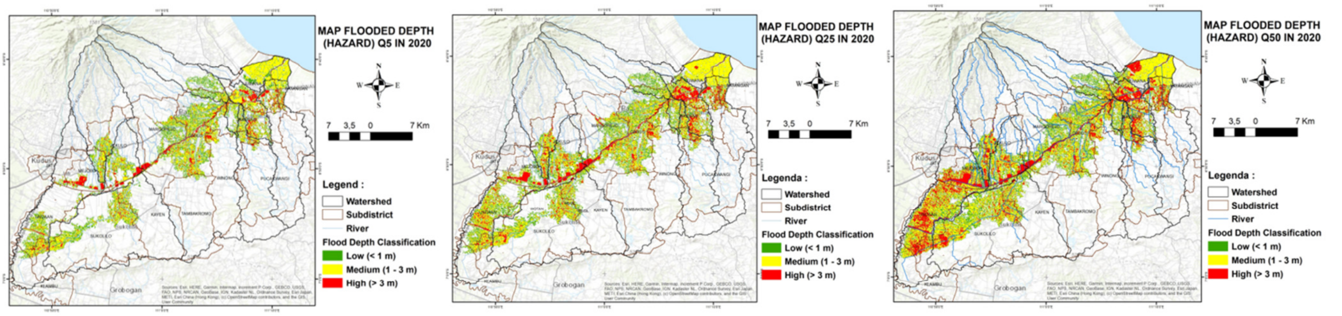
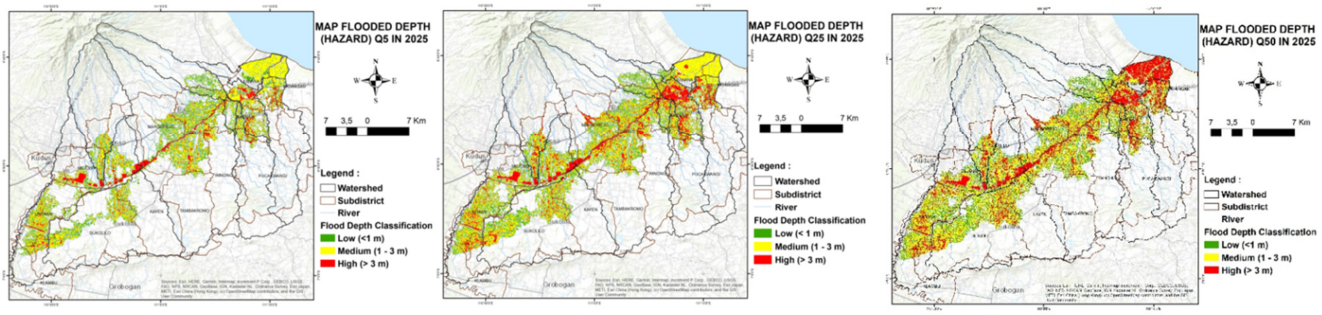


Fig. 6. Flooded area (Ha) and return periods of 5, 25, and 50 years in land use for 2020 and 2025.



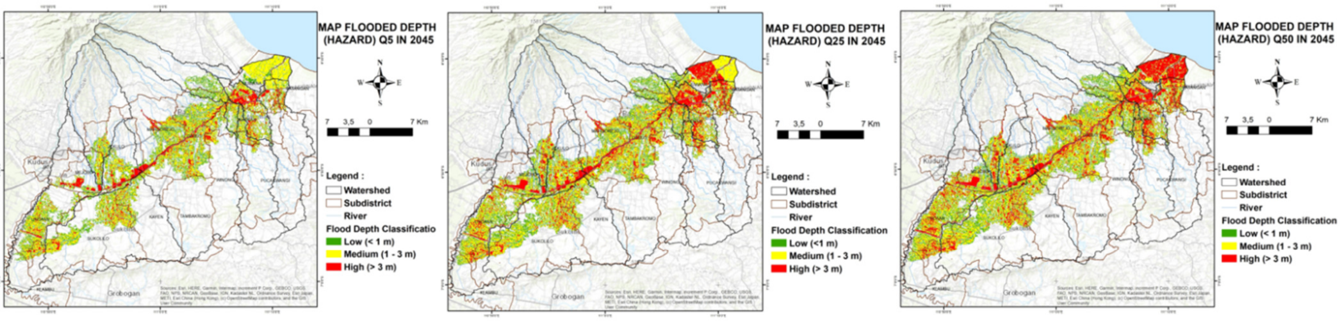
(i) Q5 (ii) Q25 (iii) Q50

Fig. 7. Map of flooded depth (hazard) in 2020.



