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RESEARCH PAPER

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Mapping and analyzing the risk of frost and chilling damage on horticultural crops (study case: Taftan border area, Southeast of Iran)

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Key words: Chilling, Frost, Taftan, Sistan and Baluchestan, Geographical Information System (GIS).

Abstract

Frosts have obvious effects on the energy, transport, and agriculture, while their greatest impact is on agriculture. Since chilling and frost cause's lots of damage to crops in Taftan area, it is essential to examine the chilling and frost in this area. To study this phenomenon in Taftan area, the minimum temperature data of 4 synoptic stations (Zahedan, Khash, Nosratabad, Mirjaveh) and 4 climatology stations (Goharkouh, Karvandar, Cheshme ziarat, and Korin) were used. Early autumn and late spring frost dates at the desired thresholds (zero and lower) for chilling, and temperatures of 1.1, 2.2, 3.3, 4.4 ° C for frost damage were extracted, and duration, frequency of frost and chilling days and the growing season was calculated. Then, determining the appropriate probability distribution, the probability of early and late, chilling and frost was estimated. After examining the relationship between chilling and elevation, zoning maps were drawn by using the geographical information system (GIS), and finally using the Spearman correlation method, the relationship between chilling and frost and horticultural crops was analyzed. The results showed that the earliest autumn chilling and the latest spring chilling occur in Taftan mountains, and the latest autumn chilling and earliest spring chilling occur in the West and Southeast regions. The analysis and interpretation of the results also showed that spring chilling has the greatest impact on horticultural crops such as apricot, almond, and cherry. The relationship between the yield of horticultural crops and late chilling indicated that only horticultural crops at Taftan mountain border have suffered from frost damage.

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Introduction

Alterations to the frequency and intensity of extreme temperature events, predicted with climate change, pose a threat to the health of trees in many areas of the world (Allen *et al.* 2010; Williams *et al.* 2012).

Frost damage is a serious concern for many types of temperate climate crops. Frost may damage leaves and fruit, impact on plant health and cause death, depending on the severity of a frost and the susceptibility of a particular plant. Frost is generally divided into radiation frost, i.e. created in cloudless, calm conditions by the longwave radiative cooling of near-surface air, and advective frost, which is caused by large-scale cold air masses moving into an area in windier conditions(Richards and Baumgarten 2003).

Research on the factors affecting the frost and chilling needs to study and understand the history of the chilling and the related factors. Considering that the first autumn cold weather and the last spring cold weather surprise the farmers, and the lack of necessary measures by them can cause severe frost damage, it has long been an area interest for agricultural researchers. Crawford (1965) studied the effect of different types of heaters in reducing frost damage to fruit trees.

The World Meteorological Organization (1981) studied the late spring frosts and discussed ways to prevent the damages in the last 150 years. This paper showed that 120 to 180 years ago, the physical and meteorological conditions affecting late spring frosts included free energy radiation in clear sky and well known calm winds. Even, recommendations of smoke and coating were made. In this paper, for the first time a service of chilling prognosis was proposed and organized after establishment of the storm prognosis service.

Rosenberg and Myers (1962) believed the type of chilling in agriculture is more important than its date of occurrence. They classified radiative and advective cooling. They presented their results based on the date of the last spring cold weather and the first autumn cold weather in radiative and advective forms.

Thom and Shaw (1985) determined the dates of frost damage in Iowa, and showed that the dates of the first autumn chilling and last spring chilling are completely independent and stochastic, and their return period can be determined for any crop.

Michalska (1986) examined the possibility of the occurrence of late spring frosts in the Netherlands, and determined the proper planting date for corn in the spring.

Timmer *et al* (1988) divided frosts into two types of advective and radiative, and concluded that advective frost is harmful for horticultural products.

Waylen (1989) in a study entitled as the statistical properties of the frost date and duration of the growing season variables, forecasted the occurrence of frost using the daily minimum temperature at Lake City station and Regina airport. For this purpose, he used statistical methods as normal distribution, the coefficient of skewness, elongation, regression, correlation and the chi-square test for fitting the date of the first and last frost dates and duration of the growing season.

Aron and Gat (1991) drew curves of frost damage risk, and examined its probability of occurrence due to the topography of Israel. Watkins (1991) using the calendar of the date of the first and last daily temperature of zero ° C and below zero in England (1989-1850), showed that early spring frosts have ended earlier annually, and autumn frosts have started with delay, and as a result, the duration of frost season has reduced 2 days per decade.

Miller and Downton (1992) examined the way how to estimate the losses caused by frost in Florida citrus orchards, and demonstrated that the exact estimation should be based on the long-term knowledge of climate.

Based on the five characteristics of chilling, Boer *et al* (1993) divided one of Australia's rich wheat regions into four homogeneous regions, and on the basis of weighted regression analysis concluded that elevation is the best predictor of chilling features, and latitude and other factors are in the next levels of importance. Kozloskaya and Myalik (1998) found that the degree of damage to apple and pear buds as a result of low temperature is varied. Grafted apple buds suffer more severe due to the low temperatures compared to other ones. In the case of pear, damage to buds with the main root system is more intense than the buds with the branching root system. Rodrigo (2000) examined the effects of late spring frosts on the reproductive organ of fruit trees in temperate regions.

Perry (2002) studied the effect of chilling in the reduction of horticultural products. He separated advective and radiative chilling to assess frost damage in horticultural crops. He also suggested methods to reduce frost damage.

Zinoni *et al* (2002) studied the date of occurrence of late spring frosts in 161 locations in Emilia-Romagna in Italy during the period 1987 to 2000. The researchers presented a frost risk index based on phenology and made a relationship between the minimum temperature of stations studied and the risk index of station, and presented a map of frost risk in the region.

Madelin and Beltrando (2005) performed zoning for risk of spring frost in the vineyard in France. Using multivariate regression analysis based on digital terrain model, obtained the minimum temperature distribution in the region, and based on that map, drew the distribution of frost risk for the entire region based on meteorological data of 20 stations.

