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RESEARCH ARTICLE

Reliability of rainfall and cloud cover forecasts over the hills of northeastern India

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Abstract

Weather forecasts are very crucial for day-to-day agricultural management in the recent era of enhanced climatic variability. The study verified the weather forecast (medium-range) for rainfall and total cloud cover (TCC) issued by the India Meteorological Department (IMD) over the northeastern hill (NEH) region of India. The daily forecast was compared to the observed weather parameters in four districts corresponding to four hill states (Meghalaya, Nagaland, Manipur and Mizoram). The analysis was done for qualitative as well as quantitative verification of rainfall forecast with various skill score calculations using five years of daily datasets to provide a robust and consistent result. The results clearly indicate that qualitative rainfall forecasts were very good over the NEH region during all the seasons. The skill scores indicated the maximum accuracy during winter followed by post-monsoon, pre-monsoon, and monsoon months. The quantitative rainfall forecast evaluation revealed that the accuracy was very good during winter and post-monsoon with acceptable accuracy during pre-monsoon, but it was poor during the monsoon season. The TCC forecasts had average accuracy (51–63%) throughout the year over all the places of the NEH region. Overall, the IMD weather forecast was found to be of useful accuracy from the qualitative point of view but improvement in quantitative accuracy especially during high rainfall seasons like monsoon and pre-monsoon months needs to be done for higher impact and thereby adoption by the farmers of the NEH region.

Keywords: Forecast verification, Skill scores, Climate variability, NEH-region.

Introduction

The climate is crucial for the determination of the vegetation and crop types of any region, while weather determines the growth, management, and productivity of the crop during a particular season. The climate is determined by the location and especially in plateaus, hills, and mountains, it varies frequently in short spatial distances due to elevation and aspect. The success or failure of agricultural production depends very much on the occurrence and severity of adverse weather conditions. Successful agricultural production is very much dependent on adverse weather (Rana *et al.,* 2005, 2021; Laitonjam *et al*., 2021; Chakraborty *et al.,* 2022). Although the modification of weather is almost impossible to favor agriculture, reorientation of agricultural management can be done to reduce adverse weather impacts (Rana *et al.,* 2013, 2021; Sarmah *et al.,* 2015). Nowadays, the planning of various agricultural resources is growing in order to develop appropriate coping strategies for a world having a scarcity of resources in the near future when climatic extremes are expected to become more frequent and widespread (Saha *et al.,* 2018). The northeastern zone of India is blessed with natural resources like biodiversity and water resources. The region receives significantly more rainfall than the rest of the country, and its distribution is also quite different (Saha *et al.,* 2015, 2018; Chakraborty *et al.,* 2017). As the landscape is hilly and crops are grown on sloppy soils (particularly the Shifting cultivation/ *Jhum* lands, which are predominantly on slopes greater than 25–30%), the water acquired from rainfall is rapidly drained from the effective root zone through surface runoff and sub-surface drainage.

