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Analysis of changes in viticultural climatic indices in northwestern and western Iran

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Summary

Climate and climatic variables are very important factors in grape growth. Usually, temperature variables (maximum, average and minimum), as well as precipitation variables (annual, monthly and daily), are used to determine the regional climate and to study the type and amount of climate change. Most of the viticultural climatic indices presented by researchers have been using the above variables. Northwestern and western regions of Iran are considered as the most important areas of grape cultivation with different climatic conditions in different parts that have led to the cultivation of grape cultivars. In this study, five temperature indices (Huglin, latitude-temperature, night cooling, temperature variability and Winkler) and two precipitation indices were investigated based on De Martonne and hydrothermal drought indices. Then, they were analyzed by Mann-Kendall method and Sen's slope estimator index. The studies showed significant positive trends in Huglin, Winkler, night cooling and latitude-temperature indices, while the temperature variability index is significant only in a few stations. On the other hand, the indices related to drought and hydrothermal show no trend. However, some southern stations in the region showed a different trend in some indices. As a result, the trend of changes in temperature indices can lead to the expansion of cultivation of grape cultivars in the coming years, although the limitation of water resources will be a negative factor.

Key words: trend analysis; climatic indices; grapes; northwest of Iran.

Introduction

Climate is one of the important factors in agricultural production (Rosenzweig and Hillel 2008) with any change in its parameters possibly having a great impact on the quantity and quality of products. Although effective factors such as soil and water requirements may be manageable through soil remediation methods or irrigation calendars, climate is a factor that according to its changes, certain management must be applied to prevent a decline in production. Grape is also one of the top five agricultural products in the world in terms of production, which is produced in at least 40 countries (FAO 2011). Accordingly, the climate of each region affects production, growth periods, crop ripening, cultivar selection, and berry composition. (Gladstone 1992 and Dubourdieu 1990). Jackson and Lombard (1992) determined the effect of high average temperature during the ripening period on the aroma and colour of grapes. Also, Jones *et al.* (2005) determined the effect of degree-day during the growing season on the accumulation of sugar in the grape. The researchers have developed different indices in order to monitor the growing conditions of grapes such as degree-day (GDD or WI) by Winkler *et al.* (1974), Heliothermal Index (HI) by Huglin (1978), Latitude-Temperature index (LTI) by Jackson and Cherry (1988), Cool Night index (CI) by Tonietto and Carbonneau (1999), Temperature Variability Index (TVI) and Biologically Effective Degree-Day (BEDD) by Gladstones (1992), growth season temperature (GST) by Fregoni (2003), WO index by Tonietto and Carboneau (2004), and the GDH by Gu (2016) accordingly. Many researchers around the world have used one or more of the above indices to measure the climate of grape-growing areas and the resulting changes in the production of this product, including the work of Jarvis *et al.* (2017) and Liles and Verdon-Kidd (2020) for Australia, Köse (2014) for Turkey, Campbell (2013) and Jones *et al.* (2010) for the United States, Blanco-Ward *et al.* (2007) for Spain, Cardell *et al.* (2019) for Western Europe (France, Spain, Italy), Conceição and Tonietto (2005) for Brazil and Mesterházy *et al.* (2014) for Hungary.

Therefore, according to the above, it is clear that grape cultivation, regardless of different temperature needs, is completely affected by climatic parameters and any change can affect the quantity and quality of grapes. Today, it is clear that the global climate is changing. Studies on climate change and grapes have begun mainly since the 1990s, and more articles expressing concern about climate change are being published (Marx *et al.* 2017). This issue, especially in the Mediterranean region, has caused many changes in the amount of product between regions and over the years (Honorio *et al.* 2018). The impact of such changes on agriculture and the local and national economies of countries has attracted the attention of various experts in agriculture, climatology and the environment. It has also led farmers to cultivate and develop a variety of grape cultivars in some areas. Different researchers to detect these changes have mainly used the numerical analysis methods of viticultural climatic indices based on Mann-Kendall and Sen's test (Jones 2018), interpolation techniques based on Kriging regression method (Moral *et al.* 2014, 2016), downscal-

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ing method (Moriondo *et al.* 2013) and synoptic climatology (Jones 2007), accordingly.

