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Performance Evaluation of Historical CESM2 Rainfall Before and After Linear Scaling Bias Correction in the Sadar Watershed, Indonesia

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Abstract: Accurate rainfall data is fundamental for hydrological analysis, yet Global Climate Models (GCMs) such as CESM2 exhibit systematic biases compared to ground observations. This study evaluates historical CESM2 monthly rainfall before and after Linear Scaling (LS) bias correction in the Sadar Watershed, East Java, Indonesia (2000–2014). Observed rainfall from seven stations was spatially averaged using Thiessen Polygon method and compared against downscaled CESM2 outputs at 0.25° × 0.25° resolution. Model performance was assessed using Nash–Sutcliffe Efficiency (NSE), RMSE-Observations Standard Deviation Ratio (RSR), and Percent Bias (PBIAS). Prior to correction, CESM2 showed unsatisfactory performance (NSE = 0.410, RSR = 0.768). After LS correction, NSE improved to 0.516 (marginally satisfactory, near 0.50 threshold) and RSR to 0.696 (satisfactory), with PBIAS improving from −10.218% to 1.439% (very good). However, LS corrects only monthly-scale mean bias; daily-scale temporal variability and extreme rainfall remain unimproved. The 15-year period is shorter than the WMO-recommended 30-year climate baseline. Results demonstrate that LS-corrected CESM2 data are suitable for watershed-scale water balance assessment but insufficient for daily hydrological modeling without advanced bias correction methods, highlighting the importance of method selection for sustainable water resource management under climate change (SDG 6 & 13).

Keywords: Bias correction; CESM2; Climate change; Linear scaling; Rainfall; Water resources; SDG 6; SDG 13; Sustainable development

Introduction

Rainfall is one of the most critical hydrological variables controlling watershed responses, including runoff generation, streamflow variability, flooding, and water resource availability (Zhou et al., 2021). The Sadar Watershed, located in Mojokerto Regency, East Java, is among the watersheds with high flood vulnerability, with recorded flood events causing significant socioeconomic impacts on local communities (Nurdianyoto et al., 2019). Accurate and continuous rainfall data is therefore essential for supporting reliable hydrological analysis at the watershed scale. However, observed rainfall data in the Sadar Watershed is constrained by a limited spatial distribution of rain gauge stations, with records dependent on manual observation methods that introduce risks of recording errors and data gaps (Maria et al., 2022). Although seven rain gauge stations currently operate in the watershed, their spatial coverage remains uneven, and the absence of long-term continuous records restricts the use of observational data alone for extended climate and hydrological assessments.

To overcome these limitations, Global Climate Models (GCMs) are increasingly utilized as sources of long-term continuous climate data. The Community Earth System Model Version 2 (CESM2), developed by the National Center for Atmospheric Research (NCAR) as part of CMIP6, provides historical daily rainfall simulations from 1850 to 2014 (Danabasoglu et al., 2020;

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Eyring et al., 2016). In this study, the globally downscaled version of CESM2 at 0.25° × 0.25° resolution was used, allowing extraction of rainfall data at a spatial scale closer to the Sadar Watershed extent. This downscaled dataset has been widely applied in climate and hydrological studies across Southeast Asia, including Indonesia (Hsu et al., 2025; Prasetya et al., 2026). However, even at downscaled resolution, raw CESM2 outputs exhibit systematic biases relative to local observations, including overestimation of light rainfall events and underestimation of moderate to extreme rainfall due to model structural uncertainty and differences between GCM grid-scale and local hydrometeorological processes (Kurniadi et al., 2023; Sa'adi et al., 2025). These biases must be corrected before CESM2 data can be reliably applied in watershed-scale hydrological studies.

Bias correction is therefore a critical preprocessing step to improve the statistical agreement between GCM outputs and observed data prior to hydrological application (Teutschbein & Seibert, 2012), adjusting the statistical properties of model rainfall such as the mean without altering the spatial resolution of the GCM grid. Among available methods, Linear Scaling (LS) is widely applied due to its computational simplicity and effectiveness in correcting monthly-scale mean bias, as demonstrated both globally (Mahmood et al., 2018; Safura & Sekaranom, 2024) and in several Indonesian watersheds (Jauhari & Suhartanto, 2025; Zahrani et al., 2025). However, because LS applies a uniform monthly multiplier, it does not alter daily-scale temporal variability or extreme rainfall events, aspects that require more advanced methods such as Quantile Mapping or Distribution Mapping (Fang et al., 2015; Sa'adi et al., 2025). Evaluation using NSE, RSR, and PBIAS is therefore essential to quantify both the benefits and limitations of this method (Moriasi et al., 2007).

Despite the widespread application of CESM2 in Indonesian climate studies, a critical research gap remains: no study has systematically evaluated the performance of historical CESM2 rainfall data before and after bias correction at the watershed scale in the Sadar Watershed, East Java. Previous studies in this watershed focused on satellite rainfall validation using TRMM and CHIRPS (Maria et al., 2022) and rainfall-runoff modeling using HEC-HMS (Nurdianyoto et al., 2019), but none evaluated GCM-based historical rainfall data against local observations. Similar GCM-based bias correction studies in nearby East Java watersheds have instead relied on regional climate model products such as CORDEX-SEA rather than CESM2 (Anggraini et al., 2026; Satria et al., 2025). Furthermore, the specific capacity and limitations of Linear Scaling in correcting CESM2 mean bias while explicitly acknowledging its inability to improve daily-scale temporal dynamics have not been quantitatively assessed for small tropical watersheds in East Java.