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Hence, efficient planning of agricultural activities, beginning with land and soil preparation, transplanting/sowing, plant protection, intercultural operations, and concluding with harvest, is contingent on advanced information about the weather, particularly rainfall. Heightened climatic variability due to climate change in the recent era, especially over the mountains, makes crop production more risk-prone (Schneiderbauer *et al.*, 2021). With the help of a medium-range weather forecast, farmers may better plan and implement methods that augment the productivity/quality of their crop produce and reduce the loss of inputs, thereby boosting resource-use efficiency and income/profit. Such types of information are very crucial for the small and marginal farmers of the hilly regions who are predominantly resource-poor and risk-prone (Chakraborty *et al.,* 2022). Inherently, the northeastern hill (NEH) region had low inter-annual rainfall variability, however, in recent years this region has also faced increased climate variability (Chakraborty *et al.,*2017). These variations heighten the hazard and demand for precise quantitative forecasts of weather parameters to develop appropriate management options. Considering the requirements, the India Meteorological Department (IMD) developed the system to issue medium-range weather forecasts. The quantitative forecasts (5 days forecast every Tuesday and Friday) are provided at the district scale. These forecasts form the premise for the development of district-level agro-advisory bulletins (AAB). The quality and usefulness of these AABs depend on the accuracy of the weather forecasts, necessitating verification of the forecasts to measure their accuracy and the development of subsequent forecasts (Chattopadhyay *et al.,* 2016). Forecasts must be evaluated at local scales since the weather is highly unpredictable and the forecasting model accuracy is not consistent over a wide and diverse spatial extent (Mandal *et al.,*2007). Different studies related to the rainfall forecasts evaluation over different parts of India were conducted (Rana *et al.,* 2005,2013; Vashisth *et al.,* 2008; Sarmah *et al.,* 2015; Chattopadhyay *et al.,* 2016; Rajavel *et al.,* 2019), only a few studies analyzed the rainfall forecast in the NEH region (Saha *et al.,* 2021; Chakraborty *et al.,* 2022). Saha *et al.,* (2021) analyzed the rainfall forecast over a small part of NEH i.e. the Mizoram state while Chakraborty *et al.,* (2022) focused on the qualitative part of the rainfall forecast only over four states of the NEH region. Therefore, this study was conducted to quantify the reliability of rainfall and cloud cover forecasts over the Himalayan hills of NEH. We undertook a detailed analysis to assess the correctness and usability of the rainfall and total cloud cover forecast by qualitative as well as quantitative criteria over the NEH region. Hence, the study critically evaluates the medium-range rainfall forecasts and points out the crucial lacunae that should be improved for better applicability.

Materials and Methods

The northeastern hill region of India is a natural resource-rich part receiving much higher rainfall (about 2.5 times) than the national average (Chakraborty *et al.,* 2017, 2022). We used weather datasets of four different meteorological observatories from four hill states of NEH namely, Nagaland (District: Dimapur, Place: Jharnapani, Latitude: 25°45'N, Longitude: 93°50'E, Altitude: 250 m), Meghalaya (District: Ri-Bhoi, Place: Umiam, Latitude: 25°41'N, Longitude: 91°55'E, Altitude: 1010 m), Manipur (District: Imphal West, Place: Imphal, Latitude: 24°45'N, Longitude: 93°54'E, Altitude: 774 m) and Mizoram (District: Kolasib, Place: Kolasib, Latitude: 24°12'N, Longitude: 92°40'E, Altitude: 635 m) for the accuracy assessment. The location of the agrometeorological observatories is depicted in Figure 1. Though this region is bestowed with lots of rainfall, there is the existence of large inter-annual and intra-annual variability (Saha *et al.,* 2015, 2018). Therefore, we analyzed five years of daily datasets (2014–2018) for both, the forecast as well as observed, to get a complete result of the preciseness of the medium-range rainfall forecast. The weather forecast data (medium-range forecast for 5 days received every Tuesday and Friday) were received from the Regional Meteorological Centre (RMC), Guwahati of India Meteorological Department (IMD), New Delhi. The forecast (5 days) is generated using a multi-model ensemble (MME) technique. They consider five different numerical weather prediction (NWP) models for the process

Figure 1: The meteorological observatories (green-coloured) located in four different hilly states of northeastern India (created using Google Earth)

(Sarmah *et al.,*2015; Chattopadhyay *et al.,*2016). Following that, the region-specific value additions/improvements are done by the respective RMCs (Rajavel *et al.,* 2019). The standard seasonal system of IMD i.e. winter (Jan-Feb), pre-monsoon (Mar-May), monsoon (June-Sept), and post-monsoon (Oct-Dec) was used for the verification process. In this study, two weather parameters, rainfall and total cloud cover (TCC) were analyzed. The evaluation was done following the error structure described in Table 1 (Vashisth *et al.,* 2008; Kaur and Singh 2019).

