Original Research Article

Seasonal Rainfall Forecast Verification Analysis for Vridhachalam, Tamil Nadu

ABSTRACT

This study examined the forecast accuracy of four different seasons (northeast monsoon, winter, summer, and southwest monsoon), using various metrics such as forecast accuracy ratio, critical success index, true skill score, and false alarm ratio for Virdhachalam block, Cuddalore district. The results showed that the summer season had the highest forecast accuracy (0.76) followed by winter (0.69), northeast monsoon (0.63), and southwest monsoon (0.66). However, the critical success index was highest during northeast monsoon (0.48) followed by southwest monsoon (0.38), winter (0.36), and summer (0.27) indicating a higher rate of correct rainfall prediction with fewer false alarms. The true skill score index was highest during summer, while the false alarm ratio was highest in summer as well as winter. These findings highlight the need for improving forecast accuracy during the monsoon season to ensure successful crop sowing and farm operations, while ~~it~~ also emphasizing the importance of accurate forecasts during winter and summer to prevent crop failures and aid in soil water conservation for subsequent crops. Furthermore, the study found that accurate forecasts during the northeast monsoon and southwest monsoon could lead to better planning and management of agricultural activities ~~results~~ in improved yields and profits for farmers.

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Keywords: *Rainfall forecast; Forecast Accuracy; True skill score; False alarm ratio; Rainfall Verification techniques*

1. INTRODUCTION

Agricultural production is highly dependent on weather conditions such as temperature, rainfall, relative humidity and wind (1). Changes in weather patterns can significantly impact agricultural production and food security (2). For instance, droughts can lead to water scarcity which leads to crop failure (3) and loss of livestock (4), ~~result~~ in food insecurity. Similarly, floods can cause soil erosion, damage crops and displace livestock which results in reduced agricultural productivity and food insecurity. Therefore, accurate weather forecasting and monitoring are essential for agricultural productivity and food security. Farmers need to be aware of the expected weather conditions to make timely decisions (5) regarding planting, harvesting and other agricultural activities. Accurate and timely weather forecasting can help farmers to manage risks, minimize losses, improve yields (6), and lead to enhanced food security.

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~~The~~ ~~w~~Weather forecasting is a complex system (7) that involves the analysis and prediction of various atmospheric variables such as temperature, rainfall, wind speed, wind direction and relative humidity. These variables interact with ~~oneanother~~ in ~~a~~ complicated ways and are influenced by many factors such as topography, land use and atmospheric circulation patterns (8). The future state of the atmosphere is predicted using a combination of observations, numerical models and statistical techniques (9). The current weather conditions such as temperature, pressure and humidity are collected from various sources like weather stations, satellites and radar systems (10). These data are then utilized to generate numerical models that simulate the

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atmosphere's behavior ~~of the~~ ~~overtime~~. ~~The s~~Statistical techniques are also used for prediction by analyzing past weather patterns and identifying trends and patterns that can help predict future weather conditions.

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However~~, it is essential for~~ forecasters need to quantify the accuracy of their forecasts by comparing the forecast and observed weather conditions. This comparison can be done either qualitatively or quantitatively. Qualitative verification includes a visual inspection of the forecast and observed weather conditions in search of similarities and differences. Quantitative verification consists of statistical measures that compare the forecast and observed weather conditions, such as mean absolute error, root mean square error and correlation coefficient (11). Verification is necessary to determine the accuracy and reliability of weather forecasts and to identify areas for improvement in the forecasting system.

Although weather forecasting is complex, recent years have seen improvements in technology and data analysis, which have improved the accuracy of weather forecasts. The accuracy of weather forecasting is crucial for various sectors, including agriculture, transportation, energy and emergency management, and helps to mitigate the impact of extreme weather events on human lives and infrastructure.

Accurate rainfall forecasts can help farmers to optimize their use of resources (12) such as water, fertilizer and minimize the risk of crop failure due to water scarcity or excess ~~of~~ rainfall. In addition to agricultural applications, water resource management, flood control, and disaster are also essential for planning. Therefore, verification of rainfall forecasts is crucial for ensuring the overall resilience of communities and the economy tools.

