Development of a Hybrid Ensemble Rainfall Biascorrection Technique using Copulas and Enhanced Kohonen Self-Organizing Maps

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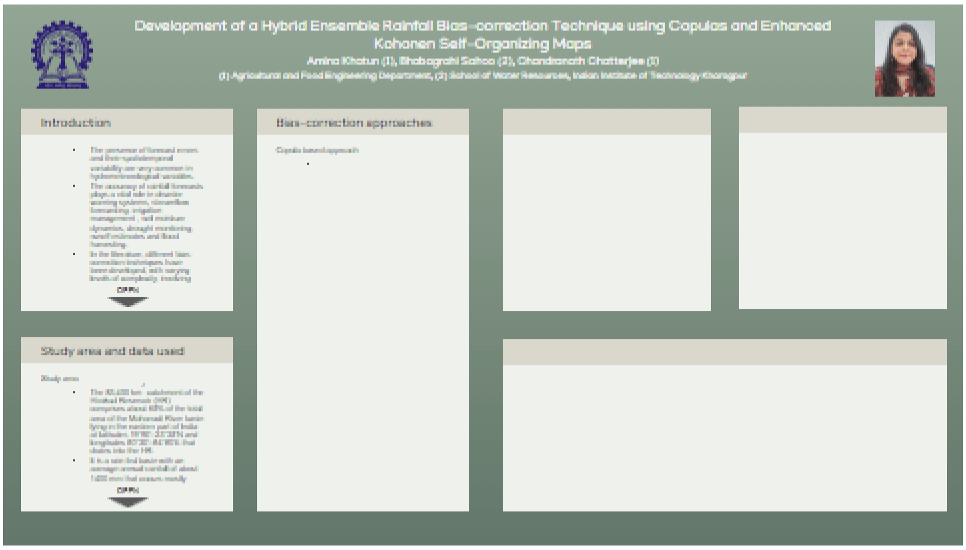

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PRESENTED AT:

INTRODUCTION

- The presence of forecast errors and their spatiotemporal variability are very common in hydrometeorological variables.
- The accuracy of rainfall forecasts plays a vital role in disaster warning systems, streamflow forecasting, irrigation management , soil moisture dynamics, drought monitoring, runoff estimates and flood harvesting.
- In the literature, different bias-correction techniques have been developed, with varying levels of complexity, involving correction of mean, correction of both mean and variance, and adjustment of quantile values.
- the Kohonen self-organizing map (KSOM) is an unsupervised neural network (NN)-based algorithm having wide applications in the field of data analysis.
- Unlike many NN-based algorithms, KSOM has proven to be explicitly advantageous in input–output mapping and handling missing data.
- Moreover, copula is a multivariate statistical tool used for modelling the non-linear dependence between random variables, which has been widely applied in hydrology to analyse floods, droughts, rainfall, soil moisture, streamflow in ungauged catchments and variability in groundwater levels.
- Many studies used copulas for downscaling of rainfall.
- A few studies also employed the bivariate distribution functions for bias correction of the regional climate model outputs.
- Maity et al. (2019) developed an improved technique for bias correction of zero-inflated daily rainfall data using the copulas.
- Since a major proportion of the data series, especially the tropical rainfall, constitutes of zero rainfall values, the newly developed copula-based bias-correction method can serve as a potential tool for correcting the daily rainfall forecast errors.

STUDY AREA AND DATA USED

Study area

- The 83,400 km^2 catchment of the Hirakud Reservoir (HR) comprises about 65% of the total area of the Mahanadi River basin lying in the eastern part of India at latitudes 19°90′–23°35′N and longitudes 80°30′–84°80′E that drains into the HR.
- It is a rain-fed basin with an average annual rainfall of about 1400 mm that occurs mostly during the southwest monsoon season (June–September).
- The basin has a tropical climate with a minimum temperature of 4–12°C (December–January) and a maximum of about 42–45°C (May–June).
- The major purpose of the HR is flood protection, with a live storage capacity of about 4823×10^6 m^3.
- Therefore, accurate rainfall forecasts with sufficient lead times are very important for forecasting inflow into the large reservoir for facilitating its operation.

