



# Monitoring the Past and Future Trends of Urban Thermal Comfort Conditions Through a New Methodology

Savaş Çağlak<sup>1</sup> · Muhammet Bahadır<sup>2</sup> · Süleyman Toy<sup>3</sup>

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## Abstract

Human thermal comfort representing the satisfaction of mind with ambient air conditions has significant effects on socio-economic activities. Climate change is affecting thermal comfort conditions (TCCs) negatively. Therefore, it is important to estimate their past and future trends to take accurate measures for mitigation and adaptation efforts in especially urban areas. However, it is difficult to calculate TCCs for the future since they are the combined effect of several meteorological parameters on a person outdoor together with her/his own physiological characteristics, which must be evaluated individually. This study is aimed at determining the TCCs trends in the past compared to the present whilst estimating the future conditions using a new methodology in the case of Kayseri city in the Interior Anatolia Region of Turkey. As the result of the study, all the change trends considering temporal and spatial results show that thermal comfort conditions signal warmer and higher heat stress in the past and future trends. This means human thermal sensation ranges (e.g., very cold) have replaced with the next warmer range, and their spatial distribution in percentage has also changed towards warmer. Increase in the prevalence of unfavourable thermal comfort conditions causes the decrease in the liveability indicators in especially urban areas, including serious economic losses based on energy consumption, health care expenses, and efficiency of activities. It is required that both past and expected future trends be considered in the planning and design works to make cities resilient and have higher adaptive capacity to climate change.

**Keywords** Climate change · Adaptation and mitigation · Thermal comfort · Kayseri · Urban climate

## Introduction

As the average conditions of observed weather conditions over a vast region and a long time period at least 30 years (for WMO), climate has still affected (in)directly the life styles, clothes, food, health and wellbeing, psychological characteristics, production, and consumption habits of

humans (Türkeş, 2017). Majority of human beings inhabit temperate climate zone where four seasons are clearly experienced; therefore, some diseases are prevalent, and humans have developed different and similar cultural and physiological characteristics based on the various effects of prevalent climate characteristics. People in the atmospheric environment are exposed to individual or combined effects of climatic elements like temperature, relative humidity, wind velocity, solar radiation, and precipitation. The combined effect is perceived as thermal effect and expressed as human thermal comfort which is generally defined as the conditions where people state their satisfaction with their ambient air conditions (in every updated version of ANSI/ASHRAE Standard 55 from 1966 to 2015). In this respect, there is an expression of “no discomfort, stimulation or stress” about the thermal environment and human body needs nearly no energy to adapt itself to physical and emotional conditions, i.e., neutral situations between discomforting warm and cold (Çağlak, 2021; Öngel & Mergen,

✉ Savaş Çağlak  
savas\_caglak@hotmail.com

Muhammet Bahadır  
muhammetbahadr@gmail.com

Süleyman Toy  
stoy58@gmail.com

- <sup>1</sup> Ministry of National Education, Amasya, Turkey
- <sup>2</sup> Department of Geography, Faculty of Science and Letters, Ondokuz Mayıs University, Samsun, Turkey
- <sup>3</sup> City and Regional Planning Department, Architecture and Design Faculty, Atatürk University, Erzurum, Turkey

2009; Parsons, 2003). The human body balances body core temperature according to its surrounding (Lai et al., 2017) by stimulating the brain. Under unfavourable thermal conditions, when the body is exposed to heat or cold stress, then people face health problems like fatigue, chronic diseases, headache, psychologic defects, loss of work efficiency, and interference of activities and increase in death rates (Zaninovic & Matzarakis, 2009; Nastos & Matzarakis, 2011; Błażejczyk et al., 2018; Schlegel et al., 2020; Konefal et al., 2020).

In its approximately 4.6 billion-year history, earth's climate system has experienced natural tendencies for changes (Atalay, 2005; Türkeş, 2013). However, human-induced changes in climate beginning from the nineteenth century depending on intensifying anthropogenic activities (industrialisation, deforestation, increase in urban areas, asphaltting, concreting, etc.) and their impacts are expected to get larger in near and distant future (IPCC, 2021). Climate change continues to adversely affect soil, agriculture, forest, water resources, flora, fauna, coasts, and the natural environment by leading led to migration, damage in public and environmental areas, economic losses, and even the deterioration of wild life ecosystem.

Extreme weather conditions and air content, e.g., excessively cold, hot, moist, or dry air, have negative impacts on public health (T.R. Ministry of Health, 2015). In spite of the great advancements in technology, survival of individuals and societies depends strictly on atmospheric factors which have direct or indirect effects (Blażejczyk et al., 2018). Climate change is expected to change thermal comfort conditions since thermal comfort is the combined effect of climatic elements which experience change individually. Altered thermal comfort conditions will inevitably affect human life and activities. Increase in the density, frequency, and length of the effective periods of heat and cold stress is expected to affect sensitive groups like the elderly, children, and those with chronic disease and suppressed immune system.

Impacts of climate change are so multifocal that results of all studies assessing the future climate conditions including the perspectives of several fields like hydrology, biodiversity, disasters, economy, and others are vitally important (IPCC, 2021; Turp et al., 2014). Effects of climate change on thermal comfort conditions are investigated in various parts of the world. Some of such studies stated that time period when cold stress is prevalent will be shortened whilst heat stress will prevail in longer periods. Due to the impacts of increased frequency of heat waves in especially summer seasons, heat stress is expected to be severe to threaten public health (Cheung & Hart, 2014; Matzarakis & Amelung, 2008; Matzarakis & Endler, 2010; Mcgregor et al., 2002; Nastos & Matzarakis, 2019).

Turkey located in the Mediterranean region is amongst the countries expected to be under the impact of climate

change higher than those in other regions. Therefore, with the impact of climate change, thermal comfort conditions are also expected to be altered in a larger rate causing more serious health, economic, and even social problems in especially cities. Studies in Turkey carried out on the effects of climate change on thermal comfort conditions are limited to the West Mediterranean region of Turkey related majorly to tourism (Kum, 2011; Şensoy, 2020; Demiroğlu et al., 2020). Studies examining the effects of climate change on thermal comfort conditions in urban areas have also been limited. Studies have been carried out for only two urban centres in Turkey, and these are cities in the Black Sea climate region where humid climatic conditions are experienced. In a study conducted in Amasya, one of these cities, it was determined that 'cold' stress, 'comfortable' conditions will decrease and 'hot' stress will increase in winter seasons in Amasya in the coming years (Çağlak, 2022). In the other study, it was determined that whilst there are 'warm' stresses in the summer season in the city of Bolu, 'hot' and 'very hot' stresses will be effective in the future (Çağlak & Türkeş, 2022). Continental climatic conditions are effective in a large part of Turkey. However, the thermal comfort conditions of the cities in the continental climate zone, depending on the climate change, have not been examined. For this reason, the city of Kayseri, which is one of the important cities of Turkey, where continental climate conditions are experienced characteristically, has been determined as the study area. The aim of the study is to calculate thermal comfort conditions for the present, near future, and distant future to determine the possible impact of climate change on these conditions to take measures to adapt or mitigate the effects for preventing the socioeconomic losses caused by the worsening thermal comfort conditions by taking the city of Kayseri as the example. Therefore, this study is important to track the possible changes in thermal comfort conditions which are calculated considering the combined effects of meteorological parameters on the human body.

