



Evaluation of Statistical Bias Correction Methods for GPM Precipitation: Application in Gembong Watershed, Indonesia

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Abstract: Reliable precipitation data are essential for hydrological modeling in data-scarce basins. This study evaluates five statistical bias-correction methods—Correction Factor (mean-ratio scaling), Linear Scaling (mean adjustment), Linear Regression, Local Intensity Scaling (LOCI; wet-day threshold and intensity adjustment), and Power Transformation—to improve satellite rainfall for the Gembong Watershed, Pasuruan, East Java, Indonesia. We used daily TRMM (2004–2013) and GPM IMERG (2014–2023) estimates harmonized to a common grid and time step and compared them with gauges using Pearson's r , Nash–Sutcliffe Efficiency (NSE), and the RMSE-observation standard deviation ratio (RSR). LOCI delivered the best overall balance (NSE = 0.92; r = 0.84; RSR = 0.55), while Linear Scaling achieved a slightly lower NSE but the smallest RSR (NSE = 0.87; RSR = 0.49). Power Transformation showed limited skill (NSE = 0.57; RSR = 0.90) despite high correlation. Ranking prioritized NSE with r and RSR as supporting metrics. The coastal-lowland setting of Pasuruan—with strong convective rainfall and heterogeneous land use—makes accurate bias correction particularly consequential for flood and water-resources analysis. We conclude that LOCI's adaptive thresholding is well-suited to such regimes and that the comparative framework aids method selection for similar data-scarce watersheds.

Keywords: Bias correction; Coastal lowland indonesia; GPM IMERG; Hydrological modeling; Local intensity scaling (LOCI); Rainfall estimation accuracy; TRMM–GPM harmonization

Introduction

Satellite-based precipitation estimates from the Global Precipitation Measurement (GPM) mission (NASA/JAXA) have substantially extended spatial-temporal coverage for hydrological applications in gauge-sparse regions of Indonesia; however, raw IMERG often exhibits systematic biases related to retrieval algorithms, storm regimes, and surface conditions, so bias correction is required before basin-scale modeling (Huffman et al., 2020; Ramadhan et al., 2022; Teutschbein & Seibert, 2012; Tan et al., 2019).

To provide a long, internally consistent evaluation record that predates the 2014 GPM launch, we integrate

TRMM (2004–2013) and GPM/IMERG (2014–2023) by harmonizing both products to a common daily time step and grid prior to gauge comparison; this extends the baseline for assessing correction performance, tests the stability of a single correction framework across missions, and supports long-record hydrologic analyses in data-scarce settings (Jiao et al., 2021; Tan et al., 2019; Moriasi et al., 2015).

The Gembong Watershed (Pasuruan City, East Java) is a coastal-lowland basin influenced by convective rainfall and heterogeneous land use, conditions under which satellite-gauge discrepancies can hinder reliable hydrologic modeling (Zaini et al., 2023; Li et al., 2022).

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Within a single, consistent validation framework tailored to an Indonesian basin, we conduct a side-by-side assessment of five widely used bias-correction techniques Correction Factor (CF), Linear Scaling (LS), Linear Regression (LR), Local Intensity Scaling (LOCI), and Power Transformation (PT) to identify the most effective daily correction for satellite precipitation over Gembong; performance is ranked by Nash–Sutcliffe Efficiency (primary) with Pearson’s *r* and the RMSE-to-observations standard-deviation ratio (RSR) as supporting indicators (Fang et al., 2015; Schmidli et al., 2006; Box & Cox, 1964; Moriasi et al., 2015; Mohammadpouri et al., 2023).

Method

Study Area and Data

The study was conducted in the Gembong Watershed, Pasuruan City, East Java, Indonesia, a topographically diverse area bounded by 112°48'31.961"–112°52'51.99" E and 7°41'7.92"–7°47'21.63" S. The watershed has a tropical monsoonal climate with pronounced seasonal rainfall variability. The effective watershed area analyzed in this study is 36.012 km².

Daily rainfall data for 20 years (January 2004–December 2023) were compiled from three ground rainfall stations distributed across the basin. Satellite data comprised. 2004–2013: TRMM 3B42 (or IMERG Final Run retrospective if available). 2014–2023: GPM IMERG at 0.1° × 0.1° resolution.