Datasets

- Based on the period of data availability, the short-to-medium range forecasts of meteorological variables, such as rainfall and temperature from the IMD-MME forecast datasets over six years (2008–2013) is used in this study.
- The IMD-MME forecast datasets are developed using five ensemble members: i) National Centre for Medium Range Weather Forecasting (NCMRWF T-254) at $0.5^{\circ}\times0.5^{\circ}$, ii) European Centre For Medium Range Weather Forecasting (ECMWF T-799) at $0.25^{\circ}\times0.25^{\circ}$, iii) Japan Meteorological Agency (JMA T-959) at $0.25^{\circ}\times0.25^{\circ}$, iv) United Kingdom Meteorological Office (UKMO) at $1^{\circ}\times1^{\circ}$, and v) National Centre for Environmental Prediction Global Forecast System (NCEP GFS T-382) at $1^{\circ}\times1^{\circ}$ spatial resolution.

BIAS-CORRECTION APPROACHES

Copula-based approach

- As the Copula-based technique of bias-correction considers the probability mass accumulated at zero values, this method is used to correct the biases in rainfall forecasts from 1 to 5 days lead-time for the years 2008–2013.
- The training dataset is split into three parts.
- In the first dataset, the ten univariate marginal distributions (viz. Generalized Pareto, Generalized Extreme Value, Generalized
Normal, Generalized Logistic, Exponential, Gumbel, Normal,
Pearson Type III, Weibull and Wakeby) are fitted to both the observed and forecasted rainfalls using the L-moments method.
- The Gaussian, Gumbel, Frank
and Clayton copulas are fitted to the observed and forecasted rainfall data pairs.
- In the second dataset, an exponential decay curve is fitted.
- In the third dataset (pairs where forecasted rainfalls are zero valued), the frequencies of zero observed rainfall are computed.
- Then the mixed conditional distribution of the bias correctedrainfall forecasts is obtained focusing on the zero-inflated rainfall values.
- Subsequently, the pseudo-observations at the 50th quantile of the bias-corrected rainfall are computed to obtain the bias corrected rainfall
estimates.

eKSOM

- Kohonen Self-Organizing Maps (KSOM) are the unsupervised neural networks that use the clustering approach to train itself by first quantifying the training dataset into code or weight vectors and then mapping them into a two-dimensional grid of nodes.
- In this method, the input–output dataset forms a matrix with N rows of d-dimensional data vector, represented by a two dimensional grid of nodes (output layer).
- The nodes or neurons are d-dimensional code or weight vectors, termed as ‘map units’.
- The present study tests the application of eKSOM as a bias-correcting technique by varying the map units externally with a sequential increment of 10 units from the default value, M up to a value less than the total number of data points.

Cop-SOM

- The NWP models are characterized with high systematic biases.
- Ideally, a suitable bias-correction approach is expected to reduce the systematic error component in the total associated model prediction errors.
- Thus, to reduce the effects of both the random and systematic errors in the NWP model forecasts, this study proposes a hybrid Copula and eKSOM-based bias-correction approach, the ‘Cop-SOM’.
- In the hybrid Cop-SOM approach, the pre-processed outputs of the Copula-based bias-correction method for the years 2008–2013 are forced as inputs into the eKSOM.

RESULTS

- The relatively higher SE (median = 49.5–55.6%) present in the raw IMD-MME rainfall justifies the use of a bias-correction tool to improve the lead-time rainfall forecasts.
- The results reveal that the Copula-based rainfall forecasts could address the random error component at each lead-time, however, with a higher systematic error as compared to the IMD-MME forecasts.
- The PBias estimates for the raw IMD-MME rainfall forecasts ranges from -0.9% to 79.3% across all the grids at 1–5 days lead-times.
- The eKSOM performed very well as a bias-correction tool with PBias <15% across all the lead-times; whereas the Cop-SOM performed the best with PBias < 7% (mostly).
- The higher mKGE estimates by the eKSOM (median = 0.27–0.36) and Cop-SOM (median = 0.39–0.43) reveal improved forecast skills as compared to the raw IMD-MME (median = 0.04–0.20) and Copula (median = -0.09 to 0.02). The lower mKGE (<0.5) estimates reveal that a daily temporal resolution.

CONCLUSIONS

The raw IMD-MME rainfall forecasts with relatively high biases make them inappropriate for river-flow forecasting. While the Copula-based bias-correction approach focuses on reducing the random error component of the total rainfall forecast errors, the enhanced KSOM-based methods (eKSOM and Cop-SOM) show improvement in forecast skills of the raw IMD-MME rainfall. Out of the eKSOM and Cop-SOM approaches, the Cop-SOM performs the best with relatively lower |PBias| and higher modified KGE values.