Iran is one of the grape and raisin producing countries in the world that produces about 3 million tons of grapes per year on 300,000 ha (Dolati Baneh *et al.* 2007). In this country, from 250 to 1000 genotypes, about 250 cultivars have grown and are mostly used for fresh eating and raisin production (Najafi *et al.* 2006). In recent years, with the increase of farmers' awareness, they are looking for and finding high-quality cultivars to increase the area under cultivation and increase production to maximum profitability. But, due to its geographical location, Iran is especially exposed to climate change and related issues. For this reason, various researchers such as Asakereh (2007 and 2020), Esmaeili *et al.* (2011), Mahmoudi and Abbasnia (2015), Rahimzadeh *et al.* (2003) and others have worked with different methods on climate change and have reached different results. Rahimi *et al.* (2019) have summarized and extracted their general results, which in general terms indicate an increasing temperature and decreasing precipitation in the country. The effect of these changes can be in the form of a decrease in production or a reduction in the area under cultivation of grape in the country. Except for limited studies such as Shojaee and Fallah Ghalhari (2017) and Heydari and Saeidabadi (2009), no comprehensive research has been done before with grapevine climate indices in a major producing area of Iran in terms of appropriately describing them according to international standards and in terms of foreseeing potential impact of climate change.

The study area, which includes 10 provinces of Iran, is located in the northwest and west of Iran, between 31° to 40° north latitude and 44° to 51.5° east longitude. According to the Statistical Center of Iran (2003), this region has produced about 64 % of the country's grapes. With an increase of 38,000 ha of vineyards in 2019 compared to 2003, the region's production is increasing. To conduct this research, grape production areas with economic production of more than 1,000 t per year were first identified from the site of the Statistical Center of Iran. Then, the mentioned areas were matched to the meteorological stations of the Meteorological Organization, and finally, the areas that had commercial production and at the same time had a meteorological station were identified. Based on this, meteorological statistics of 22 meteorological stations in the northwest and west of Iran were used (Tab. 2). Fig. 1 shows the distribution of meteorological stations in the study area. In determining these stations, it was tried to use stations that have almost a complete statistical period and in some limited cases, regression method was used to determine the missing statistics with a correlation coefficient greater than 0.8.

Although there are several grape climate indices in the scientific literature, in this study, the indices that are often used by researchers to monitor growth conditions in grape growing areas around the world, have been used including the Huglin index (HI) as an index to show potential heliometry and sugar content of the crop, Winkler index (WI) as an index to express the active vegetative cycle, night cooling index (CI) to evaluate the quality potential of grapes about aroma, colour and polyphenols, Latitude-temperature index (Tonietto and Carbonneau 2004), (LTI) as an index to determine the production capacity of grapes relative to latitude, temperature variability index (Jackson

