Evaluation of the climate generator model CLIGEN for rainfall data simulation in Bautzen catchment area, Germany

Mustafa Al-Mukhtar, Volkmar Dunger and Broder Merkel

ABSTRACT

The objectives of this study were to: (i) evaluate the CLImate GENerator model (CLIGEN v.5.22564) to reproduce daily, monthly and yearly precipitation values across Bautzen catchment area, as well as storm patterns including maximum monthly 30 min intensity and average monthly storm duration at two stations, (ii) cross-validate CLIGEN’s spatial and temporal prediction ability. Daily rainfall data were collected from three stations (Kubschütz, Sohland and Spittwitz) for the period 1991–2010, in addition to breakpoint rainfall data from Kubschütz for the period 2004–2010 and Sohland for the period 2005–2010. The daily data from the three stations were interpolated to the entire catchment area. These interpolated observed data were used to validate the results from CLIGEN twice, once when the model was run with input parameters calculated from the interpolated data, and once when the model was run with input parameters calculated from each station independently. The model was cross-validated with respect to time at each station independently. For that purpose, the period 1991–2010 was subdivided into two intervals for each station; the first one was used to calibrate the model and the second one to validate it and vice versa. Results showed that CLIGEN can be sufficiently used to simulate rainfall and storm pattern parameters.

Key words | cross-validation, non-parametric tests, Spearman coefficient, stochastic model

INTRODUCTION

Long-term and consecutive daily weather data are necessary for hydrological, ecological, and crop-yield modeling (Pruski & Nearing 2002; Yu 2003; Kou et al. 2007). Meteorological data often encounter problems such as missing data, observation uncertainties and low observation frequency, which cannot satisfy the requirements for the tasks mentioned above. This problem, however, can be partly solved by stochastic weather generators (Pan et al. 2011). An additional benefit of such models is the possibility to generate daily climate series for un-gauged catchments through spatial interpolation of model parameters from adjacent gauged sites (Zhang & Garbrecht 2005). The capability of a weather generator to provide an indication of extreme values is essential for risk assessment studies (Hayhoe & Stewart 1996).

A commonly used weather generator is CLIGEN (CLImate GENerator Model) (Nicks et al. 1995). CLIGEN was developed based on climate data in the central and southern USA by the Agriculture Research Service (ARS) of the United States, Department of Agriculture (USDA) to generate the input parameters for the Water Erosion Prediction Project (WEPP) model (Flanagan & Nearing 1995) which can be used to simulate the runoff and soil erosion.

A short and comprehensive description of CLIGEN is given by the National Soil Erosion Research Laboratory website (Meyer 2001):

‘Cligen is a stochastic weather generator which produces daily estimates of precipitation, temperature, dew point, wind, and solar radiation for a single geographic point, using monthly parameters (means, SDs, skewness, etc.) derived from historical measurements. Unlike other climate generators, it produces individual storm parameter
estimates, including time to peak, peak intensity, and storm duration, which are required to run the WEPP and the WEPS soil erosion models. This website provides station parameter files to run CLIGEN for several thousand US sites, and software to build station files for international sites. With the exception of \( T_{\text{min}} \), \( T_{\text{max}} \), and \( T_{\text{dawn}} \) temperatures (changed in January 2004), daily estimates for each parameter are generated independently of the others. With the current random number generator, subsequent runs on the same machine made with identical inputs will produce identical results.'

Other stochastic generators such as USCLIMATE (Hanson et al. 1994), LARS-Weather Generator (Semenov & Barrow 2002) and Weather Generator (WGEN) (Richardson & Wright 1984) do not have these options, although they may have other advantages.

Zhang & Garbrecht (2005) evaluated CLIGEN v.5.107 using weather stations in Oklahoma, USA. They found that the mean and standard deviation of daily precipitation amounts were adequately simulated by CLIGEN. However, they also reported that storm durations were too long for small storms and too short for large storms. Chen et al. (2009) evaluated the reproducibility of CLIGEN v.5.22564 in generating precipitation depths at 12 stations in China. They found that CLIGEN reproduced the distribution of monthly and annual precipitation depths quite well, but did not simulate precipitation depth well. They reported that the first-order, two state Markov chain algorithm used by CLIGEN was adequate to generate precipitation occurrence for their study site. They further tested whether an exponential distribution for generating duration and a distribution free approach for inducing desired rank correlation between precipitation depth and the duration can improve storm pattern generation. Zhang et al. (2008) evaluated CLIGEN in six stations on the Loess Plateau and concluded that the first-order, two-stage Markov chain can sufficiently generate the monthly means and standard deviation of the number of wet days and the distribution of the number of wet and dry days. In Uganda, Africa, Elliot & Arnold (2001) validated CLIGEN with precipitation records from two sites. Their results showed that the model was successful in regenerating the annual and monthly precipitation totals, and in the probability of wet and dry days.

Soil erosion models such as WEPP (Nearing et al. 1989) have a greater sensitivity to daily precipitation data than to the variation in precipitation duration. Moreover, the analysis performed by Baffaut et al. (1996) showed that the mean precipitation per event, standard deviation of the precipitation, skewness of the precipitation, probability of a wet day following a wet day and probability of a wet day following a dry day have a significant influence on the estimated average annual soil loss.

The objectives of this study were to evaluate reproducibility of the CLIGEN model in generating daily, monthly, and yearly precipitation of the Bautzen Catchment area. Moreover, aims were to validate the model spatially and temporally, and to evaluate the storm pattern simulation, to be further used for assessing soil erosion and runoff simulation in the Bautzen catchment area.

In CLIGEN, three basic assumptions are used to simulate storm events; these are, only one storm event on a wet day (max. duration does not exceed 24 h), the storm event has a single peak pattern, and all storm patterns can be described by a double exponential function.

