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Review Article

Determination of Effective Weather Parameters on Rainfed Wheat Yield Using Backward Multiple Linear Regressions Based on Relative Importance Metrics

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Wheat (*Triticum aestivum* L.) is the most imperative crop for man feeding and is planted in numerous countries under rainfed conditions in semiarid zones. It is necessary for decision-makers and governments to predict the yield of rainfed wheat before harvest and to determine the effect of the major factors on it. Different methods have been suggested for forecasting yield with various levels of accuracy. One of these approaches is the statistical regression model, which is simple and applicable for regions with scarce data available. Since the weather is the most important factor affecting the production of wheat, particularly in rainfed cultivation, regression models using weather parameters are very common. However, the coefficients of these models are location based and should be determined locally. Therefore, in this research, backward multiple linear regression (BMLR) technique based on relative importance metrics was used to determine the most important effective weather parameters (11 parameters) on rainfed wheat productions in Fars Province, south of Iran, during 2006–2013. The influence of each parameter in the final model was analyzed using the values of LMG relative importance metric. The result indicated that sunshine hours had the biggest LMG (34.73%) and, therefore, was the most effective parameter. Also, among the other considered parameters, rainy days, minimum relative humidity, and average relative humidity with LMG values of 21.97%, 21.69%, and 21.62%, respectively, had the most effects on rainfed wheat yield in the studied area. All parameters except for the sunshine hours positively affected rainfed wheat yield. The most important reason for the significance of these parameters can be the prevailing dry and semidry climate in the southern areas of Iran. The proposed model for determination of weather parameters effects on rainfed wheat could be a great guidance and aid for different stakeholders such as farmers, decision-makers, and governments.

1. Introduction

Climate recognition and study of the agricultural plants requirements are some of the most important factors contributing to crop productions. Understanding and managing the effect of weather parameters on crop production could lead to increase in their yield. This issue is especially more crucial in rainfed farming conditions because climate shows the greatest impact on yield in rainfed farming [1]. Wheat is a globally vital crop and a strategic product in Iran. The Fars province located in the south of Iran ranks first in the production of wheat in this country. The rainfed wheat cultivation includes a large portion of this production so that out of about 550000 hectares cultivated area under wheat in this region, 150000 hectares is rainfed farming [2]. The predominant climate of this province is dry and semidry, and water resources are limited [3]. Therefore, identifying the effective weather parameters involved in plant growth and crop yield is necessary. Several factors affect the variability of yield and product quality in the field, but, data collection and data analysis are also costly, time-consuming, and hard work [4]. Many researchers tried to analyze these factors and proposed different methods to forecast yield. For example, Mumtaz et al. estimated the wheat yield based on the weather parameters applying remote sensing information for Chakwal rainfed croplands, Punjab Province, and Pakistan [5]. In another study, Sabzevary et al. investigated the effects of climatic parameters on rainfed and irrigated wheat yields using bivariate linear regression analysis in chosen stations of Hamedan State, Iran. They concluded that the sensitivity of rainfed wheat yield index to atmospheric and agroclimatic factors was higher compared to irrigated wheat [6].

In order to analyze the plant response to the weather parameters, three arbitrary categories of models are suggested: simple statistical models, parameterization models, and analog-physical models [7]. Among these, most statistical models are crop yield-weather models, in which their main advantage is the simplicity and straightforward relation between yield and one or more weather factors. Consequently, several research studies have been performed to develop a regression relationship between weather parameters and rainfed crop yield [8–17].

Drought has a significant impact on the production of wheat [18]. The study of Wu et al. showed that rainfed yield was related to drought severity and decreased due to increased temperature and reduction of precipitation [19]. Zarei et al. evaluated the most important effective time period on the changes of the annual yield of rainfed wheat under the impact of drought changes by using the correlation between calculated SPEI drought index in different time scales and simulated annual yield using the AquaCrop model based on the backward multiple generalized estimation equation method in the northwest of Iran [20].

Some researchers have tried to estimate the yield of wheat in different regions of Iran and under different weather conditions. Mehnatkesh et al. determined the most significant variables on rainfed wheat yield applying sensitivity analysis in Central Zagros, Iran [21]. They used the variable collections of ground properties, soil physicochemical characteristics, precipitation, and weed biomass including 54 parameters as the inputs of the artificial neural network method while considered wheat grain and biomass yield as the objectives. The sensitivity analysis outputs revealed that all the variables were effective on the grain yield, given that the weekly precipitation owned the most impact. Zarei and Mahmoudi evaluated the impact of climatic parameters on the annual yield of rainfed wheat based on the records of 10 stations from 1967 to 2016 scattered in Iran. They included that in all stations, the wind speed and minimum temperature parameters were the most effective and sunshine hour parameter was the least effective variables on the annual yield [22]. Kazmi and Rasul predicted the agrometeorological rainfed wheat yield in the Potohar area, Pakistan, using a linear regression model. In their studied region, the final yield was forecasted reliably by the variables of minimum temperature, sunshine duration, and rainfall depth in January (tilling and stem extension stage) [23]. Siosemarde and Sakine predicted the rainfed wheat yield applying weather variables in the Khoy region at West Azarbaijan State, Iran. Results indicated that the average temperature in October and the number of frost days in April influenced directly on the yield and the average of maximum relative humidity in December affected indirectly [24]. Khoorani et al. modeled and predicted the rainfed wheat (*Triticum aestivum*) yield in Kurdistan Province, Iran, using five weather parameters including total amount of precipitation, number of days with precipitation, maximum wind speed, mean evapotranspiration, and the average daily temperature as independent variables in linear regression models and the bootstrap resampling method during 1991–2003. Results indicated that using the bootstrap resampling method for modeling and estimating the crop yield increased the interior accuracy of the models [25].

