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Verification of WRF model forecasts and their use for agriculture decision support in Bihar, India

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सार – कृषि और जल प्रबंधन में निर्णय लेने के लिए उच्च स्थानिक विभेदन के साथ मौसम का पूर्वानुमान प्रासंगिक हो गया है। यह शोध कार्य भारत के बिहार में नालंदा, सुपौल और पूर्वी चंपारण जिलों के लिए भारत मौसम विज्ञान विभाग- मौसम अनुसंधान और पूर्वानुमान मॉडल (आईएमडी-डब्ल्यूआरएफ) द्वारा तीन दिनों की लीड अवधि के लिए वर्षा पूर्वानुमान के सत्यापन के लिए किया गया है। तीन दिनों की लीड अवधि तक मॉडल के कौशल का मूल्यांकन 2020 और 2021 के मॉनसूनके लिए पंचायत स्तर पर उसी स्थान के लिए दैनिक आधार पर किया गया है। परिणामों से पता चलता है कि पूरे क्षेत्र में और विशेष रूप से सुपौल जिले में पूर्वानुमान और प्रेक्षण में अच्छे तालमेल की पुष्टि हुई है, जहां सभी पंचायतों के लिए लगभग 70% वर्षा और अनावृष्टि वाले दिनों का सही पूर्वानुमान किया गया है। इसके अलावा, कुल 812 पंचायतों में से 90 प्रतिशत में गलत अलार्म का अनुपात < 0.3 रहा है, तथा हैनसेन और कुइपर का स्कोर भी लगभग सभी स्थानों पर > 0.25 पाया गया है। यह मूल्यांकन कृषि में तीन दिनों के अग्रिम पूर्वानुमान के लिए डब्ल्यूआरएफ मॉडल के उपयोग का समर्थन करता है। हालाँकि, मात्रात्मक सत्यापन से पता चलता है कि मध्यम वर्षा के लिए मॉडल से मिले परिणाम अधिक विश्वसनीय हैं।

ABSTRACT. Weather forecasting with high spatial resolution has become increasingly relevant for decision support in agriculture and water management. Present work is carried out for verification of India Meteorological Department-Weather Research and Forecasting Model's (IMD-WRF) rainfall forecast with three day lead time over Nalanda, Supaul and East Chamaparan districts in Bihar, India. The model's skills up to a lead time of three days are evaluated with panchayat level daily in situ observations for Monsoon 2020 and 2021. Results confirmed show good agreement of forecast and observation throughout the domain and particularly over Supaul district, where about 70% of rain and no-rain days are correctly predicted for all panchayat. Also, False Alarm Ratio is < 0.3 in 90 percent of the total 812 panchayat and Hanssen and Kuiper's score is also found > 0.25 in almost all places. This evaluation supports the use of the WRF model forecast in agriculture up to three days in advance. However, the quantitative verification suggests that model output is more reliable for moderate rainfall.

Key words – WRF model, Agriculture, Weather and climate.

1. Introduction

Weather and climate play an important role in agriculture. Weather plays a profound influence on crop growth, development and yields; also on the incidence of pests and diseases; water requirement; fertilizer application and so on. The Meteorological condition of any region plays a crucial role in determining the success or failure of crop production during the phase of growth and development of plant. Variability in the weather *i.e.* delay in the monsoon, excessive rains, low rainfall, flood, high temperatures, *etc*. during the crop period, would affect the crop growth and the quality and quantity of the total production. Accurate and regular meteorological information has great potential for management optimization of farmers. The weather based Agromet advisory Services for the farmer have the potential to reduce the weather aberration associated losses to a large extent by suitable adoptive measure dissemination to the farmer and planner's community Rathore *et al*., (2009). Weather forecast supports improve the production of agriculture in scientific way, reduce risks and losses and increases water use efficiency Cabrera *et al*., (2007), Ziervogel and Opere, (2010) Hansen *et al*., (2011). Availability of weather forecast in different time scale in advance provides opportunity to efficiently minimize the loss from adverse weather and took the benefit from benevolent weather. By optimum weather forecasts, losses in crops can be optimized by undertaking some crop management in time and selecting agriculture crops most suitable for the anticipated climatic conditions Kenkel and Norris, (1995). Stone and Meinke (2006) looked at weather information as a product for farmers in two distinct forms; tactical (short-term) and strategical (long-term) based on the time range to which key management decisions are influenced by weather information. Therefore, understanding the expected short-run and long run changes in the weather variables will go a longways to assist smallholder farmers to plan for the farming activities with the aim of lessening the potential effect of the weather.