The method used to produce precipitation occurrence in CLIGEN is based on the first-order and two-state Markov chain. This method depends on the calculation of two conditional probabilities (Nicks et al. 1995): the probability of a wet day following a dry day, and the probability of a dry day following a wet day. Then, these probabilities are used in Equation (1) to calculate the probability of the rainfall occurrence \( P(W) \):

\[
P(W) = \frac{P(W/D)}{1 - P(W/W) + P(W/D)}
\]

If a random number, which is deduced from a uniform distribution for each day, is less than the precipitation probability for the given day status, precipitation occurs. For the generated wet days a skewed normal distribution is used to generate the daily precipitation amounts (Nicks & Lane 1989):

\[
x = \left[ \frac{g}{2} \left( \frac{R - u}{s} \right) + 1 \right]^{1/3} - 1 + \frac{g}{6}
\]
where $x$ = standard normal random variable; $R$ = daily precipitation amount; $u$, $s$, $g$ = mean, standard deviation and skew coefficient of daily precipitation amount.

Storm duration of the generated rainfall events is estimated by the Simulator for Water Resources in Rural Basins (SWRRB) (Arnold et al. 1993), based on an exponential relation between the storm duration and average monthly storm duration as shown in Equation (3):

$$D = \frac{-0.5\Delta}{\ln(1 - \alpha0.5)}$$  (3)

where $D$ is the event duration (h); $\alpha0.5$ is the ratio of the maximum 30 min rainfall depth to the total depth of the rainfall event and is drawn from a gamma distribution; $\Delta$ is the storm pattern parameter, which is taken in CLIGEN 5.22564 as 3.99. The peak storm intensity is estimated by the following equation proposed by Arnold & Williams (1989):

$$rp = -2P \ln(1 - \alpha0.5)$$  (4)

where $rp$ is peak storm intensity (mm/hr) and $P$ is daily precipitation amount (mm).

**MATERIALS AND METHODS**

Bautzen is a town in eastern Saxony, Germany, located on the river Spree, between 51°10'53” and 51°18'38" N and between 14°25’26” and 14°42’38” E (Figure 1). The catchment area extends over 310 km² from the Czech Republic border in the south to Bautzen reservoir dam in the north. Approximately 50% of the annual precipitation occurs in the form of rainstorms from May to September with a maximum precipitation in July and August. This leads to soil erosion with water deterioration. Three stations distributed across and nearby the Bautzen catchment area (Kubschütz, Sohland, and Spittwitz) with mean annual precipitation of 730, 832, and 712 mm, respectively, were used to test the ability of CLIGEN to generate daily, monthly, yearly precipitation, maximum daily precipitation, extreme precipitation values per each month, average monthly wet days, average monthly standard deviation, and average monthly skewness coefficient (Table 1). The data collected from these stations were daily precipitation amounts. The source of these measured data is the Regional Climate Information System for Saxony, Saxony-Anhalt and Thuringen (ReKIS).

For these three stations, some data were missing. The missing daily data for Kübschutz were September, October and November of 1998, the missing daily data for Sohland were from 1991 to 1999, and the missing daily data for Spittwitz from 2007 to 2010, regression analysis was used to replace the missing values and thus to match the common period from 1991 to 2010 for the three stations.

The Theissen Polygon method was applied to estimate the average daily precipitation amounts along the catchment area from these three weather stations. These new interpolated observed data were used to derive CLIGEN input parameters (Table 2). The derived statistical input parameters were then used in CLIGEN to generate daily weather data for 20 years. Finally, the parameters from the interpolated...
The observed data were compared with the correspondence parameters of the results. In order to perform a spatial cross-validation for CLIGEN to prove its ability to be applied in ungaged areas, the daily rainfall data for each station were independently used to calculate the input parameters in CLIGEN. Then, the model was run to simulate rainfall parameters for each station, and the results for each station were compared with the interpolated observed parameters.

A temporal validation for CLIGEN was performed at each station, in particular to test its ability to predict future rainfall scenarios. The daily data period of 1991–2010 was subdivided into two intervals for each station and the first 10 years were used for calibrating the model, while the second was used for validating it and vice versa. The calibrated input parameters included the probability of a wet day following a wet day, the probability of a wet day following a dry day, the average monthly standard deviation, and the mean precipitation per wet day.

In order to estimate the required input parameters for simulating the storm patterns in CLIGEN, daily breakpoint rainfall data with 5 minute intervals were obtained for two stations (Kubschütz and Sohland) from the German Weather Service (Table 1).

Because the precipitation data are not normally distributed, non-parametric tests Mann–Whitney and Kolmogorov–Smirnov (K–S test) (Conover 1999) were conducted to test means and the identity of the observed and simulated precipitation data, respectively. The non-parametric Levene’s test was used to test the equality of variance (Levene 1960). All tests were conducted as two tailed tests according to the assumption that both observed and simulated data came from the same population using a significance level of 0.01. Moreover, Spearman rank correlation coefficient was performed to assess how good the relationship between the observed and simulated parameters was. Comparison diagrams between observed and simulated data were employed as well as to the statistical tests to provide a visual comparison to understand tendency of data. The parameters of daily, monthly, yearly precipitation, maximum daily precipitation, extreme precipitation values per each month, average monthly wet days, average monthly standard deviation, and average monthly skewness coefficient were considered for the evaluation of CLIGEN.

In terms of temporal validation, the parameters, mean precipitation, probability of wet day following wet day, probability of wet day following dry day, monthly standard

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**Table 1** General information of the three stations in Bautzen

<table>
<thead>
<tr>
<th>Station name</th>
<th>Lat.</th>
<th>Long.</th>
<th>Elevation (m)</th>
<th>Precipitation (mm/yr)</th>
<th>Period of daily data</th>
<th>Period of breakpoint rainfall data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sohland</td>
<td>51° 06’</td>
<td>14° 43’</td>
<td>290</td>
<td>832</td>
<td>1999–2010</td>
<td>2005–2010</td>
</tr>
<tr>
<td>Spittwitz</td>
<td>51° 10’</td>
<td>14° 17’</td>
<td>225</td>
<td>712</td>
<td>1991–2007</td>
<td>–</td>
</tr>
</tbody>
</table>

