

Evaluating Linear Scaling and Random Forest Bias Correction of GPM-IMERG V7 Rainfall in Moluccas Islands Watersheds

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ABSTRACT

Reliable, high-resolution daily rainfall data are essential for hydrological assessments and flood-risk management in tropical island watersheds; however, rain-gauge networks in the Moluccas Islands are sparse and unevenly distributed. This study assesses the daily performance of the GPM-IMERG Version 7 (Final Run) precipitation product. It develops bias-correction strategies for six coastal watersheds (Dodaga, Sangaji, Kobe, Inggol, Wai Ruhu, and Wai Batumerah) using daily gauge observations from 2022 to 2025 as reference. A conventional mean-based Linear Scaling (LS) approach is implemented as a benchmark and compared with a non-parametric Random Forest (RF) regression model developed using matched IMERG-gauge pairs and evaluated against gauge observations over 2022-2025. Model skill is measured at the daily level using the Nash-Sutcliffe efficiency (NSE), Pearson correlation coefficient (R), and the RMSE-to-standard-deviation ratio (RSR). LS shows poor daily performance (NSE -0.53 to 0.18; R 0.12-0.49; RSR 0.91-1.40), indicating that mean adjustment alone is insufficient to address event-scale errors and intensity-related biases. In contrast, RF significantly enhances agreement with gauge observations across all watersheds (NSE 0.85-0.90; R 0.96-0.98; RSR 0.32-0.39). These results suggest that RF-corrected IMERG V7 offers a reliable daily rainfall input suitable for hydrological applications in data-limited tropical islands. Additionally, it provides a correction workflow that can be adapted to similar coastal watersheds.

Keywords-GPM-IMERG V7; bias correction; linear scaling; random forest; Moluccas islands watersheds

I. INTRODUCTION

The Global Precipitation Measurement (GPM) mission and its Integrated Multi-satellite Retrievals for GPM (IMERG) product provide near-global, high-resolution precipitation estimates that are extensively utilized in hydrological and climate studies, especially in regions with limited data availability [1]. However, IMERG performance depends on context and scale and can decline over coastal zones and small islands, where land-sea contrasts and localized convection

create sharp rainfall gradients [2]. In the Moluccas Islands of Eastern Indonesia, sparse and uneven rainfall gauge networks increase reliance on satellite rainfall products. At the same time, residual retrieval errors can propagate into flood and drought-related decisions [3]. To reduce these uncertainties, bias-correction methods range from basic mean adjustments to more advanced distributional and model-based techniques. Conventional methods such as LS, quantile mapping, and distribution matching can enhance mean or distributional features but often fail to correct intensity-dependent biases,

extreme values, and error structures associated with local physiography [4]. In contrast, machine-learning methods, especially RF, can learn non-linear relationships between satellite estimates and gauge observations and have demonstrated advantages in heterogeneous environments [5]. However, for small tropical island catchments, daily-scale assessment of IMERG Version 7 and a thorough comparison of LS and RF remain limited, leaving the incremental value of RF over a traditional benchmark insufficiently documented.

This study addresses this gap by assessing daily GPM IMERG V7 rainfall from 2022 to 2025 for six coastal watersheds in the Moluccas Islands (Dodaga, Sangaji, Kobe, Inggol, Wai Ruhu, and Wai Batumerah), using rain-gauge observations as a reference. Two working hypotheses are examined: (i) raw and LS-corrected IMERG V7 maintain significant systematic and random errors on a daily basis, characterized by underestimation of heavy rainfall and overestimation of light rainfall, thus constraining their hydrological applicability; and (ii) a bias-correction model based on RF, trained on paired IMERG gauge data, more accurately captures local non-linear error structures and yields substantially improved NSE, R, and RSR.

II. MATERIALS AND METHOD

A. Study Area and Data Used

This study examines six coastal watersheds in the Moluccas Islands of Eastern Indonesia, such as Dodaga, Sangaji, Kobe,

