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Utilization of CORDEX-SEA Rainfall Data for Rainfall Projections Using the RCP 4.5 Secenario in the Beringin Sila Dam Catchment Area Sumbawa Regency

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Abstract: Climate change poses significant challenges to water resource management, particularly in regions dependent on reservoirs. This study evaluates the performance of CORDEX-SEA rainfall data in the Beringin Sila watershed and applies a bias correction using the Linear Scaling (LS) method. Historical analysis for 2001–2022 revealed that the raw CORDEX-SEA output overestimated rainfall, with a mean of 147.88 mm/month compared to 93.10 mm/month observed (PBIAS = 35.5%, Willmott's d = 0.03). After applying LS, model accuracy improved substantially, yielding an adjusted mean of 100.30 mm/month, PBIAS of 3.07%, Willmott's d of 0.748, and correlation coefficient of 0.580. These results confirm that LS effectively reduces systematic bias. The corrected dataset was then used to project rainfall for 2023–2050 under the RCP 4.5 scenario. Projections indicate an average of 98.49 mm/month, or 5.8% higher than the historical baseline, with considerable interannual variability ranging from less than 50 mm in dry years to more than 300 mm in wet years. Such findings highlight both the potential for modestly increased water availability and the need for adaptive reservoir operation to manage variability across wet and dry seasons. The results provide a valuable reference for future water balance studies and operational strategies in newly constructed reservoirs such as Beringin Sila.

Keywords: Beringin sila reservoir; Bias correction; CORDEX-SEA; Linear scaling; Rainfall projection; RCP 4.5

Introduction

The increase in intensity and variability of rainfall due to climate change poses a serious challenge for the management of water resources at both local and regional scales, including in the preparation of water balance and planning responses to hydrometeorological extremes (Robertson et al., 2023). To address the uncertainty in climate projections at the local level, data from regional climate models such as CORDEX (Coordinated Regional Downscaling Experiment) becomes very important as input for hydrological analysis, including in the water balance of reservoirs. However, the raw output from these models often contains significant biases, which, if not corrected, can result in unrealistic or even absurd predictions at the local level. Climate change has affected rainfall patterns and increased the frequency of extreme hydrometeorological events worldwide. This phenomenon has a direct impact on the hydrological cycle, causing uncertainty in water availability, flood risks, and drought (IPCC, 2023). Climate change has led to increased climate variability and extreme hydrometeorological events in various parts of the world. The average global temperature rise of 0.7°C over the last hundred years has directly affected the hydrological cycle, including the intensity and distribution of rainfall (Sipayung et al., 2019). In

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Indonesia, the average temperature has increased by 0.45–0.75°C, and the Nusa Tenggara region is known as one of the areas most vulnerable to both drought and seasonal floods (Bappenas, 2011). This condition poses a major challenge to water resource management, especially in areas with a high dependence on multifunctional reservoirs.

The Beringin Sila Watershed in Sumbawa Regency is a real example. The Beringin Sila dam was completed in 2021 and started operating in 2023, with the main functions of providing irrigation water, raw water, flood control, and hydroelectric power generation. Although this dam is new, the Beringin Sila watershed has historical rainfall records from 2001 to 2022. This data allows for the calibration and bias correction of climate models to develop rainfall projections that can serve as a basis for water balance planning and future reservoir operation patterns. Therefore, this research is important as it provides relevant medium-term climate information for new long-lived infrastructure. Rainfall intensity estimation is carried out by utilizing satellite (Mardyansyah et al., 2024). One common method for projecting future climate conditions is by using Global Circulation Models (GCM). However, GCMs have limitations due to their coarse spatial resolution (100–250 km), which often makes them less capable of capturing climate variability at regional or local levels. This condition creates a gap between model data and observational conditions, particularly in areas with diverse topography and climate like Indonesia (Wilby, 2006). Therefore, a downscaling approach is needed to improve GCM results to be more suitable for local scale use. One of the downscaling products that is widely used is CORDEX-SEA (Coordinated Regional Climate Downscaling Experiment – Southeast Asia). This dataset is the result of various global climate models downscaled using Regional Climate Models (RCM), with a higher spatial resolution of 25 × 25 km. CORDEX-SEA provides model outputs for several Representative Concentration Pathways (RCP), namely RCP 2.6 (low), RCP 4.5 (moderate), and RCP 8.5 (high). Nevertheless, the outputs of CORDEX-SEA often still show biases against field observation data, requiring further correction steps before they can be used practically (Nur et al., 2021).