The result of previous research illustrated that the significant weather parameters and their coefficients in the proposed regression models are location based and are dependent on the climate of the study region. Therefore, using the aforementioned regression techniques without local calibration would suffer from low accuracy, particularly in the case of a short period of time. In addition, no significant attempt has been made to estimate the rainfed wheat yield in the Fars province, so far. Accordingly, the purpose of this research is to provide a higher-accuracy (more significant) statistical model for rainfed wheat yield estimation in terms of weather parameters. In the other words, we evaluated the feasibility of using backward multiple linear regression (BMLR) based on relative importance metrics to determine the most important effective meteorological parameters as independent variables on rainfed wheat yield in Fars Province, south of Iran, during 2006–2013.

2. Materials and Methods

2.1. Study Area. This research was conducted for Fars Province situated in 27°02′ to 31°42′ N and 50°42′ to 55°38′ E (Figure 1). Fars is in the south of Iran and has three distinct climatic zones: (a) the north and northwest includes mountains that have moderately cold winters and mild summers; (b) the center of the province has relatively rainy mild winters and hot dry summers; (c) the south and southeast areas have cold winters with hot summers.

Fars Province with about 133000 Km^2 area is the fourth largest province of Iran. The important districts with their major cities are Shiraz, Marvdasht, Jahrom, Fasa, Abadeh, Eghlid, Estahban, Firouzabad, Kazeroun, and Lar. The population of the province in 2017 was 4,851,274 of which 67.6% were urban dwellers, 32.1% were rural dwellers, and 0.3% were nomad tribes. The major activities of the inhabitants are industry, agriculture, and the service sector. Wheat, barley, fig, walnut, citrus fruits, especially lemon, dates, apple, pomegranate, beet, cotton, various grains, and saffron are the major agricultural products. The chemical and petrochemical, metal, electrical and electronics, leather, cellulose, food, and medicinal industries are the main industrial activities in this province.

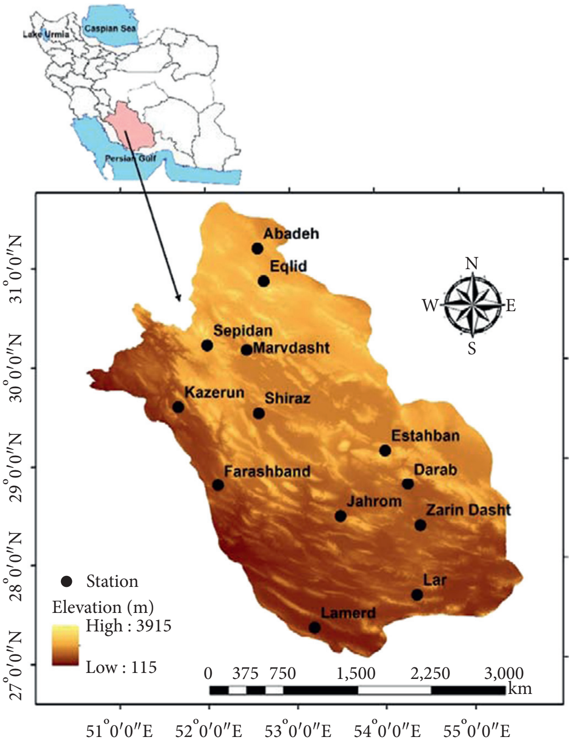

Figure 1: Location of studied area.

2.2. Data. The rainfed wheat yield data for Fars Province districts, including Abadeh, Eghlid, Estahban, Jahrom, Darab, Zarindasht, Sepidan, Shiraz, Farashband, Kazeroun, Lar, Lamerd, and Marvdasht, were obtained from the Agriculture Organization of Fars Province for the period 2006–2013. This crop is cultivated in Fars Province under irrigated and rainfed conditions from October to June. The yield was expressed as the average grain production (kg/ha) for the harvested area.

Furthermore, necessary weather parameters including minimum, maximum, and average temperature (T_{min}, T_{max}, and T_{avg}), minimum, maximum, and average relative humidity (RH_{min}, RH_{max}, and RH_{avg}), wind speed, sunshine hours, reference evapotranspiration (ET_0), rain, and rainy days of regions over 2006–2013 were obtained from I.R. of Iran Meteorological Organization (IRIMO). A simple average method was applied to filling the missing data. A homogeneity test using a standard normal homogeneity test at a 5% significance level was carried out on the dataset to recognize any nonhomogeneity. The descriptive statistics of climate parameters in studied stations are given in Table 1. The climate conditions of the studied stations were determined by using De-Martonne aridity index [26].

2.3. Data Analysis. The obtained data were introduced to the model one by one pursuant to their quantities and were investigated utilizing the Minitab and R programs. In order to determine the effect of factors on yield, a set of backward multiple linear regressions based on relative importance metrics was run.

2.3.1. Multiple Linear Regression. To analyze the data, multiple linear regression (MLR) is a flexible technique that can be suitable whenever a dependent parameter Y is to be investigated in relation to any other parameters $X_1, X_2, \ldots, X_k$ (the independent parameters). The generalized formula of MLR is given as

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki} + \boldsymbol{\varepsilon}_i, \text{for observations } i = 1, \ldots, n, \tag{1}$$

where $\beta_0, \beta_1, \ldots, \beta_k$, are equation factors (coefficients) and ε_i, $i = 1, \ldots, n$, are the random components of the equation which pursue independent normal distributions with mean 0 and variance σ^2.

The coefficients $\beta_0, \beta_1, \ldots, \beta_k$ were approximated using the dataset. The prevailing formula of predictive MLR technique is given as

$$\widehat{Y}_i = b_0 + b_1 X_{1i} + b_2 X_{2i} + \ldots + b_k X_{ki}, \tag{2}$$

where $b_0, b_1, \ldots, b_k$, are approximations of method variables and $\widehat{Y}_i$ is the forecasted value of Y_i.

