



Available online at
<https://jurnalteknik.unisla.ac.id/index.php/CVL>
<https://doi.org/10.30736/cvl.v2i2>



Hydrological Analysis of Flash Floods Using FFPI and API in the Krueng Meuh Watershed, Aceh

Muhammad Rona¹, Cut Azizah^{2*}, Zuraihan³

^{1,2*,3} Universitas Almuslim, Bireuen, Aceh, Indonesia

Email : ¹ronamhd6@gmail.com, ^{2*}cut.azizah13@gmail.com, ³zuraihan.almuslim@gmail.com

ARTICLE INFO

Article History :

Article entry : 02-02-2026

Article revised : 20-04-2026

Article received : 22-08-2026

Keywords :

Antecedent Precipitation Index (API); Curve Number (CN); Flash Flood Potential Index (FFPI); flash floods; humid tropics

IEEE Style in citing this article :

M. Rona, C. Azizah, and Zuraihan, "Hydrological Analysis of Flash Floods Using FFPI and API in the Krueng Meuh Watershed, Aceh", *CVL*, vol. 11, no. 2, pp. 246–255, Sep. 2026.

ABSTRACT

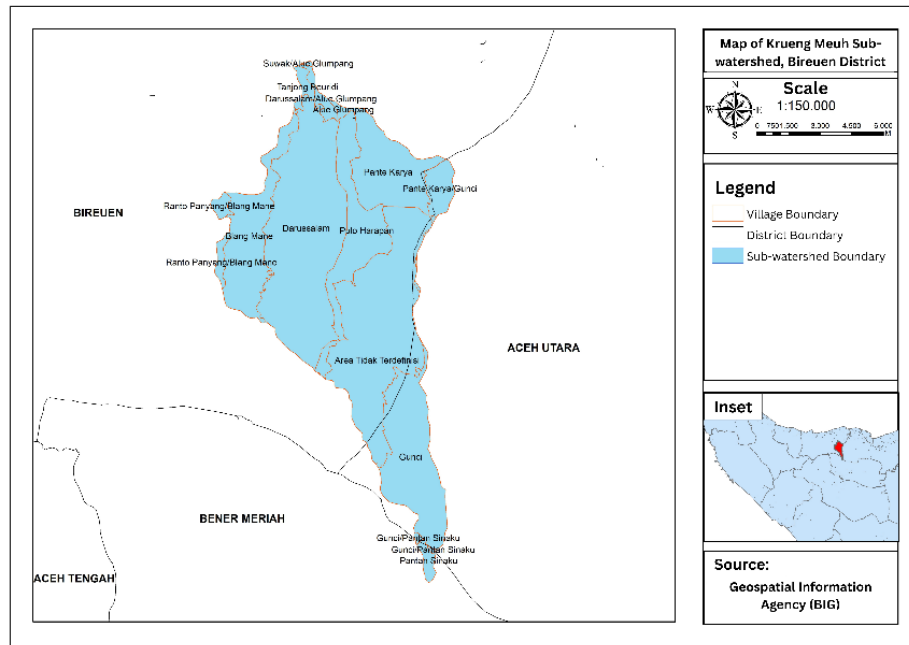
Flash floods are highly destructive hydrometeorological disasters that threaten infrastructure integrity and public safety in the Krueng Meuh Sub-watershed, Bireuen District. This study aims to conduct a comprehensive hydrological analysis of flash flood triggers by evaluating physical characteristics and land-use dynamics. The methodology integrates Digital Elevation Model (DEM) analysis for slope mapping, daily rainfall data (2020-2024) to calculate the five-day Antecedent Precipitation Index (API5), and remote sensing to detect land-cover changes. These parameters were synthesized within a Geographic Information System (GIS) using the Flash Flood Potential Index (FFPI) approach to identify spatial vulnerability zones. The results reveal that over 50% of the study area consists of steep to very steep slopes dominated by erodible geological materials. Soil conditions reached high saturation levels prior to flood events, with API5 values ranging from 57.6 to 71.3 mm. Furthermore, the massive conversion of forest into plantations (57.68%) has significantly increased surface runoff coefficients. FFPI analysis classifies the majority of the sub-watershed into moderate to very high vulnerability levels. These findings provide critical scientific evidence for local authorities to formulate spatial-based mitigation strategies and adaptive watershed management.

