Journal of Agriculture, Biology and Applied Statistics
Vol. 2, No. 2, 2023, pp. 97-104

URL : www.arfjournals.com
https://DOI:10.47509/JABAS.2023.v02i02.03

Statistical Analysis of Impact of Weather Parameters on Grape Yield in Vijayapura District of Karnataka

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To cite this article

Manoj B.G., Vasantha Kumari J., Ashalatha K.V., Huchesh Buddihal, Lakshmi Narsimhaiah, Ashwini C.B. & Nikil Gowda A.M. (2023). Statistical Analysis of Impact of Weather Parameters on Grape Yield in Vijayapura District of Karnataka. Journal of Agriculture, Biology and Applied Statistics. Vol. 2, No. 2, pp. 97-104. *https://DOI:10.47509/JABAS.2023.v02i02.03*

Abstract: The study examines the intricate connection between weather parameters and grape yield in Vijayapura district, Karnataka, India, with a focus on the impact of maximum temperature, minimum temperature, relative humidity, rainfall, and windspeed on grape production. Correlation analysis revealed significant relationships between these weather parameters and grape yield. Maximum and minimum temperatures exhibited positive associations, suggesting that higher temperatures contribute to increased grape production by reducing disease incidence. In contrast, windspeed showed a significant negative influence on grape yield, indicating that increased windspeed is associated with reduced production. Stepwise regression analysis further emphasized the importance of maximum temperature, minimum temperature, and windspeed in predicting grape yield. These findings hold implications for vineyard management and grape growers, highlighting the need to consider specific weather factors to optimize grape production. Understanding the interplay of weather parameters and grape yield is crucial for adapting to climate change and ensuring the sustainability of grapevine productivity. It also underscores the broader concerns of climate change's impact on agriculture and the need for informed policy decisions to safeguard the agricultural sector.

Introduction

Agriculture plays a crucial role in India's economy, especially evident during the COVID-19 period, where it significantly contributed to the country's GDP. The impact of changing climatic conditions on the agricultural industry's development has been emphasized (Kohli and Singh, 2023). Agriculture stands out as a particularly vulnerable sector due to its inherent susceptibility to climatic variations. Climate change directly influences production and efficiency in agriculture, with its adverse effects disproportionately affecting impoverished

Article History Received : 18 September 2023; Revised : 19 October 2023; Accepted : 29 October 2023; Published : 30 December 2023

rural households reliant on agriculture and natural resources. This dependence leads to a decline in farm income and profitability (Ashalatha *et al*., 2013). Consequently, it becomes imperative to comprehend the causes and repercussions of climate change to formulate effective adaptation and mitigation policies.

Grapes hold significant importance as a fruit crop in India, encompassing an area of 155.30 thousand hectares, which constitutes 2.24% of the total area in the year 2021-22. Karnataka, with a notable share of 24% in the same year, stands as the second-largest grape producer, according to data from APEDA (2021). Leading districts of grape production in Karnataka are Vijayapura, Bagalkot, Chikkaballapur, Belgaum, and Bengaluru Rural. Global viticulture faces colossal challenges from unchecked climate change, as growing regions grapple with mounting pressure. The interplay of pedo-climatic and topographic factors significantly impacts table grapes and wine quality and production (Rafique *et al*., 2023). Altered precipitation patterns and intensified extreme weather events, such as high temperatures and heat waves, detrimentally affect crop productivity (Rajath *et al*., 2023). Different crop stages exhibit varying sensitivities to weather fluctuations, necessitating precise interval-based forecasting throughout the growth cycle.

Due to the irregularity and erratic behaviour of monsoon accompanied by inadequate irrigation facilities agricultural production of the state have resulted in severe fluctuations. Given this context, it is imperative to gain a comprehensive understanding of the production behavior and the impact of climatic factors on the yield of different crops in the state (Bhattacharya *et al*., 2021). The weather parameters, including maximum and minimum temperature, relative humidity, rainfall, and wind speed, exert a notable influence on grape cultivation. It affects its growth and yields, as well as the prevalence of pests and diseases, water requirements and fertilizer requirements. Weather anomalies may make crop damage and soil erosion worse. Understanding and managing these weather effects are crucial for optimizing grape yield and ensuring vineyard productivity and quality.

