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DOCTORAL THESIS

Climate changes detected in biometeorological and tourism-climate indices in large cities of Romania

~ Summary ~

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INTRODUCTION

Climate change is a major global issue, affecting health, tourism and economy (Banc et al., 2020), therefore being prioritised in national and regional policy documents. international policy strategies (UN, 2015; National Strategy for the Sustainable Development of Romania 2030, 2018; European Environmental Pact, 2019; New EU Strategy on Adaptation to Climate Change, 2021; Sustainable Development of Romania in the European Context - CCSD, 2023)..

Rising global average temperatures lead to more frequent and intense extreme events (CCSD, 2023; Scripcă, 2023; Council of the European Union, 2021; Croitoru et al., 2016), affecting natural systems and human society, including the economic sector and tourism (IPCC, 2023), influencing tourism demand and seasonality and having implications for the competitiveness of destinations and the profitability of the tourism industry (Matei et al., 2023).

Adaptation of society to these changes is therefore essential to mitigate negative impacts or to harness potential climate benefits (Croitoru et al., 2024; de Freitas, 2009). In this sense, biometeorological indices represent one of the most realistic and objective ways of assessing thermal stress and comfort, providing a more complete and reliable picture of climate change at the individual level (Fröhlich & Matzarakis, 2018; Banc et al., 2020).

The paper analyses biometeorological data from 1961-2021 period, for ten large cities in Romania, observing changes in the duration (DOP), frequency (FO), first (PZ) and last day (UZ) of occurrence of thermal comfort classes, highlighting optimal periods for tourism according to the ETCI climate-tourism index and providing insights into the evolution of future bioclimatic conditions by modelling the HCI index.

I. STATE OF THE ART

1.1 International research on biometeorological and climate-tourism indices

This study is among the few in Romania that combines biometeorology with climate change, analysing the interactions between people and the environment in the 10 largest cities in the country over a 60-year period (1961-2021).

Over the last 25-30 years, numerous studies have investigated how thermal (dis)comfort influences human behaviour, with most of the research conducted for urban areas (Radinović & Ćurić, 2012; Lindner-Cendrowska, 2018; Ichim & Sfîcă, 2020; Scripcă et al., 2022).

Using biometeorological and climate-tourism indices, the study provides a realistic and objective assessment of heat stress and perception (Fröhlich & Matzarakis, 2018), highlighting the importance of these indices in describing weather effects on people and understanding the impact of climate on individual thermal comfort (Banc et al., 2020).

1.2 National research on biometeorological and climate-tourism indices

Most studies in Romania on bioclimatology have focused on theoretical aspects (Croitoru & Sorocovschi, 2012; Ionac & Ciulache, 2008; Teodoreanu, 2002, 2013; Ionac, 1998) and recently a large study has been carried out on the five largest urban areas, analysing the impact of heat stress on human health (Scripcă, 2023). Additional research has integrated biometeorological indices, most of which have considered only specific regions of the country (Banc et al., 2020; Ichim & Sfîcă, 2020; Velea et al., 2019, 2022, 2023; Sfîcă et al., 2018; Maftei & Buta, 2017).

TCI, developed by Mieczkowski in 1985, assesses climatic comfort for outdoor tourism activities (Perch-Nielsen et al., 2010), using five weather variables and providing a numerical score, and is considered the most widely used tool for quantifying climate friendliness in the context of tourism (Croitoru et al., 2024; Croitoru et al., 2022; Noome & Fitchett, 2022; Scott et al., 2016). However, TCI has limitations, including subjectivity of assessment and low temporal resolution of climate data.

To address these shortcomings, the Holiday Climate Index (HCI) has been developed, which provides a more detailed assessment of the climate friendliness of tourist destinations, including coastal and urban tourism (Matei et al., 2023; Scott et al., 2016), the latter being used in this paper. Although the TCI was not originally developed to assess the impact of climate change on the thermal comfort of tourists, subsequent studies suggest its usefulness for this purpose as well (Amelung et al., 2007; Scott & McBoyle, 2001). The HCI has demonstrated superior performance to the TCI in various regions, including the Caribbean and China, showing a stronger correlation between climate friendliness and tourist arrivals (Rutty et al., 2020; Yu et al., 2021) And has been used to develop climate services to improve local tourism prediction and management (Matthews et al., 2021). In Europe and Romania, HCI has provided more accurate assessments and highlighted an increase in days suitable for outdoor activities in the future (Velea et al., 2022, 2023). Recently, a software module has also been developed, in R, to help identify optimal holiday periods, highlighting climate variability and its impact on tourism planning (Magyari-Sáska & Attila, 2023).

1.3 Research on climate change

Studies on climate change reflected in bioclimatic indices, although limited, show significant changes with impacts on human comfort and health. In Romania, a reduction in cold discomfort and an increase in comfortable conditions and warm discomfort have been observed (Banc et al., 2020). In the Mediterranean area, the Thom Discomfort Index (TDI) indicates an increase in thermal discomfort in August and September due to increased temperatures and humidity (Monforte & Ragusa, 2022).

