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Effect of Weather Parameters on Wheat Productivity: A Statistical Analysis Using SPSS

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ABSTRACT

The present study was conducted during the year March, 2021 to March, 2022 at Krishi Vigyan Kendra (KVK) Baghpat, Uttar Pradesh, India under Gramin Krishi Mausam Seva-District Agromet Unit (GKMS-DAMU) scheme to identify the effects of weather parameters on wheat productivity in two districts of Uttar Pradesh, namely Baghpat and Meerut for the five *rabi* seasons (October-April) from 2012 to 2017 using statistical analysis technique in the Statistical Package for the Social Sciences (SPSS). The study utilized *in-situ* collected weekly data of weather parameters *viz*., bright sunshine hours, maximum temperature, minimum temperature, rainfall, maximum relative humidity, minimum relative humidity and wind speed. The data of wheat yield (t ha^{-1}) was collected from Directorate of Economics and Statistics, Department of Agriculture website (http://aps.dac.gov.in/APY/Public_Report1.aspx). The SPSS analysis revealed that weather conditions play a significant role in wheat productivity in both districts. The results showed that maximum temperature during April first week had a positive correlation with wheat yield for Baghpat district. Meanwhile, in Meerut, the most significant weather parameters that affected wheat yield were February's fourth week rainfall, followed by bright sunshine hours of March third week, and minimum relative humidity of April third week. It was also observed that intense rainfall reduced wheat yield in Meerut during the 2014–15 *Rabi* season. The findings of present study could be useful for policymakers & farmers in developing strategies to improve wheat productivity. The study emphasized the importance of considering local weather conditions for better decision making in agricultural operations.

KEYWORDS: Wheat productivity, weather parameters, SPSS, regression model

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1. INTRODUCTION

The agricultural sector holds a pivotal position in the global economy, with wheat standing as one of the paramount cereal crops cultivated worldwide (Giraldo et al. 2019; Jakhar et al., 2023). It is one of the major staple food crop, with a global annual production of over 700 million tons in 2020 (Guarin et al., 2022; Guo 2023). In India, it is extensively grown in Uttar Pradesh (Balaganesh et al. 2019). Due to the exceptional significance of wheat in Indian agriculture and economy, it is imperative to gain a comprehensive understanding of the various factors that exert influence upon its productivity (Baig et al. 2023). Among the numerous factors, the growth and development of wheat crop is highly sensitive to weather conditions (Sonkar et al. 2019). The better understanding of weather and crop relation is crucial to ensure food security and sustainable agricultural practices (Wu et al., 2023).

Over the years, researchers have conducted various studies to understand the complex relationship between weather parameters and crop yield (Chahal et al. 2007; Mishra et al., 2013; Das et al., 2018; Dubey et al., 2020). The weather parameters such as temperature, precipitation, humidity, etc. affect plant growth, flowering, grain development and ultimately productivity of wheat crop (Zhang et al., 2023). The temperature plays a crucial role in determining the protein content of wheat and affects different stages of its growth (Cai et al., 2022; Wieser et al., 2023). The occurrence of hot wind poses a substantial agrometeorological hazard for wheat crops due to its potential to trigger a decline in humidity levels. This reduction in atmospheric moisture availability consequently culminates in diminished wheat production (Wang et al., 2021). Heat stress in wheat can also result in pollen sterility, smaller grain size, and decreased yield (Ullah et al., 2022). Rainfall during the reproductive stage of wheat growth plays a pivotal role in determining the crop yield. Optimum rainfall at this stage is essential as it provides the necessary moisture required for successful pollination, fertilization, and grain development (Dhaliwal et al., 2022). Cool climate during early wheat growth aids optimal development, while high temperatures during tillering reduce yield. In contrast, cool climates in later growth stages accelerate grain formation (Kingra et al., 2018).