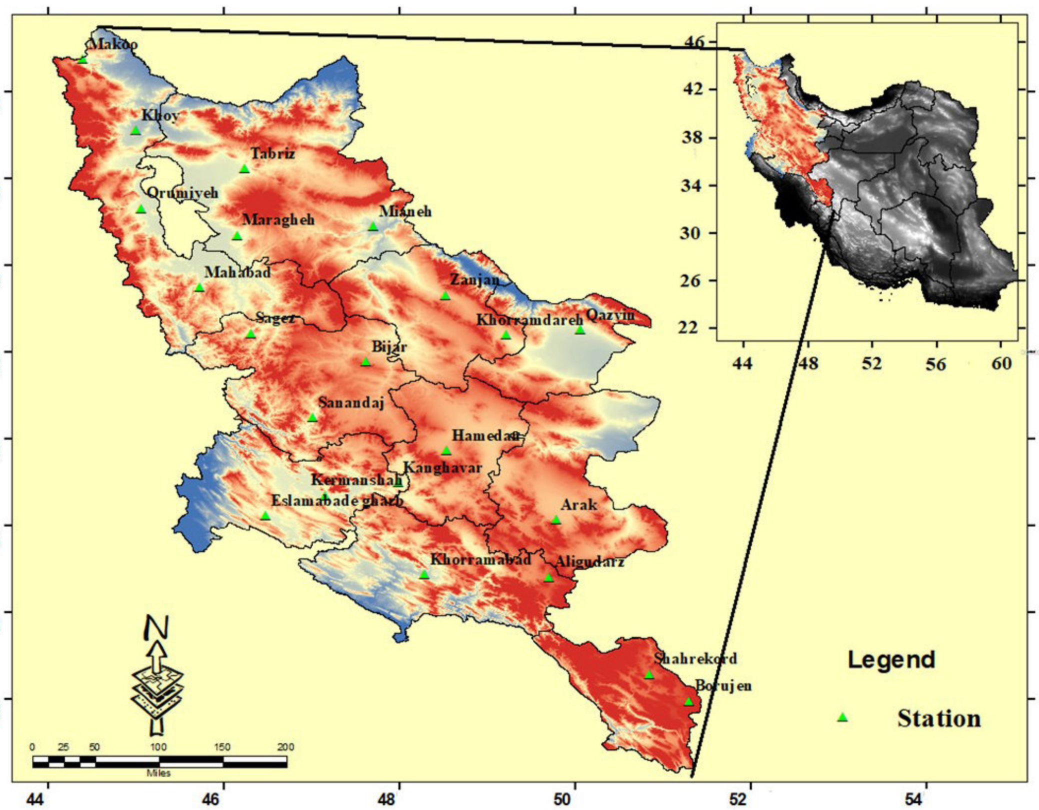

Fig. 1: Location map of selected stations.

Table 1

Characteristics of grape climate indices

Huglin Index (HI)	Σ ((Tavg-10 °C) + (Tmax-10 °C)/2)*d	Huglin (1978)
Cool Night Index (CI)	Tmin (Sept)	Tonietto and Carbonneau (1999)
Winkler Index (WI)	Σ ((Tmax+Tmin)/2 - 10 °C)	Winkler *et al.* (1974)
Latitude - Temperature Index (LTI)	MTWM (60 - Latitude)	Jackson and Cherry (1988)
Temperature Variability Index (TVI)	Σ [(TDmax-TDmin) + (TMmax-TMmin)]	Gladstones (1992)
Drought Index (DMI)	(Psum/Tavg+110)	De Martonne (1926)
Hydrothermal Coefficient (HTC)	(10Psum/T0)	Branas (1946)

Abbreviations: where Tmax, Tmin and Tavg are minimum, maximum and average temperature values, correspondingly d is length of the day by latitude, MTWM is Max Temperature of Warmest Month, TDmax and TDmin are maximum and minimum daily temperature values, TMmax and TMmin are the maximum and minimum monthly temperature values, Psum is the total monthly precipitation and T0 is the total effective degree of days with temperatures above 10 ° C.

Table 2

Specifications of selected meteorological stations

Station	Data period	Latitude	Longitude	Elevation	Missing data (number of months)
Qazvin	1985-2019	36.26	50.06	1279	-
Kermanshah	1985-2019	34.35	47.15	1319	-
Zanjan	1985-2019	36.66	48.52	1659	-
Mahabad	1985-2019	36.75	45.72	1352	-
Orumiyeh	1985-2019	37.66	45.06	1328	-
Khoy	1985-2019	38.56	45.00	1103	-
Makoo	1985-2019	39.38	44.39	1411	-
Maragheh	1985-2019	37.35	46.15	1344	-
Tabriz	1985-2019	38.12	46.24	1361	-
Sanandaj	1985-2019	35.25	47.01	1373	-
Sagez	1985-2019	36.22	46.31	1523	-
Hamedan	1985-2019	34.87	48.53	1741	-
Khorramabad	1985-2019	33.44	48.28	1148	1
Shahrekord	1985-2019	32.29	50.84	2049	2
Arak	1985-2019	34.07	49.78	1703	-
Aligudarz	1986-2019	33.41	49.70	2022	-
Khorramdareh	1986-2017	36.20	49.21	1575	1
Mianeh	1987-2019	37.45	47.70	1110	-
Bijar	1987-2017	35.89	47.62	1883	2
Kanghavar	1987-2017	34.50	47.98	1468	1
Eslamabade Gharb	1987-2017	34.12	46.47	1349	1
Borujen	1988-2015	31.98	51.30	2260	2

and Cherry 1988), (TVI) to determine the temperature changes affecting growth and also in improving the taste, aroma and colour of grapes (Gladstones 1992), which is mainly based on temperature parameters. Due to the lack of soil moisture data and therefore the impossibility of using a more general index such as Riou *et al.* (1994), De Martonne's (1926) drought coefficient and hydrothermal coefficient (Branas 1946) which are based on the average temperature and total precipitation in the growing season have been used. Average monthly and daily temperature values were used to calculate seven temperature indices and monthly precipitation values were used for Demarten index and hydrothermal coefficient (Mesterházy *et al.* 2014).