This study addresses these gaps with the following novelties: it provides the first systematic evaluation of historical CESM2 monthly rainfall performance before and after Linear Scaling bias correction specifically in the Sadar Watershed; it explicitly distinguishes between monthly-mean bias correction, which LS is designed for and directly evaluated in this study, and daily-scale temporal variability improvement, which LS is theoretically unable to achieve based on its formulation; and it establishes a baseline performance benchmark for downscaled CESM2 rainfall data in this watershed, essential for future climate change impact assessments and water resource management in support of SDG 6 and SDG 13.

This study therefore aims to evaluate the performance of historical CESM2 rainfall before and after Linear Scaling bias correction in the Sadar Watershed using NSE, RSR, and PBIAS as performance indicators. The findings are expected to provide practical guidance for selecting appropriate bias correction approaches for watershed-scale hydrological applications in data-scarce tropical regions.

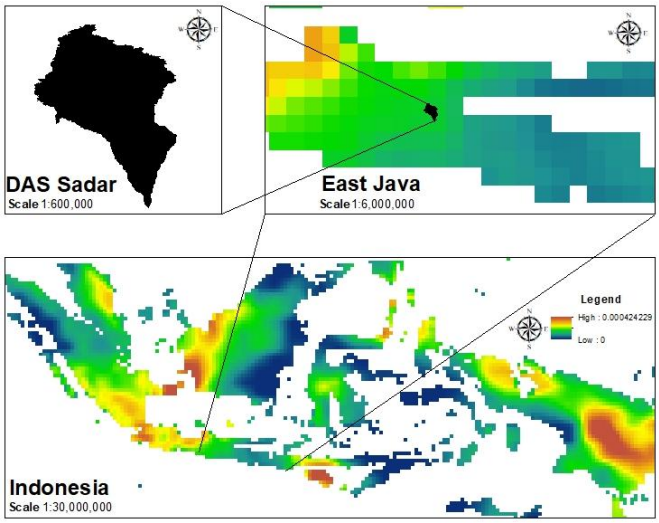


Figure 1. Location of the Sadar Watershed on the CESM2 model grid data CESM2

Method

Study Area and Data

This study is located in the Sadar Watershed, Mojokerto, East Java, Indonesia. Geographically, it is situated at coordinates 7°32'–7°42' South Latitude and 112°25'–112°35' East Longitude. The total area of the Sadar Watershed is 400.833 km². Figure 1 shows the location of the Sadar Watershed rainfall data mapped against the CESM2 Model grid data, with raw rainfall values ranging from 0 kg/m²/s (low, shown in dark

blue) to 0.00042229 kg/m²/s (high, shown in yellow–red). The original CESM2 rainfall variable (*pr*) is provided in units of kg/m²/s, equivalent to mm/s of liquid water flux. This was converted to a daily depth (mm/day) by multiplying the raw value by 86,400 (the number of seconds in one day):

$$\text{Rainfall (mm/day)} = \text{Rainfall (kg/m}^2\text{/s)} \times 86{,}400 \quad (1)$$

After conversion, the maximum grid-scale rainfall value corresponded to approximately mm/day. Watershed delineation was performed using DEMNAS data. The overall research workflow, from data acquisition through bias correction and performance evaluation, is illustrated in Figure 2.

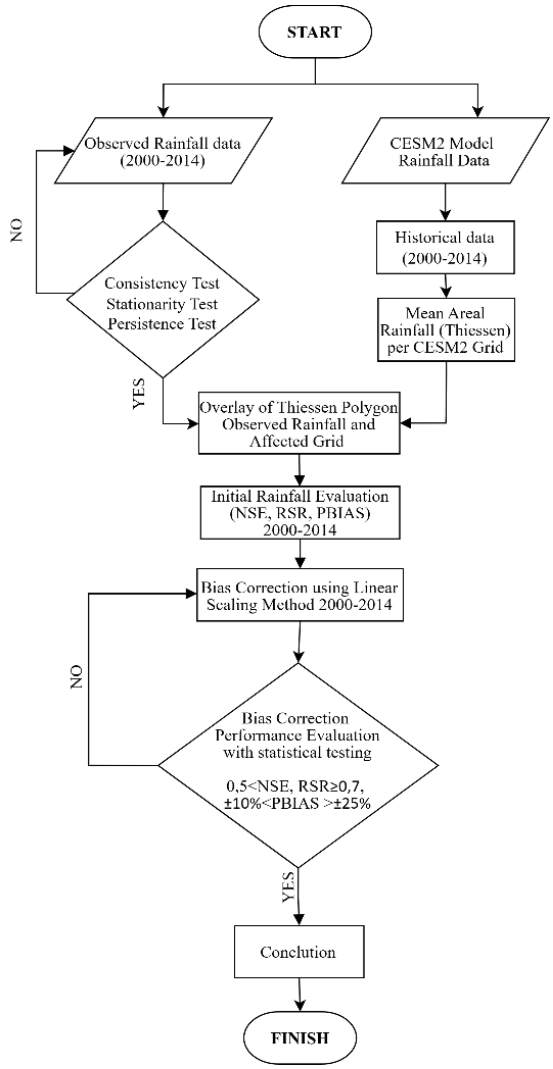


Figure 2. Research flowchart for evaluating CESM2 rainfall performance in the Sadar Watershed before and after Linear Scaling bias correction

Datasets

This study uses CESM2 rainfall data for the years 2000–2014, originally available at daily resolution and subsequently aggregated to monthly totals/means prior to bias correction and performance evaluation, consistent with the monthly-scale design of the Linear Scaling method. CESM2 is a climate model developed by the National Center for Atmospheric Research (NCAR), as part of the Coupled Model Intercomparison Project Phase 6 (CMIP6). The globally downscaled version with a resolution of 0.25° × 0.25° was used. CESM2 is a global Earth system model that represents interactions among the atmosphere, land, ocean, sea ice, and other climate components to simulate both historical and future climate variability (Danabasoglu et al., 2020). The CESM2 historical dataset is widely used in climate studies because it provides long-term simulations of rainfall data.

