# Monitoring the past and future trends of urban thermal comfort conditions through a new methodology

**Savaş Çağlak**
**Süleyman Toy** ( stoy58@gmail.com )
Ataturk Universitesi https://orcid.org/0000-0002-3679-280X
**Muhammet Bahadır**

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## Abstract

Human thermal comfort representing the satisfaction of mind with ambient air conditions has significant effects on socioeconomic 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 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 aims to determine the TCCs trends in the past compared to the present while 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 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. Future predictions have also implied the same change trend and the level of heat stress which has never been experienced in the study area e.g. strong heat stress. Increase in the prevalence of unfavourable thermal comfort conditions causes the decrease in the liveability indicators in especially urban areas, including serious economic loses 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.


## 1. Introduction

As the average conditions of observed weather conditions over a vast region and a long time period at least 30 years (for WMO) (Atalay, 2010), climate, has still affected (in)directly the life styles, clothes, food, health and wellbeing, psychological characteristics, production and consumption habits of humans (Erol, 2008; Atalay, 2010; Türkeş, 2017). Majority of human beings inhabit temperate climate zone where four seasons are clearly experienced therefore, some diseases are prevalent, 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, precipitation (WMO 1999; *Matzarakis 2000*). 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 (Parsons, 2003; Öngel and Mergen, 2009; Çağlak, 2021). Human body balances body core temperature according to its surrounding (Lai et al., 2017) by stimulating brain. Under unfavourable thermal conditions, when body is exposed to heat or cold stress then people face health problems like fatigue, chronicle diseases, headache, psychologic defects, loss of work efficiency and interference of activities and increase in death rates (Zaninovic and Matzarakis, 2009; Nastos and 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 19th century depending on intensifying anthropogenic activities (industrialization, deforestation, increase in urban areas, asphalting, 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 (Blazejczyk 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, those with chronic disease and supressed immune system.

Impacts of climate change is 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 while 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 (Mcgregor et al., 2002; Matzarakis and Amelung, 2008; Matzarakis and Endler, 2010; Cheung and Hart, 2014; Nastos and Matzarakis, 2019). Studies in Turkey carried out on the effects of climate change on thermal comfort conditions are limited to West Mediterranean region of Turkey related majorly to tourism (Kum, 2011; Şensoy, 2020; Demiroğlu et al. 2020). Turkey located in Mediterranean region is among 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. 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 human body. The aim of the study is to calculate thermal comfort conditions for present, near 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.

### 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 center 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; 35º 3' 15" – 35º 43' 51" E; 39º 2' 16" – 38º 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). Total population of the study area is 1.147.908 (most populated is Melikgazi with 582.055 people while the least one is Talas with 165.127 people; TUIK, 2020).

Climatic characteristics of the city represent those unique to continental Interior Anatolia Region, where 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 1960–2020 period in the city centre, long term mean annual temperature is 10.5°C (between 22.0 ºC in July and – 1.7 ºC 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 1.8m/s (Table 1). In winter the city is under the effect of stable air masses and exposed to inversion phenomenon.

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 | 51cm | 19.02.2008 |
| Record wind velocity | 45 m/s | 12.02.1969 |

## 2. Methods

Meteorological data measured in the meteorological observation station (with 17196 International Code) in the garden of Regional Meteorology Administration Office in the centre of the city was used to calculate thermal comfort conditions today and in the future. Measurement period is 1961–2020 and meteorological parameters included are air temperature (Ta;°C), relative humidity (RH; %), wind velocity (Wv; m/s) and cloudiness (C; octas). Ta, RH, Wv 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/m2 (as in IPCC’s AR5; IPCC 2014, Choi et al. 2019 and Şensoy, 2020).

Model outputs have some errors due to the false baseline data and some mathematical formulae used. These errors tried to be minimised by running the model for the previously measured data and calibrating the values with measurement data. In addition, the bias correction of projection data was performed using regression equation obtained from model – observation scattering. Since the correlation coefficient of regression equation is $R^2 = 0.97$, ($y = 0.9611x + 0.091$) has the available characteristics.

Thermal comfort conditions were calculated through RayMan model which is adopted word wide and considers several factors related to both human body (e.g. 35 year – 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; VDI, 1998; Höppe, 1999; Matzarakis et al., 1999). The obtained thermal comfort values were categorised considering the ranges given in Table 2.