## Study Area

The city of Kayseri was chosen to be the study area, where continental climate characteristics are prevalent. The city has a history dating back to 6 thousand years ago housing many civilizations which witnessed the beginning of history in Anatolia (the first inscriptions were found in the ancient city of Kültepe). It is the third largest city and industrial centre of the Central Anatolia Region following Ankara and Konya (Kozan, 2018). Kayseri, as a province, is located in Interior Anatolia Region, Middle Kızılırmak subregion, TR72 NUTS 2 Statistical Region. The city centre, which is the main study area, covers the neighbourhoods of Kocasinan, Melikgazi, and Talas located in a tectonic depressed and terraced plain (Somuncu, 2003) in the outskirts of mount Erciyes (3917 m;

35° 3' 15"–35° 43' 51" E; 39° 2' 16"–38° 24' 34" N) which is carved by two surface waters Kızılırmak River (the longest river in the border of Turkey) and Sarımsaklı Creek. The city is surrounded by Yozgat province, Felâhiye and Özvatan districts in the north; Bünyan district in the east; Tomarza, Develi, Hacılar, and İncesu in the south; and Nevşehir (world famous Cappadocia historic and cultural area) in the west (Fig. 1). The total population of the study area is 1.147.908 (most populated is Melikgazi with 582.055 people whilst the least one is Talas with 165.127 people; TSI, 2020).

Climatic characteristics of the city represent those unique to continental Interior Anatolia Region, where there are torrid and arid summers and extremely cold, snowy winters, and rainy springs due to convective precipitations. According to the mean values measured by the meteorological station in the 1960–2020 period in the city centre, long-term mean annual temperature is 10.5 °C (between 22.0 °C in July and – 1.7 °C in January), annual mean rainfall 397.2 mm (between 53.2 mm in May and 7.9 mm in August), mean relative humidity is 63.3%, and mean wind speed is 1.8 m/s (Table 1). In winter, the city is under the effect of stable air masses and exposed to inversion phenomenon.

### Material and Method

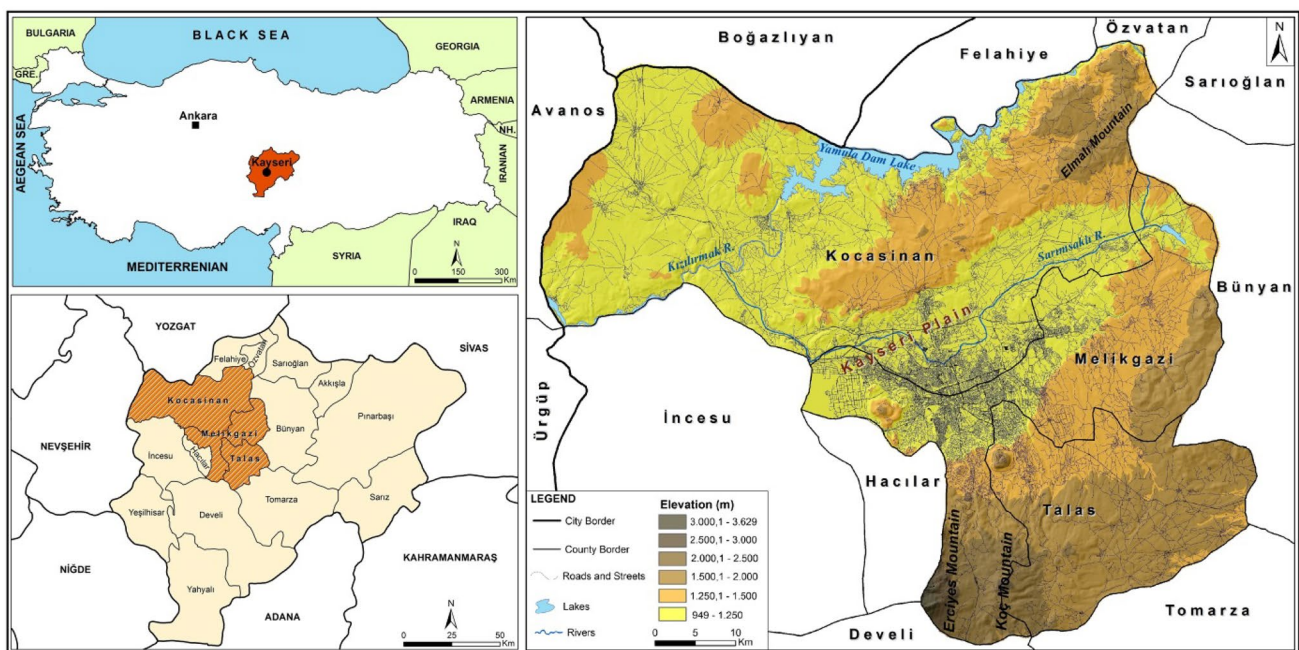
Meteorological data measured in the meteorological observation station (with 17196 International Code) in the garden of Regional Meteorology Administration Office in the centre

**Table 1** Average and extreme values for Kayseri

Observation period; 1960–2020 (38° 41' N; 35° 30' E; 1094 m)		
Parameters	Value	Date/period
Mean temperature	10.5 °C	Annual
Mean relative humidity	63.3%	Annual
Mean wind velocity	1.8 m/s	Annual
Mean total rainfall	332.6 mm	Annual
Mean number of snow-covered days	51.2 day	Annual
Extreme maximum temperature	40.7 °C	30.07.2000
Extreme minimum temperature	– 31.4 °C	18.01.1972
Record daily rainfall	59.6 mm	17.05.1999
Record snow depth	51 cm	19.02.2008
Record wind velocity	45 m/s	12.02.1969

of the city was used to calculate thermal comfort conditions today and in the future. The measurement period is 1961–2020, and meteorological parameters included are air temperature ( $T_a$ ; °C), relative humidity (RH; %), wind velocity ( $W_v$ ; m/s), and cloudiness ( $C$ ; octas).  $T_a$ , RH,  $W_v$ , and solar radiation data obtained from model scenarios (RCP4.5 and RCP8.5) were used for the near and distant future calculations. RCP4.5 and RCP8.5 scenarios are the most widely used pathways representing the radiative forcings of 4.5 and 8.5  $Watt/m^2$  (as in IPCC’s AR5; IPCC, 2014, Choi et al., 2019; Şensoy, 2020).

Thermal comfort conditions were calculated through the RayMan model which is adopted word wide and considers



**Fig. 1** Location map of Kayseri city

several factors related to both the human body (e.g. 35 years old, 175 cm, 75 kg healthy man wearing clothes with 0.9 clo and working at 80W heat load) and meteorological parameters and using Physiological Equivalent Temperature index (PET; Höppe, 1999; Matzarakis et al., 1999; VDI, 1998). The obtained thermal comfort values were categorised considering the ranges given in Table 2.

The study was designed to obtain results for four periods i.e. the past (1961–1990), present day (1991–2020), near future (2021–2050), and distant future (2069–2098). Spatial distribution of mean monthly thermal comfort conditions was described on the maps with 100 × 100 m resolution. Distributions of the values in the area were compared and the results were commented.