Effect of weather variables can vary across different regions and crop varieties, making it necessary to conduct region-specific analyses to obtain accurate and reliable results (Didari et al., 2023). The use of statistical analysis software, such as Statistical Package for the Social Sciences (SPSS), allows researchers to analyze large datasets, identify trends, and establish statistical relationships between variables (Varveris et al., 2023). SPSS provides a range of tools and techniques for data analysis, making it a valuable tool for conducting agricultural research (Tega and Bojago 2023). By employing SPSS, researchers can explore the relationship between weather variables and crop productivity, enabling policymakers and farmers to make informed decisions regarding agricultural practices, resource allocation, and risk management (Wangkheimayum and Paliwal, 2023). SPSS enables diverse statistical analyses: correlation, regression, and time series (Das and Kumar, 2019). Correlation analysis allows researchers to identify the strength and direction of the relationships between weather variables and wheat productivity (Banakara et al. 2023) Positive correlations indicate favorable weather conditions for wheat, while negative correlations suggest adverse effects. Regression models can predict productivity based on weather parameters aiding farmer decisions (Kumar et al., 2019). Time series analysis enables researchers to examine the trends and patterns in weather variables and wheat productivity (Ruan et al., 2022).

The present study was aimed to analyze the relationship between weather variables and wheat productivity using SPSS statistical package.

2. MATERIALS AND METHODS

2.1. Study area

The research focuses on Meerut and Baghpat districts of Uttar Pradesh, India. These districts are situated in the western part of the state and have a predominantly agricultural economy. Baghpat is situated at latitude 28.94°N, longitude 77.22°E, with an elevation of 253 masl, while Meerut is located at latitude 28.98°N, longitude 77.7°E, with an elevation of 247m asl. The Meerut district share its boundary with Muzaffarnagar (North), Bulandshahar (South), Ghaziabad (South) and Baghpat (West). While Baghpat share its boundary with Sonipat (West), Muzaffarnagar (North) and Meerut (East). Both districts are part of the larger Gangetic plain, characterized by fertile soil and favourable conditions for agricultural activities. The topography is relatively flat, allowing for easy cultivation and irrigation practices. The study area is characterized by a subtropical climate with hot summers and cool winters. The region receives most of its rainfall during the monsoon season, which lasts from June to September (Figure 1).

2.2. Data collection

The study was conducted in the year 2021 (March) to 2022 (March) for total duration of one year at Krishi Vigyan Kendra (KVK) Baghpat under District Agromet Unit (DAMU). The crop and weather data were collected for five *rabi* seasons (2012–2013, 2013–2014, 2014–2015, 2015–2016, and 2016–2017). The weather data for the

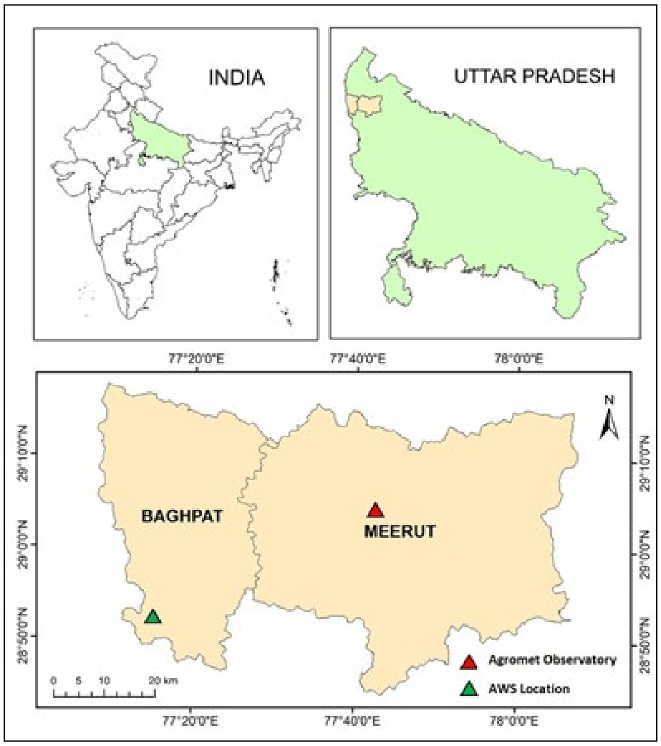

Figure 1: Study area map

Meerut District was obtained from the Agrometeorological Field Unit (AMFU), Modipuram, which operates under the Gramin Krishi Mausam Sewa (GKMS) scheme, a joint initiative of India Meteorological Department (IMD) and Indian Council of Agricultural Research (ICAR). The weather data for Baghpat District was sourced from the Automatic Weather Station (AWS) installed at KVK Baghpat under the National Innovations on Climate Resilient Agriculture (NICRA) Project. The wheat yield data (t ha^{-1}) for the five *Rabi* seasons was obtained from the Ministry of Agriculture and Farmer Welfare website (aps.dac.gov.in).

