Shiraz University

Iran Agricultural Research (2018) **37**(**1**) 19-32

Prediction of frost occurrence by estimating daily minimum temperature in semi-arid areas in Iran

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DOI: 10.22099/IAR.2018.4689

ARTICLE INFO

***Article history*:**

Received **1 October 2016**

Accepted **9 January 2017**

Available online **8 January 2018**

***Keywords*:**

Frost

Dew-point

Relative humidity

Minimum temperature

ABSTRACT- Many fruits, vegetables and ornamental crops of tropical origin experience physiological damage when subjected to low temperatures. Protection of plants from the effects of lethally low temperatures is important in agriculture, especially in horticultural production of high value fruits and vegetables. The objective of this study was to develop a simple model to predict the daily minimum air temperature for prediction of frost occurrence in Bajgah and Kooshkak semi-arid areas, Fars province. Initially, the relationship between the minimum temperature of the early morning of a day with some meteorological parameters of the previous day was developed. Meteorological parameters used in this analysis are daily relative humidity, wind speed, pan evaporation, rainfall, sunshine hours, and estimated dew-point temperature. Dew-point is an important parameter which is related to the minimum temperature in different months with low temperature in Bajgah and Kooshkak areas. Many daily weather parameters used in the regression analysis showed no significant relationship with the daily early morning minimum temperature, except the dew-point and relative humidity. The regression equation between the differences between dew-point and minimum temperature with relative humidity as a simple model was proposed to be used to predict the minimum temperature and subsequently frost occurrence in the study regions. This model was validated by independent data set with an acceptable accuracy for the study regions.

INTRODUCTION

Food production is one of the main problems in the world. Agricultural capability for food production in each region depends on weather and climate conditions. The protection of plants from the effects of lethally low temperatures is important in agriculture, especially for horticultural production of high value fruits and vegetables. Weather is usually described in terms of a series of measurements and observations that include temperature, wind, sunshine, cloud cover and precipitation. Plant physiology, seed germination, pollination, growth, photosynthesis and material transport within the plant are sensitive to climate conditions in different plant growth stages. One of the meteorological issues for many agricultural systems is frost occurrence. Different plants show different reactions to low temperatures, and it depends on the health of the plant, maturity, growth rate, and growth stages. Time of frost occurrence shows different resistance of plants to frost (Vantskevich, 1985).

Low temperature injury (e.g., chilling and freezing) can occur in all plants; however, the mechanisms and types of damage vary considerably. Many fruits, vegetables and ornamental crops of tropical origin experience physiological damage when subjected to temperatures below about 12.5 °C, hence well above freezing temperatures. However, damage above 0 °C is chilling injury rather than freeze injury. Freeze injury occurs in all plants due to ice formation in plant. Crop plants that develop in tropical climates, often experience serious frost damage when exposed to temperature slightly below zero whereas most crops that develop in colder climates often survive with little damage if the freeze event is not too severe. Frost damage may have a drastic effect on the entire plant or affect only a specific part of the plant tissue that reduces yield, or merely product quality (Rosenberg, et al., 1983).

The forecast of frost occurrence requires complicated decision analysis that uses conditional probabilities and economics. Accurate frost forecasting can potentially reduce frost damage because it provides growers with the opportunity to prepare for frost protection. The daily minimum temperature depends on meteorological parameters such as mean air temperature, radiation, wind, humidity, soil properties and cover. In many practical cases, the only information one may have is the daily maximum/minimum air temperatures, precipitation and sometimes solar radiation, vegetation cover and soil type. The ability to predict the occurrence of frost from this type of information would be quite useful in agriculture (Cary, 1982). Predicting the time of temperature fall to a critical value is important for starting active frost protection methods. In addition, the duration of temperature below the critical value is important for assessing potential frost damage. Starting at the proper temperature is important because it avoids losses resulting from starting too late and it saves energy by reducing the operation time of the various methods at any given time during the night. The critical time for starting any frost protection activity is one hour before the time that the critical damage temperature is expected. This prediction method is fairly accurate; however, it is not perfect (Snyder, 2000).

For the development of minimum temperature occurrence atlas, daily minimum temperature values were used in Fars province (Ziaee et al., 2006). In this study, the dates of different minimum temperatures were fitted to statistical distribution functions using SMADA software. Log Pearson type ш and Pearson type ш was determined as the best distribution for estimation of the frost occurrence dates. The minimum temperature occurrence atlas was also determined by the use of occurrence probability and geographical coordinates in SURFER. Using these maps is useful for frost prediction for decision making to select the planting and harvesting of crops (Ziaee et al., 2006).

There are several methods of predicting the occurrence of frost. Many involve an empirical relationship between the minimum temperature and dew-point temperature (T_d). In Victoria (Australia) frost is reckoned possible if dew-point is less than 6°C, and probable if it is below 0° C. Minimum temperature is deduced as equal to $[T_{max} + T_d]/2$ minus a correction which depends on the wind speed and cloudiness, where T_{max} is the highest temperature reached the previous day (Bagdonas et al., 1978). For preparation of frost atlas in Fars province, Iran, the minimum daily air temperatures at 27 meteorological stations were used. The values of minimum temperature ranges of 0°C to -1.5°C, -1.5°C to -3°C and below -3°C were considered as mild, moderate and severe frosts intensities, respectively. The difference between measured and estimated dates of frost was estimated by modified inverse distance weighted (*MIDW*) method. The method of *MIDW* was selected for preparation of frost atlas in Fars province, Iran (Didari et al., 2011).

Dew-point and relative humidity may be appropriate to predict the frost occurrence. The values of daily relative humidity in range of 45% to 55 % in the evening can be used accurately for estimating minimum temperature in the early morning of the next day in Jahrom, Iran, (Nazemosadat et al., 2001). In this study, for the values of relative humidity outside of this range, the minimum temperature in the next day was lower or higher than the dew-point of previous day, respectively. Therefore, it is indicated that daily relative humidity can help to estimate the next day minimum temperature.

The purpose of this study was to develop a simple model to predict the daily minimum temperatures of early morning based on daily meteorological parameters of the previous day in Bajgah and Kooshkak areas, Fars province, for frost occurrence.

MATERIALS AND METHODS

The meteorological data from 1982 to 2002 in Bajgah and from 1992 to 2002 in Kooshkak in the months of April, May, October, November, December, January, February, and March were used for estimation of the daily early morning minimum temperature from the weather parameters of the previous day for the frost forecasting. The relationship between the minimum temperature and the most important climate parameters in different months was determined by simple regression analysis. The list of these parameters is shown in Table 1.