Nevertheless, the raw output of CORDEX often still shows significant bias against observational data. For example, CORDEX-SEA can produce rainfall projections that are much higher or lower than field data (Tangang et al., 2020). Therefore, bias correction is necessary so that the model data can be used on a local scale. Linear scaling is one of the simple approaches that is widely used, which has proven effective in reducing the average deviation of the model's rainfall and maintaining the temporal pattern (Kurnia et al., 2020). Several studies in Southeast Asia also show that bias correction can improve the accuracy of regional climate projections, including for hydrological analysis and water resource planning (Faqih et al., 2023). Until now, research on rainfall projections using CORDEX data in Indonesia has mostly focused on large islands such as Java and Sumatra (Nurlatifah et al., 2023). Meanwhile, studies in the Nusa Tenggara region, particularly in the Beringin Sila watershed, are still very limited. However, this area has a different anti-monsoonal climate characteristic compared to Java, thus requiring a specific analysis.

In this study, the selected scenario is RCP 4.5, as this scenario represents a medium emission pathway that is considered the most realistic for current conditions. RCP 4.5 depicts a situation where greenhouse gas concentrations continue to rise until the mid-century but then stabilize due to the implementation of moderate mitigation policies. Therefore, the use of this scenario is seen as more suitable for analyzing the potential medium-term rainfall (2023–2050) in the Beringin Sila watershed, as well as providing a relevant basis for planning water resource management in the new reservoir (Faqih, 2017). The focus of this research is on the projection of rainfall in the Beringin Sila Watershed (DAS), an area with a new reservoir that requires climate projections for long-term planning. This research is the first effort to integrate CORDEX-SEA data with a simple bias correction method in this watershed, thus providing relevant scientific information to support climate change adaptation strategies and the management of the newly operational reservoir.

Method

The research area is located in the Beringin Sila River Basin, Sumbawa Regency, West Nusa Tenggara Province. Geographically, this Basin is situated at coordinates 8°27'43.77" S and 117°7'21.17" E, with a catchment area of approximately 62.05 km² and a main river length of about 17.53 km. This river flows into the Beringin Sila Reservoir, which began operations in 2023 after a construction process that started in 2018. The Beringin Sila Reservoir is designed as a multifunctional reservoir with the main purpose of providing irrigation water, raw water supply, hydropower generation, flood control, as well as supporting the fisheries and tourism sectors. The existence of this new reservoir makes the Beringin Sila watershed a strategic area in the management of water resources in Sumbawa Island. Although this reservoir has only recently become operational, historical rainfall data from climatology stations and hydrology posts around the watershed has been available since 2001. The availability of this long-term data allows for calibration and validation of climate model outputs. Therefore, the Beringin Sila watershed was chosen as the research location because it represents a real need for medium-term climate projections to support future water balance planning and reservoir operations. The location of the Beringin Sila Reservoir can be seen in Figure 1.