2.3. Statistical analysis

To achieve the stated objective, the statistical analyses were performed using the SPSS software. The investigation focused on assessing the influence of various weather parameters on wheat yield during five consecutive *rabi* seasons spanning from 2012 to 2017. The mean weekly weather data of seven weather parameters *viz.*, rainfall, maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, bright sunshine hours, and wind speed was meticulously computed for the period from the third week of December to the second week of May for each of these seasons. Subsequently, a multiple regression equation model was developed using the SPSS software. To ascertain the efficacy of this model, a comparison was drawn between the simulated yield and the actual observed yield, with the root mean square error (RMSE %) being employed as a metric for evaluation. Furthermore, the predictive capabilities of the developed models were assessed by employing the SPSS-generated equations to simulate wheat yield. This entailed a thorough examination of the concordance between the simulated yields and the observed yields. As a result of this comprehensive analysis, the weather parameters that exerted significant effects on wheat yield were effectively identified using the aforementioned methodology.

3. RESULTS AND DISCUSSION

3.1. Effect of weather parameters on wheat yield in Meerut

The outcomes of a meteorological yield model designed to forecast wheat yield in the Meerut district had been depicted in Table 1. Three distinct models, labeled as M_1, M_2, and M_3, were constructed using regression equations that incorporated specific weather parameters which exerted significant effect on yield of wheat crop. These parameters included February fourth week rainfall, March third week bright sunshine hours, and April third week minimum relative humidity. The goal of these models was to predict Meerut wheat yield based on these weather parameters. .

Table 1: Yield prediction models for wheat crop based on weekly weather parameters in Meerut District

Model	Regression equation	R^2
M_1	Ym=4.238-0.262*X1	0.95
M_2	Ym=3.440.222*X1+0.099*X2	0.99
M_3	Ym=3.511-0.231*X1+0.078*X2+0.003*X3	1.00

The models differed in terms of the predictor variables they consider. Model M_1 solely employed February fourth week rainfall as a predictor, M_2 combined February fourth week rainfall and March third week bright sunshine hours, while M_3 incorporated all three variables-February fourth week rainfall, March third week bright sunshine hours, and April third week minimum relative humidity. The coefficients in the regression equations indicate the direction and strength of the impact of each meteorological parameter on wheat yield. Negative coefficients for February fourth week rainfall (X_1) in Model M_1 and M_3 suggested that higher rainfall during these periods correlated with decreased yields. Positive coefficients for March third week bright sunshine hours (X_2) and April third week minimum relative humidity (X_3) in Model M_2 and M_3 indicated that increased bright sunshine hours and minimum relative humidity during their respective weeks correlated with higher yields. The coefficient of determination (R^2) values provide insights into how well each model fits the observed data. Model M_1, which relied solely on X_1, demonstrates an R^2 of 0.95, indicating that 95% of the variation in wheat yield could be explained by February fourth week rainfall. Model M_2, considering both X_1 and X_2, boasted an impressive R^2 of 0.99, explaining 99% of the yield variation. Notably, Model M_3 achieved a perfect R^2 of 1.00, implying that the combined influence of X_1, X_2 and X_3 fully accounted for the observed wheat yield variability in Meerut District. The root mean square error (RMSE) values provide a measure of the average prediction error of each model across all the *Rabi* seasons. Lower RMSE values indicated that the model's predictions were closer to the actual observed values. In this case, both Model M_3 and M_2 had the lowest RMSE value of 0.008, followed by Model M_1 with an RMSE of 0.09 (Table 2). This also suggested that Model M_3 was the most accurate in predicting the crop yields, but the differences in accuracy among the models were quite small. Across all the models, the predicted yields were generally very close to the observed yields, with only minor variations. This indicated that the models were performing consistently and were able to capture the patterns in the observed data effectively.