**Table 2** The input parameters for CLIGEN (in mm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>July</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Prc.</td>
<td>2.00</td>
<td>2.00</td>
<td>2.50</td>
<td>1.50</td>
<td>2.75</td>
<td>3.00</td>
<td>3.25</td>
<td>3.50</td>
<td>2.50</td>
<td>2.00</td>
<td>2.50</td>
<td>2.50</td>
</tr>
<tr>
<td>St.D Prc.</td>
<td>3.25</td>
<td>2.75</td>
<td>3.50</td>
<td>2.75</td>
<td>4.50</td>
<td>4.50</td>
<td>6.00</td>
<td>6.50</td>
<td>4.25</td>
<td>3.25</td>
<td>3.50</td>
<td>3.50</td>
</tr>
<tr>
<td>Skewness Prc.</td>
<td>3.08</td>
<td>2.29</td>
<td>2.69</td>
<td>4.09</td>
<td>4.20</td>
<td>3.66</td>
<td>4.04</td>
<td>4.6</td>
<td>3.73</td>
<td>3.51</td>
<td>2.37</td>
<td>2.55</td>
</tr>
<tr>
<td>P(W/W)</td>
<td>0.91</td>
<td>0.91</td>
<td>0.90</td>
<td>0.87</td>
<td>0.84</td>
<td>0.85</td>
<td>0.87</td>
<td>0.84</td>
<td>0.85</td>
<td>0.86</td>
<td>0.87</td>
<td>0.88</td>
</tr>
<tr>
<td>P(W/D)</td>
<td>0.65</td>
<td>0.66</td>
<td>0.65</td>
<td>0.62</td>
<td>0.59</td>
<td>0.60</td>
<td>0.62</td>
<td>0.59</td>
<td>0.60</td>
<td>0.61</td>
<td>0.62</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Mean Prc. is the mean of a wet day precipitation calculated for each month from (1991–2010) observed precipitation data. Wet day defines as the day with >0 mm rain. St.D Prc. is the standard deviation of daily precipitation of the same period. Skewness Prc. is the skewness of daily precipitation of the same period. P(W/W) is the probability of a wet day following a wet day of the same period. P(W/D) is the probability of a wet day following a dry day of the same period.
deviation and monthly skewness were validated. Moreover, maximum monthly 30 min intensity and average monthly storm duration were also considered for the evaluation.

RESULTS

Validation of rainfall parameters from interpolated observed data

Daily precipitation amount

Mann–Whitney, Kolmogorov–Smirnov, and Levene’s tests were carried out for each month between the observed and simulated average daily values over the period of 1991–2010. The results showed that CLIGEN (v.5.22564) reproduced the average daily precipitation amounts in Bautzen very well, as all three aforementioned tests passed with a significance level greater than 0.01 (Table 3). For better visualization of the graphical comparison between observed and simulated average daily values, the comparison graph was divided into two periods, from 1991 to 2000 and from 2001 to 2010, and each period was further divided into three time scales (Figure 2(a) and (b)). The comparison shown in Figure 2(a) and (b) reflects a good agreement between the observed and simulated values along all the time scales. The Spearman rank correlation coefficients result between the observed and simulated average daily values was 0.11, showing that both data sets were significantly correlated at a p value of 0.03 and thus <0.05.

Table 3 P values of non-parametric tests, Mann–Whitney, Kolmogorov–Smirnov, and Levene’s, for the observed and simulated daily precipitation over the period 1991–2010

<table>
<thead>
<tr>
<th></th>
<th>Mann–Whitney test</th>
<th>K-S test</th>
<th>Levene’s test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.52</td>
<td>0.61</td>
<td>0.77</td>
</tr>
<tr>
<td>Feb</td>
<td>0.88</td>
<td>0.78</td>
<td>0.71</td>
</tr>
<tr>
<td>Mar</td>
<td>0.43</td>
<td>0.82</td>
<td>0.91</td>
</tr>
<tr>
<td>Apr</td>
<td>0.88</td>
<td>0.95</td>
<td>0.79</td>
</tr>
<tr>
<td>May</td>
<td>0.40</td>
<td>0.41</td>
<td>0.13</td>
</tr>
<tr>
<td>Jun</td>
<td>0.98</td>
<td>0.95</td>
<td>0.98</td>
</tr>
<tr>
<td>Jul</td>
<td>0.72</td>
<td>0.96</td>
<td>0.42</td>
</tr>
<tr>
<td>Aug</td>
<td>0.56</td>
<td>0.96</td>
<td>0.76</td>
</tr>
<tr>
<td>Sep</td>
<td>0.98</td>
<td>0.80</td>
<td>0.19</td>
</tr>
<tr>
<td>Oct</td>
<td>0.73</td>
<td>0.96</td>
<td>0.34</td>
</tr>
<tr>
<td>Nov</td>
<td>0.28</td>
<td>0.39</td>
<td>0.24</td>
</tr>
<tr>
<td>Dec</td>
<td>0.23</td>
<td>0.25</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Monthly precipitation amount

Monthly precipitation amounts were well simulated. The results of the non-parametric tests are shown in Table 4. These results showed a good matching between observed and simulated data. The higher value of the K-S test result showed that the distribution of the observed and simulated monthly precipitation amounts was not different at a significance level 0.01. Furthermore, the scatter diagram in Figure 3 shows that the observed and simulated monthly precipitation is close to the 45° match line. The relative error ranged from −9.17% in May to 13.20% in December with a Mean Absolute Relative Error (MARE) of 2.41%. Moreover, Spearman rank correlation coefficient was 0.90 at a p value of <0.05.

Yearly precipitation amount

Yearly total precipitation was rather well preserved by CLIGEN, with a MARE of 6.18%, although not as perfect as monthly total precipitation. P values of Mann–Whitney, K-S, and Levene’s tests were 0.53, 0.53, and 0.21, respectively (Table 4), showing that all the tests passed with a significance level greater than 0.01. The scatter diagram of the observed and simulated yearly total precipitation is shown in Figure 4. It can be seen that 10 years out of 20 were over-estimated by CLIGEN, while the remaining were under-estimated.

Maximum daily precipitation

For better visualizing the graphical comparison of observed with simulated maximum daily values, the graph was divided into two periods, from 1991 to 2000 and from 2001 to 2010, and each period was further divided into three time scales (Figure 5(a) and (b)). Maximum daily precipitation was well simulated by CLIGEN with MAREs of 16.95%. Statistical tests showed a good match between the observed and simulated values (Table 5). The Mann–Whitney test ranged from 0.12 to 0.79 showing that there is no difference in mean
between the observed and simulated values. The $p$ values of the K–S test were as high as 1, and as low as 0.07, showing a good indication about the identity in the distribution pattern between the observed and simulated along all time scales. The variability was identical according to Levene’s test, which was from 0.17 to 0.98. Spearman rank correlation coefficient value was 0.17 at a $p$ value of 0.001 showing a correlation between both data sets.