Inggol, Wai Ruhu, and Wai Batumerah (Figure 1). Steep hillslopes drain directly into adjacent bays, resulting in rapid response times, intricate orography, and pronounced land-sea forcing that facilitates localized convective rainfall. The resulting sharp spatial gradients and mesoscale variability challenge satellite precipitation retrievals across the Indonesian Maritime Continent [6]. Daily rainfall totals (mm/day) for 2022–2025 were sourced from official operational records maintained by stations operated by the Moluccas River Basin Agency and the North Moluccas River Basin Agency of the Public Works Ministry of Indonesia, situated within or adjacent to each watershed, and are accessible subject to agency authorization. The gauge dataset encompasses station identifiers and geographical locations, including latitude, longitude, and elevation where available, in addition to daily accumulated rainfall totals. Records underwent quality control to eliminate duplicate entries, resolve inconsistencies, and remove days with no observations. The GPM IMERG Version 7 Final Run precipitation product was obtained from NASA Earthdata at a 0.1° spatial resolution and used in its original gridded format before being aggregated into daily totals to match the gauge time step. For each gauge station, the IMERG grid cell containing the station's location was extracted. The satellite and gauge series were matched daily to create paired datasets ($P_{sat,t}$, $P_{obs,t}$), which were used to validate raw IMERG and to develop and evaluate the LS and RF bias-correction models in line with the study hypotheses.

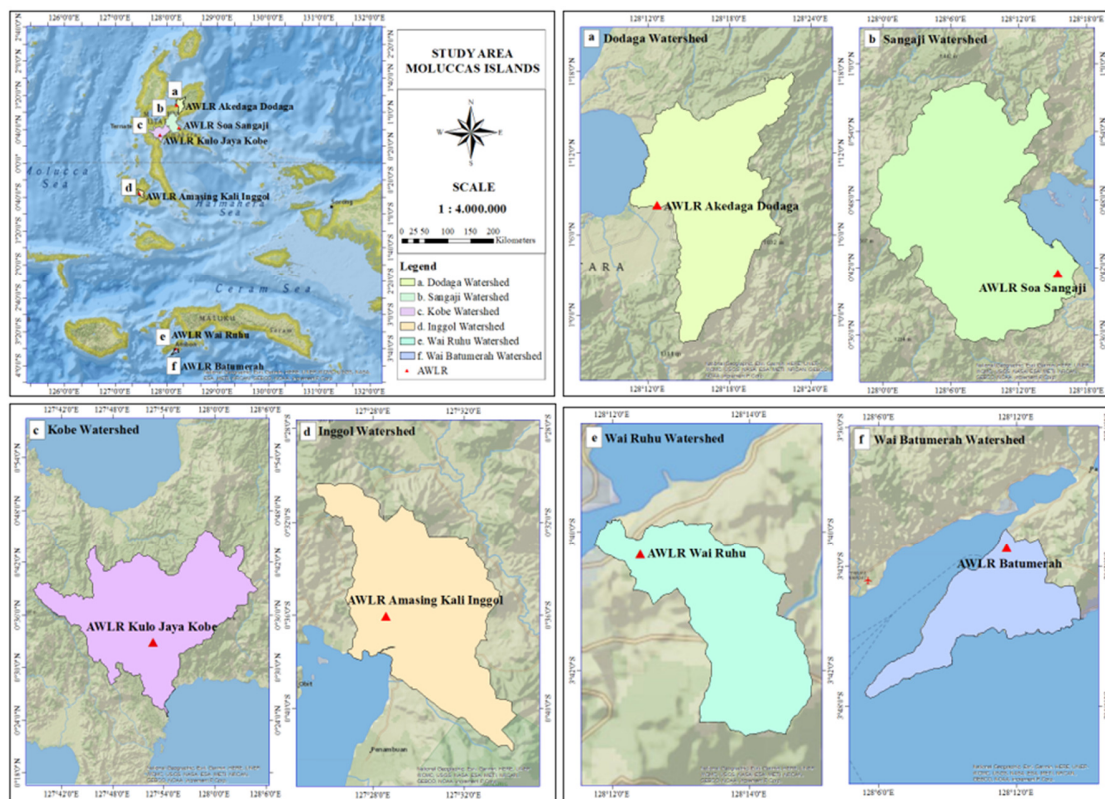


Fig. 1. The study area in the Moluccas islands watersheds: (a) Dodaga watershed; (b) Sangaji watershed; (c) Kobe watershed; (d) Inggol watershed; (e) Wai Ruhu watershed; (f) Wai Batumerah watershed.