All indices were analyzed using the Mann-Kendall test and Sen's slope estimator index. Mann-Kendall is one of the statistical methods of the non-parametric tests proposed by the World Meteorological Organization as a standard method for climate change analysis (Mitchell *et al.* 1966 and Kundzewicz and Robson 2000). This test is used for trend data and is based on a ranking process. The Mann-Kendall test is less affected by extreme values (Partal and Kahya 2006) and is also suitable for skewed data (Hammed 2008). It can also be used in data sets that do not have a specific statistical distribution and contain residual values or nonlinear trends (Karpouzos *et al.* 2010). In this test, the occurrence of any significant trend is characterized by a normal approximation and a value of Z. If Z-values are positive, indicate an upward trend and negative values indicate a downward trend. In the Mann-Kendall test, there is no need for the data to be normal. The Sen's slope estimator is also a linear trend analysis test, indicating the amount of change. This test is indicating by the value of Q (Sen 1968). In fact, it is based on calculating a median slope (Q) for time series and judging the significance of the slope obtained at different confidence levels (Salmi *et al.* 2002). In recent years, the above tests have been widely used by various researchers in Iran and have shown good results by the climatic reality that has occurred in the study area (Amirrezaeieh *et al.* 2017 and Alijani *et al.* 2012). In this research, the climatic indices of grapes have been analyzed through Makesens v.1 software with the two above-mentioned tests.

Results

A summary of the climatic indices used in the research are presented in Tabs 3 and 4 in the form of minimum and maximum values of the indices as well as the values of Z and Q for Mann-Kendall and Sen's slope estimator, correspondingly. As can be seen in Tab. 3, HI, CI, LTI and WI indices show significant levels above 99 % in terms of trend changes. However, there is no significant trend in the CI index at Urmia and Khoy stations, in the LTI index at Saqez and Shahrekord stations, in the Wi index at Shahrekord station, and in the TVI index at most stations. The most significant positive trend is observed in HI and CI indices at Maragheh station, in LTI index at Khoy station and in WI index at Arak station. Also, TVI index at Shahrekord station shows the most changes in Q statistic.

Examination of DMI and HTC indices (Tab. 4) also indicates a weak trend at both stations. Meanwhile, in both indices, Shahrekord shows a positive trend with weak significance. Although these two indices have not been able to show a significant trend change during the statistical period, the positive trend of most temperature-related indices can indicate that even with no significant trend change in precipitation during the growing season, the intensity of evaporation and changing irrigation patterns should be considered.

To more accurately study the changes in the indices used, the graphs of their changes as an example in the two stations of Maragheh (north) and Khorramabad in the south of the study area are shown in Fig. 2. In this figure, the diagrams on the left are related to Maragheh and the diagrams on the right are related to Khorramabad. As can be seen in the figure, all indices in Maragheh station have a positive trend. However, DMI and HTC indices have a negative trend and indicate an increase in drought intensity in this station. However, a closer look at the charts shows a separation in the distribution of data points for the indices, which began differently from 2000 to 2008. As the values of DM and HTC indices have been changing from scattered (random) to concentrate since 2006, it shows that the station is moving slowly towards almost continuous and progressive dryness. On the other hand, the study of Khorramabad station shows a positive trend of all indicators except CI and TVI, and even unlike Maragheh station, DM and HTC indices also show a positive trend. A closer look at the diagrams of this station also shows the separation in the distribution of data points for the indices, which started differently from 2000 to 2014. Shahrekord and Aligudarz stations have almost the same conditions, which may be due to changes in synoptic conditions in these stations. The comparison of these two stations is due to the fact that in examining the studied indices, they show different conditions than other stations.