Table 1. Observed rain gauge stations in the Sadar Watershed

Rain Gauge Station	Area (km²)	Longitude	Latitude	Sub Dist.
Pudaksari	49.791	112.4868	-7.5035389	Bangsal
Pasinan	66.634	112.4509063	-7.4923699	Bangsal
Mojosari	72.260	112.556944	-7.5154028	Mojosari
Janjing	48.523	112.5820611	-7.5946444	Trawas
Pacet	47.969	112.5312638	-7.6619778	Pacet
Ketangi	75.223	112.4932777	-7.5663611	Dlangu
Pandan	40.444	112.53225	-7.6085833	Pacet

In addition, observed data from 7 rain gauge stations was required for the process of computing areal rainfall using the Polygon Thiessen (Figure 3). Observed rainfall data were obtained from the East Java Province Public Works and Spatial Planning Agency (Dinas PUPR Sumber Daya Air Jawa Timur). Table 1 presents the distribution of rain gauge stations in the Sadar Watershed, Mojokerto.

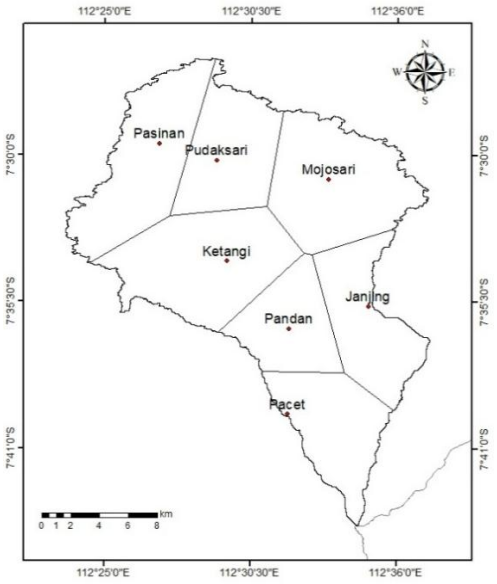


Figure 3. Thiessen polygon map of observed rain gauge stations

Model Evaluations

In estimating historical rainfall data, the CESM2 model exhibits bias relative to observed data. The corrected data represent raw inputs prior to hydrological simulation, including rainfall and temperature data (Knight & Shamseldin, 2005). One of the bias correction methods is Linear Scaling (LS). The LS method is one of the bias correction approaches, specifically a statistical approach commonly used to correct bias in climate model rainfall data by adjusting the mean value of the model data against the observed data (Anggraini et al., 2026; Satria et al., 2025; Teutschbein & Seibert, 2012).

$$P_{cor,m} = P_{raw,m} \times \frac{\mu(P_{obs,m})}{\mu(P_{raw,m})} \quad (2)$$

Where:

$P_{cor,m}$ = corrected rainfall value for month m
$P_{raw,m}$ = raw model rainfall for month m
$\mu(P_{obs,m})$ = mean observed rainfall for month m
$\mu(P_{raw,m})$ = mean model rainfall for month m

To quantitatively assess the effectiveness of Linear Scaling in this study, model performance was evaluated using three statistical indicators: Nash–Sutcliffe Efficiency (NSE), RMSE-Observations Standard Deviation Ratio (RSR), and Percent Bias (PBIAS), which are widely applied in hydrological model evaluation due to their sensitivity to systematic bias and error variance (Gupta et al., 2009; Krause et al., 2005; Moriasi et al., 2007).

Nash-Sutcliffe Efficiency (NSE)

The Nash-Sutcliffe Efficiency (NSE) index was originally used to assess the error between model outputs and observed data (Nash & Sutcliffe, 1970). With the NSE index, model parameters can be measured accurately and stably after the calibration process. According to Moriasi et al. (2007), NSE approaching 1 is the optimal result, and values between 0 and 1 are considered acceptable. NSE can be calculated using the following formula:

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2} \quad (3)$$

Where:

Y_i^{obs} = observed data (actual data)
Y^{mean} = mean of observed data (actual data)
Y_i^{sim} = simulated data (estimated data)
n = number of data points

PBIAS – Percent Bias

Percent Bias is a measure of the bias tendency expressed as a percentage to determine the average deviation of the CESM2 model simulation from its observed data. An accurate simulation is indicated by PBIAS = 0; a negative value indicates overestimation and a positive value indicates underestimation (Fang et al., 2015). The following PBIAS formula can be used (Gupta et al., 1999; Teutschbein & Seibert, 2012):

$$PBIAS = \frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_1^{sim})}{\sum_{i=1}^{n} Y_i^{obs}} \times 100 \quad (4)$$

Where:

Y_i^{obs} = observed data (actual data)
Y_i^{sim} = simulated data (estimated data)
n = number of data points

RMSE-Observations Standard Deviation Ratio (RSR)

