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Spatio-Temporal Analysis of the Universal Thermal Climate Index (UTCI) for the Summertime in the Period 2000–2021 in Slovenia: The Implication of Heat Stress for Agricultural Workers

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Abstract: Due to climate change crisis, the risk of occupational heat stress for agricultural workers has recently increased. The temporal and spatial biometeorological conditions in different climatic regions of Slovenia during summer were analyzed using the Universal Thermal Climate Index (UTCI), and additionally the water loss index (SW) and the accepted level of physical activity (MHR). Term values of air temperature, relative air humidity, wind speed at 10 m and cloud cover at 14:00 CEST were used as input for the BioKlima 2.6 software package and were retrieved from the Slovenian Environment Agency for the summer months in the period 2000–2021. The rise in the average UTCI values was shown to be positive and statistically significant for summer (0.7 °C/decade) as well as for all three months, the highest being for June (0.9 °C/decade). The percentage of summer days during 2000–2021 that were under strong or very strong heat stress varied widely by location, ranging from one-third to more than one-half. Average monthly UTCI values at 14:00 CEST were the highest in July, reaching 30 °C in a submediterranean climate, Črnomelj is the only station with this average higher than 32 °C. Daily highest UTCI value was 47 °C (Črnomelj). It was shown that conditions in the middle of a hot summer day are not suitable for moderate or severe agricultural workloads.

Keywords: UTCI; heat stress; water loss index; physical activity; agricultural workers; Slovenia

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1. Introduction

Due to rising global air temperatures and consequent more frequent and intense heat waves, the risk of heat stress has been constantly increasing in recent decades. Heat stress negatively affects human health and activity, reduces work efficiency, and increases the risk of accidents at work [1,2]. More sensitive groups to extreme heat are older people, children, outdoor and manual workers, chronic patients, and the poor [3]. Agricultural workers are particularly vulnerable to heat stress due to the nature of their work, which takes place mostly outdoors under the influence of sometimes extreme weather conditions [4]. A survey about occupational heat stress, including more than 300 agricultural workers in Slovenia, showed that more than 80% of them have already experienced negative effects like excessive sweating, thirst, tiredness, headaches, fatigue and even nausea or vomiting, and more time is required to complete daily duties during heat waves [5]. Given that air temperatures in Slovenia have risen in recent decades, the number of heat waves is increasing, and climate change projections show that this trend will continue [6], it is important to determine biometeorological conditions, especially in summertime with the highest temperatures and intensive work in agriculture. To analyze the influence of weather conditions on human health and well-being, a complex index is needed, which combines several relevant meteorological parameters such as air temperature and humidity, solar radiation, and wind speed, with a human heat balance model.

More than 100 simple bioclimatic indices have been developed so far to facilitate this, however, most of these indices have proved to be of limited applicability [7,8]. Among the most frequently used indices for measuring heat stress are the physiologically equivalent

temperature (PET), predicted mean vote (PMV), physiological subjective temperature (PST), perceived temperature (PT), standard effective temperature (SET), temperature-humidity index (THI), Universal Thermal Climate Index (UTCI), wet-bulb globe temperature (WBGT), water loss index (SW), and accepted level of physical activity (MHR) [9,10]. The study that evaluated a comprehensive register of 162 thermal indices sorted them into devised groups according to different classification classes with the aim to organize and evaluate the full range of all human thermal climate indices [11].

At the initiative of the International Society of Biometeorology and with the participation of many experts in the COST (Cooperation in Science and Technical Development) Action 730, UTCI was developed in 2009 [7], derived from the Fiala multi-node model of human heat balance [12]. UTCI is a human biometeorological parameter for assessment of the linkages between human well-being and outdoor thermal environment [13]. UTCI is defined as the air temperature of the reference condition causing the same model response as actual conditions [7,13] and describes the heat exchanges between the human body and its thermal environment [14]. Because UTCI can be used in different climate zones and across all seasons and fully reflects human heat exchange processes with the real environment, it has been widely used in last 15 years in the fields of human biometeorology, urban bioclimate, tourism, sport, health, epidemiology, and climate impact research [15]. Among the key applications of UTCI are also daily forecasts in public weather services, advice about outdoor activities, and warnings of the heat and cold stress [16].

Climate change has increased the risk to workers' health and safety, especially those working outdoors for example in agriculture where they are at increased risk of heat stress, occupational injuries, and lower productivity at work [17]. Agricultural sector worldwide represents about 26% of the world's total labor force [18]. Agricultural workers are the group of workers most vulnerable to heat stress, consequently the agricultural sector accounted for 83% of global working hours lost due to heat stress in 1995 and is furthermore expected to account for 60% of the loss in 2030. ILO Convention No. 184 [19] states, that employers have a duty to ensure the safety and health of agricultural workers in every aspect related to the work, and that they should carry out risk assessments. Researchers in the U.S. [20] found out that the average U.S. crop worker is exposed to 21 unsafe working days each summer growing season (out of 153 total) because of heat stress, and the estimation is that the average number of days spent working in unsafe conditions will double by mid-century, and, without mitigation, triple by the end of it. UTCI is an appropriate tool for assessing occupational heat stress risk among agriculture workers [21], and so are MHR (W/m^2) and SW (g/h). Heat stress diminishes the capacity of outdoor workers for manual labor and recent analysis showed that physical work capacity is projected to be highly affected by the ongoing anthropogenic global warming [22]. A decrease of the accepted level of physical activity has already been observed in some places [23].

The Greek literature review [24] suggests that agriculture includes the most energy-demanding work among the five selected industries (agriculture, construction, manufacturing, tourism, and transportation industries), with an average energy cost of 6.0 kcal/min for male and 2.9 kcal/min for female workers. The tasks with the highest energy cost estimates within agriculture were digging, weeding, mowing, threshing, and picking. High temperatures and hard physical work accelerate the loss of water from the human body. Dehydration of outdoor workers is a significant problem during the summer months [1,5] and affects labor productivity [25]. To reduce the negative consequences on workers' health and work efficiency, it is important to know how water losses from the body correlate with UTCI increases.

Although some articles have been published for Slovenia regarding bioclimatic conditions in recent years [6,25–29] and others that dealt with Slovenian average bioclimatic conditions in a broader context [21,30,31], detailed bioclimatic situations have not yet been studied by UTCI, nor have the most recent changes in the twenty-first century been assessed. There is a need to analyze such indices regarding agriculture workers in the

case of summer season, as it is often difficult to reduce heat-related risks, such as avoiding exposure to the sun or reducing tasks during hot weather, since the obligations they have to fulfill largely depend on seasonal growing cycles and market demands [25].

The objective of this study was the spatial and temporal analysis of biometeorological conditions in different climatic regions of Slovenia during the summer season, using UTCI. For the calculated UTCI values, we made a comparison with two other bioclimatic indices, MHR and SW. Frequency of various heat stress categories at 14:00 CEST (Central European Summer Time) have been evaluated and discussed in relation to MHR and SW in agricultural work to assess the number of unsafe working days due to heat.

2. Materials and Methods

To analyze biometeorological conditions in different climatic regions, we have chosen nine meteorological stations of the Slovenian national weather network, which represent the variability of the climate in Slovenia. The combination of many factors, such as geographical location, relief, the orientation of mountain ridges, and the proximity of the sea, results in very diverse climatological conditions. According to the most recent objective climate classification [32], there are six climate regions in Slovenia: the submediterranean climate region, wet climate of hilly region, moderate climate of hilly region, subcontinental climate region, subalpine climate region, and the Alpine climate region. The spatial distribution of the average annual temperature follows the relief of Slovenia, and it is warmest on the coast, where the average annual temperature exceeds 12 °C. It is also warmer (10–12 °C) in the rest of the Primorska region and in the lowlands of eastern Slovenia, while in the lower parts of central Slovenia the average annual temperature is between 8 and 10 °C. The highest daily temperatures are usually recorded around 14:00 CEST, the warmest month is July, in the mountains August. In the period 1961–2011 mean air temperature increased by 1.7 °C. The greatest warming is observed in summer and spring [33]. Projected air temperature increase for the first half of the 21st century in Slovenia is of 1 to 4 °C, compared to the average 1961–1990, summer is projected to warm up the most [34]. In the case of an optimistic greenhouse gas emissions scenario (RCP2.6) the number of hot days in Slovenia will increase by about 6 days by the end of the century, and in the case of a pessimistic scenario (RCP8.5) for about 27 days [34].