Lurie and Carlos (2005) examined the frost effect on peaches and nectarines under different climatic conditions. Cai *et al* (2006) examined the effect of temperature on the risk of frost damage after harvest of loquat fruit, and calculating the browning index, evaluated the effect of low temperatures on the reshape of the fruit.

Vargas *et al* (2006) considered losses caused by seasonal frost on the size, color, and the taste of a peach tree in Chile. Cittadini *et al* (2006) studied historical events related to the occurrence of harmful cold for Cherry with a threshold of 3 ° C in the Patagonia region of Chile in order to determine suitable areas for the cultivation of that plant. Sameshima *et al* (2007) examined the freezing risk for the soya in Japan, and using a network, showed it as a map based on the probability of occurrence of frost damage.

Khosravi *et al* (2008) examined the effect on risk of a late frost on orchards of Mahvelat. In this study, using of GIS facilities, drew time-location curves of spring frost at two mild or severe frost damage threshold with the likelihood of 50, 75, 95, and 99% due to nearby stations and application of the correlation coefficient between the region's elevation and the thresholds. Overlapping these maps identified high risk, medium risk, and low risk regions.

Mokarram (2012) studied the effect of frost damage on the dry farming wheat crop for Lorestan province. The results showed that in different return periods, the earliest frost beginnings and the latest frost endings relate to the northwest, north, and east parts of the province, and the latest onset of frost beginnings and the earliest frost endings are related to the south and southwest regions of the province. Stations with the earliest frost have also the latest frost, and southern regions such as Poldokhtar and Doroud had the longest growing season, since those stations do not have spring frost.

Nodehi (2013) examined the relationship between early autumn and late spring frost and production and yield of some horticultural products in Khorasan Razavi province. The results showed that the northern part of the province is affected by A threshold frosts. The results of the study on different crops showed that the start and end of chilling and frequency of frost days are more effective to reduce or increase the amount of production and yield.

According to statistics of Sistan and Baluchastan Department of Agriculture, about 600 hectares of apricot orchards have suffered frost damage; in other words, they suffered a 60% loss with an estimated value of 43,200 million IRR. Pomegranates gardens with 450 hectares suffered 40% damage with monetary value of 14,400 million IRR. In addition, 400 hectares of tropical palms in the southern city of Khash suffered from 30%frost damage with estimated monetary value of 3840 million IRR. In Mirjaveh, crops such as tomatoes, cucumbers, potatoes, and strawberries suffered from an average of 26.9% of frost damage, between10 to 100 percent (Sistan and Baluchastan Department of Agriculture., 2014). The purpose of this study was to investigate the phenomenon of frost damage on the horticultural crops using daily minimum temperature, and the dates of occurrence of the first early autumn frost and the last late spring frost, so that with prediction and trending of late spring and early autumn frost, and informing the farmers in this regard, as well as by zoning of severity of frost in the area, we can provide solutions that help the farmers reduce their economic damage.

Material and methods

Data and Methodology

Study Area

Taftan volcano was constructed along a volcanic zone in Beluchestan, SE Iran, that extends into northern Pakistan. There are fresh-looking lava flows that were erupted from the SE cone. The deeply eroded NW cone is extinct and of pleistocene age. The Taftan is now in an active post volcanic and fumaroles stage (Boomeri, 2005) According to iranian maps, the elevation of the volcanically active SE summit shown is 3,940 m and the order dissected NW summit 3,840 m. Several necks, remnants of older cinder cones,are located in the plain W from taftan.

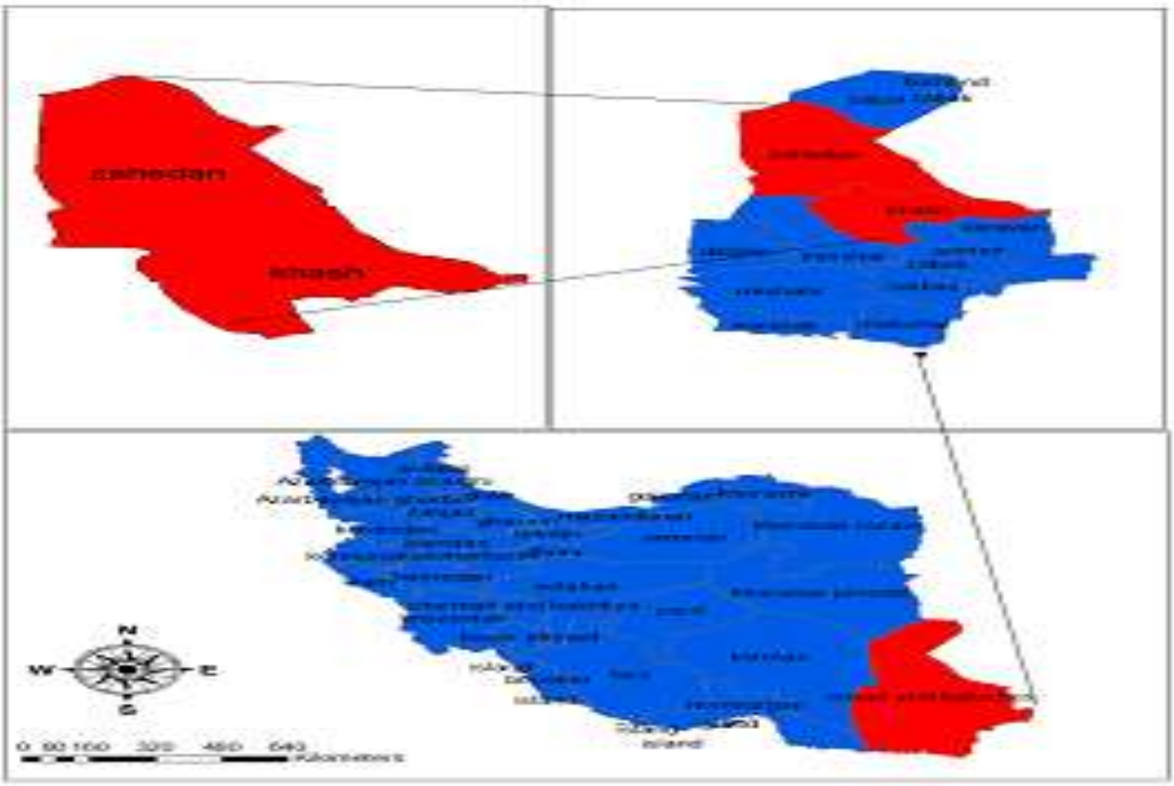

Fig. 1. The location of stations in study area.