In order to test and enhance the forecasting system, verification of the forecast is useful with maximum possible years of data. The verification is mostly performed by calculating the forecast accuracy and its variation/improvement over the time. According to Murphy (1993), the goodness of a forecast is distinguished by consistency (*i.e.*, degree which the forecast corresponds to the forecaster's best judgement about the situation), value (the degree to which the forecast helps a decision maker to realize some incremental economic and other benefits) and quality (degree to which the forecast corresponds to what actually happened). Murphy, (1993) has described nine aspects (attributes) that contribute to the quality of a forecast. These include bias, resolution, accuracy, skill, discrimination, association, uncertainty, reliability and sharpness. The scope of the present study is operational monitoring of forecast quality over time along with the better understanding of the forecast errors which would help model improvement and integration of output in advisory services. In the study panchayat level WRF rainfall forecast verification for monsoon between 2020 and 2021 was performed for 3 districts of Bihar, *viz.*, Nalanda, East Champaran and Supaul in two ways, *i.e.*, (*i*) Categorical (Yes/No) Verification: Ratio Score (RS), Hansen Kuipers skill score (HK), Probability of Detection (POD), False alarm rate (FAR)to verify the (Yes/No). Rainfall forecast (*ii*) Quantitative Verification: Hit Rate to verify the category.

2. Study area

Bihar state is located in the eastern part of India covers an area of 94,163 square kms bounded by 24º 20′ N to 27º 31′ N latitude and 83º 20′ E to 88º 18′ E longitude. Total annual rainfall of the state is 116.4 cm and maximum rainfall is received over the North eastern part of the state. The southwest monsoon season is the main rainy season over the state and the total amount of rainfall of about 86% is received in the southwest monsoon season (June to September), about 2% in the winter season (December, January and February) about 6% in the pre-monsoon (March-May) and about 6% in post monsoon season (October and November). The average annual rainfall of Supaul, Nalnda and East Champaranis 1253.0 mm, 903.0 mm and 1144.8 mm respectively, as per the India Meteorological Department Met Monograph. The Selected 3 districts in the present study belong to 3 different agroclimatic zones of Bihar, where East Champaran belongs to Agroclimatic Zone I having medium acidic heavy textured soil with the main crops rice, wheat maize and arhar. Supaul is in Agroclimatic Zone II having light to medium textured soil and the main crops are maize, mustard, jute and sugarcane, whereas Nalanda belongs to Agroclimatic Zone III with old alluvium soil and rice wheat and gram as major crop Singh (2013).

TABLE 1

WRF model configuration

Dynamics/Physics	WRF
Horizontal Resolution	3 km
Data Assimilation	WRFDA
Dynamics	Eulerian
Vertical level in eta co-ordinate	45 Normallized pressure level
Planetary Boundary Layer scheme	Mellore-Yamada-Janjic scheme
Shortwave/Longwave Radiation Scheme	Goddard shortwave/RRTM scheme
Cumulus parameterization	Grell 3D Ensemble cumulus scheme
Cloud microphysics	WRF Single-Moment 5 class scheme
Land surface Process scheme	NOAH land surface model

3. Material and methodology

3.1. *WRF model*

The Weather Research and Forecasting (WRF) Model is an atmospheric model designed for both research and numerical weather prediction (NWP). The WRF model is officially supported by the National Centre for Atmospheric Research (NCAR), it has become a true community model due to its long-term development through the interests and contributions of a worldwide user base. From this, WRF has grown to provide special capabilities for a range of Earth system prediction applications, such as mesoscale weather forecast, air chemistry, hydrology, wild land fires, hurricanes and regional climate. NCAR developed ARW (Advance Research WRF) version of WRF is used by the India Meteorological Department it also consists of the assimilation component WRF Data Assimilation (WRFDA). IMD WRF (ARW) IMD-WRF is run at 3 km resolution four times at 0000, 0600, 1200 and 1800 UTC. Forecast outputs at 3 km resolution are made available after 6 hrs of model run time for the next 3 days. Inclusion of Land use Land cover change in WRF helps to evaluate the impacts of the use of different LULC data on simulated meteorological variables and meso scale forecasting. In Table 1, WRF model configuration with physics and dynamics is elaborated.