Stations used from the submediterranean climate region are Bilje (45°54′ N, 13°38′ E, 55 m a.s.l.) and Portorož (45°29′ N, 13°37′ E, 2 m). From the subcontinental climate region are Črnomelj (45°34′ N, 15°9′ E, 157 m), Ljubljana (46°4′ N, 14°31′, 299 m), Maribor (46°32′ N, 15°39′ E, 275 m), and Novo mesto (45°48′ N, 15°11′ E, 220 m). From the moderate climate of hilly region are Postojna (45°46′ N, 14°12′ E, 533 m), and Slovenj Gradec (46°29′ N, 15°7′ E, 455 m) and from subalpine climate region is Rateče (46°30′ N, 13°43′ E, 864 m) (Figure 1).

Term values of four meteorological variables at 14:00 CEST were used to calculate UTCI: air temperature (T, °C), relative air humidity (f, %), wind speed 10 m above surface (v, ms^{-1}), and cloud cover (N, %). We used data for global irradiance instead of some missing data for cloud cover for Rateče from 1 July 2017 onwards and for Slovenj Gradec for 36 missing data out of a total of 2015. The meteorological data set was retrieved from the archive of the Slovenian Environment Agency for the summer months (June, July, August) in the period 2000–2021 [35]. Table 1 summarizes the climate conditions in the studied areas during this period.

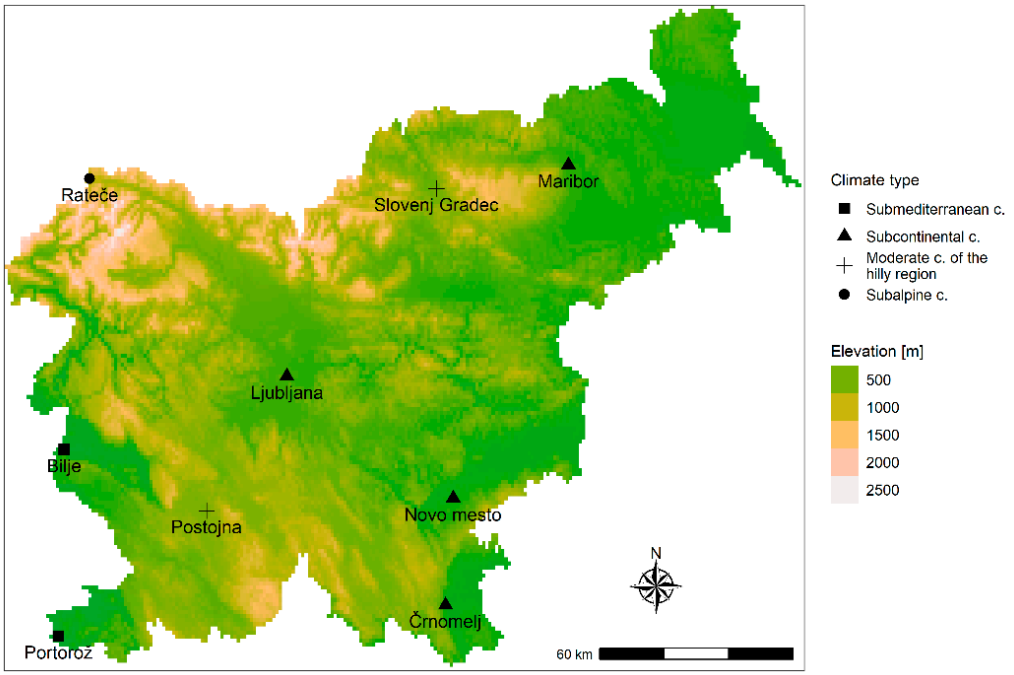


Figure 1. Distribution of selected meteorological stations on the base of climate regions of Slovenia.

Table 1. Summer (June, July, August) mean values ± standard deviations of air temperature (T), relative humidity (f), wind speed (v), and cloudiness (N) at 14:00 CEST for studied locations in the period 2000–2021.

	T (°C)	f (%)	v (ms^{-1})	N (%)
Bilje	28.1 (±4.3)	43.3 (±14.6)	2.9 (±1.4)	38.8 (±28.3)
Črnomelj	27.0 (±4.8)	49.1 (±16.0)	0.8 (±1.0)	42.2 (±32.7)
Ljubljana	26.1 (±4.8)	48.7 (±15.7)	2.2 (±1.1)	49.0 (±26.2)
Maribor	25.6 (±4.9)	49.5 (±15.2)	2.4 (±1.1)	52.0 (±27.5)
Novo mesto	26.3 (±4.4)	50.5 (±17.7)	2.1 (±1.0)	44.1 (±30.5)
Portorož	27.8 (±3.5)	50.0 (±12.3)	4.0 (±1.4)	33.5 (±25.4)
Postojna	24.5 (±4.6)	51.2 (±16.4)	3.0 (±1.6)	46.1 (±28.5)
Rateče	22.6 (±4.8)	50.2 (±18.2)	1.7 (±0.9)	49.3 (±30.9)
Slovenj Gradec	24.2 (±4.7)	50.9 (±17.1)	2.2 (±1.4)	50.3 (±28.1)

Indices UTCI, SW and MHR were calculated with the BioKlima 2.6 software package [36,37]. BioKlima software allows the calculation of about 60 various bioclimatological indices for a general or detailed analysis of bioclimatic conditions or human heat balance. Table 2 presents the labeled heat stress categories [12,38]. UTCI has 10 categories in terms of thermal stress, 4 for heat stress (UTCI values higher than 26), 1 for no thermal stress (UTCI values between 9.1 and 26), and 5 for cold stress (UTCI values 9 or lower). The thermal comfort zone is indicated by values between 18 and 26 [12,39].

Table 2. Universal Thermal Climate Index (UTCI) threshold values regarding heat thermal stress [39].

UTCI (°C)	>46.0	38.1–46.0	32.1–38.0	26.1–32.0	9.1–26.0 *
stress category	extreme heat stress	very strong heat stress	strong heat stress	moderate heat stress	no thermal stress
class	4	3	2	1	0

* 18–26: thermal comfort zone.

Average monthly, seasonal, and annual values of UTCI for Europe for the period 1979–2020 are available on the European Climate Adaptation Platform [13] based on the ERA5 prepared at the Climate Data Store of the Copernicus Climate Change Service (C3S) /EMS/ECMWF. The Climate-ADAPT platform supports countries in adapting to climate change, sharing data on current and future vulnerability of regions and includes a database that contains quality checked information that can be easily searched. One of the purposes of this UTCI indicator is to identify adaptation needs at the regional level. For Slovenia, the UTCI index is calculated for two basic macro-regions: eastern Slovenia (SI03) and western Slovenia (SI04). According to the Classification of territorial Units for Statistics NUTS (Nomenclature of Territorial Units for Statistics) [40], a geocode standard, was developed by the European Union for different regional analyses. Data for the period 1980–2020 were used.

Index SW is calculated based on the potential values of evaporative heat loss (E_{pot}): SW = 2.6xE_{pot}. E_{pot} is derived from a man-environment heat exchange model MENEX [41]. In line with ISO standard 8996, the threshold values of SW depend on human activity and acclimatization level as showed in Table 3.

Table 3. Water loss index (SW) threshold values regarding heat thermal stress (ISO standard 8996).

	Activity Level	
	≤70 W/m^2	**>70 W/m^2**
	acclimatized person	
warning SW value	520 g/h	780 g/h
hazardous value	780 g/h	1040 g/h
	non-acclimatized person	
warning SW value	260 g/h	520 g/h
hazardous value	390 g/h	650 g/h

Index MHR indicates the upper limit of activity under given meteorological conditions that will not provoke a warning heart rate value 90 beats per minute. MHR was calculated [38] as follows: MHR = [90 − 22.4 − 0.25(5xT + 2.66xvp)]/0.18 where T is air temperature (°C) and vp is water vapor pressure (hPa).

According to international standards [42,43] and the mentioned literature review [26], different kinds of activities lead to particular metabolic rates (Wm^{-2}). For example, the value for a sitting person is 60 Wm^{-2} and for a standing posture 70 Wm^{-2}. In agriculture, the metabolic rate is about 300 Wm^{-2} for a moderate physical activity (like picking fruits or vegetables, raking, machining), about 415 Wm^{-2} for a heavy physical activity (like intense arm and trunk work, carrying loads, shoveling, landscaping), and about 520 Wm^{-2} for a very heavy physical activity (intense shoveling or digging, using an axe, climbing a ladder, any activity done at near maximum pace).