The application of a multiple linear regression model proves highly beneficial in examining the influence of weather conditions on grape yield. Azfar *et al.* (2018) conducted a study on the impact of weather variables on rapeseed and mustard yield, employing various statistical models to forecast yield for the Faizabad district at different crop stages. Similarly, Kumar *et al.* (2019) utilized simple linear regression models with the least square method to predict wind power in Rajasthan. This study aims to investigate the impact of weather parameters on grape yield through the utilization of multiple linear regression, acknowledged as an extension of straightforward linear regression for a more comprehensive model. It permits plenty of terms in a mean function instead of a unique intercept and single slope (Rana *et al*., 2019).

Materials and Methods

Nature of Study Area

Vijayapura is located at a height of 592 meters above sea level. The prevailing climate in this area is classified as a local steppe climate and receives little rainfall throughout the year.

BSh is the Koppen-Geiger classification for climate. The latitude and longitude of Vijayapura are 16.8302° N and 75.7100° E. It comes under the Northern Dry Zone of Karnataka. The major crops grown in the district are jowar, bajra, maize, grapes, pulses, oil seeds and vegetables.

Nature and Sources of Data

The present study was based on secondary data on weather parameters from a period of 1981-2021. The climatic scenario dataset for 1981-2021 was downloaded from Coupled Model Intercomparison Project Phase-6 (CMIP-6) with a resolution of 0.5 x 0.5 degree. The data was then analysed and sorted to the specific locations using the FERRET software in the Linux platform. Crop yield data were collected from the District Statistical Office, Vijayapura and District Statistical Office, Dharwad.

Correlation Analysis

Correlation quantifies the level of proximity or connection between two variables, indicating the intensity of the relationship among various parameters. Correlation heatmaps are generated in the form of a matrix with radiant colours, if darker colour signifies a stronger correlation, then lighter colour signifies a weak correlation, and vice-versa. The correlation heatmap was generated using the Seaborn library written in Python language.

Multiple Regression Analysis

Regression serves as a measure of the average relationship between two or more variables. In cases of correlation between two variables, the unknown value of one variable can be estimated using the known value of the other variable. Sir Francis Galton initially introduced the theory of regression in the field of genetics (Galton, 1997). When data on two variables are available, assuming one as dependent on the other, a linear equation is fitted to the data using the method of least squares. In this study, linear regression models were established with crop yield as the dependent variable (Y) and weather parameters as independent variables (X1, X2, ..., X5). The linear regression equation is expressed as per Nageshwara Rao (2008).

$$Y_i = \alpha + \beta X + \varepsilon$$

where, Y is the dependent variable, α intercept parameter, X is independent variable with β as the simple regression coefficient of Y on X and ε is the error term.

Stepwise Regression Analysis

In cases where the regression equation involves numerous variables, those that do not contribute significantly to the R^2 can be eliminated. Conversely, when dealing with fewer variables, additional ones with a noteworthy impact on the dependent variable can be incorporated to enhance the R^2 through stepwise regression analysis. The fundamental steps outlined by Draper and Smith (1966) in this procedure are detailed below:

1. A regression equation that includes all variables is computed.
2. The partial F-test value is calculated for every variable, assuming it is treated as though it were the last variable to enter the regression equation.
3. The lowest partial F-test value, denoted as FL, is compared with a preselected significance level F0.
4. If FL < F0, the variable XL, which gave rise to FL, is excluded from consideration. The regression equation is then recomputed with the remaining variables, and the process returns to stage 2. If FL > F0, the calculated regression equation is adopted.The initial equation in the model of stepwise regression is

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots\ldots + \beta_p X_p + \varepsilon.$$

In the initial stage, all variables are entered into the model. Subsequently, variables that contribute the least to the dependent variable are systematically eliminated one by one. At each stage, the Multiple R2 is computed to assess the model's explanatory power.