Spatial distribution of PET values was mapped through ArcGIS 10.5 (Demo version) on monthly base for both the past and future. The percentage ratio of the comfort ranges was also calculated in the area and given in a table. In the spatial distribution of PET values, the newly developed method, which was tested with an accuracy of over 95%, was used (Çağlak, 2021). In the modelling of the spatial distribution of PET values, land-use, elevation, mean radiant temperature (T<sub>mrt</sub>), wind velocity, and solar radiation maps were prepared at 100 × 100-m resolution and their individual effects on PET index value were also considered: these effects, wind velocity 1 (m/s) unit PET value 2.5 C, mean radiant temperature (T<sub>mrt</sub>) 1 C unit PET value 0.6 C, elevation 100 m unit PET value 0.5 C, solar radiation 100 (w/m<sup>2</sup>) unit PET value 1.2 C (time 07:00), and 0.4 C (time 14:00) affects. Data related to land-use classes in the past was obtained from Corine land-use system on Copernicus web site (URL 1) and 1/25.000-scaled topographic maps produced in 1987 by Turkish General Command of Mapping. Maps representing present-day land-use information were produced using the data downloaded from Urban Atlas (URL 2) belonging to 2018. Urban Atlas data were

preferred in the study since they can give urban land-use types in details. Wind maps representing the wind velocity at 1.1-m height were prepared considering wind data obtained as the result of a formula (1) to downscale the wind speed to 1.1 m from 2.0 m standard measurement height for purpose of bioclimatic analysis (Nastos et al., 2013; 2019). Formula (1) was employed to downscale the wind speed values measured at 2 m at meteorology station to 1.1 m height.

$$WS_{1.1} = WSh \times (1.1/h)^a \quad (1)$$

where  $a = 0.12 \times z_0 + 0.18$ , WSh is the wind speed measured at standard heights (m/s) (at 10 or 2 m),  $h$  is the height of the measurement point (generally 10 m),  $a$  is the empirical variable for surface roughness, and  $z_0$  is the surface roughness depending on the land-use characteristics (Troen & Petersen, 1989), which was determined according to the surrounding area at 500-m distance from the station (Troen & Petersen, 1989). The roughness value (height;  $z_0$ ) was derived from European Wind Atlas.

## Results

Spatial distribution of monthly thermal comfort conditions is presented over four periods: past (1961–1990), present (1991–2020), near future (2021–2050), and distant future (2069–2098) covering 30 years. The order of astronomical seasons was followed to express the similar conditions consecutively in a year. In this respect, winter months were evaluated first and then the following seasons were taken in the order.

### Thermal Comfort Conditions in the Past (1961–1990)

Results of the analysis conducted for the past conditions are presented in Figs. 2 (spatial) and 8 (temporal and percentage rates of thermal comfort ranges). According to the figure developed for the past, in the city of Kayseri, in winter months, ‘extremely cold’ and ‘very cold’ ranges are prevalent throughout the area except for the densely-built spots, where ‘cold’ stress range is observed. In early spring season (March), great majority of the study area is under the effect of ‘very cold’ range whilst again in the densely built-up spots in the city centre ‘cold’ and ‘cool’ ranges are dominant. In April, ‘cool’ and ‘cold’ ranges prevail on lower plains and highlands, respectively, whilst on the higher ridges of Mt. Erciyes ‘very cold’ range is observable. Built-up zones in the city centre reflect ‘slightly cool’ range. ‘Comfortable’ range is seen for the first time in a year in May in built-up urban area. The rural part of the study area faces ‘cool’ and ‘slightly cool’ ranges. In the summer season, June is the first month to observe ‘slightly

**Table 2** Human thermal sensation and stress ranges for PET (adjusted from Höppe, 1999; Matzarakis et al., 1999)

PET (°C)	Thermal sensation	Level of thermal stress
<−4	Extremely cold	Freezing cold stress
−3.9–4.0	Very cold	Extreme cold stress
4.1–8.0	Cold	Strong cold stress
8.1–13.0	Cool	Moderate cold stress
13.1–18.0	Slightly cool	Slight cold stress
<b>18.1–23.0</b>	<b>Neutral (comfortable)</b>	<b>No thermal stress</b>
23.1–29.0	Slightly warm	Slight heat stress
29.1–35.0	Warm	Moderate heat stress
35.1–41.0	Hot	Strong heat stress
>41.0	Very hot	Extreme heat stress

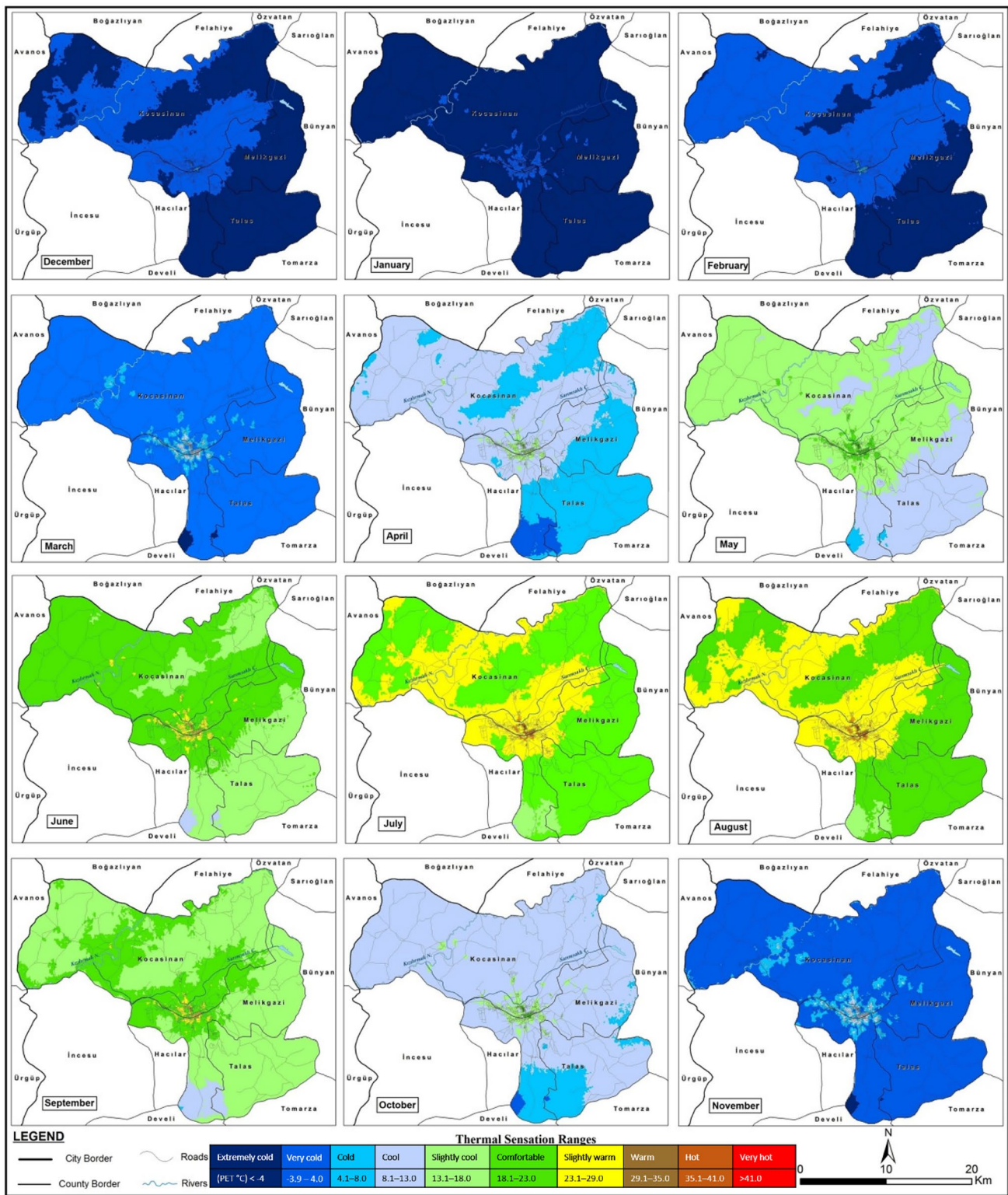


Fig. 2 Monthly distribution of thermal comfort conditions of Kayseri in the past (1961–1990)

warm’ range in a year in built-up urban area, where ‘warm’ range is prevalent in July and August. In the parts out of urban surface (rural, semi-rural) in the study area, June

is the scene for ‘comfortable’ and ‘slightly cool’ ranges whilst in July and August, ‘comfortable’ and ‘slightly warm’ ranges are perceived. In the autumn season, heat

stress is still present in September with ‘slightly warm’ range in the densely built-up area in the city centre, where ‘comfortable’ and ‘slightly cool’ ranges are prevalent in October and ‘cold’ and ‘cool’ ranges are in November. The rural part of the study area is exposed to ‘comfortable’ and ‘slightly cool’ ranges in September, ‘cool’ range in October, and ‘very cold’ in November in great majority.