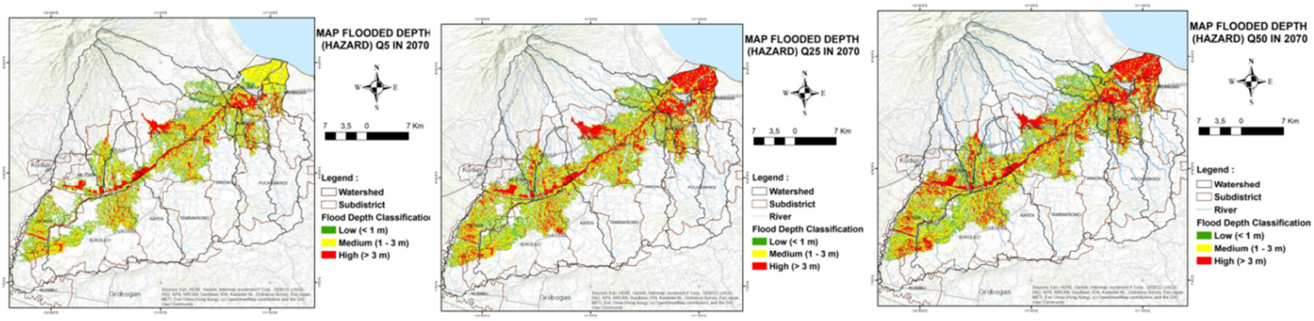
(i) Q5 (ii) Q25 (iii) Q50

Fig. 8. Map of flooded depth (hazard) in 2025.



(i) Q5 (ii) Q25 (iii) Q50

Fig. 9. Map of flooded depth (hazard) in 2045.



(i) Q5 (ii) Q25 (iii) Q50

Fig. 10. Map of flooded depth (hazard) in 2070.

IV. CONCLUSION

The flood hazard is evaluated based on the flood depths derived from the simulation results for each scenario. Flood hazard classification follows the Rules of BNPB (National Institution of Flood Control) No. 01, 2012, which uses depth as the primary parameter, categorized into the following levels: low (<1 m), moderate (1-3 m), and high (>3 m). The results of the flood classification in Juana Watershed for 5-, 25-, and 50-year return periods are displayed in Figure 6. In Juana Watershed, for the 25-year return period, the flood hazard is mostly low and moderate; however, high hazard occurs less often and spreads randomly from upstream to downstream Juana River. The low flood hazard is mainly in the southern area of Juana River due to the flatter river morphology. Conversely, the flood hazard in the northern upstream and downstream areas of Juana River is influenced by the valley of Serang River and the Juana River estuary downstream. A spatial approach to managing the flood disaster risk is the most effective way to prevent increased flood risks by actively controlling the land development and property growth in the Juana River region. The climate change impacts, especially the rising sea levels, also increase the risk of flooding. At all return periods (Q5, Q25, and Q50), high hazard classes steadily increase from 2020 to 2070. The rise in flood hazard levels is especially notable at the 5-year return period, increasing by more than 60% compared to the land use changes from 2020 to 2070. Additionally, in the 25- and 50-year return periods, the increase in high hazard flood classes reaches 47% and 35.5%, respectively. Future land use planning should focus on reorganizing the spatial and land use arrangements to mitigate the flood risk, informed by these findings. Flood management strategies must include improving the early warning systems, revising the land use plans, and upgrading the infrastructure. Future research will develop a performance index model for flood risk management, acknowledging the inherent limitations or boundaries.