Results and Discussion

It is essential to investigate the associations between weather parameters and production of grapes in order to gain insights into the interplay of different weather parameters. Thus, correlation analysis was carried between grape yield and various weather parameters for Vijayapura district. This analysis allows to discern the nature and strength of the relationships between grape yield and different weather elements.

Table 1: Correlation Matrix between Weather Parameters and Grape Yield for Vijayapura District

	Yield	*Max T*	*Min T*	*RH*	*RF*	*WS*
Yield	1.000					
Max T	0.433**	1.000				
Min T	0.411**	0.312*	1.000			
RH	-0.007	-0.124	0.162	1.000		
RF	0.114	-0.196	-0.038	0.451**	1.000	
WS	-0.372*	-0.032	-0.017	-0.031	-0.278	1.000

Note: ** - Significant at 1% level
* - Significant at 5% level

In the case of Vijayapura district, as illustrated in the correlation heatmap (Fig.1), it becomes evident that there is a significant connection between weather parameters and grape production. Notably, there is a positive relationship observed between grape production and both maximum and minimum temperatures, signifying that an increase in these temperatures is highly significant in boosting grape production. Conversely, a non-significant negative association is found between grape production and relative humidity, suggesting that higher relative humidity levels are linked to reduced grape production. Additionally, a positive, albeit non-significant, correlation is noted between grape production and rainfall.

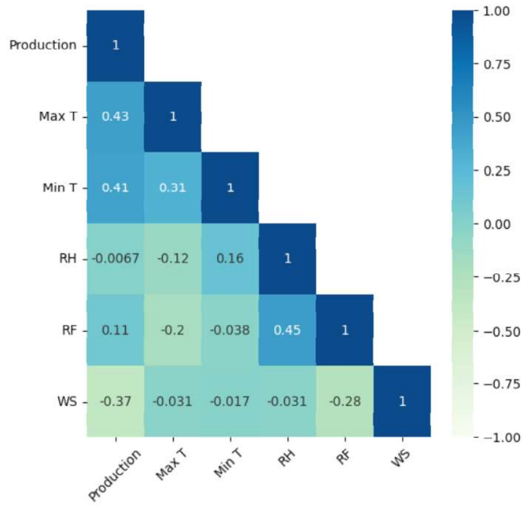

Figure 1: Correlation heatmap for Vijayapura district

However, a significant negative association is observed between grape production and windspeed, indicating that an increase in windspeed has a detrimental effect on grape production. Furthermore, it's worth mentioning that certain weather parameters, such as rainfall and relative humidity, exhibit multicollinearity, suggesting interrelatedness among these variables.

Table 2: Multiple Linear Regression on Yield of Grapes with Weather Parameters for Vijayapura District

District	*Multiple linear regression equation*	*F-ratio*	R^2
Vijayapura	$Y = -4544.85 + 103.58X_1{}^* + 123.27X_2{}^* - 5.15X_3 + 0.55X_4 - 316.34X^*{}_5$	4.80**	0.41

Note: ** - Significant at 1% level
* - Significant at 5% level
Y- Production of grapes
X_1 -Maximum temperature
X_2- Minimum temperature
X_3- Relative humidity
X_4- Rainfall
X_5- Windspeed

As depicted in Table 2, for the Vijayapura district, only maximum and minimum temperature showed a significant positive influence on grape yield; whereas windspeed was found to have a significant but negative influence on grape yield. The model F ratio (4.80) was also highly significant with an R^2 value of 0.41. The multiple regression model obtained for grape yield of Vijayapura district was $Y= -4544.85 + 103.58X_1{}^* + 123.27X_2{}^* - 5.15X_3 + 0.55X_4 - 316.34X_5{}^*$.