### Thermal Comfort Conditions at Present (1991–2020)

Figures 3 and 8 represent the results of the analysis carried out for the present thermal conditions by considering their spatial and temporal distributions, respectively. According to the distribution map of comfort ranges, it is seen that at present situation, the size of the areas where ‘extremely cold’ range is prevalent in winter season shrinks and the area where ‘extremely cold’ range was once dominant is taken over by ‘cold’ range depending on the expansion of the built-up urban surface (urban sprawl) and climate change. In a similar way with the winter season, present thermal comfort conditions in spring gets milder from the point of cold stress i.e. the size of the surface where ‘cold’ range was prevalent in the past period reduces by leaving the areas ‘cool’ and ‘slightly cool’ ranges.

In March built-up urban areas are exposed to ‘slightly cool’ range, ‘comfortable’ range in April, and ‘slightly warm’ range in May. Present conditions in spring months are different from those in the past since ‘very cold’ and ‘cold’ ranges were experienced in March and April whilst only ‘comfortable’ range was seen in May in the past contrarily to ‘slightly warm’ stress at present. In the summer month, differently from the past, prevalence of ‘cool’ and ‘slightly cool’ ranges decreases and surface area of the ‘warm’ range dominant zone increases. In June, ‘slightly warm’ and ‘warm’ ranges occupy larger area in the built-up urban area compared to their counterparts in the past. In July and August, nearly whole urban part of the study area is exposed to ‘warm’ range, i.e. heat stress whilst the rest of the study area including rural is dominated with ‘slightly warm’ range (slight heat stress) in July and ‘comfortable’ range in August. In autumn, the extent of the area under the effect of ‘cold’ range (strong cold stress) reduces compared to the past and this area is invaded by ‘slightly cool’ and ‘comfortable’ ranges. In September, summer conditions still prevail and in the urban area moderate heat stress is experienced with ‘warm’ range whilst in October ‘comfortable’ range takes over the ‘warm’ range zone in especially the urban area and the rest of the area is exposed to ‘cool’ range. November is under the effect of ‘slightly cool’ in urban area and ‘cold’ and ‘very cold’ ranges in rural area. In also November, surface area of the cold stress is less than that in the past.

### Thermal Comfort Conditions in the Near Future (2021–2050)

It is predicted based on the analysis taking both scenarios (RCP4.5 and RCP8.5) into consideration that surface area of the zones where ‘extremely cold’ and ‘very cold’ ranges are prevalent will shrink by leaving their areas to ‘cold’ range in winter. Similarly, ‘cold’ range will lose its area and ‘comfortable’ and ‘slightly cool’ ranges will gain larger place in spring compared to present situation of thermal comfort conditions. Summer season will be the scene for moderate to extreme heat stress with more prevalent ‘slightly warm’, ‘warm’, ‘hot’ and ‘very hot’, which have never been experienced before in urban area. It is also expected that the area of ‘comfortable’ range will also decrease. July is predicted to be the month when the extreme heat stress will be observed more prevalently in urban area. In autumn, prevalence of ‘cold’ and ‘cool’ ranges is predicted to decrease and ‘comfortable’ and ‘slightly warm’ ranges are expected to gain larger areas (Figs. 4 and 5).

### Thermal Comfort Conditions in the Distant Future (2069–2098)

According to the both scenarios for distant future, in winter season ‘extremely cold’ range is predicted to prevail in the elevated areas around Erciyes mount close to the city centre, which is exposed to ‘cold’ range. In spring, ‘comfortable’ and ‘slightly warm’ ranges are expected to enlarge their impact area. It is also predicted that in summer surface area of the ‘comfortable’ zones is will decrease dramatically, ‘warm’ and ‘hot’ ranges will extend their impact areas. In especially July, city centre is predicted to be under the effect of ‘hot’ and ‘very hot’ ranges which are perceived as strong and extreme heat stress. In autumn, September will still sustain summer thermal characteristics with ‘warm’ and ‘slightly warm’ ranges causing heat stress whilst in October ‘comfortable’ zones and in November ‘slightly cool’ zones will enlarge their surface areas (Figs. 6, 7 and 8).

### Percentile Spatial Distribution of Thermal Comfort Conditions

The study area consists of the neighbourhoods, Kocasinan (1471 km<sup>2</sup>), Melikgazi (668 km<sup>2</sup>), and Talas (444 km<sup>2</sup>) all of which cover a surface area of 2583 km<sup>2</sup>. Figure 8 gives the percentile ratios of comfort ranges all over the study area in the past and at the present. According to the results, ‘extremely cold’ conditions are prevalent in 62.5%, 97.2%, and 38.2% of the study area in December, January, and February, respectively in the past whilst in the period representing the present