This index represents the standardization of RMSE by the standard deviation of observed data. The RSR index is generally used to assess the magnitude of model error relative to observed data. The lower the RSR value, the better the model performance (Moriasi et al., 2007). The following RSR formula can be used:

$$RSR = \frac{RMSE}{STDEV_{obs}} = \sqrt{\frac{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y^{mean})^2}} \quad (5)$$

Where:

Y_i^{obs} = observed data (actual data)
Y^{mean} = mean of observed data (actual data)
Y_i^{sim} = simulated data (estimated data)
n = number of data points

Result and Discussion

Evaluation of Historical CESM2 Rainfall Before Bias Correction

To evaluate the CESM2 model, analysis was conducted using observed rainfall data for the period 2000–2014. The results are presented in Figure 4 on a monthly scale. In general, CESM2 was able to adequately reproduce the regional seasonal rainfall pattern, as demonstrated by the consistency of both data series in capturing the wet season (October–April) and dry season (May–September).

However, there were significant systematic deviations between the two datasets. As shown in Figure 4, CESM2 (solid line) tended to overestimate rainfall relative to the observed data (dashed line) during peak wet season periods, where the simulated peaks visibly exceeded the corresponding observed values. This deviation occurs because CESM2 is a global climate model operating at coarse spatial resolution (~100 km per grid), meaning that local hydrometeorological processes that determine the magnitude and timing of rainfall events in the Sadar Watershed (400.833 km²) cannot be accurately represented (Keller et al., 2022; Teutschbein & Seibert, 2012). As a result, the model tends to average rainfall distribution over a grid scale far

larger than actual field conditions, such that the peak values produced do not always correspond to the actual local rainfall intensity that occurred. This limitation is consistent with findings by Tuasikal et al. (2026), who reported that a conventional mean-based Linear Scaling approach exhibited poor daily-scale performance (NSE ranging from −0.53 to 0.18) when applied to satellite-based rainfall data across six tropical watersheds in the Moluccas Islands, confirming that mean-adjustment methods alone are insufficient to correct event-scale and intensity-related biases in coarse-resolution climate data.

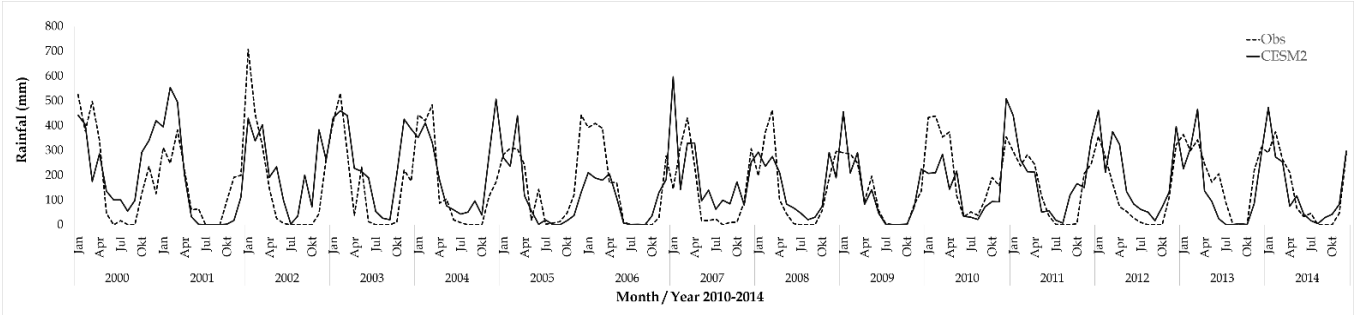


Figure 4. Relationship between observed and historical CESM2 rainfall before bias correction during the 2000-2014

To strengthen the evaluation results, this study used assessment indicators including Nash–Sutcliffe Efficiency (NSE), RMSE-Observations Standard Deviation Ratio (RSR), and Percent Bias (PBIAS). This is consistent with the evaluation criteria developed by Moriasi et al. (2007). Table 2 presents the results of CESM2 evaluation before correction.

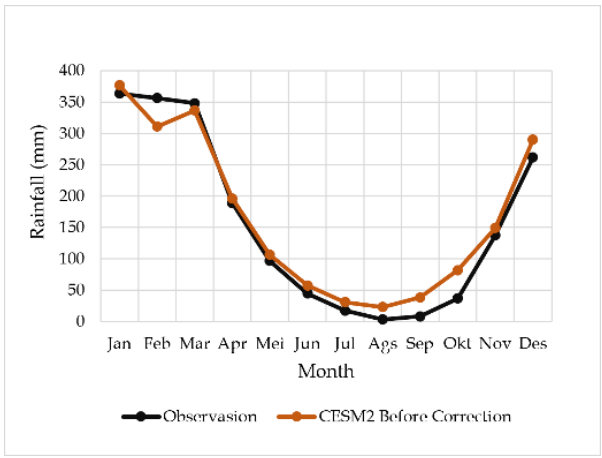
Table 2. Performance indicator evaluation before correction

Performance Model	Performance Rating	Conclusion
NSE	0.41	Unsatisfactory
RSR	0.77	Unsatisfactory
PBIAS	-10.22%	Very Good