Discussion

Comparison of the outputs of the indices with the work of Tonietto and Carboneau (2004) shows that most of the stations are in the HI-1 and HI+2 groups or temperate and warm climate classes with Hi values for the growing season ranging from 1800 to 2100. However, this study shows that in 11 stations the trend of changes to HI+2 class (hot) and in 11 other stations to HI+3 (very hot) has taken place during the statistical period. Although these changes cause the growth and production of a wide range of cultivars with higher temperature requirements and degree-day, at the same time can cause a significant decline in the quality of a large number of available varieties. Examination of the WI index shows that Islamabad Gharb, according to Winkler *et al.* (1974), is even higher than class 5 (2223-2700). In the meantime, the study of other stations shows that most of the stations located in mountainous areas are in class 1 (850-1389), which are moving towards class 4 (1945-2222) or class 5 (2223-2700) with a significant positive trend. Therefore, it is possible to cultivate sensitive *V. vinifera* varieties that need a longer growing season. But, the occurrence of cold winters in some years, especially in mountainous areas, can cause frostbite and damage to farmers. The study of CI index, which is used to measure the temperature trend during the grape ripening period in September, also indicates that except for Khoy, Khorramabad and Shahrekord, which have a negative trend, there is a weak positive trend in other stations. So that it has changed mainly from the class of very cool nights (CI+2) to mild nights (CI-1). According to Tonietto and Carboneau (1999), who consider the heat threshold of 14.2 °C to be effective in colour and aroma intensity, this can cause a relative decline in grape quality. In this regard, as the value of Sen's Q shows, the trend is slowly occurring in most stations, among which the stations of Maragheh, Hamedan, Miyaneh and Khorram Dareh show a higher trend. In other words, the increase in night temperature in stations with

Table 3

Summary of temperature statistics

Station	HI			CI			WI		
	Range	MKZ	Sen's Q	Range	M-KZ	Sen's Q	Range	M-KZ	Sen's Q
Qazvin	2450-3287	3.69***	9.61	10.4-14.8	2.47*	0.04	1723-2486	3.75***	8.33
Kermanshah	2792-3507	3.47***	9.75	10-14.8	3.83***	0.07	1962-2607	3.83***	10.48
Zanjan	2712-3507	3.21**	8.78	10-14.8	3.01**	0.05	1452-2302	4.26***	12.50
Mahabad	2095-3065	4.15***	14.32	10.5-14.9	3.75***	0.06	1452-2305	4.23***	12.48
Orumiyeh	1812-2701	3.66***	12.12	9.4-12.6	0.11	0.00	1236-1919	3.47***	8.67
Khoy	2049-2977	4.54***	15.06	9.4-14.2	-1.36	-0.03	1385-2258	5.03***	15.27
Makoo	1609-2450	3.41***	11.54	10.5-14.9	3.72***	0.07	1105-1883	3.58***	11.34
Maragheh	2069-3143	4.97***	17.13	13.3-18.2	4.66***	0.09	1536-2373	5.14***	15.66
Tabriz	2201-3001	3.29***	9.71	13.3-17.4	2.29*	0.04	1659-2373	3.32***	8.53
Sanandaj	2527-3325	4.69***	12.66	7.6-13.9	3.86***	0.10	1728-2405	4.83***	12.15
Saqez	1864-2755	2.33*	7.42	5.2-11.6	3.41***	0.06	1065-1947	2.19*	7.56
Hamedan	2037-2844	4.54***	8.07	6.1-10.2	4.62***	0.09	1279-1956	4.54***	8.73
Khorramabad	2924-3773	5.00***	14.43	12.3-21	-2.05*	-0.08	1994-2877	5.79***	19.12
Shahrekord	2067-2590	2.36*	4.25	4.5-9.6	-1.85±	-0.05	1249-1728	-0.03	-0.20
Arak	2924-3773	5.00***	14.43	11.1-19.6	1.87±	0.05	1994-2877	5.79***	19.12
Aligudarz	2093-2714	3.20**	6.62	10.6-14.1	3.85***	0.06	1456-1998	3.71***	6.46
Khorramdareh	1952-2792	4.01***	12.74	8.6-13.8	4.17***	0.09	1296-2056	4.43***	13.37
Mianeh	2465-3390	3.83***	12.34	12.3-16.8	4.26***	0.08	1788-2628	3.95***	12.24
Bijar	1784-2654	4.11***	13.81	9.6-14.6	3.77***	0.08	1195-1992	4.32***	13.88
Kanghavar	2392-3076	3.77***	10.05	6.6-11.2	3.20**	0.08	1551-2110	3.94***	9.53
Eslamabade Gharb	2510-3522	2.69**	8.58	8-21.1	3.16**	0.08	1639-3076	3.06**	8.86
Borujen	1843-2397	2.86**	6.85	5.3-9.1	3.65***	0.07	1112-1617	3.42***	8.83