The main findings of IPCC reports, including WGII AR5 and the Special Report on Global Warming by 1.5°C, have highlighted the impact of warming and variations in precipitation on Europe, particularly in southern Europe and mountain areas (Kovats et al., 2014). Climate change negatively affects urban quality of life, in particular through heat waves that intensify urban heat islands (UHIs), increase water and energy consumption and increase pollution (Antonescu et al., 2023). Adapting to these changes includes general and specific measures such as educating the population, conserving natural resources and expanding green spaces (Banc et al., 2020). Climate change is extending the summer season in Romania, favouring coastal tourism, although long-term sustainability is uncertain due to the potential discomfort caused by very high temperatures. (Dumitrescu et al., 2021).

II. DATA AND METHODS

2.1 Study area

The choice of the 10 cities (Botoșani, Bucharest, Cluj-Napoca, Constanța, Craiova, Galați, Iași, Oradea, Sibiu, Timișoara) had in mind both to ensure a good spatial coverage of the entire national territory, being chosen at least one representative city for each region of the country, and the choice of municipalities with a population of about 100 000 inhabitants or more (according to *INS, Population and Housing Census 2021, provisional data*). Also, due to the fact that these weather stations are located within the built perimeter of each city, we consider them sufficiently representative to describe the meteorological conditions in urban areas with low-rise buildings.

2.2 Weather and climate data

Historical daily and hourly climate datasets for a period of 61 years (1961-2021) were considered for all weather stations included. The meteorological parameters on which the indices were calculated are: mean daily temperature *(T,* °C), maximum daily temperature *(TX,* °C), mean (*RH, %*) and maximum relative humidity *(RHmax,* %), daily precipitation amount *(RR,* mm), sunshine duration (*SS,* h), and wind speed at 10 m (v_{10}) (km/h). The main dataset (1961-2016) was provided by the National Meteorological Administration (ANM) and the online sources ECA&D, Meteomanz and Reliable prognosis 5.

2.3 HCI climate projections

They were taken from Copernicus (C3S), the European Commission's database, for both the historical period 1986-2005 and the future periods 2021-2040, 2041-2060, 2061-2100, based on the RCP 8.5 scenario, with a spatial resolution of 12.5 km (0.11°). From here, the already calculated monthly and decadal mean values of this index were downloaded, as well as the number of days with *good*, *acceptable* and *unfavourable* conditions at decadal and monthly level.

2.4 Calculation of bioclimatic indices

The following biometeorological indices were considered: Equivalent Temperature (TeK), Effective Temperature (TE), Cooling Power (H), Universal Thermo-Climate Index (UTCI), Temperature Humidity Index (TIU), which were calculated for the period 1961-2016 for each city. Both for the calculation of the indices mentioned here and for their parameters, BioKlima 2.6 software, freely available (https://www.igipz.pan.pl/bioklima-crd.html, Scripca, 2023For each index was calculated: *frequency of production (FO)*, *DOP (duration of production interval)*, respectively *first/last day of production (PZ, UZ) for* highlighting the possible range of thermal comfort/discomfort in a year and identifying any change during the analyzed period. The trend was also calculated using the Mann-Kendall test (Kendall, 1975; Mann, 1945).

2.5 Calculation of climate-tourism indices - ETCI

Taking into account the limitations of the original TCI formula and the adjustments proposed in the literature, the improved version of this index (ETCI) has been used in this study, which implies the following modifications: (i) calculation at daily level, being later integrated at decadal level; (ii) use of maximum and average *TE* instead of diurnal and daily thermal comfort indices (CId and CIa); (iii) days with heavy (10 mm) and very heavy (20 mm) precipitation were given a lower score in the precipitation reclassification data. The weight of variables or indices in the final calculation formula was maintained as in the original version of the TCI calculation.

2.6 Calculation of climate-tourism indices - HCI:Urban

It is designed to be specific to major tourism segments and destination types. This index is based on objective methods, empirically validated in the tourism market and based on tourists' climate preferences. The HCI includes all three aspects of climate that are important for leisure tourism activities: *thermal comfort* (TC), *weather aesthetics* (A) (cloudiness - %) and *physical aspect*, given by the combination of precipitation (R - mm) and wind speed (F - km/h).

III. RESULTS AND DISCUSSIONS

3.1 Equivalent Temperature (TeK)

The FO indicates the predominance of days with *cold* discomfort in the cities of Botoșani and Sibiu (almost 150 days annually) and between 120 and 130 days in Craiova, Galați and Oradea. *Comfortable* days vary between 50 and 100 days, with the minimum in Galați and the maximum in Craiova. *Slightly sultry* days are slightly above 50/year, and *slightly cool, cool* and *sultry* days are below 50 days/year, with the *sultry* class having the fewest days (below 20/year) *(Fig. 1)*.

Fig. 1. FO and DOP for TeK index (in number of days)

The DOP shows that days with *mildly cool* and *cool* heat stress predominate, with about 250 and more than 200 days/year respectively. *Cool* and *comfortable* classes have between 150 and 200 days, and the *slightly sultry* class less than 100 days in Sibiu and a little over 100 in Botosani, respectively between 120 and 130 days in Craiova, Galati and Oradea. The DOP values are higher in the extra-Carpathian stations, especially in the lowland areas, and lower in the centre of the country (Sibiu) (*Fig. 1)*.

Decreases in the number of days (*FO*) characterized as *cold* and *comfortable and* in the length of the production interval (*DOP*) of *cold* and *cool* days are shown, at the expense of increases in both the number of days and the length of the production period during the year of days characterized as hot discomfort. In terms of *comfort* class, there is an increase in *DOP* but a decrease in *FO, which* means that *comfortable* days occur earlier in spring and later in autumn during the year, but at the same time their frequency is lower.