We can rewrite the MLR technique in the following matrix form:

$$Y = X\beta + \varepsilon, \tag{3}$$

where $Y = (y_1, \ldots, y_n)^T$ is the response vector, X is a $n \times (k+1)$ full-rank design matrix with the first column produced by $(1, \ldots, 1)^T$ and the l^{th} $(2 \le l \le k+1)$ column produced by $(x_{l-1,1}, \ldots, x_{l-1,n})^T$, $\beta = (\beta_0, \ldots, \beta_k)^T$ is unknown parameters vector, and $\varepsilon = (\varepsilon_1, \ldots, \varepsilon_n)^T$ is random error vector. Also, $\widehat{Y} = Xb$, where $\widehat{Y} = (\widehat{y}_1, \ldots, \widehat{y}_n)^T$ is the predicted value vector and $b = (b_0, \ldots, b_k)^T$ is the coefficient vector.

It must be considered that in the model without an intercept ($\beta_0 = 0$), the column $(1, \ldots, 1)^T$ should be eliminated from matrix X.

The simple least squares (maximum likelihood) approximation of the coefficient vector β is represented as

$$b = \left(X^T X\right)^{-1} X^T Y. \tag{4}$$

This usual procedure hypothesizes that there are adequate measurements to state meaningful something about β.

2.3.2. Backward Multiple Linear Regression (BMLR) Based on Relative Importance Metrics. As can be observed, the MLR technique includes linear impacts of $X_1, X_2, \ldots, X_k$. However, because of colinearity between $X_1, X_2, \ldots, X_k$, some of these impacts may not be significant ($p > 0.05$). In this state, the backward method (BMLR) is applied and step by step the nonimpressive parameters are eliminated. The last equation has parsimonious parameters and acceptable accuracy. Usual BMLR technique eliminates the predictors from the model based on their p values. Since the reported regression estimates do not take into an account the model building process and, therefore, is advised to stop this common practice [27]. There are numerous widely discussed

Table 1: Climate and descriptive statistics of studied stations.

Station	Climate	T_{min} (°C)	T_{max} (°C)	T_{avg} (°C)	RH_{min} (%)	RH_{max} (%)	RH_{avg} (%)	Wind speed (m/s)	Sunshine hours	ET_0 (mm)	Rain (mm)	Rainy days
Abadeh	Arid	3.20	17.53	10.37	22.42	61.70	42.06	2.51	8.43	754.50	105.81	29.75
Eghlid	Semiarid	2.86	15.30	9.08	23.96	59.15	41.56	3.02	8.47	744.78	285.40	41.75
Estahban	Arid	5.83	21.07	13.45	24.10	62.95	43.52	2.99	8.66	925.58	192.60	35.75
Jahrom	Arid	9.06	25.19	17.12	28.18	74.57	51.38	1.11	8.41	675.54	216.97	28.00
Darab	Arid	10.19	25.26	17.72	25.74	65.37	45.56	1.04	8.89	757.99	181.69	31.00
Zarindasht	Arid	11.41	26.48	18.94	20.64	60.56	40.60	1.36	8.82	1022.25	164.30	20.00
Sepidan	Humid	5.51	15.08	10.30	34.56	58.98	46.77	2.34	8.33	709.46	581.48	52.00
Shiraz	Semiarid	6.35	21.86	12.55	25.70	71.04	48.37	1.51	8.48	704.23	256.79	38.00
Farashband	Arid	9.94	26.21	18.07	24.86	78.07	51.46	2.24	8.40	1156.04	240.40	35.00
Kazeroun	Semiarid	11.70	25.24	18.47	29.19	69.53	49.36	1.54	7.97	833.30	348.40	38.50
Lar	Hyperarid	11.99	27.98	19.73	23.38	60.81	42.09	1.14	8.97	841.37	118.08	18.75
Lamerd	Hyper-arid	13.49	30.15	21.82	26.62	63.34	44.98	2.14	8.60	1070.24	151.68	21.50
Marvdasht	Semiarid	5.33	20.87	13.10	32.18	73.23	52.70	1.06	8.63	654.98	265.55	37.75

limitations of stepwise methods, such as misleadingly small p values not adjusted to account for the iterative fitting and biased R^2 measures [28]. For choosing an optimal model, there are systematic criteria including Akaike information criterion (AIC), Bayesian information criterion (BIC), and adjusted R^2. There are many recommendations for on application of variable selection methods, e.g., [29]. In usual BMLR technique, the relative importance of predictors is investigated using standardized regression coefficients. However, there are several issues listed in [30, 31]:

(i) In the situation of multicolinearity, regression coefficients including standard regression coefficients are not interpretable.

(ii) High multicolinearity may lead not only to serious distortions in the estimations of the magnitudes of the regression coefficients but also to reversals in their signs.

(iii) In the situation of multicolinearity, regression coefficients are not reliable indicators of relative importance, because it does not provide a natural decomposition of R^2.

To solve this problem, there are several measures how to decompose R^2. The LMG measure proposed by Lindeman, Merenda, and Gold is one of the recommended metrics and available through the *R package* "*relaimpo*" [32]. Also, there are several measures benchmarked against each other for variable selection [33, 34].

In this work, the BMLR technique based on LMG relative importance metric (BMLR-LMG) was applied to analyze the observed dataset.

3. Results and Discussion

The first subsection concerns the descriptive statistics representing means and standard deviations of research variables under investigation. Subsection two reports the results of BMLR procedure to investigate the effect of factors on yield.

