PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 12(2): 1-7
https://doi.org/10.14719/pst.7460

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Validation of medium range rainfall forecast accuracy in Jagtial district of Telangana

Srilaxmi Bottu*, **Gade Sreenivas, Eligeti Rajanikanth, Dandugudumu Rajini Devi, Nagula Sainath, Nenavath Balram & Boddupalli Srinivas**

Regional Agricultural Research Station, Jagtial, PJTAU, Telangana 505 529, India

*Email: srilaxmibottu95@gmail.com

OPEN ACCESS

ARTICLE HISTORY
Received: 27 January 2025
Accepted: 10 march 2025
Available online
Version 1.0 : 10 April 2025
Version 2.0 : 23 April 2025

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Srilaxmi B, Sreenivas G, Rajanikanth E, Rajini Devi D, Sainath N, Balram N, Srinivas B. Validation of medium range rainfall forecast accuracy in Jagtial district of Telangana. Plant Science Today. 2025; 12(2): 1-7. https://doi.org/10.14719/pst.7460

Abstract

Rainfall is found to vary to a greater extent in its amount, intensity and distribution than any other weather parameter. Variation in rainfall during the crop season, including delay in monsoon arrival, heavy downpours and prolonged dry spells, can have a more significant impact on crop growth and development. If farmers have timely access to a medium-range rainfall forecast, they can take full advantage of unfavourable weather situations in scheduling their agricultural operations. The present study was taken by Agromet Field Unit (AMFU), Regional Agricultural Research Station, Jagtial, to analyze and verify the accuracy of medium-range rainfall forecast issued by the India Meteorological Department using a location-specific Multi-Model Ensemble (MME) technique for the Jagtial district from 2017 to 2023. The methodology included adopting quantitative and qualitative methods with the Ratio score, Hanssen and Kuipers (H.K) Score, RMSE, usability analysis and correlation of validation for verifying the accuracy of rainfall forecast for the monsoon. The results of the study revealed that rain forecast accuracy for past 7 years is excellent for post monsoon (October - December) in Jagtial district that has high skill score (RS range 77.2 to 93.5 %) with lower Root Mean Square Error (RMSE) of rainfall (3.17 to 14.2) in contrast to poor to moderate skill score (RS range 47.5 to 60.7 %) of accuracy for south-west monsoon with higher RMSE (14 to 29.5). The percent usability of forecast was also found to be higher for the post-monsoon (88.5 to 100 %) than the southwest monsoon (39.3 to 84.9 %). Among the essential predictions, rainfall is the most crucial one, which affects the crop output over a given region and, finally, the farmer's economics. Hence, with access to enhanced accuracy of rain forecast, farmers of Jagtial can limit the damages caused directly or indirectly by adverse weather situations by executing timely need-based farm operations.

Keywords

post monsoon; rainfall; south-west monsoon; weather forecast

Introduction

In India, where more than 55 % of agriculture is rainfed, medium-range weather forecasts, in particular, information on the expected rainfall over the next five days, have a more significant influence on agricultural operations. A more accurate prediction would enable farmers to plan and make the required decisions, lowering the risks associated with weather-related events (1). The amount of rainfall received during a crop growth season has a significant impact on agricultural productivity. Since rainfed agriculture accounts for a large amount of cropland globally, variations in rainfall throughout the growing season might keep food production systems at risk.

Rainfall forecasts assist farmers in choosing the best crops, which improves output and maintains pricing stability. During any crop growth season, rainfall in distribution and quantity is the important variable (2). Rainfall affects planting and harvesting schedules, increases the requirement for agricultural inputs like fertilizers, irrigation, pesticides and ultimately determines agricultural output (3). Rainfall affects crop productivity by supplying irrigation water, impacting agricultural pricing and yield.

Farmers in India make better investment decisions have access to extremely highly accurate monsoon forecasts, which shows that governments may improve weather forecasting to safeguard their economies from climate change. Precise predictions of rainfall can assist farmers in making the most efficient use of resources like water and fertilizer while reducing the possibility of crop failure due to insufficient water or excessive precipitation (4). By using weather forecast services, farming communities can reduce the effects of weather variance and reap socioeconomic benefits by making better and more informed decisions. Weather forecasts and the timely information provision to farmers can assist to boost agricultural output, lower losses and improve efficiency about important farming inputs like labour, energy and water for irrigation (5-7). The information on weather forecasts also helps to assist farmers in making timely decisions regarding crop selection, when to sow or plant and when to sow or plant. Weather forecasts also help farmers make timely decisions regarding crop selection, when to sow or plant and how to prevent crop damage. This allows them to take advantage of favourable seasons and reduce the adverse effects of climate change on their crops and maximizing agricultural yields.