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

| PET (°C) | Thermal Sensation | Level of Thermal Stress | Colours |
|---|---|---|---|
| < -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 | |
| **18.1–23.0** | **Neutral (comfortable)** | **No thermal stress** | |
| 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 | |

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 x 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 past and future. Percentage ratio of the comfort ranges was also calculated in the area and given in a table. In the modelling of the spatial distribution of PET values, land-use, elevation, mean radiant temperature (Tmrt), wind velocity and solar radiation maps were prepared at 100 x 100 – m resolution and their individual effects on PET index value were also considered. 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 1.1m form 2.0m standard measurement height for purpose of bioclimatic analysis (Nastos and Matzarakis, 2013; 2019). Formula (1) was employed to downscale the wind speed values measured at 2 m at meteorology station to 1.1 m height.

**Formula (1)** $WS1.1 = WSh \times (1.1/h)^{a}$, where

$a = 0.12 \times z0 + 0.18$

**WSh:** wind speed measured at standard heights (m/s) (at 10 or 2 m)

**h:** height of the measurement point (generally 10 metre)

**a:** empirical variable for surface roughness

**z0:** surface roughness depending on the land-use characteristics (Troen and Petersen,1989), which was determined according to the surrounding area at 500 – m distance from the station (Troen and Petersen, 1989). Roughness value (height; z0) was derived from European Wind Atlas.

## 3. 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.

# 3.1. Thermal comfort conditions in the past (1961–1990)

Results of the analysis conducted for the past conditions are presented in Fig. 2 (spatial) and Table 3 (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 while 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 while 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. Rural part of the study area faces “cool” and “slightly cool” ranges. In summer season, June is the first month to observe “slightly 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 while 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. 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.

## 3.2. Thermal comfort conditions at present (1991–2020)

Figure 3 and Table 3 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 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 while only “comfortable” range was seen in May in the past contrarily to “slightly warm” stress at present. In 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 while 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 while 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.

## 3.3. 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 war”, “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 (Fig. 4; Fig. 5).

## 3.4. Thermal comfort conditions in 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 while in October “comfortable” zones and in November “slightly cool” zones will enlarge their surface areas (Fig. 6; Fig. 7; Table 3).

## 3.5. Percentile spatial distribution of thermal comfort conditions

The study area consists of the neighbourhoods, Kocasinan (1471 $km^2$), Melikgazi (668 $km^2$) and Talas (444 $km^2$) all of which cover a surface area of 2583 $km^2$. Table 3 gives the percentile ratios of comfort ranges all over the study area in the past and at 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 while in the period representing the present 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 most dominantly in March (95.4%) which is followed by November (92.5%) and February (61.7%) while at present this range is prevalent over 7 months and in winter moths its prevalence increased at important rates (73.6%, 29.0% and 33.2%, in January, February and December, respectively) while decreasing in spring (March and April) and autumn (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) while 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 range reflects an increase in spring (April 15.3%) and autumn (November 4.4%) while 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%) while 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.

Table 3

Spatial percentile distributions (%) past and present thermal comf

| Past (1961–1990) (%) | | | | | | | | | Present (1991–2020) (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months/ Ranges | **Extremely cold** | **Very cold** | **Cold** | **Cool** | **Slightly cool** | **Comfortable** | **Slightly warm** | **Warm** | **Extremely cold** | **Very cold** | **Cold** | **Cool** | **Slightly cool** | **Comfort** |
| I | 97.2 | 2.8 | | | | | | | 22.4 | 76.4 | 1.2 | | | |
| II | 38.2 | 61.7 | 0.1 | | | | | | 6.5 | 90.7 | 2.8 | | | |
| III | 0.6 | 95.4 | 3.3 | 0.7 | | | | | 0.2 | 29.4 | 64.4 | 5.8 | 0.2 | |
| IV | | 3.6 | 40.6 | 54.4 | 1.4 | | | | | 2.0 | 23.3 | 69.7 | 4.8 | 0.2 |
| V | | 0.0 | 0.9 | 33.1 | 64.2 | 1.8 | | | | | 0.3 | 6.5 | 85.1 | 7.4 |
| VI | | | | 1.0 | 35.2 | 62.1 | 1.7 | | | | | 0.1 | 4.0 | 80.7 |
| VII | | | | | 2.9 | 62.7 | 33.9 | 0.5 | | | | | 0.5 | 10.6 |
| VIII | | | | | 2.5 | 56.7 | 40.3 | 0.5 | | | | 0.1 | 3.4 | 71.2 |
| IX | | | | 3.3 | 68.9 | 26.9 | 0.9 | | | | | 0.3 | 6.1 | 84.9 |
| X | | 0.6 | 9.3 | 87.4 | 2.6 | 0.1 | | | | 0.2 | 3.2 | 69.8 | 24.8 | 2.0 |
| XI | 0.5 | 92.5 | 6.0 | 1.0 | | | | | 0.2 | 35.7 | 58.5 | 5.4 | 0.2 | |
| XII | 62.5 | 37.4 | 0.1 | | | | | | 27.8 | 70.6 | 1.6 | | | |