3. Results

3.1. Average Summer UTCI for 1980–2020 for Slovenia at NUTS 2 Level

Average UTCI is shown for the period 1980–2020 for summertime (Table 4). Eastern Slovenia has average summer UTCI (20.1 °C) slightly higher than the western part (19.8 °C). Both regions have the highest UTCI in July due to the highest summer temperatures occurring also in July. The highest monthly UTCI for July is 24.2 °C for the eastern part and 23.7 °C for the western part of Slovenia. The UTCI trends for both regions are positive (Figure 2) and statistically significant for summer (0.7 °C/decade) as well as for all three individual months, the largest being for June (0.9 °C/decade).

Table 4. Universal Thermal Climate Index (UTCI) average, maximum and minimum values, and trend for June, July, August, and the whole summer for the period 1980–2020 for East and West Slovenia.

		UTCI (°C) for the Period 1980–2020			
		June	**July**	**August**	**Summer**
East Slovenia	avg	16.6 (±1.7)	21.1 (±1.5)	20.7 (±1.6)	20.1 (±1.2)
	max	23.4	24.2	24.1	23.2
	min	15.8	18.0	17.7	18.0
	trend	0.87 °C/decade	0.60 °C/decade	0.60 °C/decade	0.69 °C/decade
West Slovenia	avg	18.3 (±1.6)	20.8 (±1.5)	20.4 (±1.5)	19.8 (±1.2)
	max	22.9	23.7	23.6	22.9
	min	15.6	17.7	17.5	17.7
	trend	0.87 °C/decade	0.57 °C/decade	0.56 °C/decade	0.67 °C/decade

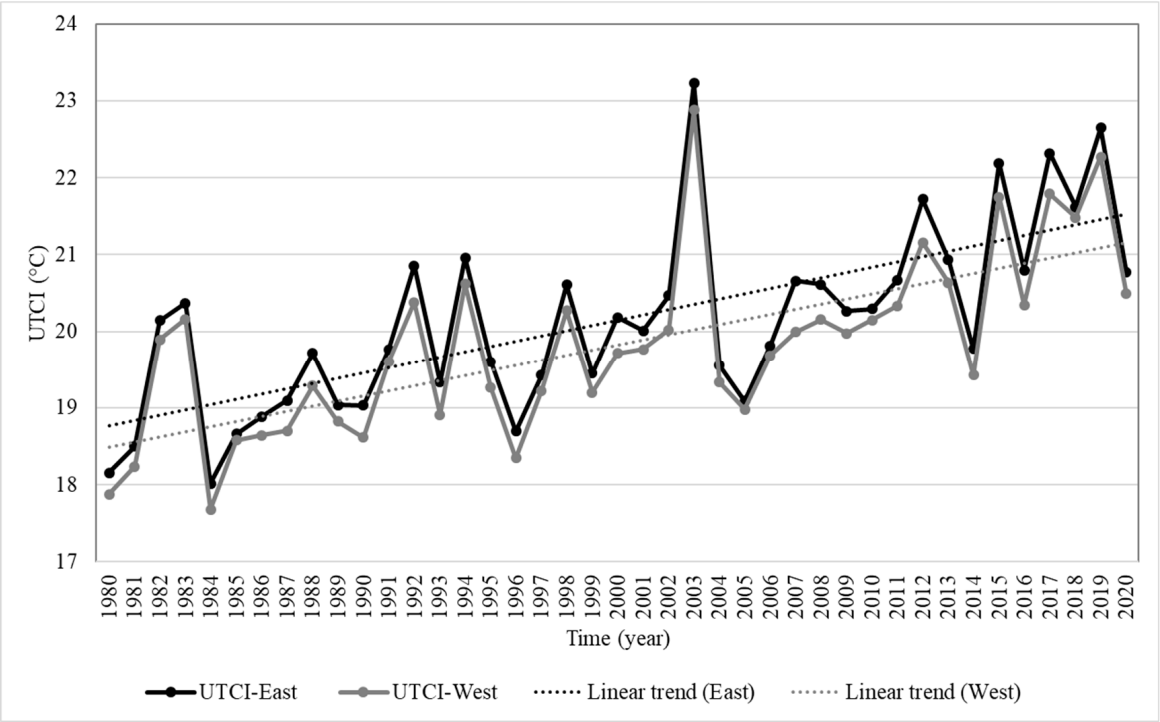


Figure 2. Average summer Universal Thermal Climate Index (UTCI) (June to August) in the period 1980–2020 for eastern and western Slovenia.

UTCI in June rarely exceeds the values of July or August. In Figure 3, for the eastern part, we can see that June UTCI values were higher than July values only in two years, 2000 and 2003, and August values were lower than June values in the years 2005 to 2007. These are, of course, average monthly values, that do not reflect individual daily high values. Based on the averages, this can lead us to the wrong conclusion that heat stress in Slovenia in summer is not a problem, as all values fall into the category without stress. We have therefore additionally presented the actual situation based on daily values at 14:00 CEST, when maximum air temperatures are reached.

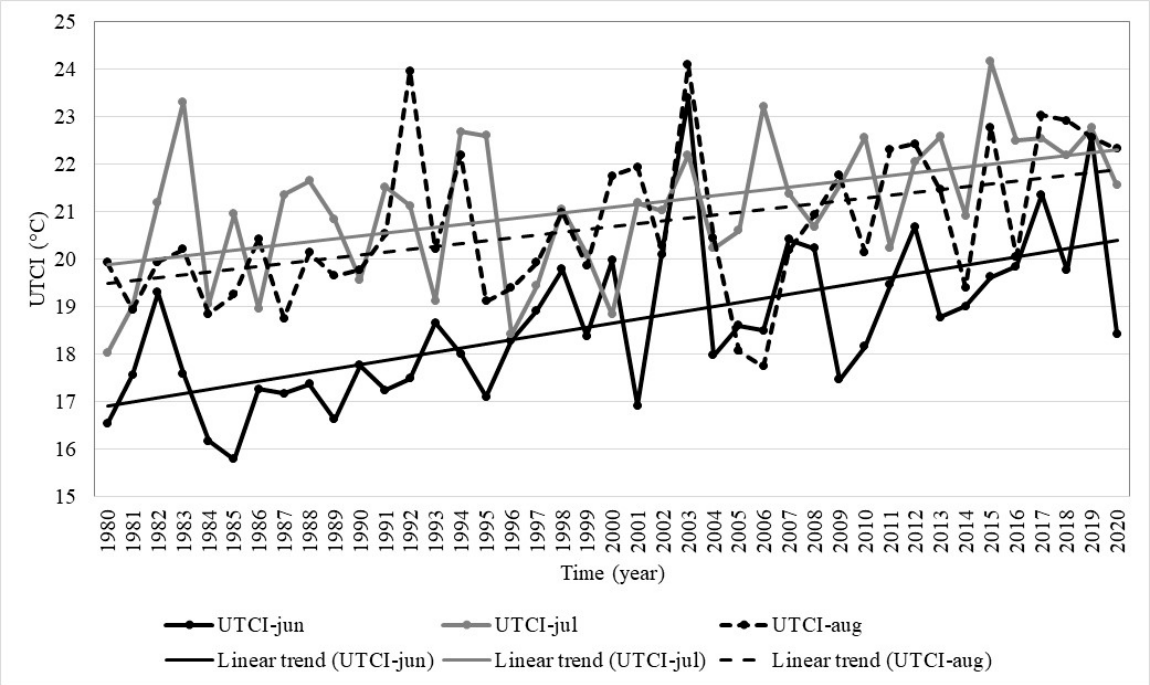


Figure 3. Average Universal Thermal Climate Index (UTCI) for June, July, and August in the period 1980–2020 for eastern Slovenia.

3.2. Average Monthly and Summer Values of Temperature and UTCI at 14:00

Average temperatures at 14:00 CEST (T; Table 5) at most stations are highest in July, and the differences between the months of July and August are very small, on average around 0.2 °C. In June, the average T value is around 2 °C lower than in the other two summer months. The highest measured T in all summer months are in Bilje and Portorož (submediterranean climate), followed by Črnomelj (subcontinental climate), significantly lower temperatures are in Postojna and Slovenj Gradec (moderate climate of hilly region) and Rateče (Subalpine climate). In the period 2000–2021, the absolute highest T was in Črnomelj on 8 August 2013 (40.3 °C), only slightly lower than 40 °C in Ljubljana, Maribor, and Novo mesto on the same date. The highest T in Portorož was lower, only 36.5 °C, as the influence of the proximity to the sea is noticeable here, which means that coastal climate is less extreme.