The rainfall forecast was verified both based on qualitative as well as quantitative aspects whereas for TCC only quantitative analysis was carried out. Qualitative evaluation of rainfall is simply considering the rainfall events as forecasted and observed as explained in Table 1 (bottom portion). The sum of hits (H) and correct negatives (Z) provides the correct forecasts (H+Z) while the sum of misses (M) and false alarms (F) provides the incorrect forecasts (M+F). On the other hand, in the case of quantitative evaluation, the error structure in Table 1 is applied based on the daily rainfall amount to get the correct, usable, and not-usable forecast values. All these values are expressed in percentages for easier comparisons among the seasons.

Besides these, several indices/scores were also calculated for the verification of the rainfall forecast (Sarmah *et al.,* 2015; Chattopadhyay *et al.,* 2016). The formulae for the indices/scores are following:

Ratio score (RS) forecast accuracy (ACC) or hit score is the ratio of the correct numbers of forecast rainfall events to the total forecast events. It ranges from 0 to 1. It is expressed as:

$$RS = \frac{H+Z}{H+F+M+Z} \quad (1)$$

Hanssen-Kuipers score (H. K. Score) or true skill statistic is the ratio between economic saving over climatology due to a forecast to that of a set of perfect forecasts (Chattopadhyay *et al.,* 2016). It ranges from -1 to +1 where +1 indicates perfect skill. It is expressed as:

$$HK\ Score = \frac{Z*H - F*M}{(Z+F)(M+H)} \quad (2)$$

Critical success/score index (CSI) or threat score is the ratio of hits (H) to that of the hits plus incorrect forecasts (F and M). Its values range between 0 to 1, where 1 indicates a perfect forecast. It is calculated as:

$$CSI = \frac{H}{H+F+M} \quad (3)$$

Heidke skill score (HSS) is the ratio of correct forecasts after excluding those that would be correct due to random chance. It ranges between negative values to +1, where 0 indicates no skill and +1 indicates perfect forecast. It is calculated as:

$$HSS = \frac{2(Z*H - F*M)}{(H+M)(M+Z)+(H+F)(F+Z)} \quad (4)$$

We have also worked out the root mean square error (RMSE) and mean bias error (MBE) to understand the differences and biases between the forecast and observed parameters, respectively. The formulae are as follows:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(O_i - F_i)^2}{n}} \quad (5)$$

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(O_i - F_i) \quad (6)$$

Where, O_i and F_i denote the observed and forecasted values respectively, and n denotes the total number of observations. The correlation coefficients between the observed and forecasted parameters were also calculated and those were also tested for significance using a two-tailed Pearson test.

Results and Discussion

Rainfall evaluation

Qualitative evaluation

Rainfall forecast verification was done both qualitatively and quantitatively using the criteria depicted in Table 1. To understand the rainfall forecast accuracy in a better way, different ratios/scores were also calculated and presented in Figure 2 (mean values of 2014-2018 are presented as bars and error bars indicate the standard error). The ratio score (RS) which explains the simple forecast accuracy (ACC) or hit score was maximum during the winter season followed by post-monsoon and varied similarly during pre-monsoon and monsoon season over all the places of the NEH region. A similar trend in the RS among different seasons was also reported by Sarmah *et al.,* (2015) for Sonitpur district which comes under the North Bank Plain Zone (NBPZ) of Assam. But all the values for Sonitpur were lower than that of this study,

Table 1: Error structure for evaluation of the rainfall and total cloud cover in this study

Usability	*Rainfall (mm)*		*Total Cloud Cover (Octa)*
	< 10 mm	*> 10 mm*	
Correct	< 0.2 mm	< 2%	<1
Usable	0.2 mm – 2.0 mm	2% – 20%	1-2
Not Usable	> 2.0 mm	> 20%	> 2
Forecasted		*Observed*	
		Rain	*No Rain*
Rain		Hits (H)	False Alarms (F)
No Rain		Misses (M)	Correct Negatives (Z)

Note: All the values indicate the absolute difference between the observed and forecasted values.