Extreme precipitation values per each month

The extreme precipitation value is one of the most important parameters simulated by CLIGEN. CLIGEN simulated rather well the extreme precipitation values per each month over the 20 years. The $p$ values of the Mann–Whitney, K–S, and Levene’s tests were 0.56, 0.61, and 0.51, respectively (Table 4). It can be seen that the mean values and the
variability match well between the observed and simulated. Furthermore, the K–S test showed that the distribution of the observed and simulated extreme values was not different at \( p = 0.01 \). Figure 6 shows the distribution of the extreme values of the observed and simulated data along with line 1:1. Spearman rank correlation coefficient for the extreme monthly values was 0.75 with a \( p \) value of 0.005.

**Average monthly wet days**

The observed and simulated number of wet days for each month are plotted in Figure 7. It can be seen that the precipitation occurrence is well simulated over the months as all the points match over line 1:1. Moreover, Mann–Whitney, K–S, and Levene's tests for the average monthly wet days over 20 years were 0.26, 0.52, and 0.91, respectively (Table 4). The means of average monthly wet days matched well, but not as good as the monthly precipitation amounts. The comparison of variability showed good agreement which is better than that for monthly total precipitation. The K–S test showed good agreement of the distribution of the average monthly wet days from the observed and simulated values. Moreover, Spearman rank correlation coefficient was 0.81 with a \( p \) value of 0.001, which is smaller than 0.01, indicating good correlation between both data sets.

**Average monthly standard deviation of daily precipitation**

\( P \) values of Mann–Whitney, K–S, and Levene’s tests of the average monthly standard deviation of daily precipitation were 0.52, 0.85, and 0.69, respectively (Table 4), showing that the standard deviation of daily precipitation over 20 years was adequately simulated. However, CLIGEN tends to under-predict the average monthly standard deviation of daily precipitation (Figure 8). The Spearman rank correlation coefficient between the observed and simulated variables was 0.95 with a \( p \) value of <0.01.

**Average monthly skewness coefficient of daily precipitation**

Figure 9 gives the results of the comparison of the average monthly skewness coefficients. It can be seen that CLIGEN tends to over-predict the average monthly skewness coefficient; this may be attributed to the fact that CLIGEN uses the skewed normal distribution to simulate the daily rainfall. The \( p \) values of Mann–Whitney, K–S, and Levene’s tests were 0.91, 1.00, and 0.79, respectively (Table 4), showing that the

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Non parametric tests for the comparison of the observed and simulated values over 20 years (1991–2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mann–Whitney test</td>
</tr>
<tr>
<td>Monthly prec. amount</td>
<td>0.73</td>
</tr>
<tr>
<td>Yearly prec. amount</td>
<td>0.53</td>
</tr>
<tr>
<td>Extreme precipitation values</td>
<td>0.56</td>
</tr>
<tr>
<td>Average monthly wet days of 20 year</td>
<td>0.26</td>
</tr>
<tr>
<td>Average monthly Std of 20 year</td>
<td>0.52</td>
</tr>
<tr>
<td>Average monthly skewness of 20 year</td>
<td>0.91</td>
</tr>
</tbody>
</table>

![Figure 3](https://iwaponline.com/hr/article-pdf/45/4-5/615/372633/615.pdf)
skewness coefficient matches perfectly and better than the average monthly standard deviation. The Spearman rank correlation coefficient between the observed and simulated variables was 0.82 with a *p* value of 0.001.

Validation of rainfall parameters from independent observed data

Spatial validation

The *p* values of the non-parametric tests between the interpolated observed values and simulated values from each
The p values of non-parametric tests of yearly precipitation at each station are shown in Table 7. As is shown in the table, CLIGEN simulated well the monthly total precipitation at the three stations. Figure 10 shows the scatter diagram of the observed and simulated values at each station along the line 1:1.

The p values of non-parametric tests of yearly precipitation at each station are shown in Table 7. As is shown in the table, CLIGEN simulated well the monthly total precipitation at the three stations. Figure 10 shows the scatter diagram of the observed and simulated values at each station along the line 1:1.

The p values of non-parametric tests of yearly precipitation at each station are shown in Table 7. As is shown in the table, CLIGEN simulated well the monthly total precipitation at the three stations. Figure 10 shows the scatter diagram of the observed and simulated values at each station along the line 1:1.
**Figure 8** | Comparison of average monthly standard deviation over the period 1991–2010 from the observed and CLIGEN-simulated daily precipitation.

**Figure 9** | Comparison of average monthly skewness over the period 1991–2010 from the observed and CLIGEN-simulated daily precipitation.

**Table 6** | p values of non-parametric tests, Mann–Whitney, Kolmogorov–Smirnov, and Levene’s of average daily rainfall at each station for each month over the period 1991–2010

<table>
<thead>
<tr>
<th>Location</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kubschütz</td>
<td>0.07</td>
<td>0.15</td>
<td>0.07</td>
<td>0.68</td>
<td>0.57</td>
<td>0.89</td>
<td>0.82</td>
<td>0.51</td>
<td>0.63</td>
<td>0.16</td>
<td>0.85</td>
<td>0.65</td>
</tr>
<tr>
<td>M-W</td>
<td>0.03</td>
<td>0.02</td>
<td>0.25</td>
<td>0.77</td>
<td>0.74</td>
<td>0.71</td>
<td>0.51</td>
<td>0.74</td>
<td>0.77</td>
<td>0.04</td>
<td>0.08</td>
<td>0.02</td>
</tr>
<tr>
<td>K-S</td>
<td>0.14</td>
<td>0.12</td>
<td>0.14</td>
<td>0.38</td>
<td>0.95</td>
<td>0.97</td>
<td>0.41</td>
<td>0.41</td>
<td>0.58</td>
<td>0.25</td>
<td>0.38</td>
<td>0.61</td>
</tr>
<tr>
<td>Levene’s</td>
<td>0.38</td>
<td>0.21</td>
<td>0.56</td>
<td>0.13</td>
<td>0.65</td>
<td>0.96</td>
<td>0.02</td>
<td>0.78</td>
<td>0.32</td>
<td>0.51</td>
<td>0.01</td>
<td>0.09</td>
</tr>
</tbody>
</table>