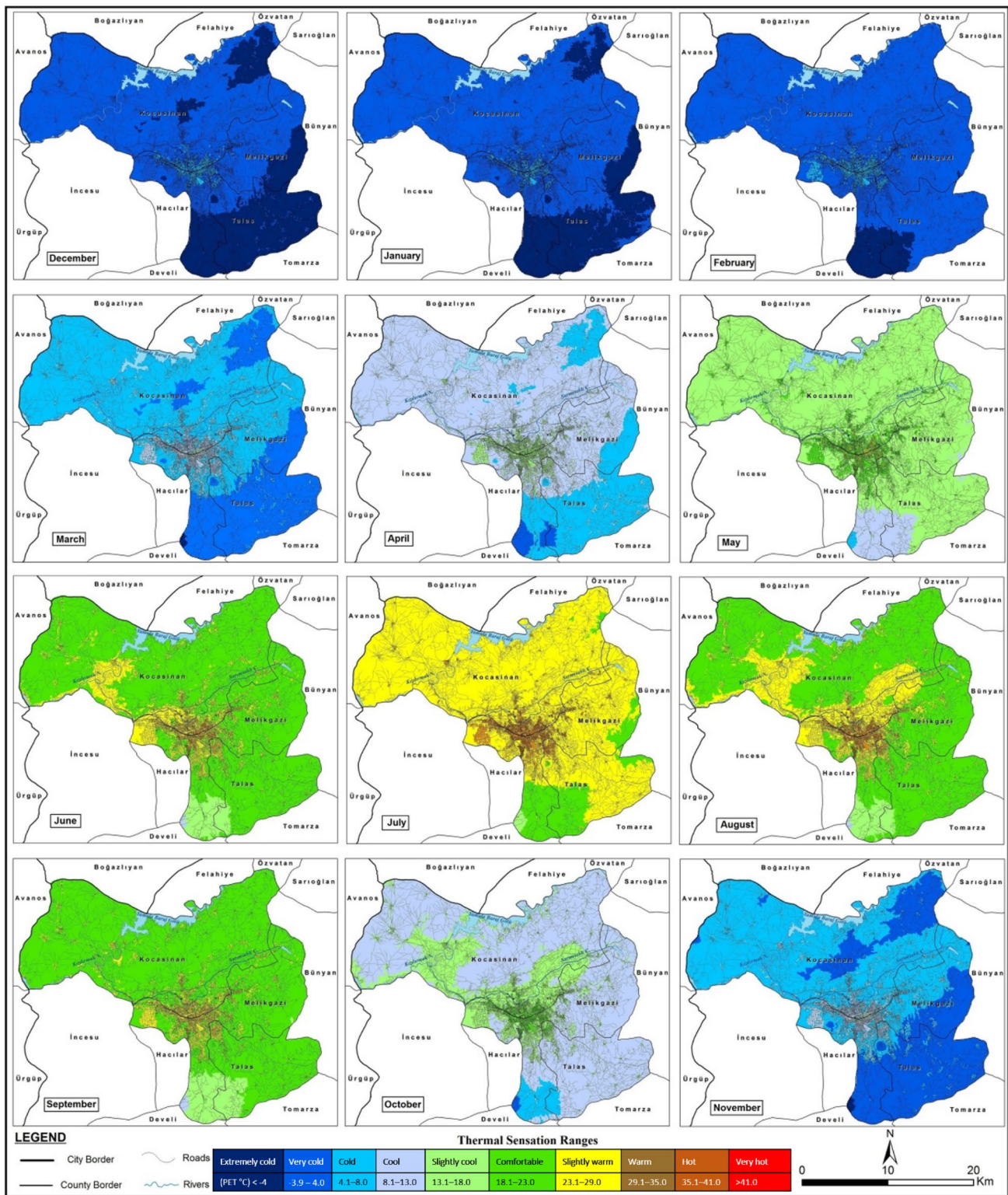
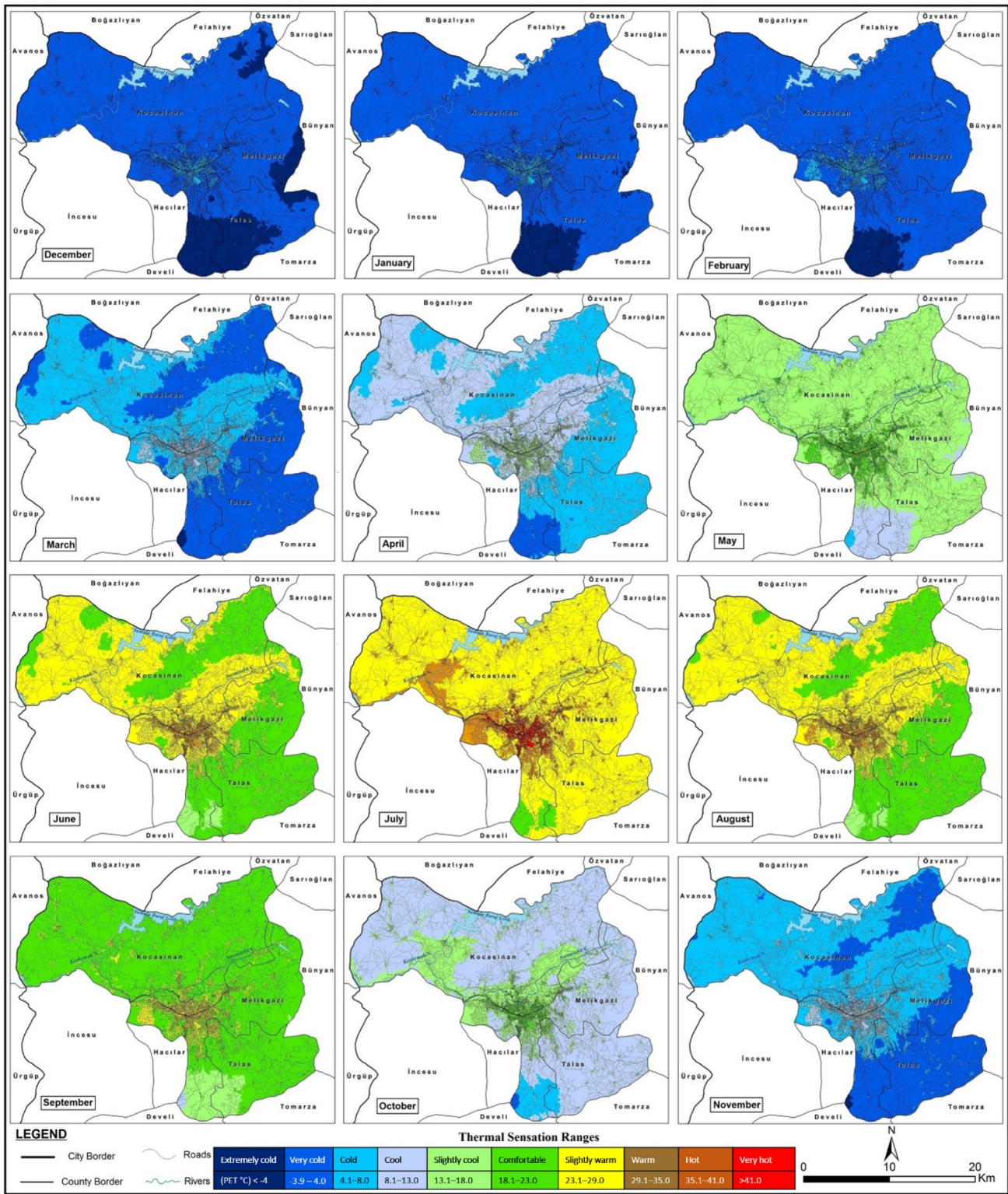


Fig. 3 Monthly distribution of thermal comfort conditions of Kayseri in the present (1991–2020)

time, the mentioned range has lost area by reaching 27.8%, 22.4%, and 6.5% in December, January, and February, respectively. This range is prevalent in both period over 5 months

even though its prevalence lowered by 74.8%, 31.7%, and 34.7% in January, February, and December, respectively. ‘Very cold’ range is prevalent over 8 months in the past and



**Fig. 4** Kayseri’s monthly distribution of thermal comfort conditions in the near future (2021–2050) according to the RCP4.5 scenario

most dominantly in March (95.4%) which is followed by November (92.5%) and February (61.7%) whilst at present this range is prevalent over 7 months and in winter months its

prevalence increased at important rates (73.6%, 29.0% and 33.2%, in January, February and December, respectively) whilst decreasing in spring (March and April) and autumn