Due to climate change, weather forecasting is becoming increasingly important for farmers' crop productivity and agricultural decision-making. Therefore, it is recommended that developing weather and climate services be a key component of managing the risk of climate variability and change (8, 9). A crucial factor that needs to be considered when forecasting weather for small-scale rainfed agriculture is contextualizing timeline (10). Whether choosing which crops to grow in a particular season or whether to invest in infrastructure or equipment, medium-to-long-term projections that span timelines of weeks or months are equally crucial for planning reasons (11). With the accuracy of weather forecasts, adopting the AAS in agriculture helps reduce crop losses for farmers. Weather-based agro warnings that are promptly disseminated to reduce the significant risks to agricultural production (12). Verification is required to assess the precision and dependability of weather forecasts and to identify areas where the forecasting system needs to be improved (13). The India Meteorological Department (IMD) in collaboration with the National Centre for Medium Range Weather Forecasting (NCMRWF) has adopted district-level Agromet Advisory Services (AAS) for disseminating medium-range weather forecast information to farmers. The Agromet Field Unit (AMFU) of the Regional Agricultural Research Station, Jagtial, has started issuing agromet advisory bulletins since 1997 under the Gramin Krishi Mausam Sewa (GKMS) scheme of the India Meteorological Department (IMD) by utilizing the medium-range weather forecast. The prepared weather-based agro-advisories are disseminated biweekly on every Tuesday and Friday through various sources of multimedia, viz., Whatsapp, SMS through M-Kisan, radio, local news TV channels, press coverage, Meghdoot mobile app, etc., to the farming community of Jagtial district. Limited access to scientific weather forecasts with high accuracy is a major constraint in the present highly changing climatic scenario (14). The knowledge gap for confirming the accuracy of rainfall forecasts includes several issues about the validation processes as well as the inherent unpredictability of rainfall. Both geographically (in terms of location) and temporally (in terms of time and duration), rainfall varies greatly. Large regions are frequently covered by forecasts, but it is more difficult to depict local variations, or microclimates precisely. High-resolution models that can synchronously produce precise forecasts at the regional and global scales are few and the validation techniques currently in use frequently fail to consider fine-scale rainfall changes. It involves multidisciplinary collaboration between meteorologists, climate scientists, hydrologists, statisticians and data scientists to develop validation procedures, enhance model accuracy and assure more dependable rainfall forecasts. Hence, the present study was taken with the research objective to verify the usability and correctness of accuracy of rain forecast information disseminated to the farming community of Jagtial since past 7 years of 2017 to 2023 during the period of south-west and post monsoon as this will help to assess the accuracy of forecast and improvise agromet advisories that help to cater the needs of farming community to minimize the impact of abberant weather on crops and aid in increasing crop production.

Materials and Methods

Study area

Jagtial district is located at 18^0 49' 40" N latitude and 78^0 50' 45" E longitude in the northern region of Telangana state of India. It is bounded by the Nirmal and Mancherial districts on the north and northeast, to the south and southwest by the Karimnagar and Peddapalli districts, respectively. On the west is the Nizamabad district (Fig. 1). It is a semi-arid area with a predominantly hot and dry climate. With average high temperatures in the range of 42 ^{0}C, summers begin in March and last in May. Rainfall is received majorly from the southwest monsoon that arrives in June and lasts till September with 826.7 mm normal accounting 81.5 % of the average annual rainfall of 1014.4 mm. Secondly, the post-monsoon season holds 11.2 % (114 mm) of the average annual rainfall. When considering the monsoon situation, the district experiences adverse weather conditions like variability in onset of monsoon in June, excess rainfall situations in July and September, intermittent dry spells during August and October showing a drastic impact on the agricultural production in predominant cultivation of Kharif season.