Analysis of Sen slope values for FO shows a significant decrease in days with *cold* and *comfortable* stress conditions. In Craiova, Galati and Oradea, *cold* days decrease by more than 2.5 days/decade and *comfortable* days decrease by more than 3 days/decade in Botoșani and more than 2.3 days/decade in Craiova and Oradea. These decreases translate into a net reduction of almost 2 weeks for *cold* days and more than half a month for *comfortable* days in Botoșani. The decreases are compensated by increases in *hot* days. *Slightly sultry* days increase by 2.3 days/decade in Botoșani, 2.7 days/decade in Oradea and 3.2 days/decade in Sibiu. *Suffocating* days increase more modestly: 1.1 days/decade in Botoșani, 1.6 days/decade in Galați and 1.4 days/decade in Oradea, i.e. almost one week for the whole period analysed. For the DOP, only three statistically significant trends are identified: a decrease of 4.1 days/decade in Botoșani for the *slightly cool* class and two increases of about 4 days/decade for the *sultry* class in Botoșani and Oradea *(Table 1)*.

Table 1. Sen slope values of TeK index trends, expressed in days/decade

Parameter	Comfort class	Botoșani	Craiova	Galati	Oradea	Sibiu
FO	Rece	-1,818	**-2,500**	**-2,857**	**-2,857**	-1,224
	Cool	0,80	0,91	1,38	1,33	0,91
	Slightly cool	0	0,351	0,909	0,000	-0,854
	Comfortable	**-3,333**	**-2,390**	-1,667	**-2,444**	-1,250
	Slightly suffocating	**2,279**	2,000	1,319	**2,739**	**3,239**
	Suffocating	**1,111**	1,357	**1,625**	**1,429**	0,000
DOP	Rece	-1,071	-2,703	-1,111	-2,000	-2,800
	Cool	-3,077	-0,909	-2,778	-4,054	-1,667
	Slightly cool	1,547	1,357	**-4,138**	5,872	2,339
	Comfortable	1,355	1,481	0,000	1,875	2,222
	Slightly suffocating	0	1,277	0,000	2,000	2,819
	Suffocating	**4,0**	2,6	3,3	**4,4**	0,0

* values written aldin have statistical significance.

3.2 Effective Temperature (TE)

The analysis for the TE index shows that FO is highest for the *very cold* and *cold* discomfort classes, with almost 150 days annually for *very cold* discomfort and just over 100 days for *cold* discomfort. Days with *cold* thermal discomfort range between 50 and 100, with the maximum in Sibiu, and *slightly cool days* approaching 50 days/year. The *comfortable* and *warm* classes have the lowest values, below 20 and 10 days/year respectively *(Fig. 2)*.

The DOP shows the presence of *cold* conditions throughout the year, with almost 300 days/year in Galati and more than that in the other cases. Days with *very cold* and *cold* discomfort have a DOP close to 200 days/year. For the *comfortable* class, the DOP is about 50 days at the stations in the lowland areas (Craiova, Galati and Oradea) and less than 30 days for the *warm* class *(Fig. 2).*

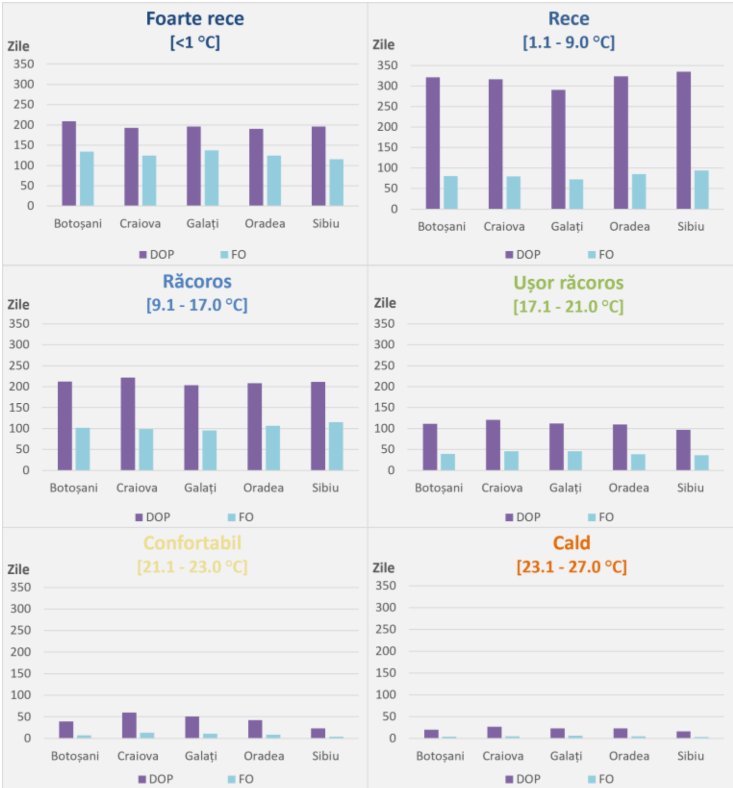

Fig. 2. FO and DOP for TE index (in number of days)

The 55-year analysis shows decreasing trends at all stations for DOP and FO for the *very cold* class and for FO for the *cool* class, with most of these decreases being statistically significant. In contrast, the *comfortable* and *warm* classes show increasing trends for both FO and DOP, with statistical significance at 3 stations (Oradea, Craiova and Galati) for *comfortable* days and at 2 stations (Oradea and Galati) for *warm* uncomfortable days.