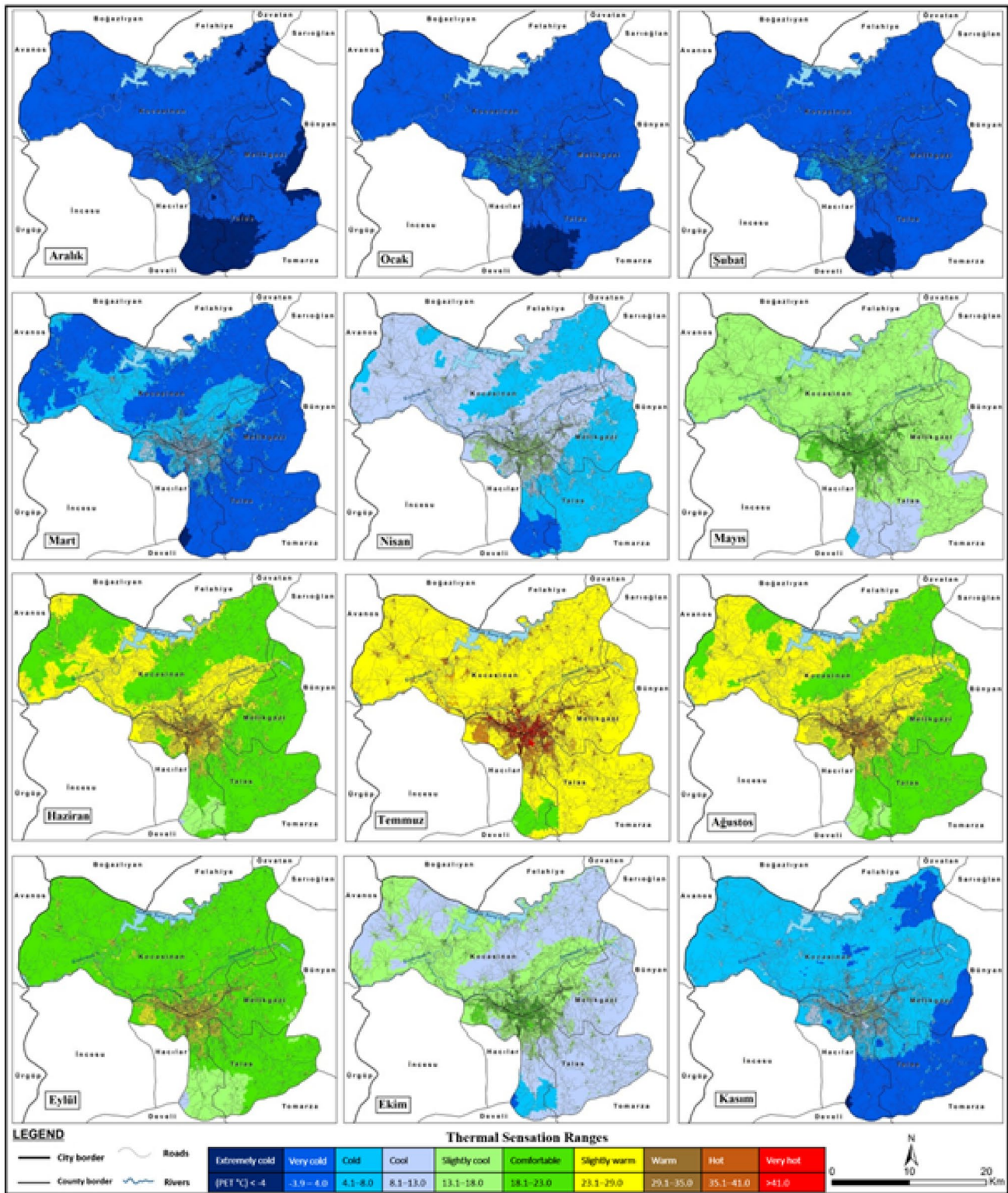


Fig. 5 Kayseri’s monthly distribution of thermal comfort conditions in the near future (2021–2050) according to the RCP8.5 scenario

(October and November). ‘Cold’ range is observed in the past over 7 months and its prevalence increased in March and November at the largest rates (61.1% and 52.5%, respectively)

whilst decreasing in late spring (May) and early autumn (September) compared to present time. ‘Cool’ range is observed over 7 and 8 months in the past and present, respectively. This

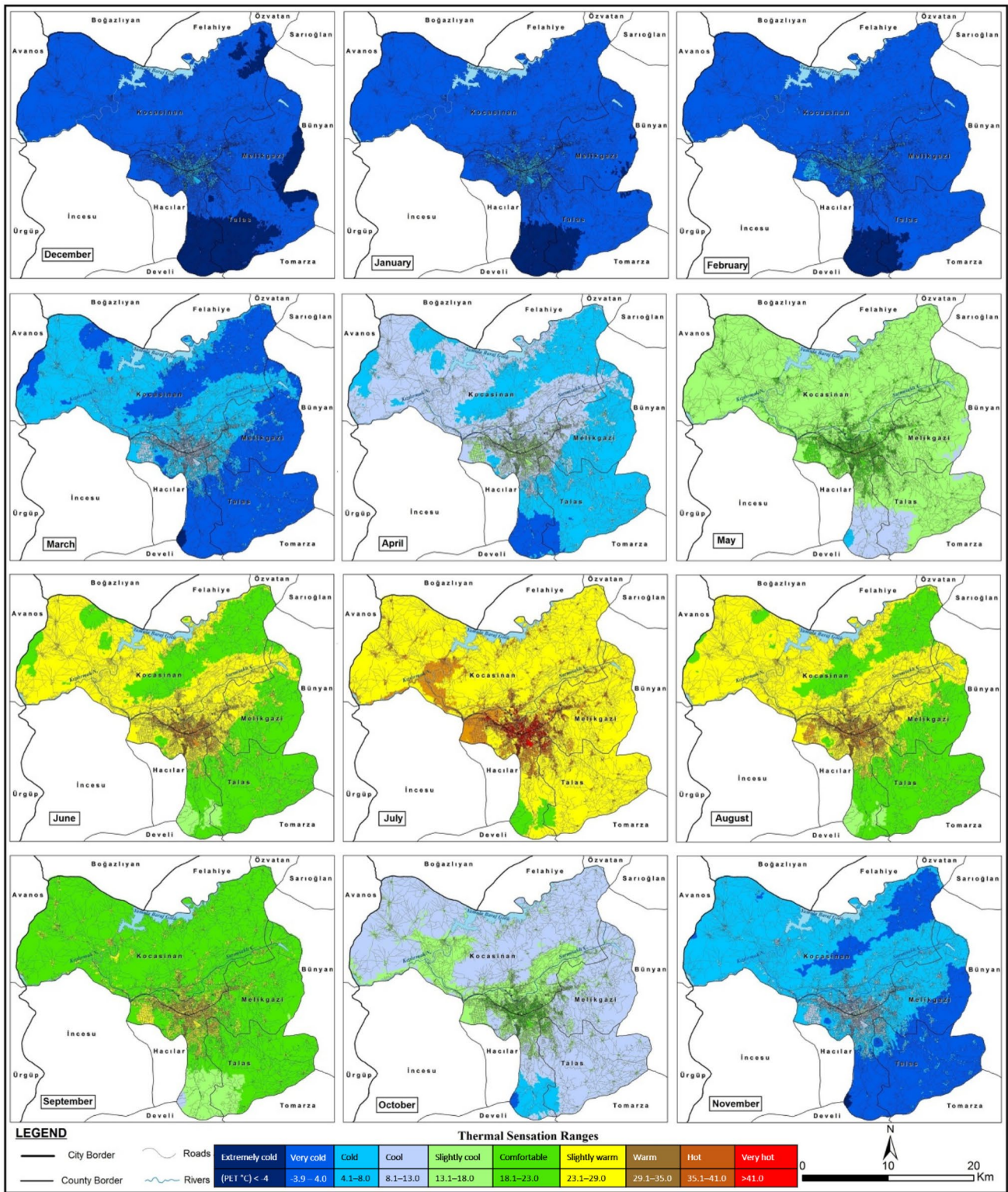


Fig. 6 Kayseri’s monthly distribution of thermal comfort conditions in the far future (2069–2098) according to the RCP4.5 scenario