Table 5. Mean and max air temperature (T; °C) and Universal Thermal Climate Index (UTCI; °C) at 14:00 CEST, monthly and seasonal values for the period 2000–2021.

	Mean T (°C) at 14:00 CEST			Mean UTCI (°C) at 14:00 CEST			Max T	Max UTCI
	June	July	August	June	July	August	Summer	Summer
Bilje	26.6	28.7	28.8	27.6	30.4	30.6	38.8	44.4
Črnomelj	25.7	27.7	27.4	30.0	32.2	31.7	40.3	47.0
Ljubljana	24.9	26.8	26.4	26.3	29.1	28.7	39.6	44.3
Maribor	24.4	26.2	26.0	25.2	27.7	27.7	39.7	42.8
N. mesto	24.7	26.6	26.4	26.6	29.1	28.8	39.6	44.0
Portorož	26.4	28.5	28.3	26.9	29.8	29.6	36.5	40.8
Postojna	23.2	25.2	25.2	23.3	26.0	26.0	36.2	40.7
S. Gradec	23.1	24.9	24.6	24.0	26.4	26.4	37.0	41.5
Rateče	21.6	23.3	22.8	23.3	25.5	24.8	35.1	39.3

Average monthly UTCI values at 14:00 CEST follow the temperature pattern and are also highest in July at most stations. Postojna and Rateče have an average July UTCI of 26.0 °C and 25.5 °C, respectively, which means no thermal stress, or even a comfort zone,

but values are at the upper limit. In the range between 28 °C and 30 °C are July UTCI values in Maribor (27.7 °C), Ljubljana, Novo mesto (29.1 °C), Portorož (29.8 °C), and Bilje (30.4°C), which already means the moderate heat stress category. Črnomelj is the only station that has an average UTCI at 14:00 CEST higher than 32 °C (32.2 °C) in July, which means the strong heat stress (SHS) category. In August, UTCI values at most stations are also in the moderate heat stress range, in Slovenj Gradec the value is 26.4 °C, and in Črnomelj 31.7 °C. Postojna and Rateče have on average no thermal stress in August. In June, which is the coolest of the summer months, four of the considered stations are in the no stress UTCI class (Maribor, Postojna, Slovenj Gradec, Rateče), while the other stations already record moderate heat stress. Five considered stations (Bilje, Črnomelj, Ljubljana, Novo mesto and Portorož) have UTCI values in the moderate heat stress range at 14:00 CEST in all three summer months. Postojna and Rateče are in the no stress class in all three months, but Postojna is at the upper limit value (26.0 °C) in July and August.

Of course, individual daily UTCI values at 14:00 CEST can deviate significantly from the average monthly values. Thus, the highest UTCI value for Črnomelj is 47 °C, which means extreme heat stress. Such a high value appeared in our research only this once—on 4 August 2017, when the air temperature at 14:00 CEST was 39.8 °C in clear weather. The absolute highest UTCI values for an individual location do not necessarily coincide with the absolute highest temperatures. With the otherwise highest measured temperature of 40.3 °C (8 August 2013), UTCI in Črnomelj was the second highest, 44.6 °C, influenced by lower relative humidity and partly cloudy weather. The absolute highest UTCI values for other stations range from 39.3 °C (Rateče) to 44.4 °C (Bilje).

3.3. Temporal Distribution of Heat Stress Classes

Figure 4 shows the monthly percentage of days in each stress class for each location. Cold stress (UTCI < 9.1 °C) can also occur in summer, although the probability is very low, in most places less than 1%. The exceptions are Postojna, where even in the summer there are 3.1% of days with cold stress, and Slovenj Gradec with 1.4%. Most days with cold stress during summer occur in the month of June.

The most favorable thermal conditions for people are in the UTCI range from 18 °C to 26 °C, i.e., the thermal comfort zone (Table 6). The most days in this class, roughly estimated at around a third of summer days, are in Rateče (36.5%), Slovenj Gradec (34.6%) and Postojna (31.8%). Between 20 and 30% of summer days in the thermal comfort zone are in Bilje, Portorož, Novo mesto, Ljubljana, and Maribor. In Črnomelj, however, there are only 17% of summer days in the thermal comfort zone. Figure 4 and Table 6 show that the variability between locations is very high, and the average percentage of such summer days is around 35%. In Črnomelj, there are only 18.9% of summer days without heat stress, while in Rateče there is more than half of such days (51.7%). Bilje (25.3%) and Portorož (26.4%), both in the submediterranean climate region, have a similar percentage of summer days without heat stress.

Table 6. The percentage of summer days in the period 2000–2021 within strong or very strong heat stress, thermal comfort zone or no thermal stress for each location.

% of Summer Days with	Bilje	Črnomelj	Ljubljana	Maribor	N. mesto	Portorož	Postojna	Rateče	S. Gradec
no stress	25.3	18.9	33.2	37.6	32.9	26.4	45.8	51.7	45.6
thermal comfort zone	20.9	17.1	25.5	27.3	25.1	22.8	31.8	36.5	34.6
strong or very strong stress	39.2	51.4	29.8	23.5	33.0	27.7	16.7	9.0	15.1

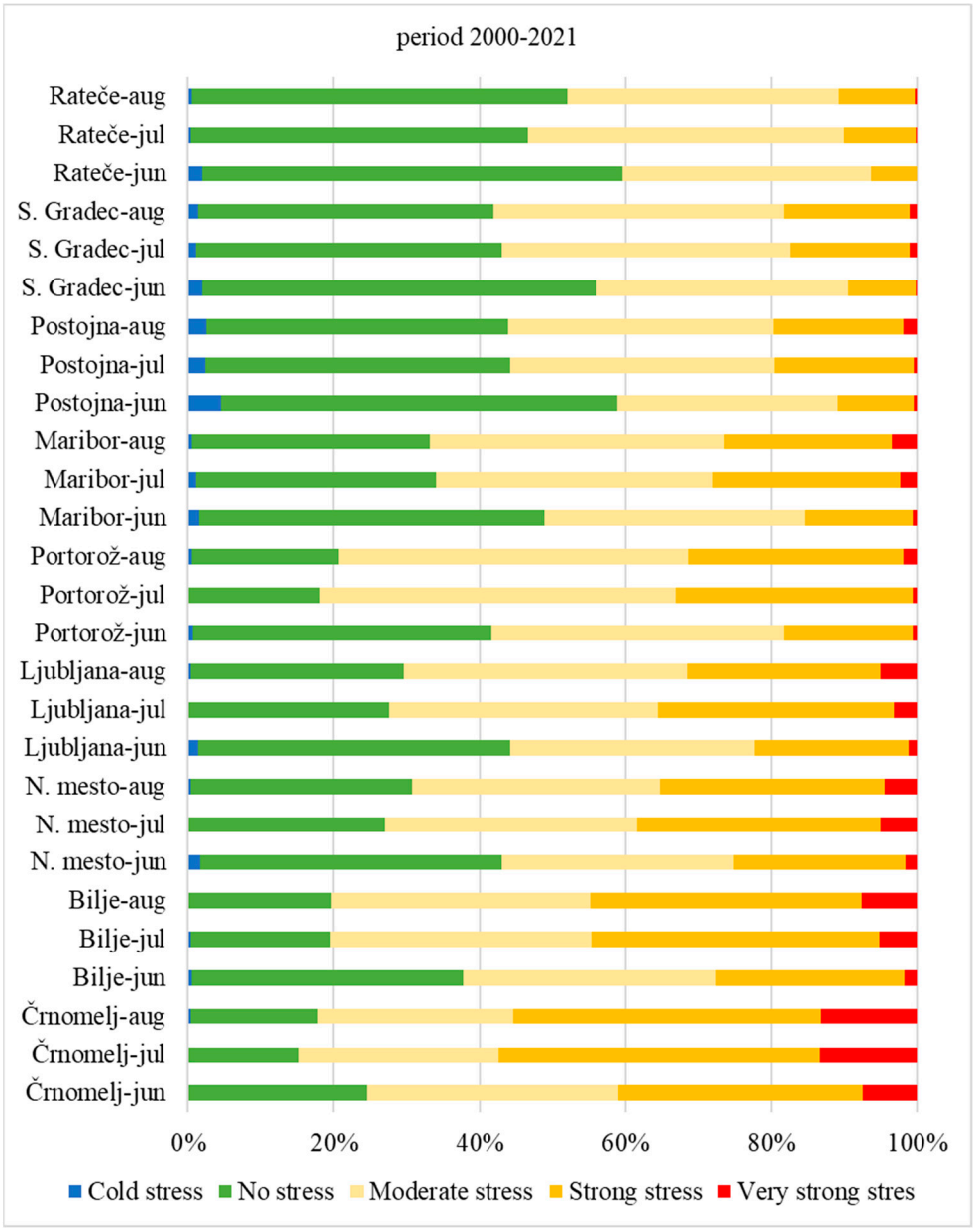


Figure 4. The percentage of days in each UTCI thermal stress class by summer month and station for the period 2000–2021.