B. Linear Scaling

LS served as a simple benchmark for calibrating the mean of GPM-IMERG V7 daily rainfall to gauge observations while preserving the satellite's temporal pattern [7]. LS presumes a systematic, consistent multiplicative bias over time between IMERG and gauges, allowing proportional correction based on observed climatology [8]. For each station grid pair, which means daily rainfall from IMERG ($\overline{P_{sat}}$) and from gauges ($\overline{P_{obs}}$) was computed over the validation period (2022-2025). A constant scaling factor α was derived and applied as [9]:

$$\alpha = \frac{\overline{P_{obs}}}{\overline{P_{sat}}} \quad (1)$$

$$P_{cor,t} = \alpha P_{sat,t} \quad (2)$$

where $P_{cor,t}$ is the LS-corrected daily rainfall and $P_{sat,t}$ is the raw IMERG daily rainfall at day t . Distinct α values capture spatial differences in mean bias across gauges [10]. Performance was assessed against gauge data using NSE, R, and RSR [11].

C. Random Forest

RF was used as a non-parametric machine-learning bias-correction model to capture non-linear error structures in daily GPM-IMERG V7 rainfall [12]. RF constructs an ensemble of decision trees through bootstrap resampling and combines their predictions. In this study, the response variable is the observed daily rainfall at each gauge, while the predictors include raw daily IMERG rainfall and temporal descriptors (month and season) that capture systematic variability in satellite errors [13]. Paired IMERG-gauge records were created by matching, for each gauge and day from 2022 to 2025, the IMERG estimate from the nearby grid cell with the quality-controlled gauge observation. RF-corrected rainfall was calculated by averaging predictions from all trees for each input vector. Skill was assessed against gauge observations over the 2022-2025 period using NSE, R, and RSR, consistent with the evaluation of raw and LS-corrected IMERG rainfall [14].

III. RESULTS AND DISCUSSION

A. Linear Scaling

The LS bias correction provides poor, at best marginal, skill for daily GPM-IMERG V7 rainfall across the watersheds of the Moluccas Islands (Figure 2). NSE remains negative in Dodaga (-0.53), Sangaji (-0.09), Kobe (-0.07), and is only slightly positive in Inggol (0.18), Wai Ruhu (0.14), and Wai Batumerah (0.06), indicating performance that often matches or is no better than using the observed mean. Correlation is weak ($R = 0.12-0.49$), while RSR values near or above unity (0.91-1.40) suggest substantial residual random error. These statistics indicate persistent underestimation of high-intensity events and overestimation of light rainfall, aligning with known limits of mean-based corrections in convective regimes with strong spatial gradients [15].

Even in the relatively better-performing basins (Inggol, Wai Ruhu, Wai Batumerah), LS does not reach skill levels generally regarded as acceptable for hydrological design, supporting the first hypothesis that a time-invariant, intensity-independent

correction is insufficient for complex coastal or island error structures [16]. LS primarily adjusts long-term averages, while event-scale mismatches remain largely unchanged. Timing errors and wet-dry day misclassification typical of convective rainfall persist, leading to ongoing missed events and false alarms. Because a single multiplicative factor is applied to all intensities, light rainfall is often overestimated, whereas heavy rainfall is consistently underestimated, especially in topographically influenced basins such as Dodaga and Sangaji [17].

B. Random Forest

The RF bias-correction model shows a significant and consistent upgrade in daily IMERG V7 performance compared to LS across all six watersheds (Figure 3). RF-corrected rainfall achieves uniformly high NSE values (0.85-0.90), demonstrating that most of the observed daily variability is captured, while correlations remain strong ($R = 0.96-0.98$). Concurrently, RSR decreases to 0.32-0.39, reflecting substantial reductions in both systematic and random error components. Improvements are most noticeable for moderate-to-heavy rainfall, where RF reduces the usual pattern of underestimating peak rainfall and overestimating low-intensity rainfall by learning non-linear satellite-gauge relationships. Importantly, RF skill remains high across basins of different sizes, reliefs, and coastal settings, indicating that the inferred error structures are generally applicable within the Ambon small-island context [18]. These results strongly support the second hypothesis that RF-based correction can provide hydrologically credible daily rainfall estimates for data-scarce tropical island watersheds. RF enhances the temporal dynamics of rainfall by better capturing the onset, persistence, and termination of wet spells. Time-series analysis (not shown) provides more precise timing and magnitude estimates of major rainfall events than LS, reducing the likelihood of missing heavy events and falsely identifying light-rainfall days, which are crucial for hydrological modeling and flood warning [19]. By exploiting non-linear interactions between IMERG intensity and temporal descriptors, RF also captures seasonal shifts in error structures between monsoonal and transition periods, thereby improving event-scale accuracy in flash-flood-prone watersheds in the Moluccas Islands.