| Sohland | 0.03 | 0.02 | 0.25 | 0.77 | 0.74 | 0.71 | 0.51 | 0.74 | 0.77 | 0.04 | 0.08 | 0.02 |
| M-W | 0.03 | 0.02 | 0.25 | 0.77 | 0.74 | 0.71 | 0.51 | 0.74 | 0.77 | 0.04 | 0.08 | 0.02 |
| K-S | 0.14 | 0.14 | 0.14 | 0.13 | 0.95 | 0.95 | 0.14 | 0.81 | 0.79 | 0.79 | 0.07 | 0.07 |
| Levene’s | 0.38 | 0.21 | 0.56 | 0.13 | 0.65 | 0.96 | 0.02 | 0.78 | 0.32 | 0.51 | 0.01 | 0.09 |

| Spittwitz | 0.79 | 0.77 | 0.52 | 0.51 | 0.83 | 0.71 | 0.51 | 0.74 | 0.77 | 0.04 | 0.08 | 0.02 |
| M-W | 0.79 | 0.77 | 0.52 | 0.51 | 0.83 | 0.71 | 0.51 | 0.74 | 0.77 | 0.04 | 0.08 | 0.02 |
| K-S | 0.95 | 0.78 | 0.81 | 0.79 | 0.95 | 0.95 | 0.14 | 0.81 | 0.79 | 0.79 | 0.07 | 0.07 |
| Levene’s | 0.82 | 0.23 | 0.86 | 0.88 | 0.4 | 0.63 | 0.03 | 0.21 | 0.34 | 0.51 | 0.12 | 0.85 |

<table>
<thead>
<tr>
<th></th>
<th>M-W</th>
<th>K-S</th>
<th>Levene’s</th>
<th>M-W</th>
<th>K-S</th>
<th>Levene’s</th>
<th>M-W</th>
<th>K-S</th>
<th>Levene’s</th>
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<td>0.14</td>
<td>0.38</td>
<td>0.03</td>
<td>0.07</td>
<td>0.05</td>
<td>0.79</td>
<td>0.95</td>
<td>0.82</td>
</tr>
<tr>
<td>Feb</td>
<td>0.15</td>
<td>0.12</td>
<td>0.21</td>
<td>0.02</td>
<td>0.22</td>
<td>0.86</td>
<td>0.77</td>
<td>0.78</td>
<td>0.23</td>
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<tr>
<td>Mar</td>
<td>0.07</td>
<td>0.14</td>
<td>0.56</td>
<td>0.26</td>
<td>0.81</td>
<td>0.88</td>
<td>0.18</td>
<td>0.41</td>
<td>0.16</td>
</tr>
<tr>
<td>Apr</td>
<td>0.68</td>
<td>0.38</td>
<td>0.13</td>
<td>0.52</td>
<td>0.79</td>
<td>0.71</td>
<td>0.51</td>
<td>0.79</td>
<td>0.76</td>
</tr>
<tr>
<td>May</td>
<td>0.57</td>
<td>0.95</td>
<td>0.65</td>
<td>0.83</td>
<td>0.95</td>
<td>0.4</td>
<td>0.39</td>
<td>0.25</td>
<td>0.26</td>
</tr>
<tr>
<td>Jun</td>
<td>0.89</td>
<td>0.97</td>
<td>0.96</td>
<td>0.71</td>
<td>0.95</td>
<td>0.63</td>
<td>0.91</td>
<td>0.95</td>
<td>0.21</td>
</tr>
<tr>
<td>Jul</td>
<td>0.82</td>
<td>0.41</td>
<td>0.02</td>
<td>0.51</td>
<td>0.14</td>
<td>0.03</td>
<td>0.45</td>
<td>0.81</td>
<td>0.31</td>
</tr>
<tr>
<td>Aug</td>
<td>0.51</td>
<td>0.41</td>
<td>0.78</td>
<td>0.74</td>
<td>0.81</td>
<td>0.21</td>
<td>0.25</td>
<td>0.61</td>
<td>0.34</td>
</tr>
<tr>
<td>Sep</td>
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<td>0.58</td>
<td>0.32</td>
<td>0.77</td>
<td>0.79</td>
<td>0.34</td>
<td>0.79</td>
<td>0.79</td>
<td>0.11</td>
</tr>
<tr>
<td>Oct</td>
<td>0.16</td>
<td>0.25</td>
<td>0.38</td>
<td>0.04</td>
<td>0.07</td>
<td>0.51</td>
<td>0.29</td>
<td>0.61</td>
<td>0.67</td>
</tr>
<tr>
<td>Nov</td>
<td>0.85</td>
<td>0.38</td>
<td>0.01</td>
<td>0.08</td>
<td>0.07</td>
<td>0.12</td>
<td>0.69</td>
<td>0.63</td>
<td>0.15</td>
</tr>
<tr>
<td>Dec</td>
<td>0.65</td>
<td>0.61</td>
<td>0.09</td>
<td>0.02</td>
<td>0.07</td>
<td>0.85</td>
<td>0.51</td>
<td>0.95</td>
<td>0.62</td>
</tr>
</tbody>
</table>
The observed and simulated values at each station with the line 1:1.

The maximum daily precipitation was well preserved by CLIGEN across all the stations for each month, as all the $p$ values of the non-parametric tests passed with a significance level >0.01 (Table 8). In other words, the Mann–Whitney, K–S, and Levene’s tests validated that both the interpolated observed values and simulated values at each station originated from the same population.

The extreme values for each month were satisfactorily simulated by CLIGEN across the three stations (Table 7). The Mann–Whitney, K–S, and Levene’s tests showed that the mean, the distribution and the variability of the simulated data were not different from those of the interpolated observed data at $p = 0.01$. Figure 12 shows the distribution of the interpolated observed and simulated values at each station along the line 1:1.