2. MATERIALS AND METHODS

Observed rainfall values received from District Agromet Unit (DAMU) ~~is~~ being implemented at KVK, Cuddalore since 2018 by the India Meteorological Department (IMD). From IMD medium range weather forecast received at biweekly intervals (Tuesday and Friday). The various statistical tools like Forecast Accuracy Ratio or Hit score (HS), Critical Success Index (CSI), True Skill Score (TSS) and False Alarm Ratio (FAR) using for verification of rainfall during the Northeast Monsoon (NEM) (October 2020 to December 2020), winter (January 2021 to February 2021), summer (March 2021 to May 2021) and Southwest Monsoon (SWM) (June 2021 to September 2021).

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2.1 Forecast accuracy ratio score or Hit score

	Predicted	
Observed	**No rain**	**Rain**
No rain	Z (NN)	F (NY)
Rain	M (YN)	H (YY)

Where,

Z = No. of correct prediction of no rain

F = No. of false alarms

M = No. of misses

H = No. of Hits

It is the ratio of correct forecasts to the total number of forecasts. The score was expressed between 0 and 1 and higher value, more will be accuracy.

$$\text{Forecast accuracy ratio} = \frac{\text{Correct forecast (CF)}}{\text{Total forecsast (N)}}$$

$$\frac{\text{H} + \text{Z}}{\text{Z} + \text{F} + \text{M} + \text{H}} = \frac{\text{YY} + \text{NN}}{\text{NN} + \text{NY} + \text{YN} + \text{YY}}$$

Where correct forecast refers to the number of correct forecasts and total forecasts refers to the total number of forecasts made.

2.2 Critical success index or the Threat Score

The Critical Success Index (CSI) or Threat Score is a statistical measure used to evaluate the accuracy of weather forecasts for binary events, such as the occurrence of precipitation or the presence of a severe weather event. The CSI measures the ratio of correct predictions to the total number of events that occurred, regardless of whether the event was predicted**.**

It is a measure of relative forecasting accuracy. It varies from 0 to 1 and the 1 indicates perfect forecast. It is defined as the ratio of the number of hits (correct event forecast) to the correct and incorrect events.

$$\text{Critical success index} = \frac{\text{Correct forecast (CF)}}{\text{Correct} + \text{In correct}}$$

$$\frac{\text{H}}{\text{F} + \text{M} + \text{H}} = \frac{\text{YY}}{\text{NY} + \text{YN} + \text{YY}}$$

2.3 Hanssen and Kuipers discriminant or True Skill Score

It is defined as the ratio of economic saving over climatology due to the forecast to that of a set of perfect forecasts. A perfect forecast with no misses or false alarms would have a TSS of one, while a forecast that misses all events and predicts many false alarms would have a TSS close to zero.

$$\text{HK} = \frac{\text{Hits}}{\text{Hits} + \text{Misses}} - \frac{\text{False alarms}}{\text{False alarms} + \text{correct negatives}}$$

$$\text{HK} = \frac{(\text{YY} \times \text{NN}) - (\text{YN} \times \text{NY})}{(\text{YY} + \text{NY}) \times (\text{YN} + \text{NN})}$$

Where hits refer to the number of correct predictions, misses refer to the number of events that were not predicted but occurred, false alarms refer to the number of events that were predicted but did not occur and correct negatives refer to the number of events that were not predicted and did not occur.

2.4 False alarm ratio

False alarm ratio sensitive to false alarms, but ignores misses. A perfect forecast with no false alarms would have a 0, while a forecast that predicts many false alarms would have a FAR close to one.

$$\text{False alarm ratio (FAR)} = \frac{\text{False alarms}}{\text{Hit} + \text{False alarms}}$$

$$\text{FAR} = \frac{\text{YN}}{\text{YY} + \text{YN}}$$

3. RESULTS AND DISCUSSION

The result of the seasonal analysis revealed variations in the performance of rainfall forecasts for different seasons (Table 1). During the southwest monsoon, 33 days had both forecasted and observed rain (YY), while 35 days had not forecast but observed rain (YN). Additionally, 4 days of rain was forecasted but that was not observed (NY) and 50 days of rain was neither forecasted nor observed (NN). The total number of matching cases (YY+NN) for this season was 83 days among 122 days, indicating a relatively moderate level of forecasting accuracy. Conversely, in the northeast monsoon, both forecasted and observed rain (YY) was occurred in in 31 days, while not forecast but observed rain (YN) was occurred in 33 days. Likewise, rain was not forecast but observed for 1 day (NY) and 27 days had neither forecasted nor observed rain (NN). The total number of matching cases (YY+NN) for this season was 58 days among 92 days, suggesting a better forecast performance compared to the southwest monsoon.