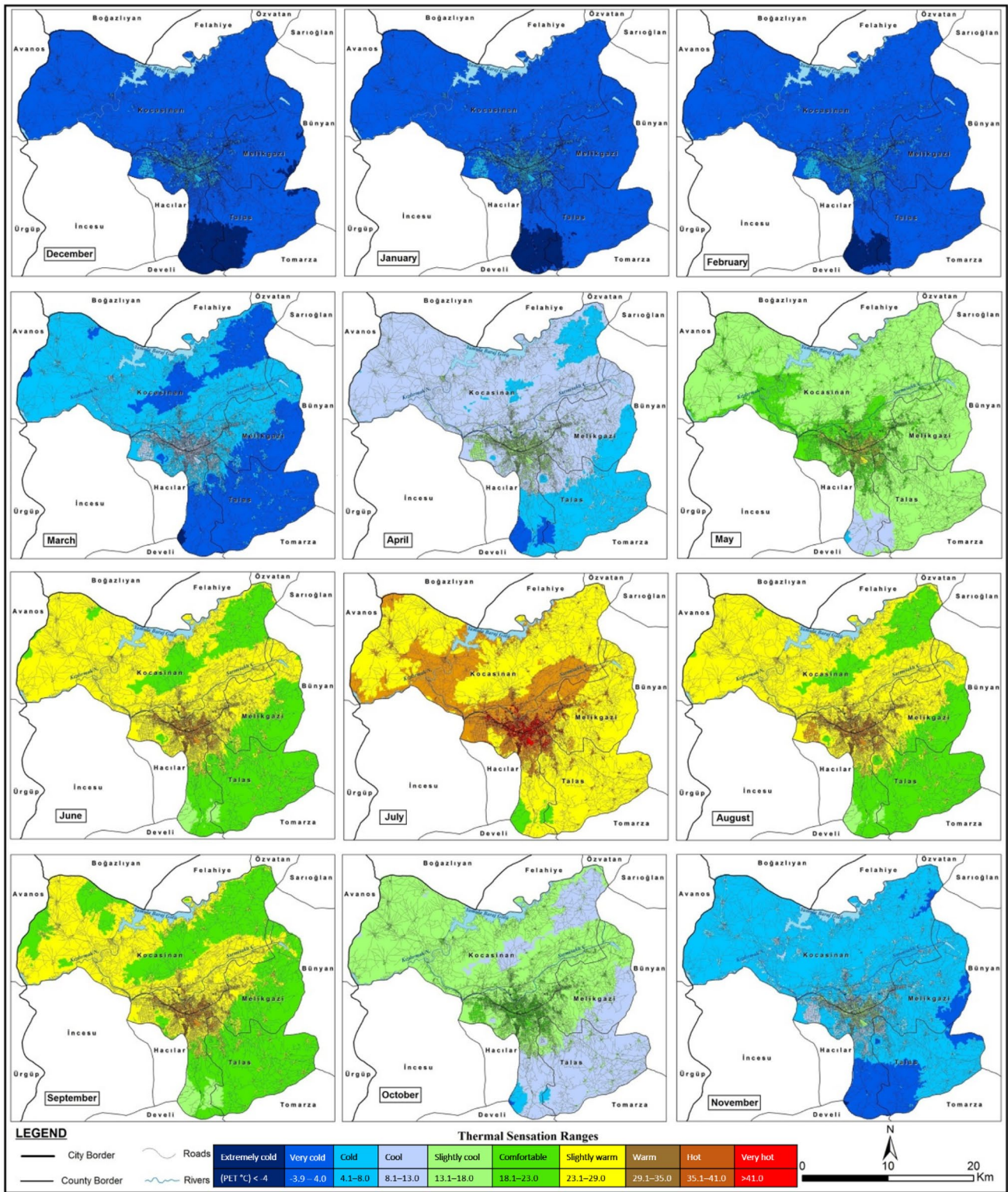


Fig. 7 Kayseri’s monthly distribution of thermal comfort conditions in the far future (2069–2098) according to the RCP8.5 scenario

Months/ Ranges	Past (1961 – 1990) (%)								Present (1991 – 2020) (%)								Difference (%)								
	Extremely cold	Very cold	Cold	Cool	Slightly cool	Comfortable	Slightly warm	Warm	Extremely cold	Very cold	Cold	Cool	Slightly cool	Comfortable	Slightly warm	Warm	Extremely cold	Very cold	Cold	Cool	Slightly cool	Comfortable	Slightly warm	Warm	
I	97.2	2.8							22.4	76.4	1.2						-75	73.6	1.2						
II	38.2	61.7	0.1						6.5	90.7	2.8						-32	29	2.7						
III	0.6	95.4	3.3	0.7					0.2	29.4	64.4	5.8	0.2				-0.4	-66	61.1	5.1	0.2				
IV		3.6	40.6	54.4	1.4					2	23.3	69.7	4.8	0.2				-1.6	-17	15.3	3.4	0.2			
V		0	0.9	33.1	64.2	1.8					0.3	6.5	85.1	7.4	0.7				-0.6	-27	20.9	5.6	0.7		
VI				1	35.2	62.1	1.7					0.1	4	80.7	14.5	0.7				-0.9	-31	18.6	12.8	0.7	
VII					2.9	62.7	33.9	0.5					0.5	10.6	84.2	4.7					-2.4	-52	50.3	4.2	
VIII					2.5	56.7	40.3	0.5				0.1	3.4	71.2	23.5	1.8				0.1	0.9	14.5	-17	1.3	
IX				3.3	68.9	26.9	0.9					0.3	6.1	84.9	8.5	0.2					-3	-63	58	7.6	0.2
X		0.6	9.3	87.4	2.6	0.1				0.2	3.2	69.8	24.8	2						-0.4	-6.1	-18	22.2	1.9	
XI	0.5	92.5	6	1					0.2	35.7	58.5	5.4	0.2							-0.3	-57	52.5	4.4	0.2	
XII	62.5	37.4	0.1						27.8	70.6	1.6									-35	33.2	1.5			

Fig. 8 Spatial percentile distributions (%) past and present thermal comfort conditions of Kayseri

range reflects an increase in spring (April 15.3%) and autumn (November 4.4%) whilst considerable rates of decrease are seen in May (26.6%) and October (17.6%). ‘Slightly cool’ range is prevalent over 7 and 9 months of a year in the past and present, respectively. This range shows considerable decrease rates in early summer (June 31.2% and September 62.8%) compared to the past. ‘Comfortable’ range is prevalent over 6 and 7 months of a year in the past and present, respectively. This range reflects a significant decrease in July (52.1%) and increase in September (58.0%). ‘Slightly warm’ range is seen only 4 months in the past but 5 months at present. This range increases its prevalence in summer months especially in July (50.3%) whilst decreasing in August (16.8%). The number of months when ‘warm’ range is prevalent increased from 2 in the past to 4 at present, and its prevalence increased in all of the months.

It can be stated from the results obtained from the differences between past and present time that the ranges which are prevalent in their expected season or months

(e.g. extremely cold in winter) changed their prevalent time at present conditions by wholly deviating or expanding the time intervals. The ranges in cold and cool categories deviated or expanded one or two months by passing to next warmer categories. Warm and hot categories also replaced with next warmer categories. Also, neutral conditions began to be seen in mid spring, early summer and autumn whilst in the mid-summer (July) it leaves its place to warmer by reducing its prevalent area.

Figure 9 shows the future spatial distribution of thermal comfort conditions in near and distant future based on RCP4.5 and 8.5 scenarios. According to the table, in both periods, there is an increase in the percentile and length of the prevalent period of warm ranges (i.e. slightly warm, warm, and hot). Even though ‘hot’ range is not seen in both the past and present, it is predicted to be seen in the future. Prevalence of cold, cool, and comfortable ranges is predicted to reduce, and a deviation of all ranges to the next warmer range is also expected.

