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The Observed Changes in Climate Characteristics in the Trebinje Vineyard Area (Bosnia and Herzegovina)

Tijana Banjanin [1], Zorica Ranković-Vasić [2], Milica Glišić [2] and Zoran Pržić [2,*]

[1] Department of Horticulture, Faculty of Agriculture, University of East Sarajevo, 71123 East Sarajevo, Bosnia and Herzegovina; tijana.pekic@pof.ues.rs.ba

[2] Department of Horticulture, Faculty of Agriculture, University of Belgrade, 11080 Belgrade, Serbia; zoricarv@agrif.bg.ac.rs (Z.R.-V.); milical@agrif.bg.ac.rs (M.G.)

* Correspondence: zoranata4@yahoo.com

Abstract: The productivity and quality of grapes and wine are significantly influenced by changing climate conditions in vineyard regions worldwide. This study assesses changes in temperature, precipitation, and viticultural indices between the periods of 1971–1990 and 2000–2019 in Trebinje, a vineyard area located in the Herzegovina region of Bosnia and Herzegovina. Between the two periods, mean annual temperature increased by 2 °C and mean vegetational temperature by 2.4 °C, while mean precipitation remained within the range of climatological variability, with annual values increasing by 6% and vegetational values decreasing by 4.6%. Warming resulted in a longer duration of the vegetation season by 23.7 days, a reduced risk of late spring frosts, and an increased risk of very high temperatures during summer. These changes led to the reclassification of Trebinje vineyards' climate from Region III to Region V, based on the Winkler index values, from a "temperate warm" to a "warm" category, based on the Huglin heliothermic index, and from "cool nights" to "temperate nights" based on the cool nights index. The category of the dryness index remained unchanged between the two periods. The findings emphasize the necessity for a renewal of the viticultural zoning and the development of climate change-adaptation plans for this region.

Keywords: climate change; bioclimate indices; Trebinje; grapevine; zoning

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1. Introduction

Alongside the selection of suitable grape varieties, climate is one of the most important factors for the production of grapes and wine. Climate processes and climate change are accelerating under human influence [1], which leads to changes in the phenology of the vine [2], the spread of pests and diseases [3], and even the appearance of new pests, thus reducing the productivity and quality of the wine [4]. In many traditional wine-growing regions, including the Mediterranean, significant shifts in the suitability of climate are expected, which may lead to a decline in production in the wine sector and significant socio-economic losses [5]. As climate change is very likely to continue in the future [1], understanding the character and the impact of these changes in a specific region is crucial for the development of an adaptation strategy to the upcoming climate conditions.

An assessment of climate change impacts to the viticultural sector mostly begins with an analysis of changes in the thermal and precipitation conditions of a location or a region, including extreme weather events which may significantly disturb normal vine development. A low risk of frost in spring and autumn and a long frost-free period have a favorable effect on vines, while the occurrence of frost in spring can reduce the fertility of the buds, resulting in lower yields and poorer-quality grapes [6]. Temperature has a major influence on the duration of the ripening phase of the grapes, the taste, the color of the skin of the berry, and thus the quality and characteristics of the wine. Daytime temperatures affect the color intensity of the skin of the berry, but too-warm nights may reduce the anthocyanin concentration [7]. Additionally, the amount of precipitation and its seasonal distribution are important factors determining the quality of the wine. The availability of water is very important for vines at the beginning of vegetation, from budding to inflorescence development, while dry and stable conditions are favorable from flowering to maturity [8,9]. The water status of the vines affects the accumulation of phenolic compounds in the grapes, with a water deficit having a positive effect on the phenolic composition of the berries. For this reason, the distribution and efficiency of rainfall and the water-storage capacity of the soil are of great importance [10].