In the present study, daily rainfall forecast of WRF models for monsoon 2020 and 2021 was verified with panchayat level automatic rain gauge observed rainfall of 3 districts of Bihar. There were 175,395 and 242 point location observation data received from Supaul, East Chamaparan and Nalanda districts respectively under the Meghdoot scheme of the State Government of Bihar. In general, forecasts are obtained at regular grid intervals and not at particular locations, hence forecast at the nearest grid point is considered as the forecast for that location, Kumar *et al*., (2000).

The rainfall forecast verification (Table 2) was performed in two ways, *i.e.*, (*i*) Categorical (Yes/No) Verification: Ratio Score (RS), Hansen Kuipers skill score (HK), Probability of Detection (POD), False alarm rate (FAR) have been used to verify the Rainfall forecast (Yes/No). (*ii*) Quantitative Verification: Hit Rate has also been used to verify the rainfall forecast. The Following are the skill scores used for verification study, Bhardwaj *et al*., (2009), Kumar *et al*., (2017).

3.1.1. *Skill scores used for verification are as follows*

The standard skill scores are used for rainfall and other weather parameters for verification study Murphy and Katz (1985).

(*a*) *Skill scores for Yes/No Rainfall* : A=No. of Hits (predicted and observed), B=No. of False Alarms (predicted but not observed), C=No. of misses (observed but not predicted), D= No. of correct predictions of no rain. (Neither predicted nor observed)

(*i*) *Forecast Accuracy (ACC) or Ratio Score or Hit Score*

It is the ratio of correct forecasts to the total number of forecasts.

$$\mathrm{RS} = \frac{\text{Correct Forecast}}{\text{Total Forecast}} = \frac{\mathrm{A+D}}{\mathrm{N}} = \frac{\mathrm{YY+NN}}{\left(\mathrm{YY+NN+YN+NY}\right)}$$

Range : 0 to 1
Perfect : 1

(*ii*) *Hanssen and Kuipers Scores or True Skill Score (HK score)*

It is the ratio of economic saving over climatology due to the forecast to that of a set of perfect forecasts. It shows how well the forecast separates the "yes" events from the "no" events.

$$\mathrm{HK} = \frac{\text{Correct Forecast} - (\text{Correct Forecast})_{\text{random}}}{\mathrm{N} - \left(\text{Correct Forecast}\right)_{\text{random, unbiased}}}$$

$$\mathrm{HK} = \left(\mathrm{Acc}\right)_{\text{events}} + \left(\mathrm{Acc}\right)_{\text{non-events}} - 1 = \frac{\mathrm{AD-BC}}{\left(\mathrm{A+C}\right)\left(\mathrm{B+D}\right)}$$

Range: -1 to +1
Perfect:1

Advantage: equal emphasis on yes/no events

(*iii*) *False alarm rate (FAR)*

Fraction of the predicted "yes" events actually did not occur.

$$\mathrm{FAR} = \frac{\text{False alarms}}{\text{Hits} + \text{False alarms}}$$

$$\mathrm{FAR} = \frac{\mathrm{B}}{\mathrm{A+B}}$$

(*iv*) *Probability of detection (POD)*

The fraction of the observed “yes” events which were correctly forecasted.

3.1.2. *Skill score for quantitative precipitation*

The quantitative precipitation is divided into the following six classes as per the IMD criteria;

o_1, f_1; less than threshold (Th) is no rain
o_2, f_2; greater than Th and less than 15.5 mm
o_3, f_3; greater than 15.5 mm and less than 64.5 mm
o_4, f_4; greater than 64.5 mm and less than 115.5 mm

Fig. 1. Skill score of Monthly and Seasonal skill score of Monsoon 2020

o_5, f_5; greater than 115.5 mm and less than 204.5 mm
o_6, f_6; greater than 204.5 mm

Then a 6×6 contingency table is defined as follows.