Taftan area that consists of parts of Khash and Zahedan has a moderate climate in summer and cold climate in winter. It begins from Qatarkhanjak in Zahedan and continues to Karvandar at Khash city, and in other words, it begins from the latitude 27° 48' N and 60° 45' E, and continues to the latitude 29 ° 14' N and 60° 44' E. Taftan volcano is located in Iran's southeast and in 50 kilometers northeast of Khash.

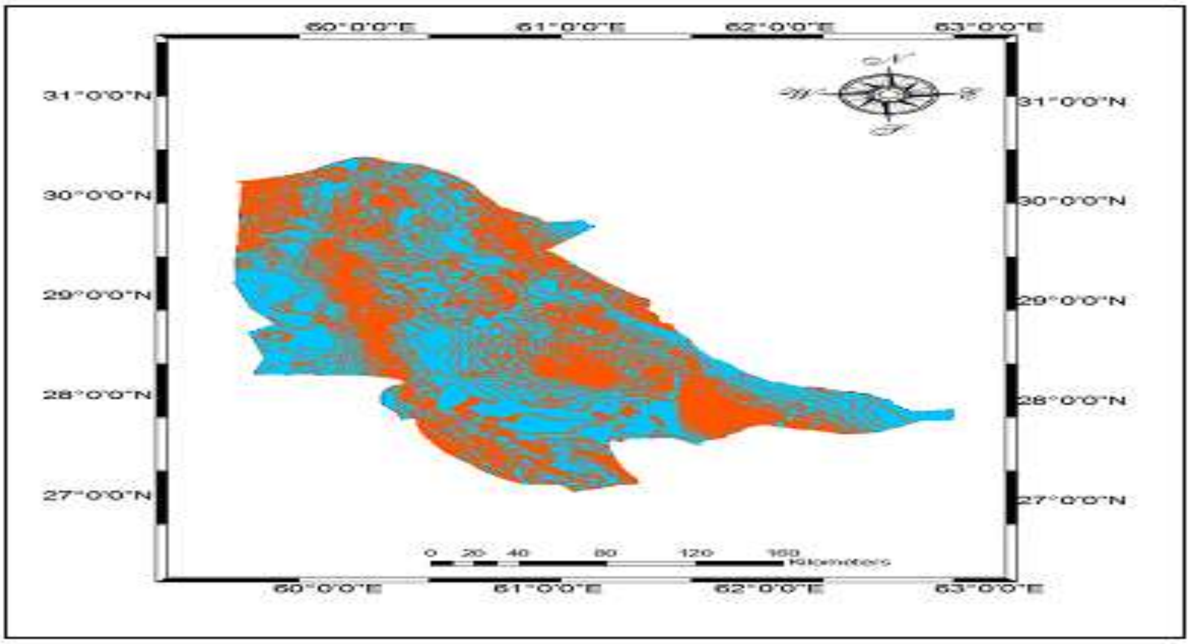

Fig. 2. Topographic map of the region with 50-meter contour lines.

Climate Data

To describe the climatic characteristics of the region, and to examine the role of chilling and frost on the horticultural products, data of synoptic and climatology stations in the region were used. The station consists of four synoptic stations (Zahedan, Khash, Mirjaveh, and Nosratabad), and four climatology stations (Goharkouh, Mohammadabad Korin, Karvandar, and Cheshme ziarat). The study was based on the data of minimum temperature for a period of 12 years (2001- 2013), that was received from Sistan and Baluchestan Meteorological Organization (Table 1).

Agricultural data

According to the Sistan and Baluchestan province Agriculture Department, data of production and yield of horticultural crops were collected. In addition, the chilling and frost thresholds of agricultural products, and the cultivation and harvest dates of horticultural of the region were obtained.

Research methodology

After removing the defects in the statistical data, the daily minimum temperature was converted to Julius calendar based on the cropping season. In order to make the date extracted as the first and last autumn and spring chilling applicable for analysis, they should be converted into calendar numbers. For this purpose, the conventional method of the Julian calendar was used, in which 23 September is considered the first day of the calendar, and 22 September is considered the last day.

Modeling the statistical properties of chilling and frost using the geostatistical factors

To prepare zoning maps for statistical properties of chilling in the region, a Digital Elevation Model(DEM) with appropriate scale was required. Therefore, after preparing a digital elevation map, the 50-meter contour curved lines of the region under study were prepared and saved based on the maps (Figure 2).

However, since no numerical or statistical curve can be applied to topographic maps, all contours curved lines defined for the region were converted into point features. Total points obtained for the whole region reached 3858 points (Figure 3).