Table 1. Meteorological parameters used in this study

Variable	Definition	Unit
T_{max}	Maximum daily temperature	°C
T_{min}	Minimum daily temperature	°C
T_{mean}	Mean daily temperature	°C
RH_{max}	Maximum daily relative humidity	%
RH_{min}	Minimum daily relative humidity	%
RH_{mean}	Mean daily relative humidity	%
N	Daily sunshine hours	hour
R	Daily rainfall	mm
U2	Wind speed 2 m height	m/s
E_p	Daily pan evaporation	mm

Estimation of Dew-Point

In this study, the daily dew-point (T_d) is an important parameter that should be estimated and included in the regression analysis. To estimate the daily dew-point (T_d) the values of maximum/minimum temperature, maximum/minimum relative humidity and vapor pressure were used. The T_d temperature in °C is determined by the following equation (Allen et al., 1998):

$$T_d = \frac{116.91 + 237.3 \ln(e_a)}{16.78 - \ln(e_a)} \quad (1)$$

where T_d is the dew-point temperature (°C), e_a is the actual vapor pressure (kPa). To calculate e_a, we need to determine $e^0(T)$, the saturation vapor pressure in temperature of T in °C as follows (Allen et al., 1998):

$$e^0(T) = 0.6108 \exp\left[\frac{17.27\,T}{T + 237.3}\right] \quad (2)$$

The value of e_a can be determined by three methods that are given in Eqs. (3) to (5) (Allen et al., 1998) as follows:

$$e_a = \frac{e^0(T_{min})\,RH_{max} + e^0(T_{max})\,RH_{min}}{200} \quad \text{(method 1)} \quad (3)$$

Method 1 [Eq. (3)] is used in situations where the measured values of maximum and minimum temperature and relative humidity are known.

$$e_a = \frac{e^0(T_{\min}) RH_{\max}}{100} \quad \text{(method 2)} \qquad (4)$$

Method 2 [Eq. (4)] is used in situations where the accuracy of minimum relative humidity measurement is low or suspicious and we can use maximum relative humidity.

$$e_a = \frac{RH_{mean}}{100}\left[\frac{e^0(T_{\max}) + e^0(T_{\min})}{2}\right] \quad \text{(method 3)} \qquad (5)$$

Method 3 [Eq. (5)] is used in situations where minimum and maximum relative humidity are not measured and the average relative humidity is available.

In Eqs. (3) to (5) e_a is the actual vapor pressure (kPa), $e^0(T_{min})$ and $e^0(T_{max})$ are the saturation vapor pressure in minimum and maximum temperature (kPa), respectively; RH_{min} , RH_{max} , and RH_{mean} are the minimum, maximum and mean relative humidity (%), respectively; and T_{min} and T_{max} are the minimum and maximum temperature (°C), respectively.

Methods 1 to 3 based on Eqs. (3) to (5) were used to determine the e_a and consequently T_d in correlation analysis. Based on available measured data, the appropriate method may be different although in determining e_a, the best suggestion is Method 1 [Eq. (3)] according to Whiteman (1957). However, in this study, all three methods were used to determine e_a for estimation of T_d in order to find the appropriate method. In the present study, the difference between calculated daily dew-point and the minimum temperatures of the early morning of the next day is used as a tool to develop the simple model and is showed by d as follows:

$$d=T_d(i)-T_{min}(i+1) \qquad (6)$$

where $T_d(i)$ is the daily dew-point temperature in day i (°C) and $T_{min}(i+1)$ is the minimum temperature in day $i+1$ (°C). The relationship between d values and daily RH was developed as a simple model for prediction of T_{min} .

The calculated daily dew-points by the three methods in Eqs. (3) to (5) are displayed by $Td(1)$ and $Td(2)$ and $Td(3)$, respectively, and corresponding d values are shown by $d1$ and $d2$ and $d3$, respectively. SPSS, Stat graphics, Curve Expert, Excel and SMADA are soft-wares that were used to determine the best relationships between data, linear and nonlinear regressions, comparing multiple data sets in pairs or in groups, data impacts on each other, analysis of variance, eliminate outlier data, and statistical distributions and occurrence probability of minimum temperatures.

Statistical Analysis

There has been a concomitant and deepening interest in comparing and evaluating the models accuracy. To assess the validity of models, statistical analysis is used. Some of the most important statistical parameters of model evaluation analysis are the Normal Root Mean Square Error (NRMSE), Mean Absolute Error (MAE), Mean Error (ME**),** Index of agreement (d) and Coefficient of Nash-Sutcliff (C_{NS}). These statistical parameters are determined by Eqs. (7) to (11) as follows (Nash et al., 1970., Willmott, 1982):

$$NRMSE = \frac{1}{\overline{O}}\sqrt{\frac{\sum_{i=1}^{n}\left(O_i - P_i\right)^2}{n}} \qquad (7)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|P_i - O_i\right| \qquad (8)$$

$$ME = \frac{1}{n}\sum_{i=1}^{n}\left(P_i - O_i\right) \qquad (9)$$

$$d = 1 - \frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{\sum_{i=1}^{n}\left(\left|P_i - \overline{O}\right| + \left|O_i - \overline{O}\right|\right)^2} \qquad (10)$$

$$C_{NS} = 1 - \frac{\sum_{i=1}^{n}\left(P_i - O_i\right)^2}{\sum_{i=1}^{n}\left(O_i - \overline{O}\right)^2} \qquad (11)$$

where P_i and O_i are the predicted and observed values of a parameter, $\overline{O}$ is the average of observed data and n is the number of observations. Lower values of MAE, and the values of NRMSE and ME near zero show a higher similarity between the measured and estimated values in the model. The values of d near to 1 indicate the best agreement between measured and estimated values. Values of C_{NS} range from minus infinity to 1, with higher values indicating better agreement. The values of measured and predicted daily minimum temperatures by the simple regression models were evaluated by using Eqs. (7) to (11). Furthermore, for evaluation of the accuracy of the model, the relationship between the measured and predicted values were compared with 1:1 line by Fisher F statistics.

RESULTS AND DISCUSSION

Probability of Minimum Temperature Occurrence

Distribution function as a result of probability analyses by SMADA software was determined. Return periods of minimum temperatures in the studied months were evaluated in Bajgah and Kooshkak. We determined the probabilities of below 0 °C temperatures occurrence in different months with danger of frost occurrence. Results are shown in Table 2. By knowing the minimum temperature for frost injury of a plant, the necessary steps to prevent the frost damage is anticipated.

Table 2. Minimum temperatures in different return periods in Bajgah and Kooshkak areas

Month	Return period, year									
	Bajgah					Kooshkak				
	1	5	10	25	50	1	5	10	25	50
April	-6.0	-7.5	-8.0	-11.5	-15.0	-7.5	-8.0	-8.5	-11.5	-14.0
May	-5.0	-7.5	-8.0	-11.0	-13.5	-5.0	-6.0	-7.5	-11.0	-13.5
Oct.	-.35	-5.0	-6.0	-8.0	-10.0	-2.5	-4.5	-5.0	-7.5	-10.5
Nov.	-4.0	-5.5	-6.0	-8.5	-11.0	-3.5	-4.5	-6.0	-9.0	-12.0
Dec.	-5.0	-8.0	-9.0	-10.5	-12.0	-5.0	-8.0	-8.5	-10.5	-12.0
Jan.	-5.5	-9.0	-10.0	-13.5	-17.5	-5.0	-8.5	-10.0	-13.5	-17.0
Feb.	-8.0	-11.0	-12.0	-16.0	-19.0	-7.5	-10.5	-12.0	-16.0	-19.0
Mar.	-10.0	-12.5	-15.0	-18.5	-22.5	-9.0	-12.0	-14.0	-17.5	-21.0

For instance, the return period for -7.5°C temperatures occurrence in May in Bajgah is 5 years. Furthermore, in April, every year temperature is expected to drop to -7.5°C in Kooshkak. Information presented in Table 2 is useful for providing some protection actions to prevent plant injuries by knowing the occurrence probability of minimum temperatures in these areas. Also, by knowing the values of minimum temperature, the crop type and planting date can be managed properly.

