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Exploring the Association of Heat Stress and Human Health in Cyprus †

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Abstract: High temperatures during the summer months are a common feature in countries with a Mediterranean climate, such as Cyprus and Greece. However, anthropogenic climate change is responsible for the increase in the frequency, intensity and duration of extreme high temperatures in the wider Eastern Mediterranean region, especially since 1990. At the same time, future climate projections show that high temperatures and heatwaves that were observed at the beginning of the 21st century and characterized as extreme will become the norm in the coming years. This study confirms the increasing trend in maximum and minimum temperature for the last four decades in Cyprus. Bioclimatic indices provide a measure of human thermal discomfort caused by the thermal environment. In the present study, the UTCI index from the dataset ERA5-HEAT was used to estimate the heat stress of the average person under conditions of heat events. The spatial distribution of maximum monthly $UTCI_{daily}$ values was carried out for the period 2004–2019. At the same time, the correlation of patient admissions to hospitals, as well as the relationship of mortality with high $UTCI_{daily}$ values, was assessed. Mortality data and data from eight public hospitals located in five districts of Cyprus were analyzed as obtained from the Ministry of Health and the Cyprus Statistical Service. The data reveal that $UTCI_{daily}$ values were positively associated with hospital admissions and mortality in some cases.

Keywords: climate change; high temperatures; UTCI; thermal stress; public health; mortality; hospital admissions; Cyprus

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1. Introduction

Climate change poses a significant threat to life on our planet, including both ecosystems and human civilization. The evidence of this has grown more robust since the initial Intergovernmental Panel on Climate Change (IPCC) reports an observable increase in frequency, intensity, and duration of extreme events in most continental regions in the recent decades [1,2]. It is widely known that, compared to the large-scale climate behavior, the Mediterranean region is a climate-change hotspot due to intensive warming and drying [3]. High temperatures can lead to a variety of health outcomes, ranging from discomfort and severe illnesses that require hospitalization (as dehydration, heat exhaustion, heat syncope and heat stroke) to mortality [1]. According to the World Health Organization (WHO), extended periods of high temperatures are among the most dangerous natural hazards and can cause significant societal impacts, including an increase in heat–related fatalities. Between 1998 and 2017, over 166,000 individuals lost their lives due to heatwaves, with more than 70,000 loses during the 2003 heatwave in Europe and 56,000 Russians in 2010 [4,5].

Cyprus is an island located in the eastern Mediterranean, characterized by a warm climate that falls within the Mediterranean climate (Csa) and Mid-latitude steppe and desert climate (BSh) categories in the Koppen–Geiger Climate Classification [6]. Studying the historical data in Cyprus, there is an increasing trend in temperature over the last 40 years. Specifically, the annual mean temperature in Nicosia for the period 1960–1991 was 19.5 °C, while for the period 1992–2004, it was 20.3 °C, which is an increase of 0.77 °C. At the same time, future scenarios project a warming in the range 1.5–2.0 °C for the 30-year period of 2031–2061 and a warming of up to 4 °C for the 30-year period of 2071–2100 [7].

To assess the impact of air temperature on human beings in a thermophysiologically meaningful and useful way, more than 100 indices were developed over the past century, such as Heat Index (HI), Physiologically Equivalent Temperature (PET), wet-bulb globe temperature (WBGT) and others. In the present study, the Universal Thermal Climate Index (UTCI) was used, as it presents the best biothermal conditions for human beings compared to other indices [8]. UTCI is defined as an equivalent temperature (°C) of a reference environment and represents the physiological response of the human body in the actual environment [8–10].

Recent studies examined the relationship between UTCI and morbidity/mortality. In Bavaria, they confirmed that admissions to hospitals, mortality and even road accidents were associated with UTCI changes [11]. In Paris, France, the mortality peak was highly correlated to the UTCI category "very strong heat stress" during the 2003 European heatwave [12]. In Cyprus, only a few studies have examined weather-related health impacts, focusing on mortality for the period 2004–2009 [13,14]. Pantavou et al. [15] used the UTCI index to examine the impact of thermal conditions on the daily number of hospital admissions for the 2009–2018 period [15]. This study set out to determine bioclimatic conditions during extreme temperature events and their relationship to hospital admissions and mortality for Cyprus.

2. Materials and Methods

2.1. Meteorological Data

Gridded observational datasets (CY-OBS) [16,17] were extracted by a comprehensive network of meteorological stations with an exceptionally high-spatial resolution of 1×1 km, which takes into account various topographical parameters, including elevation, slope, orientation, etc. To assess the observed climate trends of seasonal maximum and minimum temperature, we applied K-means Clustering [18] to summarize the results for regions sharing similar geographical and climate characteristics.