1. Introduction

Flash floods in humid tropical regions such as Indonesia are more than just routine natural occurrences; they are the result of a complex interplay between extreme precipitation, steep topographical gradients, and massive environmental degradation [1], [2], [3], [4]. In the Krueng Meuh sub-watershed of Bireuen Regency, this threat has transformed into a tangible risk that jeopardizes the stability of upstream infrastructure and the safety of downstream settlements [5], [6], [7]. The characteristic suddenness of these flows, coupled with the transport of heavy debris, renders such disasters exceptionally destructive and difficult to predict without in-depth hydrological analysis. Geographically, the study area is defined by significant elevation variations, which serve as the primary control for the region's drainage patterns.



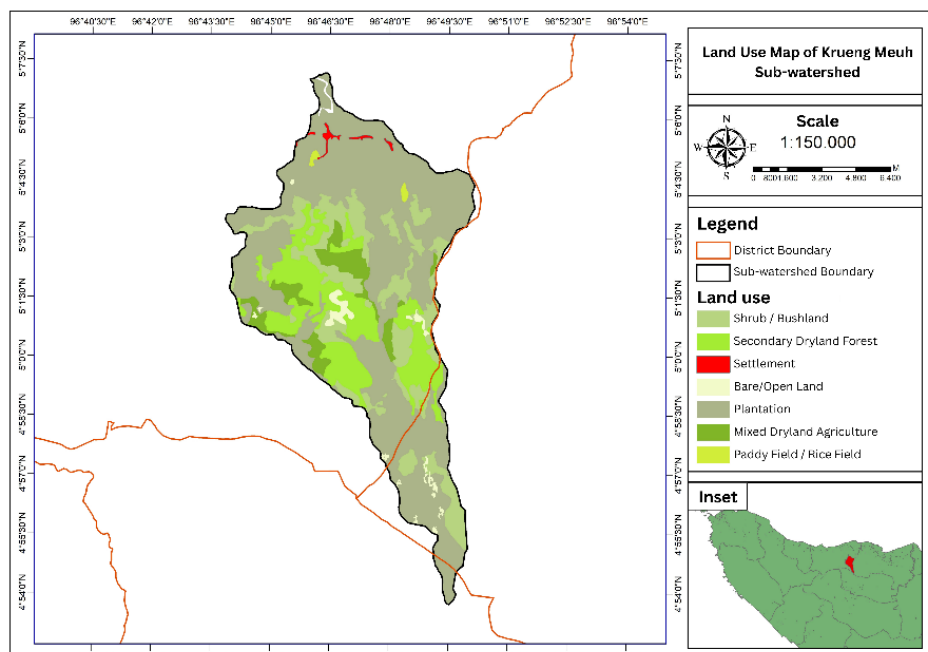
Copyright © 2026 Muhammad Rona, et al. This work is licensed under a [Creative Commons Attribution-ShareAlike 4.0 International License](https://creativecommons.org/licenses/by-sa/4.0/). Allows readers to read, download, copy, distribute, print, search, or link to the full texts of its articles and allow readers to use them for any other lawful purpose.



Source: Author's analysis (2025)

Figure 1. Topographic Map of the Krueng Meuh Sub-Watershed

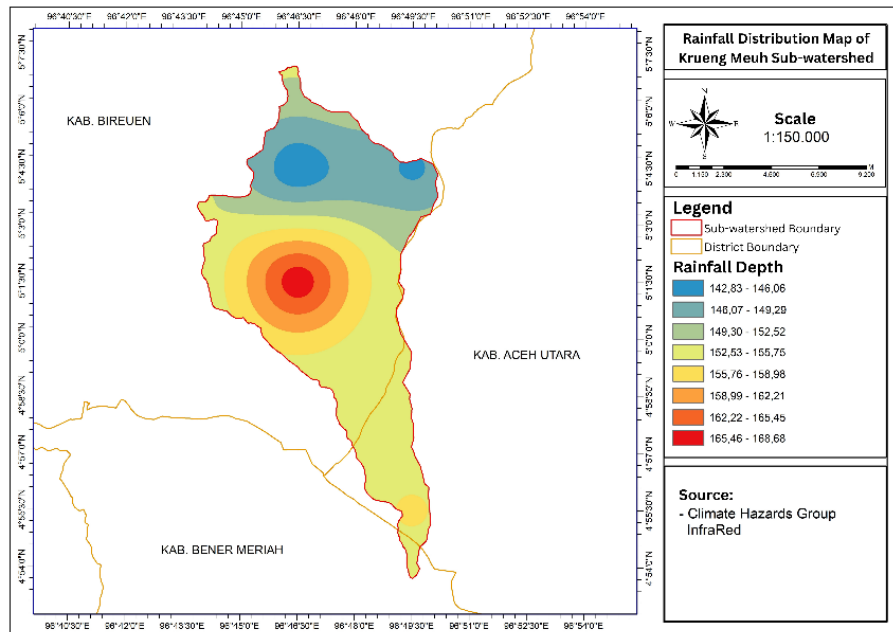
Landscape transformation, particularly the conversion of forests into plantation areas, drastically alters how a watershed responds to precipitation. These changes in land cover trigger a surge in surface runoff coefficients, which in turn significantly increases peak discharge volumes [8], [9], [10], [11]. In the Aceh region, the correlation between forest vegetation loss and the accelerated time of concentration toward river outlets has become a serious concern, as it shortens the evacuation window for affected residents [12], [13], [14]. Investigations reveal that forest cover depletion in the Krueng Meuh sub-watershed has reached 57.68%, a critical condition that exacerbates vulnerability to flash floods.