Hence, in this study, multiple linear regression analysis was carried out to ascertain the total impact of weather parameters on grape yield. When a model is having a greater number of independent variables, every factor need not be contributing significantly on the dependent variable and the data set did have a multi-collinearity issue, however, as evidenced by the high correlation and significance between any two or more independent variables like rainfall and relative humidity. Therefore, stepwise regression was carried out to know variables which are contributing significantly on the dependent variable i.e., grape yield. The results were on par with the study conducted by Bhagat *et al*. (2021), reported that the production of cotton in Jalgaon district of Maharashtra was highly dependent on relative humidity at evening and bright sunshine hours. However, wind velocity was adversely affecting the productivity of cotton in the Jalgaon district.

Table 3: Stepwise Regression on Yield of Grapes with Weather Parameters for Vijayapura District

Model	*Stepwise regression equation*	*Variables added*	*Variables removed*	*F-ratio*	*R^2*
1	$Y= -4303.14 + 131.75X_1^{**}$	Maximum temperature (X_1)	Minimum temperature, Relative humidity, Rainfall, Windspeed	8.76**	0.18
2	$Y= -2941.63 + 128.31X_1^{**} -356.85X_5^{*}$	Maximum temperature (X_1), Windspeed (X_5)	Minimum temperature, Relative humidity, Rainfall	8.53**	0.31
3	$Y= -4313.17 + 99.56X_1^{*} -354.64X_5^{**}+ 116.74X_2^{*}$	Maximum temperature (X_1), Windspeed (X_5), Minimum temperature (X_2)	Relative humidity, Rainfall	7.94**	0.39

Note: ** - Significant at 1% level
* - Significant at 5% level

Table 3 illustrates the application of the Stepwise regression technique to assess the impact of each weather parameter on grape yield. In a systematic manner, parameters with the least contribution to grape yield were eliminated step by step. The regression model for predicting grape yield in Vijayapura district, based on maximum temperature, windspeed, and minimum temperature, emerged as the most effective, displaying the highest R2 value. This suggests a significant contribution from these three weather parameters.

The positive influence of both maximum and minimum temperature on grape yield was observed, potentially attributed to a decrease in disease incidence with an increase in temperature. Conversely, an increase in windspeed was associated with higher disease severity, resulting in a negative impact on grape yield. This finding aligns with the results of multiple regression analysis, indicating that maximum temperature, minimum temperature, and windspeed significantly contribute to grape yield. These outcomes are consistent with a study by Himanshu Shekhar (2014), wherein a regression model based on minimum temperature, maximum relative humidity, and minimum relative humidity was found superior for predicting Kharif potato yield, eliminating rainfall and maximum temperature from consideration.

Conclusion

The study focused on understanding the intricate relationship between weather parameters and grape yield in the Vijayapura district, Karnataka, India. The findings reveal that weather parameters indeed have a significant impact on grape production. Maximum and minimum temperatures exhibited a positive association with grape yield, signifying that higher temperatures contribute to increased grape production. This could be attributed to reduced disease incidence with rising temperatures. Conversely, windspeed displayed a significant negative influence on grape yield, as increased windspeed was associated with reduced production. The stepwise regression analysis further confirmed the importance of these three weather parameters (maximum temperature, minimum temperature, and windspeed) in predicting grape yield. This information is crucial for vineyard management and grape growers as it highlights the need to consider these specific weather factors for optimizing grape production. Understanding the relationship between weather parameters and grape yield is vital for the agricultural sector, especially in the context of climate change. This knowledge can inform strategies for mitigating the adverse effects of changing climatic conditions and maintaining grapevine productivity. Additionally, it underscores the broader concern about the impact of climate change on agriculture, which is essential for policymakers and stakeholders when crafting adaptation and mitigation policies to safeguard the agricultural industry in the face of evolving climate patterns.

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