Station	TVI			LTI		
	Range	M-KZ	Sen's Q	Range	M-KZ	Sen's Q
Qazvin	32-36	2.50*	0.05	605-718	3.52***	1.23
Kermanshah	36-42	-0.31	-0.01	678-770	3.24**	1.27
Zanjan	30-42	0.20	0.01	510-701	3.27**	1.17
Mahabad	28-33	2.30*	0.08	548-664	4.40***	2.09
Orumiyeh	25-34	4.43***	0.16	497-587	3.12**	1.19
Khoy	28-33	-0.26	-0.01	491-626	5.31***	2.56
Makoo	21-26	0.00	0.00	442-557	3.55***	1.52
Maragheh	23-28	3.49***	0.08	568-683	4.66***	2.37
Tabriz	24-28	3.49***	0.06	546-668	3.72***	1.58
Sanandaj	35-42	1.53	0.06	639-732	3.92***	1.36
Saqez	33-42	1.73+	0.06	500-660	1.62	0.96
Hamedan	33-41	0.43	0.01	578-667	4.89***	1.61
Khorramabad	37-45	-4.97***	-0.19	715-838	4.80***	2.41
Shahrekord	35-44	4.89***	0.21	605-694	1.08	0.32
Arak	37-45	-4.97***	-0.19	671-762	4.09***	1.56
Aligudarz	28-33	-0.92	-0.02	619-718	3.32***	1.14
Khorramdareh	28-33	-0.99	-0.02	530-616	4.10***	1.89
Mianeh	28-33	0.42	0.01	587-710	4.04***	1.77
Bijar	26-29	-1.70+	-0.03	538-640	4.49***	1.86
Kanghavar	37-44	0.27	0.01	618-964	3.26	1.20
Eslamabade Gharb	20-42	-1.16	-0.03	639-852	2.48*	1.17
Borujen	32-39	-2.23*	-0.07	566-681	1.96±	1.18

*** 99.99 % confidence interval for Mann-Kendal Z-Statistics
** 99 % confidence interval for Mann-Kendall Z-Statistics
* 95 % confidence interval for Mann-Kendall Z-Statistics
+ 90 % confidence interval for Mann-Kendall Z-Statistics
Huglin index (HI)
Cool night index (CI)
Winkler index (WI)
Latitude – temperature index (LTI); Temperature Variability index (TVI)