3.1. Descriptive Statistics. The descriptive statistics of studied factors are represented in Table 2. According to these data, during 2006–2013, the rainfed wheat yield in Fars Province ranged from 0 to 2431.22 kg/ha. The average yield of rainfed wheat in this region was 619.20 kg/ha, which is low compared to 1181 Kg/ha average value of Iran. The low yield of rainfed wheat in Fars Province compared to Iran is mainly due to successive droughts and poor agricultural management [2].

3.2. Effective Parameters on Yield. In this part, the impact of different weather parameters on yield was investigated. In this research, the yield was the response variable and the other parameters were continuous predictors. The prevailing formula of MLR was as follows:

$$\text{Yield}_i = \beta_0 + \beta_1 T_{\text{Max}_i} + \ldots + \beta_{11} \text{Rainy Days}_i + \varepsilon_i, \quad (5)$$

where the independent variables of the equation are the meteorological parameters.

The BMLR-LMG technique was used by applying R software. At first, all parameters were introduced and the MLR model was run. The results are summarized in Table 3.

The results showed that because of colinearity, some of variables were nonsignificant (p value >0.05). Therefore, the BMLR-LMG was applied to eliminate the worst parameter (the parameter owing the smallest LMG, T_{min}) in the next run. T_{min} was eliminated, and the model was run again. This operation proceeded step by step to the point that only significant parameters remained. The summary of omitted parameters in each step in the BMLR-LMG technique is represented in Table 4.

Finally, Table 5 indicates the results of the final run. The influence of each parameter in the final model was analyzed using the values of LMG. According to these results, the relative importance of RH_{min}, RH_{avr}, sunshine hours, and rainy days on yield were significant (LMG more than 20%). The result indicated that sunshine hours had the biggest LMG and, therefore, was the most effective parameter. Also, among the other considered parameters, RH_{min} (21.69%), RH_{avr} (21.62%), sunshine hours (34.73%), and rainy days

Table 2: Descriptive statistics of studied factors.

	N	Minimum	Maximum	Mean	Std. deviation
Yield (Kg/ha)	46	0.00	2431.22	619.20	612.49
T_{max} (°C)	46	14.05	30.94	22.43	4.80
T_{min} (°C)	46	2.17	14.07	7.93	3.56
T_{avr} (°C)	46	7.81	22.31	15.01	4.20
RH_{max} (%)	46	50.19	78.38	65.35	7.63
RH_{min} (%)	46	19.13	42.35	26.70	5.37
RH_{avr} (%)	46	34.79	57.09	46.03	5.74
Wind speed (m S^{-1})	46	0.45	4.01	1.88	0.79
Sunshine hours (h/day)	46	7.46	9.34	8.54	0.43
ET_0 (mm/period)	46	112.03	1444.16	810.11	391.14
Rain (mm/period)	46	14.70	854.80	246.52	166.86
Rainy days (day/period)	46	10.00	63.00	33.80	12.99

Table 3: Outputs of MLR.

Parameter	p value	LMG (%)
T_{max}	0.942	2.86
T_{min}	0.703	1.35
T_{avr}	0.614	1.63
RH_{max}	0.291	8.63
RH_{min}	0.288	14.21
RH_{avr}	0.291	13.84
Wind speed	0.229	1.43
Sunshine hours	0.015*	23.38
ET_0	0.017*	3.25
Rain	0.005**	10.55
Rainy days	0.012*	18.85

*Statistically significant at the 5% significance level; **statistically significant at the 0.01 significance level.

Table 4: Summary of omitted parameters in BMLR-LMG technique.

Step	Omitted parameter	LMG (%)
1	All variables are included	
2	T_{min}	1.35
3	Wind speed	1.45
4	T_{avr}	1.75
5	ET_0	2.61
6	T_{max}	2.96
7	RH_{max}	9.47
8	Rain	10.87

Table 5: Final run of BMLR-LMG.

Parameter	Coefficient	LMG (%)
RH_{min}	20.03	21.69
RH_{avr}	19.41	21.62
Sunshine hours	−592.77	34.73
Rainy days	4.95	21.97

(21.97%) had the most effects on rainfed wheat yield in the studied area. All parameters except for the sunshine hours positively affected rainfed wheat yield.

Consequently, the formula of the last run of BMLR-LMG technique was as

$$\widehat{\text{Yield}} = 20.03\ \text{RHmin} + 19.41\ \text{RHavr} - 592.77\ \text{Sunshine Hours} + 4.95\ \text{Rainy Days}. \quad (6)$$

According to the final model, the independent variables of rainy days, RH_{min}, and RH_{avr} have the strongest positive effect on rainfed wheat yield in Fars Province, respectively. In other words, the higher the number of rainy days, minimum relative humidity, and average relative humidity, the more yield will be. Pishbahar and Darparnian found that for dry farming wheat crop in warm climates of Iran, lack of adequate heat throughout plantation time (October), overheating throughout initial growth time (December and January), and lack of adequate rainfall throughout initial growth time (November and December) were the systematic risk factors [35].

The rainy days which has the most positive impact on the rainfed wheat yield in this study mentions the nonuniform temporal distribution of rainfall in the south areas of Iran [3]. Barkley et al. analyzed the effect of weather parameters on wheat yield across Kansas. Their result indicated that the most determinative parameter for wheat yield is often rainfall distribution [36]. In fact, in rainfed regions, the plant products are completely dependent on the frequency and distribution of rainfall. The abundance or scarcity of rainfall can, therefore, unfavorably influence the yield, particularly at crucial wheat growth stages [5]. The same results have been reported by Abi Saab et al. [37].

Also, many researchers conclude that rainfall is the most significant climatic parameter that impacts the crop growth and production in the rainfed areas [5, 16, 38–40]. Holman et al. indicated the impact of growing season rainfall on wheat yields in western Kansas [41]. In fact, the whole rainfall is not the only parameter that can operate the increment or reduction in yield, but a proper quantity of rainfall at different crop growth stages is essential for maximizing the yield.