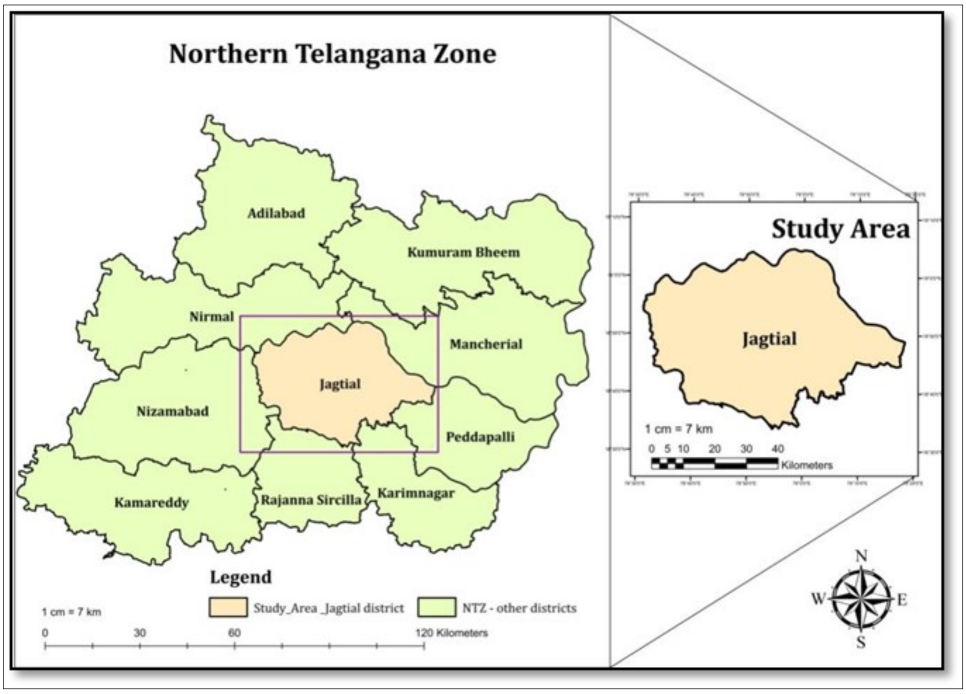

Fig. 1. Map showing area of Jagtial district of Northern Telangana Zone.

Data sets used

The daily recorded rainfall data of Agrometeorological Observatory, RARS, Jagtial and also the medium range weather forecasted rainfall issued by Meteorological Centre, Hyderabad using location specific Multi-Model Ensemble (MME) technique for the period of past 7 years i.e., 2017-2023 for southwest monsoon (June to September) and post monsoon (October to December) were used for determining the effectiveness of rainfall forecast in Jagtial district. The outputs of many numerical weather prediction (NWP) models, each with its advantages and disadvantages, are combined in this MME technique to provide predictions that are more accurate and thorough. The ensemble offers probabilistic predictions that provide insights into forecast uncertainty and possible weather scenarios by including several configurations, such as different horizontal resolutions and model physics, to address diverse weather phenomena. IMD assures the accuracy of its observational data by periodically calibrating instruments and maintaining the observatories. This method aids in eliminating systematic mistakes and boosting data dependability.

Verification of rainfall forecast

An essential component of any scientific forecasting system is forecast verification, which is the act of evaluating forecast correctness (15). Both qualitative and quantitative approaches were used to confirm the accuracy of rainfall forecasts provided by the India Meteorological Department (IMD). These techniques aid in evaluating how accurately the predictions reflect actual rainfall occurrences. When assessing the success of a forecast, qualitative approaches emphasize descriptive and non-numerical analysis. These techniques often entail subjective or visual comparisons between observations and predictions. In contrast, quantitative approaches assess the precision of rainfall forecasts using statistical analysis and numerical data. These approaches are more data-driven and objective.

Quantitative verification

The error structure in rainfall quantitative verification indicates how well the forecast system predicts observed rainfall, aiding meteorologists in evaluating the precision of rainfall forecasts. The error structure shows where and why mistakes happen, explaining how effectively a forecast system works. The error structure for rainfall quantitative verification is verified using the following usability difference.

Forecast usability: Difference between forecast and observed value

- Correct Diff ≤ 25 % of obs
- Usable 25 % of obs< Diff ≤ 50 % of obs
- Unusable Diff > 50 % of obs

Here, obs is the observed rainfall (in mm) and Diff is the absolute difference between the observed and forecasted values (in mm)

The Root Mean Square Error (RMSE) represents the total absolute difference between the observed and predicted values.

Correlation is figuring out how the predicted and observed values correlate (range: -1 to +1).

Qualitative verification

Ratio score or Hit score or Forecast accuracy (ACC)

Forecasting efficiency is measured by taking the ratio of accurate forecasts to the total number of forecasts. The formula shown below was used to determine the ratio score (Eqn. 1)

$$Ratio\ score = \frac{(YY + NN)}{(YY + NN + NY + NY)}\ X\ 100 \quad \text{…. (Eqn. 1)}$$

Hanssen and Kuipers scores or true skill score (HK score)

It demonstrates how effectively the forecast distinguishes between "yes" and "no" events. It represents the proportion of economic savings over climatology due to the forecast to that of a set of perfect forecasts (Eqn. 2).