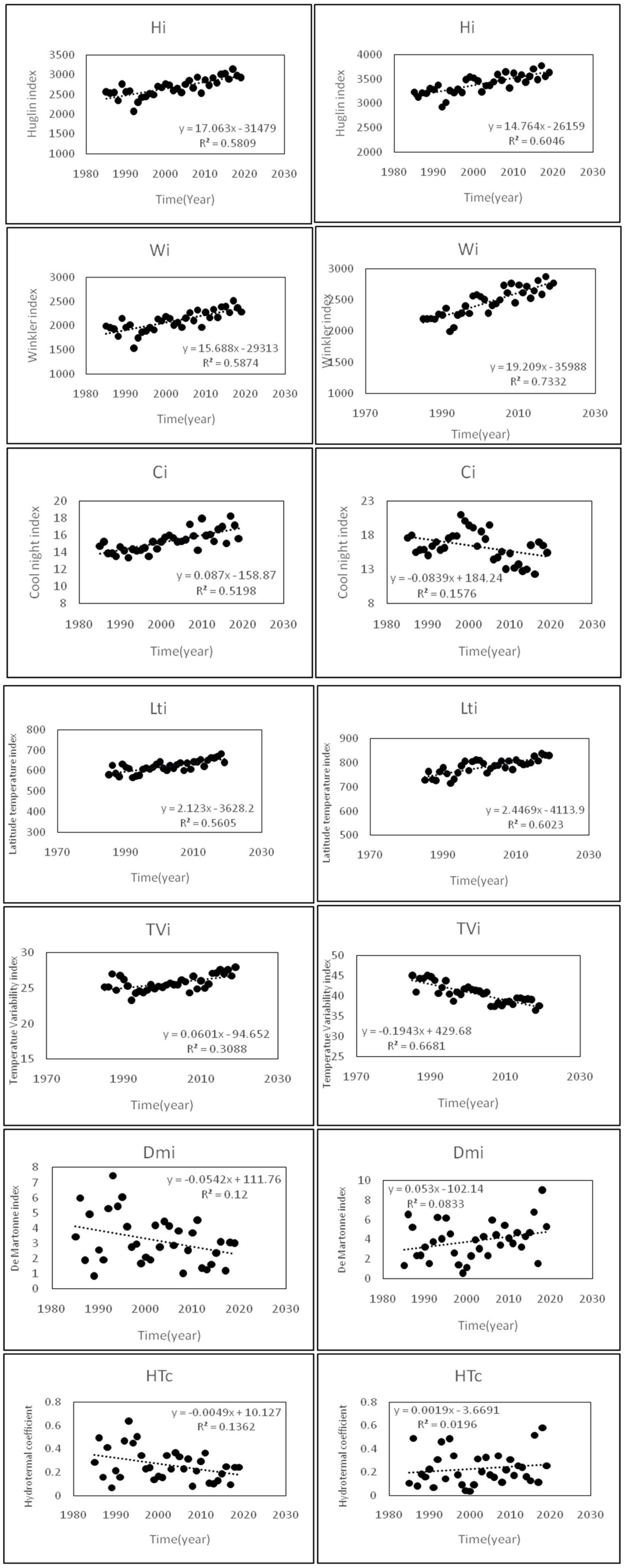

Fig. 2: Climate indices trend for Maragheh (left column) and Khorramabad (right column) stations.

positive trend can reduce the quality level of the product.

LTI climatic index also shows a significant positive trend in most stations except Saqqez and Shahrekord. The high significance of Shahrekord station in TVI index may be due to its relatively high altitude, which has caused a large variability in daily temperature and ultimately created a general variability trend (Robinson 2006). According to this index, most of the stations are in class D and the long growing season is due to the geographical location of Iran, which is located in the lower half of the mid-latitude region. These conditions have made it possible to cultivate a variety of grapes specific in hot to very hot regions. At the same time, the climatic and thermal conditions of the region provide the ability to cultivate grapes of B and C classes cultivars, which according to Jackson and Perry (1988) are in the range of 200-375 of Lti in the mountainous regions of Iran. However, in some years, especially in the mountainous areas of northwestern Iran, these grapes are exposed to extreme low temperatures and cause damage to farmers. It should be noted that this index is based on temperature classification including class A, subclasses 1 and 2 for grape cultivars in very cold and cold regions, class B for cultivars warmer than class A or mesoclimate regions such as hillsides, class C for cultivars in tropical regions, and class D is for hot to very hot areas (Jackson and Cherry 1988). The study of grape cultivation in Iran in the period 2003 to 2019 shows its increase from 155203 hectares to 193737 ha (Statistical Center of Iran 2019). Therefore, the trend of changes in Lti index in the northern and even mountainous regions of Iran can provide the necessary ability to produce different cultivars, especially even classes B and C, and in the southern regions, class D such as 'Shirazi', 'Soltani' (Thompson Seedless), 'Rish Baba' and 'Shahroudi'. The next index is TVI, which, as shown in Tab. 3, has a significant trend in only a few stations, among which the most positive trend has occurred in Shahrekord and the most negative trend has occurred in Khorramabad and Arak stations. Although it seems that this index could be a good indicator to show climate variability, but due to the position of Iran, which is located in the middle latitude region, it cannot show a good measure in terms of grape growing ability.