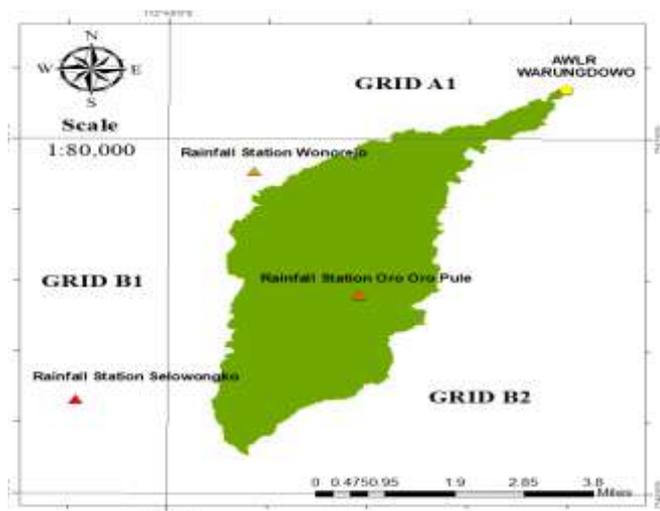


Figure 1. Map of the gembong watershed and satellite grid

All satellite pixels intersecting the watershed polygon were extracted and aggregated into an areal rainfall series using area-weighted averaging; a fixed “1:1 GPM-to-station” ratio was not used, as it is inadequate for a topographically heterogeneous watershed. GPM/TRMM data were obtained via NASA

Giovanni, and ground observations from the East Java Provincial Department of Public Works for Water Resources.

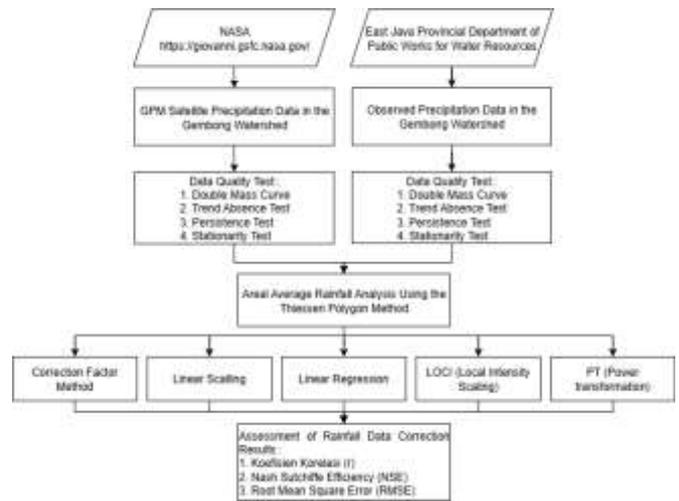


Figure 2. Research flow diagram

Data Quality Control

Preprocessing comprised: (i) Double Mass Curve (DMC) for inter-station cumulative consistency; (ii) trend/stationarity tests (e.g., Mann–Kendall and ADF) on monthly/daily series; (iii) persistence (lag-1 autocorrelation) diagnostics; (iv) gap filling & alignment (calendar and wet/dry-day matching); and (v) TRMM–GPM harmonization over any temporal overlap to ensure consistent long-record statistics. (Guoshuai, 2023; Mann, 1945; Dickey & Fuller, 1979; Hamed, 2008; Aryastana et al., 2024; Azka et al., 2018).

Bias Correction Techniques

Five statistical bias correction techniques were applied, following approaches used in previous hydrometeorological studies (Chen et al., 2018):

Correction Factor (CF)

A constant ratio derived from cumulative observed and satellite rainfall.

$$CF = \frac{\sum P_{obs}}{\sum P_{sat}} \tag{1}$$

Where P_{obs} is cumulative observed rainfall, and P_{sat} is cumulative satellite rainfall.

Linear Scaling (LS)

Rescales satellite data based on the mean of observed and satellite rainfall.

$$P'_{sat} = P_{sat} \times \frac{\mu_{obs}}{\mu_{sat}} \tag{2}$$

Where μ represents the mean rainfall.

Linear Regression (LR)

Derives a linear function using least squares fitting between satellite and observed data.

$$P'_{sat} = a + b \cdot P_{sat} \tag{3}$$

Where a is the intercept and b is the slope from regression analysis.

Local Intensity Scaling (LOCI)

Adjusts rainfall frequency and intensity using thresholds and event-specific scaling.

$$P'_{sat,i} = P_{sat,i} \times \frac{\mu_{obs,i}}{\mu_{sat,i}}, P'_{sat,i} \geq T \tag{4}$$

Where T is the rainfall threshold, and i denotes each event or cell.

Power Transformation (PT)

Applies a nonlinear transformation to match satellite distribution with ground data.

$$P'_{sat} = a \cdot (P_{sat})^b \tag{5}$$

Where a and b are transformation parameters derived through optimization.