It ranges from -1 to +1, with 0 indicating no skill.

$$\text{HK score} = \frac{[(YYxNN) - (YNxNY)]}{[(YY + YN)(NY + NN)]} \quad \text{.... (Eqn. 2)}$$

where,

- YY is the number of days when rain was forecasted and observed
- NN is the Number of days when rain was not forecasted and not observed
- YN is the number of days when rain was observed but not forecasted
- NY is the number of days when rain was not observed but forecasted.
- Similar quantitative and qualitative calculations have been used for rainfall verification (16).

Results and Discussion

Realized rainfall data of Jagtial district

Realized rainfall status of South-west monsoon

The past septennial (7 years) rainfall situation of the Jagtial district showed that there was deficient rainfall in 2017 with a deviation of -49 %, normal rainfall of -18 % in 2018, -7 % in 2019 and +1 % in 2020, which is against normal. However, rainfall increased in the past three years, with a deviation of +45 % excess in 2021, + 83 % large excess in 2022 and + 44 % excess in 2023. Therefore, rainfall received from the southwest monsoon was found to increase from 2017 to 2023 (Fig. 2).

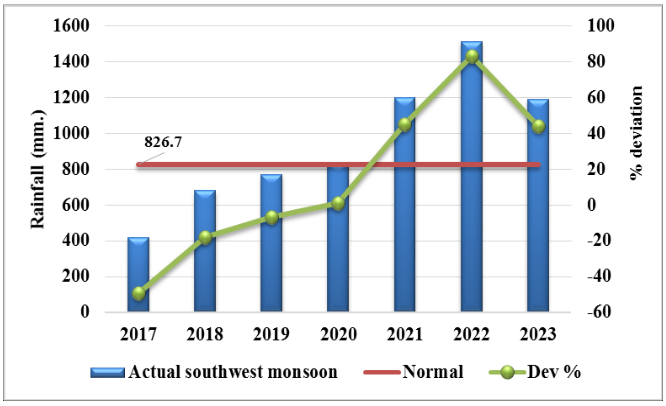

Fig. 2. South-west monsoon rainfall scenario of Jagtial district from 2017-2023.

Realized rainfall from post monsoon

The real-time observed rainfall data of post-monsoon revealed that there was excess rainfall of +32 % in 2017, +59 % in 2018 and +35 % in 2019, while deficient rainfall of -35 % was reported in 2021. Meanwhile, ample deficient rainfall of -87 %, -75 % and -79 % against normal (114 mm) was experienced in 2018, 2022 and 2023 respectively. Therefore, the rainfall received during post-monsoon in the Jagtial district from 2017 to 2023 was found to be irregular in pattern (Fig. 3).

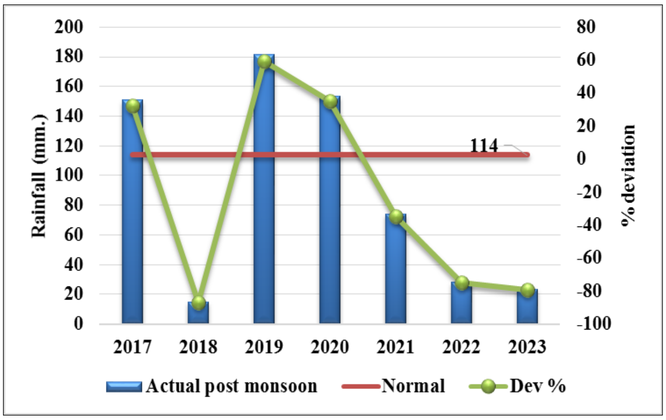

Fig. 3. Post monsoon rainfall scenario of Jagtial district from 2017-2023.

Validation of rainfall forecast of Jagtial district

The district-level rainfall forecast issued using MRF (medium range forecast) for Jagtial district during the southwest (June to September) and post-monsoon (October to December) seasons of the past 7 years was verified with the observed rainfall data recorded at Agrometeorological Observatory, RARS, Jagtial.

Validation of southwest monsoon forecast

The period from June to September has 122 calendar days. The highest number of matching cases (74) was found in 2023 and the lowest number (59 cases) was in 2017.

The results from the quantitative method of validation indicated that the usability percentage of rainfall of matching cases was found to be highest (84.9 %) for 2018 and lowest (39.34 %) for 2022. The RMSE value was lowest (14) in the year 2020, which recorded the rainfall of 763.9 mm as against the forecasted rainfall of 789 mm, indicating the lowest difference between the observed and forecasted rainfall values. The RMSE value was highest (29.5) in 2022, with observed rainfall of 1411.0 mm as against forecasted rainfall of 3008 mm, representing the highest difference. From the scattered plot of forecasted and observed values of total rainfall during the south-west monsoon revealed that there is a strong correlation (Fig. 4) and the correlation of rainfall was observed to be lowest (-0.1) in the year 2018 and highest (0.58) for the year 2023 (Table 2 & 3).