REFERENCES

[1] R. Kumar and J. Singh, "Application of the RUSLE Modeling Tool for Quantification of Soil Erosion towards Sustainable Planning: The Case of Kosi River Basin, Bihar, India," *Engineering, Technology & Applied Science Research*, vol. 15, no. 1, pp. 19910–19916, Feb. 2025, https://doi.org/10.48084/etasr.9088.

[2] W. Shao, S. Xian, N. Lin, H. Kunreuther, N. Jackson, and K. Goidel, "Understanding the effects of past flood events and perceived and estimated flood risks on individuals' voluntary flood insurance purchase behavior," *Water Research*, vol. 108, pp. 391–400, Jan. 2017, https://doi.org/10.1016/j.watres.2016.11.021.

[3] J. Ntajal, B. L. Lamptey, I. B. Mahamadou, and B. K. Nyarko, "Flood disaster risk mapping in the Lower Mono River Basin in Togo, West Africa," *International Journal of Disaster Risk Reduction*, vol. 23, pp. 93–103, Aug. 2017, https://doi.org/10.1016/j.ijdrr.2017.03.015.

[4] A. Mustafa *et al.*, "Effects of spatial planning on future flood risks in urban environments," *Journal of Environmental Management*, vol. 225, pp. 193–204, Nov. 2018, https://doi.org/10.1016/j.jenvman.2018.07.090.

[5] M. P. Mohanty, V. H, V. Yadav, S. Ghosh, G. S. Rao, and S. Karmakar, "A new bivariate risk classifier for flood management considering hazard and socio-economic dimensions," *Journal of Environmental Management*, vol. 255, Feb. 2020, Art. no. 109733, https://doi.org/10.1016/j.jenvman.2019.109733.

[6] M. Kaufmann and M. Wiering, "The role of discourses in understanding institutional stability and change – an analysis of Dutch flood risk governance," *Journal of Environmental Policy & Planning*, vol. 24, no. 1, pp. 1–20, Jan. 2022, https://doi.org/10.1080/1523908X.2021.1935222.

[7] H.T. Nguyen, "Spatial Planning in Flood-prone Areas", Ph.D. dissertation, Department of Civil and Environmental Engineering, Technische Universität Darmstadt, Germany, 2019.

[8] K. Potter and T. Vilcan, "Managing urban flood resilience through the English planning system: insights from the 'SuDS-face," *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, vol. 378, no. 2168, Feb. 2020, Art. no. 20190206, https://doi.org/10.1098/rsta.2019.0206.

[9] K. Takeuchi, "Increasing vulnerability to extreme floods and societal needs of hydrological forecasting," *Hydrological Sciences Journal*, vol. 46, no. 6, pp. 869–881, Dec. 2001, https://doi.org/10.1080/02626660109492882.

[10] M. Vis, F. Klijn, K. M. De Bruijn, and M. Van Buuren, "Resilience strategies for flood risk management in the Netherlands," *International Journal of River Basin Management*, vol. 1, no. 1, pp. 33–40, Mar. 2003, https://doi.org/10.1080/15715124.2003.9635190.

[11] U. C. Nkwunonwo, M. Whitworth, and B. Baily, "A review of the current status of flood modelling for urban flood risk management in the developing countries," *Scientific African*, vol. 7, Mar. 2020, Art. no. e00269, https://doi.org/10.1016/j.sciaf.2020.e00269.

[12] M. Saidani and A. Shibani, "Use of Physical and Numerical Models in Engineering Design Education," in *Proceedings of the 2014 International Conference on Industrial Engineering and Operations Management*, Bali, Indonesia, January 7–9, 2014, pp. 61-67.

[13] J. W. Hall, I. C. Meadowcroft, P. B. Sayers, and M. E. Bramley, "Integrated Flood Risk Management in England and Wales," *Natural Hazards Review*, vol. 4, no. 3, pp. 126–135, Aug. 2003, https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(126).

[14] M. Meng, M. Dąbrowski, L. Xiong, and D. Stead, "Spatial planning in the face of flood risk: Between inertia and transition," *Cities*, vol. 126, p. 103702, July 2022, https://doi.org/10.1016/j.cities.2022.103702.