The autocorrelation of minimum temperature of consecutive days with different lags in all years has been analyzed to know the presence or lack of relationship between them. If there is a relationship between minimum temperatures of consecutive days, further calculations may be simpler; also we should be able to determine a relationship between the minimum temperature of consecutive days and develop a simple usable model for prediction of daily minimum temperature. The results of the time series correlation obtained for the minimum temperature in Bajgah and Kooshkak showed a significant correlation of the minimum temperature in the consecutive days with one lag and other lags were not significant. The partial autocorrelation coefficients were 0.68 and 0.77 for Bajgah and Kooshkak, respectively with standard error of 0.026 and 0.028 for Bajgah and Kooshkak, respectively. This indicated that there is significant relationship only between daily minimum early morning temperature with minimum early morning temperature of the next day. This indicated that the minimum temperature of the consecutive day with one lag is related to each other and lags higher than one showed no correlation. Therefore, the relationship between daily minimum temperature and other weather parameters was investigated in the next step.

Relationship Between Daily Minimum Temperature and Other Weather Parameters

Initially, the relationship between the daily minimum temperature and some meteorological parameters was developed. The results showed in Table 3 indicated that the minimum temperature showed a significant relation with dew-point temperature estimated by three different methods [Eqs. (3) to (5)] and mean relative humidity. In other words, relative humidity and dew-point temperature were the most significant parameters correlated with the daily minimum temperature. It is evident that daily relative humidity and dew-point significantly influenced the daily minimum temperature of the early morning. The relationship between the dew-point of three methods and the meteorological parameters are shown in Table 4. In general, the coefficients of determination (R^2) indicated that there is a better relation between the dew-point estimated by Eq. (3) [$T_d(1)$] and other parameters. This supported the suggestion of Whiteman, (1957); therefore, the results of Method 1 [Eq. (3)] were used in the next analysis.

Table 3. Coefficients of determination (R^2) between minimum temperature and some meteorological parameters in Bajgah and Kooshkak

Weather parameter	Bajgah	Kooshkak
$T_d(1)$	0.55**	0.48**
$T_d(2)$	0.60**	0.63**
$T_d(3)$	0.59**	0.55**
RH_{max}	0.13**	0.21**
RH_{min}	0.12**	0.16**
RH_{mean}	0.18**	0.24**
U2	0.050	0.060
Rain	0.007	0.003
Ep	0.100*	0.060
N	0.003	0.004

**, *: Significant at 1 % and 5 % probability levels, respectively

Relationship Between Minimum Temperature and Dew-Point Difference with Other Weather Parameters

The relationship between *d* values (d= difference between daily dew-point temperature ($T_d(i)$), and daily early morning minimum temperature of next day ($T_{min}(i+1)$)) of method 1 [Eq. (3)] and meteorological parameters is shown in Table 5. The relationship between *d1* and average relative humidity showed higher R^2 than other parameters. Therefore, *d1* is used in the simple model for T_{min} prediction.

The coefficient of determination (R^2) for the relationship between *d1* and average relative humidity in each month and for all combinations for months of the study period was analyzed separately. Because of the possibility of outlier data entry in the relationship, the results after removing the outliers were used in this study.

Table 4. Coefficients of determination (R^2) between the dew-point estimated by three different methods and some meteorological parameters in Bajgah and Kooshkak

	Bajgah			Kooshkak		
Weather parameter	$T_d(1)$	$T_d(2)$	$T_d(3)$	$T_d(1)$	$T_d(2)$	$T_d(3)$
RH_{max}	0.10*	0.18**	0.10*	0.32**	0.29**	0.34**
RH_{min}	0.59**	0.27**	0.24**	0.67**	0.15**	0.40**
RH_{mean}	0.56**	0.29**	0.24**	0.69**	0.24**	0.45**
U2	0.13**	0.17**	0.09*	0.14**	0.09*	0.09*
Rain	0.20**	0.08	0.003	0.34**	0.22**	0.22**
Ep	0.25**	0.24**	0.11*	0.02	0.05	0.03
N	0.08	0.03	0.04	0.04	0.04	0.05

**, *: Significant at 1 % and 5 % probability levels, respectively

Table 5. Coefficients of determination (R^2) between the minimum temperature and dew-point difference (d1) of method 1 [Eq. (3)] and some meteorological parameters in Bajgah and Kooshkak

Weather Parameter	Bajgah	Kooshkak
RH_{max}	0.24**	0.46**
RH_{min}	0.59**	0.71**
RH_{mean}	0.60**	0.74**
U2	0.07	0.02
Rain	0.27**	0.25**
Ep	0.21**	0.04
N	0.18**	0.05

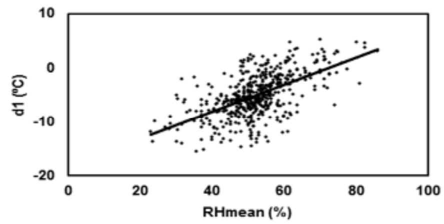
**: Significant at 1 % probability level

The equation of linear relationship and coefficient of determination (R^2) of the relationship between *d1* and average relative humidity before and after correction in Bajgah and Kooshkak are given in Table 6 and Figs. 1 and 2, respectively. For the values of mean relative humidity between 65 and 75 % in Bajgah, in all cases, the daily difference between dew-point and minimum temperature of the next day is near zero. In this range of RH, we can equate the daily minimum temperature to the dew-point of previous day. This rule is applicable in the colder months (months with low average temperature) with high relative humidity (75 %) and in the warmer months (months with high average temperature) with low relative humidity (65 %). For example, according to Fig. 1 in March, with the mean relative humidity of 73%, the daily dew-point is equal to the next day minimum temperature. Whereas, in May when the average temperature is higher than March, the *d1=0* occurred with mean relative humidity of 65 %. According to Fig. 1, the value of mean relative humidity is above 75 %, that is usually characteristic of colder months; therefore, the daily dew-point is higher than the minimum temperature of the next day. In this situation, it is suggested to subtract a few degrees from dew-point for prediction of minimum temperature of the next day. The corrected dew-point value for each month can be determined by the equations obtained from Table 6. In the months with low mean relative humidity (below 65%), which usually occurred in months with higher temperatures, the daily dew-point is less than the next day minimum temperature. In such cases, it is suggested to add a few degrees to the daily dew-point and use it in equations in Table 6 to predict the T_{min}.

The determination coefficient (R^2) of the relationship between the minimum temperature and dew-point in Kooshkak is higher than that of Bajgah (Table 6). It might be due to the lower number of recorded data obtained for recent years with lower variability than the recorded data in Bajgah. According to Fig. 2, with higher values of mean relative humidity (over 66%) in Kooshkak, the daily dew-point is higher than the minimum temperature of the next day. In case of low mean relative humidity (less than 64%), the daily dew-point is less than the next day minimum temperature. The corrected dew-point value for each month can be determined by the equations obtained from Table 6. In case of mean relative humidity between 64 to 66 % in Kooshkak, the daily dew-point is equal to the next day minimum temperature in all cases. Therefore, in cases of relative humidity of 65 % in Kooshkak, the next day minimum temperature is equal to the daily dew-point.