According to the prevailing dry and semidry climate of the studied area, minimum relative humidity and average relative humidity have a strong positive role in rainfed wheat productivity.

In this study, the only weather parameter that has a negative effect on rainfed wheat yield was sunshine hours. The negative effect of sunshine hours in the current study can be due to the fact that cereal crops after anthesis are more susceptive to temperature and sunshine that function principally on the production of carbohydrate to fill grain, rather than on the sink capacity of the grain [26]. In the studied area, wheat is planted near the onset of autumn rainfall and fills its grains throughout spring when rainfall is declining and evaporation is enhancing. Therefore, the crop may be exposed to a postanthesis water deficit. Lollato et al. illustrated that cumulative solar radiation and average T_{max}, respectively, had a strong positive and negative impact on wheat yield throughout the anthesis-physiological maturity period [42]. Contrary to our findings, Chaurasia et al. found the positive effect of sunshine hours on wheat yield in central Punjab, Pakistan [43]. The sunshine hours is an effective parameter for preventing favorable conditions for the multiplication of pest and diseases even in the areas with good cloud cover [38]. In general, the solar radiation in Fars Province is high and the plants do not have a shortage of radiation energy. Therefore, in all regions of the province especially in the north areas, more cloudiness and fewer sunshine hours are directly related to rainfall. Consequently, in such arid and semiarid areas, occurrence of rainfall and satisfaction of rainfed crops water requirement are very important. Finally, the goodness of the fitted model was investigated using the coefficient of determination (R^2), adjusted coefficient of determination (R^2_{adj}), root mean square error (RMSE), residual analysis, and comparison between the real values and the fitted values of rainfed wheat yield. A lesser RMSE quantity and higher R^2 and R^2_{adj} quantities (12.4, 0.944, and 0.895, respectively) are considered to indicate the goodness of the fitted predictive model based on these metrics.

The performance of the proposed model for determination of weather parameter effects on rainfed wheat yield indicates the power of this model as compared with other literature studies (Table 6).

The end of the wheat's growing season is spent in summer. In the study area, at this time due to the absence of precipitation and the lack of cloudy days, there is not much variability in meteorological parameters presented in the proposed model through the years. Since reliable early wheat production forecasts are very useful for policymakers, it is possible to determine an appropriate approximation of these parameters using long-term statistics or forecast data and then predict the yield before harvest. This information can be very important for producers and planners.

Then, the residual analysis was utilized to investigate the goodness of the fitted model. Independent normal residuals with stable variance are considered to exhibit the goodness of the fitted predictive model. The quantile-quantile (QQ) plot and Kolmogorov–Smirnov (K–S) normality test were utilized to assess the normality of residuals. According to the results in Figure 2, the normal probability plot satisfied the normality of residuals because the points are nearby to the line $y = x$. The normality was also satisfied with the K–S test (p value >0.05).

On the other hand, according to Figures 3 and 4, the plot of residuals against time and fitted values were completely random about of horizontal axis ($y = 0$). Hence, the independence and stability of residuals were satisfied.

Figure 5 shows the real values versus the fitted values of rainfed wheat yield. As can be seen, the points are nearby to line 1 : 1. Consequently, the BMLR-LMG nicely modeled the rainfed wheat yield at Fars Province during 2006–2013.

To study the validation and robustness of the BMLR-LMG model, the final equation of the BMLR-LMG model was applied to estimate the rainfed wheat yield of year 2014. Figure 6 shows the real values versus the predicted values of

Table 6: Comparison of the BMLR-LMG performance with other studies.

Reference	Method	Effective parameters	R^2	R^2_{adj}	Error
[21]	Multiple linear regression	Precipitation	0.53	—	RMSE = 0.055
[22]	Backward time series regression, backward logistic generalized estimating equation, backward generalized estimating equation	Wind speed, T_{min}	Based on ranking		
[23]	Linear regression	T_{min}, sunshine hours, rainfall amount	0.87	0.84	S.E[1] = 265.80
[24]	Multivariate regression	T_{avg}, number of frost days, RH_{max}	0.74	0.67	SE = 171
[25]	Linear regression	Rainfall, ET_0, T_{avg}	0.92	—	SE = 77
Current study	Backward multiple linear regressions	Sunshine hours, rainy days, RH_{min}, RH_{avg}	0.944	0.895	RMSE = 12.4

[1]Standard error.

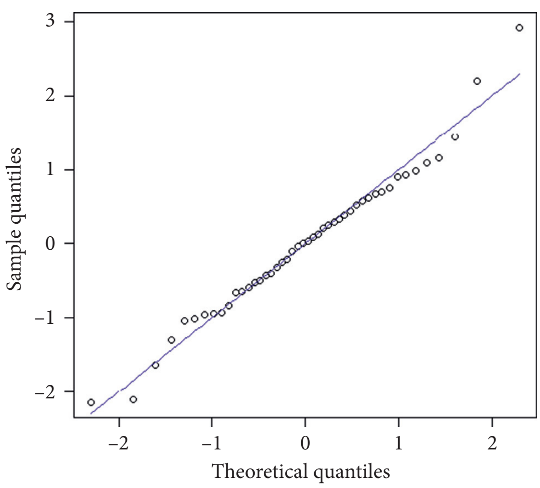

Figure 2: Normal QQ plot of residuals for the BMLR-LMG model.