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 moths (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 while in the mid – summer (July) it leaves its place to warmer by reducing its prevalent area.

Table 4 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 period 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 past and present it is predicted to be seen in the future. Prevalence of cold, cool and comfortable ranges are predicted to reduce and a deviation of all ranges to the next warmer range is also expected.

Table 4
Spatial percentile distributions (%) past and present thermal comfort conditions of Kayseri

| | **Near future (2021–2050) RCP4.5** | | | | | | | | | | | | **Near future (2021–2050) RCP8.5** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Months/ Ranges | **I** | **II** | **III** | **IV** | **V** | **VI** | **VII** | **VIII** | **IX** | **X** | **XI** | **XII** | **I** | **II** | **III** | **IV** | **V** | **VI** | **VI** |
| **Extremely cold** | 8,3 | 5,9 | 0,5 | | | | | | | | 0,2 | 21,3 | 6,2 | 4,1 | 0,4 | | | | |
| **Very cold** | 89,8 | 90,9 | 87,6 | 2,4 | | | | | | 0,3 | 27,7 | 77,0 | 90,7 | 91,8 | 69,7 | 3,9 | | | |
| **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 | | |
| **Cool** | - | - | 3,0 | 66,7 | 11,8 | 0,2 | | 0,1 | 0,5 | 75,8 | 5,5 | - | - | - | 4,0 | 49,9 | 11,0 | 0,1 | |
| **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, |
| **Comfortable** | | | | - | 5,9 | 74,4 | 3,7 | 49,9 | 80,3 | 1,8 | | | | | | - | 6,2 | 62,0 | 2, |
| **Slightly warm** | | | | | - | 20,8 | 87,5 | 45,8 | 6,0 | | | | | | | | - | 33,7 | 87 |
| **Warm** | | | | | | 1,1 | 8,2 | 1,9 | - | | | | | | | | | 1,2 | 8, |
| **Hot** | | | | | | | 0,5 | | | | | | | | | | | | 1, |
| Very hot | | | | | | | | | | | | | | | | | | | |
| | **Distant future (2069–2098) RCP4.5** | | | | | | | | | | | | **Distant future (2069–2098) RCP8.5** | | | | | | |
| Months/ Ranges | **I** | **II** | **III** | **IV** | **V** | **VI** | **VII** | **VIII** | **IX** | **X** | **XI** | **XII** | **I** | **II** | **III** | **IV** | **V** | **VI** | **VI** |
| **Extremely cold** | 7,6 | 5,5 | 0,3 | | | | | | | | 0,2 | 16,1 | 4,6 | 3,2 | 0,2 | | | | |
| **Very cold** | 90,5 | 91,1 | 50,5 | 4,4 | | | | | | 0,2 | 33,6 | 82,2 | 91,5 | 91,8 | 37,8 | 2,2 | | | |
| **Cold** | 1,9 | 3,9 | 44,7 | 48,1 | 0,3 | | | | | 3,4 | 60,4 | 3,0 | 3,9 | 4,9 | 56,6 | 24,7 | 0,2 | | |
| **Cool** | - | - | 4,5 | 43,9 | 7,2 | | | | 0,3 | 72,7 | 5,6 | - | - | 0,0 | 5,3 | 68,3 | 3,8 | | |
| **Slightly cool** | - | - | - | 3,6 | 84,7 | 2,2 | | 1,7 | 6,1 | 21,8 | 0,2 | - | - | - | - | 4,8 | 78,1 | 1,6 | |
| **Comfortable** | | | | - | 7,5 | 47,1 | 2,3 | 39,6 | 84,9 | 1,9 | | | | | | 0,0 | 16,3 | 37,6 | 1, |
| **Slightly warm** | | | | | 0,2 | 49,0 | 83,6 | 56,0 | 8,5 | | | | | | | | 1,6 | 59,6 | 68 |
| **Warm** | | | | | | 1,7 | 12,8 | 2,7 | 0,2 | | | | | | | | | 1,8 | 28 |
| **Hot** | | | | | | - | 1,4 | - | | | | | | | | | | - | 1, |
| Very hot | | | | | | | - | | | | | | | | | | | | - |