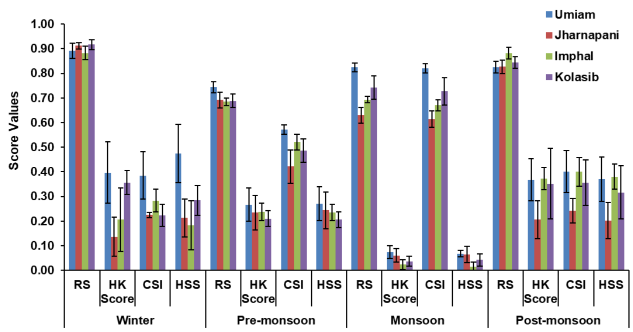

Figure 2: Values of different skill scores for verification of rainfall forecast over different places of the northeastern hill region

especially the RS during pre-monsoon and monsoon season were mostly below 0.6 or 60% whereas in this study it was always more than 63%. Rana *et al.,* (2005) also reported the values of RS as more than 67% for all the seasons over mid hills of Himachal Pradesh from a study of five years though the inter-seasonal variations were different from this study.

Hanssen-Kuipers score (H. K. Score) or true skill statistic was maximum during post-monsoon (~0.32) followed by winter (~0.27), pre-monsoon (~0.24) and lowest in monsoon season (<0.05) over the whole NEH region. However, it showed a similar pattern during pre-monsoon and monsoon seasons over different locations of the NEH region with comparatively lower variability than in winter and post-monsoon seasons. During the winter season, HK score was maximum in Umiam (~0.39) followed by Kolasib (~0.36), Imphal (~0.21), and Jharnapani (~0.14). These values of HK score were well within the limits as reported by Rana *et al.,* (2005), Sarmah *et al.,* (2015), and Kaur and Singh (2019). The results of this study were closer to that of Rana *et al.,* (2005) where the values of the HK score varied from 0.25 to 0.35. The closeness may be due to the reason that for both cases the study area is a hilly region. Similar to this study, Sarmah *et al.,* (2015) also reported the highest values of HK score during the post-monsoon season and the lowest during the monsoon season for the Sanitpur district of Assam which is a part of the northeastern region of India. It indicates that when the rainfall amount is quite higher (as during monsoon), the HK score tends to be quite lower.

Critical Success/Score Index (CSI) or threat score was maximum during monsoon (~0.71) followed by pre-monsoon (~0.50), post-monsoon (0.35), and winter (~0.28) seasons. Sarmah *et al.,* (2015) also reported a similar pattern in CSI for the seasons. The reason for this pattern may be the fact that this region receives high rainfall during monsoon months (~60% of the annual rainfall) with a quite higher number of rainy days (> 60), thereby increasing the number of hits (H) compared to that of false alarms (F) and misses (M) which gives rise to higher values of CSI. Heidke Skill Score (HSS) was maximum during post-monsoon (~0.32) followed by winter (~0.28), pre-monsoon (~0.24), and minimum during monsoon season (~0.05). These values are also in agreement with the studies of Vashisth *et al.,* (2008) and Sarmah *et al.,* (2015). Similar to this study, Sarmah *et al.,* (2015) also reported a maximum value of HSS during post-monsoon and a minimum value during monsoon seasons. Very low values of HSS during monsoon season (mostly <0.07) over all the places of the NEH region clearly indicate that the forecast skill was very poor as a zero value of HSS depicts no skill. The higher values of RS and CSI with the lowest values of HK score and HSS during monsoon season over the NEH region clearly indicated that as there were many rainy days hence the chance of the number of hits (H) automatically increased, but when this chance factor was taken out, the real quality of forecast became very poor. The above-mentioned reason was the same for lower values of HK score and HSS during the pre-monsoon season as this season also received a significant amount of rainfall over the NEH region (Saha *et al.,* 2015, 2018; Chakraborty *et al.,* 2017).