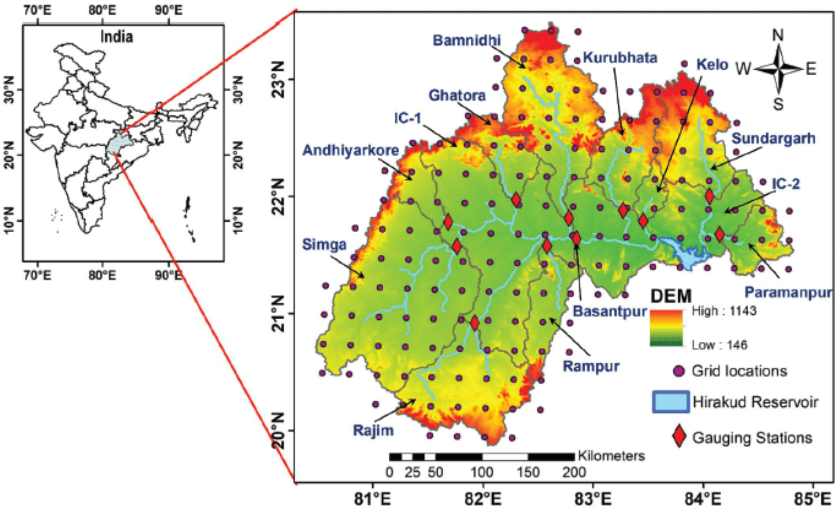


Figure 1. Location map of the study area showing the sub-catchments with respect to the streamflow gauging stations. DEM: digital elevation model.