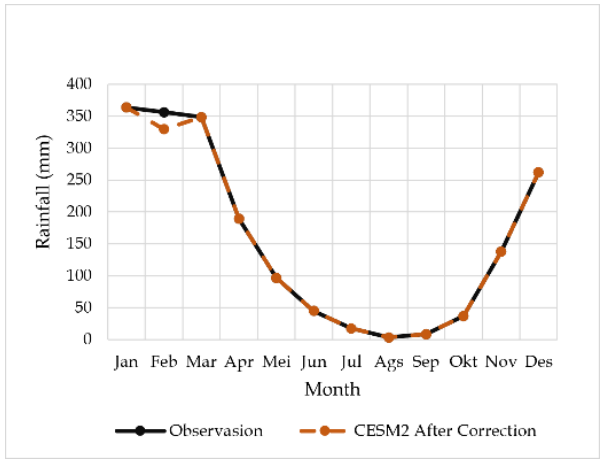
Based on the criteria of Moriasi et al. (2007), the NSE and RSR values indicate unsatisfactory performance, demonstrating that the CESM2 model has limited ability to represent observed rainfall variability. The low NSE indicates that CESM2 model rainfall has not yet optimally aligned with observations. The RSR indicates the presence of model deviation. The PBIAS result, showing a negative value (-10.22%) falls within the very good category, and on average CESM2 exhibits a slight bias. However, the negative sign indicates overestimation, where the model produces slightly higher rainfall than observations. Overall, the CESM2 model still has limitations in consistently representing rainfall before the bias correction process.

Effect of Linear Scaling on Mean Rainfall Characteristics

Linear Scaling is a bias correction method that adjusts mean values. Therefore, Figure 5 compares the mean rainfall before and after Linear Scaling. It can be seen that in February, CESM2 rainfall was relatively lower than observed data. After applying bias correction using the Linear Scaling (LS) method, the mean rainfall pattern of the model showed better agreement with observations, as evidenced by the CESM2 line more closely following the observed mean pattern across almost all months.



(a)



(b)

Figure 5. Mean relationship between observed and historical CESM2 rainfall during the 2000-2014: a) before correction and b) after correction

This demonstrates that the Linear Scaling method is effective in reducing bias in mean rainfall. Therefore, the correction of mean rainfall serves as an approach to adjust CESM2 model rainfall to better match observed values (Londhe et al., 2023). Although Linear Scaling successfully corrected the mean values of CESM2 to align with observations, statistical evaluation using NSE, RSR, and PBIAS is still required to assess the overall quality of the corrected CESM2 rainfall data.

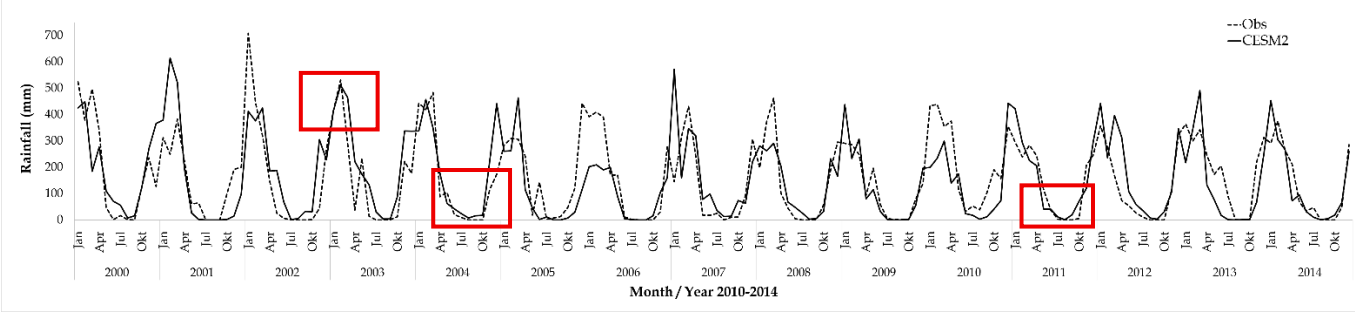


Figure 6. Relationship between observed and historical CESM2 rainfall after bias correction during the 2000-2014

Performance Evaluation After Linear Scaling

Figure 6 shows a comparison of observed and CESM2 simulated rainfall after bias correction using the Linear Scaling method for the period 2000–2014. Visually, the agreement between the two datasets shows a noticeable improvement compared to before correction, particularly in terms of overall magnitude during peak wet season periods that previously experienced considerable overestimation. The most notable improvement is shown in the areas marked by red boxes in 2003, 2004, and 2011, where CESM2 simulation peaks that previously deviated considerably from observations now show closer agreement in magnitude. It should be noted, however, that Linear Scaling calculates a single monthly scaling factor from the ratio of long-term observed and raw model means, which is then applied uniformly to every daily value within that month (Teutschbein & Seibert, 2012; Zhang et al., 2024)). Because this correction operates purely on the monthly mean, the temporal position of daily rainfall peaks remains identical to that of the raw model output (Zhang et al., 2024). The improvement observed in Figure 6 therefore reflects a reduction in peak magnitude bias, not a correction of the temporal timing or daily-scale variability of the rainfall events.

This improvement is quantitatively validated in Figure 7 based on the criteria of Moriasi et al. (2007)., showing that prior to bias correction, the model produced NSE = 0.410 and RSR = 0.768, which fall within the unsatisfactory category. However, after applying bias correction using LS, model performance showed improvement, with NSE increasing from 0.410 to 0.516 and RSR decreasing from 0.768 to 0.696, shifting the performance category to satisfactory. In addition, the PBIAS value changed from −10.218% to 1.439%, indicating that the systematic bias of the model approached zero after correction.