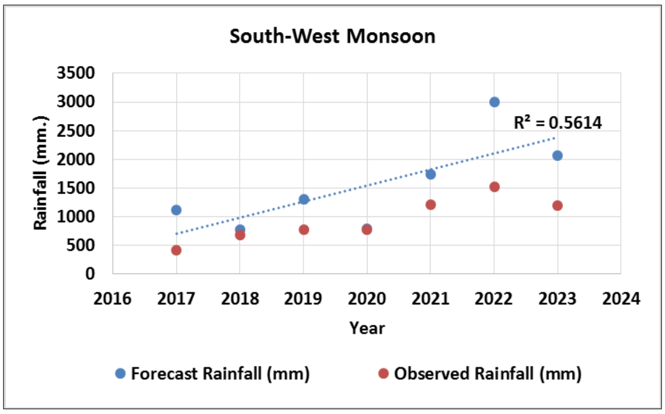

Fig. 4. Correlation of observed and forecast rainfall during South-West monsoon.

The results from qualitative method of rain forecast verification showed that the Hansenn & Kuipers index (H.K. score) indicated low skill during the year 2017 (0.08), moderate skill score during the years 2018 to 2021 (HK. Range of 0.10 to 0.16) and high skill score for the years 2022 and 2023 with 0.28 and 0.34 values respectively. The ratio score of rainfall revealed that there is low skill score (RS range 47.5 to 48.4 %) in 2017 and 2021 and moderate skill score (RS range 50 to 60.7 %) accuracy for the years 2018, 2019, 2020, 2022 and 2023 for the period of south-west monsoon in Jagtial district (Table 1).

Validation of post-monsoon forecast

The forecast was given for 92 calendar days from October to December. The highest number of matching cases (86) was found in 2023 and the lowest number (71) was found in 2021.

The quantitative method of validation results for post-monsoon revealed that there is 100 % usability of rainfall of matching cases for the years 2018 and 2023, followed by 97.4 %, 96 %, 95.8 %, 92.8 % and 88.5 % for the years 2022, 2017, 2021, 2020 and 2019, respectively. The RMSE value was found to be lowest during the year 2018 (3.17) followed by the year 2023 (3.25) which recorded the observed rainfall of 15 mm as against forecasted rainfall of 87 mm in 2018 and 23.5 mm observed rainfall as against 59 mm forecasted rainfall in the year 2023 indicating the lowest difference. The RMSE value was highest (14.2) in 2022, with observed rainfall of 28.4 mm against forecasted rainfall of 543 mm, representing the highest difference. From the scattered plot of forecasted and observed values of total rainfall during the post monsoon revealed that there is a negative correlation for post monsoon (Fig. 5). The correlation of rainfall was observed to be lowest (0) during the years 2018 and 2023 and highest (0.5) for the year 2019 (Table 2, 3).

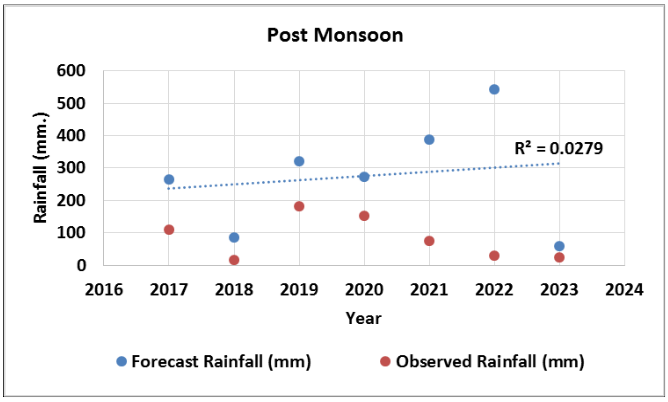

Fig. 5. Correlation of observed and forecast rainfall during post monsoon.

The results from qualitative method of rain forecast verification indicated that the Hansenn & Kuipers index (H.K. score) showed high skill during the years 2020 (0.45) and 2019 (0.42), moderate skill score during the years 2017, 2021 and 2022 (HK. Range of 0.11 to 0.16) and low skill score (0) for the years 2018 and 2023. The ratio score of rainfall revealed that there is a high skill score (RS range 77.2 to 93.5 %) accuracy for all the 7 years (2017-2023) for the period of post-monsoon in the Jagtial district (Table 3).