The Sen slope values *(Table 2)* for FO show significant decreases for the *very cold* class: 2 days/decade in Oradea, 4 days/decade in Craiova and 8.5 days/decade in Galati (a net decrease of 46.5 days). Decreases for *cool* days range from 2.2 days/decade (Sibiu) to 3.7 days/decade (Craiova). The increases are smaller, with the maximum of 5 days/decade in Galați for the *slightly cool* class. The *comfortable* class varies between 1.1 days/decade (Oradea) and 2.9 days/decade (Galati), and for the *warm* class between 1 day/decade (Oradea) and 1.5 days/decade (Galati). For the DOP, statistically significant decreases are only for the *extreme cold stress* class, with 4.6 days/decade in Craiova and more than 7 days/decade in the other stations. Maximum increases for DOP are 10 days/decade for the *cold* and *comfortable* classes.

Table 2. Sen slope values of TE index trends, expressed in days/decade

Parameter	**Comfort class**	**Botoșani**	**Craiova**	**Galati**	**Oradea**	**Sibiu**
FO	Very cold	-2,222	**-4,0**	**-8,462**	**-2,0**	-0,769
	Rece	0	1,863	1,856	0,333	0

	Cool	-0,667	**-3,750**	**-3,679**	**-2,952**	**-2,20**
	Slightly cool	0,667	**2,50**	**5,0**	**2,679**	**1,929**
	Comfortable	0,667	**1,944**	**2,889**	**1,111**	0,247
	Warm	0,286	0,233	**1,481**	**1,0**	0
DOP	Very cold	-4,286	**-4,615**	**-7,826**	**-7,857**	**-7,20**
	Rece	-0,779	-0,274	**10**	3,191	-0,50
	Cool	1,292	0,682	**6,80**	-0,476	-1,470
	Slightly cool	-1,0	1,859	**5,652**	2,061	0
	Comfortable	2,740	**5,250**	**10**	**7,727**	1,20
	Warm	0,270	0,909	**4,037**	**7,010**	3,125

* values written below are statistically significant.

3.3 Cooling power (H)

Fig. 3. FO and DOP for index H (in number of days)

According to the H index, the number of days with *neutral*, *cool* and *slightly cool* temperatures varies between 50 and 100 per year. The *neutral* class has the most days, with values between 120 days/year in Sibiu and 70 days/year in Galati. For the *cool* class, the number of days varies between 58 in Sibiu and 102 in Galati. The *slightly cool* class has the maximum number of days in Sibiu (96 days) and the minimum in Galați (74 days). The *warm* feeling class has just over 50 days/year, with a maximum of 77 days in Sibiu, and the other classes have less than 50 days/year. In terms of DOP, the *cool* and *slightly cool* heat sensation classes are present throughout the year. The *cool* class has more than 350 days/year at all stations, and the *slightly cool* class has more than 350 days/year at all stations except Galati. The *neutral* class has DOP over 300 days/year, except for Galati, where there are less than 250 days/year. The *cold* and *warm* heat stress classes have about 150 days/year at each station, and the extreme classes less than 50 days/year *(Fig. 3)*.

The changes detected in FO and DOP reveal predominantly decreasing trends over the study interval, with a reduction in the frequency and duration of *extreme cold* stress conditions in favour of an increase in milder (*cool*) conditions, and a decrease in *neutral* conditions in favour of an increase in *hot* and *very hot* heat stress conditions. Moderate classes (*slightly cool* and *warm*) show decreases in DOP and increases in FO, indicating a condensation of days with these thermal conditions into a shorter time span (*Fig. 3.*).

The Sen slope shows decreases of less than 2 days/decade for extreme *cold* stress classes and increases of less than 1 day/decade for extreme *warm* stress class in the case of FO. For DOP, significant decreases are greater than 19 days/decade in Galati for *very cold* stress days, while significant increases are less than 1 day/decade for *cold* class and up to 6.8 days/decade for *hot* class in Oradea and Galati *(Table 3)*.

Table 3. Sen slope values of H index trends, expressed in days/decade

Parameter	Comfort class	Botoșani	Craiova	Galati	Oradea	Sibiu
FO	Extremely cold	0,000	0,000	**-0,625**	-1,081	0,000
	Very cold	**-0,769**	-0,323	**-1,957**	**-0,370**	0,000
	Rece	**-3,033**	**-4,211**	**-8,688**	**-2,500**	**-2,043**
	Cool	2,500	**3,110**	**-5,392**	2,113	3,333
	Slightly cool	2,222	0,385	**2,308**	-0,667	**3,333**
	Neutral	-0,889	**-2,500**	0,000	**-2,718**	-2,110
	Warm	0,646	**4,599**	**13,170**	**2,829**	-3,468
	Very hot	0,000	0,000	**0,980**	**0,909**	1,080
DOP	Extremely cold	-0,250	0,000	**-1,213**	-17,838	0
	Very cold	-6,857	-2,143	**-19,167**	**-1,742**	0
	Rece	**-18,750**	**-9,375**	**-24,531**	**-9,798**	**-15,652**
	Cool	**0,323**	**0,526**	**0,222**	**0,278**	**1,030**
	Slightly cool	-0,213	-0,286	**5,000**	**-1,818**	-0,339
	Neutral	**-10,321**	**-9,231**	5,774	**-11,716**	**-6,334**
	Warm	-3,463	-2,278	**6,821**	**-5,955**	**-7,000**
	Very hot	0,000	0,000	**3,889**	**6,771**	2,509

* values written below are statistically significant.