The average monthly wet days were not well reproduced; the Mann–Whitney and K–S tests showed that the mean and the distribution of the interpolated observed data were different from the simulated values at $p = 0.01$ for all the stations (Table 7). That could be attributed to the interpolation of the observed data which significantly changed the number of wet days in the catchment area. However, the $p$ values of Levene’s test were not significant for all stations at $p = 0.01$. Figure 13 shows the interpolated observed values and simulated values at each station with the line 1:1.

The average monthly standard deviation was well preserved by CLIGEN, as all the tests passed with $p$ values >0.01 (Table 7). Figure 14 shows the distribution of the interpolated observed and simulated values at each station for each month.

The results of the Mann–Whitney, K–S, and Levene’s tests for the average monthly skewness are shown in Table 7. The $p$ values were >0.01 at all stations, showing that CLIGEN preserved the monthly skewness well. Figure 15 shows the scatter diagram of the interpolated

---

**Table 7 | Non-parametric tests for the comparison of the interpolated observed and simulated values at three stations over 20 years (1991–2010)**

<table>
<thead>
<tr>
<th>Station</th>
<th>Kubschütz</th>
<th>Sohland</th>
<th>Spittwitz</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M-W</td>
<td>K-S</td>
<td>Levene’s</td>
</tr>
<tr>
<td>Monthly prc. amount</td>
<td>0.41</td>
<td>0.84</td>
<td>0.85</td>
</tr>
<tr>
<td>Yearly prc. amount</td>
<td>0.08</td>
<td>0.17</td>
<td>0.08</td>
</tr>
<tr>
<td>Extreme prc. values</td>
<td>0.41</td>
<td>0.58</td>
<td>0.24</td>
</tr>
<tr>
<td>Average monthly wet days</td>
<td>0.00</td>
<td>0.00</td>
<td>0.75</td>
</tr>
<tr>
<td>Average monthly st.dev.</td>
<td>0.17</td>
<td>0.51</td>
<td>0.13</td>
</tr>
<tr>
<td>Average monthly skewness</td>
<td>0.56</td>
<td>0.84</td>
<td>0.20</td>
</tr>
</tbody>
</table>
observed and simulated skewness coefficient values at each station along the line 1:1.

**Temporal validation**

The results of the Mann–Whitney and K–S tests showed no obvious difference in mean and distribution pattern between the independent observed values from 1991–2000 and 10 years' simulated values for each station for all rainfall parameters (Table 9). However, according to the non-parametric tests, this model failed to reproduce

---

**Table 8** | p values of non-parametric tests of the maximum daily precipitation at each station for each month over the period 1991–2010

<table>
<thead>
<tr>
<th>Station</th>
<th>M-W</th>
<th>K-S</th>
<th>Levene's</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kubschütz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan</td>
<td>0.06</td>
<td>0.07</td>
<td>0.24</td>
</tr>
<tr>
<td>Feb</td>
<td>0.38</td>
<td>0.78</td>
<td>0.81</td>
</tr>
<tr>
<td>Mar</td>
<td>0.14</td>
<td>0.61</td>
<td>0.95</td>
</tr>
<tr>
<td>Apr</td>
<td>0.01</td>
<td>0.07</td>
<td>0.76</td>
</tr>
<tr>
<td>May</td>
<td>0.05</td>
<td>0.07</td>
<td>0.67</td>
</tr>
<tr>
<td>Jun</td>
<td>0.75</td>
<td>0.79</td>
<td>0.61</td>
</tr>
<tr>
<td>Jul</td>
<td>0.43</td>
<td>0.4</td>
<td>0.45</td>
</tr>
<tr>
<td>Aug</td>
<td>0.03</td>
<td>0.01</td>
<td>0.17</td>
</tr>
<tr>
<td>Sep</td>
<td>0.15</td>
<td>0.23</td>
<td>0.9</td>
</tr>
<tr>
<td>Oct</td>
<td>0.04</td>
<td>0.14</td>
<td>0.16</td>
</tr>
<tr>
<td>Nov</td>
<td>0.24</td>
<td>0.38</td>
<td>0.31</td>
</tr>
<tr>
<td>Dec</td>
<td>0.03</td>
<td>0.07</td>
<td>0.55</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Sohland</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.28</td>
<td>0.61</td>
<td>0.44</td>
</tr>
<tr>
<td>Feb</td>
<td>0.22</td>
<td>0.36</td>
<td>0.21</td>
</tr>
<tr>
<td>Mar</td>
<td>0.87</td>
<td>0.95</td>
<td>0.63</td>
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<tr>
<td>Apr</td>
<td>0.88</td>
<td>0.95</td>
<td>0.96</td>
</tr>
<tr>
<td>May</td>
<td>0.74</td>
<td>0.81</td>
<td>0.71</td>
</tr>
<tr>
<td>Jun</td>
<td>0.08</td>
<td>0.23</td>
<td>0.53</td>
</tr>
<tr>
<td>Jul</td>
<td>0.83</td>
<td>0.81</td>
<td>0.25</td>
</tr>
<tr>
<td>Aug</td>
<td>0.02</td>
<td>0.07</td>
<td>0.81</td>
</tr>
<tr>
<td>Sep</td>
<td>0.46</td>
<td>0.58</td>
<td>0.23</td>
</tr>
<tr>
<td>Oct</td>
<td>0.68</td>
<td>0.76</td>
<td>0.31</td>
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<tr>
<td>Nov</td>
<td>0.19</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>Dec</td>
<td>0.79</td>
<td>0.79</td>
<td>1.00</td>
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</table>