Table 2: Wheat yield predicted using SPSS for Meerut

Rabi season	Observed yield (t ha^{-1})	Yield predicted by model 1 (t ha^{-1})	Yield predicted by model 2 (t ha^{-1})	Yield predicted by model 3 (t ha^{-1})
2012-2013	4.13	4.15	4.13	4.13
2013-2014	4.29	4.23	4.29	4.30
2014-2015	3.22	3.21	3.21	3.23
2015-2016	4.09	4.23	4.08	4.09
2016-2017	4.36	4.23	4.35	4.37
RMSE (%)		0.09	0.008	0.008

The SPSS results for the Meerut district revealed a negative correlation between the rainfall of the fourth week of February and wheat yield. The fourth week of February during 2014-15 season observed a rainfall of 3.9 mm, while there were no other rainfall events recorded for other weeks of this month. Subsequently, the most substantial damage to wheat yield was also observed in 2014-15, with a yield as low as 3.22 t ha^{-1}. The SPSS analysis indicated that rainfall can result in damage to wheat crops. On analyzing the combined effect of rainfall (Table 3) and wind speed (Table 4) data for the month of February, it was observed that rainfall accompanied by high wind speeds during the grain-filling stage of wheat growth in February can lead to crop damage. A plausible explanation for this damage could be the lodging of crops during this grain-filling stage due to heavy rainfall coupled with elevated wind speeds. The descending order of yields was as follows: 4.36 (2016-17), 4.29 (2013-14), 4.13 (2012-13), 4.09 (2015-16), and 3.22 (2014-15). To achieve the highest yield in 2016-17, low wind speeds and the absence of rainfall events were necessary. In this year, a rainfall event occurred during the second week of February, amounting to 0.2 mm, which was insufficient to damage the wheat crop but did satisfy the crop's water requirements during the grain-filling stage. During this week, the wind speed was recorded at 2.6 m s^{-1}, higher than the 2014-15 event (1.7 m s^{-1}). However, due to the absence of rainy days, its detrimental impact was less pronounced than in 2014-15. Consequently, it can be concluded that rainfall accompanied by wind speed has the potential to damage crops, particularly if there are rainy days (>2.5 mm rainfall). Rainy days coupled with a gentle breeze can collectively reduce crop yield through lodging. Kingra (2016) further noted that diminished rainfall and a reduced frequency of rainy days throughout the reproductive growth phase of wheat, spanning the months of February

Table 3: Effect of February month's weekly rainfall on wheat yield

Rabi season	Crop yield (t ha^{-1})	February 1st week rainfall (mm)	February 2nd week rainfall (mm)	February 3rd week rainfall (mm)	February 4th week Rainfall (mm)
2012-2013	4.13	4.9	2.2	9.2	0.3
2013-2014	4.29	0.1	0.1	5.4	0.0
2014-2015	3.22	0.0	0.0	0.0	3.9
2015-2016	4.09	0.0	0.1	0.0	0.0
2016-2017	4.36	0.0	0.2	0.0	0.0

Table 4: Effect of february month's weekly wind speed on wheat yield

Rabi season	Crop yield (t ha^{-1})	February 1st week wind speed (m s^{-1})	February 2nd week wind speed (m s^{-1})	February 3rd week wind speed (m s^{-1})	February 4th week wind speed (m s^{-1})
2012-2013	4.13	0.4	1.0	0.7	0.9
2013-2014	4.29	0.1	0.8	1.4	0.6
2014-2015	3.22	1.5	1.1	1.3	1.7
2015-2016	4.09	1.6	0.7	0.9	2.2
2016-2017	4.36	1.7	2.6	2.1	4.4

and March, had demonstrated propitious outcomes for achieving an elevated grain yield.