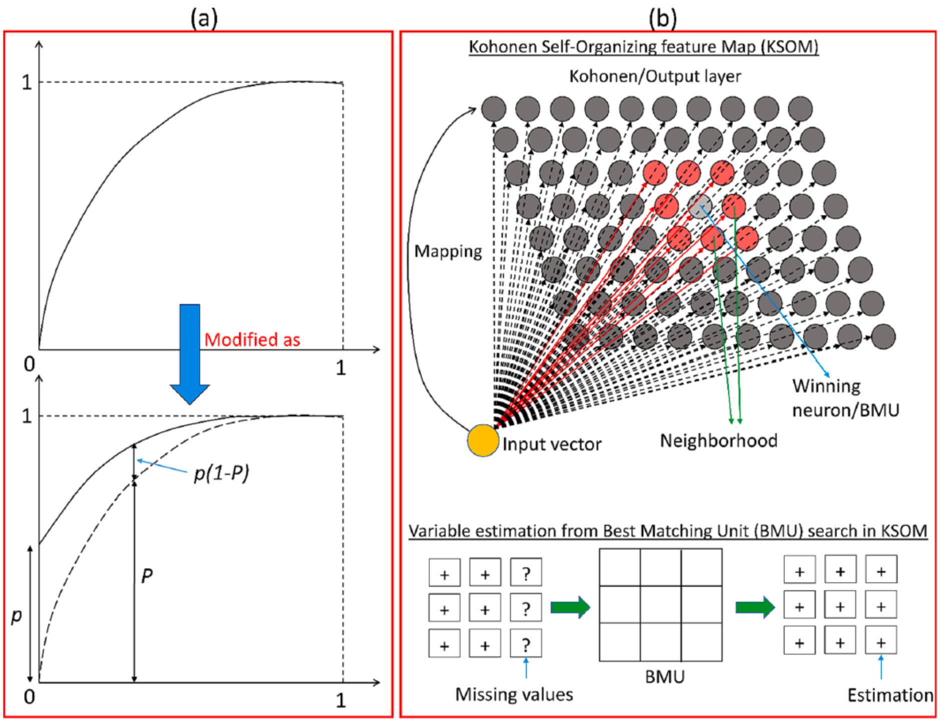
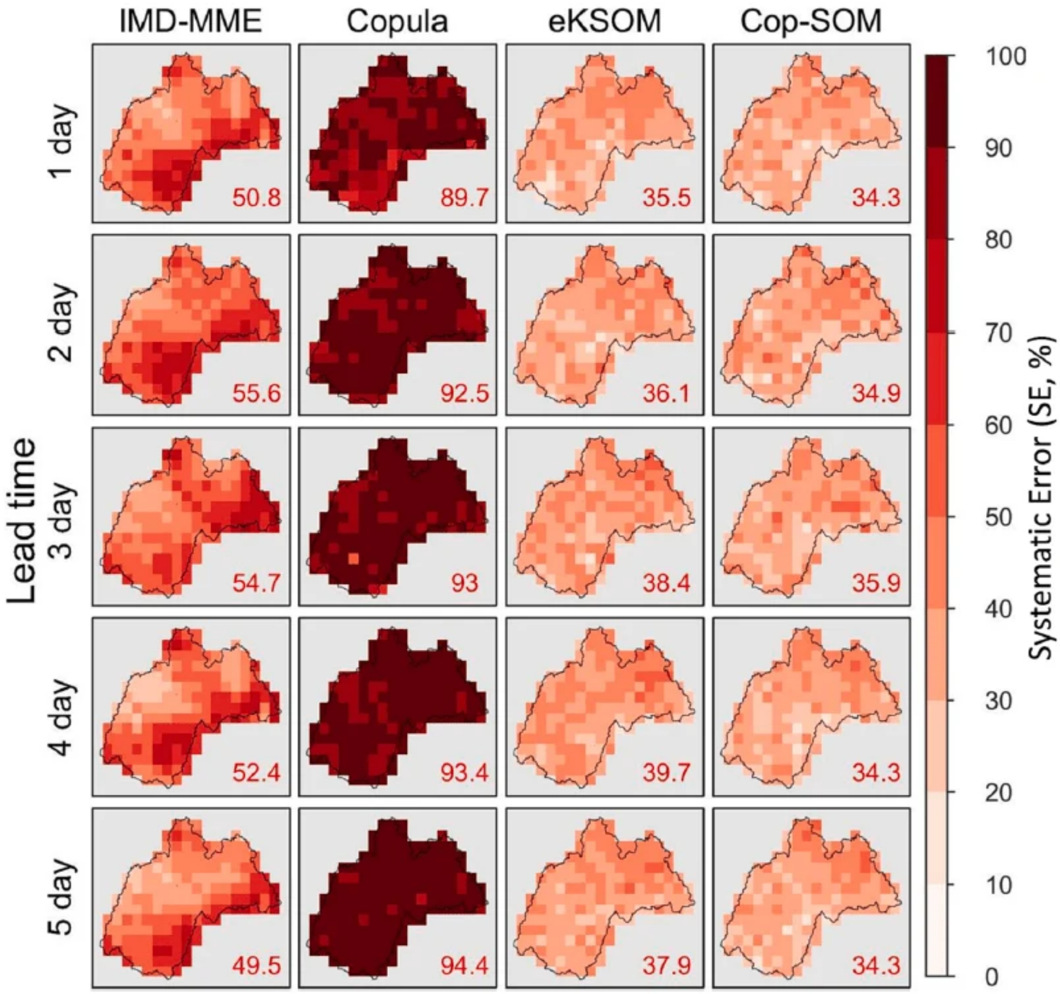