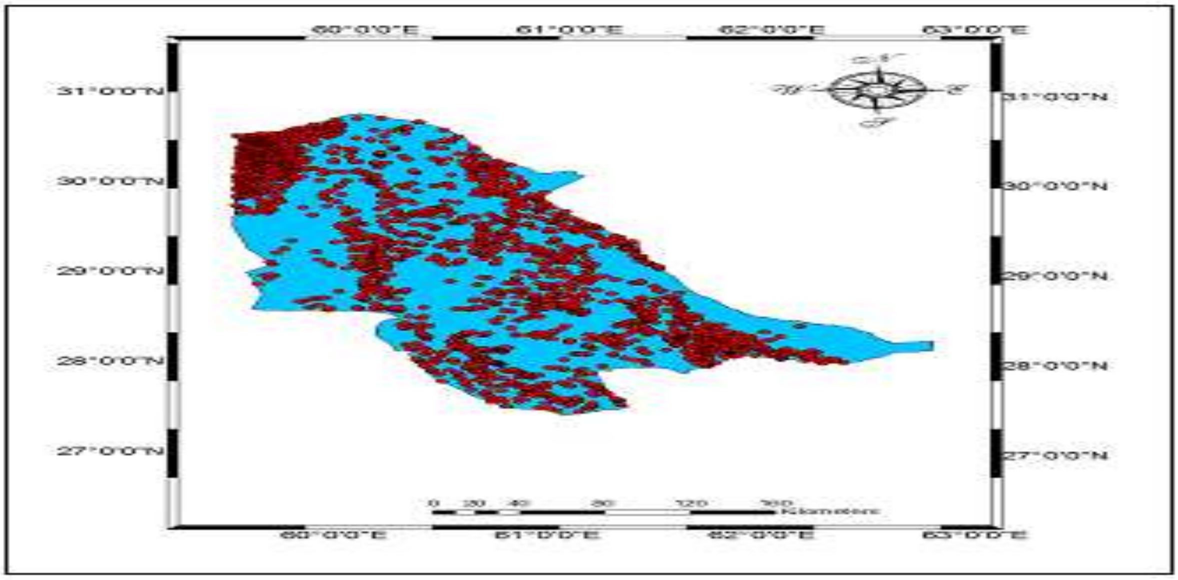

Fig. 3. The map of converting contour curved points into point map.

Zoning the statistical properties of chilling and frost in the region

After adjusting the data based on Julius calendar, five chilling indicators, including average starting date of chilling, average ending date of chilling, average duration of chilling season, average duration of the growing season, and average monthly frequency were extracted separately. To draw zoning maps, Kriging method was used. Kriging estimator is named so in the name of a pioneer in the field of Geostatistics, D.G. Krige. Ordinary kriging is an estimator of geostatistics, which is used in regional and local scale. In general, the geostatistical estimation process includes two stages of variogram analysis and using kriging estimator to estimate the intended variable in non-measured locations (Interpolation).

Variogram analysis is a method for describing spatial changes of a regional variable. Calculation and interpretation of variogram curve is one of the most important geostatistical operations that is achieved through the following equation.

Equation 1.

$$y(h) = \frac{1}{2N(h)} \sum_{i-1}^{n(h)} \left\lfloor z(x_i) - z(x_i + h \right\rfloor^2$$

Y (h) = the value of variogram for a pair of points that are in distance of h

N (h) = number of pairs of points in a certain direction and at a distance of h.

$Z(x_i)$ = The observed value of variable Z in position X_i

$Z(x_i + h)$ = The observed value of the variable Z in position $x_i + h$

The most important application of the variogram is using its information in geostatistical estimation algorithms. However, before their application for estimating, the most appropriate theoretical model, including spherical, Gaussian, or exponential models should be fit over them. The following equation shows ordinary kriging estimator as a weighted linear sum that will find the statistical weights of samples, so that the bias and variance of estimate is minimized.

Equation 2.

$$z(x_0) = \sum_{i=1}^{m} \lambda_i z(x_i)$$

In this equation, Z is the estimated value of a piece or a point, (zx_i) is the sample value of x_i, and λ_I is the statistical weight assigned to the sample *i*. m is the number of samples located in the neighborhood of the point.

No, this estimate should be unbiased with minimum variance. To make the estimate z * unbiased, the following equation should be used.

Equation 3.

$$E(z) = E\left[\sum_{i=1}^{n} \lambda z(x_i)\right] = \mu$$

In other words, for unbiased estimate, the sum of the statistical coefficients should be equal to 1. This is in fact a necessary condition for kriging estimator.

Then, for each of the indicators, using kriging's interpolation, zoning maps were prepared in the geographic information system (GIS).