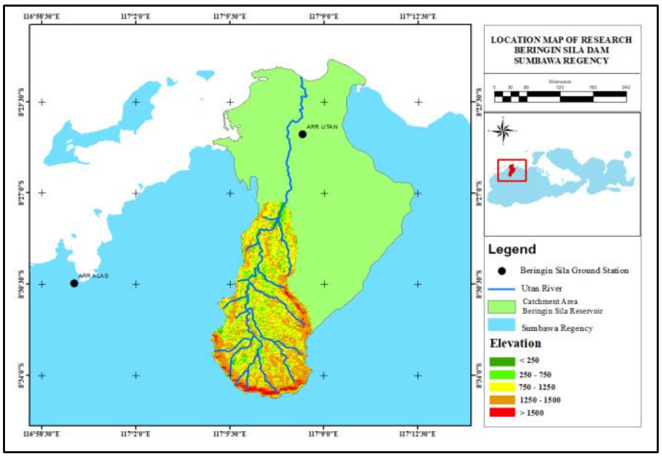

Figure 1. Catchment area of Beringin Sila Reservoir

Research Material

The data used in this research consists of observational data and climate model data. Rainfall data are obtained from two rain stations, namely the Automatic Rain Recorder (ARR) Alas and the Automatic Rain Recorder (ARR) Utan, which are located around the Beringin Sila watershed. The data used consists of monthly rainfall from 2001 to 2022. Rainfall of the area which will be used in research to convert rainfall into discharge(Putri et al., 2025) This data serves as the basis for evaluating and correcting bias in climate model outputs. The selection of a period of more than 20 years is intended to be representative for describing historical climate conditions and long enough for calibration and validation (World Meteorological Organization (WMO), 2021). An average rainfall (Zaini et al., 2023). Rainfall projection data is obtained from the downscaling results of CORDEX-SEA, using the driving model CNRM-CERFACS-CNRM-CM5 combined with the Regional Climate Model RCA4. CORDEX-SEA data has a spatial resolution of 0.22° × 0.22° (~25 km × 25 km), making it more suitable for watershed scale analysis compared to Global Circulation Models (GCM) with coarser resolution (Wilby, 2006).

CORDEX-SEA provides climate projections for several Representative Concentration Pathways (RCP) scenarios, namely RCP 2.6, RCP 4.5, and RCP 8.5. In this study, the RCP 4.5 scenario was chosen, which represents a moderate emission path with an equivalent radiation level of 4.5 W/m² by the year 2100. This scenario is considered the most realistic for medium-term projections as it assumes the presence of moderate mitigation efforts relevant to the current development conditions in Indonesia (Faqih, 2017). Observation data from 2001 to 2022 is used as a historical basis and calibration period, while the period from 2023 to 2050 is used as projection data. To obtain model data, everything can be accessed through the official ESGF WRCP CORDEX website http://esgfdata.dkrz.de/search/cordex-dkrz/.

Analysis

In estimating rainfall data as the output of a model, there is certainly bias or error present in the model data. Therefore, a bias correction model is needed to minimize the discrepancies between model data and observation data. One of the bias correction methods used is the linear scaling method. Linear scaling is a simple bias correction method that only corrects the model's mean value against the observation's mean value. After that, to obtain the corrected rainfall prediction for month m, the correlation (relationship) between the model's mean value and the observation's mean value for month m is first sought, thereby obtaining the correction factor. This correction factor is then multiplied by the model's rainfall prediction for month m to obtain the corrected rainfall value. In general, the formula used to calculate the corrected rainfall value is as follows (Faqih, 2017).

Linear Scaling (LS) method is the simplest bias correction method, this method only corrects the raw model average against the observational average (a statistical moment). To obtain the corrected precipitation predictions for month µ (*Pcor, m*), we first seek the relationship between the observational mean µ (P*obs*, *m*) and the model mean µ (*Praw, m*) for month m during the training period, thus obtaining a correction factor. This correction factor is then multiplied. with the prediction of raw model rainfall in month µ (P*raw, m*) during the testing period, here is the formula for bias correction using Linear Scaling. The following are the steps for calculating rainfall data calibration using bias correction with the linear scaling method (Kurnia et al., 2020). LS is considered quite effective in improving the seasonal and annual averages, although it does not detail the improvement of extreme distributions (Piani et al., 2010).

$$P_{cor,m} = P_{raw,m} \frac{\mu(P_{obs,m})}{\mu(P_{raw,m})} \quad (1)$$

Description:
Pcor,m = corrected Rainfall For Month m
Praw,m = raw model rainfall for month mm
µ(*Pobs,m*) = mean observed rainfall for month m
µ(*Praw,m*) = mean model rainfall for month m

Although LS has limitations, such as being less optimal in handling extreme quantile distributions, this method is considered relevant in the context of this research because the main objective is to improve the medium-term average rainfall that will be used as the basis for water resource management planning (Kurnia et al., 2020).