C. Comparative Performance of Bias-Correction Techniques

The comparative statistics in Table I summarize the differences between LS and RF across watersheds and metrics. For LS, NSE values cluster near or below zero, correlation rarely exceeds 0.5, and RSR remains close to or above 1.0, indicating that a single multiplicative adjustment cannot adequately correct IMERG V7 errors in these basins. In contrast, RF shows consistently high skill across Dodaga, Sangaji, Kobe, Inggol, Wai Ruhu, and Wai Batumerah ($NSE = 0.86-0.90$; $R = 0.96-0.98$; $RSR = 0.32-0.39$). The consistent performance of RF across catchments with different physiographic features highlights its suitability for operational use in ungauged or sparsely gauged small-island environments [20]. Overall, the results demonstrate that RF outperforms LS in NSE, R, and RSR, confirming the study's hypotheses and emphasizing the added value of machine-learning-based bias correction for satellite rainfall over the Moluccas Islands.

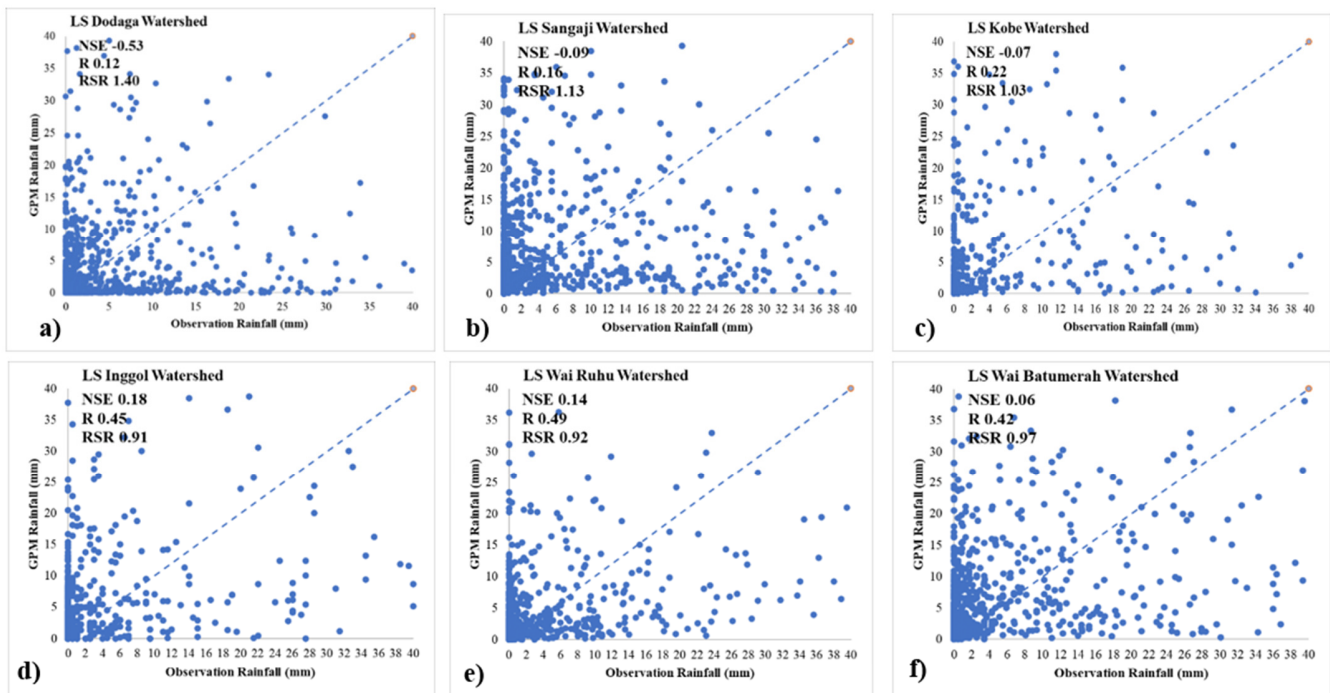


Fig. 2. Evaluation of GPM-IMERG V7 precipitation estimations against terrestrial measurements with LS: (a) Dodaga watershed; (b) Sangaji watershed; (c) Kobe watershed; (d) Inggol watershed; (e) Wai Ruhu watershed; (f) Wai Batumerah watershed.