During the winter season 11 out of 59 days have both forecasted and observed rain (YY), indicating a relatively lower accuracy in predicting rainfall during this period. The summer season showed forecasted and observed rain for 9 days (YY) out of 92 days, suggesting a higher level of uncertainty in the rainfall forecasts during this season.

The annual analysis further consolidated the performance of the rainfall forecasts throughout the entire year. Out of the total 365 days, 84 days was occurred both forecasted and observed rain (YY), while 108 days had observed rain without being forecasted (YN). Only 5 days had forecasted rain that was not observed (NY) and a significant number of 168 days was occurred neither forecasted nor observed rain (NN).

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Table 1.Seasonal and Annual Rainfall Verification

Particulars	Seasonal				Annual
	South West Monsoon (June-September 2021)	North East Monsoon (October to December 2020)	Winter (Jan-Feb)	Summer (March-May)	
Number of days when rain was forecast + Observed YY	33	31	11	9	84
Number of days when rain was not forecast + Observed YN	35	33	18	22	108
Number of days when rain was forecast + not Observed NY	4	1	0	0	5
Number of days when rain was not forecast + not observed NN	50	27	30	61	168
Total number of matching cases (YY+NN)	83	58	41	70	252
Total Number of forecasted	122	92	59	92	365

By using on various metrics, such as forecast accuracy ratio, critical success index, true skill score, and false alarm ratio. According to the result, the summer season had the highest forecast accuracy was (0.76) followed by winter (0.69) southwest monsoon (0.66) and northeast monsoon (0.63). The critical success index was highest during the northeast monsoon (0.48) followed by the southwest monsoon (0.38), winter (0.36) and summer (0.27). The true skill score index had the highest score during summer (0.74) followed by winter (0.55), southwest monsoon (0.48) and northeast monsoon (0.42). The false alarm ratio was highest in summer (0.73) followed by winter (0.63), southwest monsoon (0.60) and northeast monsoon (0.52). It also appears that during summer and winter the false alarm ratio was relatively higher (0.73 and 0.69, respectively) compared to southwest monsoon and northeast monsoon (0.60 and 0.52 respectively) (Table 2).

Table 2. Verification of forecast rainfall by different method for different seasons

Verification methods	Southwest Monsoon	Northeast Monsoon	Winter	Summer
Forecast Accuracy Ratio	0.66	0.63	0.69	0.76
Critical Success Index	0.38	0.48	0.36	0.27
True Skill Score	0.48	0.42	0.55	0.74
False Alarm Ratio	0.60	0.52	0.63	0.73

The crop sowing area in the Virdhachalam block is higher during northeast monsoon and southwest monsoon compared to winter and summer seasons. To ensure the success of crop sowing and farming activities, it is important to increase forecast accuracy during the monsoon season. In addition, good forecast accuracy during winter and summer can help to avoid the failure of dryland crops due to extreme weather events and it can also aid in soil water conservation for kharif crops.

The critical success indices were found to be better in northeast monsoon and southwest monsoon compare with winter and summer, indicating a higher rate of correct rainfall prediction with fewer false alarms this was supported by (13). This finding suggests that accurate forecasts during the northeast monsoon and southwest monsoon can lead to better planning and management of agriculture activities (14) could be resulting in better yields and profits for farmers. Overall, the statement highlights the importance of accurate weather forecasting for agriculture activities in different seasons and suggests that improving forecast accuracy during monsoon season and minimizing false alarms can be beneficial for the agriculture system in Virdhachalam block.

The false alarm ratio ranges from 0.52 to 0.73, indicating that there is a need for improvement in the accuracy of the forecasts. However, it is important to note that achieving a false alarm ratio score of 0 is often not feasible, as there will always be some level of uncertainty in weather forecasting. A low false alarm rate is usually preferred in weather forecasts because it indicates a higher level of accuracy in predicting actual threats. However, there is also a risk of failing to raise the alarm when a true catastrophic risk exists. In the context of agriculture management, failing to raise the alarm can have negative consequences, such as crop damage or loss. However, it is also important to strike a balance between raising the alarm too frequently, which can lead to unnecessary disruptions in agricultural operations, and failing to raise the alarm when a true threat exists. The key is to continuously improve the accuracy of the forecasts and strive for a balance between accuracy and the potential consequences of false alarms or missed threats (15).