The percentage of days with moderate stress (UTCI between 26.1 °C and 32 °C) is on average the same as for those without stress (36.5%). The distribution is similar among the stations, except for Portorož, where we can expect more, around 46% of summer days with moderate heat stress, because due to the influence of the sea there are much fewer days with very strong heat stress (VSHS). Otherwise, moderate stress dominates the sum of SHS and VSHS in summer, the exceptions being Bilje and Črnomelj, where SHS dominates over moderate stress (Figure 4; Tables 6 and 7).

Since extreme heat stress occurs only once in Črnomelj (UTCI = 47 °C), we have not shown or commented on this class separately. The largest number of days with SHS or VSHS is in Črnomelj, where in summer, on average, more than half of all days are in this range (51.4%). In addition to pronounced temperature extremes, Črnomelj also has much lower wind speeds (0.8 m/s on average) than other locations, e.g., Bilje with 40% of days with SHS or VSHS and the average wind speed 2.9 m/s, or Ljubljana with 30% of days with SHS and VSHS and average wind of 2.2 m/s. There are relatively few summer

days with SHS in Postojna (16.7%), Slovenj Gradec (15.1%), and Rateče (9.0%), where the average temperatures are lower than at the other analyzed locations. Besides, Postojna is characterized by higher wind speeds during typical local wind bora.

Table 7. Monthly and seasonal values of average, minimum and maximum number of days with strong heat stress (UTCI values above 32 °C) in the period 2000–2021 in Črnomelj.

Number of Days	June	July	August	Summer
Minimum	5	10	2	29
Maximum	21	22	26	63
Average	12	18	17	47

3.4. Comparing UTCI to MHR and SW

Figure 5 shows the relationship between the three bioclimatic indices for Črnomelj, calculated for each of 2023 summer days (ordered by increasing UTCI) in the period 2000–2021. When the UTCI values exceed the threshold for SHS, the number of days with SW above the warning limit, i.e., 520 g/h [40], increases, but the variability is very high. At the same time as UTCI and SW increase, MHR decreases, and all indices indicate worsening conditions for agricultural workers.

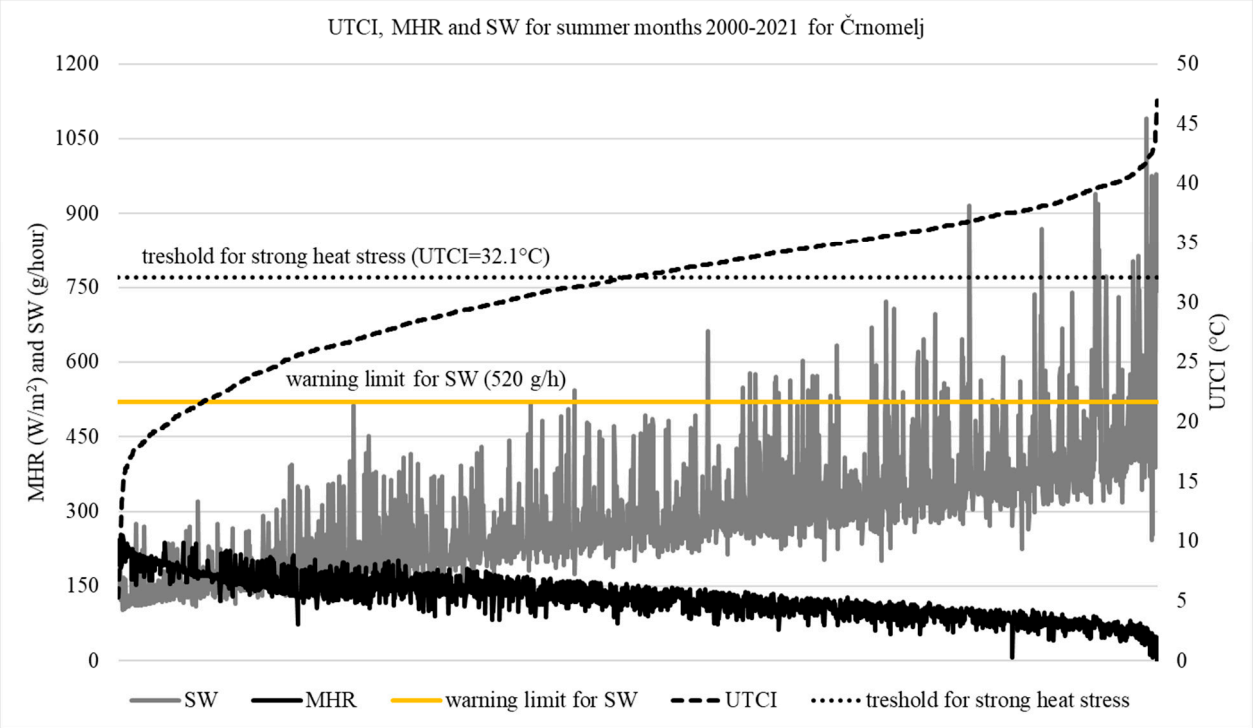


Figure 5. Values of Universal Thermal Climate Index (UTCI), accepted level of physical activity (MHR) and water loss index (SW) for each summer day in the period 2000–2021 in Črnomelj, ordered by increasing UTCI, and denoted UTCI threshold for strong heat stress and warning limit for SW.

Average summer daily SW values (Figure 6) range from 238 g/h in Rateče with the lowest temperatures to almost 400 g/h in Bilje and Portorož, nowhere exceeding the warning limit of 520 g/h (risk of dehydration). However, daily values can be very high, even over 1000 g/h (Črnomelj, Ljubljana, Novo mesto, Maribor), typically occurring in days with very low relative air humidity (<20%) and extremely high temperatures (>37 °C). The highest shares of days with an increased risk of dehydration occur in Bilje and Portorož, 16 and 13% of all summer days, respectively, which is certainly related to higher temperatures and wind speeds at these two stations (Table 1). Other stations record between 3 and 6% of

summer days with a risk of dehydration, the exception being Rateče, where this kind of risk is extremely rare due to relatively low temperatures and wind speeds. The presented risk threshold refers to already acclimatized workers, but for those not yet acclimatized, the warning limit according to the ISO standard for SW is significantly lower, i.e., 260 g/h. For non-acclimatized workers the limit is exceeded in over 80% of summer days in Bilje and Portorož, and in between 50 and 60% days at the other stations, except in Rateče (36%).