3.4 Universal Thermoclimate Index (UTCI)

As far as FO is concerned, the predominant bioclimatic class during the year is the one *without* heat *stress*, with a number of days varying between 141 days/year in Galati and 175 days/year in Sibiu. Days with *mild* and *moderate* cold stress exceed 50 days/year, with maximums of 80 days/year (*mild cold stress* at Sibiu) and 75 days/year (*moderate cold stress* at Galați), while days with *moderate heat stress* vary between 46 days/year at Craiova and 37 days/year at Sibiu, and extreme heat stress has less than 10 days/year at all stations analysed.

In terms of DOP, the class with the largest annual extension is the *mild cold* stress class, ranging from 338 days in Galati to 356 days in Sibiu. The class *without* heat *stress* extends between 256 days/year in Galati and 306 days/year in Sibiu, while the class with *moderate cold stress* varies significantly between stations, having more than 350 days/year in the east of the country (Galati and Botoșani) and less than 200 days/year in the west *(Fig. 4)*.

There is a general trend of increasing *hot* stress classes and decreasing *cold* stress classes, with a greater presence of stationary trends for both extreme and middle classes. Significant increasing trends for *high* and *moderate hot* stress are present at Oradea, Craiova and Galati stations, while significant decreases are predominant for *high* and *very high cold stress*. The *non-heat stress* class shows insignificant trends, with increases for DOP in the west of the country and decreases for FO at all stations. The city of Galati stands out with significant increasing trends for DOP in the first 4 bioclimatic classes (*warm stress*, *no stress* and *mild cold stress*) and decreases for FO in the last 4 classes (*cold stress*).

Fig. 1. FO and DOP for the UTCI index (in number of days)

The Sen slope shows the largest increases for FO in the *moderate heat stress* class, ranging from 6.9 to 3.1 days/decade depending on the station, and for DOP, significant increases of more than 10.5 days/decade are observed in Galati in the *no heat stress* class and significant decreases ranging from 10 to 15 days/decade for the *high* and *very high cold stress* classes at most stations *(Table 4)*.

Table 4. Sen slope values of UTCI trends, expressed in days/decade

Parameter	Comfort class	Botoșani	Craiova	Galati	Oradea	Sibiu
FO	Hot Sea Stress	0,370	**1,000**	**2,500**	**1,304**	0,000
	Moderate Hot Stress	0,278	**3,114**	**6,910**	**3,333**	1,652
	Stress-free	-0,223	-1,429	-1,340	-1,250	-1,188

	Stress Cold Easy	1,765	**2,620**	**2,559**	0,000	0,000
	Cold Stress Moderate	0,000	-0,769	**-2,174**	0,000	0,392
	Cold Stress Sea	-1,569	**-3,077**	**-6,429**	**-2,340**	**-1,250**
	Very High Cold Stress	**-1,154**	**-0,482**	**-1,881**	**0,000**	**0,000**
	Extreme Stress	**0,000**	**0,000**	**-0,294**	0,000	0,000
DOP	Hot Sea Stress	1,000	**5,714**	**9,224**	**4,807**	0,000
	Moderate Hot Stress	-1,429	0,639	**5,142**	1,127	0,106
	Stress-free	-0,527	1,511	**10,507**	2,145	3,735
	Stress Cold Easy	-0,957	0,000	**4,211**	0,732	-0,769
	Cold Stress Moderate	0,000	-2,265	0,000	**-5,000**	**-7,679**
	Cold Stress Sea	**-14,157**	**-10,147**	**-15,000**	-4,464	**-12,941**
	Very High Cold Stress	**-14,157**	**-10,147**	**-15,000**	-4,464	**-12,941**
	Srtes Rece Extrem	**0,000**	0,000	**0,000**	0,000	0,000

* values written below are statistically significant.

3.5 Temperature-humidity index (TIH)

The *comfortable* class is predominant throughout the year, characterizing between 136 days/year in Craiova and 154 days/year in Sibiu, while the *cool* class is the most frequent in terms of DOP, exceeding 300 days/year at all stations, followed by *comfortable* conditions with more than 250 days/year *(Fig. 5).*

Fig. 5. FO and DOP for ITU index (in number of days)

Analysis of changes over the 56 years shows general trends of increasing both parameters for the *warm* discomfort classes and decreasing for the *cold* discomfort classes. Significant decreasing trends are observed for the *very cold* discomfort class at all stations for FO and at Galati for DOP, while the *cool* air thermal sensation class shows increasing trends, highlighting the decrease of *extreme cold stress* conditions in favour of milder ones. The *hot* discomfort class shows significant increases for

FO in all cities except Craiova, and insignificant for DOP, while the *very hot* feeling class shows significant increases in Oradea, Botoșani and Galați for both parameters, with stationary trends for the *stifling* heat stress class.