The complex relationship between climate potential and crop stability is commonly assessed through a set of bioclimatic indices often used in viticultural zoning for the evaluation of climatic suitability and grape-variety selection [11]. They are also used to make an initial assessment of the impact of climate change on viticulture and changes in the climatic suitability of wine-growing regions [12,13]. Among the most commonly used indices in viticultural planning are the Winkler index, the Branas index and quality index of Fregoni [14], the Huglin index (HI), the cool night index (CI), and the dryness index (DI). The last three indices are part of the multi-criteria climate classification system (Geoviticulture MCC system), which has been used in the classification of climate characteristics and for evaluating climate change impacts in wine-growing zones [15]. Numerous studies have found statistically significant changes in the Winkler, Huglin, and cool night indices, shifting the climate of the traditional wine-growing regions worldwide towards warmer climates [16–19], among others, and introducing new regions with potentially suitable climates for high-quality wine production [17,20].

The production of grapes and wine in Bosnia and Herzegovina is primarily associated with the Herzegovina region. Favorable natural conditions for vine cultivation, combined with the traditional orientation of the local population towards viticulture and wine making, have established a centuries-old tradition of grape growing and wine production. Today, the wine-growing region of Herzegovina boasts a diverse array of grape varieties, with particular economic significance attributed to the autochthonous varieties of Žilavka, Blatina, and Vranac, as well as international varieties such as Merlot and Cabernet Sauvignon [21]. However, the current viticultural zoning in Bosnia and Herzegovina dates back to 1977 and has not been updated since then. This study aims to analyze the changes in the climate of the Trebinje vineyard area with the objective of providing updated insights into the Trebinje area's viticultural climate suitability.

2. Materials and Method

The area studied in this work belongs to the Herzegovina region, the sub-region of the middle Neretva and the Trebišnjica rivers, and the Mostar vineyard area. The altitude of Trebinje is about 275 m above sea level. The geographical position is 42°42′ N and 18°20′ E. Trebinje is the most important wine-growing area in the Republic of Srpska, and this study presents the first detailed analysis of the observed climate change in this locality.

For the analysis of climate conditions, daily temperature and precipitation data for Trebinje were obtained from the synoptic meteorological station of the Republic of Srpska Hydrometeorological Institute. These data were used to calculate the mean monthly, annual, and vegetational climatological (normal) values of temperature and precipitation, as well as the values of selected bioclimatic indices, for two 20-year periods, 1971–1990 and 2000–2019.

The following viticultural indices were analyzed:

- Winkler index (*WI*)—the sum of effective temperatures (mean daily temperatures above 10 °C) during the vegetation season. It represents the thermal potential of the locality and categorizes the climate of the wine-growing regions into five classes [22], namely: Region I, from 850 to 1388 °C; Region II, from 1389 to 1667 °C; Region III, from 1668 to 1944 °C; Region IV, from 1945 to 2222 °C; and Region V, from 2223 to 2700 °C. This index is calculated according to the following formula:

$$WI = \sum_{01.04}^{31.10} \left(\frac{Tx + Tn}{2} \right) - 10\ ^\circ\text{C} \quad (1)$$

where Tx—maximum daily air temperature (°C) and Tn—minimum daily air temperature (°C).

- Huglin heliothermic index (*HI*)—expresses the heliothermic potential of the locality, taking into account the temperature during the growing season, but also the duration of daylight at a given latitude [23]. This index is calculated using the following formula:

$$HI = \sum_{01.04}^{30.09} \left[\frac{(T - 10) + (Tx - 10)}{2} \right] \cdot \text{k} \quad (2)$$

where T—mean daily air temperature (°C), Tx—maximum daily air temperature (°C), and k is an adjustment for the length of day in different latitudes, with the value 1.03 used for Trebinje.

On the basis of this index, the wine-growing climate is divided into 6 classes: very cool—(HI-3) ≤ 1500; cool—(HI-2) > 1500 and ≤1800; temperate—(HI-1) > 1800 and ≤2100; temperate warm—(HI+1) > 2100 and ≤2400; warm—(HI+2) > 2400 and ≤3000; and very warm—(HI+3) > 3000.