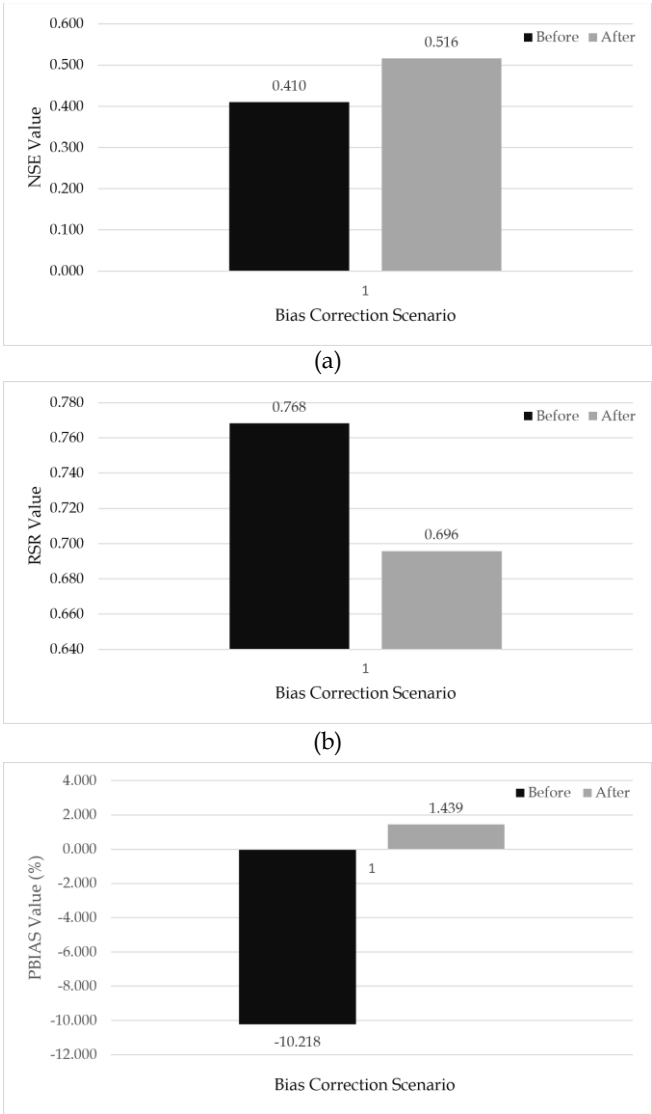


Figure 7. Performance comparison of historical CESM2 rainfall before and after linear scaling correction: (a) Nash-Sutcliffe Efficiency (NSE), (b) RMSE-Observations Standard Deviation Ratio (RSR), and (c) Percent Bias (PBIAS)

The LS method can be considered quite effective in reducing bias and improving the agreement of CESM2 model rainfall, although the positive PBIAS indicates a slight underestimation tendency with a relatively small deviation that still falls within the very good category. Nevertheless, the performance improvement from LS remains moderate, indicating that while the LS method is effective in correcting the mean rainfall of the model, it still has limitations in the overall representation of temporal rainfall variability. This is consistent with findings reported by Londhe et al. (2023) and Menapace et al. (2025), who noted that the LS method performs bias correction through mean value adjustment and tends to preserve the original temporal structure of the climate model output, a limitation also observed by Jaiswal et al. (2022), who found that linear scaling performed comparatively well for mean adjustment but was less effective than empirical quantile mapping in reproducing wet-day frequency and rainfall intensity distributions.

General Assessment of Linear Scaling Performance

Overall, the evaluation results demonstrate that the application of Linear Scaling provided a modest improvement in the mean CESM2 rainfall performance in the Sadar Watershed, with the corrected values falling at the lower bound of the satisfactory range. The increase in NSE from 0.410 to 0.516 and the decrease in RSR from 0.768 to 0.696 indicate that bias correction statistically improved the agreement between the model and observations, although this improvement remains marginal and close to the satisfactory threshold defined by Andari et al. (2024), Azman et al. (2021), and Moriasi et al. (2007). The shift in PBIAS from −10.218% to 1.439% demonstrates that the correction successfully reduced the model's overestimation tendency to a slight underestimation, which still falls within the very good category. Nevertheless, because Linear Scaling applies a uniform monthly correction factor, it does not alter the temporal distribution of rainfall events; its benefit is therefore limited to correcting mean bias rather than improving daily-scale variability or extreme rainfall representation. For hydrological studies requiring more precise representation of rainfall distribution, more advanced bias correction methods such as Quantile Mapping or Distribution Mapping may be considered as more comprehensive alternatives (Jaiswal et al., 2022; Teutschbein & Seibert, 2012). The results of this study reinforce the importance of the bias correction process as a preprocessing step prior to the utilization of historical CESM2 data in watershed-scale hydrological modelling.

Conclusion

This study evaluated the performance of historical CESM2 monthly rainfall data in the Sadar Watershed, Mojokerto, before and after bias correction using the Linear Scaling (LS) method over the period 2000–2014. Prior to correction, CESM2 exhibited unsatisfactory performance at the monthly evaluation scale, with NSE of 0.410 and RSR of 0.768, while PBIAS (−10.218%) fell within the very good category despite the model's limited ability to capture rainfall variability. Following the application of Linear Scaling, model performance improved, with NSE increasing to 0.516, RSR decreasing to 0.696, and PBIAS shifting to 1.439%, also within the very good category. These findings confirm that Linear Scaling is effective in reducing systematic mean bias in historical CESM2 rainfall data and improving the mean agreement between simulated and observed rainfall, although the improvement remains moderate, as the method primarily corrects bias through mean adjustment and does not substantially improve the representation of temporal variability or extreme rainfall events. Overall, bias correction is confirmed as a necessary preprocessing step before historical CESM2 rainfall data can be reliably used for watershed-scale hydrological analysis in the Sadar Watershed. Future studies are recommended to apply more advanced bias correction methods, such as Distribution Mapping or Quantile Mapping, to better capture rainfall distribution and variability, and to incorporate longer observation periods or additional GCM ensembles to strengthen the reliability of climate-based hydrological assessments in this watershed.