Sen slope values for ITU are below 10 days/decade at all stations and comfort classes, with significant increases in the *warm* discomfort class, ranging from 2.2 to 2.9 days/decade for FO. The *very hot* and *cool* classes have similar slopes, and the *cold stress* classes show significant decreases, with a reduction in *very cold* discomfort days between 2.6 and 5.3 days/decade. For the DOP, the *very hot* class shows significant increases between 6.9 and 8.1 days/decade, and the *comfortable* and *cool* air classes show significant expansions, with only one significant decrease in Galati for the *very cold* discomfort class *(Table 5).*

Table 5. Sen slope values of UTCI trends, expressed in days/decade

Parameter	Comfort Class	Botoșani	Craiova	Galati	Oradea	Sibiu
FO	Suffocating	0,000	0,000	0,000	0,000	0,000
	Very hot	**1,732**	1,333	**2,222**	**1,290**	0,000
	Warm	**2,209**	1,327	**2,657**	**2,857**	**2,500**
	Comfortable	**-3,050**	-2,562	**-2,667**	-1,518	-0,745
	Cool	1,802	**2,620**	1,559	1,745	0,556
	Rece	1,429	0,250	1,250	-0,625	-0,572
	Very cold	**-5,251**	**-4,286**	**-4,796**	**-3,077**	**-2,590**
DOP	Suffocating	0,000	0,000	0,000	0,000	0,000
	Very hot	**6,843**	3,660	**8,077**	**7,791**	0,308
	Warm	2,948	0,931	**3,050**	2,384	2,000
	Comfortable	3,381	**7,232**	3,889	3,333	2,581
	Cool	4,211	**5,217**	1,818	**3,892**	**4,619**
	Rece	-1,263	1,667	2,381	-2,236	-0,909
	Very cold	-2,753	-4,120	**-4,019**	-0,625	-3,824

* values written below are statistically significant.

3.6 Enhanced Tourism Climate Index (ETCI)

In terms of the changes detected in the ETCI, i.e. the increase in FO for the *ideal* and *excellent* condition classes over the last 10 years indicates a trend of improving weather conditions for outdoor recreation at certain times of the year, while the decreases for the lower classes point to a possible decrease in days with unfavourable conditions. In the long term, these changes suggest a gradual shift in bioclimatic conditions that needs to be taken into account in developing climate change adaptation strategies to optimise resources and improve urban quality of life.

Regarding the length of the season suitable for outdoor recreation, the following important aspects stand out according to the ETCI index *(Fig. 6)*:

(i) Its onset takes place in the second decade of March in most cities;

(ii) The existence of *acceptable* or *superior* conditions for outdoor recreation is recorded by the first decade of November in most cities.

(iii) in lowland cities and those at lower altitudes (Bucharest, Craiova and Timisoara), the peak season, which includes *very good* or *better* conditions, is longer, starting earlier and ending later than in depressed cities (Cluj-Napoca, Sibiu), where mountain influences shorten the optimal period;

(iv) In the last 10 years, ideal conditions for recreation and tourism have started earlier, with a trend towards an extension of the favourable season in certain cities;

(v) In terms of socio-economic impact, the city of Bucharest stands out as the city with the highest number of outdoor events due to its capital status and high population, taking advantage of the longest duration of *favourable* conditions. At the opposite pole, other cities, such as Craiova and Galati, even with *excellent* conditions, have a low number of events, indicating an as yet untapped opportunity for increased tourism and recreational activities;