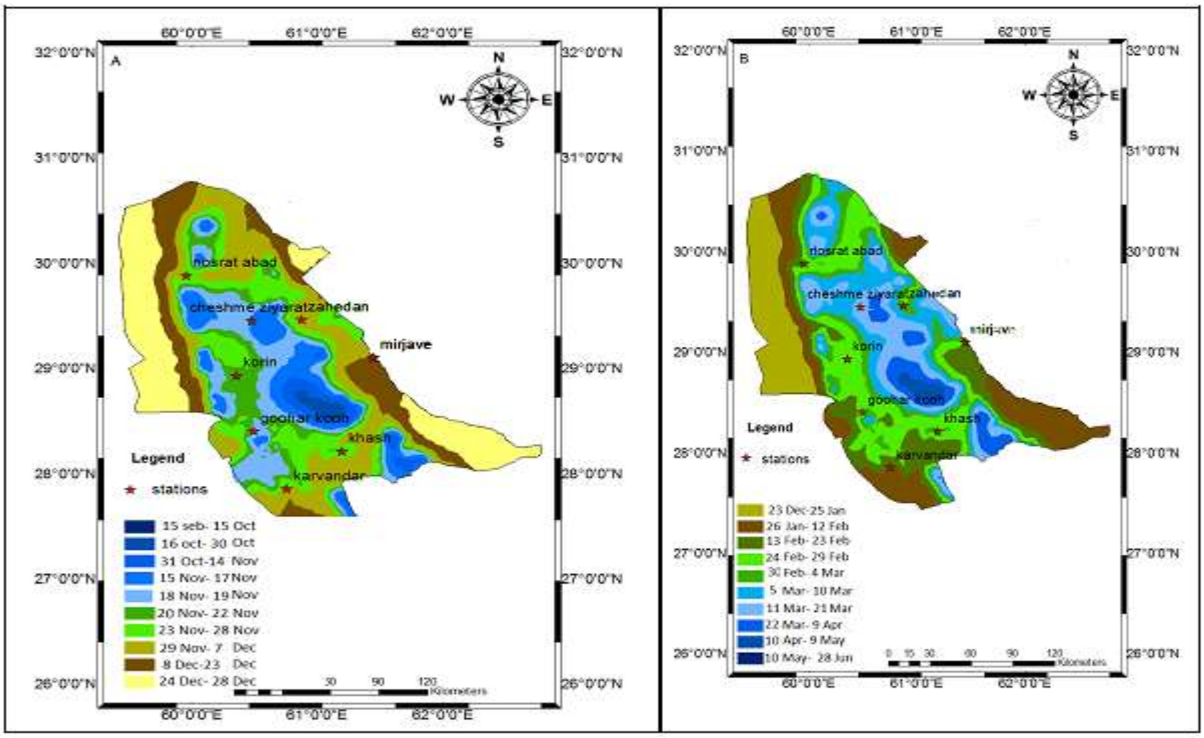

Fig. 4. The map of the average first day of chilling and frost at the region.

However, considering that the highest weather station is established at an altitude of 1385 meters during the study period, while the highest point is more than 3994 elevation, it is clear that a large part of the mountainous areas under study area are not climatically monitored, and meteorological data are not available. The same problem exists in desert areas. Therefore, in order to solve this problem and have maps in accordance with the reality, multivariate regression analyzes were used. Then, in the second step, the five significant characteristics of chilling in the region extracted in the first step were modeled separately by three factors of altitude, longitude, and latitude using multivariate regression models. Regression models are models used to study relationships between variables, especially the dependence of a variable with other variables. In these statistical models, it is assumed that the relationship between independent variables (altitude, longitude, and latitude), and dependent variables (five statistical features of chilling) is as follows.

Equation 4.

$$b_1 x_1 + b_2 x_2 + \ldots + b_n x_n \; Y = a + b$$

Where, $b_{1,2,\ldots}$ are partial regression coefficients, x_i is independent parameters affecting the problem, Y is the dependent variable, and a is value of intercept that is also called the regression constant. The method selected to enter variables into the model in simultaneous entering of variables. In this method, all variables collected, enter into the model simultaneously and with no transposition, and the model will be calculated. To measure the accuracy of regression models, four fundamental assumptions should be considered that include.

Assumption of a linear relationship between the dependent variable and independent variables

This assumption will be tested using the F statistic and its value is derived from the following equation.

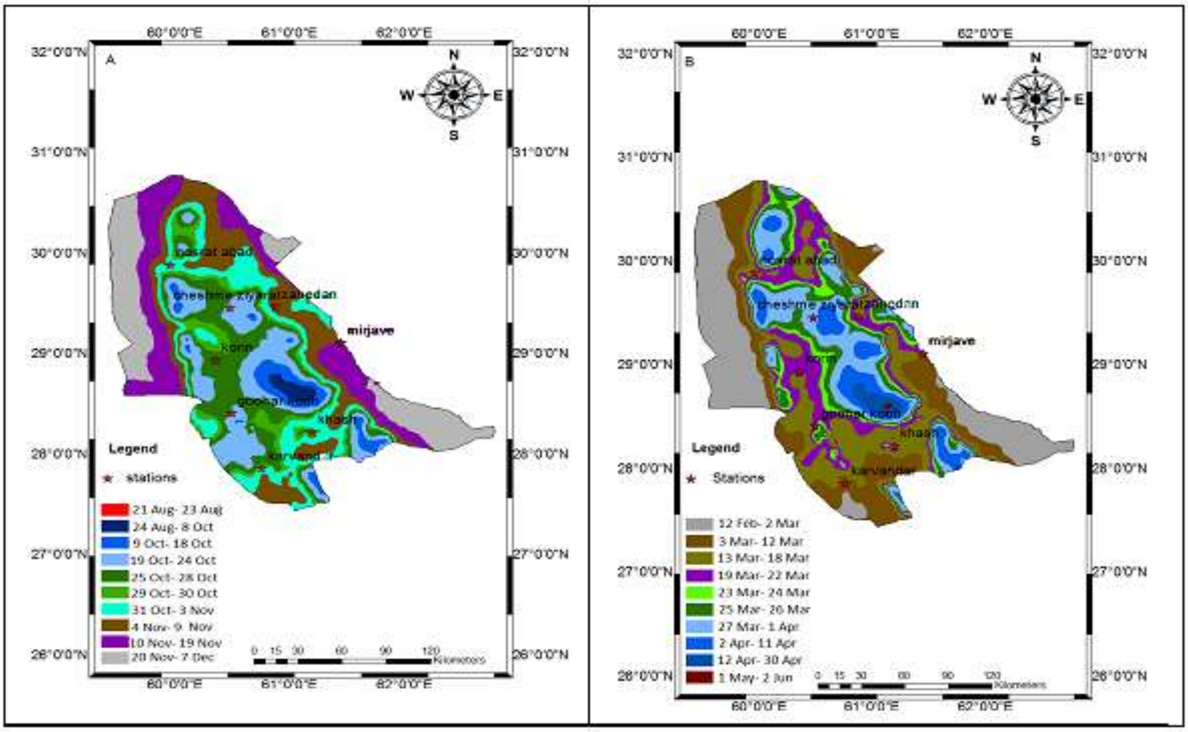

Fig. 5. The map of the average last day of chilling and frost at the region.

Equation 5.

$$F = \frac{R^2}{1-R^2} \times \frac{n-1-p}{p}$$

Where P and is the number of predictor variables, and n is the number of available items. If the calculated F is larger than F value of Fisher table, it suggests that the relationship between the dependent variable and independent variables linear combination may not be the result of an accident.

Assumption of normality of errors

that is the most fundamental assumption is regression, and is tested using PP Plot. X-axis of the graph is the difference between the observed values of (yi) and predicted values of (yi), and $\phi^{-1} \frac{(j - 1/2)}{n}$ calculated from the normal distribution table will be obtained from y-axis. If points are found around a straight line, *ei* is normal.