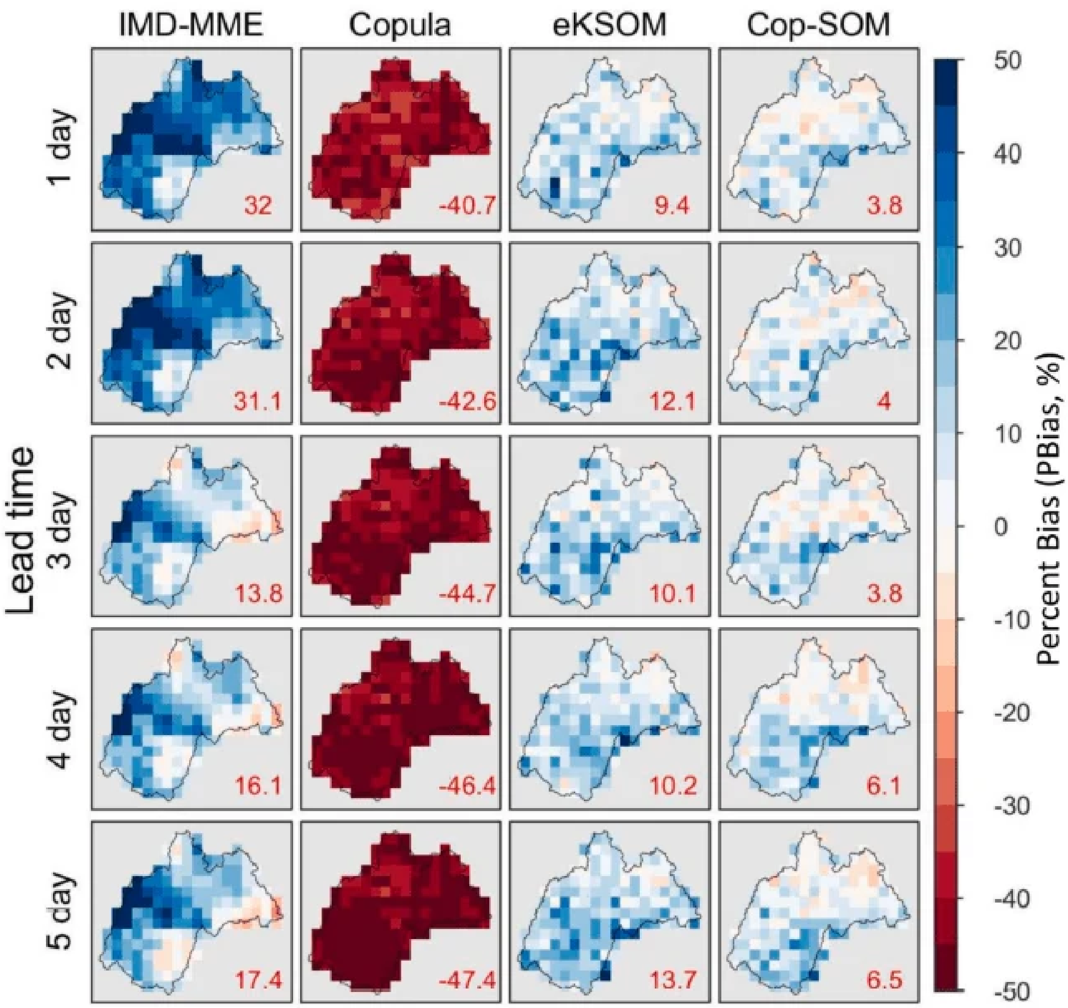
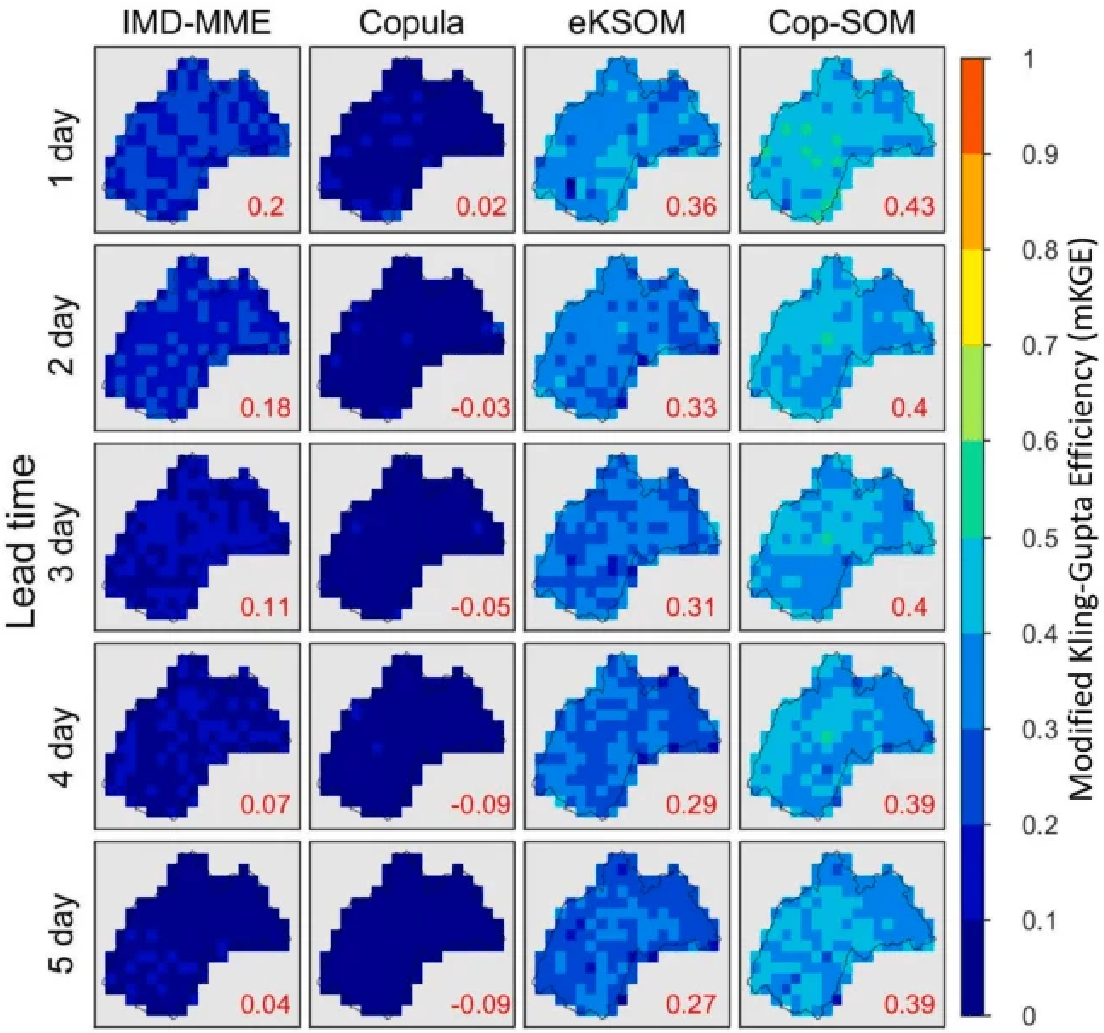