Daily mean relative humidity and dew-point were used in simple models of Table 6 to estimate daily minimum temperature of the next day. Comparisons of the measured and estimated T_{min} by the proposed simple models in Bajgah and Kooshkak are shown in Figs. 3 and 4. The linear relationship and coefficient of determination (R^2) of the relationship between the measured and estimated T_{min} in Bajgah and Kooshkak are given in Table 7. Determination coefficient (R^2) in Table 7 is significant at 1 % level of probability, which showed a good relationship between the measured and estimated T_{min} by simple models in Table 6. The determination coefficients (R^2) of all combinations for months in Kooshkak is higher than those in Bajgah. It might be due to the lower number of recorded data obtained for recent years with lower variability than the recorded data in Bajgah. In general, in both areas, the values of R^2 for all month combinations were equal or sometimes higher than those for each month; therefore, we can use the equation obtained of all month combinations, even better than those obtained for different months.

In general, the relationship between the early morning minimum temperature of the next day and daily dew-point was significant in Bajgah and Kooshkak. As the difference between the daily dew-point and the minimum temperature of the next day is closer to zero, we can equate tomorrow morning minimum temperature to the dew-point of today with higher confidence. These results are similar to those found by Nazemosadat et al. (2001).



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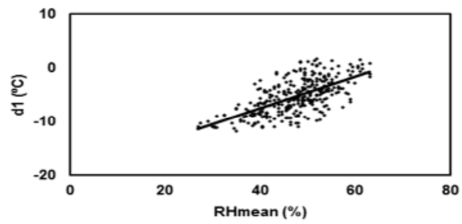
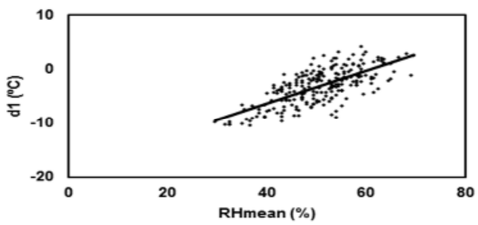
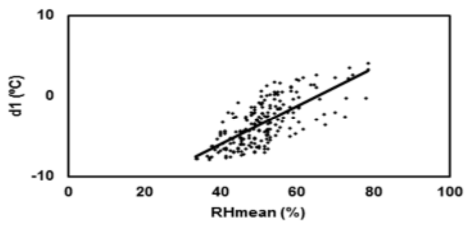


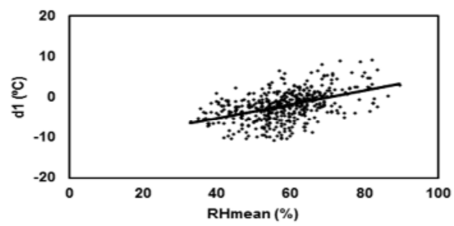
(b) May



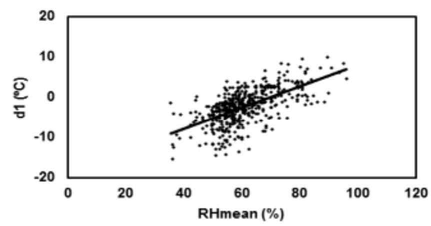
(c)October



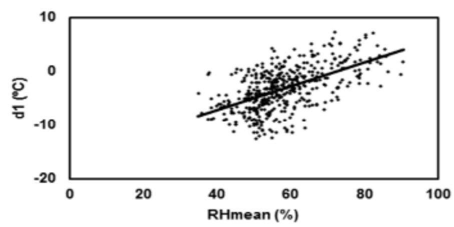
(d)November



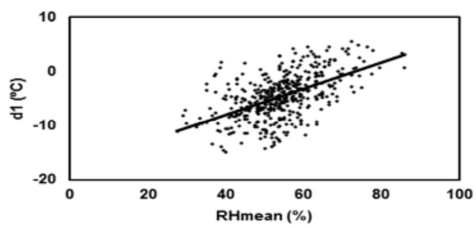
(e) December



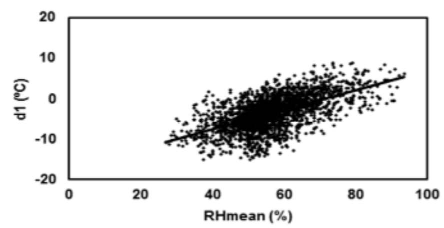
(f) January



(g) February

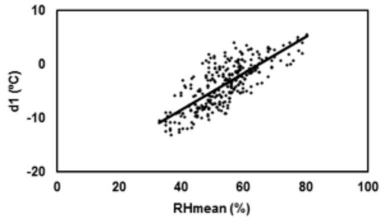


(h) March



(i)all months

Fig. 1. Relationship between *d1* and RH_{mean} in the study period in Bajgah



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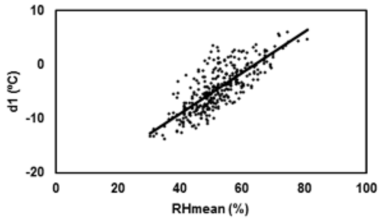
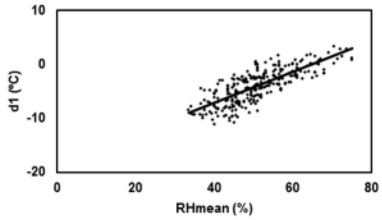


(b) May



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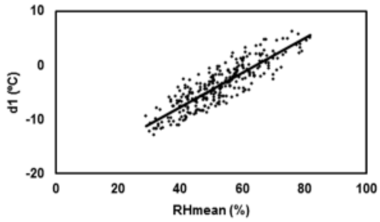
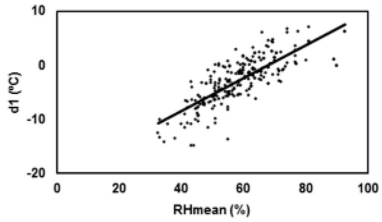
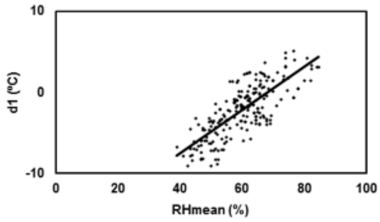