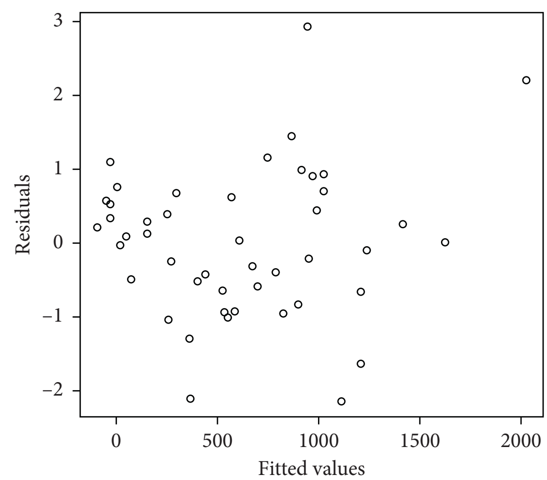

Figure 4: Plot of residuals against fitted values for the BMLR-LMG model.

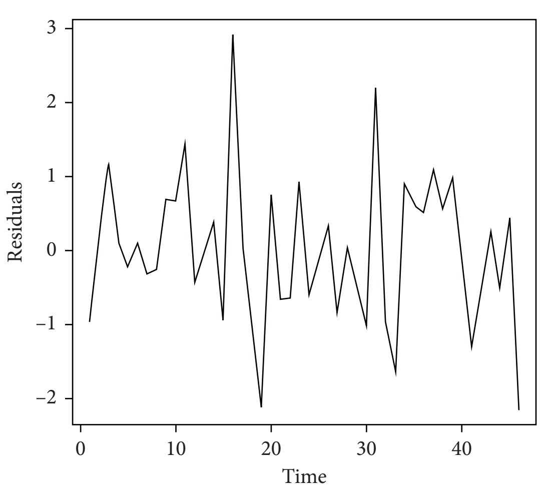

Figure 3: Plot of residuals against time for the BMLR-LMG model.

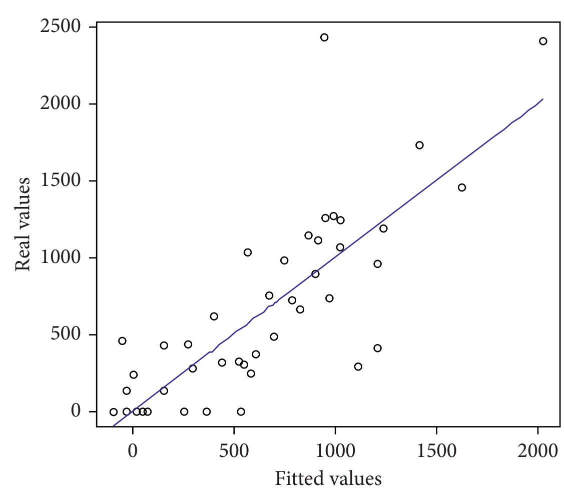

Figure 5: Real values of yield versus fitted (predicted) values for the BMLR-LMG model.

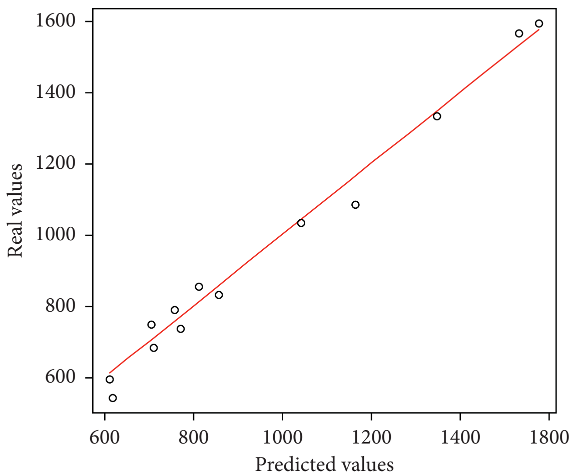

Figure 6: Real values of yield versus predicted values for the BMLR-LMG model.

Table 7: Comparison of the BMLR-LMG performance with BMLR and FMLR techniques.

Method	R^2	RMSE
BMLR-LMG	0.987	40.386
BMLR	0.736	179.488
FMLR	0.870	167.681

rainfed wheat yield of year 2014. As can be seen, the points are nearby to line 1 : 1. Consequently, the BMLR-LMG nicely estimated the rainfed wheat yield of year 2014 at Fars Province.

The results have been also compared with usual backward MLR (BMLR) and forward MLR (FMLR) techniques. As it can be observed in Table 7, the BMLR-LMG model had the maximum value of R^2 and the minimum value of RMSE. Therefore, the BMLR-LMG model is a robust and able technique to estimate the rainfed wheat yield compared with other alternatives.

4. Conclusion

The most contributing weather parameters on rainfed wheat crop yield were examined by using backward multiple linear regression analysis based on relative importance metrics in arid and semiarid Fars Province, southern Iran, during 2006–2013. As Pishbahar and Darparnian concluded, the cultivation of rainfed wheat in warm climates compared to the moderate and cold areas is at higher risk [35]. The current study results indicated that parameters of rainy days, minimum relative humidity, and average relative humidity have a significant and positive impact on rainfed wheat yield. Sunshine hours was highly significant and negatively correlated with rainfed wheat yield.

Because of the lack of appropriate rainfall distribution in the arid regions of southern Iran [44, 45], the most positive significant parameter is the number of rainy days. The significant positive effect of minimum relative humidity and average relative humidity is due to the prevailing dry and semidry climate in the study areas and consequently the crucial role of relative humidity in reducing water deficit stresses in wheat.

The sunshine hours is the only weather parameter that has a negative significant effect on rainfed wheat yield in the study area. This can be due to the temperature and sunshine susceptibility of cereals after anthesis.

This technique is a development in the direct application of weather parameters in the linear regression method, as shown by the findings. Besides, the information of these weather variables is readily accessible; hence, this simple linear regression technique can be regarded as a suitable tool to predict the wheat yield in rainfed Fars Province, southern Iran.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Disclosure

The sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Conflicts of Interest

The authors declare no conflicts of interest.