Source: Author's analysis (2025)

Figure 2. Land Use Map of the Krueng Meuh Sub-Watershed

In addition to land-use changes, the antecedent moisture condition (AMC)—referring to the soil's degree of saturation prior to a rainfall event—plays a pivotal role in determining flood magnitude. When the soil reaches its saturation threshold, infiltration capacity is effectively nullified, causing nearly all precipitation to transform into instantaneous surface runoff [15]. Consequently, accurate risk estimations within early warning systems must integrate the dynamics of land-use change to produce discharge predictions that are both realistic and applicable [16]. This integration is crucial, given that rainfall intensity variability in tropical regions has trended upward over recent decades, as represented by the distribution of precipitation across observation stations.



Source: Author's analysis (2025)

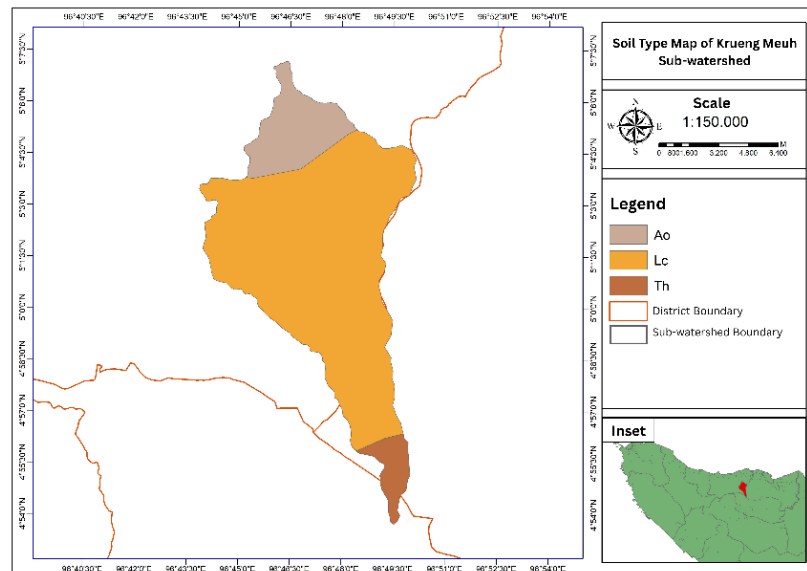
Figure 3. Spatial Rainfall Distribution Map of the Krueng Meuh Sub-Watershed.

While general hydrological studies are well-established, the specific integration of the Antecedent Precipitation Index (API_5) with spatial vulnerability mapping using the Flash Flood Potential Index (FFPI) remains under-explored within the Krueng Meuh sub-watershed. This study evaluates flash flood potential by synthesizing these physical and hydrological parameters to develop a more adaptive watershed management framework. The findings are intended to serve as a scientific benchmark for stakeholders in formulating preventive disaster mitigation strategies based on spatial data for the Bireuen Regency.