The second weather parameter affecting wheat yield, as indicated by SPSS analysis, was the bright sunshine hours during the third week of March. The range of bright sunshine hours varied from 6.5 and 9.2 hours for the third week of March during 2012 to 2017 seasons (Table 5). Upon comparing the patterns of bright sunshine hours during this period with the yield of all *Rabi* seasons, it was observed that an increase in bright sunshine hours corresponded with an increase in yield. The rise in bright sunshine hours elevated temperatures, with the highest temperature recorded at 36.1°C (Table 6) coinciding with 10.2 hours of bright sunshine. The comparison results for bright sunshine hours revealed the lowest values in the year 2014–15, with only one instance where bright sunshine hours exceeded 7.5. In contrast, other years exhibited two or more such instances. Throughout all years, the relative humidity (RH) exceeded 96% on a total of six occasions, with the highest frequencies occurring in 2014–15 and 2015–16, both of which yielded the lowest outputs (Table 7). The reduction in yield for 2014–15 was attributed to relatively lower temperatures and high humidity levels. A comparison between two years with lower yields revealed that the slight increase in bright sunshine hours led to a higher yield in 2015–16 compared to 2014–15. Notably, the lowest RH was observed in 2013–14. Overall, the comparison indicated that bright sunshine hours more than 7.5 hours during the month of March could enhance crop yield. Mishra et al. (2015) documented similar results for the relationship between bright sunshine hours and wheat yield where they observed that increase in bright sunshine hours was found to increase the yield in all wheat cultivars and vice versa.

The third weather parameter which affected the wheat yield, as indicated by SPSS analysis, was the minimum relative humidity recorded for the third week of April. It

Table 5: Effect of March month's weekly bright sunshine hours on wheat yield

Rabi season	Crop yield (t ha^{-1})	March 1st week bright sunshine hours (hrs)	March 2nd week bright sunshine hours (hrs)	March 3rd week bright sunshine hours (hrs)	March 4th week bright sunshine hours (hrs)	March 5th week bright sunshine hours (hrs)
2012-2013	4.13	8.1	9.3	7.7	8.7	8.1
2013-2014	4.29	5.9	8.1	8.6	6.4	6.7
2014-2015	3.22	5.3	7.4	6.5	9.4	7.5
2015-2016	4.09	7.9	6.2	6.5	8.2	7.2
2016-2017	4.36	8.6	6.8	9.2	9.3	10.2

Table 6: Effect of March month's weekly maximum temperature on wheat yield

Rabi season	Crop yield (t ha^{-1})	March 1st week maximum temperature (°C)	March 2nd week maximum temperature (°C)	March 3rd week maximum temperature (°C)	March 4th week maximum temperature (°C)	March 5th week maximum temperature (°C)
2012-2013	4.13	25.6	29.5	28.8	30.6	28.3
2013-2014	4.29	23.0	24.7	27.3	27.8	30.2
2014-2015	3.22	23.4	24.6	25.5	30.7	30.6
2015-2016	4.09	29.4	28.9	28.0	30.8	32.1
2016-2017	4.36	27.6	25.5	25.5	31.4	36.1

Table 7: Effect of March month's weekly relative humidity on wheat yield

Rabi season	Crop yield (t ha^{-1})	March 1st week relative humidity (%)	March 2nd week relative humidity (%)	March 3rd week relative humidity (%)	March 4th week relative humidity (%)	March 5th week relative humidity (%)
2012-2013	4.13	95.3	95.0	96.2	94.9	94.1
2013-2014	4.29	92.9	93.2	94.3	90.6	91.3
2014-2015	3.22	96.0	94.7	96.1	95.1	94.7
2015-2016	4.09	96.7	93.5	96.1	82.7	91.9
2016-2017	4.36	95.2	95.0	94.6	91.8	86.2

was observed that an increase in minimum relative humidity during the third week of April, compared to the second week of April, led to an increase in wheat yield (Table 8). Conversely, in the years 2014–15 and 2015–16, when relative humidity decreased from the second week to the third week of April, wheat yield was at its lowest.