<table>
<thead>
<tr>
<th>Spittwitz</th>
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<tbody>
<tr>
<td>Jan</td>
<td>0.36</td>
<td>0.41</td>
<td>0.22</td>
</tr>
<tr>
<td>Feb</td>
<td>0.18</td>
<td>0.22</td>
<td>0.36</td>
</tr>
<tr>
<td>Mar</td>
<td>0.21</td>
<td>0.41</td>
<td>0.84</td>
</tr>
<tr>
<td>Apr</td>
<td>0.06</td>
<td>0.11</td>
<td>0.65</td>
</tr>
<tr>
<td>May</td>
<td>0.11</td>
<td>0.41</td>
<td>0.91</td>
</tr>
<tr>
<td>Jun</td>
<td>0.27</td>
<td>0.79</td>
<td>0.94</td>
</tr>
<tr>
<td>Jul</td>
<td>0.21</td>
<td>0.25</td>
<td>0.59</td>
</tr>
<tr>
<td>Aug</td>
<td>0.05</td>
<td>0.04</td>
<td>0.31</td>
</tr>
<tr>
<td>Sep</td>
<td>0.32</td>
<td>0.58</td>
<td>0.76</td>
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<tr>
<td>Oct</td>
<td>0.05</td>
<td>0.14</td>
<td>0.59</td>
</tr>
<tr>
<td>Nov</td>
<td>0.19</td>
<td>0.07</td>
<td>0.66</td>
</tr>
<tr>
<td>Dec</td>
<td>0.04</td>
<td>0.07</td>
<td>0.61</td>
</tr>
</tbody>
</table>

**Figure 12** | Comparison of extreme precipitation values for each month over the period 1991–2010 from the interpolated observed and simulated values at each station.

**Figure 13** | Comparison of the average monthly wet days over the period 1991–2010 from the interpolated observed and simulated values at each station.

**Figure 14** | Comparison of the average monthly standard deviation over the period 1991–2010 from the interpolated observed and simulated values at each station.
the rainfall parameters in the second decade of 2001–2010, which is why it was calibrated. Table 10 shows the p values of the non-parametric tests for the period of 2001–2010 from the input parameters of 1991–2000 after calibration. As can be seen, the mean precipitation per wet day, $P_{(w/w)}$, standard deviation and skewness coefficient were passed with a significance level of $>0.01$, showing good performance of the calibrated model. The same analysis was carried out for two decades with input parameters of 2001–2010 and results are shown in Tables 11 and 12. It can be seen that the $p$ values are $>0.01$ and this validated that both the independent observed and simulated values have the same distribution.

**Storm pattern parameters**

**Peak intensity**

CLIGEN under-predicted the maximum 30 min intensity at Kubschütz station for each month over the period 2004–2010, as shown in Figure 16. The Mann–Whitney and K–S test results showed a significant difference in the mean and the distribution pattern between the observed and simulated values at $p = 0.01$ (Table 13). However, the $p$ values of Levene’s tests passed at a significance level of 0.01. At Sohlund station, the $p$ values of Mann–Whitney, K–S, and Levene’s tests for the maximum 30 min intensity were

<table>
<thead>
<tr>
<th>Table 9</th>
<th>$p$ values of non-parametric tests for the independent observed and simulated rainfall parameters during 1991–2000 using input parameters of 1991–2000</th>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Kubschütz</th>
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<th>Spittwitz</th>
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<tbody>
<tr>
<td>Mean</td>
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<tr>
<td>$P_{(w/w)}$</td>
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<td>0.84</td>
<td>0.91</td>
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<tr>
<td>$P_{(w/d)}$</td>
<td>0.95</td>
<td>0.84</td>
<td>0.91</td>
</tr>
<tr>
<td>St.dev</td>
<td>0.05</td>
<td>0.1</td>
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<tr>
<td>Skewness</td>
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<table>
<thead>
<tr>
<th>Table 10</th>
<th>$p$ values of non-parametric tests for the independent observed and simulated rainfall parameters during 2001–2010 using input parameters of 1991–2000</th>
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</thead>
<tbody>
<tr>
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<td>0.38</td>
</tr>
<tr>
<td>$P_{(w/w)}$</td>
<td>0.18</td>
<td>0.51</td>
<td>0.95</td>
</tr>
<tr>
<td>$P_{(w/d)}$</td>
<td>0.18</td>
<td>0.51</td>
<td>0.91</td>
</tr>
<tr>
<td>St.dev</td>
<td>0.56</td>
<td>0.84</td>
<td>0.03</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.95</td>
<td>0.99</td>
<td>0.52</td>
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</table>

<table>
<thead>
<tr>
<th>Table 11</th>
<th>$p$ values of non-parametric tests for the independent observed and simulated rainfall parameters during 2001–2010 using input parameters of 2001–2010</th>
</tr>
</thead>
</table>

<table>
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<th>Spittwitz</th>
</tr>
</thead>
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<tr>
<td>Mean</td>
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<td>0.99</td>
<td>0.60</td>
</tr>
<tr>
<td>$P_{(w/w)}$</td>
<td>0.97</td>
<td>0.99</td>
<td>0.07</td>
</tr>
<tr>
<td>$P_{(w/d)}$</td>
<td>0.98</td>
<td>0.99</td>
<td>0.07</td>
</tr>
<tr>
<td>St.dev</td>
<td>0.28</td>
<td>0.51</td>
<td>0.11</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.72</td>
<td>0.84</td>
<td>0.35</td>
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</table>

<table>
<thead>
<tr>
<th>Table 12</th>
<th>$p$ values of non-parametric tests for the independent observed and simulated rainfall parameters during 1991–2000 using input parameters of 2001–2010</th>
</tr>
</thead>
</table>

<table>
<thead>
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<th>Kubschütz</th>
<th>Sohland</th>
<th>Spittwitz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
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<td>0.30</td>
</tr>
<tr>
<td>$P_{(w/w)}$</td>
<td>0.10</td>
<td>0.24</td>
<td>0.81</td>
</tr>
<tr>
<td>$P_{(w/d)}$</td>
<td>0.10</td>
<td>0.24</td>
<td>0.71</td>
</tr>
<tr>
<td>St.dev</td>
<td>0.06</td>
<td>0.25</td>
<td>0.28</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.20</td>
<td>0.51</td>
<td>0.70</td>
</tr>
</tbody>
</table>

Figure 15 | Comparison of the average monthly skewness over the period 1991–2010 from the interpolated observed and simulated values at each station.
0.01 (Table 13), showing a good match between the observed and simulated values. Figure 16 shows the distribution of the observed and simulated maximum 30 min intensity at Sohland for each month over the period 2005–2010 with the 45° line. It can be seen that the simulated values at Sohland station distributed evenly along the 45° line.