Fig. 3. Schematic representation of (a) the Copula-based bias-correction approach (revised from Maity et al., 2019), and (b) the Kohonen Self-Organizing Maps (KSOM; revised from Adeloye et al., 2011).


IMD-MME
Copula
eKSOM
Cop-SOM
Lead time
1 day
2 day
3 day
4 day
5 day
50.8
89.7
35.5
34.3
55.6
92.5
36.1
34.9
54.7
93
38.4
35.9
52.4
93.4
39.7
34.3
49.5
94.4
37.9
34.3
Systematic Error (SE, %)
100
90
80
70
60
50
40
30
20
10
0


IMD-MME
Copula
eKSOM
Cop-SOM
Lead time
1 day
2 day
3 day
4 day
5 day
32
-40.7
9.4
3.8
31.1
-42.6
12.1
4
13.8
-44.7
10.1
3.8
16.1
-46.4
10.2
6.1
17.4
-47.4
13.7
6.5
Percent Bias (PBias, %)
50
40
30
20
10
0
-10
-20
-30
-40
-50


IMD-MME
Copula
eKSOM
Cop-SOM
Lead time
1 day
2 day
3 day
4 day
5 day
0.2
0.02
0.36
0.43
0.18
-0.03
0.33
0.4
0.11
-0.05
0.31
0.4
0.07
-0.09
0.29
0.39
0.04
-0.09
0.27
0.39
Modified Kling-Gupta Efficiency (mKGE)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

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TRANSCRIPT

ABSTRACT

Hydrometeorological variables are equipped with forecast errors and spatiotemporal variability. The accuracy of rainfall forecasts play a critical role in streamflow forecasting. In this study, a hybrid bias-correction technique (Cop-SOM) is developed employing a recently suggested copula-based approach and enhanced Kohonen Self-Organizing Maps (eKSOM), for correcting the biases in daily ensemble rainfall forecasts. Since the tropical river basins receive rainfall with high spatiotemporal variability, the copula-based approach with special focus on zero-inflated rainfalls become an ideal candidate for the hybrid approach. Moreover, the eKSOM method with spatially varying optimum map units has already proved its efficacy as a suitable bias-correction tool. A bias-correction technique is ideally expected to reduce the systematic error component in the raw rainfalls. With this view, in the hybrid approach, the outputs of the copula-based method are forced as inputs to the eKSOM. The upper reaches of the Mahanadi River basin in eastern India is considered as the test case. The findings reveal that the Cop-SOM approach outperforms the standalone copula and eKSOM with the least (median) systematic error of 34.3% to 35.9% (1-5 days lead times) across all the grids in the study area. The median percentage bias in the gridded rainfall forecasts ranges from 3.8% to 6.5% at 1-5 days lead times. The overall findings reveal significant improvement in the accuracy of the raw rainfall forecasts with the hybrid Cop-SOM approach performing the best in comparison to the standalone copula and eKSOM approaches.