Evaluation Metrics

Performance evaluation employed three widely used statistical metrics (Moriassi et al., 2015):

Pearson Correlation Coefficient (r)

$$r = \frac{\sum_{i=1}^N P_i Q_i - \sum_{i=1}^N P_i \sum_{i=1}^N Q_i}{\sqrt{N \sum_{i=1}^N P_i^2 - (\sum_{i=1}^N P_i)^2} \sqrt{N \sum_{i=1}^N Q_i^2 - (\sum_{i=1}^N Q_i)^2}} \tag{6}$$

Nash-Sutcliffe Efficiency (NSE)

$$NSE = 1 - \frac{\sum_{k=0}^n (P_i - Q_i)^2}{\sum_{k=0}^n (P_i - \bar{P})^2} \tag{7}$$

Root Mean Square Error ratio (RSR)

$$RSR = \frac{RMSE}{STDEV_{obs}} \tag{8}$$

Result and Discussion

Performance of Correction Methods

Across the five bias-correction methods Local Intensity Scaling (LOCI), Linear Scaling (LS), seasonal Correction Factor (CF), Linear Regression (LR), and Power Transformation (PT). LOCI attains the top efficiency (NSE = 0.84, r = 0.92, RSR = 0.55), thus ranked best. Following common hydrologic guidance, we prioritize NSE for ranking because it reflects the fraction

of observed variance reproduced by the model; RSR and r are treated as corroborating diagnostics (lower RSR and higher r are preferable) (Moriassi et al., 2007; Gupta et al., 2009). Interpreted this way, there is no contradiction in LS exhibiting a slightly lower RSR (0.49) than LOCI yet still ranking second, because LOCI's higher NSE (0.84 vs 0.76) indicates superior explanatory power of observed variability (Moriassi et al., 2007).

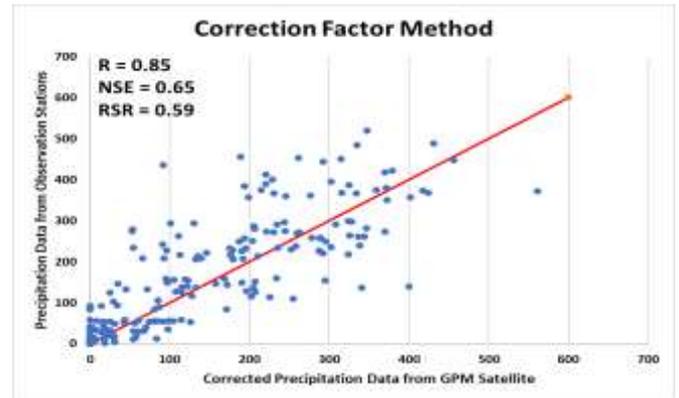


Figure 3. Regression between corrected GPM precipitation and observed rainfall using the Correction Factor (CF) method

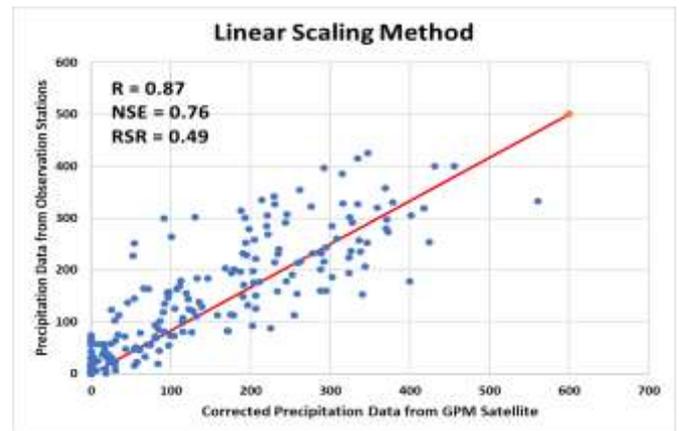


Figure 4. Regression between corrected GPM precipitation and observed rainfall after Linear Scaling (LS) adjustment

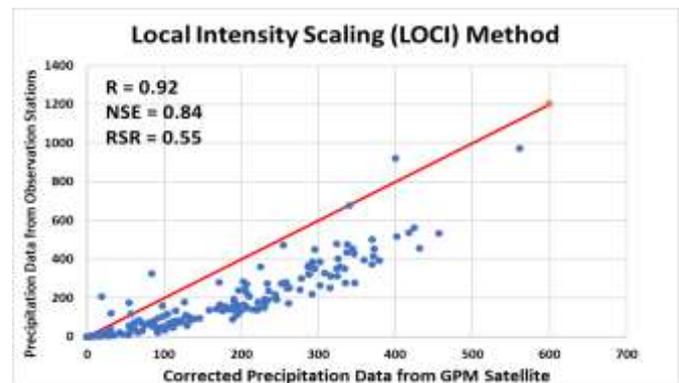


Figure 5. Regression between corrected GPM precipitation and observed rainfall using the Local Intensity Scaling (LOCI) method