Quantitative evaluation

The quantitative evaluation of the rainfall forecast is shown in Figure 3 (mean values of 2014-2018 are presented as bars and error bars indicate the standard error). The quantitative rainfall forecast was correct with maximum frequency during winter (~88%) followed by post-monsoon (~74%) but a drastic decrease during pre-monsoon (~34%) and in monsoon months it was lesser than 6% for all the places of NEH region. Chattopadhyay *et al.,* (2016) have reported that the cumulative values of correct and usable forecasts make the total forecast accuracy, but in this study, even after cumulating correct and usable forecasts, the pattern in total accuracy among different seasons did not change much. After cumulating correct and usable forecasts, the total forecast accuracy during monsoon season improves but varies from 9.5 to 13.0% among the four different places of the NEH region which is still quite low. The not usable forecast was maximum during monsoon season (~89%) followed by pre-monsoon season (~55%), post-monsoon (~21%), and winter season (~8%). The average correctness of the quantitative rainfall forecast considering all the seasons and places over the NEH region was about 49%. The results

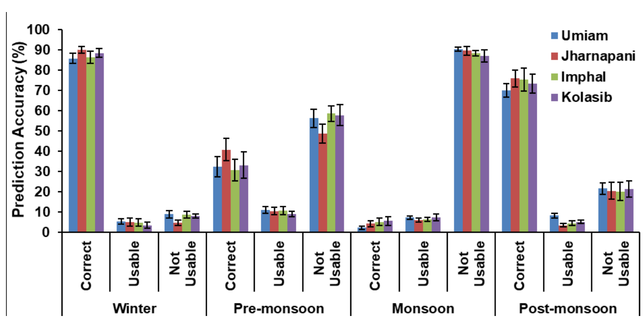

Figure 3: Quantitative verification of rainfall forecast over different places of the northeastern hill region

of this study, particularly the pattern of accuracy among the seasons, were similar to that of Sarmah *et al.,* (2015) though the values differed. They found higher values of forecast accuracy during all the seasons compared to this study, but the difference was minor during winter and post-monsoon seasons, whereas it was quite high during pre-monsoon and monsoon seasons. During monsoon season, they reported accuracy ranging from 31.0 to 34.6%. The observations of Rana *et al.* (2005) for post-monsoon and winter seasons were similar to this study whereas for monsoon they reported an average accuracy of 40% over the western Himalayan region of Himachal Pradesh. Chattopadhyay *et al.* (2016) reported that the MME model forecast could predict the weather with considerable accuracy in the Northern hill regions except in other hilly areas. Similarly, they analyzed the data of Assam and Tripura states of northeastern India and concluded that in the northeastern region, the accuracy was very low due to the humid sub-tropical climate with hot, humid summers, severe monsoons, and mild winters. Mandal *et al.* (2007) reported that the global spectral model (GSM) was most efficient in predicting rainfall between 2.5 to 12.8 mm and beyond that range, the efficiency decreased drastically for West Bengal, Andhra Pradesh, and Rajasthan. None of these studies analyzed the rainfall data of the NEH region which gets many rainfall events beyond the threshold mentioned in the above study.

The values of statistical indices (Figure 4) also showed the same pattern, between the seasons, winter had the smallest error followed by post-monsoon, pre-monsoon, and monsoon seasons. The overall trend matches with the normal monsoon rainfall of these places as Kolasib gets the maximum followed by Umiam, Jharnapani, and Imphal (Chakraborty *et al.,* 2017). The MBE also followed the same trend in the seasons. Among the places, it showed negative values during pre-monsoon and monsoon seasons. At Umiam, Jharnapani, and Imphal during these two seasons always higher values were forecasted while it was otherwise at Kolasib. The results were in line with (especially during the monsoon season) the study of Rana *et al.* (2005, 2013, 2021), Vashisth *et al.* (2008), and Sarmah *et al.* (2015). The values of correlation coefficient (r) were significant most of the time during post-monsoon followed by pre-monsoon, winter, and monsoon seasons (Table 2). Over Umiam, Jharnapani, and Imphal during the winter season, many a time negative correlation was observed since during this season most of the time zero rainfall is forecasted but this region receives rainfall in the second fortnight of February. The values of the correlation coefficient found in this study fall in the range reported by Rana *et al.* (2013) and Sarmah *et al.* (2015). Further similar to this study, Sarmah *et al.,* (2015) also reported negative values during the winter season in some years.