Evaluation CORDEX-SEA

The next stage after correcting the bias is the evaluation of the model's data performance against observational data from the historical period (2001–2022). This evaluation aims to assess the extent to which the Linear Scaling method can correct systematic bias and improve the model's output relevance to local climate conditions in the Beringin Sila watershed.In this study, three main evaluation metrics commonly recommended in hydrology studies (Moriasi et al., 2007) are used: Percent Bias (PBIAS), Pearson correlation coefficient (r), and Wilmot's index of agreement (d). These three indicators are chosen because of their complementary nature, thus providing a comprehensive view of the model's performance.

Percent Bias (PBIAS)

Is a statistical method used to evaluate the performance of a model or simulation results compared to observational data. PBIAS measures the average tendency of the simulation to be higher or lower than the observational data. The PBIAS value is expressed in percentage (%), making it easier to interpret whether the model tends to overestimate or underestimate.

$$PBIAS = 100 \times \frac{N\sum_{i=1}^{n}(Si-Oi)}{\sum_{i=1}^{n}Oi} \quad (2)$$

Description:
Oi = observation data at time i,
Si = simulation data (model),
n = number of data.

PBIAS value close to 0% indicates good performance; a positive value indicates the model tends to underestimate, while a negative value indicates the model tends to overestimate.

Table 1. Classification of Evaluation Result

PBIAS	Category
≤ ± 5	Very Good
± 5 ≤ ± 10	Good
± 10 ≤ ± 15	Satisfactory
≥ ± 15	Unsatisfactory

Correlation Coefficient (R)

The correlation coefficient (R) test is conducted to determine the strength of the linear relationship between two variables. The value of the correlation coefficient ranges from -1 < r < 1 (Soewarno, 1995). To determine the magnitude of the correlation coefficient (R), the following equation can be used:

$$\boldsymbol{R} = \frac{N\sum_{i=1}^{N}P_iQ_i - \sum_{i=1}^{N}P_i x \sum_{i=1}^{N}Q_i}{\sqrt{N\sum_{i=1}^{N}Pi^2-(\sum_{i=1}^{N})^2}\sqrt{\sum_{i=1}^{N}Q_i^2-(\sum_{i=1}^{N}Qi)^2}} \quad (3)$$

Description:
R = Correlation coefficient
Pi = Field observation value (m^3/dt)
Qi = Modeling result value(m^3/dt)

After obtaining the R value, the value will be classified based on the level of relationship, the following is a clasification table of criteria from the value of the correlation coefficient:

Table 2. Classification of R Value

Value Range	Level of Relationship Linkage
0.00 – 0.19	Very Low
0.20 – 0.39	Low
0.40 – 0.59	Medium
0.60 – 0.79	Strong
0.80 – 1.00	Very Strong

Willmott's Index of Agreement (d)

Willmott's Index of Agreement (d) is a statistical measure developed by Willmott 1981 to evaluate the level of agreement between simulated/model data and observational data. (Miao et al., 2015) using Willmott's Index to validate TRMM satellite precipitation data against station data. This index is designed as an alternative to the correlation coefficient and the coefficient of determination (R^2), as both measures are often considered less capable of showing the magnitude of errors between the model and observational data. According to (Willmott C. J., 1984), this index is considered to be more sensitive in describing the absolute deviation between simulation and observation data, thus making it more representative for the evaluation of hydrological, climatological, and geophysical models. Willmott's Index of Agreement Formula:

$$d = 1 - \frac{\sum_{i=1}^{n}(Pi-Oi)^2}{\sum_{i=1}^{n}(|Pi-\bar{O}|+|Oi-\bar{O}|)^2} \quad (4)$$

The value of d is in the range of 0–1, where a value close to 1 indicates a high agreement between the model and the observations. Where it is defined that Pi is the simulated model data, Oi is the variable from the actual observational data in the field. For O it represents the average of the observational data and n is the number of known data.