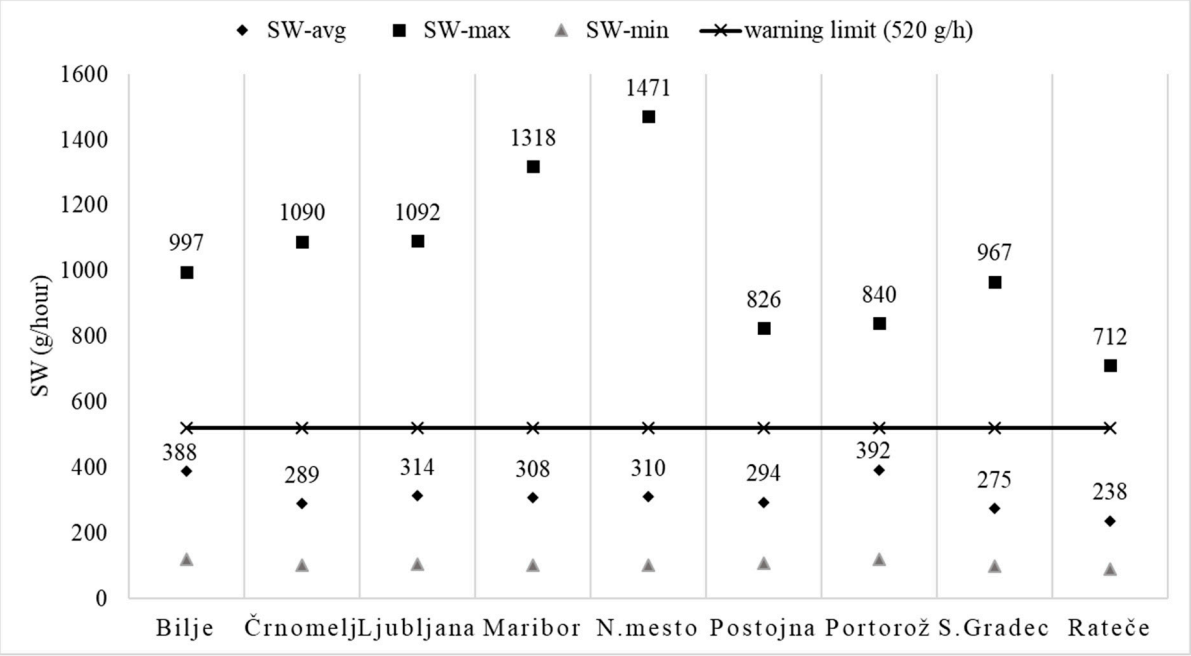


Figure 6. Minimum (min), mean (avg), and maximum (max) summer values of the water loss index (SW) at the studied locations, the line indicates the warning limit for the risk of dehydration.

Calculated average MHR for summer days at 14:00 CEST are the lowest in Portorož (115 Wm^{-2}), Bilje (122 Wm^{-2}), and Črnomelj (125 Wm^{-2}), slightly higher in Ljubljana, Novo Mesto (135 Wm^{-2}), and Maribor (139 Wm^{-2}), around 150 Wm^{-2} in Postojna and Slovenj Gradec, and the highest value, 170 Wm^{-2}, applies to Rateče.

4. Discussion

Analysis of weather conditions on the days with the highest UTCI values shows that wind speed and air humidity have a very large influence on UTCI in addition to air temperature. Thus, for example, in Portorož, the absolute highest UTCI was 40.8 °C on 23 June 2018, at T = 33.8 °C, v = 1 m/s and f = 48%, and at a much higher temperature (36.5 °C) on 4 August 2017 UTCI was lower (40.2 °C) with lower humidity (33%) and higher wind speed (4 m/s). During the considered years of 2000–2021, the most cases of VSHS occurred in the years 2013, 2015, and 2017, when there were intense heat waves and extremely high temperatures in Slovenia [6]. Weather conditions are of course influenced by the micrometeorological conditions of individual locations, in larger cities such as Ljubljana as well as by the impact of the urban heat island [29]. Additionally, there is a high probability that maximum daily temperatures were in fact higher than the ones at 14:00 CEST, which we used in our calculations. For example, in Ljubljana on 8 August 2013, the air temperature at 14:00 CEST was 39.6 °C, but the maximum for that day was slightly higher, 40.2 °C [35]. This means that the maximum UTCI for that day in Ljubljana was probably even higher than our calculated 44.3 °C. At climatological stations there are typical measurements at 14:00 CEST, therefore data for the whole day are not available everywhere to enable capturing all extremes. For comparison, in some other studies, data at 14:00 CEST were also used to calculate UTCI [44].

In recent years, there has been an increased number of the UTCI values around 44 °C and 45 °C, which means that we are approaching the upper class, i.e., extreme heat stress conditions. The bioclimatic indices considered in the Polish study [23] showed significant changes during the studied period (1826–2006), mainly in the winter season. The accepted level of physical activity decreased from about 380 Wm^{-2} in the first years of the studied period to 350 Wm^{-2} in the last. Besides, previous study [26] showed as well that Slovenia's bioclimatic conditions have changed during the period 1951–2000. Significant changes were noted for the Physiological Equivalent Temperature (PET), which increased significantly by almost 3 °C during the last 25 years in Ljubljana.

Similar to Slovenia, SW values above 800 g/h were also confirmed in the colder parts of Europe during the summer months [45]. This can be a problem, since in agriculture most of the seasonal workers are employed only in the summer, often for a short period during peak periods, such as agricultural harvest, but according to OSHA guidelines, an effective heat acclimatization program should last 714 days for an unacclimatized worker. Additionally, acclimatized workers who are not exposed to heat stress for a week or more may need some time to reacclimatize, typically two or three days [43]. Slovenian MHR values also indicate that on average conditions in the middle of a summer day are not suitable for moderate or heavy level of workload in agriculture. Not only the average values, even the highest calculated MHR values are not high enough to perform moderate or heavy tasks like digging, weeding, mowing, or picking. Based on the calculated MHR values at 14:00 CEST, we should not generalize that these are days above safe heat levels, since for such a claim we would have to analyze the course of bioclimatic indices throughout the whole day, but it is undoubtedly clear that for at least part of the day conditions of thermal comfort for outdoor work are risky.

The agricultural and construction sectors are two strategic occupational fields that noticed in recent years an increasing number of migrant workers, and therefore require a better management regarding heat-related risks. A recent study in Italy [44] revealed that migrant workers required greater effort than native Italian workers, but reported less impact from heat on productivity and thermal discomfort. Numerous studies in the last two decades have addressed the health risks and reduced work productivity by agricultural workers in hot locations [2,4,5,46] where one of the greatest risks during heat stress is dehydration. Although action plans are available to mitigate heat stress, there are actually a lot of health problems in the agricultural sector during hot days [22]. A survey of agricultural workers in Slovenia and Greece showed that more than two-thirds of them highlighted thirst and excessive sweating as the main experienced symptoms of heat stress [2]. Exceeded warning limits of water loss due to sweating in the case of agricultural workers were reported also for Poland and Bulgaria [45] as well as for many other countries [4,22]. Adequate hydration is necessary for proper thermoregulation to avoid heat-related illness [25,47] and more efforts will be required also to ensure that workers are adequately hydrated at the start of the work-shift [47,48]. The impact of heat stress on labor productivity is for now relatively small in southern Europe, though it is higher than in the other European subregions, but it is projected that 0.02% of working hours will be lost owing to heat stress in 2030, which means the equivalent of 14,400 full-time jobs [25]. The recent comprehensive review [22] showed that occupational heat stress already diminishes the capacity of outdoor workers for manual labor at current temperatures and that physical work capacity is projected to be highly affected by the ongoing anthropogenic global warming. According to the researchers, about 30% of global heavy labor losses could be recovered by shifting work hours and having them rescheduled during cooler hours of the day [49]. Systematically reviewed available literature about climate change-related hazards such as extreme weather events, extreme heat, and psychological stress, showed that these hazards tremendously affect outdoor agricultural workers' health, which leads to low income in the agricultural sector [50].

A scoping review, summarizing the existing knowledge regarding the health impacts associated with climate change and heat stress across all world regions (Africa, America,

Asia, Australia and Europe) [4], indicates that migrant agricultural workers and child farmworkers are at particularly high risk of heat stress. In addition, this review also found that a lack of research in this area remains among agricultural workers in Sub-Saharan Africa and North Africa, the Middle East, and Southeast Asia. U.S.A. crop workers are twenty times more likely to die from illnesses related to heat stress than other civilian workers overall, because of the nature of the work and high physical demands in agricultural tasks [20]. Moreover, climate change is likely to make the situation even worse; at the current rate, it will double crop worker heat risk by the middle of this century and triple it by the end of it in the U.S.A. Deadly heat stress conditions might become commonplace also across South Asia even at 1.5 °C warming [51]. Due to such unfavorable forecasts for many regions, it is very important to take appropriate measures among agricultural workers. For summer tree fruit harvesters in Washington, it has been found that their productivity was greatly affected by adequate pre-work-shift hydration and proper optimization of sleep and work-shift timing [48].

Our results about MHR, SW and UTCI values for the hottest hours of summer days suggest that immediate urgent measures are needed to reduce the health risk of extreme heat amongst agricultural workers, since climate change will further increase their vulnerability. The increasing thermal burden on the shoulders of agriculture-related physical workers may cause several problems in Slovenia such as lower productivity, difficulties with finding workers willing to work, and higher expenses with mitigation measures. The main challenge will be to keep workers healthy and satisfied and at the same time ensure all tasks are done, which calls at least for the rescheduling of working hours where possible, providing shadow and cold water in the fields and allowing regular breaks.