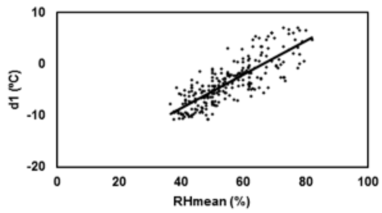
(d)November



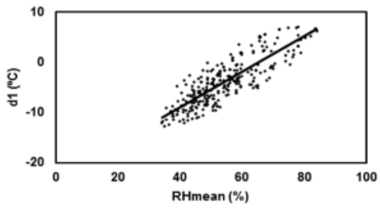
(e) December



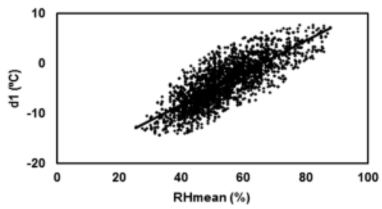
(f)January



(g) February



(h) March



(i) all months

Fig. 2. Relationship between *d1* and RH_{mean} in the study period in Kooshkak

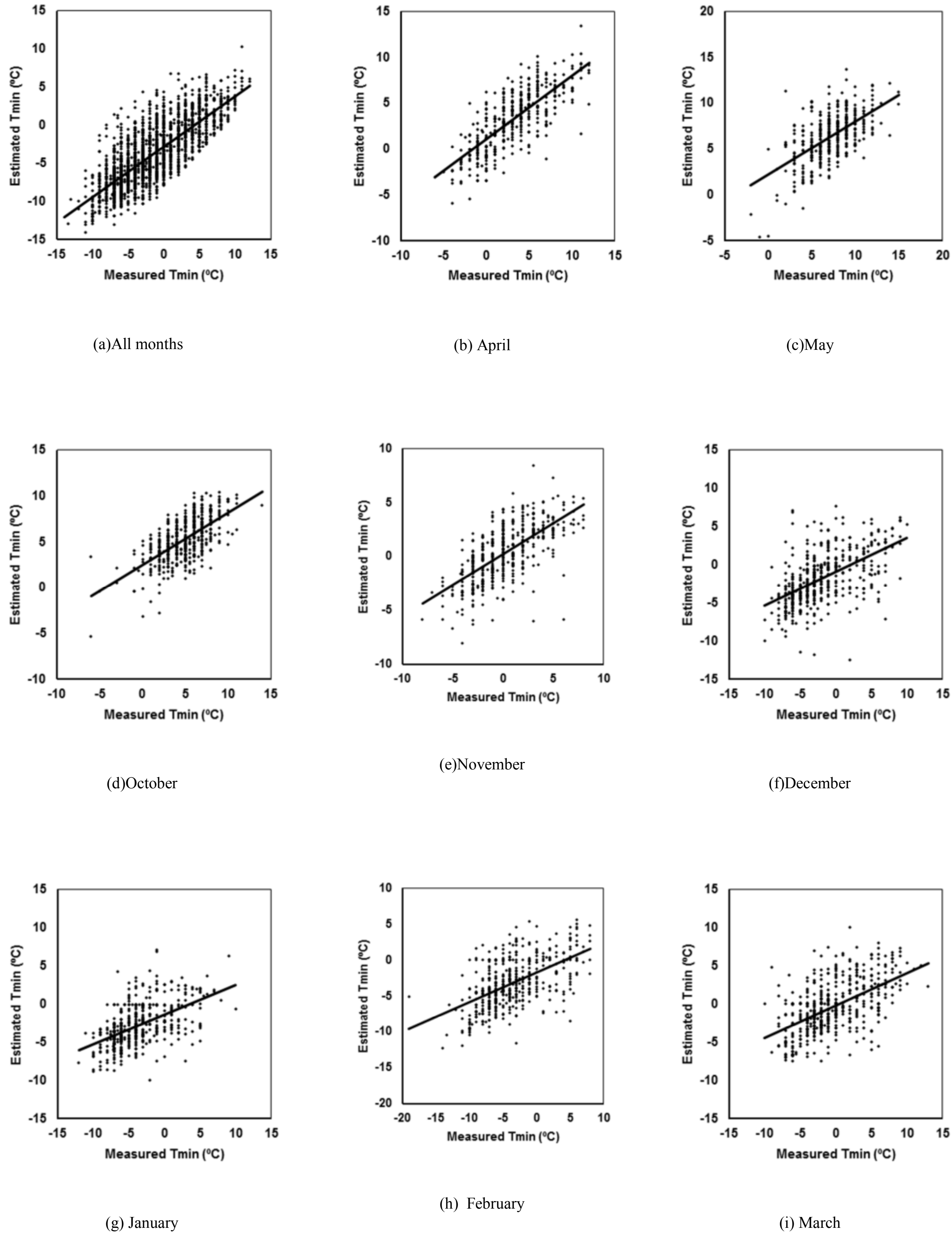
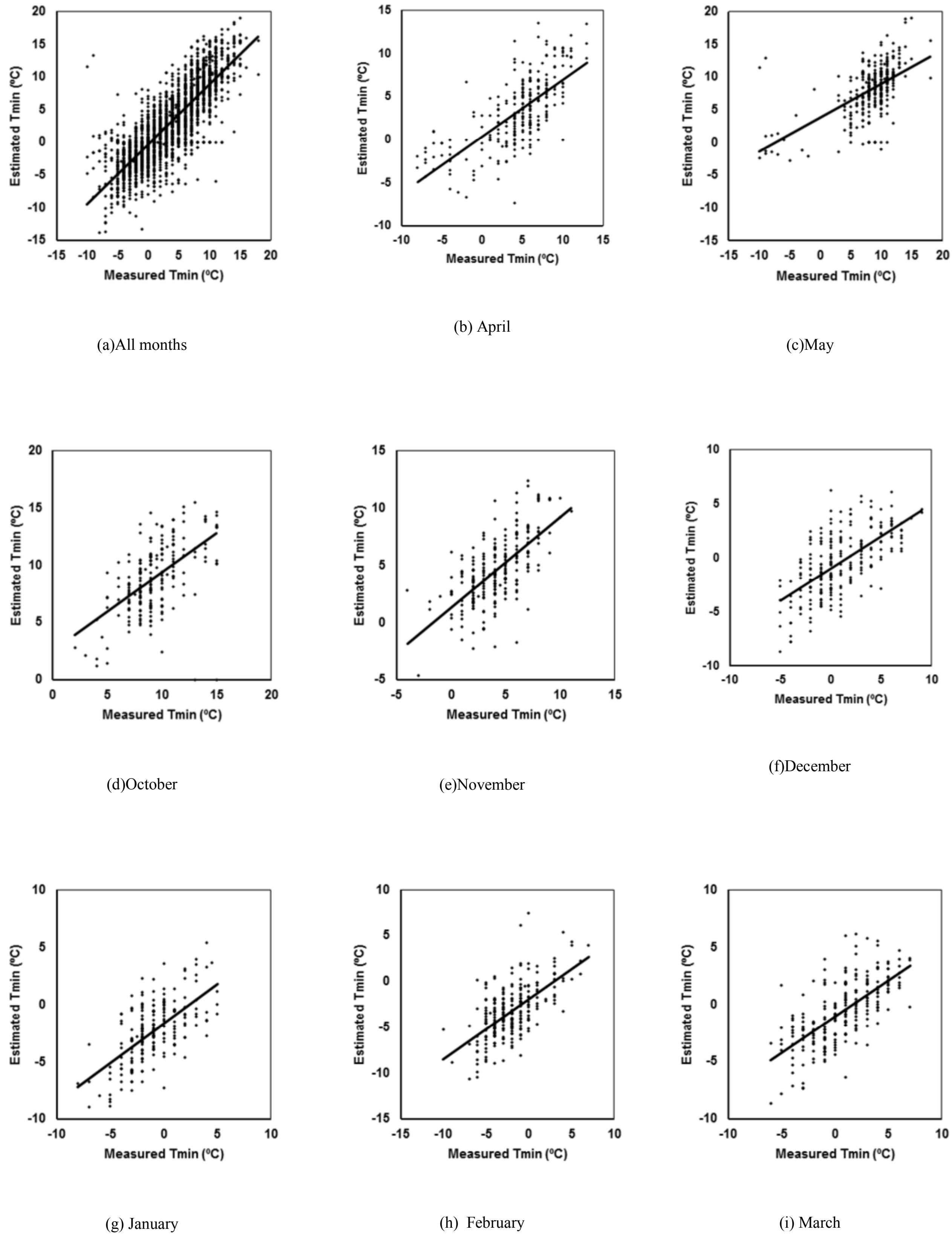


Fig. 3. Comparison of the measured and estimated T_{min} by the simple models in Bajgah



(a)All months (b) April (c)May

(d)October (e)November (f)December

(g) January (h) February (i) March

Fig. 4. Comparison of the measured and estimated T_{min} by the simple models in Kooshkak.