Months/ Ranges	Near future (2021 – 2050) RCP4.5												Near future (2021 – 2050) RCP8.5											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Extremely cold	8.3	5.9	0.5							0.2	21.3	6.2	4.1	0.4								0.2	12.7	
Very cold	89.8	90.9	87.6	2.4						0.3	27.7	77	90.7	91.8	69.7	3.9						0.2	25.9	85.4
Cold	1.8	3.2	8.9	26.3	0.5					3.6	65.9	1.7	3.1	4.1	25.9	42.3	0.5					2.6	67.5	1.9
Cool			3	66.7	11.8	0.2		0.1	0.5	75.8	5.5				4	49.9	11	0.1		0.1	0.3	56.5	5.8	
Slightly cool				4.6	81.9	3.6	0.2	2.3	13.2	18.5	0.7					3.9	82.3	2.9	0.1	3.3	7	37.8	0.7	
Comfortable					5.9	74.4	3.7	49.9	80.3	1.8						-	6.2	62	2.8	68.1	84.7	2.9		
Slightly warm						20.8	87.5	45.8	6								-	33.7	87.4	26.7	7			
Warm						1.1	8.2	1.9										1.2	8.4	1.8	0.2			
Hot							0.5													1.3				
Months/ Ranges	Distant future (2069 – 2098) RCP4.5												Distant future (2069 – 2098) RCP8.5											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Extremely cold	7.6	5.5	0.3							0.2	16.1	4.6	3.2	0.2								0	7.7	
Very cold	90.5	91.1	50.5	4.4						0.2	33.6	82.2	91.5	91.8	37.8	2.2						0.1	11.8	89.3
Cold	1.9	3.9	44.7	48.1	0.3					3.4	60.4	3	3.9	4.9	56.6	24.7	0.2					1.1	79.7	3
Cool			4.5	43.9	7.2				0.3	72.7	5.6			0	5.3	68.3	3.8					30.5	6.8	
Slightly cool				3.6	84.7	2.2		1.7	6.1	21.8	0.2					4.8	78.1	1.6		1.4	2.5	64.1	1.6	
Comfortable					7.5	47.1	2.3	39.6	84.9	1.9						0	16.3	37.6	1.5	33.8	52	4.3		
Slightly warm					0.2	49	83.6	56	8.5								1.6	59.6	68.7	61.6	43.7			
Warm						1.7	12.8	2.7	0.2									1.8	28.2	3.2	1.8			
Hot							1.4													1.6				

Fig. 9 Spatial percentile distributions (%) past and present thermal comfort conditions of Kayseri

### Discussion and Conclusion

People are tolerable to a range of thermal stress varying depending on several factor groups, most important of which includes climatic parameters from temperature to solar radiation. As a combined effect of ambient atmospheric conditions, thermal comfort conditions are vitally important for the performance of human activities efficiently as well as public mental and physical health and economic gains based on energy savings. Climate hazards to world resources including humans as the result of climate change are expected to increase the risks and impacts of extreme events like prolonged heat waves, extreme weather events, and droughts. All the climate hazards and their related impacts are expected to play bigger roles in thermal comfort conditions. Therefore, following the trends of the past, present, near, and distant future in both climate elements and their combined effects is important to know the way of the changes.

Thermal comfort conditions are hard to determine and calculate since they depend on more than one factor. When the spatial distribution of meteorological factors can be estimated using some methods, e.g., interpolation, it is hard to determine the spatial distribution of a parameter which is calculated through a formula considering partial effects of each parameter. Therefore, firstly, the spatial distribution of these parameters should be estimated individually; then they should be taken in the model to obtain a model result. In addition, the parameters like temperature and rainfall are evaluated individually to determine future climate hazards and the changes in climate elements. Another aspect of the thermal comfort calculations is the difficulty of estimating index values in the future as the future values of the component parameters in the index should be known individually. Therefore, in the present study meteorological parameters taking place amongst the index components were estimated daily according to RCP4.5 and RCP8.5 and then taken into the RayMan model to calculate thermal comfort index values.

The city of Kayseri, which has been developing socio-economically and enlarging spatially since the first years of the modern Turkish Republic, is amongst the industrialised settlements in the country. The city centre is the combination of three densely built and crowded city parts (the neighbourhoods of Kocasinan, Melikgazi, and Talas). One-third of the provincial population was inhabited in the city centre in 1950 by reaching 50% in 1980 due to the industrialisation and 87.6% today (Kaya & Toroğlu, 2015). Both spatial and spatiotemporal analyses revealed that in the city centre in the past winter season brings freezing extremely cold and very cold thermal sensations whilst these effects leave the stage to cold stress. In the near and distant future, extremely cold sensation will disappear in the area in winter and cold range will be more prevalent in winter. In summer, at present conditions, warm sensation has gained base in the area by expanding its surface compared to the past. In the near and distant future, this trend is expected to continue and the surface area where warm sensation will be perceived will increase. Another important conclusion in the study is that ‘very hot’ thermal sensation and extremely heat stress will be seen in the area and this stress will be more effective in the built-up urban surface. Compared to the past, present conditions are exposed less to cold stress from ‘cold’ thermal sensation range in spring and autumn. In addition, prevalence of neutral conditions i.e. ‘comfortable’ range and ‘slightly warm’ heat stress increased at present compared to the past. In the near and distant future, in spring and autumn ‘slightly warm’ stress and ‘comfortable’ conditions are expected to enlarge their effective areas. Some studies in literature support the results in the present study. For instance, it was stated that compared to the past, an increase is experienced in the length of the period in a year when discomfort (out of neutral conditions) is prevalent at present (Mcgregor et al., 2002). In the same way, in the future, an increase is expected to happen in heat stress perception and there will be higher demands for cooling (Matzarakis & Amelung, 2008; Matzarakis & Endler, 2010; Şensoy, 2020). Cities will also experience longer time periods when strong heat stress is prevalent (Cheung & Hart, 2014). Depending on the changes in thermal comfort conditions, length and time of ‘ideal’ tourism seasons in a year are expected to change (EUROCONTROL, 2021; Kum, 2011; Nastos & Matzarakis, 2019). It has also been stated that in Bolu, which is located in the Black Sea climate region with humid conditions, the ‘hot’ stressed areas will expand in the summer season, whilst the comfortable areas will decrease in Amasya, whilst the uncomfortable areas will increase (Çağlak, 2022; Çağlak & Türkeş, 2022).

Due to the effects of urbanisation, like land-use change at local level and global climate change, thermal comfort conditions have showed variations compared to the past in the study area. In the future, the trend in the change of thermal

conditions is expected to continue depending on climate change again. With this change, people in urban parts of the study area will experience torrid heat stress. Prevalence of such unfavourable thermal conditions will cause and increase the incidence of some health problems amongst people. In addition, as can be predicted, the need for heating will be lower whilst cooling demand will increase. ‘Ideal’ tourism periods or comfortable periods for outdoor human activities will change in terms of length and time point. The results of the present study are important for the cities to revise their spatial development plans based on the experienced changes in the past trend and those to be expected in the future. In the spatial development, transformation or regeneration of cities, new and contemporary urban planning/design approaches which involve green infrastructures, ecological measures and adopt sustainability principles and ecological design efforts should be followed by local governments and decision makers.

**Author Contribution** All authors contributed to the study conception and design. Material preparation, data collection, and analysis were done by Savaş Çağlak. The interpretation of the analyses was made by Süleyman Toy. The first draft of the article was written by Muhammet Bahadır. All authors read and approved the final manuscript.

**Availability of Data and Material** Data and materials are available by request from the corresponding author or from relevant organisations.

## Declarations

**Ethics Approval** Since only numerical data were used in the study and no personal information was used, ethical approval was not required.

**Ethical Responsibilities of Authors** All authors have read, understood, and properly complied with the statement in the Instructions for Authors and are aware that, with minor exceptions, no changes in authorship can be made after submission.

**Conflict of Interest** The authors declare that have no conflicts of interest.

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