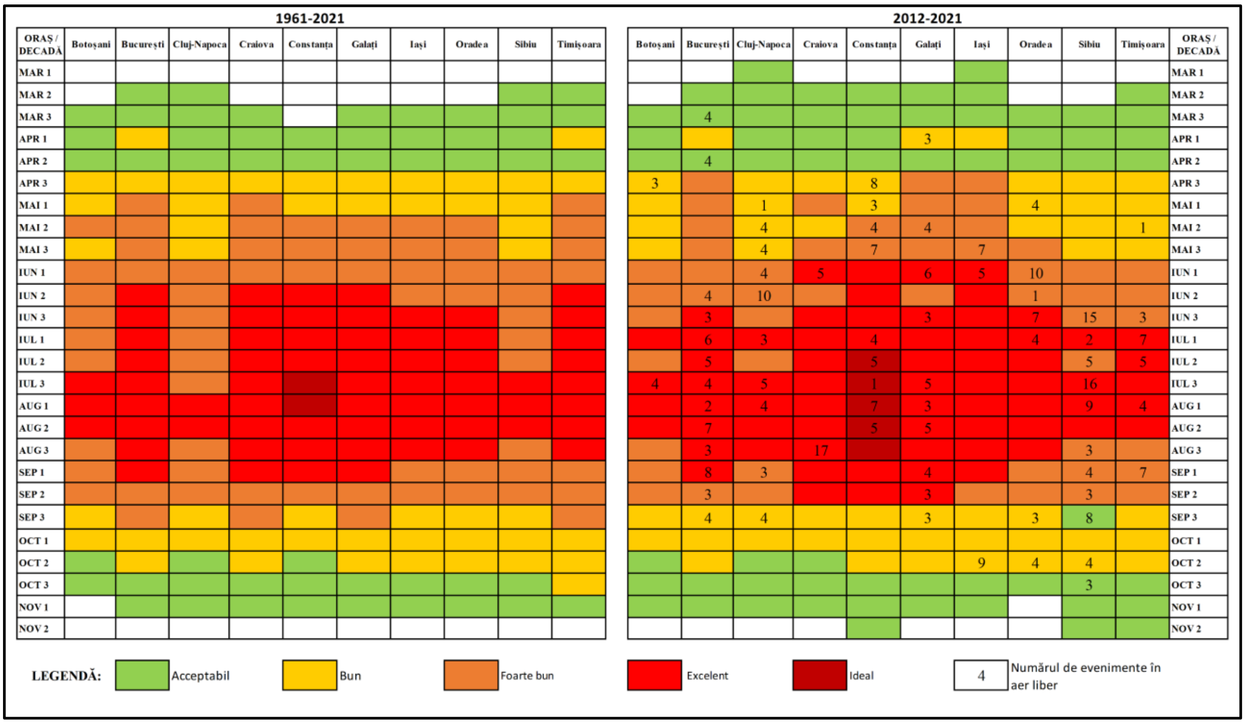

Fig. 6. Favourability periods for tourism and outdoor recreation events during the year based on the average ETCI per decade

(vi) From our perspective, it is recommended to spread the events over the whole length of the favourable season both to avoid overcrowding in the cities and pressure on the accommodation infrastructure, and to maximise the use of favourable bioclimatic conditions.

We therefore believe that these aspects can be an important starting point for strategic planning of tourism and recreational development, adapted to the climatic and socio-economic specificities of each individual city.

3.7 Holiday Climate Index (HCI:Urban)

Analysis of the HCI climate-tourism index for the historical period, as well as for future periods, showed similar patterns of the distribution of climatic conditions throughout the year (*unfavorable*, *acceptable*, and *good*), which remains relatively stable regardless of location or period analyzed, indicating the predictability and reliability of the HCI:Urban model in assessing climatic conditions for tourism and recreation. In addition, the following conclusions can be drawn from the analysis of this index:

(i) In the current period (2021-2040), days with *acceptable* conditions are more frequent in the early and late months of the year (January-April and October-December, respectively). This distribution indicates an opportunity for tourism development in these periods, especially in the intra-Carpathian regions *(Fig. 7)*.

(ii) *Good* conditions show an inverse frequency throughout the year, with lows in the winter months and highs in the summer months, suggesting the warm months, especially July and August, as ideal periods for tourist and recreational activities (*Fig. 7)*.

(iii) The evolution of bioclimatic conditions over time, observed by comparing the different periods analysed, indicates a trend of decreasing number of days with *unfavourable* and *acceptable* conditions, while the number of days with *good* conditions increases, thus favouring the extension of the summer tourist season *(Fig. 7).*

(iv) In terms of the distribution over the year, at all locations and for all time periods analysed the HCI values gradually increase in the first half of the year, from values between 60 and 65 units at most locations, peaking at 90 units in July and August, and then in October-December they return more slowly, with smaller decreases from month to month, to slightly higher values than in January *(Fig. 8)*.

In terms of the evolution of HCI scores from one time period to another, the sharpest increase is observed in the period 2061-2100 in all locations. However, slight variations between months, especially in the summer months, are significant between locations. In the latter period, most cities show a drop in HCI score below 85 units in July, a slight increase in August and a peak in September. The increase in HCI values from one time period to another with the peak in September also leads to higher HCI values in the autumn months, i.e. December, compared to the months in the first half of the year *(Fig. 8)*.

Fig. 2. Monthly frequency of days with good, acceptable and unfavourable bioclimatic conditions according to the HCI index in the present period 2021-2040 at all stations analysed

A reduction in the number of decades with average HCI between 50 and 60 units is observed towards the end of the 21st century. If in the historical period (1986-2005), they were recorded at four locations (Botoșani, Cluj-Napoca, Iași, Oradea), in the period 2021-2040, they are observed only at two locations (Botoșani and Oradea), respectively in the periods 2041-2060 and 2061-2100 only in Oradea. The frequency of lags with HCI values above 90 units is