The results of the present investigation are like the previous findings which suggested that improving forecast accuracy during monsoon season and minimizing false alarms can benefit the agriculture system (17, 18). With precise predictions of rainfall and other climate variables critical for crop growth and development, weather forecasting in India helps farmers make informed decisions about planting, irrigation, pest and disease management and harvesting schedules. Ultimately, this allows them to maximize crop yields, reduce losses from unfavourable weather events and conserve resources by effectively managing water usage (19).

Table 1. Year wise quantitative and qualitative methods of validation of south-west monsoon rainfall for Jagtial district

S. No.	Particular	Symbol	2017	2018	2019	2020	2021	2022	2023
1	No: of days when rain was observed and forecasted	YY	17	15	26	26	30	43	34
2	No: of days when rain was observed but not forecasted	YN	57	33	44	45	56	58	44
3	No: of days when rain was not observed but forecasted	NY	7	16	11	12	7	3	4
4	No: of days when rain was not observed and also not forecasted	NN	41	58	41	39	29	18	40
5	No: of matching cases (YY +NN)	MAT	58	73	67	65	59	61	74
6	Total no: of forecast days, N=Total no: of days-no: of missing days	N	122	122	122	122	122	122	122
7	Skill Score or Ratio Score of rainfall (%)	RS	47.5	59.8	54.9	53.3	48.4	50	60.7
8	Hanssen & Kuipers index (H.K. Score)	H. K	0.08	0.1	0.16	0.13	0.15	0.28	0.34
9	Root Mean Square Error	RMSE	14.4	17.8	19.4	14	21	29.5	21.6
10	Error structure for rainfall (for matching cases)	Correct	72.4	80.8	62.7	60	49.2	29.5	56.8
		Usable	6.9	4.11	1.49	7.69	10.2	9.84	6.76
		Unusable	20.7	15.1	35.8	32.3	40.7	60.7	36.5
		% Usability	79.3	84.9	64.2	67.7	59.4	39.3	63.5
11	Correlation of rainfall	R	0.15	-0.1	0.1	0.38	0.34	0.46	0.58

Note: RS (Ratio score): High Skill (>=70 %); Moderate Skill (>=50 % & <70 %); Low Skill (<50 %).

Hanssen and Kuipers (HK) Score: High Skill (>=0.25); Moderate Skill (>=0.10 and <0.25); Low Skill (<0.10)

Table 2. Year and season wise forecast and observed rainfall (mm) status for Jagtial district

Year	South-west monsoon			Post monsoon		
	Fcst (mm)	Obs (mm)	Diff (mm)	Fcst (mm)	Obs (mm)	Diff (mm)
2017	1108	408.9	-699.1	265	110.8	-154.2
2018	769	679.8	-89.2	87	15	-72
2019	1294	770.7	-523.3	320	181.3	-138.7
2020	789	763.9	-25.1	273	153.7	-119.3
2021	1739	1200.9	-538.1	389	74.1	-314.9
2022	3008	1512.7	-1495.3	543	28.4	-514.6
2023	2071	1192.4	-878.6	59	23.5	-35.5

***Fcst** - forecasted rainfall in mm ***Obs** - observed rainfall in mm ***Diff** - Difference between observed and forecasted rainfall in mm

Table 3. Year wise quantitative and qualitative methods of validation of post monsoon rainfall for Jagtial district

S. No.	Particular	Symbol	2017	2018	2019	2020	2021	2022	2023
1	No: of days when rain was observed and forecasted	YY	3	0	10	7	3	2	0
2	No: of days when rain was observed but not forecasted	YN	14	7	13	8	20	16	5
3	No: of days when rain was not observed but forecasted	NY	1	1	1	1	1	0	1
4	No: of days when rain was not observed and also not forecasted	NN	74	84	68	76	68	74	86
5	No: of matching cases (YY +NN)	MAT	77	84	78	83	71	76	86
6	Total no: of forecast days, N=Total no: of days-no: of missing days	N	92	92	92	92	92	92	92
7	Skill Score or Ratio score of rainfall (%)	RS	83.7	91.3	84.8	90.2	77.2	82.6	93.5
8	Hanssen & Kuipers index (H.K. Score)	H.K	0.16	0	0.42	0.45	0.12	0.11	0
9	Root Mean Square Error	RMSE	7.71	3.17	6.5	10.9	8.92	14.2	3.25
10	Error structure for rainfall (for matching cases)	Correct	96.1	100	87.2	91.6	95.8	97.4	100
		Usable	0	0	1.28	1.2	0	0	0
		Unusable	3.9	0	11.5	7.23	4.23	2.63	0
		% Usability	96.1	100	88.5	92.8	95.8	97.4	100
11	Correlation of rainfall	R	0.31	0	0.5	0.2	0.17	0.18	0