## 4. 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 etc. All the climate hazards and their related impacts are expected to play bigger roles in thermal comfort conditions. Therefore, following the trends of 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 among the index components were estimated daily according to RCP4.5 and RCP8.5 and then taken into RayMan model to calculate thermal comfort index values.

The city of Kayseri, which has been developing socioeconomically and enlarging spatially since the first years of the modern Turkish Republic, is among 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 and 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 while 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 and Amelung, 2008; Matzarakis and Endler, 2010; Şensoy, 2020). Cities will also experience longer time periods when strong heat stress is prevalent (Cheung and Hart, 2014). Depending on the changes in thermal comfort conditions, length and time of "ideal" tourism seasons in a year are expected to change (Kum, 2011; Nastos and Matzarakis, 2019; EUROCONTROL 2021).

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 among people. In addition, as can be predicted, the need for heating will be lower while 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.

## Declarations

**Disclosure of potential conflicts of interest**

The authors declare that they have no conflicts of interest.

**Authors Contributions**

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by S.Ç and S.T. The first draft of the manuscript was written by ST and MB and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**Informed consent**

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**Availability of data and materials**

The data that support the findings of this study are available from the corresponding author, [S.T], upon reasonable request.

**Research involving Human Participants and/or Animals**

This article does not contain any studies involving animals performed by any of the authors.

The authors have no financial or proprietary interests in any material discussed in this article.