Examination of DMI and HTC indices also showed that there is no significant trend, among which only Khorramabad and Shahrekord stations in terms of DMI index changes and Maragheh and Shahrekord stations in terms of HTC index changes have a significant trend at 90 % confidence level. The values of these two indices are normal and of course different be-

Table 4

Summary of precipitation statistics

Station	DMI			HTC		
	Range	M-KZ	Sen's Q	Range	M-KZ	Sen's Q
Qazvin	0.47-6.38	0.03	0.00	0.04-0.55	-0.03	0.000
Kermanshah	0.74-7.57	0.71	0.02	0.06-0.61	0.57	0.001
Zanjan	0.35-7.83	0.14	0.00	0.03-0.65	0.03	0.000
Mahabad	0.78-7.62	-0.26	-0.01	0.07-0.65	-0.40	-0.001
Orumiyeh	1.37-9.53	0.37	0.01	0.11-0.87	0.28	0.001
Khoy	1.29-7.43	0.88	0.03	0.11-0.59	0.71	0.002
Makoo	2.48-12.32	0.71	0.04	0.20-1.10	0.43	0.002
Maragheh	0.86-7.45	-1.62	-0.05	0.07-0.64	-1.79+	-0.005
Tabriz	1.55-6.54	0.37	0.01	0.13-0.54	0.03	0.000
Sanandaj	0.35-9.03	-0.23	0.00	0.02-0.55	-0.31	-0.001
Sagez	0.95-8.30	-0.94	-0.03	0.08-0.81	-1.02	-0.002
Hamedan	0.30-6.68	1.08	0.03	0.02-0.60	0.99	0.002
Khorramabad	0.58-9.0	1.79+	0.06	0.04-0.58	0.82	0.002
Shahrekord	0.04-4.67	1.96+	0.04	0.00-0.42	1.87+	0.003
Arak	0.33-6.30	1.11	0.04	0.03-0.54	1.11	0.003
Aligudarz	0.62-7.70	1.27	0.05	0.05-0.67	1.16	0.004
Khorramdareh	0.84-6.27	-0.15	-0.01	0.07-0.53	-0.28	-0.001
Mianeh	1.19-5.60	-0.39	-0.01	0.10-0.46	-0.60	-0.001
Bijar	0.99-9.34	-1.16	-0.04	0.08-0.83	-1.39	-0.004
Kanghavar	0.64-5.94	0.54	0.01	0.05-0.50	0.44	0.001
Eslamabade gharb	0.79-5.01	0.27	0.00	0.08-0.56	0.07	0.000
Borujen	0.14-3.60	1.32	0.03	0.01-0.32	1.01	0.002

Drought Index (DMI)
Hydrothermal Coefficient (HTC)

tween stations and the values of Q are very low and around zero, which may change in the future. Changes in regime and type of precipitation can have important effects on water supply and grape cultivation in the future. At Maragheh station, this may be due to the drying up of Urmia Lake, which began around 2000 and is located to the west of the station. It should be noted that most of the precipitation in Maragheh station is due to humid westerly winds and based on this, perhaps the dryness of Urmia Lake has been effective in the downward trend of precipitation in this region. Although these two indices do not show any significant change in most stations in the study area, but the studies such as Babaeian *et al.* (2009), Rahimi *et al.* (2019), Alvankar *et al.* (2020) and others show a change in the negative trend of annual precipitation. Also, the study of some researchers such as Omidvar *et al.* (2013) and Amir Rezaieh *et al.* (2017) indicate the temporal changes of precipitation.

Conclusion

This study showed that changes in viticultural climatic indices have occurred in northwestern and western Iran, although the trend of some of them has been very slow. Among the studied indices, HI, WI, LTI and CI indices showed the most significant changes in different areas of grape cultivation, respectively. However, the occurrence of very low temperatures in the cold season in mountainous areas and the increase in temperature in the growing season as well as the increase in night-time temperature remain important factors causing damage. Therefore, farmers can cultivate a variety of cultivars of *Vitis vinifera*. However, in the medium term, an increase in temperature could cause a quantitative and qualitative decline in the production of this product. Study of precipitation in the growing season does not indicate a significant change, especially in summer. In this regard, it has also provided the possibility of suitable cultivation and adaptation of many European and American cultivars. The upward trend of temperature indices on the one hand has caused severe evaporation and lack of rainfall in the dry season on the other hand, has practically limited the dryland cultivation of different grape cultivars, which in this regard requires farmers to pay more attention to the irrigation calendar. Because, according to statistics in 2019, more than 86 % of the area under grape cultivationin in Iran was allocated to irrigation farming (Statistical Center of Iran 2019). These changes can negatively affect the production process and related costs in the long term. Also, this study showed that despite the increase in the length of the growing season, the occurrence of late spring and early autumn frosts is still a negative factor.

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