2.2. Mortality and Hospital Data

Mortality data were provided by the Health Monitoring Unit from Ministry of Health of the Republic of Cyprus [19]. The data include information on date of death, sex, age, place of death (hospital, home, road etc.), and IDC10 description for the diagnosis of death, according to the International Statistical Classification of Diseases and Related Health Problems (ICD—10th Revision) [20,21]. Hospital data were provided by the Statistical Service of the Republic of Cyprus [22], derived from eight General and Rural Hospitals of the State and includes information on admission and discharge date, sex, age and the main diagnosis of patients according to the ICD10 code. All data refer to the period from 1 January 2004 to 31 December 2019. Both mortality and hospital health data covers all types of diseases but, for the purpose of our work, only diseases of the circulatory and respiratory system were used (J00–J99, I00–I99, respectively), due to the fact that these type of diseases are among the most common medical conditions more likely to be affected by the extreme temperatures of heatwaves [23].

2.3. Universal Thermal Climate Index—UTCI

UTCI is commonly used to describe how the human body experiences atmospheric conditions. The calculation of UTCI is based on the multi-node 'Fiala' model: a dynamic

mathematical thermoregulation model which is coupled with a clothing model. Its value depends on the actual values of air temperature (Ta), mean radiant temperature (Tmrt), wind speed (Va) and humidity, expressed either as water vapor pressure (vp) or relative humidity (RH) [8–10]. The values of UTCI were extracted from the European Environment Agency dataset ERA5-HEAT (Human thermal comfort), which is the first global historical dataset of two human biometeorology indices (MRT and UTCI), and computed via variables from ERA5 European Center for Medium-Range Weather Forecasts (ECMWF). The dataset covers from January 1940 and close to the present time, and provides hourly values at 0.25° × 0.25° resolution [24,25]. The data were processed by CDO (Climate Data Operators) and R Project for Statistical Computing (Version 4.2.1) [26] to convert hourly to daily values of UTCI.

3. Results

3.1. Evolution of Summer Temperature (1981–2018)

According to K-means clustering analysis, due to their significant influence from elevation, the climate characteristics of the island are divided into five classes (Figure 1—left panel) with the climatic pattern presenting many similarities to the topographic map. The results of the trend seasonal analysis reveal that Cyprus presents a gradual increase in the summer maximum and minimum temperatures for the period 1981 to 2018, which is in agreement with global and regional warming patterns. As shown in Figure 1 (right panel), these increasing trends are visible in all classes.

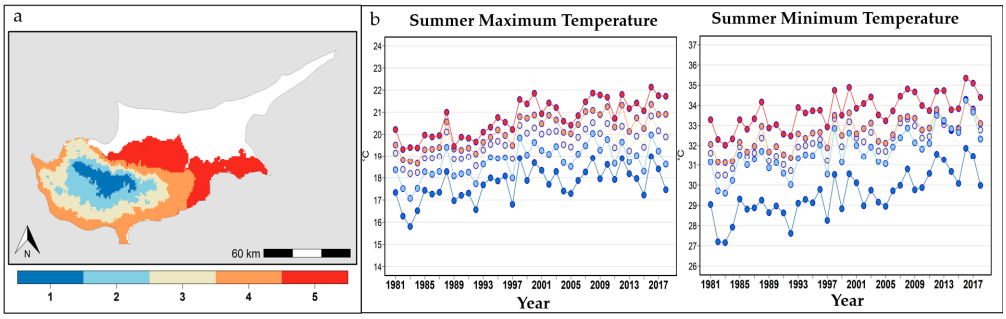

Figure 1. (**a**) K-means cluster analysis for Cyprus (**b**) Seasonal time—series of maximum and minimum temperature for the period 1981–2018 of each cluster.

3.2. Thermal Stress, Mortality and Hospital Admissions

$UTCI_{daily}$ was used to examine the spatial variability of thermal comfort of humans for a better representation of biothermal conditions. Figure 2 shows the spatial distribution of mean maximum monthly values of $UTCI_{daily}$ for the period 2004 to 2019. A center with high values of $UTCI_{daily}$ is observed in the middle of the island, near Nicosia, the capital of Cyprus. It is probably related to the Urban Heat Island (UHI), specific climatic conditions that prevail in a large metropolitan area. The highest $UTCI_{daily}$ values, corresponding to category "Strong Heat Stress", are recorded in August, followed by July, September and June. May is mostly on the "Moderate Heat Stress" category and April is characterized with "No thermal stress" (Figure 2).

The number of days corresponding to the "strong heat stress" category per month and per year were estimated. Months presenting the number of "strong heat stress" days that were higher than 20 were selected (Table 1). Moreover, for June, the selection threshold was defined to 4 days. Then, the correlation between the maximum values of $UTCI_{daily}$ with mortality and admissions were estimated and divided in a period of ten days per month, as shown in Table 1. The highest positive correlation between UTCI and admissions (0.76) was found in the first ten-day period of August 2014, while the highest positive correlation between UTCI and mortality (0.68) was found in the second ten-day period of July 2017. Notably, the correlation between the UTCI and deaths or admissions in June is quite high compared to the other warm months.