- Cool night index (*CI*)—represents the mean value of the minimum temperature during the ripening month (September). Low night temperatures during ripening are of great importance for the accumulation of polyphenols and volatile compounds, so that this index can be used to estimate the potential of the wine-growing region for the production of high-quality wines [15]. The cool night index (*CI*) was calculated using the following formula:

$$CI = \frac{1}{30} \cdot \sum_{01.09}^{30.09} Tn \quad (3)$$

where Tn—minimum daily air temperature (°C).

Based on this index, the climate in the vineyard is divided into 4 classes: very cool nights—(CI+2) ≤ 12 °C; cool nights—(CI+1) > 12 and ≤14 °C; temperate nights—(CI-1) > 14 and ≤18 °C; and warm nights—(CI-2) > 18 °C.

- Dryness index (*DI*)—represents an estimate of the amount of water in the soil available to the vine during vegetation. This index is used to determine the degree of humidity or dryness of the climate. The dryness index (*DI*) was calculated according to the following formula [15]:

$$DI = W_0 + \sum_{01.04}^{30.09} (P - Tv - Es) \quad (4)$$

where W_0—usable water reserve in the soil at the beginning of vegetation accessible via the roots (usually estimated at 200 mm), P—monthly precipitation sum, Tv—potential transpiration in the vineyard, and Es—evaporation from the bare soil surface.

Based on this index, the vineyard climate is divided into 4 classes: very dry (DI+2) ≤ −100 mm; moderately dry (DI+1) > −100 and ≤50 mm; subhumid (DI−1) > 50 and ≤150 mm; and humid (DI−2) >150 mm.

All selected indices are important for characterizing the climate in viticultural practice and are often used in the selection of grape varieties. The HI, CI, and DI together form the multi-criteria climate classification system [15], which enables the globally uniform categorization of vineyards and mutual comparisons of climatic conditions among them.

In addition, the following climatological and bioclimatological indices were calculated:

- Number of days in the vegetation period (from 1 April to 31 October) with a daily minimum temperature below 0 °C;

- Number of days in the vegetation period (from 1 April to 31 October) with a daily maximum temperature greater than or equal to 35 °C;
- Number of days in dormancy (from 1 November to 31 March) with a minimum daily temperature less than or equal to −15 °C;
- The date of the beginning of the vegetation, defined as the date of the first occurrence; of the sixth consecutive day with a mean daily temperature greater than or equal to 10 °C since the beginning of the year;
- The date of the end of vegetation, defined as the date of the first occurrence of the sixth consecutive day with a mean daily temperature less than 10 °C in the second half of the year;
- The length of the vegetation, i.e., the number of days between the calculated start and end dates of the vegetation;
- The date of the last spring frost;
- The date of the first autumn frost;
- The length of the frost-free period, i.e., the number of days between the last spring frost and the first autumn frost in a year.

All indices were calculated on an annual basis. Climatological mean values (normal) of the indices were calculated for the two climatological periods as averages of their annual values. The statistical significance of the change among the two periods at the 95% confidence level was determined using the independent *t*-test.

3. Results

The normal mean annual air temperature in Trebinje (Table 1) showed an increase of 1.9 °C over the last fifty years. During the same period, the normal mean vegetation temperature (from 1 April to 31 October) was 2.4 °C from 18.2 to 20.6 °C. The normal annual maximum temperature increased by 1.8 °C, and the normal annual minimum temperature by 2.0 °C between the two periods. These changes were more pronounced in the vegetation period, with a rise of 2.3 °C for maximum and 2.4 °C for minimum temperature. Annual and vegetational temperature changes are statistically significant according to the *t*-test.

Table 1. Climatological normal annual and vegetational mean (*T*), maximum (*Tx*), and minimum (*Tn*) temperatures, and precipitation (RR) in Trebinje.