	O1	O2	O3	O4	O5	O6	
F1	n11	n12	n13	n14	n15	n16	n1t
F2	n21	n22	n23	n24	n25	n26	n2t
F3	n31	n32	n33	n34	n35	n36	n3t
F4	n41	n42	n43	n44	n45	n46	n4t
F5	n51	n52	n53	n54	n55	n56	n5t
F6	n61	n62	n63	n64	n65	n66	N6t
	nt1	nt2	nt3	nt4	nt5	nt6	Ntt

3.1.3. *The hit rate (HR) for quantitative precipitation is defined as*

$$\mathrm{HR} = \left(\mathrm{n11} + \mathrm{n22} + \mathrm{n33} + \mathrm{n44} + \mathrm{n55} + \mathrm{n66}\right) / \mathrm{ntt}$$

4. Results and discussion

Contingency tables for daily precipitation events were computed for all stations in the study area. The skill scores were then computed for each station for 3 days forecast lead time. Rainfall forecast verification based on skill scores is presented in the result section using location rainfall data, for JJAS 2020 and JJAS 2021. For presentation purposes district wise station percent falling into the respective category of scales are presented and the

Fig. 2. Skill score of Monthly and Seasonal skill score of Monsoon 2021

scale of each score is divided into low, medium and high category.

Ratio score (RS) is a measure of the percent of correct forecast; this score is ranges from 0-1 or 0-100% score, where 1 or 100 implies a perfect scores. Monthly *i.e.* June, July, August and September Day 1, Day 2, Day 3 Ratio score and Monsoon/JJAS scores are presented in Figs. 1&2 where > .75 RS is considered as high score, 5-.75 medium and < .5 as low. Results depict that the ratio score of both 2020 and 2021 lies in the range of medium and high only.

The false alarm ratio (FAR) is a measure of the fraction of predicted 'yes' events that actually did not occur (*i.e.*, false alarms). The FAR, ranges from value 0 to 1 and a score value of 0 imply a perfect forecast. This score is sensitive to false alarms, but it ignores the missed events. It is very sensitive to the climatological frequency of the event. Monthly D1, D2, D3 FAR for JJAS scores are presented in Figs. 1&2, where < .3 FAR is considered as high score whereas .3 - .5 and > .5 as medium and high respectively. FAR for both 2020 and 2021 lies in the medium and high range only.

The Hanssen and Kuiper's (HK) score indicates how well the forecasts separate the 'yes' events from the 'no' events. The score value ranges from −1 to 1 where 0 indicating no skill and 1 indicating a perfect score. The HK score uses all the elements of the contingency table. In the present study, HK score was found in the range of 0 to .25 in more than 90% of the cases however, negative

TABLE 2

Forecast verification matrix

Event forecasted	Event observed		Total (forecasted)
	Yes	No	
Yes	A (hit)	B (false alarm)	A+B
No	C (miss)	D (correct rejection)	C+D
Total (observed)	A+C	B+D	N=A+B+C+D

TABLE 3

Rainfall classification

Descriptive Term Used	Rainfall Amount (mm)
No Rain	<.01
Light Rain	.1 to 15.4
Moderate Rain	15.5 to 64.4
Heavy Rain	64.5 to 115.4
Very Heavy Rain	115.5 to 204.4
Extremely Heavy Rainfall	>=204.5

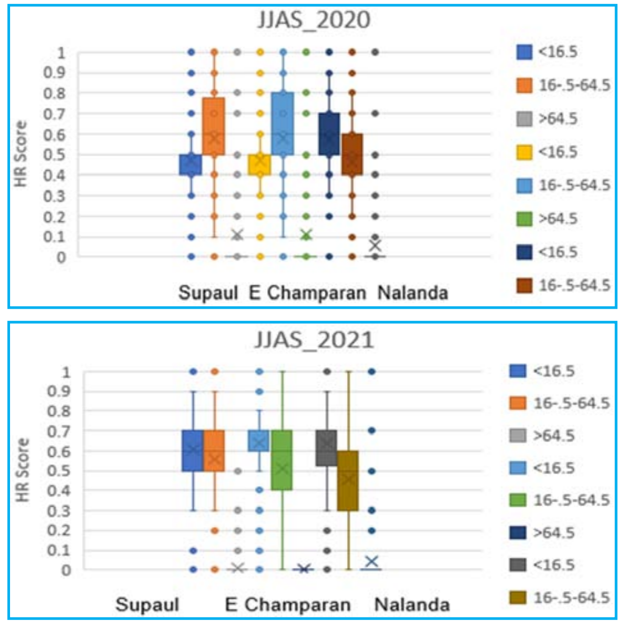

Fig. 3. Box plot of quantitative scores over study area in 2020 and 2021

scores are rare events 1 - 3 % only during 2020 and 2021 monsoon. Probability of Detection POD was also calculated which lies between .98 to 1 for both 2020 and 2021, a graphical representation of POD is not depicted in result, since the values were ranged from .98 to 1 in all cases.