2. Research Method

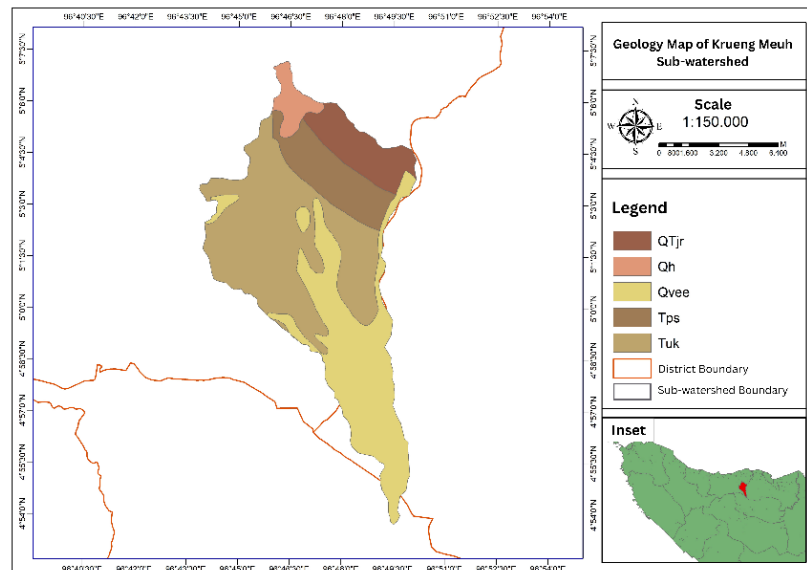
The research procedure is structured through an integrated technical approach to evaluate flash flood risk within the Krueng Meuh sub-watershed. The initial phase involves identifying the physical parameters of the region using Digital Elevation Model (DEM) data to extract slope information and drainage network characteristics [1], [13]. Slope is a critical variable, as steep terrain mechanically accelerates surface runoff and shortens the time of concentration toward the river outlet [17]. This geomorphological analysis enables the identification of areas that inherently possess high kinetic energy, capable of triggering debris movement during extreme precipitation events.

Furthermore, this study conducts an in-depth investigation into Land Use and Land Cover Change (LULCC) dynamics using satellite imagery over a specified observation period. The primary focus is directed toward the transition of natural vegetation, such as forests, into open land or plantations.



Source: Author's analysis (2025)

Figure 4. Soil Type Map of the Krueng Meuh Sub-Watershed.



Source: Author's analysis (2025)

Figure 5. Geological Map of the Krueng Meuh Sub-Watershed.

Based on a systematic review of global flood modeling trends, land-cover change is a determinant factor that consistently increases runoff coefficients and flood discharge volumes [18], [19]. In a local context, similar effects have been observed across various watersheds in Indonesia, where the decline in land retention capacity due to LULCC serves as the primary driver for increasing vulnerability to peak flooding [20], [21].

Hydrometeorological conditions were analyzed using daily precipitation data (2020–2024) to calculate the initial soil moisture index via the five-day Antecedent Precipitation Index (API_5) method. The API_5 parameter is employed to measure the soil saturation threshold at a specific saturation point, the soil's infiltration capacity decreases drastically, causing precipitation to be converted into instantaneous surface runoff [10], [22], [23]. This is consistent with hydrological modeling principles, which emphasize that flood risk increases exponentially when high-intensity rainfall interacts with already saturated soil.

In the final stage, all physical and hydrological parameters were synthesized using the Flash Flood Potential Index (FFPI) approach within a Geographic Information System (GIS) environment. Each variable—ranging from slope and soil type to land cover patterns—was assigned specific weightings to generate a spatial zoning map of flash flood vulnerability. The integration of this method has proven effective in predicting the hydrological impacts of future land-use changes and supporting the development of more adaptive mitigation strategies for the communities in Bireuen Regency. Detailed information regarding the weights and scores for each parameter, adapted from flood risk assessment methodologies for humid tropical regions [1] is presented in depth in **Table 1**.

Table 1. Parameters, Scores, and Weighting for FFPI Variables

No	Parameter	Sub-Criteria (Characteristics)	Score	Weight
1	Slope	>45% (Very Steep) to <8% (Flat)	5–1	30%
2	Land Cover	Open Land to Permanent Forest	5–1	25%
3	Soil Type	Highly Sensitive to Non-Sensitive	5–1	25%
4	Geology	Unconsolidated Rocks to Igneous Rocks	5–1	20%

Source: Author's Analysis (2025), adapted from Azizah et al. (2022) [1]

3. Results and Discussions

3.1 Hydrological Dynamics and Soil Saturation Characteristics

Analysis of precipitation data throughout the 2020–2024 period reveals a significant hydrological variability within the Krueng Meuh sub-watershed, particularly regarding five-day rainfall accumulation patterns. By employing the five-day Antecedent Precipitation Index (API₅) approach, this study successfully identifies the soil saturation thresholds prior to flood events. The calculation results indicate that API₅ values in the study area fluctuate between a range of 57.6 mm and a peak of 71.3 mm [22], [25], [26].