Period	Normal Annual Values				Normal Vegetational Values			
	T (°C)	*Tx* (°C)	*Tn* (°C)	RR (mm)	*T* (°C)	*Tx* (°C)	*Tn* (°C)	RR (mm)
1971–1990	13.8	18.9	8.7	1588.0	18.2	23.8	12.7	739.4
2000–2019	15.7	20.7	10.7	1683.7	20.6	26.1	15.1	705.3

A temperature increase between the two periods was observed in all months (Figure 1). The largest anomaly in mean temperature is observed during the summer months (June 3.0 °C, July 2.8 °C, and August 3.3 °C), while the smallest was in January (0.7 °C). The increase in normal maximum temperature was most pronounced in August (3.9 °C), and least in January (0.4 °C), whereas for the minimum temperature, the largest deviation is observed in June (3.1 °C) and the smallest in February (0.7 °C). Anomalies in normal minimum temperatures were larger than those for maximum temperatures in all months except the two hottest, July and August, when maximum temperature anomalies were dominant. Changes of mean and minimum temperatures were found to be statistically significant in all months except in January and February, while changes in maximum temperatures were statistically significant in all months except in winter (December, January, and February) and September.

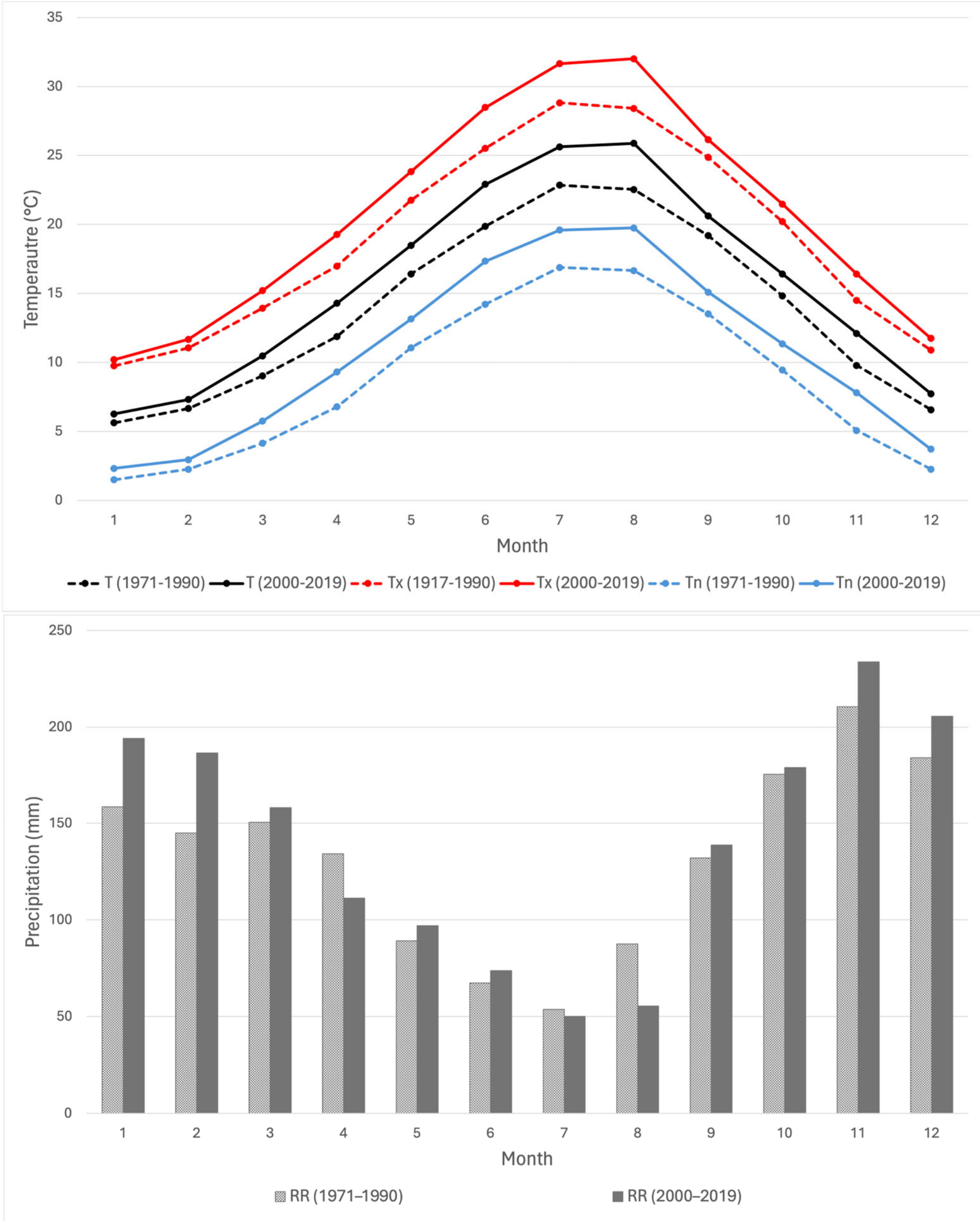

Figure 1. Monthly normal mean (*T*), maximum (*Tx*), and minimum (*Tn*) temperature, and precipitation (RR) in Trebinje.

Normal annual precipitation (Table 1) increased by 6% between the two periods, rising from 1588 mm in 1971–1990 to 1683.7 mm in 2000–2019. Conversely, normal vegetation precipitation in the April–October period decreased by 4.6%, dropping from 739.4 mm (1971–1990) to 705.3 mm (2000–2019). These changes were not found to be statistically significant and can be attributed to natural climate variability.

The wettest month in both climatological periods was November (210.5 mm in 1971–1990 and 233.7 mm in 2000–2019), while the driest month was July (53.7 mm in 1971–1990 and 50.1 mm in 2000–2019). A decrease in monthly precipitation (Figure 1) was observed in April (−17.1%), July (−6.6%), and August (−36.6%). In the other months, an increase in normal precipitation was observed, especially in winter (28.7% in February and 22.3% in January).