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## Figures

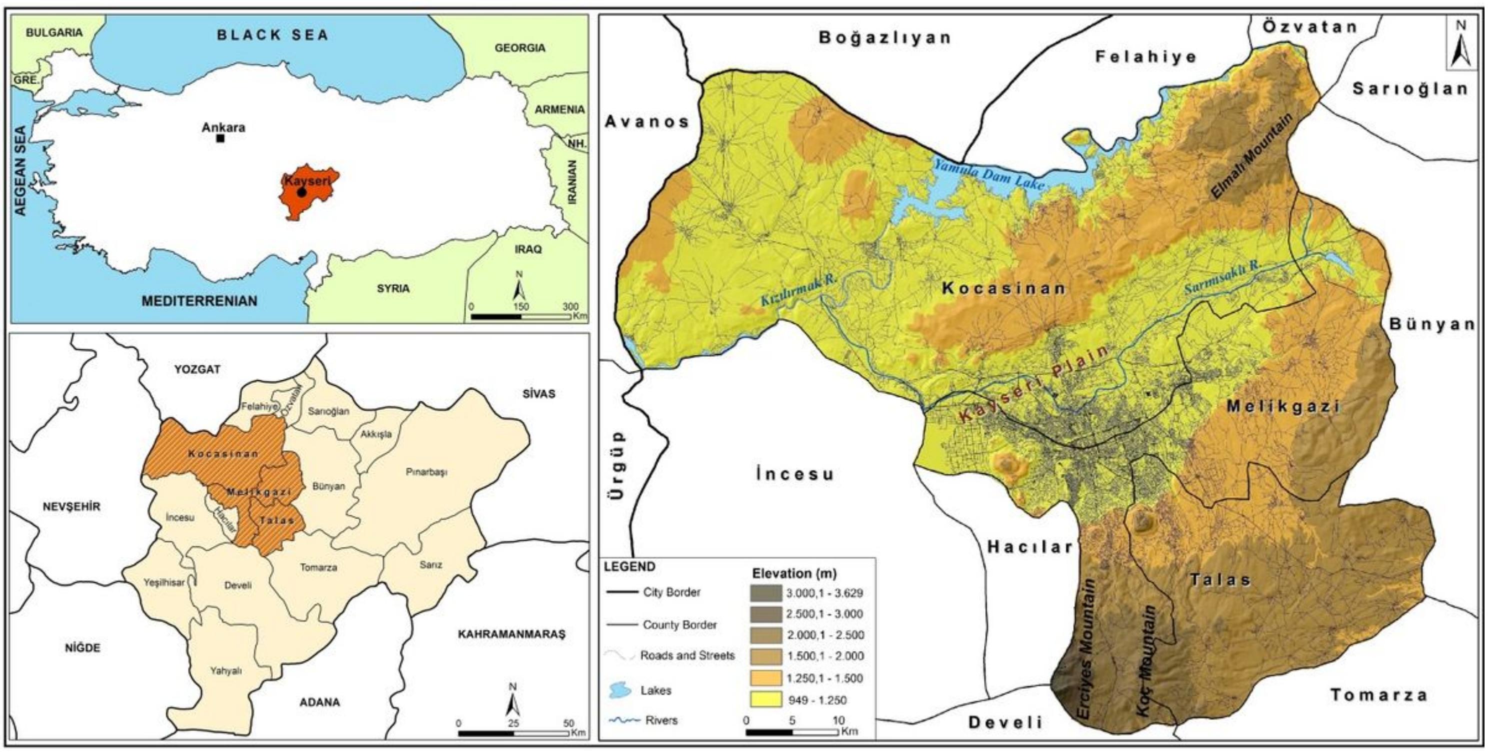
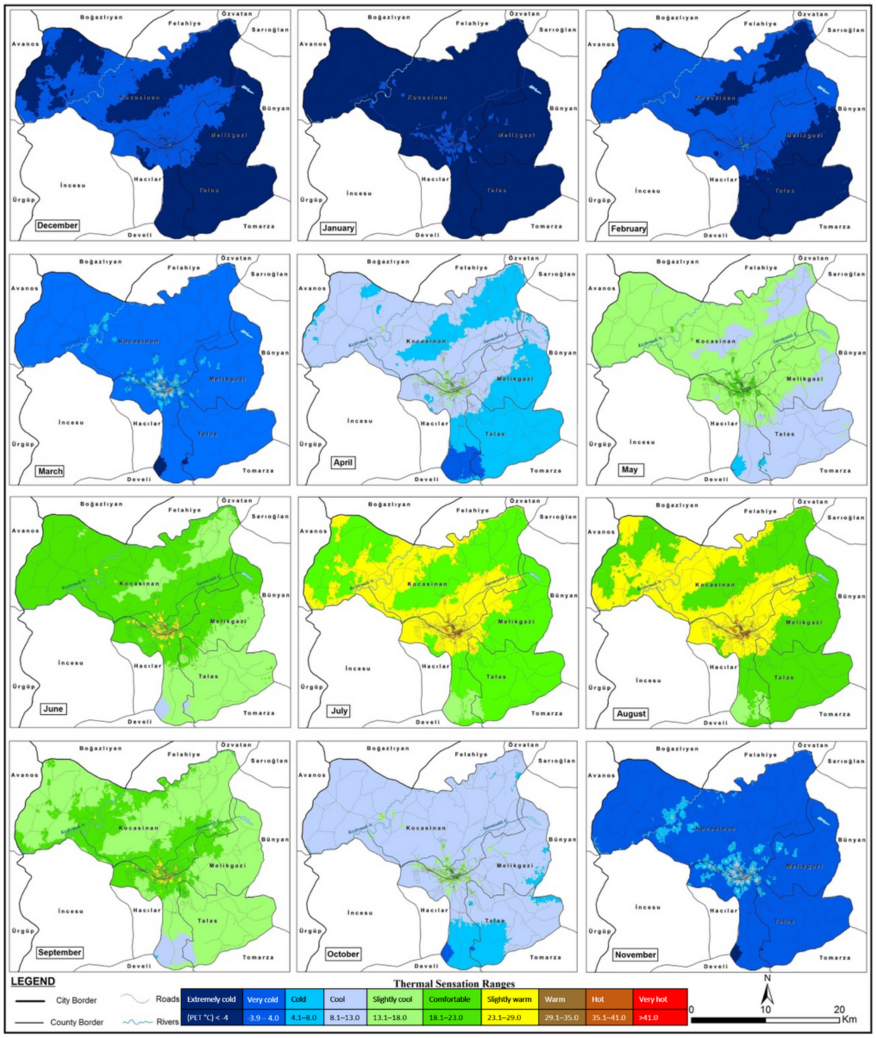