4. CONCLUSION

In conclusion, the verification of rainfall forecasts is critical for accurate and reliable weather forecasting, particularly for the agricultural sector. The use of verification techniques can help to assess the performance of rainfall forecasts. For Vridhachalam block there is a need to improve the accuracy of forecasts for the northeast monsoon and southwest monsoon seasons, especially during cropping seasons. It's also important for forecasters to focus on missed weather events that could potentially have a significant impact on crop and livestock production. To achieve better accuracy in weather forecasting, forecasters can take advantage of new data sources and technology advancements, such as machine learning algorithms and artificial intelligence models.

These technologies can help to improve the accuracy of forecasts and detect missed weather events. The outcomes of this study contribute to the ongoing efforts to build resilience and adaptive capacity in the face of changing weather patterns and climate variability.

REFERENCE

1. Kingra, P. K., & Kaur, H. Microclimatic modifications to manage extreme weather vulnerability and climatic risks in crop production. J.Agric.Phys. 2017,17(1), 1-15.
2. Kotir, J. H. Climate change and variability in Sub-Saharan Africa: a review of current and future trends and impacts on agriculture and food security. Environ.Dev.Sustain. 2011, 13, 587-605.

Commented [YA9]: bibliography of more than 10 years

3. Dinar, A., Tieu, A., & Huynh, H. (2019). Water scarcity impacts on global food production. Glob. Food Sec. 2019, *23*, 212-226.
4. Ruwanza, S., Thondhlana, G., &Falayi, M. Research progress and conceptual insights on drought impacts and responses among smallholder farmers in South Africa: a review. Land, 2022, *11*(2), 159.
5. Abbot, J., &Marohasy, J. Input selection and optimisation for monthly rainfall forecasting in Queensland, Australia, using artificial neural networks. Atmos. Res. 2014,*138*, 166-178.
6. Prasad, S. A., Vijayashanthi, V. A., Manimekalai, R., Yogameenakshi, P., &Pirathap, P. Impact assessment on knowledge of weather based agro-advisory services among farmers in Tiruvallur district, Tamil Nadu. Curr.Appl.Sci.Technol. 2020, *39*(36), 96-101.
7. Guhathakurta, P. Long-range monsoon rainfall prediction of 2005 for the districts and sub-division Kerala with artificial neural network. Curr.Sci. 2006, *90*(6), 773-779.

Commented [YA10]: bibliography of more than 10 years

8. Mass, C. F., & Kuo, Y. H. (). Regional real-time numerical weather prediction: Current status and future potential. Bull.Am.Meteorol.Soc. 1998, *79*(2), 253-264.

Commented [YA11]: bibliography of more than 10 years

9. Iseh, A. J., &Woma, T. Y. Weather forecasting models, methods and applications. Int. J. Eng. Res. Technol.2013, *2*, 1945-1956.
10. Albers, S. C., McGinley, J. A., Birkenheuer, D. L., & Smart, J. R. The Local Analysis and Prediction System (LAPS): Analyses of clouds, precipitation, and temperature. WAF.1996, *11*(3), 273-287.

Commented [YA12]: bibliography of more than 10 years

11. Jaseena, K. U., &Kovoor, B. C. Deterministic weather forecasting models based on intelligent predictors: A survey. J.King Saud Univ.-Comput.Inf. Sci. 2022 *34*(6), 3393-3412.
12. Wu, C. L., & Chau, K. W. Prediction of rainfall time series using modular soft computingmethods. Eng.Appl.Artif.Intell. 2013, *26*(3), 997-1007.
13. Dheebakaran, G. A., Arulprasad, S., Kokilavani, S., & Panneerselvam, S. (2017). Astrometeorology: An option to improve the accuracy of numerical daily rainfall forecast of Tamil Nadu. *Editorial Board*, *2017*, 205.
14. Jayawardena, I. S. P., Punyawardena, B. V. R., & Karunarathne, M. D. R. K. (2022). Importance of integration of sub seasonal predictions to improve climate services in Sri Lanka case study: Southwest monsoon 2019. *Climate Services*, *26*, 100296.
15. Bala, R., & Reiff, P. (2018). Data Availability and Forecast Products for Space Weather. In *Machine learning techniques for space weather* (pp. 27-41). Elsevier.