Rainfall Projection

After correcting the bias, the CORDEX-SEA data adjusted to local conditions is used to produce rainfall projections in the Beringin Sila watershed. Projections are made for the period 2023–2050 using the RCP 4.5

emission scenario, which represents a medium emission pathway with an equivalent radiation level of 4.5 W/m² by the year 2100. This scenario was chosen because it is considered the most realistic for current development conditions and relevant for medium-term planning in the water resources sector in Indonesia (Faqih, 2017). Projection analysis is conducted in several stages. First, the corrected monthly rainfall series is calculated for the projection period. Second, a comparison is made with the historical period (2001-2022) to identify potential changes in seasonal and annual patterns. Third, the projection results are analyzed on a seasonal climatological scale and on an annual scale to assess long-term trends. The projection results are not intended to evaluate the operational performance of the Beringin Sila Dam during the period before 2023, but rather as an initial basis for planning the water balance and operational patterns of the dam in the future. Thus, this projection is expected to provide initial information regarding the potential changes in water availability and climate risks in the Beringin Sila watershed, which is important to support adaptation strategies to climate change.

The RCP 4.5 scenario was chosen because it is considered the most relevant for mid-to-late 21st-century analysis, representing a medium emissions pathway targeting radiation stabilization of 4.5 W/m² by 2100 (Thomson et al., 2011). In Indonesia, the use of RCP 4.5 has been applied in various studies, such as in the classification of climate types in South Sumatra (Utara et al., 2018), rainfall projections around the Wonogiri Reservoir with bias correction based on neural networks (Hastina et al., 2025), estimation of decreasing rainfall and drought on Bintan Island through quantile mapping (Narulita et al., 2025), and changes in Oldeman climate types in North Aceh using the MIROC5 model Adopting this scenario in this research allows for more realistic and contextually relevant projections for the Beringin Sila watershed.

Result and Discussion

Simulation Result

Simulation Result (Historical 2001-2022)

Figure 2 shows a comparison of monthly rainfall between observational data and the CORDEX-SEA model output (RCP 4.5) during the historical period of 2001–2022. It is clear that the model tends to produce higher rainfall values compared to observations, with an average of 147.88 mm/month for the raw model data compared to 93.10 mm/month for the observational data. This significant difference indicates the presence of a systematic bias in the form of an overestimation of 58.9%. In addition, the seasonal pattern produced by CORDEX-SEA is relatively consistent with observations, although there are differences in the intensity of the rainy season peak. For example, in December-February (DJF), the raw CORDEX data shows much higher rainfall compared to observations, while during the transitional months (MAM and SON), the model still shows deviations, albeit with the same trend. This condition is in line with previous findings that outputs from regional climate models (RCMs) often still contain significant biases when used directly without correction (Teutschbein & Seibert, 2012).

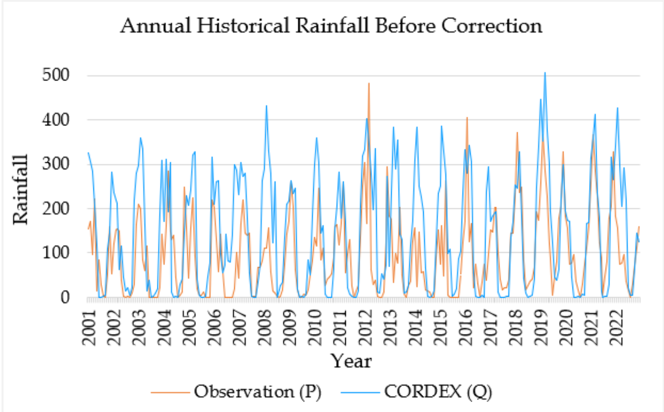

Figure 2. comparison of monthly rainfall between observation data and the output of the CORDEX-SEA model (RCP 4.5)

In Indonesia also reported a significant overestimation in the outputs of CORDEX-SEA before bias correction was carried out, especially in areas with high topographic complexity such as Nusa Tenggara (Faqih, 2017). Therefore, the bias correction stage becomes important to ensure that the projected data used is more representative of local climate conditions.