Table 6. Coefficients of determination (R^2) between *d1* and mean RH_{mean} before and after correction in Bajgah and Kooshkak

Period	Bajgah			Kooshkak		
	Linear equation	R^2 After correction	R^2 Before correction	Linear equation	R^2 After correction	R^2 Before correction
All months	$d1=0.28\ RH_{mean}-16.6$	0.41^{**}	0.38^{**}	$d1=0.32\ RH_{mean}-21.7$	0.62^{**}	0.56^{**}
April	$d1=0.25\ RH_{mean}-18.2$	0.36^{**}	0.35^{**}	$d1=0.34\ RH_{mean}-22.1$	0.57^{**}	0.44^{**}
May	$d1=0.30\ RH_{mean}-19.4$	0.41^{**}	0.39^{**}	$d1=0.37\ RH_{mean}-24.2$	0.62^{**}	0.60^{**}
Oct.	$d1=0.30\ RH_{mean}-18.5$	0.51^{**}	0.50^{**}	$d1=0.29\ RH_{mean}-18.6$	0.61^{**}	0.59^{**}
Nov.	$d1=0.24RH_{mean}-15.3$	0.51^{**}	0.49^{**}	$d1=0.32\ RH_{mean}-20.4$	0.75^{**}	0.73^{**}
Dec.	$d1=0.17\ RH_{mean}-12.2$	0.23^{**}	0.20^{**}	$d1=0.32\ RH_{mean}-21.3$	0.67^{**}	0.61^{**}
Jan.	$d1=0.26\ RH_{mean}-18.5$	0.37^{**}	0.36^{**}	$d1=0.27\ RH_{mean}-18.3$	0.61^{**}	0.52^{**}
Feb.	$d1=0.22\ RH_{mean}-16.1$	0.32^{**}	0.30^{**}	$d1=0.32\ RH_{mean}-21.2$	0.64^{**}	0.59^{**}
Mar.	$d1=0.24\ RH_{mean}-17.6$	0.31^{**}	0.29^{**}	$d1=0.36\ RH_{mean}-23.2$	0.72^{**}	0.64^{**}

**: Significant at 1 % probability level

Table 7. Linear relationships between the measured (T_{mm}) and predicted (T_{mp}) minimum temperature for different months in Bajgah and Kooshkak

Period	Bajgah		Kooshkak	
	Linear equation	R^2	Linear equation	R^2
All months	$T_{mp}=0.63\ T_{mm}-2.90$	0.58^{**}	$T_{mp}=0.92\ T_{mm}+0.29$	0.67^{**}
April	$T_{mp}=0.69\ T_{mm}+1.11$	0.57^{**}	$T_{mp}=0.66\ T_{mm}+0.33$	0.50^{**}
May	$T_{mp}=0.58\ T_{mm}+2.17$	0.35^{**}	$T_{mp}=0.51\ T_{mm}+3.80$	0.33^{**}
Oct.	$T_{mp}=0.57\ T_{mm}+2.52$	0.41^{**}	$T_{mp}=0.68\ T_{mm}+2.50$	0.31^{**}
Nov.	$T_{mp}=0.57\ T_{mm}+0.20$	0.44^{**}	$T_{mp}=0.79\ T_{mm}+1.31$	0.43^{**}
Dec.	$T_{mp}=0.44\ T_{mm}-0.93$	0.30^{**}	$T_{mp}=0.60\ T_{mm}-0.98$	0.40^{**}
Jan.	$T_{mp}=0.39\ T_{mm}-1.34$	0.28^{**}	$T_{mp}=0.69\ T_{mm}-1.42$	0.41^{**}
Feb.	$T_{mp}=0.42\ T_{mm}-1.76$	0.31^{**}	$T_{mp}=0.66\ T_{mm}-1.90$	0.40^{**}
Mar.	$T_{mp}=0.43\ T_{mm}-0.15$	0.31^{**}	$T_{mp}=0.64\ T_{mm}-1.06$	0.45^{**}

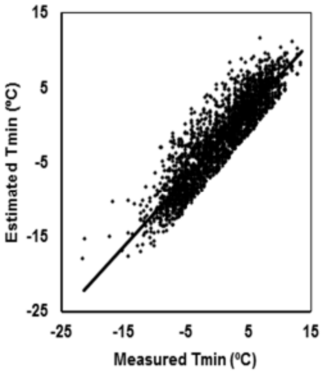
**: Significant at 1 % probability level

Model Validation

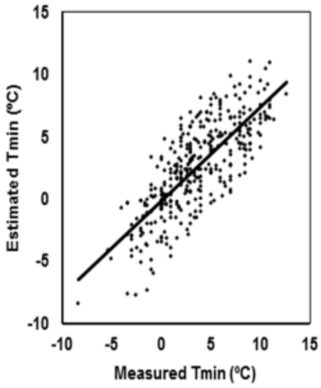
The measurements of weather parameters from 2003 to March of 2015 were used for validation of the simple regression models showed in Tables 8 and 9. Comparisons of the measured and estimated daily minimum early morning temperature (T_{min}) for all combinations for months and different months in Bajgah and Kooshkak are shown in Figs. 5 and 6. The linear relationships between the measured and predicted daily T_{min} for each month and their combination in Bajgah and Kooshkak are shown in Tables 8 and 9, respectively.

For the linear relationship where the slope is close to 1.0, it is close to 1:1 line. This situation occurred in the equations for all combinations for months in Bajgah and Kooshkak with higher R^2; therefore, we can use this general equation for all month combinations, even better than the equations for different months. In this case, the higher number of data made more similarity between the observed and estimated values in the model. In general, the measured values of daily minimum temperature are fairly close to the predicted values due to non-significant slope and intercept compared with 1.0 and zero (Tables 8 and 9).