Assumption of constant error variance (ei)

This assumption is tested by drawing (e_i, γ_i) graph. If the results do not follow a certain trend, and are distributed randomly in coordinate axes, the variance is constant.

Assumption of uncorrelated errors (ei)

In order to better estimate rainfall amounts according to multiple regression model, Durbin-Watson test was used to measure the autocorrelation of errors. Durbin-Watson indicator (D) is between zero and four. D between 1.5 to 2.5 indicates a lack of autocorrelation of errors (Mahmoodi *et al.*, 2013).

Now, using regression models obtained, each of the five statistical characteristics of chilling can be generalized to all 3858 points were obtained from converting contour curved lines into point features. Finally, using the kriging method, each of the five characteristics of chilling were reclassified.

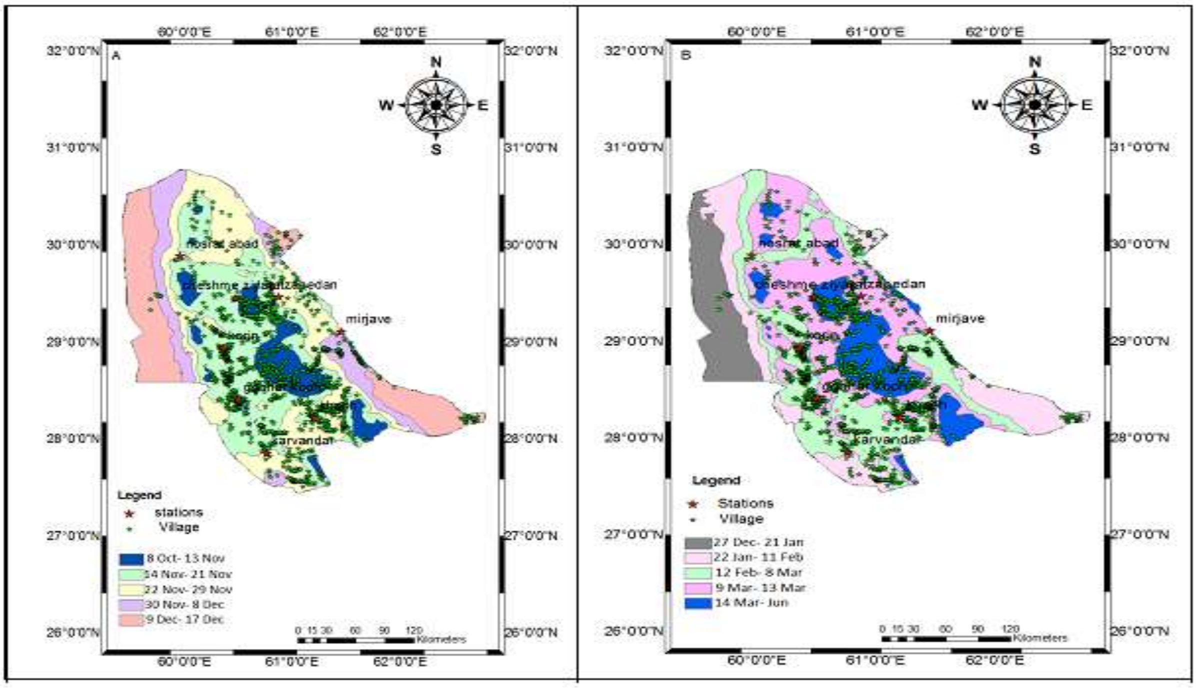

Fig. 6. Map of agricultural poles and villages at risk of the first autumn chilling and frost.

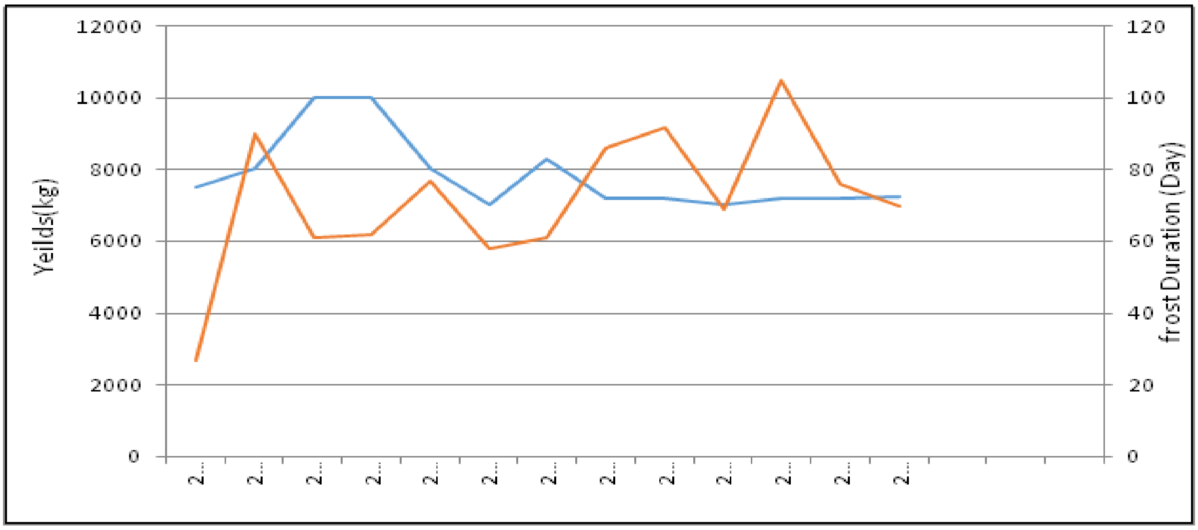

Fig. 7. The correlation between yield of stone fruits (blue line) and frost duration (red line) in Zahedan region

Determining the areas at risk of chilling and frost

Identifying the pole of crops in regions at risk of autumn and spring chilling and frost is another priority. However, using Arc GIS software, different autumn and spring chilling and frost maps, autumn chilling with 50 and 100-year return period, and spring chilling with the 50 and 100-year return period can be drawn. Then, after preparing those maps, the layer of the region's villages can be overlaid on the maps to identify villages at risk of autumn and spring chilling.