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References

[1] N. Tavanpour and A. A. Ghaemi, "Zoning of Fars Province in terms of rainfed winter wheat cultivation based on precipitation and morphological factors," *Iranian Journal of Irrigation & Drainage*, vol. 4, pp. 544–555, 2016, In Persian.

[2] M. Ghadiryanfar, A. Keyhani, A. Akram, and S. Rafiee, "Investigating the cost of wheat production in Iran and the effect of combine availability on harvesting cost," *Agricultural Engineering International: The CIGR Journal. Manuscript MES*, vol. 1261, 2009.

[3] M. Bahrami, S. Bazrkar, and A. R. Zarei, "Modeling, prediction and trend assessment of drought in Iran using standardized precipitation index," *Journal of Water and Climate Change*, vol. 10, no. 1, pp. 181–196, 2019.

[4] Y. Miao, D. J. Mulla, and P. C. Robert, "Identifying important factors influencing corn yield and grain quality variability using artificial neural networks," *Precision Agriculture*, vol. 7, no. 2, pp. 117–135, 2006.

[5] R. Mumtaz, S. Baig, and I. Fatima, "Analysis of meteorological variations on wheat yield and its estimation using remotely sensed data. A case study of selected districts of Punjab Province, Pakistan (2001-14)," *Italian Journal of Agronomy*, vol. 12, pp. 254–270, 2017.

[6] A. Sabzevary, M. Torkaman, and Z. Meryanji, "Survey the effect of parameters and meteorological variables in optimal

performance of wheat (a case study: Hamedan Province)," *Journal of Soil and Water Agriculture Science and Technology*, vol. 26, pp. 1554–1567, 2012.

[7] J. Norman, "Modeling the complete crop canopy," in *Modification of the Aerial Environment of the Crop*p. 538, ASAE, St. Josephs, MI, USA, 1979.

[8] H. S. Mavi, *Introduction to Agrometeorology*, p. 281, Oxford and IBH Publication, Delhi, India, 1994.

[9] V. A. Alexandrov and G. Hoogenboom, "The Impact of climate variability and change on crop yield in Bulgaria," *Agricultural and Forest Meteorology*, vol. 104, no. 4, pp. 315–327, 2000.

[10] S. Landau, R. A. C. Mitchell, V. Barnett, J. J. Colls, J. Craigon, and R. W. Payne, "A parsimonious, multiple-regression model of wheat yield response to environment," *Agricultural and Forest Meteorology*, vol. 101, no. 2-3, pp. 151–166, 2000.

[11] D. B. Lobell, J. I. Ortiz-Monasterio, G. P. Asner, P. A. Matson, R. L. Naylor, and W. P. Falcon, "Analysis of wheat yield and climatic trends in Mexico," *Field Crops Research*, vol. 94, no. 2-3, pp. 250–256, 2005.

[12] B. Qian, R. De Jong, R. Warren, A. Chipanshi, and H. Hill, "Statistical spring wheat yield forecasting for the Canadian prairie provinces," *Agricultural and Forest Meteorology*, vol. 149, no. 6-7, pp. 1022–1031, 2009.

[13] S. Kumar, B. M. K. Raju, C. A. R. Rao, K. Kareemulla, and B. Venkateswarlu, "Sensitivity of yields of major rainfed crops to climate change," *Indian Journal of Agricultural Economics*, vol. 66, pp. 340–352, 2011.

[14] K. R. Paltasingh, P. Goyari, and R. K. Mishra, "Measuring weather impact on crop yield using aridity index: evidence from Odisha," *Agricultural Economics Research Review*, vol. 25, pp. 205–216, 2012.

[15] H. Zare Abyaneh, "Evaluating roles of drought and climatic factors on variability of four dry farming yields in Mashhad and Birjand," *Journal of Water and Soil Science*, vol. 23, pp. 39–56, 2012.

[16] D. Tigkas and G. Tsakiris, "Early estimation of drought impacts on rainfed wheat yield in Mediterranean climate," *Environmental Processes*, vol. 2, no. 1, pp. 97–114, 2015.

[17] M. Hemavathi and K. Prabakaran, "A statistical study on weather parameters relationship with rice crop yield in Thanjavur district of Tamil Nadu," *International Journal of Agricultural Science and Research*, vol. 7, no. 5, pp. 25–32, 2017.

[18] A. A. Leilah and S. A. Al-Khateeb, "Statistical analysis of wheat yield under drought conditions," *Journal of Arid Environments*, vol. 61, no. 3, pp. 483–496, 2005.

[19] L. Wu, L. Feng, Y. Li, J. Wang, and L. Wu, "A yield-related agricultural drought index reveals spatio-temporal characteristics of droughts in Southwestern China," *Sustainability*, vol. 11, no. 3, p. 714, 2019.

[20] A. R. Zarei, A. Shabani, and M. R. Mahmoudi, "Evaluation of the influence of occurrence time of drought on the annual yield of rain-fed winter wheat using backward multiple generalized estimation equation," *Water Resources Management*, vol. 34, no. 9, pp. 2911–2931, 2020.

[21] A. Mehnatkesh, S. Ayoubi, A. Jalalian, and A. A. Dehghani, "Prediction of rainfed wheat grain yield and biomass using artificial neural networks and multiple linear regressions and determination the most factors by sensitivity analysis. Information Technology, Automation and Precision Farming," in *Proceedings of the International Conference of Agricultural Engineering-CIGR-AgEng 2012: Agriculture and Engineering for a Healthier Life*, Valencia, Spain, July 2012.