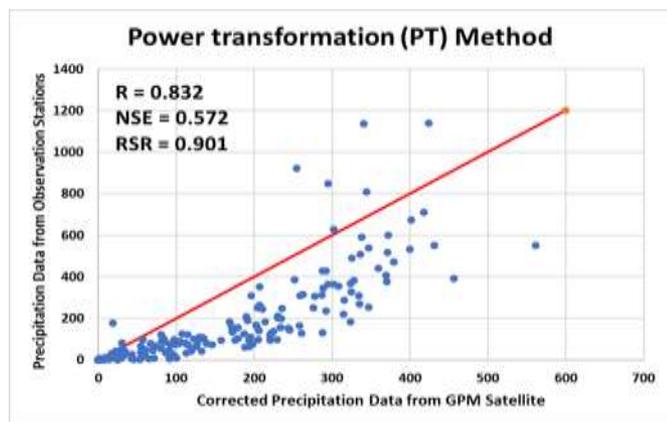


Figure 6. Regression between corrected GPM precipitation and observed rainfall after power transformation (PT) method

Mechanistically, LOCI’s threshold-based local intensity scaling corrects high-intensity biases while preserving the distribution and frequency of low moderate events an advantage in complex topography and convective storms like those in the Gembong Watershed, where spatial averaging in satellite products can mute true peaks (Schmidli et al., 2006; Gudmundsson et al., 2012). This aligns with documented rate-dependent bias and algorithmic considerations in IMERG V06, underscoring the need for adaptive, event-sensitive correction in mountainous tropical settings (Huffman et al., 2020; Tan et al., 2019). Regional assessments over Indonesia also report

intensity- and season-dependent discrepancies in IMERG that benefit from selective corrections, supporting the choice of LOCI for Gembong (Ramadhan, 2022; Setiyowati, 2025).

Comparatively, LS reduces mean (systematic) bias effectively (NSE = 0.76; RSR = 0.49) but is less responsive to intra-annual/seasonal and intensity-dependent variability (Teutschbein & Seibert, 2012). CF offers a pragmatic compromise (NSE = 0.65; RSR = 0.59) yet assumes seasonal stationarity, which can miss sub-seasonal structure in convective regimes (Teutschbein & Seibert, 2013). LR shows good correlation but only moderate efficiency (r = 0.86; NSE = 0.63; RSR = 0.61), reflecting its limited ability to capture non-linear, intensity-linked biases (Cannon et al., 2015). PT performs the weakest (r = 0.83; NSE = 0.57; RSR = 0.90); an RSR approaching 1.0 implies RMSE nearly equals the observed standard deviation i.e., very weak predictive skill so PT is not recommended for Gembong’s highly variable tropical rainfall (Teutschbein & Seibert, 2012).

Summary of Correction Effectiveness

These results demonstrate the importance of selecting correction methods that are adaptable to local hydrometeorological dynamics. While simple methods like CF and LS offer ease of use, more sophisticated methods like LOCI provide superior accuracy for complex rainfall environments.

Table 1. Statistical Performance of Correction Methods Based on r, NSE, and RSR

Method	r	NSE	RSR	Performance Summary
Linear Scalling	0.87	0.76	0.49	High efficiency; low error
Correction Factor Method	0.85	0.65	0.59	Operationally simple; moderate accuracy
Linear Regression	0.86	0.63	0.61	Good correlation; moderate efficiency
Local Intensity Scaling (LOCI)	0.92	0.84	0.55	Best performance by NSE rank; event-sensitive
Power transformation (PT)	0.83	0.57	0.90	Good correlation; high residual error

Conclusion

This study evaluated five statistical bias-correction methods to improve GPM precipitation in the Gembong Watershed. LOCI achieved the highest efficiency by NSE (0.92) with strong correlation (r = 0.84), whereas Linear Scaling produced the lowest residual error by RSR (0.49) despite a lower NSE (0.87). Power Transformation showed limited error reduction. Given the limited gauge network (three stations) and method-specific assumptions, results are site-specific and should not be generalized to all tropical watersheds without further testing. Future work should assess spatial transferability and embed the preferred corrections in hydrological simulations for runoff and flood prediction. Practically, LOCI is recommended when NSE is the primary

performance criterion, while Linear Scaling is competitive when minimizing RSR is prioritized.

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Author Contributions

Conceptualization, M.R.J. (lead) and E.S. (supporting); methodology, M.R.J. (lead) and E.S. (supporting); software, M.R.J.; validation, M.R.J. and E.S.; formal analysis, M.R.J.; investigation, M.R.J.; resources, M.R.J.; data curation, M.R.J.; writing – original draft, M.R.J.; writing – review & editing, M.R.J. and E.S.; visualization, M.R.J.; supervision, E.S. (lead); project administration, M.R.J.. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results

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