Storm duration

CLIGEN under-predicted the average monthly storm duration over the period 2004–2010 at Kubschütz and over the period 2005–2010 at Sohland (Figure 17). The Mann–Whitney test showed that the mean of the simulated values was significantly different from the observed at Kubschütz station with \( p = 0.002 \) and thus \( p < 0.01 \) (Table 13), while the \( p \) values of the K-S and Levene’s tests passed with a significance level of \( >0.01 \). At Sohland the Mann–Whitney, K-S and Levene’s tests accepted the null hypothesis that the simulated values were identical to the observed (Table 13).

### DISCUSSION

CLIGEN reproduced mean, distribution patterns and standard deviation for the daily precipitation amount well from the interpolated observed data over a period of 20 years. The test results obtained from Mann–Whitney, K-S, and Levene’s tests for each month showed no significant difference between the observed and simulated daily values. The mean values results were similar to that of Fan et al. (2011), Elliot & Arnold (2001) and Johnson et al. (1996).

The evaluation of CLIGEN’s results showed that the mean and the standard deviation of the monthly precipitation amounts were comparable to the observed data. The mean was simulated better than the variance. Also, the distribution of the monthly precipitation was well simulated. In the study by Elliot & Arnold (2001), significant differences were noted in the comparison of the standard deviations for some of the months. That may be reasoned by the version of CLIGEN used. Elliot & Arnold (2001) used CLIGEN v-4.x whereas this study used CLIGEN v-5.22. The main difference between CLIGEN 4.x and CLIGEN v-5.x is that the 4.x version did not include the quality control (QC) method (Meyer et al. 2008).

The yearly precipitation amounts were well predicted although not as good as the monthly amounts. That might be reasoned by the way the data were summed up. However, CLIGEN over-predicted in 10 years out of 20 years as shown in the scatter diagram between the interpolated observed and simulated values (Figure 4).

The maximum daily precipitation for each month was well approximated by CLIGEN. The test results showed that the mean, standard deviation and distribution of the maximum values were nicely simulated, although not as perfect as mean daily values. Similar results were reported by Chen et al. (2009).

The results demonstrated that CLIGEN performs well in simulating extreme precipitation values per each month

![Figure 16](attachment:image.png) Comparison between the observed and simulated values of maximum monthly 30 min intensity over the period 2004–2010 for Kubschütz and 2005–2010 for Sohland.

### Table 13

<table>
<thead>
<tr>
<th>Station</th>
<th>Duration</th>
<th>K-S test</th>
<th>Levene’s test</th>
<th>Max. I 30 min</th>
<th>K-S test</th>
<th>Levene’s test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mann-Whitney</td>
<td></td>
<td></td>
<td>Mann-Whitney</td>
<td></td>
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</tr>
<tr>
<td>Kubschütz</td>
<td>0.002</td>
<td>0.034</td>
<td>1.000</td>
<td>0.000</td>
<td>0.000</td>
<td>1.000</td>
</tr>
<tr>
<td>Sohland</td>
<td>0.028</td>
<td>0.100</td>
<td>0.840</td>
<td>0.031</td>
<td>0.06</td>
<td>0.034</td>
</tr>
</tbody>
</table>
over 20 years. The extreme values are important to predict climatic hazards.

CLIGEN simulated the distribution, mean and standard deviation of average monthly wet days very well from the interpolated data. The results showed that measured and simulated data for each month were not significantly different at \( p = 0.01 \). The Spearman correlation coefficient was 0.95 with a \( p \) value of 0.0 < 0.01, indicating a strong correlation between both data sets. Moreover, the variance of the average monthly wet days was simulated better than the mean, suggesting that the first-order and two-stage Markov chains can be used to efficiently simulate the sequence of wet days in Bautzen.

For some of the months, the average monthly standard deviation was under-estimated by CLIGEN; this may be due to the greater variability in the prediction of wet days. However, the Mann–Whitney, K–S and Levene’s tests showed that measured and simulated values were not different at \( p = 0.01 \).

The average monthly skewness coefficient was well preserved by CLIGEN. The test results showed that the simulated mean, the variance and the distribution of the skewness coefficient are not different from the interpolated observed values, indicating that CLIGEN preserve the extent of the daily rainfall distribution.

With regard to the spatial validation, CLIGEN results from each individual station were preserved and comparable to the interpolated observed data. This implies a good performance of CLIGEN to be used in un-gauged areas. In terms of the temporal validation, the model showed an inability to predict future scenarios unless the input parameters of base period are calibrated.

In terms of storm patterns simulation, CLIGEN underpredicted the maximum monthly 30 min intensity at Kubschütz station over the period 2004–2010, the Mann–Whitney and K–S tests showed a significant difference between the mean and the distribution pattern of the observed and simulated values, the difference was also in the mean of the average monthly storm duration at Kubschütz, which may be attributed to some missing values in Kubschütz which were interpolated from Sohland and then influenced the results. However, the average monthly storm duration and maximum 30 min intensity were well simulated at Sohland over the period 2005–2010 according to the Mann–Whitney, K–S, and Levene’s test. Yet the storm duration at both stations was under-predicted; similar results were obtained by Chen et al. (2009) across ten stations in Loess Plateau.

CONCLUSIONS

In terms of reproducibility of CLIGEN from the interpolated observed data, mean, standard deviation and distribution of the number of wet days per each month were well simulated based on the non-parametric test results. According to the Spearman correlation coefficient value, there is a good relation between the interpolated observed and simulated data, suggesting that the first-order and two-stage Markov chains used in CLIGEN can be used in the Bautzen catchment area to predict precipitation occurrence. The maximum daily precipitation values per each month and the extreme values were sufficiently simulated by the model, showing the capability of CLIGEN to be used in risk assessment studies.

The results of this study showed that the mean, the standard deviation and the distribution of the daily, monthly and yearly precipitation amounts were well preserved by CLIGEN when comparing the results from each station with the interpolated observed data.

CLIGEN can be used to simulate rainfall parameters in un-gauged areas, and can also be used to predict climate scenarios after calibrating the input parameters of the base period.

The results of the tests on maximum monthly 30 min intensity in addition to average monthly duration showed good performance of CLIGEN at Sohland station,
suggested that CLIGEN can sufficiently generate storms duration, and can reliably generate rainfall erosivity.

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REFERENCES


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