The high index values represent soil moisture conditions at a state of high saturation. Under these conditions, soil pores can no longer absorb water optimally, causing infiltration capacity to drop to its minimum threshold. This phenomenon reinforces established theories regarding tropical regions, which posit that antecedent soil conditions play a crucial role in triggering massive surface runoff; specifically, the interaction between moderate-intensity rainfall and pre-saturated soil will immediately trigger destructive surface flows. The dynamics of this soil saturation are visualized in **Table 2**.

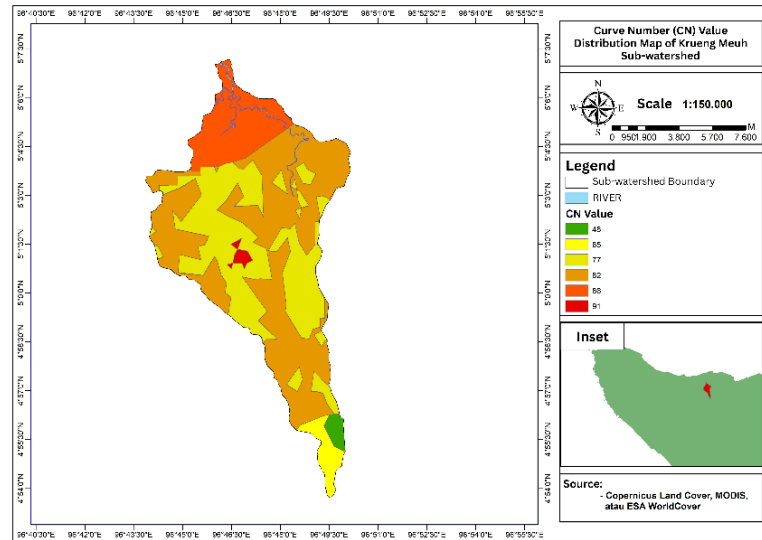
Table 2. API₅ Calculation Table

Event Date	Day (H-n)	Date	Rainfall (mm)	Total API ₅ (mm)
May 4, 2023	H-5	29-04-2023	0,0	57,6
	H-4	30-04-2023	0,0	
	H-3	01-05-2023	22,0	
	H-2	02-05-2023	0,0	
	H-1	03-05-2023	35,6	
	Total API ₅			
Oct 8, 2023	H-5	03-10-2023	0,0	71,3
	H-4	04-10-2023	0,0	
	H-3	05-10-2023	21,3	
	H-2	06-10-2023	21,7	
	H-1	07-10-2023	28,3	
	Total API ₅			

Source: Daily rainfall data from the Aceh Climatology Station (BMKG, 2023).

3.2 Spatial Analysis of Curve Number (CN) and FFPI Vulnerability

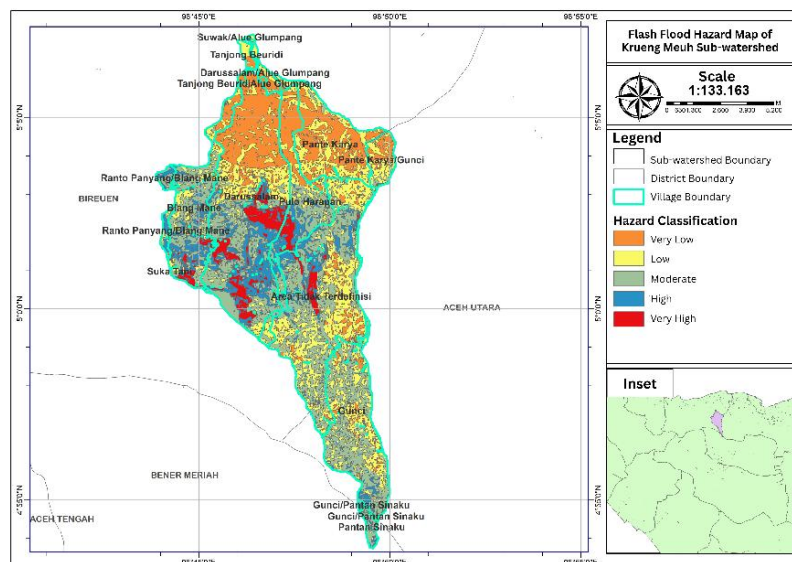
The land's capacity for rainwater retention was analyzed using the Curve Number (CN) parameter, derived from the synthesis of soil characteristics and land-use data. The spatial distribution of CN values in the Krueng Meuh sub-watershed indicates a rising runoff potential, primarily driven by the degradation of permanent vegetation into open land. This CN map serves as a crucial baseline for determining how each land unit responds to precipitation by generating flood discharge, as illustrated in **Figure 6**.