Results indicate that model performance was in medium to high range for all scores and for all stations. Monthly verification indicates that June, July and August forecast performance improved in 2021 over 2020 whereas September skill scores for 2020 were better in comparison to 2021. In the overall monsoon performance of both the years 2020 had a better skill score than in 2021 due to a good skill score in September 2020. Forecast performance in Supaul and East Champaran were better than Nalanda during both the 2020 and 2021 monsoon.

4.1. *Quantitative rainfall forecast verification*

The quantitative rainfall verification scores for rainfall have been used in the study to evaluate the model performance. The rainfall categories used in the study, are the standard rainfall classification of India Meteorological Department. Rainfall classification based on rainfall amount is depicted in Table 3. The methodology used for categorical forecast verification is also grid to point where point observations of TRG data were used for verification of 3 km WRF model output.

Model performance in quantitative verification is depicted in Fig. 3, where rainfall values were classified at light < 16.5 mm moderate 16.6 to 64.5 and heavy to very heavy > 64.5. The box and whisker plot presentation of the HR scores depicts that model performance in prediction of medium rainfall range is better in agreement than light rainfall, whereas prediction of heavy and very heavy rainfall fails. Study carried out by Das *et al*. (2016) for monsoon 2010 over homogeneous region of India suggested that model forecasts carry more points with lower amount of rainfall and forecast by chance is more likely. Grid points with heavier rainfall are less in model forecasts and therefore, the scores degrade rapidly as seen for other scores. However, the chance of a random forecast within the medium rainfall category is less likely during the monsoon as compared to other category. Rainfall verification of 2014 Indian monsoon with IMD gridded data by Bohmia *et al.* (2019) found that low and moderate rainfall was forecasted reasonably well by the WRF model compared to heavy rainfall and the verification over five homogeneous rainfall zones of India show that the WRF model was able to predict rainfall reasonably well with higher correlation coefficient, lower bias and root mean square deviation in most of the zones.

4.2. *Extreme weather event*

To analysis the WRF forecast for extreme events a detail analysis of July 20, 2020 rainfall in East Chamaparan district of Bihar was also carried out. As per India Meteorological Department (Monsson Report, 2020), The period, 19-23 July 2020 witnessed the first monsoon break where monsoon trough passed through the foothills of the Himalayas along with strong south-westerly winds over the region with embedded cyclonic

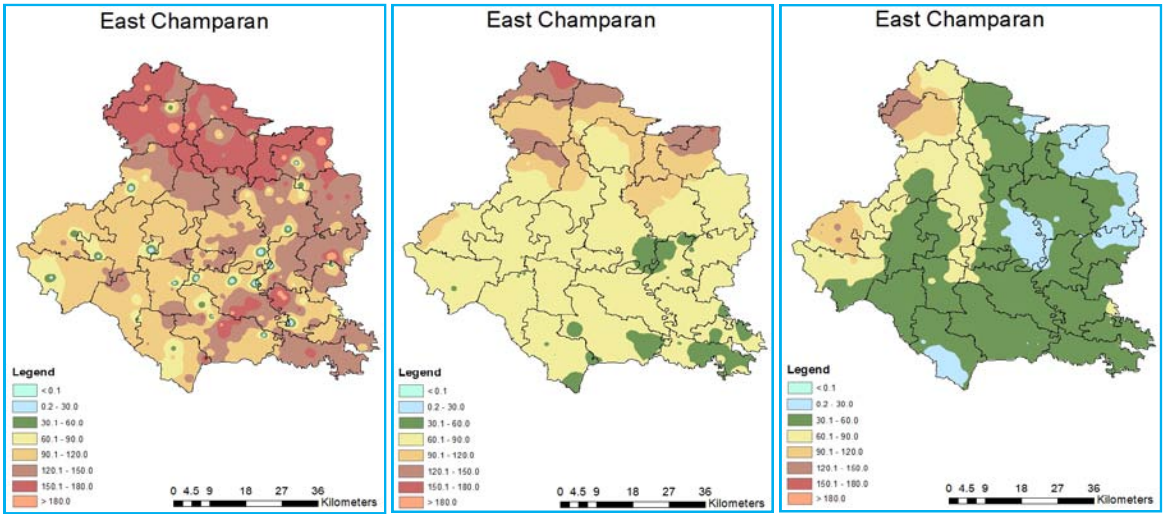

Fig. 4. Observed and D1, D2 Rainfall forecast for 20 July 2020 in East Chamaparan