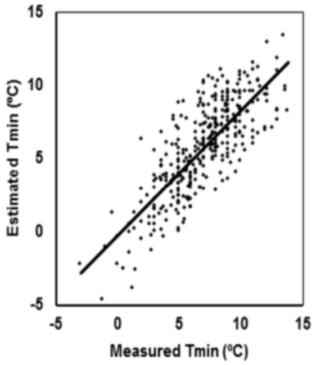
The low values of Mean Absolute Error (MAE) and Mean Error (ME) of the relationships between the measured and predicted values in each month and their combination supported the accuracy of the estimation. Lower values of MAE and NRMSE showed higher similarity between the measured and estimated values in the model in most cases. The negative values of ME showed underestimation of the measured values in all cases; therefore, the use of predicted lower minimum temperatures may be more confident for frost prediction. The values of F-test for slope and intercept of linear equations were not significant in any of the cases compared with the 1:1 line; therefore, the simple linear regression equation in Tables 8 and 9 showed similarity to 1:1 line. Similarities of linear equations to 1:1 line showed good prediction of daily early morning minimum temperature. The values of the index of agreement (d) and coefficient of Nash-Sutcliff (C_{NS}) in Tables 8 and 9 indicated that there was a high agreement between the measured and estimated T_{min} in Bajgah and Kooshkak. The most agreement was in all combinations for months. Therefore, it is concluded that the proposed simple models predicted the daily early morning minimum temperature with acceptable accuracy.



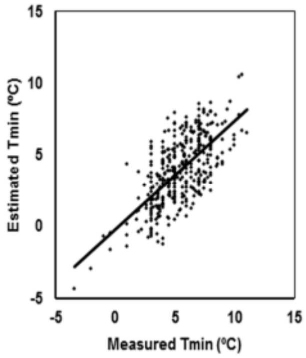
(a)All months



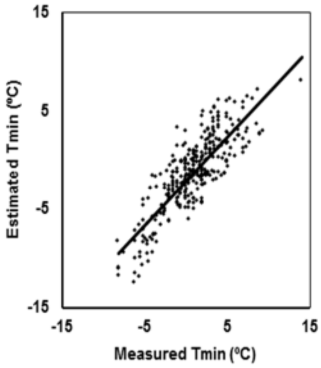
(b) April



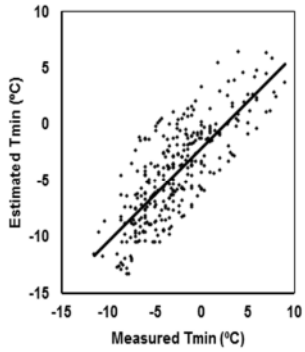
(c)May



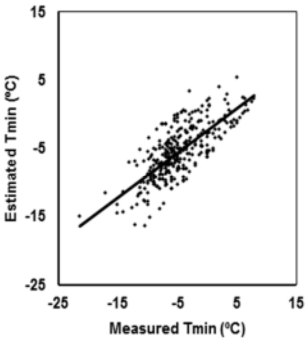
(d)October



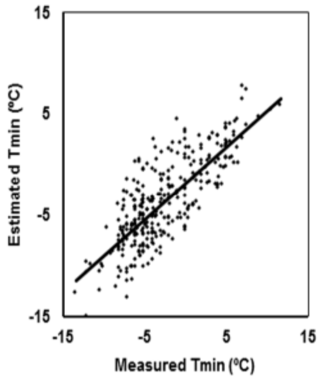
(e)November



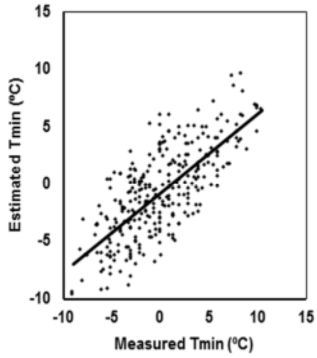
(f)December



(g) January



(h) February



(i) March

Fig. 5. Comparison of the measured and estimated T_{min} by the simple models for validation in Bajgah.

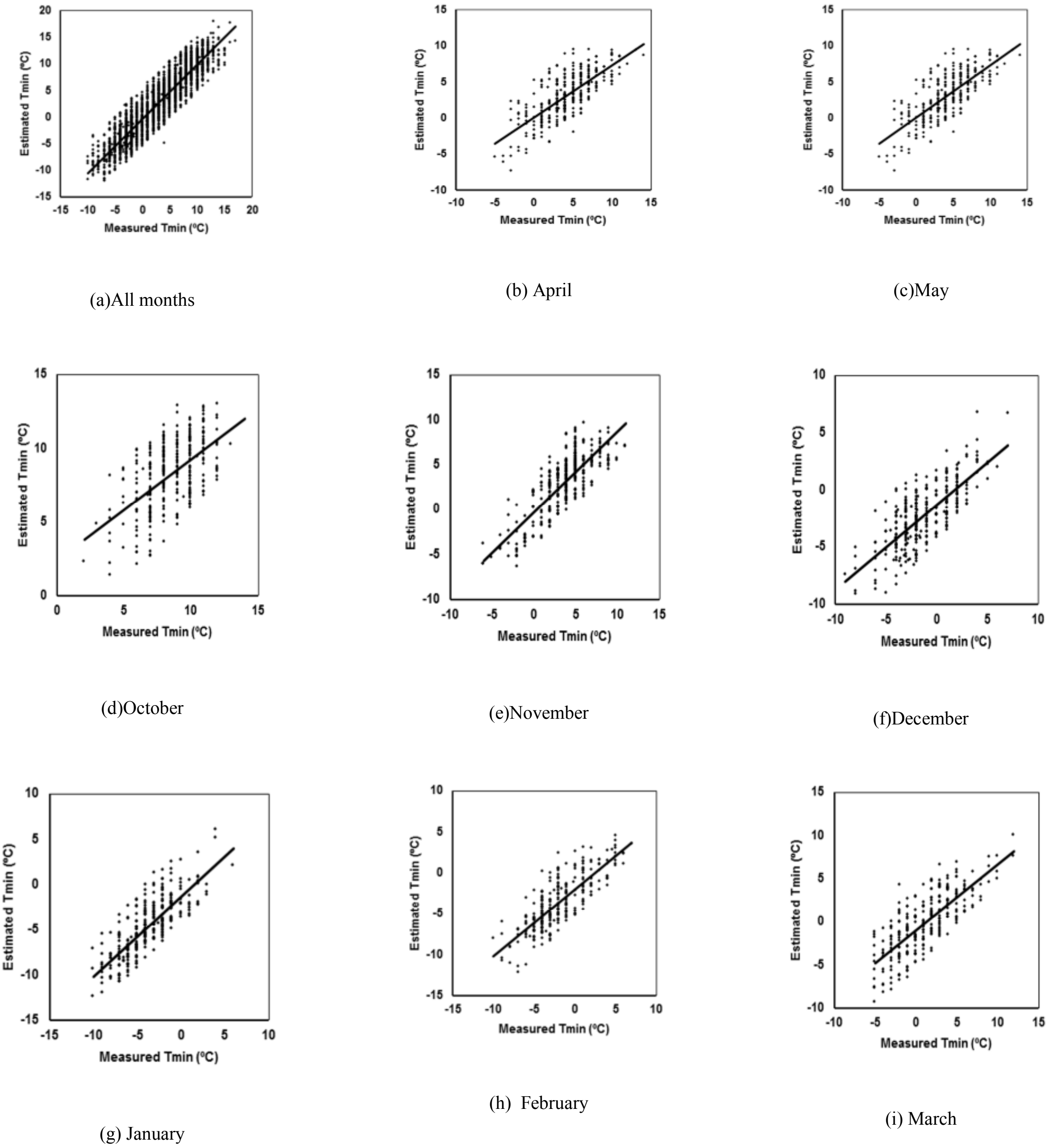


Fig. 6. Comparison of the measured and estimated T_{min} by the simple models for validation in Kooshkak.