Source: Author's Analysis (2025)

Figure 6. Spatial Distribution Map of Curve Number (CN) in the Krueng Meuh Sub-Watershed

The integration of Curve Number (CN) parameters with slope and geological variables using the Flash Flood Potential Index (FFPI) method yields a comprehensive vulnerability mapping. The results demonstrate that the study area is dominated by moderate to very high vulnerability zones. The prevalence of slopes exceeding 25% in the upstream regions acts as a primary driver of flow kinetic energy, which is further exacerbated by erosion-sensitive geological formations [1], [4]. Furthermore, the conversion of 57.68% of forest cover has systematically expanded these risk zones, as illustrated in **Figure 7**.



Source: Author's Analysis (2025)

Figure 7. Flash Flood Vulnerability Map Generated via the FFPI Method

3.3 Discussion of Findings and Mitigation Implications

This research confirms that the flash flood risk in the Krueng Meuh sub-watershed is a result of the synergy between natural geophysical factors and anthropogenic pressures. The surge in peak discharge is not triggered by rainfall alone; rather, it is more dominantly influenced by the diminished retention capacity of the upstream land [5], [6]. Spatial identification reveals that downstream settlements, such as Pante Karya Village, lie within high-risk trajectories due to the accumulation of runoff originating from the steep upstream areas.

The policy implications of these findings emphasize the necessity of adaptive, spatial-based mitigation strategies. Restoring upstream ecosystems using deep-rooted vegetation is urgent to reduce surface runoff coefficients [23], [27]. Furthermore, utilizing the API₅ index as a component within early warning systems (EWS) could assist local authorities in predicting potential floods with higher precision before a disaster occurs.

4. Conclusion and Suggestion

4.1 Conclusion

This study concludes that the Krueng Meuh sub-watershed possesses significant vulnerability to flash flood disasters, driven by a combination of natural biophysical factors and human intervention in land-use management. Based on the modeling results, steep slopes in the upstream region serve as the primary control factor that accelerates the time of concentration toward downstream areas. This condition is further exacerbated by antecedent soil moisture levels (API₅) that frequently reach maximum saturation thresholds, thereby eliminating soil infiltration capacity and triggering instantaneous surface runoff. Moreover, the massive conversion of forest into open land has increased the potential for destructive flood discharge. Overall, the integration of hydrological and spatial parameters through the FFPI method has successfully mapped critical zones in Bireuen Regency that require specialized attention in disaster risk reduction efforts.

4.2 Suggestion

To enhance the effectiveness of these research findings and support sustainable watershed management, future studies are encouraged to integrate two-dimensional (2D) hydrodynamic modeling to predict inundation extent in residential areas with greater detail. Further analysis is required to evaluate the effectiveness of flood control structures, such as check dams or Sabo dams, at locations identified with high kinetic flow energy. Additionally, developing a community-based early warning system that utilizes real-time monitoring of soil saturation indices is a crucial step toward improving downstream community preparedness against future flash flood threats.

References

- [1] C. Azizah, H. Pawitan, B. D. Dasanto, I. Ridwansyah, and M. Taufik, "Risk assessment of flash flood potential in the humid tropics Indonesia: a case study in Tamiang River basin," *International Journal of Hydrology Science and Technology*, vol. 13, no. 1, 2022, doi: 10.1504/ijhst.2022.119236.
- [2] M. Farid, M. I. Pratama, A. A. Kuntoro, M. B. Adityawan, F. I. W. Rohmat, and I. R. Moe, "Flood Prediction due to Land Cover Change in the Ciliwung River Basin," *International Journal of Technology*, vol. 13, no. 2, p. 356, Apr. 2022, doi: 10.14716/ijtech.v13i2.4662.
- [3] N. R. Hounque *et al.*, "Climate and Land-Use Change Impacts on Flood Hazards in the Mono River Catchment of Benin and Togo," *Sustainability*, vol. 15, no. 7, p. 5862, Mar. 2023, doi: 10.3390/su15075862.