5. Conclusions

The results of the analyzed three bioclimatic indices (UTCI, MHR and SW) confirm that for the considered stations in the period 2000–2021, a large share of the summer days is characterized by moderate, strong, or very strong heat stress. Outdoor workers in the submediterranean and subcontinental climate region in Slovenia face more intense and longer stressful bioclimatic conditions, as opposed to workers in Moderate climate of hilly region and Alpine climate region. With UTCI values exceeding the threshold for strong stress, the number of days with SW above the warning limit for the dehydration risk increases, and at the same time MHR values decrease. As these values indicate the limit value of activity which does not yet provoke the risk of health in given meteorological conditions, it can be seen that, on average, the conditions in the middle of the summer days are not suitable for a moderate or heavy level of workload in agriculture, showing also how diverse the nature-agriculture interactions are. As many studies show that the risk of heat stress due to ongoing climate crisis will increase and thus affect the farmers' heat-related illnesses and physical work capacity, it is very important to pay more attention to this issue. Due to the nature of agricultural work, it is not possible to change the daily routine to a certain extent, so it is very important to improve risk assessment, adopt protective measures, and enact appropriate legislation. Despite the increasing risk posed by extremely high temperatures, only a few countries in the EU have set a maximum workplace temperature in their national legislation. It varies from Member State to Member State between 28 and 36 degrees Celsius. In Slovenia, however, there are no specific regulations for outdoor work; the legislation only states that the employer must protect employees from hazardous weather conditions. Due to increasing problems with outdoor workers' exposure to heat, Slovenian members of parliament asked the European Parliament Commission (Question E-002729/2022) if it would prepare a legislative proposal that would uniformly regulate the maximum allowable temperatures in the workplace, both indoors and outdoors. The answer was that a revision of the Workplaces Directive 89/654/EEC is being prepared for 2023. The new directive will hopefully harmonize other related activities, such as transport to work or the supply and transport of agricultural products to end users. Ensuring decent working conditions in agriculture is also linked to many other areas, such as public health,

food pricing, and the labor market, as workers prefer not to be employed in agriculture given the extreme conditions of working outdoors. Thus, risk assessment of agricultural work in rising temperatures is an area ripe for joint work by the economic, agricultural, and public health sectors.

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References

1. Pogačar, T.; Casanueva, A.; Kozjek, K.; Ciuha, U.; Mekjavić, I.B.; Kajfež Bogataj, L.; Črepinšek, Z. The Effect of Hot Days on Occupational Heat Stress in the Manufacturing Industry: Implications for Workers' Well-Being and Productivity. *Int. J. Biometeorol.* **2018**, *62*, 1251–1264. [CrossRef] [PubMed]
2. Pogačar, T.; Žnidaršič, Z.; Kajfež Bogataj, L.; Flouris, A.D.; Poulianiti, K.; Črepinšek, Z. Heat Waves Occurrence and Outdoor Workers' Self-Assessment of Heat Stress in Slovenia and Greece. *Int. J. Environ. Res. Public Health* **2019**, *16*, 597. [CrossRef] [PubMed]
3. Oudin Åström, D.; Schifano, P.; Asta, F.; Lallo, A.; Michelozzi, P.; Rocklöv, J.; Forsberg, B. The Effect of Heat Waves on Mortality in Susceptible Groups: A Cohort Study of a Mediterranean and a Northern European City. *Environ. Health* **2015**, *14*, 30. [CrossRef] [PubMed]
4. El Khayat, M.; Halwani, D.A.; Hneiny, L.; Alameddine, I.; Haidar, M.A.; Habib, R.R. Impacts of Climate Change and Heat Stress on Farmworkers' Health: A Scoping Review. *Front. Public Health* **2022**, *10*, 782811. [CrossRef]
5. Pogačar, T.; Črepinšek, Z.; Bogataj, L.K.; Nybo, L. Comprehension of Climatic and Occupational Heat Stress amongst Agricultural Advisers and Workers in Slovenia. *Acta Agric. Slov.* **2017**, *109*, 545–554. [CrossRef]
6. Pogačar, T.; Bogataj, L.K.; Črepinšek, Z. Heat waves analysis and the heat load of agricultural workers during the heat waves in 2017 (using index WBGT). *Acta Agric. Slov.* **2018**, *111*, 647–659. [CrossRef]
7. Blazejczyk, K.; Jendritzky, G.; Bröde, P.; Fiala, D.; Havenith, G.; Epstein, Y.; Psikuta, A.; Kampmann, B. An Introduction to the Universal Thermal Climate Index (UTCI). *Geogr. Pol.* **2013**, *86*, 5–10. [CrossRef]
8. Zare, S.; Hasheminejad, N.; Shirvan, H.E.; Hemmatjo, R.; Sarebanzadeh, K.; Ahmadi, S. Comparing Universal Thermal Climate Index (UTCI) with Selected Thermal Indices/Environmental Parameters during 12 Months of the Year. *Weather. Clim. Extrem.* **2018**, *19*, 49–57. [CrossRef]
9. De Freitas, C.R.; Grigorieva, E.A. A Comparison and Appraisal of a Comprehensive Range of Human Thermal Climate Indices. *Int. J. Biometeorol.* **2017**, *61*, 487–512. [CrossRef]
10. Ioannou, L.G.; Mantzios, K.; Tsoutsoubi, L.; Notley, S.R.; Dinas, P.C.; Brearley, M.; Epstein, Y.; Havenith, G.; Sawka, M.N.; Bröde, P.; et al. Indicators to assess physiological heat strain—Part 1: Systematic review. *Temperature* **2022**, *9*, 227–262. [CrossRef]
11. de Freitas, C.R.; Grigorieva, E.A. A comprehensive catalogue and classification of human thermal climate indices. *Int. J. Biometeorol.* **2015**, *59*, 109–120. [CrossRef] [PubMed]
12. Fiala, D.; Havenith, G.; Bröde, P.; Kampmann, B.; Jendritzky, G. UTCI-Fiala Multi-Node Model of Human Heat Transfer and Temperature Regulation. *Int. J. Biometeorol.* **2012**, *56*, 429–441. [CrossRef] [PubMed]
13. Climate-ADAPT. Indicators: Thermal Comfort Indices-Universal Thermal Climate Index, 1979–2020. Available online: https://climate-adapt.eea.europa.eu/#t-database (accessed on 9 May 2022).
14. Gosling, S.N.; Bryce, E.K.; Dixon, P.G.; Gabriel, K.; Gosling, E.Y.; Hanes, J.M.; Hondula, D.M.; Liang, L.; Mac Lean, P.A.B.; Muthers, S.; et al. A glossary for biometeorology. *Int. J. Biometeorol.* **2014**, *58*, 277–308. [CrossRef] [PubMed]
15. Błażejczyk, K. UTCI—10 Years of Applications. *Int. J. Biometeorol.* **2021**, *65*, 1461–1462. [CrossRef]
16. Jendritzky, G.; Bröde, P.; Fiala, D.; Havenith, G.; Weihs, P.; Batchvarova, E.; de Dear, R. Universal Thermal Climate Index UTCI. In Proceedings of the 7th Conference on Biometeorology, Freiburg, Germany, 12–14 April 2010; Matzarakis, A., Mayer, H., Chmielewski, F.M., Eds.; Albert-Ludwigs-University of Freiburg: Freiburg, Germany, 2010; pp. 184–188.