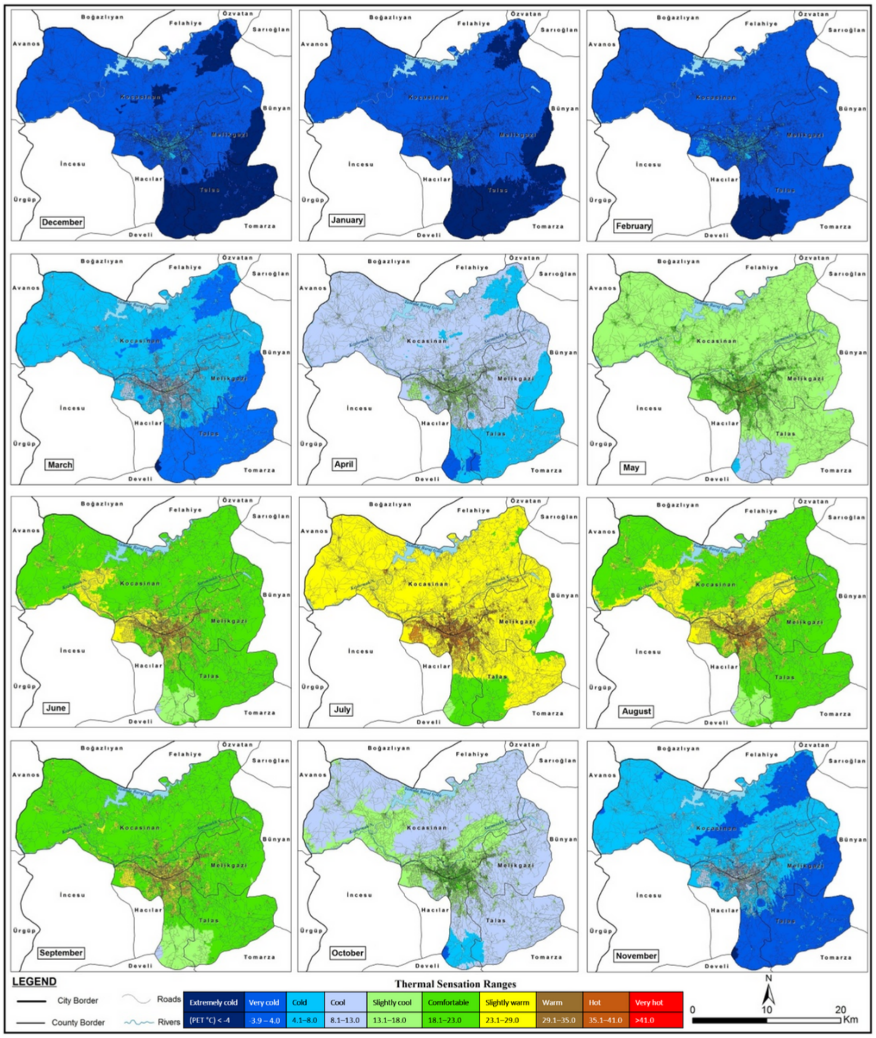

**Figure 1**

*Location map of Kayseri city*



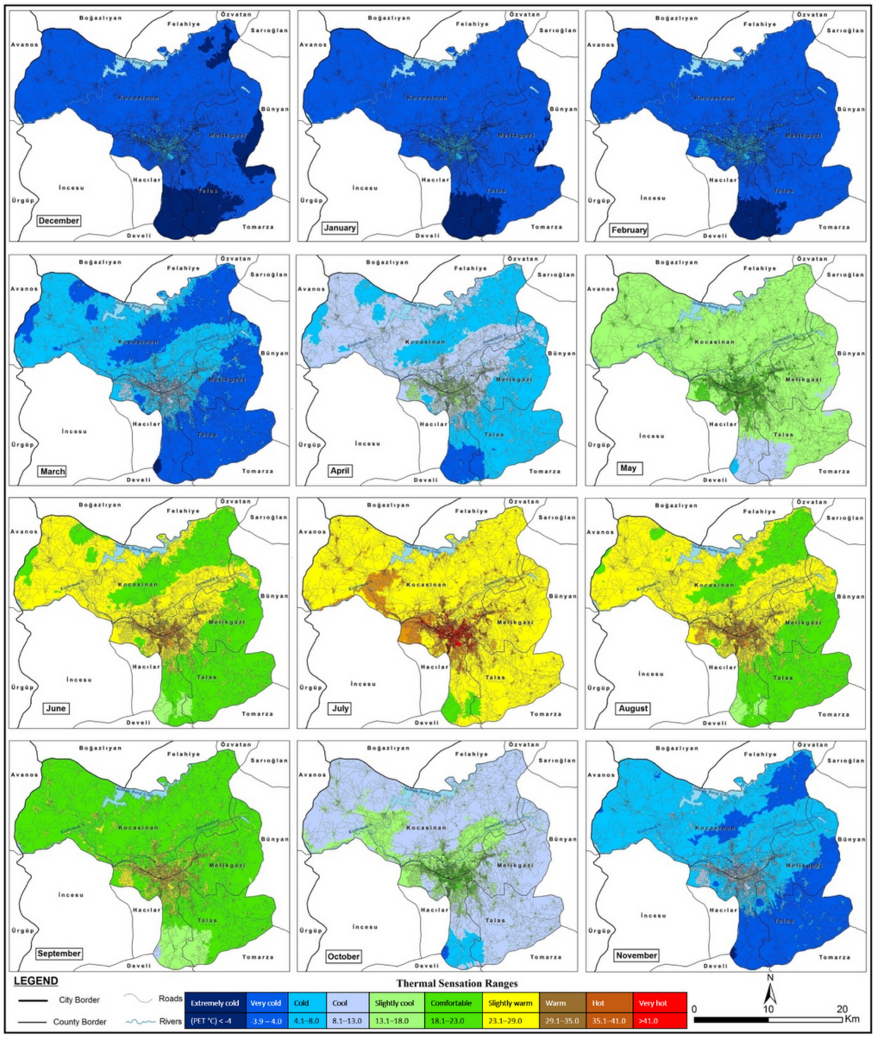

## Figure 2

*Monthly distribution of thermal comfort conditions of Kayseri in the past (1961 – 1990)*