- [4] D. Suryadi, C. Asdak, and D. R. Kendarto, "Analisis Tingkat Kerawanan Banjir Bandang Menggunakan Metode Flash Flood Potential Index (Studi kasus: Sub DAS Cipeles, DAS Cimanuk)," *Jurnal Teknotan*, vol. 18, no. 3, pp. 331–338, Dec. 2024, doi: 10.24198/jt.vol18n3.10.
- [5] S. Sugianto, A. Deli, E. Miswar, M. Rusdi, and M. Irham, "The Effect of Land Use and Land Cover Changes on Flood Occurrence in Teunom Watershed, Aceh Jaya," *Land (Basel)*, vol. 11, no. 8, p. 1271, Aug. 2022, doi: 10.3390/land11081271.
- [6] J. Akuatiklestari, D. Sabriyati, and M. P. Hadi, "Artikel penelitian 2 Kajian Hidrologi Debit Puncak Penyebab Banjir Bandang Menggunakan Pemodelan Hidrograf Satuan Sintesis-SCS (HSS-SCS) Hydrological Assessment of Peak Flood Discharge Causes of Flashflood Using SCS Synthetic Unit Hydrograph Modeling (SCS-SUH)," *OPEN ACCESS*, vol. 5, no. 2, pp. 80–90, 2022, doi: 10.31629/akuatiklestari.v5i2.4462.
- [7] B. Hastanti, "Analysis of Vulnerability Levels to the Flash Flood Based on Social Economic and Institutional Factors in Wasior, Teluk Wondama, West Papua," *Jurnal Wasian*, vol. 7, no. 1, pp. 25–38, Jun. 2020, doi: 10.20886/jwas.v7i1.4785.
- [8] P. Irawan and J. Setiawan, "Forecasting the long-term impacts of land use and cover changes on runoff coefficient and flood hydrograph: a case study of the Upper Citanduy Basin, Indonesia," *Journal of Degraded and Mining Lands Management*, vol. 12, no. 3, pp. 7417–7429, Apr. 2025, doi: 10.15243/jdmlm.2025.123.7417.
- [9] E. Alshammari, A. A. Rahman, R. Rainis, N. A. Seri, and N. F. A. Fuzi, "The Impacts of Land Use Changes in Urban Hydrology, Runoff and Flooding: A Review," *Current Urban Studies*, vol. 11, no. 01, pp. 120–141, 2023, doi: 10.4236/cus.2023.111007.
- [10] F. Hariati, D. Saputra, A. Alimuddin, and I. Yanuarsyah, "Dampak Peningkatan Intensitas Hujan dan Tutupan Lahan Terhadap Debit Banjir Puncak Sungai Ciseel," *Jurnal Komposit*, vol. 4, no. 1, p. 13, Mar. 2022, doi: 10.32832/komposit.v4i1.3748.
- [11] M. Farid, M. I. Pratama, A. A. Kuntoro, M. B. Adityawan, F. I. W. Rohmat, and I. R. Moe, "Pengaruh Perubahan Tutupan Lahan terhadap Debit Banjir di Daerah Aliran Sungai Ciliwung Hulu," *Jurnal Teknik Sipil*, vol. 28, no. 3, pp. 309–318, Jan. 2022, doi: 10.5614/jts.2021.28.3.8.
- [12] T. Z. Oo and U. W. Humphries, "Hydrological modeling of flood impacts under land use and land cover change: A systematic review of tools, trends, and challenges," *MethodsX*, vol. 16, p. 103724, Jun. 2026, doi: 10.1016/j.mex.2025.103724.
- [13] S. Shrestha, S. Cui, L. Xu, L. Wang, B. Manandhar, and S. Ding, "Impact of Land Use Change Due to Urbanisation on Surface Runoff Using GIS-Based SCS–CN Method: A Case Study of Xiamen City, China," *Land (Basel)*, vol. 10, no. 8, p. 839, Aug. 2021, doi: 10.3390/land10080839.
- [14] Dimas Harya Wisanggeni, Jessica Elisabeth Sitorus, Kahar Halim Prima Putra, and M. Bagus Adityawan, "Pengaruh Perubahan Tutupan Lahan Terhadap Debit Banjir di Kawasan Inti Pusat Pemerintahan (KIPP) Ibu Kota Nusantara," *Jurnal Teknik Sipil dan Lingkungan*, vol. 9, no. 2, pp. 327–338, Oct. 2024, doi: 10.29244/jsil.9.2.327-338.