[15] D. Zhang *et al.*, "A GIS-based spatial multi-index model for flood risk assessment in the Yangtze River Basin, China," *Environmental Impact Assessment Review*, vol. 83, July 2020, Art. no. 106397, https://doi.org/10.1016/j.eiar.2020.106397.

[16] *HEC–HMS User's Manual*, 1st ed., US Army Corps of Engineers, USACE Hydrologic Engineering Center, Davis, CA, USA, 2001.

[17] J.T. Jayadinata, *Tata Guna Tanah dalam Perencanaan Pedesaan, Perkotaan dan Wilayah (Land Use in Design of Village, Urban, and Region)*, Penerbit ITB, Bandung, Indonesia, 1992.

[18] G. Zhao, Z. Xu, B. Pang, T. Tu, L. Xu, and L. Du, "An enhanced inundation method for urban flood hazard mapping at the large catchment scale," *Journal of Hydrology*, vol. 571, pp. 873–882, Apr. 2019, https://doi.org/10.1016/j.jhydrol.2019.02.008.

[19] C. Thrysøe, T. Balstrøm, M. Borup, R. Löwe, B. Jamali, and K. Arnbjerg-Nielsen, "FloodStroem: A fast dynamic GIS-based urban flood and damage model," *Journal of Hydrology*, vol. 600, Sept. 2021, Art. no. 126521, https://doi.org/10.1016/j.jhydrol.2021.126521.

[20] R. Der Sarkissian, M. J. Al Sayah, C. Abdallah, J.-M. Zaninetti, and R. Nedjai, "Land Use Planning to Reduce Flood Risk: Opportunities, Challenges and Uncertainties in Developing Countries," *Sensors*, vol. 22, no. 18, Sept. 2022, Art. no. 6957, https://doi.org/10.3390/s22186957.

[21] S.-Y. Yang, M.-H. Chan, C.-H. Chang, and C.-T. Hsu, "A case study of flood risk transfer effect caused by land development in flood-prone lowlands," *Natural Hazards*, vol. 91, no. 3, pp. 863–878, Apr. 2018, https://doi.org/10.1007/s11069-017-3130-x.

[22] J. Hounkpè, B. Diekkrüger, A. A. Afouda, and L. O. C. Sintondji, "Land use change increases flood hazard: a multi-modelling approach to assess change in flood characteristics driven by socio-economic land use change scenarios," *Natural Hazards*, vol. 98, no. 3, pp. 1021–1050, Sept. 2019, https://doi.org/10.1007/s11069-018-3557-8.

[23] European Commission, *Best Practices on Flood Prevention, Protection*, European Commission, Brussels, Belgium, 2003, pp. 1–29.

[24] *Reducing Disaster Risk by Managing Urban Land Use: Guidance Notes for Planners*, Asian Development Bank, Mandaluyong, Philippines, 2016. ISBN: 9789292574758.

[25] R. Der Sarkissian, A. Dabaj, Y. Diab, and M. Vuillet, "Evaluating the Implementation of the 'Build-Back-Better' Concept for Critical Infrastructure Systems: Lessons from Saint-Martin's Island Following Hurricane Irma," *Sustainability*, vol. 13, no. 6, Jan. 2021, Art. no. 3133, https://doi.org/10.3390/su13063133.

[26] F. Roy and Y. Ferland, "Land Use Planning for Disaster Risk Management," *Land Tenure Journal*, vol. 34, pp. 70–103, 2014.

[27] A. Stone, J. Jenkins, and J. Westerman, *Local Government Land Use Planning*, OECD Publishing, Paris, France, 2006.

[28] R. Der Sarkissian, A. Dabaj, Y. Diab, and M. Vuillet, "Evaluating the Implementation of the 'Build-Back-Better' Concept for Critical Infrastructure Systems: Lessons from Saint-Martin's Island Following Hurricane Irma," *Sustainability*, vol. 13, no. 6, Jan. 2021, Art. no. 3133, https://doi.org/10.3390/su13063133.