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Author Contributions

Conceptualization, F.S.P. and D.H.; methodology, F.S.P., D.H., and D.S.; formal analysis, investigation, resources, data curation, writing—original draft preparation, visualization, project administration, funding acquisition, F.S.P.; review, supervision, D.H. and D.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The author declares no conflict of interest.

References

Andari, R., Nurhamidah, N., Daoed, D., & Marzuki, M. (2024). Evaluation of Bias Correction Methods for Multi-Satellite Rainfall Estimation Products. *IOP Conference Series: Earth and Environmental Science*, *1317*(1), 012008. https://doi.org/10.1088/1755-1315/1317/1/012008

Anggraini, D., Wahyuni, S., & Bisri, M. (2026). Evaluation and Bias Correction of CORDEX-SEA Precipitation for Future Rainfall Projection in the Sutami Reservoir Catchment, Indonesia. *Jurnal Penelitian Pendidikan IPA*, *12*(5), 569–577. https://doi.org/10.29303/JPPIPA.V12I5.15055

Azman, A. H., Tukimat, N. N. A., & Malek, M. A. (2021). Analysis of Linear Scaling Method in Downscaling Precipitation and Temperature. *Water Resources Management*, *36*(1), 171–179. https://doi.org/10.1007/S11269-021-03020-0

Danabasoglu, G., Lamarque, J. F., Bacmeister, J., Bailey, D. A., DuVivier, A. K., Edwards, J., … Strand, W. G. (2020). The Community Earth System Model Version 2 (CESM2). *Journal of Advances in Modeling Earth Systems*, *12*(2), e2019MS001916. https://doi.org/10.1029/2019MS001916

Eyring, V., Bony, S., Meehl, G. A., Senior, C. A., Stevens, B., Stouffer, R. J., & Taylor, K. E. (2016). Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization. *Geoscientific Model Development*, *9*(5), 1937–1958. https://doi.org/10.5194/GMD-9-1937-2016

Fang, G. H., Yang, J., Chen, Y. N., & Zammit, C. (2015). Comparing Bias Correction Methods in Downscaling Meteorological Variables for a Hydrologic Impact Study in an Arid Area in China. *Hydrology and Earth System Sciences*, *19*(6), 2547–2559. https://doi.org/10.5194/HESS-19-2547-2015

Gupta, H. V., Sorooshian, S., & Yapo, P. O. (1999). Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. *Journal of Hydrologic Engineering*, *4*(2), 135–143. https://doi.org/10.1061/(ASCE)1084-0699(1999)4:2(135)

Gupta, H. V., Kling, H., Yilmaz, K. K., & Martinez, G. F. (2009). Decomposition of the Mean Squared Error and NSE Performance Criteria: Implications for Improving Hydrological Modelling. *Journal of Hydrology*, *377*(1–2), 80–91. https://doi.org/10.1016/J.JHYDROL.2009.08.003

Hsu, J., Chen, C. A., Lan, C. W., Chiang, C. L., Li, C. H., & Lo, M. H. (2025). Impact of Land Use Changes and Global Warming on Extreme Precipitation Patterns in the Maritime Continent. *NPJ Climate and Atmospheric Science*, *8*(1), 5-. https://doi.org/10.1038/s41612-024-00883-z

Jaiswal, R., Mall, R. K., Singh, N., Kumar, T. V. L., & Niyogi, D. (2022). Evaluation of Bias Correction Methods for Regional Climate Models: Downscaled Rainfall Analysis Over Diverse Agroclimatic Zones of India. *Earth and Space Science*, *9*(2), e2021EA001981. https://doi.org/10.1029/2021EA001981

Jauhari, M. R., & Suhartanto, E. (2025). Evaluation of Statistical Bias Correction Methods for GPM Precipitation: Application in Gembong Watershed, Indonesia. *Jurnal Penelitian Pendidikan IPA*, *11*(11), 590–595. https://doi.org/10.29303/JPPIPA.V11I11.12650

Keller, A. A., Garner, K. L., Rao, N., Knipping, E., & Thomas, J. (2022). Downscaling Approaches of Climate Change Projections for Watershed Modeling: Review of Theoretical and Practical Considerations. *PLOS Water*, *1*(9), e0000046. https://doi.org/10.1371/JOURNAL.PWAT.0000046

Knight, D., & Shamseldin, A. (2005). *River Basin Modelling for Flood Risk Mitigation*. CRC Press. Retrieved from https://www.routledge.com/River-Basin-Modelling-for-Flood-Risk-Mitigation/Knight-Shamseldin/p/book/9780415383448

Krause, P., Boyle, D. P., & Bäse, F. (2005). Comparison of Different Efficiency Criteria for Hydrological Model Assessment. *Advances in Geosciences*, *5*, 89–97. https://doi.org/10.5194/ADGEO-5-89-2005