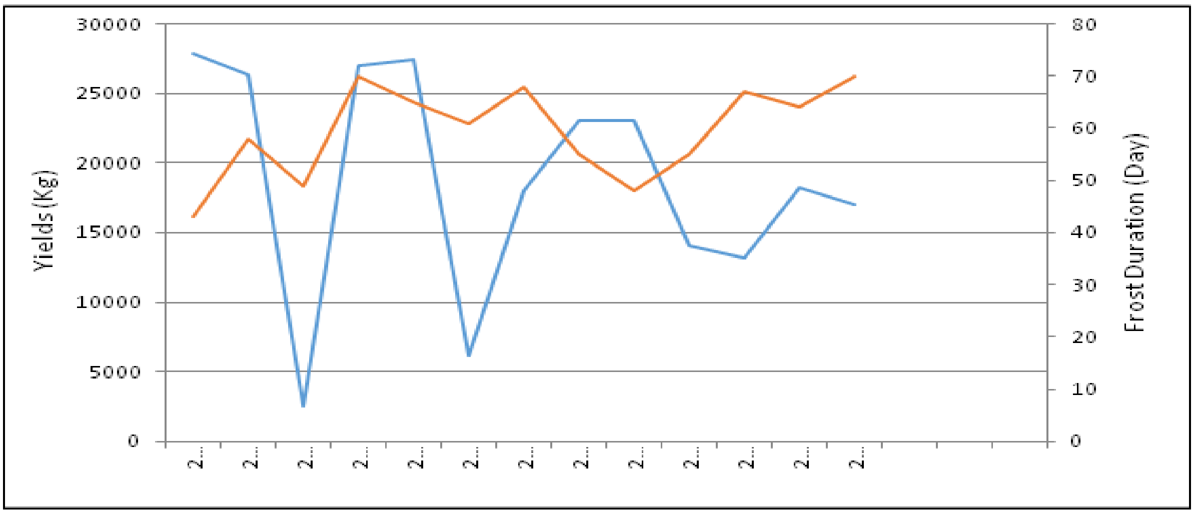

Fig. 8. The correlation between yield of subtropical fruits (blue line) and the last day of spring frost (red line) in Khash station.

Results and discussion

(Figure 4 A) zoning map of mean first frost day based on data network shows that earliest mean first frost day of autumn occurs in highlands of Taftan between 20 Sep to 15 Oct and the latest mean last Frost day of autumn occurs in West and Southeast regions between 8 Dec to 23 Dec. Earliest frost day of autumn is related to Ziyarat Springs among research stations which occur between 10 to 14 Nov and the latest date is related to Karvandar and Mirjave stations that occur between 23 to 28 Nov.

(Figure 4 B) this figure shows zoning map of mean first chilling day in highlands of Taftan that occurs between 21 to 23 Aug and that is while, latest mean chilling day of autumn occurs between 20 Nov and 17 Dec. Earliest chilling day of autumn is related to Ziyarat Spring and Gohar Kuh among research stations which occur between 19 Oct to 23 Nov and the latest date is related to Mirjave and Zahedan stations that occur between 4 to 9 Nov.

(Figure 5 A) shows mean of end frost day. As can be seen, distribution of end frost day like first frost day follows more or less the topography of area. According to the figure, the latest end of frost day occurs between 1 May to 2 Jun in central areas of Taftan highlands and the earliest end frost day occurs in West and North West areas between 12 Feb to 2 Mar. Latest end spring frsot day is related to Ziyarat station that occurs between 27 May and 1 April and the earliest end spring frost day is related to Karvandar station that occurs between 3 to 12 Mar.

(Figure 5 B) shows mean end chilling day. End chilling day occurs between 10 May to 28 June in central areas and the earliest end chilling day occurs between 23 Dec to 23 Jun. Latest end chilling day is related to Ziyarat station that occurs between 23 Mar to 9 Apr and the earliest end spring chilling day is related to Karvandar station that occurs between 13 to 25 Feb.

Topography influences the distribution of autumn and spring frost damage on trees

On the last day of chilling, as expected, with an increase in elevation, the number of frost days increases, and given the strong correlation between the number of frost days and temperature, and a significant correlation of temperature with elevation. The spatial pattern of the number of frost days will follow the topographic arrangement of the region. At highest altitude, the villages are 3000 m on the sea level, and the lowest altitude is about 406 m on sea level. Thus, this topographic variation delays blooming of fruit trees a month in the higher altitude. Since many of the gardens in Taftan area are located in the valleys, they are at higher risk of frost and chilling compared to gardens at lowland regions. Valleys are usually considered as source of cold weather at night, and are areas where temperature inversion often occurs, and the wind is less able to moderate weather circumstances there. Northern slopes experience more snow than southern slopes. The southern slopes get warm in the spring soon, while the northern slopes remain cold. The temperature difference between the northern and southern slopes reaches 20 °C. In addition, during the night, the mountaintop cold earlier due to higher altitude and the wind blows down from the mountaintop. A katabatic wind that carries high density air from a higher elevation down a slope under the force of gravity. Katabatic wind is one of the factors aggravating the chilling. Those winds with a cold source lead to the intensification of cold weather and chilling. Another issue in frost intensification is latitude. When the latitude is higher, the angle of the sun is more inclined, the sunshine will certainly have lower energy. Thus, it can be concluded that the earliest and latest chilling and the frost begin in the mountains of Taftan region, and the reduced height decreases the chilling severity.

Table 1. Characteristics of meteorological stations in region.