- [15] A. E. Elmahal, W. H. Mahmoud, A. Abdalla, and M. M. Ibrahim, "Quantifying the Impacts of Land Use and Land Cover Change on Watershed Hydrology Using Spatial Cloud Computing," *J. Flood Risk Manag.*, vol. 18, no. 1, Mar. 2025, doi: 10.1111/jfr3.70014.
- [16] M. Farid, M. I. Pratama, A. A. Kuntoro, M. B. Adityawan, F. I. W. Rohmat, and I. R. Moe, "Flood Prediction due to Land Cover Change in the Ciliwung River Basin," *International Journal of Technology*, vol. 13, no. 2, p. 356, Apr. 2022, doi: 10.14716/ijtech.v13i2.4662.
- [17] Finnyalia Napitupulu, Johnson Siallagan, and Maklon Warpur, "Pemodelan Banjir Berdasarkan Pendekatan Hidrometeorologi dan Perubahan Tutupan Lahan di Sub-DAS Distrik Abepura," *Globe: Publikasi Ilmu Teknik, Teknologi Kebumihan, Ilmu Perkapalan*, vol. 3, no. 2, pp. 56–67, Apr. 2025, doi: 10.61132/globe.v3i2.803.
- [18] T. Z. Oo and U. W. Humphries, "Hydrological modeling of flood impacts under land use and land cover change: A systematic review of tools, trends, and challenges," *MethodsX*, vol. 16, p. 103724, Jun. 2026, doi: 10.1016/j.mex.2025.103724.
- [19] S. Sugianto, A. Deli, E. Miswar, M. Rusdi, and M. Irham, "The Effect of Land Use and Land Cover Changes on Flood Occurrence in Teunom Watershed, Aceh Jaya," *Land (Basel)*, vol. 11, no. 8, p. 1271, Aug. 2022, doi: 10.3390/land11081271.
- [20] M. Farid, M. I. Pratama, A. A. Kuntoro, M. B. Adityawan, F. I. W. Rohmat, and I. R. Moe, "Pengaruh Perubahan Tutupan Lahan terhadap Debit Banjir di Daerah Aliran Sungai Ciliwung Hulu," *Jurnal Teknik Sipil*, vol. 28, no. 3, pp. 309–318, Jan. 2022, doi: 10.5614/jts.2021.28.3.8.
- [21] F. Hariati, D. Saputra, A. Alimuddin, and I. Yanuarsyah, "Dampak Peningkatan Intensitas Hujan dan Tutupan Lahan Terhadap Debit Banjir Puncak Sungai Ciseel," *Jurnal Komposit*, vol. 4, no. 1, p. 13, Mar. 2022, doi: 10.32832/komposit.v4i1.3748.
- [22] Finnyalia Napitupulu, Johnson Siallagan, and Maklon Warpur, "Pemodelan Banjir Berdasarkan Pendekatan Hidrometeorologi dan Perubahan Tutupan Lahan di Sub-DAS Distrik Abepura," *Globe: Publikasi Ilmu Teknik, Teknologi Kebumihan, Ilmu Perkapalan*, vol. 3, no. 2, pp. 56–67, Apr. 2025, doi: 10.61132/globe.v3i2.803.
- [23] J. G. Putri, S. Suharyanto, and P. S. Atmojo, "ANALISIS BANJIR SUBDAS CIMANUK UNTUK MENENTUKAN STATUS PERINGATAN DINI BANJIR KOTA GARUT," *Rang Teknik Journal*, vol. 4, no. 2, pp. 229–239, Jun. 2021, doi: 10.31869/rtj.v4i2.2369.
- [24] A. E. Elmahal, W. H. Mahmoud, A. Abdalla, and M. M. Ibrahim, "Quantifying the Impacts of Land Use and Land Cover Change on Watershed Hydrology Using Spatial Cloud Computing," *J. Flood Risk Manag.*, vol. 18, no. 1, Mar. 2025, doi: 10.1111/jfr3.70014.
- [25] M. Ardiansyah, R. A. Nugraha, L. O. S. Iman, and S. D. Djatmiko, "Impact of Land Use and Climate Changes on Flood Inundation Areas in the Lower Cimanuk Watershed, West Java Province," *Jurnal Ilmu Tanah dan Lingkungan*, vol. 23, no. 2, pp. 53–60, Dec. 2021, doi: 10.29244/jitl.23.2.53-60.

- [26] A. F. Yasin and W. Hadi, "Implementation of Retention Ponds in Flood Management in Sorong Regency â€“ Southwest Papua," *Civilla : Jurnal Teknik Sipil Universitas Islam Lamongan*, vol. 8, no. 1, pp. 7–22, Mar. 2023, doi: 10.30736/cvl.v8i1.979.