Kurniadi, A., Weller, E., Kim, Y. H., & Min, S. K. (2023). Evaluation of Coupled Model Intercomparison Project Phase 6 Model-Simulated Extreme Precipitation Over Indonesia. *International Journal of Climatology*, *43*(1), 174–196. https://doi.org/10.1002/JOC.7744

Londhe, D. S., Katpatal, Y. B., & Bokde, N. D. (2023). Performance Assessment of Bias Correction Methods for Precipitation and Temperature from CMIP5 Model Simulation. *Applied Sciences (Switzerland)*, *13*(16), 9142. https://doi.org/10.3390/APP13169142/S1

Mahmood, R., Jia, S., Tripathi, N. K., & Shrestha, S. (2018). Precipitation Extended Linear Scaling Method for Correcting GCM Precipitation and Its Evaluation and Implication in the Transboundary Jhelum River Basin. *Atmosphere*, *9*(5), 160. https://doi.org/10.3390/atmos9050160

Maria, A., Suhartanto, E., & Fidari, J. S. (2022). Validasi Data Curah Hujan Satelit dengan Data Stasiun Hujan di DAS Sadar, Kabupaten Mojokerto. *Jurnal Teknologi dan Rekayasa Sumber Daya Air*, *2*(2), 375.

https://doi.org/10.21776/ub.jtresda.2022.002.02.30

Menapace, A., Dhawan, P., Torre, D. D., Kaffas, K., Crespi, A., Larcher, M., … Cannon, A. J. (2025). Review of Bias Correction Methods for Climate Model Outputs in Hydrology. *Journal of Hydrology*, *660*, 133213. https://doi.org/10.1016/J.JHYDROL.2025.133213

Moriasi, D. N., Arnold, J. G., Liew, M. W. V., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *Transactions of the ASABE*, *50*(3), 885–900. https://doi.org/10.13031/2013.23153

Nash, J. E., & Sutcliffe, J. V. (1970). River Flow Forecasting Through Conceptual Models Part I - A Discussion of Principles. *Journal of Hydrology*, *10*(3), 282–290. https://doi.org/10.1016/0022-1694(70)90255-6

Nurdianyoto, I., Suhartanto, E., & Yuliani, E. (2019). Analysis of Rain-Flood Discharge Using HEC-HMS Model in Sadar Sub-catchment, Mojokerto. *International Research Journal of Advanced Engineering and Science*, *5*(1), 41–47. https://doi.org/10.5281/zenodo.3604593

Prasetya, R., Djuhana, D., Saputro, A. H., & Permana, D. S. (2026). Evaluation and Ranking of NEX-GDDP-CMIP6 Models Based on Monthly Precipitation Climatology Over Indonesia. *Frontiers in Climate*, *8*, 1748663. https://doi.org/10.3389/FCLIM.2026.1748663/FULL

Sa'adi, Z., Rohmat, F. I. W., Stamataki, I., Shahid, S., Iqbal, Z., Yaseen, Z. M., … Shiru, M. S. (2025). Assessing the Temporal Reliability of CMIP6 GCMs in Projecting Future Rainfall for the Majalaya Basin, West Java. *Natural Hazards*, *121*(17), 19681–19722. https://doi.org/10.1007/S11069-025-07592-7

Safura, A. H., & Sekaranom, A. B. (2024). Projections of Future Meteorological Drought in Java–Nusa Tenggara Region Based on CMIP6 Scenario. *Geographia Technica*, *19*(1), 43–60. https://doi.org/10.21163/GT_2024.191.04

Satria, I., Sumiadi, S., & Wahyuni, S. (2025). Utilization of CORDEX-SEA Rainfall Data for Rainfall Projections Using the RCP 4.5 Secenario in the Beringin Sila Dam Catchment Area Sumbawa Regency. *Jurnal Penelitian Pendidikan IPA*, *11*(9), 787–795. https://doi.org/10.29303/JPPIPA.V11I9.12744

Teutschbein, C., & Seibert, J. (2012). Bias Correction of Regional Climate Model Simulations for Hydrological Climate-Change Impact Studies: Review and Evaluation of Different Methods. *Journal of Hydrology*, *456–457*, 12–29. https://doi.org/10.1016/J.JHYDROL.2012.05.052

Tuasikal, H., Juwono, P. T., Sholichin, M., & Suhartanto, E. (2026). Evaluating Linear Scaling and Random Forest Bias Correction of GPM-IMERG V7 Rainfall in Moluccas Islands Watersheds. *Engineering, Technology & Applied Science Research*, *16*(2), 34706–34711. https://doi.org/10.48084/ETASR.17008

Zahrani, N., Suhartanto, E., & Andawayanti, U. (2025). Assessment of Bias-Correction Methods for CHIRPS Satellite Rainfall Estimates in the Petung Watershed, Indonesia. *Jurnal Penelitian Pendidikan IPA*, *11*(12), 43–51. https://doi.org/10.29303/JPPIPA.V11I12.13250

Zhang, H., Chapman, S., Trancoso, R., Toombs, N., & Syktus, J. (2024). Assessing the Impact of Bias Correction Approaches on Climate Extremes and the Climate Change Signal. *Meteorological Applications*, *31*(3), e2204. https://doi.org/10.1002/met.2204

Zhou, W., Zhu, Z., Xie, Y., & Cai, Y. (2021). Impacts of Rainfall Spatial and Temporal Variabilities on Runoff Quality and Quantity at the Watershed Scale. *Journal of Hydrology*, *603*, 127057. https://doi.org/10.1016/j.jhydrol.2021.127057