Station	Elevation	Latitude	Longitude	Statistic periods	Station type
Zahedan	1370	29,28	60,53	2001- 2013	Synoptic
Khash	1400	28,13	61,12	2001- 2013	Synoptic
Nusrat Abad	1100	29,53	59,58	2001- 2013	Synoptic
mirjaveh	900	29,01	61,27	2001- 2013	Synoptic
Goharkuh	1385	28.24	60,30	2001- 2013	Climatology
Karvandar	1065	27,51	60,46	2001- 2013	Climatology
Mohammad Abad Corine	1400	28,56	60,22	2008- 2013	Climatology
Cheshme Ziarat	1800	29,27	60,29	2006- 2013	Climatology

Analyzing agricultural poles at risk of autumn chilling and frost

(Figure 6 A) shows map of agricultural poles that are exposed to frost and frostbiting. The latest spring frost day occurs in central study area between 14 Mar to 1 Jun.There are about 312 villages in this region, some of villages in this area can be a major pole in production of agricultural products. Some of villages that are late exposed to latest frost spring include: Gazo, Kalukuh, Sangan, Tamandan, Kushe, Dushang, Deh Pabid, Mir Abad, Welan, Gourband, Anjrk, Jon Abad, Mortek, Kute, Jam Chin and Narvan.

(Figure 6 B) shows map of areas that are exposed to latest spring chilling. Also, it shows these areas are exposed to chilling between 31 Mar to 20 may. There are about 240 villages in this region that are exposed to latest spring chilling; the most important of them include: Kushe, Tamandan, Jam Chin, Sangan, Tamin, Gazuk, Rups, Ismail Abad, Abbas Abad, Karim Abad, Akbar Abad, Kam Zard, Mir Abad, Cheshme Ziarat, Gurband, Narvan, Kute.

In order to evaluate the effects of chilling and frost on the yield of horticultural crops, the Spearman correlation test was used. The results are shown in

(Table 2). According to (table 5) it is indicated that stone fruits had a significant negative correlation with the last autumn chilling. Cherry and apricot are the most common stone fruits with negative correlation with the last spring chilling; that means if the last day of spring chilling ends earlier, the yield of these crops is reduced. Fruits such as apples and greengage have a positive correlation with the last spring chilling that means if the last day of spring chilling ends earlier, the yield of these crops is enhanced. The stone fruits also have a positive correlation with duration of chilling period. The date has a positive correlation with the last spring chilling and a negative correlation with the duration of chilling period, so that longer duration of chilling period reduces yield of date. Citrus fruits had a positive correlation with the last spring chilling, and subtropical fruits such as pomegranates and figs have negative correlation with the frequency of chilling and frost days. Nuts such as pistachio and almond have a significant negative correlation with the last spring chilling, and have a positive correlation with the duration of the chilling period.

Table 2. Significant values of Spearman correlation coefficient between yield of horticultural crops and chilling at Khash region.

Product	Frost duration	Last spring frost	Frequency of frost days
Stone fruits	0. 648*	-0.658** *Apricot: -0.629*, Cherry: -0.518*, Apple: 0.509**	
Date	0. 509*	0. 720**	
Citrus		0. 522*	
Subtropical			*Fig: -0.486* , Pomegranate:-0.594 **
Dried fruits	*Pistachios: 0.554 *, Almonds: 0.570**	*Pistachios: -0.573*, Almonds: -0.784***	

The results of the Spearman correlation coefficient in yield of horticultural crops and frost at Khash shows that fine-grained fruits (0.483), date (0.506), and citrus fruits (0.714) have a significant positive correlation with the last day of spring frost, that means if the last day of spring frost ends later, the yield of these crops is enhanced; while stone fruits (589) have a significant negative correlation with the last day of frost.

(Figure 7) shows that there is a direct correlation between the yield of stone fruits and duration of chilling period, this means that the longer chilling period reduces yield.

(Figure 8) shows that in the years the last day of frost occurs later, yield increases, while in the years the last day of frost occurs earlier, yield reduces.

The results confirmed the previous works such as Khosravi *et al*(2008), Matusick *et al*(2014) and Richards & Baumgarten(2003).These research indicates that elevation and geographic locations are the most important factors in frost risks.

Conclusion

In general, the role of topography is very important in arranging climate areas, and the border of Taftan area mainly follows from topographic arrangement, that means when the elevation increases, temperature decreases.

Topoclimates in Taftan region are governed by combinations of well-known physical factors.

These include aspect, slope angle, height above sea level, relative elevation above the local valley floor, the propensity for ponding of cold air at night and topographic wind patterns. The latter includes mechanical effects such as topographic shelter (e.g. in the lee of hill) and funnelling (e.g. through a mountain saddle or canyon),and density-driven air flows, such as anabatic and katabatic winds.These factors can produce frost risks for vegetation and fruit trees in valleys and plains of Taftan region. These topographic factors causes that the earliest and latest chilling and the frost begin in the mountains of Taftan region, and the reduced height decreases the chilling severity.

On average, the earliest day of autumn frost in the Taftan mountains occurs between 20 September and 22 November, and the latest frost in Taftan highlands occurs between 1 May and 2 June. The frequency of frost days and duration of the frost period also has a significant correlation with height, and the highest frequency and duration of chilling is also related to Taftan highlands. In the study area, Cheshme ziarat station recorded the earliest day of autumn chilling and frost and the latest day of spring frost and chilling, while Mirjaveh and Karvandar stations were at risk of the latest day of autumn chilling and frost, and the earliest day of spring chilling and frost. Many agricultural poles are located in marginal areas of Taftan heights. Thus, due to the relatively high altitude of the topography, these areas are exposed to the risk of chilling and frost, which in turn reduces the yield of horticultural crops. Western and southeastern parts of the region, due to their low altitude, are rarely at risk of chilling and frost.

Examining the correlation between the yield of horticultural crops and frost indicated that the delayed end of late frost reduced the yield of horticultural crops. The results also showed that in the years the duration of chilling is reduced, horticultural products experienced increased yield. In addition, the relationship between the frequency of frost days and yield of horticultural crops showed that in the years with increased frequency of frost days, the yield of horticultural crops such as pomegranates and figs reduced dramatically. The results of this study will enable managers to make their plans in various fields of agriculture, transport, and tourism, according to the climatic conditions of the area to prevent potential damages.

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