Cloud Cover

The quantitative evaluation of total cloud cover over different places of the NEH region is presented in Figure 5 (mean values of 2014-2018 are presented as bars and error bars indicate the standard error). The results indicated that the correctness of the TCC forecast remained between 30 to 40% throughout the year across all the seasons. The unusable values varied between 35 to 65% for all seasons and locations except Jharnapani where it was more than 90% during monsoon. The statistical indices (Figure 6) also confirmed the pattern and showed similar values in all the seasons. Mostly positive values of MBE were found during winter, pre-monsoon, and post-monsoon seasons indicating higher values of observed cloud cover than the forecasted values. Whereas during monsoon season MBE was negative in all four locations, indicating higher values of the forecasts with strikingly higher values for Jharnapani. These results indicate that over the NEH region during monsoon season always higher values of TCC are forecasted but in reality, that much clouds are not observed whereas the opposite happens in the case of winter, pre and post-monsoon seasons. The correlation coefficient was maximum during post-monsoon and minimum during monsoon season over the NEH region (Table 2). Over Jharnapani, in none of the years during monsoon, the correlation coefficient was statistically significant, which justifies the above-mentioned results. Similar values of RMSE during all the seasons were also reported by Vashisth *et al.* (2008) and Rana *et al.* (2013). The values of the correlation coefficient reported by them were also similar to those in this study during winter, pre-

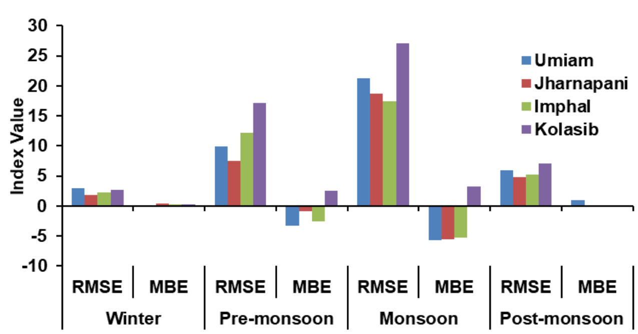

Figure 4: Statistical indices of error of the rainfall forecast over different places of the northeastern hill region

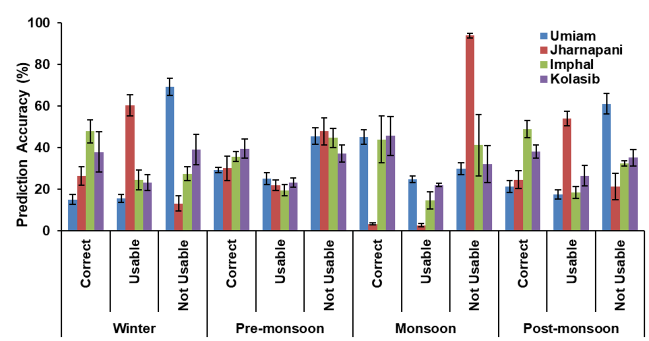

Figure 5: Quantitative verification of total cloud cover forecast over different places of the northeastern hill region

Table 2: Correlation coefficients between the forecasted and observed weather parameters over different places of the northeastern hill region