During both climatological periods, days with a minimum temperature below −15 °C, which may affect vines, were not observed. In the vegetation period, frost days (minimum daily temperature below 0 °C) occurred on average 0.6 times in the 1971–1990 period and slightly less, 0.4 times in 2000–2019. Conversely, the average number of days with a maximum temperature greater than or equal to 35 °C increased almost seven times, from 2 in the 1971–1990 period to 13.7 in 2000–2019. This change was found to be statistically significant. As a result of warming, hot weather extremes have become more frequent, which undoubtedly has an impact on the quality of grapes produced in the Trebinje area.

Between the two considered climatological periods, the average beginning of the vegetation in Trebinje shifted 15 days towards the beginning of the year, while its end moved 9 days towards the end of the year. This resulted in an extension of the average vegetation period length by 23.7 days (Table 2). In general, earlier vegetation onset increases the risk of frost damage in the spring. However, due to the increase in minimum temperatures, the average dates of the last spring frost and the first autumn frost have also shifted, by 7 days towards the beginning of the year in spring and by 9 days towards the end of the year in autumn. This led to an increase in the average length of the frost-free period by 16.1 days (Table 2).

Table 2. Date of beginning (GSS) and end (GSE) and length of the vegetation (GSL), date of the last spring frost (SF) and the first autumn frost (AF), and duration of the frost-free period (FF) in Trebinje.

Period	GSS	GSE	GSL	SF	AF	FF
1971–1990	11.04	21.11	225.7	05.03	12.11	252.4
2000–2019	28.03	01.12	249.4	26.02	21.11	268.5
Δ days	15	9	23.7	7	9	16.1