circulation over eastern Uttar Pradesh and adjoining Bihar. These synoptic condition lead to intense to very intense convection over the region, and heavy to very heavy and extremely heavy rainfall during the period ,which cause flood like situation in Ganga Basin over the Bihar region. On 20th July Ahirwalia, Chakia, Chatia, Kessariah, Lalbegiaghat, Mahedi/Mehshi, Motihari and Patahi of East Champaran witnessed 114.8, 193.4, 105.6, 187, 103, 165.8, 134.4 and 174.8 mm of rainfall respectively. In Fig. 4, the comparison of observed and Day 1 and Day 2 forecast is presented. Figure depicts that the WRF model is able to forecast the rainfall in heavy to very heavy range and extremely heavy in a few locations whereas district received very heavy to extremely heavy observed rainfall in most part. The model is able to capture extreme events in the day 1 forecast but the intensity is not properly identified. Das and Kaur (2016) shows 42 percent correct forecast of extreme rainfall events by WRF model in sub basin region during monsoon 2021. Paripathi *et al*. (2022) in their study on extreme rainfall event occurrence over India, shows an increase in extreme rainfall over major parts of India during strong La Niña except over parts of Central India and NEI where strong El Niño dominates; the feature was well captured in the WRF model. The categorical prediction is not captured very well, but the information of upcoming rainfall in 1-3 days in advance is helpful in taking tactical decision.

4.3. *Use of WRF forecast in agriculture*

Farmers are inherited the knowledge of climate based crop management and standard agronomic practices, but in the recent scenario where extreme weather is increasing day by day, climate based farming practices is no longer adequate. To decide on crop management they essentially require the weather information in advance along with a few tips for tactical decisions as to what to do and when to do their crop management to achieve higher yields on a sustainable basis. The use of meteorological forecasts depends highly on the degree of ease of access and the ease of use of the forecasts. For meteorological forecasts to be valuable, they need to be to be delivered in advance and at the right time to enable farmers to make appropriate decisions. The potential use of the WRF forecast coupled with a crop simulation model for improvement of rice yield based on fertilizer assessment in Thailand was suggested by Amnuaylojaroen & Chanvichit (2022). Application of high resolution NCAM WRF forecast for soil moisture deficit and agriculture drought characterization in Gyeonggi province of South Korea by Hong *et al*. (2021) suggests NCAM-WRF climatic variables to the modelling of Soil Moisture Content/Soil Moisture Potential profiles can lead to drought characterization on site-scale while accounting for the spatial variability of rainfall and other climatic variables. In a feedback survey carried out in Gramin Krishi Mausam Sewa scheme of India Meteorological Department for Khari 2020, the response received from framers of Bihar shows the rainfall forecast is the most desirable information by farmers. The verification results of the WRF forecast in the above study support the potential of rainfall forecast use in Agriculture decision management system in Bihar, availability of rainfall forecast and forecast based agromet products like soil moisture indicator will be helpful for the farmers.

5. Conclusion

In this study, performance of high resolution WRF forecast in three districts falling in three different Agro climatic Zone of Bihar was carried out for two year monsoon rainfall, with well-established methodology of forecast verification. For Yes/No rainfall WRF shows high skill scores for all the districts and performs better for Supaul district and comparatively lower in the case of Nalanda. Model's performance in Nalanda may be least in comparison to Supaul and East Champaran due to least number of rainy days in comparison to other districts. However, further study is required to support the finding. The performance of categorical verification also shows good agreement for Nalnda in the light rainfall then the moderate rainfall category, whereas Supaul and East Champaran show good agreement in moderate rainfall category. Overall, the performance of the WRF forecast for rainfall verification supports the potential of rainfall forecast use in the agriculture decision management system in Bihar. Model output may help to raises the alarming situation from one to three days in advance.

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