	Winter	*Pre-monsoon*	*Monsoon*	*Post-monsoon*	*Winter*	*Pre-monsoon*	*Monsoon*	*Post-monsoon*
	Umiam				*Jharnapani*			
	Rainfall							
2014	-0.07	0.40*	0.40*	-0.02	NA	0.01	0.03	0.23
2015	-0.08	0.45*	0.18	0.22	0.40*	0.34*	0.20	0.20
2016	-0.04	0.56*	0.17	0.63**	-0.04	0.37*	0.19	0.53*
2017	0.47*	0.62**	0.39*	0.58*	0.29*	0.54*	0.15	0.30*
2018	0.37*	0.27*	0.04	0.39*	0.97**	0.33*	0.14	0.51*
	Total Cloud Cover							
2014	0.29*	0.35*	0.25*	0.34*	0.03	0.27*	0.22	0.27*
2015	0.08	0.37*	0.23	0.14	0.03	0.02	0.03	0.12
2016	0.15	0.00	0.21	0.33*	0.17	0.24	0.20	0.09
2017	0.07	0.20	-0.02	0.44*	-0.31*	0.17	0.18	-0.04
2018	0.15	0.11	0.12	0.35*	-0.04	0.01	-0.10	0.23
	Imphal				*Kolasib*			
	Rainfall							
2014	-0.05	0.22	0.06	0.21*	0.51*	0.40*	-0.13	0.11
2015	0.19	0.28*	0.24	0.39*	0.77**	0.20	0.10	0.04
2016	0.45*	0.51*	-0.09	0.45*	0.36*	0.13	0.02	0.36*
2017	-0.02	0.30*	0.09	0.64**	0.52*	0.32*	0.03	0.22
2018	0.63**	0.16	0.22	0.89**	0.29*	0.09	0.11	0.42*
	Total Cloud Cover							
2014	0.12	0.23	0.23	0.53*	0.26*	0.20	0.29*	0.25*
2015	0.21	0.21	0.25*	0.49*	0.40*	0.07	0.34*	0.44*
2016	0.38*	0.29*	0.18	0.30*	0.09	0.26*	0.18	0.33*
2017	0.13	0.58*	0.26*	0.52*	0.34*	0.35*	0.04	0.25*
2018	0.40*	0.27*	0.20	0.40*	0.25*	0.06	0.03	0.39*

** and * denote 1% and 5% significance level, respectively.

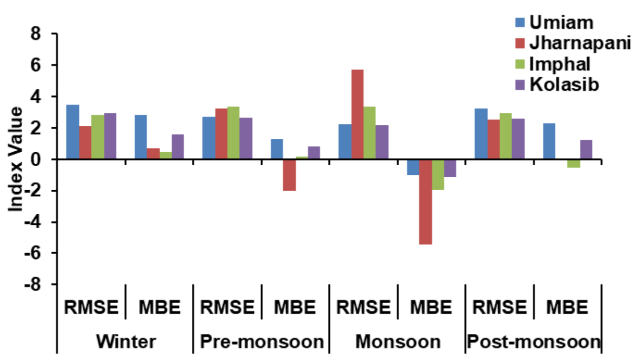

Figure 6: Statistical indices of error of the total cloud cover forecast over different places of north eastern hill region

monsoon, and post-monsoon season but during monsoon, we found much lesser values across the NEH region.

Conclusion

This study analyzed the daily observed and forecasted weather data (rainfall and total cloud cover) for five years duration over four different locations in the NEH region of India to verify the accuracy of the medium-range weather forecast. At a glance, the results indicate that the qualitative rainfall forecast was fairly good during all the seasons over the region which is at par with other parts of the country. But indices like HK score and HSS which remove the chance factor of qualitative rainfall forecast clearly depicted the poor skill of the rainfall forecast during moderate to heavy rainfall seasons like pre-monsoon and monsoon season. The quantitative verification of rainfall forecast revealed that maximum accuracy was during winter followed by post-monsoon, pre-monsoon, and least during the monsoon. Different indices/techniques clearly indicated that the accuracy of rainfall forecast was quite low during the monsoon season. The models were not able to forecast the rainfall amount during the high rainfall-receiving months over the region. The accuracy of the total cloud cover forecast was consistent throughout the year. During monsoon months, both TCC and rainfall were over-forecasted for most of the places of the NEH region. The NEH region is mostly dependent upon agriculture and that too rain-fed crop husbandry is the dominant system. Though this region is blessed with lots of water resources, still water becomes a crucial factor limiting the growth of the stagnant cropping intensity (< 120%). Therefore, focused studies need to be conducted to find out the reasons for these inaccuracies so that the quantitative forecast of rainfall over the NEH region can be improved. Accurate quantitative forecasts can pave the way for devising specific agro-advisories and proper planning to increase the cropping intensity thereby maximizing the profit of the farming community through the optimization of resources.