Bioclimatic viticultural indices are of great importance for assessing the suitability of the climate and the location for growing vines. The values of the Winkler index (*WI*), the Huglin heliothermic index (*HI*), the cool night index (*CI*), and the dryness index (*DI*) are listed in Table 3. The Winkler index changed from an average value of 1779.0 °C in the climatological period of 1971–1990 to 2278.0 °C in the period of 2000–2019, causing the shift from the Region III to the Region V category of this index. Similarly, the average values of the Huglin heliothermic index switched from the "temperate warm" (HI+1) to "warm" (HI+2) category. The warming of minimum daily temperatures in September of 1.6 °C caused the change of the cool night index category, from "cool nights" (CI+1) to "temperate nights" (CI-1). Contrary to the indices based on temperature alone, the dryness index, which includes both precipitation and evapotranspiration, did not change its 'sub-humid' category (DI-1), despite a decrease in values from 137.7 mm in the period of 1971–1990 to 86.5 mm in the period of 2000–2019. The change in total evapotranspiration during the growing season is not statistically significant. Changes in WI, HI, and CI were found to be statistically significant, in contrast to DI change, which was statistically insignificant.

Table 3. Values and categories of the Winkler index (*WI*), the Huglin heliothermic index (*HI*), the cool night index (*CI*), and the dryness index (*DI*) in Trebinje.

Period	*WI* (°C)	*HI* (°C)	*CI* (°C)	*DI* (mm)
1971–1990	1779.0 Region III	2193.4 HI+1	13.5 CI+1	137.7 DI-1
2000–2019	2278.0 Region V	2665.8 HI+2	15.1 CI-1	86.5 DI-1

4. Discussion

Climatic conditions are one of the most important factors influencing the yield and quality of the grapes and therefore also the quality of the wine. Numerous studies have shown that most wine-growing regions in Europe [9,24,25], Australia [26], New Zealand [27], and the USA [14] have been subject to significant warming trends in recent decades. Warming in the second half of the 20th century has improved the quality of wine in colder wine-growing regions such as Poland [28] and Canada [29], at the same time creating difficulties in wine-growing regions where vines are grown close to the temperature optimum, such as Australia [26,30]. Similar trends have been observed in the Western Balkan region [31].

Studies conducted in eastern Herzegovina [32,33] have identified positive trends in annual and seasonal mean, maximum, and minimum temperatures. These changes were most pronounced in summer, followed by spring, while the trends in winter and autumn in Herzegovina were weak and mostly statistically insignificant. The results from [32] indicate that the entire area of Bosnia and Herzegovina experienced significant annual warming in the period of 1961–2015, with an increase in temperature ranging from 0.2 to 0.5 °C per decade. This trend aligns with the findings of the current study, which observed a 2 °C warming between the two considered climatological periods, corresponding to 0.4 °C per decade. Positive temperature trends were noted in all months, with the most pronounced warming in June, August, December, and January. Conversely, the smallest and statistically insignificant trends were found in February, March, and from September to November [32]. The results of the current study are consistent with those of [32,33], showing the strongest increase in the mean monthly, maximum, and minimum air temperatures during the summer months, followed by the spring months, and the smallest increase during winter and autumn. At the same time, the increase in minimum temperatures is greater, except in summer, when the increase in maximum temperatures is more pronounced.

Climate change manifests not only through shifts in average conditions but also through changes in the occurrence of climate extremes. The relationship between extreme events and global warming can be non-linear, and relatively small changes in mean temperature can result in significant changes in weather extremes. One study [33] found that the frequency and the intensity of warm extremes increased (including the number of warm nights, warm days, summer days, tropical days, and the duration of the heatwaves), while cold extremes' frequency showed a negative trend in Herzegovina, especially in Mostar. Similar findings were observed in the current study for Trebinje, where the average number of frost days during the vegetation is lower despite the earlier vegetation start and prolonged growing season, while the number of very hot days in summer has increased significantly.

Herzegovina is a region strongly influenced by the Adriatic Sea, which imparts a maritime character to its precipitation regime. The majority of the precipitation falls in the cold half of the year, with the highest precipitation typically observed in November and December. Throughout the vegetation period, less than half of the annual precipitation falls, with the least rainfall in summer, particularly in July and August [34,35]. Despite this, the available precipitation would suffice for vine growth, provided it is well distributed.