Changes in the distribution of rainfall in the past decade

There has been a significant change in the distribution of rainfall during the south-west monsoon (June to September) in comparison to the period of post-monsoon (October to December) in Jagtial district since the past decade (2014- 2023) against a normal baseline of the past 30 years. The rainfall during July and September is increased with excess amount of up to 27 % in the past decade (Fig. 6). This may be due to an increase in the number of heavy rainfall events since the past decade during the period of south-west monsoon. With fewer significant disturbances and less unpredictability, the atmosphere is often more stable during the post-monsoon season. Hence, forecasting was made simpler by the fewer severe weather systems and the decreased inter-seasonal variability resulted in higher rain forecast accuracy during the post-monsoon period. The studies of uneven rainfall distribution during southwest monsoon in Srilanka and in Tamil Nadu of India resembles the results of current studies (20, 21).

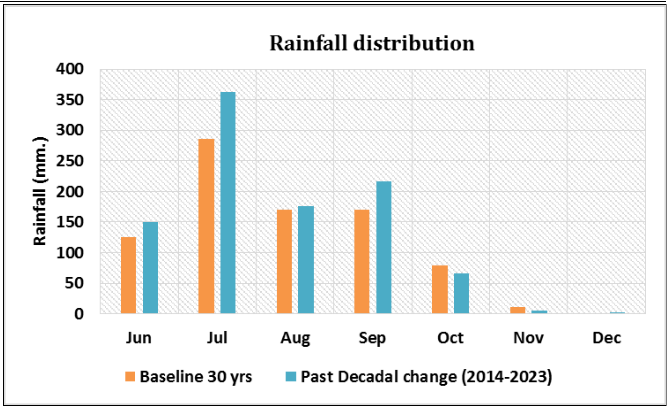

Fig. 6. Changes in rainfall distribution in Jagatai district during past decade (2014-2023) in comparison to Baseline of past 30 years.

Conclusion

From the present study, it is concluded that the medium-range weather forecast accuracy of rainfall was found to be high in the case of post-monsoon, whereas there is a moderate level of accuracy during the south-west monsoon period for the Jagtial district. There is a need for the improvement of rain forecast accuracy for the season of southwest monsoon as the rainfall received during this period is contributing up to 75 % of the annual rainfall of Jagtial district, where farming communities are primarily dependent on the cultivation of rainfed crops and sustaining their farm income as livelihood for the Kharif season. Increasing the accuracy of southwest monsoon rainfall forecasts requires new modelling methods, enhanced data gathering, cutting-edge technology and international cooperation. Planning for agriculture, water management, disaster preparedness and public safety can all benefit from the India Meteorological Department's increased capacity to provide more accurate and dependable monsoon forecasts by investing in high-resolution models, enhancing observational networks and implementing AI-based techniques. Future research directions will focus on improving the precision and impact of forecasts, particularly for extreme weather events, localized phenomena and long-term trends related to climate change, for better agriculture planning for the farmers of Jagtial in changing farming techniques. Government economic policies are heavily influenced by seasonal forecasts. Seasonal forecasts heavily influence government economic policies; if a significant drought is anticipated with precise forecasts, monetary policy can be relaxed to preserve growth targets.

Acknowledgements

The authors are thankful to the Meteorological Centre, India Meteorological Department, Hyderabad for timely assistance in provision of regular weather forecast to the Agromet Field Unit and supporting timely reach of agromet advisories to the farming community of Jagtial district from RARS, Jagtial.