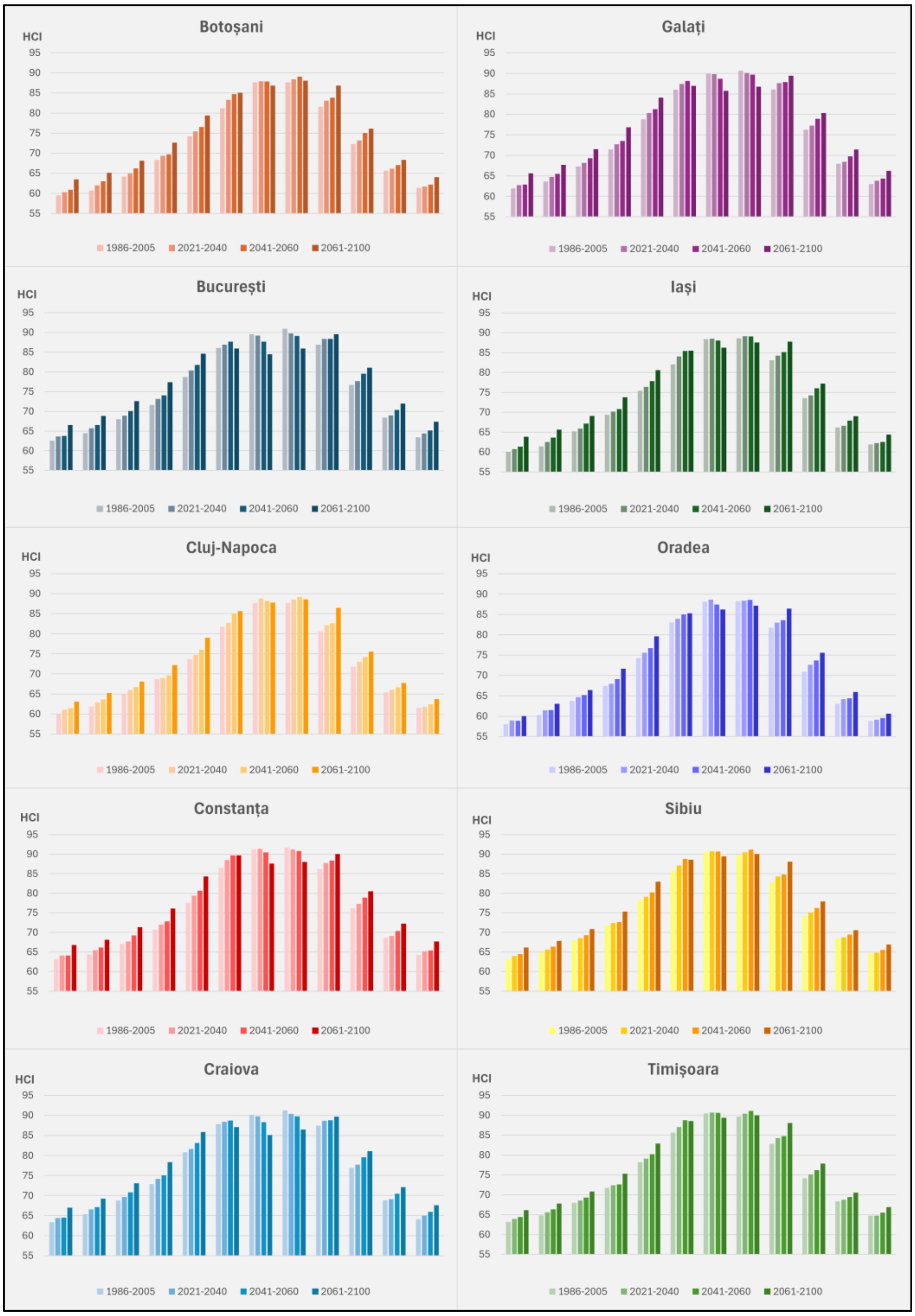

Fig. 8. Multi-year monthly average values of the HCI index in all time periods analysed: 1986-2005; 2021-2040; 2041-2060; 2061-2100

also decreasing. Currently, HCI scores between 60 and 70 units are dominant until April at Botoșani, Cluj-Napoca and Oradea, and until March at other locations. The evolution of the HCI scores indicates the extension of the favourable range, with decades with values above 80 units appearing earlier and remaining later in the year. This suggests a reduction in days with unfavourable and acceptable conditions, and an increase in those with good conditions for tourist activities, a trend also observed in other climate indices *(Fig. 8)*.

CONCLUSIONS

In the present work we believe that the proposed objectives have been achieved and thus it will find its value and usefulness both among the scientific community, as well as among citizens and local, regional and even national decision makers, the results obtained being in line with other similar studies. (IPCC, 2023; Matei et al., 2023; Scripcă, 2023).

The TeK and TE indices show the prevalence of *cold* and *cool* thermal discomfort days, while the H, UTCI and ITU indices showed a predominance of *thermal comfort* conditions. The long-term dynamics show a trend of decreasing extremely cold and chilly days and increasing thermal comfort and warm days, indicating the mitigation of extreme cold conditions in the urban areas considered. Under these circumstances, we believe that it is extremely important to continue monitoring these trends to facilitate better preparedness for the effects of climate change in these regions.

The changes detected in the evolution of bioclimatic indices over the time period analysed indicate a general trend towards a decrease in the frequency and duration of occurrence intervals associated with cold thermal discomfort conditions and an increase in those associated with warm thermal discomfort. Specifically, the significant decreases are specific to the cold and cool heat stress classes, suggesting a warming trend in all cities considered in the study. In contrast, a significant increase is observed for classes associated with hot thermal discomfort (moderate to severe), indicating an increase in the frequency of hot or stifling days. This suggests the need for adaptation in urban planning and resource management to cope with heat stress, particularly in large urban areas. These trends not only reflect ongoing climate change, but also highlight its differing impacts by region and comfort category, requiring specific adaptation measures for each area and urban context.

In terms of the changes detected in the ETCI, i.e. the increase in FO for the *ideal* and *excellent* condition classes over the last 10 years indicates a trend of improving weather conditions for outdoor recreation at certain times of the year, while the decreases for the lower classes point to a possible decrease in days with unfavourable conditions.

In the long term, these changes suggest a gradual shift in bioclimatic conditions that must be taken into account in developing climate change adaptation strategies to optimise resources and improve urban quality of life.

We therefore believe that these aspects can be an important starting point for strategic planning of tourism and recreational development, adapted to the climatic and socio-economic specificities of each individual city.

In conclusion, we believe that the present work contributes to both the extension of research in the field of biometeorology and climate change in Romania, providing a perspective on the impact of these changes at the individual level, through the bioclimatic and climatic-touristic indices used. Through the detailed analysis carried out, we believe we have highlighted the need for adaptation strategies and hope to contribute to the efforts to mitigate the negative effects, inspiring concrete actions to adapt the urban environment to this context and to protect the health of its inhabitants in the face of the increasingly pressing climate challenges.

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