However, in recent decades, Bosnia and Herzegovina has experienced frequent occurrences of drought, resulting in economically significant losses and damages to agricultural production, particularly in the form of reduced yields. The main reason for the occurrence of droughts in this region is the uneven distribution of precipitation in time and space, followed by rising air temperatures. The lack of precipitation in summer, accompanied by relatively high air temperatures, leads to moisture deficits in the active root zone, which disturbs the soil water balance and slows down the physiological processes in plants [36]. Water deficit hampers plant growth and biomass accumulation, as well as impacting photosynthesis and cell growth. It is estimated that droughts can reduce yields by approximately 20% if the genetic potential of plants is taken into account. While irrigation serves as a crucial measure to mitigate the impacts of drought, long-term planning must also consider the future availability of water resources for irrigation purposes, especially having in mind the fact that eastern Herzegovina lacks surface water, which may have severe impacts on energy production and water supply.

Another study [37] showed that there are negative trends in annual precipitation across the country. The analysis showed that negative trends are prevalent throughout the year, except for autumn. This contrasts with the findings of the current study, which observed a precipitation decrease in Trebinje only in June, August, and April. However, the trend values reported in [37] were mostly statistically insignificant, as found in the current study. Furthermore, [37] identified an increasing trend of heavy precipitation indices (such as maximum one-day precipitation, maximum five-day precipitation, standard daily precipitation intensity, and very wet days) suggesting an intensification of precipitation, which was also noted in Trebinje though more frequent occurrences of river and flash floods in recent years.

Changes in temperature and precipitation caused the changes in viticultural indices that are observed across Europe [16–19]. Statistically significant trends towards warmer categories of *WI*, *HI*, and *CI* are observed in Spain [38] and Italy [39], among other vineyard regions. In Serbia, shifts of the categories of WI and HI are noted in all vineyard regions over the last 20 years [40].

One study [41] examined projected climate changes and their impact on selected viticultural indices (*HI*, *CI*, *DI*) at three locations (Banja Luka, Sarajevo, and Mostar) in Bosnia and Herzegovina by the end of the 21st century. Mostar, the location closest to Trebinje, had the driest and the hottest climate of all three locations in the reference period of 1961–1990. Future increases in *HI* and *CI* values, as well as decreases in *DI*, are found across all locations by the end of the century, under different greenhouse gas-emission scenarios. These projected changes are in line with the findings of the current study, which observed a shift to warmer categories for *HI* and *CI* and a decrease in *DI* values, although remaining within the same category as in the period of 1971–1990. These findings indicate that climate conditions in viticultural areas of Bosnia and Herzegovina are expected to continue changing in the coming decades.

The wine industry in Bosnia and Herzegovina is predominately oriented towards high-quality wine production. Grapes cultivated in the country come almost exclusively from autochthonous varieties such as Žilavka and Blatina. These varieties are not only well adapted to the climatic and geographical conditions in Bosnia and Herzegovina, but also hold significant social importance as the part of the local tradition and cultural heritage. However, larger producers also produce less-expensive table wines and cultivate varieties such as Cabernet Sauvignon, Merlot, Shiraz, Chardonnay, Sauvignon Blanc, Vranac, Pinot Noir, and Tamjanika. Despite the country's considerable capacity and excellent conditions for the production and processing of grapes, imports of wine in Bosnia and Herzegovina are almost five times higher than exports [42]. According to official reports from the Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina, there has been a recent increase in the area under vineyards, as well as an increase in wine consumption per capita. These data show significant growth potential for viticulture in Bosnia and Herzegovina. To fully capitalize on this potential, it is imperative to develop new viticultural zoning, including adaptation strategies that will enhance sustainability and resilience of vineyards to future climate conditions.