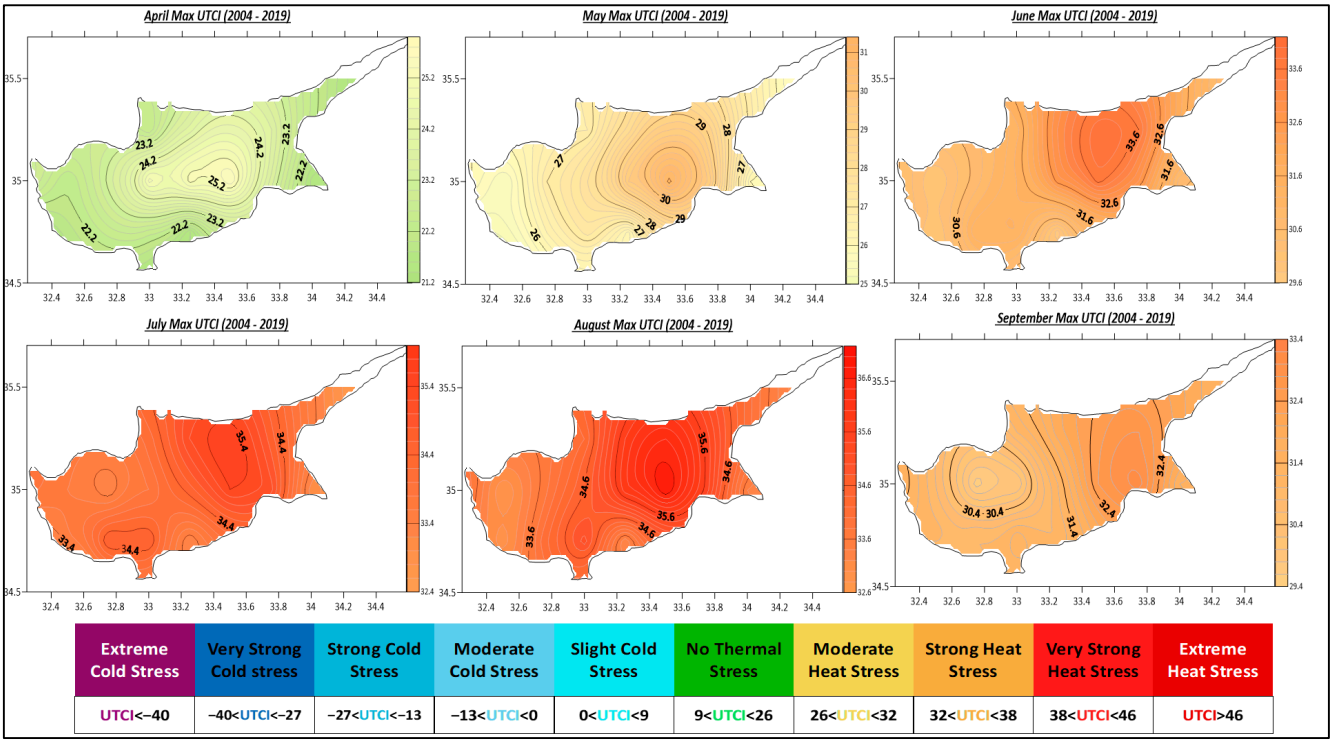

Figure 2. Average maximum values of $UTCI_{daily}$ (April–September) for period 2004–2019. Maps have the same color scale corresponding to the official UTCI classification scale expressed in Celsius (°C).

Table 1. Months with highest number of days per month with "strong heat stress" and "moderate heat stress" and the correlation between maximum $UTCI_{daily}$ with mortality and admissions. For the correlation results, each month is divided into a ten day period. Correlations greater that 0.4 are highlighted in red.

Year	Month	Moderate Heat Stress (No of Days)	Strong Heat Stress (No of Days)	Period (10 Days)	Correlation	
					Mortality—$UTCI_{daily}$	Admissions—$UTCI_{daily}$
2010	August	3	28	1st	0.22	0.15
				2nd	0.04	−0.12
				3rd	−0.12	−0.44
2014	August	8	23	1st	0.19	0.76
				2nd	0.00	−0.51
				3rd	0.32	−0.38
2016	July	10	21	1st	0.22	−0.25
				2nd	−0.03	−0.28
				3rd	0.06	−0.17
2017	July	11	20	1st	0.19	0.20
				2nd	0.68	−0.65
				3rd	−0.38	0.71
2016	June	20	6	1st	−0.19	−0.45
				2nd	0.43	−0.19
				3rd	−0.04	−0.45
2007	June	18	4	1st	−0.02	0.32
				2nd	−0.12	−0.31
				3rd	0.54	0.48

4. Conclusions

Heat exposure poses a significant risk on human health, especially when considering the effects of climate change. This study confirms the increasing trend in maximum and minimum temperature for the last four decades in Cyprus. Studying the spatial distribution of $UTCI_{daily}$ maximum values, a clear center of high values is observed in Nicosia, the capital, and the most populated city of the island. The main goal of this study was to focus on the impacts of the increasing high temperature on human health by studying the correlations of $UTCI_{daily}$ with mortality and admissions data. The results show that there is a certain positive correlation of UTCI with mortality and admissions, depending on the month and the years. However, there is a lot of noise in the results, which motivates us to use more sophisticated statistical methods of analysis in future work in order to obtain better, useful and more meaningful results. This will help the state and those responsible for better preparation in any given situation.

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