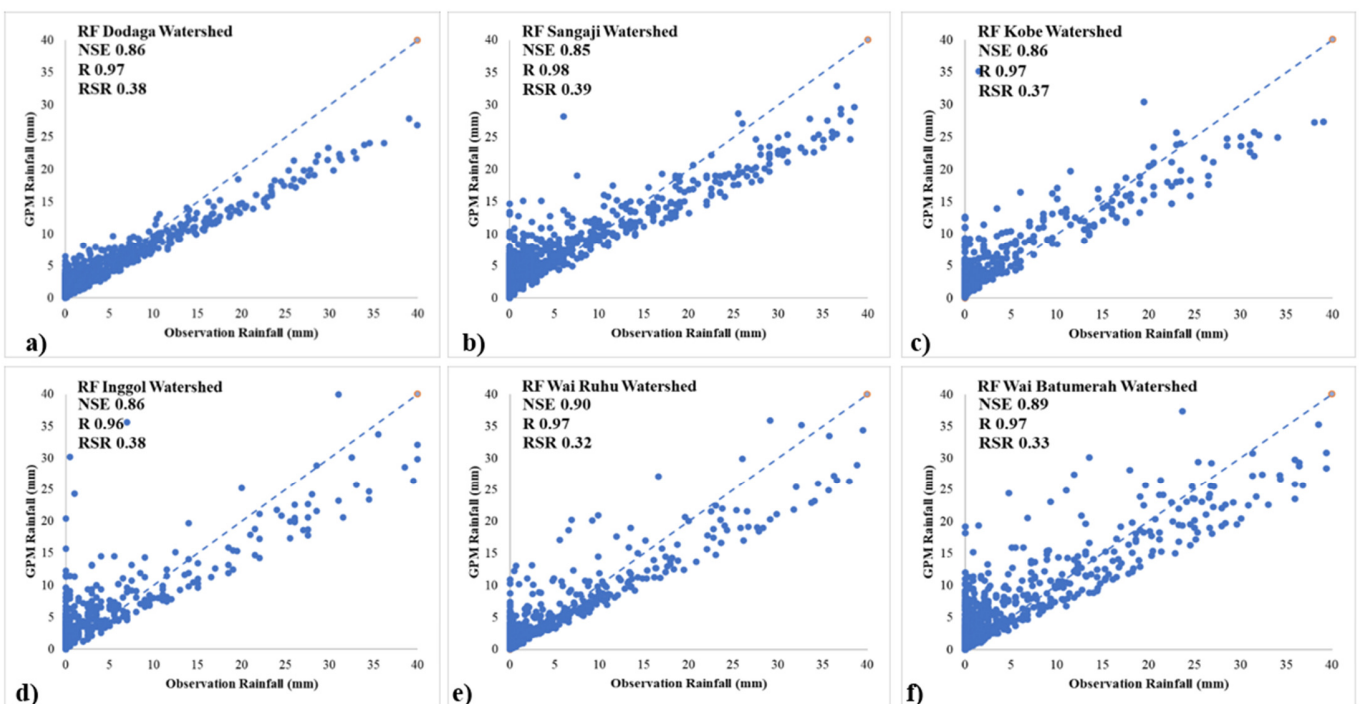


Fig. 3. Evaluation of GPM-IMERG V7 precipitation estimations against terrestrial measurements with RF: (a) Dodaga watershed; (b) Sangaji watershed; (c) Kobe watershed; (d) Inggol watershed; (e) Wai Ruhu watershed; (f) Wai Batumerah watershed.

Table I shows the trade-offs between the two correction methods. Although LS is simple, transparent, and computationally low-cost, its performance in these coastal watersheds is inadequate for applications that require realistic daily changes, such as flood modeling and real-time risk assessment. RF requires more data and computational resources, but its much higher accuracy, especially the jump from near-zero or negative NSE to around 0.9, along with the significant reduction in RSR, justifies this added complexity where reliable rainfall data is crucial [21]. Therefore, RF-corrected IMERG V7 is recommended over LS for hydrological studies in the Moluccas and tropical islands.