[22] A. R. Zarei and M. R. Mahmoudi, "Prioritization of the effectiveness rate of various climatic variables on the annual yield of rain-fed winter wheat using different statistical models," *Stochastic Environmental Research and Risk Assessment*, vol. 34, no. 5, pp. 611–625, 2020.

[23] D. H. Kazmi and G. Rasul, "Agrometeorological wheat yield prediction in rainfed Potohar region of Pakistan," *Agricultural Sciences*, vol. 3, no. 2, pp. 170–177, 2012.

[24] M. Siosemarde and A. Sakine, "Prediction of rainfed wheat yield using meteorological parameters in Khoy County at West Azarbaijan Province," *Journal of Applied Environmental and Biological Sciences*, vol. 4, pp. 47–50, 2014.

[25] A. Khoorani, M. Farajzadeh, S. Bazgeer, and P. Zeaeian, "A statistical approach for estimating wheat yield using bootstrap resampling for rainfed farming: a case study of Kurdistan province, Iran," *Bulgarian Journal of Agricultural Science*, vol. 20, pp. 267–274, 2014.

[26] A. R. Zarei and M. Bahrami, "Evaluation of quality and quantity changes of underground water in Fasa plain, Fars (2006-2013). Iran," *Journal of Irrigation and Drainage Engineering*, vol. 6, no. 24, pp. 103–113, 2016.

[27] F. E. Harrell Jr., *Regression Modeling Strategies: With Applications to Linear Models, Logistic and Ordinal Regression, and Survival Analysis*, p. 582, Springer, Berlin, Germany, 2015.

[28] S. Rose and T. G. McGuire, "Limitations of p-values and R-squared for stepwise regression building: a fairness demonstration in health policy risk adjustment," *The American Statistician*, vol. 73, pp. 152–156, 2019.

[29] G. Heinze, C. Wallisch, and D. Dunkler, "Variable selection—a review and recommendations for the practicing statistician," *Biometrical Journal*, vol. 60, no. 3, pp. 431–449, 2018.

[30] J. Bi, "A review of statistical methods for determination of relative importance of correlated predictors and identification of drivers of consumer liking," *Journal of Sensory Studies*, vol. 27, no. 2, pp. 87–101, 2012.

[31] R. Lideman, P. Merenda, and R. Gold, *Introduction to Bivariate and Multivariate Analysis*, Scott Foresman, Glenview, IL, USA, 1980.

[32] U. Grömping, "Relative importance for linear regression in R: the package relaimpo," *Journal of Statistical Software*, vol. 17, no. 1, pp. 1–27, 2016.

[33] V. Zuber and K. Strimmer, "High-dimensional regression and variable selection using CAR scores," *Statistical Applications in Genetics and Molecular Biology*, vol. 10, no. 1, 2011.

[34] R. C. Rathnayake and D. J. Olive, Bootstrapping some GLMs and survival regression models after variable selection," (http://lagrange.math.siu.edu/Olive/ppbootglm.pdf), 2019.

[35] E. Pishbahar and S. Darparnian, "Factors creating systematic risk for rainfed wheat production in Iran, using spatial econometric approach," *Journal of Agriculture, Science and Technology*, vol. 18, pp. 895–909, 2016.

[36] A. Barkley, J. Tack, L. L. Nalley, J. Bergtold, R. Bowden, and A. Fritz, "Weather, disease, and wheat breeding effects on Kansas wheat varietal yields, 1985 to 2011," *Agronomy Journal*, vol. 106, no. 1, pp. 227–235, 2014.

[37] M. T. Abi Saab, M. Houssemeddine Sellami, P. Giorio et al., "Assessing the potential of cereal production systems to adapt to contrasting weather conditions in the mediterranean region," *Agronomy*, vol. 9, no. 7, p. 393, 2019.

[38] B. Goswami, G. S. Mahi, and U. S. Saikia, "Effect of few important climatic factors on phenology, growth and yield of rice and wheat- a review," *Agricultural Reviews*, vol. 27, pp. 223–228, 2006.

[39] A. Vaseghi and A. Esmaeili, "Investigation of the economic impacts of climate change on Iran agriculture: a Ricardian approach (Case study: wheat)," *Journal of Science and Technology of Agriculture and Natural Resources*, vol. 15, pp. 685–696, 2008.

[40] A. Mukherjee, S.-Y. Wang, and P. Promchote, "Examination of the climate factors that reduced wheat yield in Northwest India during the 2000s," *Water*, vol. 11, no. 2, p. 343, 2019.

[41] J. D. Holman, A. J. Schlegel, C. R. Thompson, and J. E. Lingenfelser, "Influence of precipitation, temperature, and 56 years on winter wheat yields in Western Kansas," *Crop Management*, vol. 10, no. 1, pp. 1–10, 2011.

[42] R. P. Lollato, J. T. Edwards, and T. E. Ochsner, "Meteorological limits to winter wheat productivity in the U.S. southern Great Plains," *Field Crops Research*, vol. 203, pp. 212–226, 2017.

[43] S. Chaurasia, A. K. Joshi, R. Dhari, and R. Chand, "Resistance to foliar blight of wheat: a search," *Genetic Resources and Crop Evolution*, vol. 46, no. 5, p. 469, 1999.

[44] M. Bahrami, A. R. Zarei, M. M. Moghimi, and M. R. Mahmoudi, "Trend analysis of evapotranspiration applying parametric and non-parametric techniques (case study: arid regions of southern Iran)," *Sustainable Water Resources Management*, vol. 5, no. 4, p. 1981, 2019.

[45] A. Dindarlou, A. A. Ghaemi, A. Shekafandeh Nobandegani, M. Bahrami, and M. Dastourani, "Interaction of water salinity and different irrigation levels on physiological growth of olive (Olea europaea L.)," *Journal of Agriculture, Science and Technology*, vol. 21, pp. 1623–1637, 2019.