Authors' contributions

SB carried out data analysis and written the original draft. GS made the conceptualization and supervised the work. ER carried out data retention and interpretation. DRD aided in improvising the content. NS supported the review of work. NB and BS involved in data annotation and curation. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Kumar V, Khan S. Importance of weather prediction for sustainable agriculture in Bihar, India. Arch Agric Environ Sci. 2017;2(2):105–8.
2. Geneti TZ. Review on the effect of moisture or rain fall on crop production. Civ Environ Res. 2019;11(2):1–7.
3. Chuku CA, Okoye C. Increasing resilience reducing vulnerability in sub- Saharan African agriculture: strategies for risk coping and management. Afr J Agric Res. 2009;4(13):1524–35.
4. Arulmathi C, Arul Prasad S, Jayakumar J, Natarajan K, Vengateswari M. Seasonal Rainfall Forecast Verification Analysis for Vridhachalam, Tamil Nadu, India. Int J Environ Clim Chang. 2023;13(9):3282–87. https://doi.org/10.9734/ijecc/2023/v13i92579
5. Cabrera VE, Solís D, Baigorria GA, Letson D. Managing climate variability in agricultural analysis. Ocean Circulation and El Niño: New Research. Nova Science Publishers, Inc. Hauppauge, NY. 2009:163–79.
6. Ziervogel G, Opere A. Integrating meteorological and indigenous knowledge-based seasonal climate forecasts for the agricultural sector: lessons from participatory action research in sub-Saharan Africa. CCAA learning paper.2010:1–19.
7. Hansen JW, Mason SJ, Sun L, Tall A. Review of seasonal climate forecasting for agriculture in Sub-Saharan Africa. Exp Agric. 2011;47(2):205–40. https://doi.org/10.1017/S0014479710000876
8. Vaughan C, Dessai S. Climate services for society: Origins, institutional arrangements and design elements for an evaluation framework. Wiley Interdiscip Rev Clim Change. 2014;5(5):587–603. https://doi.org/10.1002/wcc.290
9. Sneha Babu R, Uma G. Analyzing the Impact of Rainfall Patternson Agriculture, Economy and Tourism in India: A Statistical Approach. Int J Environ Clim Chang. 2023;13(11):4626–37. https://doi.org/10.9734/ijecc/2023/v13i113642
10. Nyadzi E, Werners SE, Biesbroek R, Ludwig F. Techniques and skills of indigenous weather and seasonal climate forecast in Northern Ghana. Clim Dev. 2020;13(6):551–62. https://doi.org/10.1080/17565529.2020.1831429
11. Paparrizos S, Dogbey RK, Sutanto SJ, Gbangou T, Kranjac Berisavljevic G, Gandaa BZ, et al. Hydro-climate information services for smallholder farmers: Farmer support app principles, implementation and evaluation. Climate Services. 2023;30:100387. https://doi.org/10.1016/j.cliser.2023.100387
12. Rathore LS, Parvinder Maini. Economic impact assessment of agro-meteorological advisory service of NCMRWF 2008. Report No. NMRF/PR/01/2008, 104pp, Published by NCMRWF, Ministry of Earth Sciences, Government of India. https://www.ncmrwf.gov.in/NCMRWF_REPORT.pdf
13. Jaseena KU, Kovoor BC. Deterministic weather forecasting models based on intelligent predictors: A survey. J King Saud Univ Comput Inf Sci. 2022;34(6):3393–412. https://doi.org/10.1016/j.jksuci.2020.09.009
14. Paparrizos Spyridon, Emmanuel MNAN Attoh, Samuel J Sutanto, Nina Snoeren, Fulco Ludwig. Local rainfall forecast knowledge across the globe used for agricultural decision-making. Sci Total Environ. 2023;899:165539. https://doi.org/10.1016/j.scitotenv.2023.165539
15. Lunagariya MM, Mishra SK, Pandey V. Verification and usability of medium range weather forecast for Anand region. J Agrometeorology. 2009;11:228–33.
16. Damrath U, Doms G, Fruhwald D, Heise E, Richter B, Steppeler J. Operational quantitative precipitation forecasting at the German Weather Service. J Hydrol. 2000;239:260–85. https://doi.org/10.1016/S0022-1694(00)00353-X
17. Singh Priyanka, Mall Rajesh, Singh KK, Das Ananda, IMD Mausam. Verification of WRF model forecasts and their use for agriculture decision support in Bihar, India. Mausam. 2024; 75(1):197–204. https://doi.org/10.54302/mausam.v75i1.6037
18. Brian Collins, Yunru Lai, Uwe Grewer, Steve Attard, Justin Sexton, Keith G Pembleton. Evaluating the impact of weather forecasts on productivity and environmental footprint of irrigated maize production systems. Sci Total Environ. 2024;954:176368. Collins). https://doi.org/10.1016/j.scitotenv.2024.176368
19. Sankar T, Arul Prasad, Sudarmanian NS, Dheebakaran Ganesan. Weather Forecasting in Agriculture. 2019;16:57–81. https://doi.org/10.22271/ed.book.390
20. Jayawardena ISP, Punyawardena BVR, Karunarathne MDRK. Importance of integration of sub seasonal predictions to improve climate services in Sri Lanka case study: Southwest monsoon 2019. Climate Services. 2022;26:100–296. https://doi.org/10.1016/j.cliser.2022.100296
21. Dheebakaran GA, Arulprasad S, Kokilavani S, Panneerselvam S. Astrometeorology: An option to improve the accuracy of numerical daily rainfall forecast of Tamil Nadu. Editorial Board. 2017;19:205–11.