CORDEX Bias Correction Results Using the Linear Scaling Method

Figure 3 and Table 1 present the evaluation results after the application of the Linear Scaling (LS) bias correction method on the CORDEX-SEA output for the historical period 2001–2022. The results show a significant improvement. The PBIAS value, originally –35.3% (Unsatisfactory category), improved drastically to 3.07% (very good category). The Willmott agreement index (d) also increased from 0.03 to 0.748 (good category), indicating that the model's rainfall pattern is becoming more aligned with the observational data. Meanwhile, the Pearson correlation coefficient (R) slightly increased from 0.557 to 0.580, remaining in the moderate category, indicating that the LS method is more effective in correcting long-term averages than in enhancing temporal correlation. The average monthly rainfall corrected becomes 100.30 mm/month, which is closer to the observed average (93.10 mm/month) compared to the value before correction (147.88

mm/month). Thus, the deviation from the actual data decreases to just 7.73%, which is far more realistic compared to the initial bias of 58.9%.

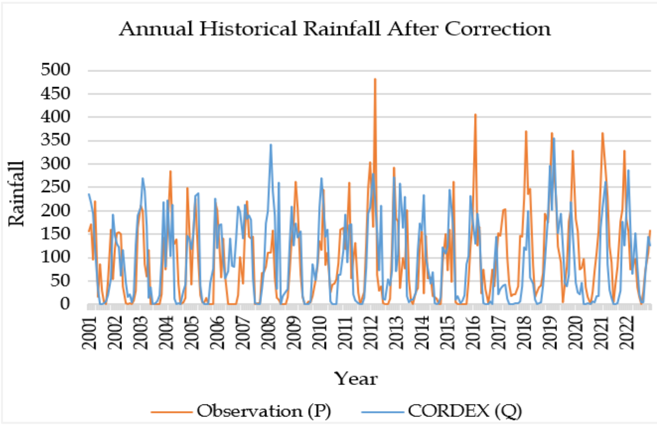

Figure 3. comparison of monthly rainfall evaluation after the implementation of the Linear Scaling (LS) bias correction method on CORDEX-SEA outputs for the historical period 2001–2022

This finding is consistent with the results of the study by Teutschbein et al. (2012), which emphasizes that the LS method is effective in reducing average bias in climate model data, although it is less optimal in handling extreme variability. In Indonesia, Faqih (2017) also reported the effectiveness of LS in adjusting CORDEX-SEA outputs to local rainfall patterns, particularly on a seasonal and annual scale.With this improvement, the bias-corrected CORDEX-SEA outputs are deemed suitable for use as input for rainfall projections in the Beringin Sila watershed.

Table 3. The Evaluation Results before the Application of the Linear Scaling Bias Correction Method

Method	RCP 4.5	
	Before Correction	Description
R	0,557	Medium
PBIAS	35.3%	Unsatisfactory
Willmot (d)	0.03%	Very Low

Table 3. The Evaluation Results After the Application of the Linear Scaling Bias Correction Method on CORDEX-SEA Outputs for the Historical Period 2001–2022

Method	RCP 4.5	
	After Corrected	Description
R	0,580	Medium
PBIAS	3.07%	Very Goog
Willmot (d)	0.03%	Good

With this improvement, the bias-corrected CORDEX-SEA output is deemed suitable for use as input for precipitation projection in the Beringin Sila watershed.

Projected Rainfall (2023–2050, RCP 4.5)

Figure 4 shows the projected monthly rainfall resulting from CORDEX-SEA (RCP 4.5) that has been bias-corrected for the period 2023–2050. In general, the average projected monthly rainfall is 98.49 mm/month, which is about 5.8% higher than the historical baseline of 2001–2022 at 93.10 mm/month. This indicates that in the future, the Beringin Sila watershed is likely to experience higher rainfall compared to historical conditions.

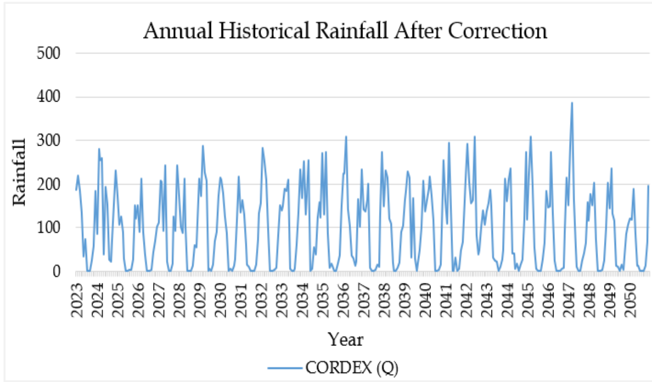

Figure 4. Results of monthly rainfall projection from CORDEX-SEA output (RCP 4.5) that has been bias-corrected for the period 2023–2050