TABLE I. COMPARATIVE ACCURACY OF BIAS CORRECTION TECHNIQUES DURING VALIDATION PERIODS (2022–2025)

BC	ET	Watersheds in the Moluccas Islands					
		Do	Sa	Ko	In	WR	WB
LS	NSE	-0.53	-0.09	-0.07	0.18	0.14	0.06
	R	0.12	0.16	0.22	0.45	0.49	0.42
	RSR	1.40	1.13	1.03	0.91	0.92	0.97
RF	NSE	0.86	0.85	0.86	0.86	0.90	0.89
	R	0.97	0.98	0.97	0.96	0.97	0.97
	RSR	0.38	0.39	0.37	0.38	0.32	0.33

Abbreviation: BC - Bias Correction; ET - Evaluation Technique; Do - Dodaga; Sa - Sangaji; Ko - Kobe; In - Inggol; WR - Wai Ruhui; WB - Wai Batumerah

This study provides one of the first daily-scale evaluations and bias-correction benchmarks of GPM-IMERG V7 (Final Run) over steep, coastal small-island watersheds in Eastern Indonesia, where land-sea contrasts and short hydrological response times amplify event-scale rainfall errors. Explicitly benchmarking a traditional mean-based approach (LS) against a non-parametric machine-learning model (RF) across six Moluccas catchments shows that non-linear, intensity-dependent error structures dominate daily IMERG performance and can be significantly reduced with an RF correction. The resulting workflow is operationally useful for data-scarce island areas because it enhances event accuracy (wet-dry transitions and moderate-to-heavy rainfall) while still being feasible with paired gauge-satellite data [7, 22].

In terms of positioning, its findings align with recent studies showing that Random Forest-based corrections can outperform simpler benchmark adjustments by learning event-dependent relationships between satellite and gauge observations, as demonstrated for IMERG bias correction in Remote Sensing [7]. Similarly, daily fusion and merging experiments in Hydrology show that tree-based ensemble learning (including RF) can produce strong improvements over linear benchmarks when combining satellite precipitation with ground observations [8]. Compared to these broader-scale studies, the present work offers new evidence from small tropical island basins with strong coastal convection and sharp rainfall gradients, emphasizing that the RF advantage remains consistent across multiple neighbouring watersheds and supporting its applicability to similar maritime-island environments.

IV. CONCLUSION

This study assessed daily GPM-IMERG V7 rainfall across six coastal watersheds on the Moluccas Islands in Eastern

Indonesia and compared two bias-correction methods: mean-based Linear Scaling (LS) and a non-parametric Random Forest (RF) model. The work addresses the high uncertainty of satellite rainfall estimates in steep, coastal basins with sparse gauges, where orographic effects and land-sea interactions challenge the Integrated Multi-satellite Retrievals for GPM (IMERG). The results confirm the first hypothesis that raw and LS-corrected IMERG V7 still exhibit significant random and systematic errors on a daily basis, as evidenced by negative or near-zero NSE values, weak correlations, and RSR values close to or exceeding unity across all watersheds. In contrast, the second hypothesis is strongly supported: RF correction consistently achieves high skill levels, with Nash-Sutcliffe efficiency (NSE) between 0.85 and 0.90, Pearson correlation coefficient (R) from 0.96 to 0.98, and RMSE-to-standard-deviation ratio (RSR) between 0.32 and 0.39. It effectively captures most of the observed daily variability while significantly reducing both systematic and random errors. Overall, LS is insufficient as a standalone correction for hydrological applications in the Moluccas. Conversely, RF-corrected IMERG V7 offers reliable daily rainfall data for flood risk assessment and water resource analysis in small-island settings. The main contribution of this study is a direct comparison between a traditional mean-based correction (LS) and a flexible machine-learning correction (RF) for IMERG V7 across multiple steep coastal watersheds in Eastern Indonesia. By filling the evidence gap on daily-scale IMERG V7 correction in small tropical island catchments and providing a transferable correction workflow with consistently improved skill, the study supports more reliable operational use of satellite rainfall in similar data-limited coastal and island settings. Future work should combine these corrected products with hydrological models and investigate additional predictors and machine-learning frameworks to enhance robustness and transferability.

DATA AVAILABILITY

The Moluccas River Basin Agency and the North Moluccas River Basin of the Public Works Ministry of Indonesia provide rainfall observations from rain gauges (2022–2025) used in this study. Available subject to agency permission through the official agency portals: <https://sda.pu.go.id/balai/bwsmaluku/> and <https://sda.pu.go.id/balai/bwsmalukuutara/>. GPM IMERG V7 final run precipitation data are publicly available from NASA Earthdata and can be accessed through Giovanni: <https://www.earthdata.nasa.gov/data/tools/giovanni>.

The authors are not permitted to redistribute the raw rain-gauge records publicly; however, all preprocessing steps used to generate the analysis-ready datasets (quality control, daily aggregation, co-location, and day-by-day time matching) are fully described in the Methods to enable reproducibility once the gauge data are obtained through the agencies. IMERG data are downloaded from NASA Earthdata.

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