Table 8. Linear relationships between the measured (T_{mm}) and predicted (T_{mp}) minimum temperature for different months in Bajgah (validation)

Month	Linear equation	R^2	NRMSE (-)	MAE (-)	ME (-)	d (-)	C_{NS} (-)	F-Test Slope	F-Test Intercept
All months	T_{mp}=0.92 T_{mm}-2.54	0.82**	0.16	3.1	-2.6	0.90	0.58	NS	NS
April	T_{mp} =0.75 T_{mm} -0.17	0.60**	0.76	2.2	-1.0	0.86	0.48	NS	NS
May	T_{mp} =0.86 T_{mm} -0.25	0.62**	0.33	1.9	-1.2	0.85	0.35	NS	NS
Oct.	T_{mp} =0.76T_{mm} -0.22	0.44**	0.43	1.9	-1.5	0.73	0.30	NS	NS
Nov.	T_{mp} =0.90 T_{mm} -2.10	0.69**	0.29	2.5	-2.2	0.83	0.24	NS	NS
Dec.	T_{mp} =0.83T_{mm} -2.09	0.61**	0.30	2.6	-1.6	0.85	0.36	NS	NS
Jan.	T_{mp} =0.66 T_{mm} -2.37	0.55**	0.24	2.5	-0.7	0.85	0.51	NS	NS
Feb.	T_{mp} =0.72T_{mm} -1.81	0.62**	0.29	2.5	-1.1	0.87	0.54	NS	NS
Mar.	T_{mp} =0.69 T_{mm} -0.74	0.54**	0.32	2.5	-0.8	0.85	0.46	NS	NS

**: Significant at 1 % probability level *: NS is non-significant

Table 9. Linear relationships between the measured (T_{mm}) and predicted (T_{mp}) minimum temperature for different months in Kooshkak (validation)

Month	Linear equation	R^2	NRMSE (-)	MAE (-)	ME (-)	D (-)	C_{NS} (-)	F-Test Slope	F-Test Intercept
All months	T_{mp} =1.02 T_{mm} -0.32	0.84**	0.19	1.9	-0.3	0.95	0.81	NS	NS
April	T_{mp} =0.73T_{mm} +0.04	0.55**	0.62	2.1	-1.1	0.84	0.38	NS	NS
May	T_{mp} =0.86 T_{mm} +1.18	0.54**	0.23	1.8	-1.1	0.85	0.37	NS	NS
Oct.	T_{mp} =0.69 T_{mm} +2.40	0.33**	0.24	1.7	-0.3	0.75	0.17	NS	NS
Nov.	T_{mp} =0.94 T_{mm} -0.17	0.66**	0.59	1.7	-0.7	0.89	0.52	NS	NS
Dec.	T_{mp} =0.76 T_{mm} -1.15	0.56**	0.34	1.8	-1.0	0.83	0.60	NS	NS
Jan.	T_{mp} =0.88 T_{mm} -1.32	0.63**	0.37	1.8	-0.9	0.87	0.44	NS	NS
Feb.	T_{mp} =0.82 T_{mm} -2.04	0.65**	0.31	2.2	-1.7	0.84	0.35	NS	NS
Mar.	T_{mp} =0.76 T_{mm} -1.03	0.60**	0.36	2.2	-1.3	0.85	0.42	NS	NS

**: Significant at 1 % probability level *: NS is non-significant

CONCLUSIONS

This study proposed a method for forecasting the daily minimum temperature based on the daily dew-point and mean relative humidity of the previous day. The daily weather parameters such as wind speed, pan evaporation, sunshine hours and rainfall showed no significant effect on the minimum temperature. Instead, parameters such as daily relative humidity and dew-point showed a significant effect on daily minimum temperature of early morning of the next day. Simple models were developed to estimate the daily minimum temperature in the next day using the dew-point and mean relative humidity of the previous day for different months and all combinations for months. For the values of mean relative humidity between 65 and 75 % in Bajgah and 64 and 66 % in Kooshkak, the daily difference between dew-point and minimum temperature of the next day was near zero in all cases. Therefore, in these ranges of relative humidity, the daily minimum temperature is equal to the dew-point of the previous day. Daily minimum temperature in the next day was predicted by using the daily mean relative humidity and dew-point in simple regression models. Daily mean relative humidity and dew-point of recent years were used for validation of the proposed simple models. Daily minimum temperatures were predicted with acceptable accuracy in the validation of simple models in both areas.

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تحقیقات کشاورزی ایران (۱۳۹۷) ۳۷(۱) ۱۹-۳۲

پیش بینی سرمازدگی با تخمین دمای حداقل روزانه در مناطق نیمه خشک ایران

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اطلاعات مقاله

تاریخچه مقاله:

تاریخ دریافت: ۱۳۹۵/۷/۱۰

تاریخ پذیرش: ۱۳۹۵/۱۰/۲۷

تاریخ دسترسی: ۱۳۹۶/۱۰/۱۸

واژه های کلیدی:

سرمازدگی

نقطه شبنم

رطوبت نسبی

دمای حداقل

چکیده- بسیاری از میوه ها، سبزی ها و گیاهان زینتی گرمسیری، در دماهای پایین در معرض آسیبهای فیزیولوژیکی جدی قرار می گیرند. حفاظت این گیاهان در مقابل اثرات مهلک دمای پایین امری مهم در کشاورزی، خصوصا در باغبانی جهت حفظ محصولات گران قیمت میوه ای و زینتی است. هدف از این پژوهش ایجاد یک مدل ساده جهت پیش بینی دمای حداقل روزانه برای پیش بینی سرمازدگی در باجگاه و کوشکک ، از مناطق نیمه خشک استان فارس می باشد. در ابتدا رابطه حداقل دمای صبح روز بعد با برخی عوامل هواشناسی روز قبل ایجاد شد. عوامل هواشناسی بکار رفته در این تحقیق مقادیر روزانه رطوبت نسبی، سرعت باد، تبخیر از تشت، بارندگی، ساعات آفتابی، و دمای نقطه شبنم برآوردشده بود. نقطه شبنم به عنوان یک مشخصه مهم در ارتباط با دمای حداقل در ماه های مختلف دارای دمای پایین در باجگاه و کوشکک می باشد. بسیاری از عوامل هواشناسی بکار رفته در تحلیل ها رابطه معنی داری با دمای حداقل صبح روز بعد نداشت مگر نقطه شبنم و رطوبت نسبی.. روابط همبستگی بین تفاوت دمای حداقل و نقطه شبنم با رطوبت نسبی به عنوان مدلی ساده جهت تخمین دمای حداقل و به دنبال آن پیش بینی وقوع سرمازدگی در مناطق مورد مطالعه به کار رفت. این مدل ها با یک سری داده های مستقل در مناطق مورد مطالعه با نتایج قابل قبولی صحت سنجی شد.