Table 8: Effect of April month's weekly minimum relative humidity on wheat yield

Rabi season	Crop yield (t ha^{-1})	April 1st week minimum relative humidity (%)	April 2nd week minimum relative humidity (%)	April 3rd week minimum relative humidity (%)	April 4th week minimum relative humidity (%)
2012-2013	4.13	30.5	29.5	32.4	25.2
2013-2014	4.29	42.2	36.5	40.1	25.3
2014-2015	3.22	57.8	49.1	37.7	43.1
2015-2016	4.09	31.8	33.6	26.6	21.4
2016-2017	4.36	39.9	42.6	48.8	39.0

3.2. Effect of weather parameters on wheat yield in Baghpat

The study investigated the impact of weather parameters on wheat yield in the Baghpat District, and the findings were analyzed using SPSS. The results obtained from SPSS indicated that single weather parameter *viz.*, maximum temperature during the first week of April was significantly affecting the yield of wheat crop in Baghpat District. The regression equation for model was derived as Y_b= -2.956 + 0.215*X_1, where X_1 represents the maximum temperature during the first week of April. In this equation, a positive coefficient suggested that as the maximum temperature during the first week of April increased, the predicted wheat yield also increased. The coefficient of determination (R^2) value for wheat yield in Baghpat was 0.98. This implied that approximately 98% of the variation in Baghpat wheat yield can be explained by the variation in the maximum temperature during the first week of April. In other words, the regression model captured a strong relationship between these variables, and the model's predictions closely matched the actual wheat yield data for Baghpat with RMSE value being 0.067 (Table 9). The high R^2 and low RMSE values suggested that the maximum temperature during the first week of April was a significant factor in determining wheat yield in the Baghpat District.

Table 9: Wheat yield predicted using SPSS for Baghpat

Rabi season	Observed yield (t ha^{-1})	Predicted yield by model 1 (t ha^{-1})
2012-2013	4.45	4.55
2013-2014	4.50	4.40
2014-2015	3.38	3.40
2015-2016	4.13	4.10
2016-2017	4.73	4.70

Table 10 illustrates that a decrease in the maximum temperature during the first week of April was associated with reduced wheat yield in the Baghpat for the *rabi* season 2014–2015. During the 2014–15 *Rabi* season, rainfall led to a decrease in wheat yield in the Meerut district, however, this phenomenon was not observed in Baghpat. The plausible explanation for this difference lied in the intensity of rainfall. Meerut experienced 3.9 mm of rainfall, while Baghpat received only 0.1 mm of rainfall during the same period in 2014-15. Consequently, the rainfall intensity was higher in Meerut as compared to Baghpat. This also underscored the substantial influence exerted by the maximum temperature during the initial week of April on the modulation of wheat crop yield exclusively within the Baghpat District. The association of wheat yield with maximum temperature of first week of April can be attributed to the fact that

Table 10: Effect of April month's weekly maximum temperature on wheat yield

Rabi season	Crop yield (t ha^{-1})	April 1st week maximum temperature (°C)	April 2nd week maximum temperature (°C)	April 3rd week maximum temperature (°C)	April 4th week maximum temperature (°C)
2012-2013	4.13	30.5	29.5	32.4	25.2
2013-2014	4.29	42.2	36.5	40.1	25.3
2014-2015	3.22	57.8	49.1	37.7	43.1
2015-2016	4.09	31.8	33.6	26.6	21.4
2016-2017	4.36	39.9	42.6	48.8	39.0

the wheat's maturity stage in April necessitates higher temperatures for the development of a healthy and fully mature crop. Singh et al. (2022) identified temperature as a critical weather parameter influencing wheat yield in their statistical model for western Uttar Pradesh. The SPSS outcomes obtained for Baghpat corroborated this, highlighting that maximum temperature during the first week of April was a significant factor in increasing crop yield. Furthermore, Aggarwal et al. (2000) noted a declining trend of solar radiation in the western region, which directly impacted the growth of wheat.

4. CONCLUSION

Effect of weather parameters on wheat yield in Meerut and Baghpat Districts using SPSS software. The inclusion of additional weather parameters in the prediction model improved yield estimation accuracy. The analysis revealed that in Meerut, the crucial weather parameters affecting wheat yield were rainfall (February 4th week), bright sunshine hours (March 3rd week), and minimum relative humidity (April 3rd week). While in Baghpat, the maximum temperature (April 1st week) had a positive correlation with wheat yield.

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