In terms of annual fluctuations, there is a fairly high variation with a minimum value approaching 30 mm/month in dry years, and a maximum of more than 300 mm/month in wet years (for example around 2035, 2041, and 2048). This pattern reflects high interannual climate variability, which is generally associated with the highly influential ENSO and IOD phenomena in the Indonesian monsoon region (Tangang et al., 2020). If viewed from the seasonal distribution (not shown in the graph), the projection results show a tendency for increased rainfall intensity in the rainy season (DJF), while in the dry season (JJA) there is a decrease in rainfall. This is in line with the study results by (Hastina et al., 2025) at the Wonogiri Dam, where the CORDEX-SEA projections indicate an increase in average annual rainfall but with significant fluctuations from year to year. This situation emphasizes the importance of an adaptive approach in water resource management, as an increase in water availability does not automatically mean being free from drought risks during the dry season.

Analysis of Simulation Results

Bias the analysis of the simulation results shows that the outputs of CORDEX-SEA during the historical period (2001–2022) have a significant bias compared to observational data. Before correction, the average monthly raw precipitation of the model was 147.88

mm/month, significantly higher than the observation of 93.10 mm/month. This indicates an overestimation of Faqih et al. (2023) about 58.9%, consistent with the findings of that the CORDEX-SEA model often displays high variability in representing rainfall in the region of Indonesia. The application of the Linear Scaling (LS) bias correction method was able to significantly improve this deviation. The PBIAS value decreased from 35.5% to 3.07%, and Willmott's d increased from 0.03 to 0.748, indicating that the correspondence of patterns between simulations and observations is getting better. The average rainfall after correction became 100.30 mm/month, closer to the observed value with a relative difference of only 7.73%. In the projection period of 2023–2050, the average corrected monthly rainfall is 98.49 mm/month, slightly higher than the historical baseline (93.10 mm/month). This increase of about 5.8% is relatively small, but the considerable annual variation still needs to be noted. As seen in Figure 4, there are wet years with rainfall exceeding 300 mm/month and dry years with values below 50 mm/month. This fluctuating pattern is consistent with the characteristics of monsoon regions influenced by the ENSO and IOD phenomena (Tangang et al., 2020). This projection result is also consistent with other studies in Indonesia. Hastina et al. (2025) reported an increase in average annual rainfall in the Wonogiri Reservoir. Overall, this analysis shows that although the raw CORDEX-SEA output contains significant bias, the application of bias correction allows the data to be used more reliably for medium-term climate projections. The high variability in projection results highlights the need for adaptive strategies in water resource management in the Beringin Sila watershed.

Conclusion

This study demonstrated that raw CORDEX-SEA rainfall data for the Beringin Sila watershed contained substantial bias, with an average monthly rainfall of 147.88 mm compared to 93.10 mm observed, indicating a clear overestimation. After applying bias correction using the Linear Scaling method, model performance improved significantly, with an adjusted mean of 100.30 mm/month and improved evaluation metrics (PBIAS = 3.07%, Willmott's d = 0.748, R = 0.580). These results confirm that Linear Scaling is effective for correcting the mean rainfall, although its influence on temporal correlation remains limite. The corrected dataset was then used to project rainfall under the RCP 4.5 scenario for 2023–2050, yielding an average of 98.49 mm/month, or 5.8% higher than the historical baseline. While this suggests a modest increase in water availability, considerable interannual variability persists, with extremes below 50 mm in dry years and above 300 mm in wet years. Such variability highlights the importance of adaptive water resources management in the Beringin Sila watershed, particularly through strategies that optimize wet-season storage to buffer against potential shortages in the dry season.

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Author Contributions

The authors contributed equally to the planning and design of this study. They were jointly responsible for data collection, analysis, and interpretation, and took the lead in drafting the manuscript and discussing the results. All authors actively participated in critically revising the manuscript for important intellectual content and approved the final version for publication.

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Conflicts of Interest

The authors declare that there are no conflicts of interest.

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