17. Levy, B.; Roelofs, C. Impacts of Climate Change on Workers' Health and safety. Oxford Research Encyclopedia of Global Public health. Available online: https://oxfordre.com/publichealth/display/10.1093/acrefore/9780190632366.001.0001/acrefore-9780190632366-e-39;jsessionid=72FC7F26D49158BCF75B00D89D787CC6 (accessed on 11 January 2023). [CrossRef]
18. ILO (International Labour Office/Organization). *World Employment and Social Outlook*; ILO: Trends, Geneva, 2018.
19. ILO (International Labour Office/Organization). *Guidelines on Occupational Safety and Health Management Systems, Safety and Health in Agriculture Convention*; ILO-OSH 2001; ILO: Trends, Geneva, 2001.
20. Tigchelaar, M.; Battisti, D.S.; Spector, J.T. Work Adaptations Insufficient to Address Growing Heat Risk for U.S. Agricultural Workers. *Environ. Res. Lett.* **2020**, *15*, 094035. [CrossRef]
21. Błażejczyk, K.; Baranowski, J.; Jendritzky, G.; Błażejczyk, A.; Bröde, P.; Fiala, D. Regional features of the bioclimate of Central and Southern Europe against the background of the Köppen-Geiger climate classification. *Geogr. Pol.* **2015**, *88*, 439–453. [CrossRef]
22. Ioannou, L.G.; Foster, J.; Morris, N.B.; Piil, J.F.; Havenith, G.; Mekjavic, I.B.; Kenny, G.P.; Nybo, L.; Flouris, A.D. Occupational Heat Strain in Outdoor Workers: A Comprehensive Review and Meta-Analysis. *Temperature* **2022**, *9*, 67–102. [CrossRef]
23. Blazejczyk, K.; Twardosz, R. Long-Term Changes of Bioclimatic Conditions in Cracow (Poland). In *The Polish Climate in the European Context: An Historical Overview*; Przybylak, E., Ed.; Springer: Dordrecht, The Netherlands, 2010; Chapter 10; pp. 235–246. [CrossRef]
24. Poulianiti, K.P.; Havenith, G.; Flouris, A.D. Metabolic Energy Cost of Workers in Agriculture, Construction, Manufacturing, Tourism, and Transportation Industries. *Ind. Health* **2019**, *57*, 283–305. [CrossRef]
25. Kjellström, T.; Maître, N.; Saget, C.; Otto, M.; Karimova, T. *International Labour Organization, Research Department. Working on a Warmer Planet: The Impact of Heat Stress on Labour Productivity and Decent Work*, 1st ed.; International labour Office: Geneva, Switzerland, 2019; 103p.
26. Cegnar, T.; Matzarakis, A. *Trends of thermal bioclimate and their applications for tourism in Slovenia In Advances in tourism climatology, Matzarakis, A., De Freitas, C.R., Scott, D., Eds.*; Berichte Des Meteorologischen Institutes der Universität Freiburg: Freiburg, Germany, 2004; pp. 66–73.
27. Zaninović, K.; Matzarakis, A.; Cegnar, T. Thermal Comfort Trends and Variability in the Croatian and Slovenian Mountains. *Meteorol. Z.* **2006**, *15*, 243–251. [CrossRef]
28. Ključevšek, N. *Pregled Kazalcev za Spremljanje Vročine*; Znanstveni Posvet o Vročinskih Valovih: Ljubljana, Vetrnica, 2017; pp. 14–28.
29. Komac, B.; Ciglič, R.; Pavšek, M.; Kokalj, Ž. 2017. Naravne Nesreče v Mestih—Primer Mestnega Toplotnega Otoka. In *Trajnostni Razvoj MEST in naravne Nesreče, Zorn, M.*; Komac, B., Ciglič, R., Tičar, J., Eds.; Geografski inštitut Antona Melika ZRC SAZU: Ljubljana, Slovenia, 2017; pp. 51–68.
30. Błażejczyk, K.; Błażejczyk, A. *Assessment of Bioclimatic Variability on Regional and Local Scales in Central Europe Using UTCI*; Scientific annals of "Alexandru Ioan Cuza", University of IAŞI Geography: Iași, Romania, 2014; pp. 67–82.
31. Di Napoli, C.; Pappenberger, F.; Cloke, H.L. Assessing Heat-Related Health Risk in Europe via the Universal Thermal Climate Index (UTCI). *Int. J. Biometeorol.* **2018**, *62*, 1155–1165. [CrossRef]
32. Kozjek, K.; Dolinar, M.; Skok, G. Objective Climate Classification of Slovenia. *Int. J. Climatol.* **2017**, *37*, 848–860. [CrossRef]
33. Vertačnik, G.; Bertalanič, R.; Draksler, A.; Dolinar, M.; Vlahović, Ž.; Frantar, P. *Climate Change and Variability in Slovenia in the Period 1961–2011: Summary*; Ministry of the Environment and Spatial Planning, Slovenian Environment Agency: Ljubljana, Slovenia, 2018; 23p.
34. ARSO—Slovenian Environment Agency. *Ocena Podnebnih Sprememb v Sloveniji do Konca 21*; Stoletja, S.P., Dolinar, M., Eds.; ARSO: Ljubljana, Slovenia, 2018; 156p.
35. ARSO—Slovenian Environment Agency, Data Archive. Available online: http://meteo.arso.gov.si/met/sl/archive/ (accessed on 20 April 2022).
36. Błażejczyk, K. BioKlima—Universal Tool for Bioclimatic and Thermophysiological Studies. Available online: https://www.igipz.pan.pl/Bioklima-zgik.html (accessed on 4 May 2022).
37. BioKlima 2.6 software package. Available online: https://www.igipz.pan.pl/bioklima-crd.html (accessed on 29 August 2022).
38. Blazejczyk, K.; Epstein, Y.; Jendritzky, G.; Staiger, H.; Tinz, B. Comparison of UTCI to Selected Thermal Indices. *Int. J. Biometeorol.* **2012**, *56*, 515–535. [CrossRef] [PubMed]
39. Błażejczyk, K.; Bröde, P.; Fiala, D.; Havenith, G.; Holmér, I.; Jendritzky, G.; Kampmann, B.; Kunert, A. Principles of the New Universal Thermal Climate Index (UTCI) and Its Application to Bioclimatic Research in European Scale. *Misc. Geogr.* **2010**, *14*, 91–102. [CrossRef]
40. Statistical Regions in the European Union and Partner Countries—NUTS and Statistical Regions 2021. Available online: https://ec.europa.eu/eurostat/web/products-manuals-and-guidelines/-/ks-gq-20-092 (accessed on 4 May 2022).
41. Błazejczyk, K. New climatological and physiological model of the Human Heat Balance outdoor (MENEX) and its applications in bioclimatological studies in different scales. *Zesz. Inst. Geogr. I Przestrz. Zagospod. PAN* **1994**, *28*, 27–58.
42. ISO, International Organization for Standardization. Ergonomics of the Thermal Environment—Determination of Metabolic Rate. (ISO Standard No. 8996). Available online: https://www.iso.org/standard/74443.html (accessed on 4 May 2022).
43. OSHA, Occupational Safety and Health Administration, United States Department of Labor. Metabolic Heat and Workload (Physical Activity Level). Available online: https://www.osha.gov/heat-exposure/hazards (accessed on 4 May 2022).

44. Messeri, A.; Morabito, M.; Bonafede, M.; Bugani, M.; Levi, M.; Baldasseroni, A.; Binazzi, A.; Gozzini, B.; Orlandini, S.; Nybo, L.; et al. Heat Stress Perception among Native and Migrant Workers in Italian Industries—Case Studies from the Construction and Agricultural Sectors. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1090. [CrossRef]
45. Pecelj, M.M.; Lukić, M.Z.; Filipović, D.J.; Protić, B.M.; Bogdanović, U.M. Analysis of the Universal Thermal Climate Index during Heat Waves in Serbia. *Nat. Hazards Earth Syst. Sci.* **2020**, *20*, 2021–2036. [CrossRef]
46. Błażejczyk, K.; Kazandjiev, V.; Degórski, M.; Dimitrov, P. Assessment of Occupational Heat Stress Risk among Agriculture Workers in Poland and Bulgaria. *Eur. XXI* **2015**, *29*, 59–72. [CrossRef]
47. Pogačar, T.; Žnidaršič, Z.; Kajfež Bogataj, L.; Črepinšek, Z. Steps Towards Comprehensive Heat Communication in the Frame of a Heat Health Warning System in Slovenia. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5829. [CrossRef]
48. Spector, J.T.; Krenz, J.; Calkins, M.; Ryan, D.; Carmona, J.; Pan, M.; Zemke, A.; Sampson, P.D. Associations between Heat Exposure, Vigilance, and Balance Performance in Summer Tree Fruit Harvesters. *Appl. Ergon.* **2018**, *67*, 1–8. [CrossRef]
49. Parsons, L.A.; Shindell, D.; Tigchelaar, M.; Zhang, Y.; Spector, J.T. Increased Labor Losses and Decreased Adaptation Potential in a Warmer World. *Nat. Commun.* **2021**, *12*, 7286. [CrossRef]
50. Pal, G.; Patel, T.; Banik, T. Effect of Climate Change Associated Hazards on Agricultural Workers and Approaches for assessing Heat Stress and Its mitigation Strategies—Review of some Research Significances. *Int. J. Curr. Microbiol. App. Sci.* **2021**, *10*, 2947–2975.
51. Saeed, F.; Schleussner, C.F.; Ashfaq, M. Deadly heat stress to become commonplace across South Asia already at 1.5 C of global warming. *Geophys. Res. Lett.* **2021**, *48*, e2020GL091191. [CrossRef]

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