The cultivation of autochthonous varieties in Herzegovina holds the potential to create a viticulture that is climate-smart, genetically diverse, and sustainable, particularly in light of the climate changes observed in recent years. These varieties offer wines with unique characteristics that are well-suited to the region's production, holding considerable economic significance. When considering the incorporation of international varieties into production, producers must carefully consider these factors and determine their percentage in relation to autochthonous varieties [43]. However, besides socio-economic factors, the influence of climate on wine quality has become increasingly significant in decision-making processes. A recent research project [44] emphasized that climatic factors significantly impact the phenolic composition of wines produced from Blatina, Vranac, Merlot, and Cabernet Sauvignon in the Trebinje area. Notably, in an exceptionally hot and dry year, wines made of autochthonous varieties Blatina and Vranac had notably higher quality than those made from international varieties Merlot and Cabernet Sauvignon in the Trebinje vineyard area. This observation suggests a potential direction for viticulture in the eastern Herzegovina, emphasizing the preference for well-adapted autochthonous vine varieties. These findings highlight the necessity of planning the adaptation of wine production and the entire wine sector in order to maximize the potential of the *terroir* [44]. The recommended measures for adapting vineyards in the Trebinje area to climate change are as follows: altering canopy geometry, minimizing water consumption, applying anti-transparent substances, using shade nets, and harvesting earlier. Sunscreen materials like kaolin are commonly used to increase canopy and fruit zone reflectivity, improving leaf cooling and photosynthetic function while enhancing antioxidant capacity and secondary metabolite production. To reduce sugar accumulation and alcohol content, manipulating the leaf-area-to-fruit-weight ratio is suggested, though it may affect wine quality [45]. Vineyard orientation optimization and the cultivation of heat-tolerant grape varieties such as Cabernet Franc, Cabernet Sauvignon, Merlot, Malbec, Tempranillo, or Syrah [46] are recommended. Preserving the biodiversity of native grapevine varieties like Žilavka, Blatina, Trnjak, and Bena is crucial for adapting to future climates. However, replacing traditional varieties with more resistant ones poses challenges due to sensory properties and consumer preferences, suggesting the need for marketing strategies promoting climate-adapted varieties. Evaluating these strategies' economic implications is essential, as some regions may become unsuitable for viticulture due to climate change. The preservation of wine style and typicity, closely linked to local terroirs, highlights the wine sector's vulnerability to climate change.

The viticulture in Bosnia and Herzegovina is characterized by the dominance of small vineyards, ranging from 0.3 to 0.4 hectares, with very few vineyards exceeding 10 hectares in one piece [42]. These small vineyards are mostly owned by family agricultural households, and there is no precise data on their exact number since there is still no registry of grape and wine producers. Adapting to climate change may require significant investments in infrastructure, technology, and education. This can pose a financial burden for grape growers and wine producers, especially for small and medium-sized enterprises, which are the most common in Bosnia and Herzegovina. Without government incentives, they will have difficulty in successfully overcoming all the challenges posed by climate change.

5. Conclusions

The analysis of the climatological data showed a statistically significant warming in Trebinje from 1971–1990 to 2000–2019, with a rise in mean annual temperature by 2 °C and average vegetation air temperature by 2.4 °C. The largest anomaly is found in summer months, while the smallest anomalies occurred in winter. At the same time, changes in precipitation were within the natural climate variability range and are not found to be statistically significant.

The observed warming has led an earlier onset (by 15 days) and later end (by 9 days) of the vegetation period. Despite this, the risk of late spring frost remained low. On the other hand, warmer summers have resulted in a significant increase in the frequency of hot days, whose number rose by seven times on average, thereby significantly increasing the risk of heat stress. The warmer vegetation season caused a shift of viticultural indices *HI* and *CI* to warmer categories, while *WI* shifted two categories up, from Region III to Region V. Although higher temperatures increase plants' water requirements, and there has been a slight decrease in precipitation during the vegetation period, the *DI* category remained unchanged, albeit with an increase in the index value, indicating a shift towards a dryer climate.

Rapid changes in climate conditions, especially in temperature, necessitate an urgent need for a renewal of the viticultural zoning in Bosnia and Herzegovina and a revision of the recommended vine varieties and agrotechnical and enological practices in order to preserve wine-making traditions within the Trebinje vineyard area.

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