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References

Chakraborty D., Saha S., Singh R.K., Sethy B.K., Kumar A., Saikia U.S., Das S.K., Makdoh B., Borah T.R., Nomita Chanu A. and Walling I. 2017. Spatio-temporal trends and change point detection in rainfall in different parts of North-eastern Indian states. *J. Agrometeorol.,* **19**(2): 160–163.

Chakraborty D., Saha S., Sethy B.K., Singh H.D., Singh N., Sharma R., Chanu A.N., Walling I., Anal P.R., Chowdhury S. and Hazarika S. 2022. Usability of the weather forecast for tackling climatic variability and its effect on maize crop yield in northeastern hill region of India. *Agronomy,* **12**: 2529. https://doi.org/10.3390/agronomy12102529

Chattopadhyay N., Ghosh K., Malathi K., Bhowmik S.R. and Singh K.K. 2016. Verification of district level weather forecast. *Mausam,* **67**: 829–840.

Kaur N. and Singh M.J. 2019. Verification of medium-range weather forecast for the Kandi region of Punjab. *Mausam,* **70**(4): 825–832.

Laitonjam N., Feroze S.M., Singh R., Passah S. and Thangjam D. 2021. Effect of temperature and rainfall on ginger production in Meghalaya. *Indian J. Hill Farm.,* **34**(2): 153–158.

Mandal V., De U.K. and Basu B.K. 2007. Precipitation forecast verification of the Indian summer monsoon with intercomparison of three diverse regions. *Weather Forecast.,* **22**: 428–443.

Rajavel M., Khare P., Sahu M.L. and Prasad J.R. 2019. District-level weather forecast verification in Chhattisgarh. *Mausam,* **70**(4): 841–852.

Rana R.S., Prasad R. and Kumar S. 2005. Reliability of medium-range weather forecast in mid hill region of Himachal Pradesh. *J. Agrometeorol.,* **7**(2): 297–303.

Rana R.S., Ruchi S., Aditya A. and Shekhar J. 2013. Validation of medium range weather forecasts in sub-temperate and subhumid climate of western Himalayas. *Indian J. Agric. Sci.,* **83**: 1357–1363.

Rana R.S., Sood R., Kalia V. and Sharma K. 2021. Validation and application of extended range rainfall forecast for crop planning in sub-humid and wet temperate climatic conditions of Himachal Pradesh. *Indian J. Hill Farm.,* **34**: 22–30.

Saha S., Chakraborty D., Choudhury B.U., Singh S.B., Chinza N., Lalzarliana C., Dutta S.K., Chowdhury S., Boopathi T., Lungmuana and Singh A.R. 2015. Spatial variability in temporal trends of precipitation and its impact on the agricultural scenario of Mizoram. *Curr. Sci.,* **109**(12): 2278–2282.

Saha S., Chakraborty D., Paul R.K., Samanta S. and Singh S.B. 2018. Disparity in rainfall trend and patterns among different regions: analysis of 158 years' time series of rainfall dataset across India. *Theor. Appl. Climatol.,* **134**(1–2): 381–395.

Saha S., Das B., Chakraborty D., Chawdhury S., Lalliansanga S. and Saithantluanga H. 2021. Quantitative accuracy assessment of district level rainfall forecast in Mizoram. *J. Agric. Phys.,* **21**: 332–340.

Sarmah K., Neog P., Rajbongshi R. and Sarma A. 2015. Verification and usability of medium range weather forecast for north bank plain zone of Assam, India. *Mausam,* **66**: 585–594.

Schneiderbauer S., Pisa P.F., Delves J.L., Pedoth L., Rufat S., Erschbamer M., Thaler T., Carnelli F. and Granados-Chahin S. 2021. Risk perception of climate change and natural hazards in global mountain regions: A critical review. Sci. Total Environ., **784**: 146957.

Vashisth A., Das D.K., Bhagawati G. and Sharma P.K. 2008. Accuracy of weather forecast for semiarid climate of Delhi for agricultural management practices. *J. Agric. Phys.,* **8**: 51–58.