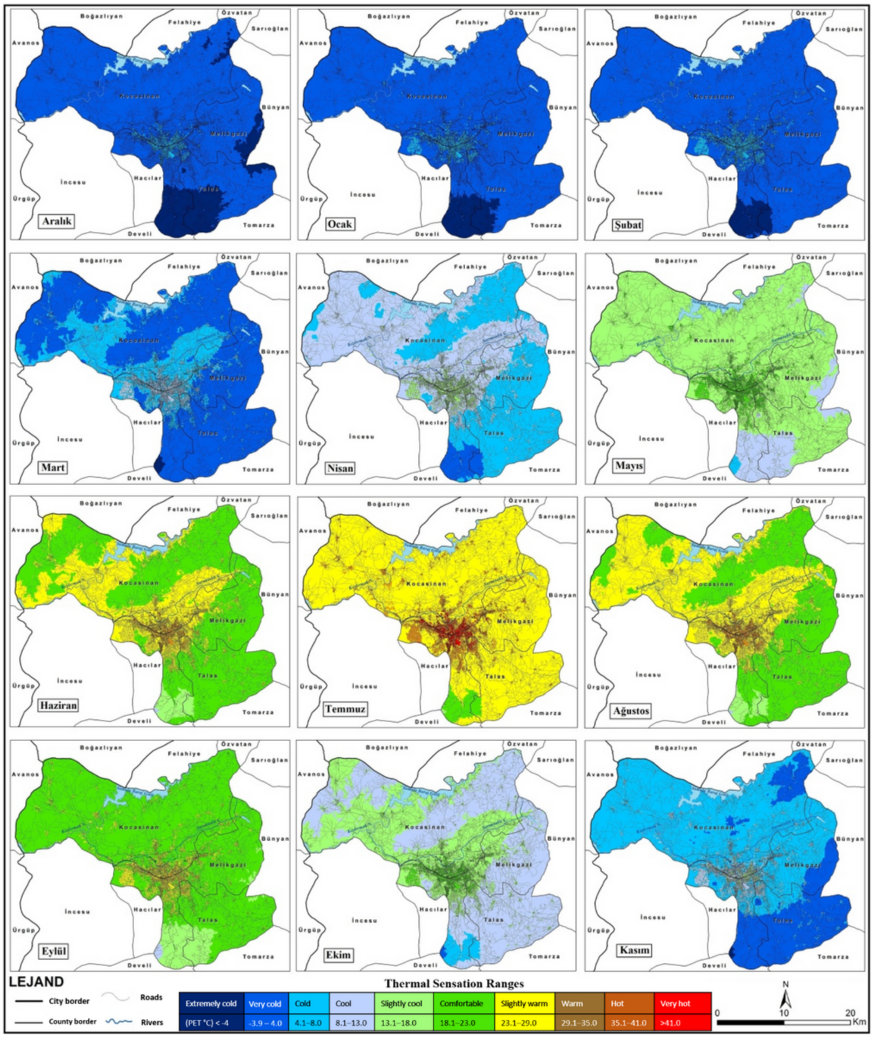

## Figure 3

*Monthly distribution of thermal comfort conditions of Kayseri in the present (1991 – 2020)*



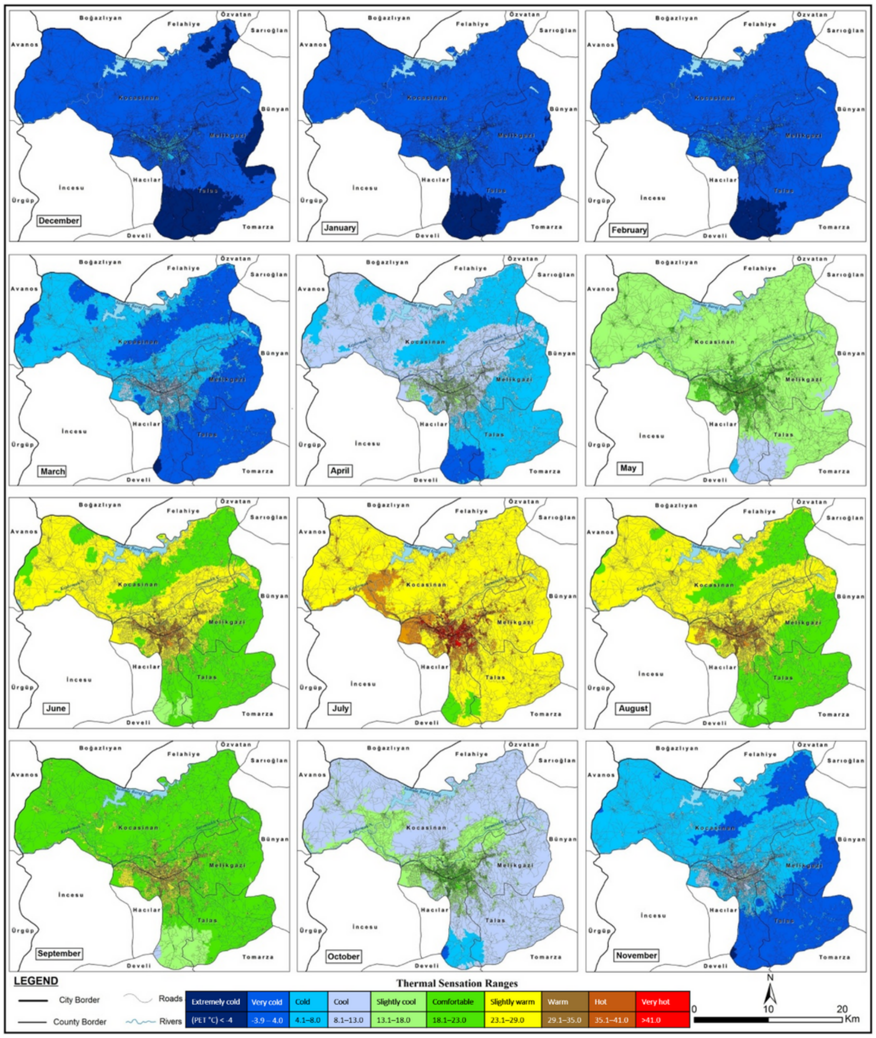

## Figure 4

*Kayseri's monthly distribution of thermal comfort conditions in the near future (2021 - 2050) according to RCP4.5 scenario*



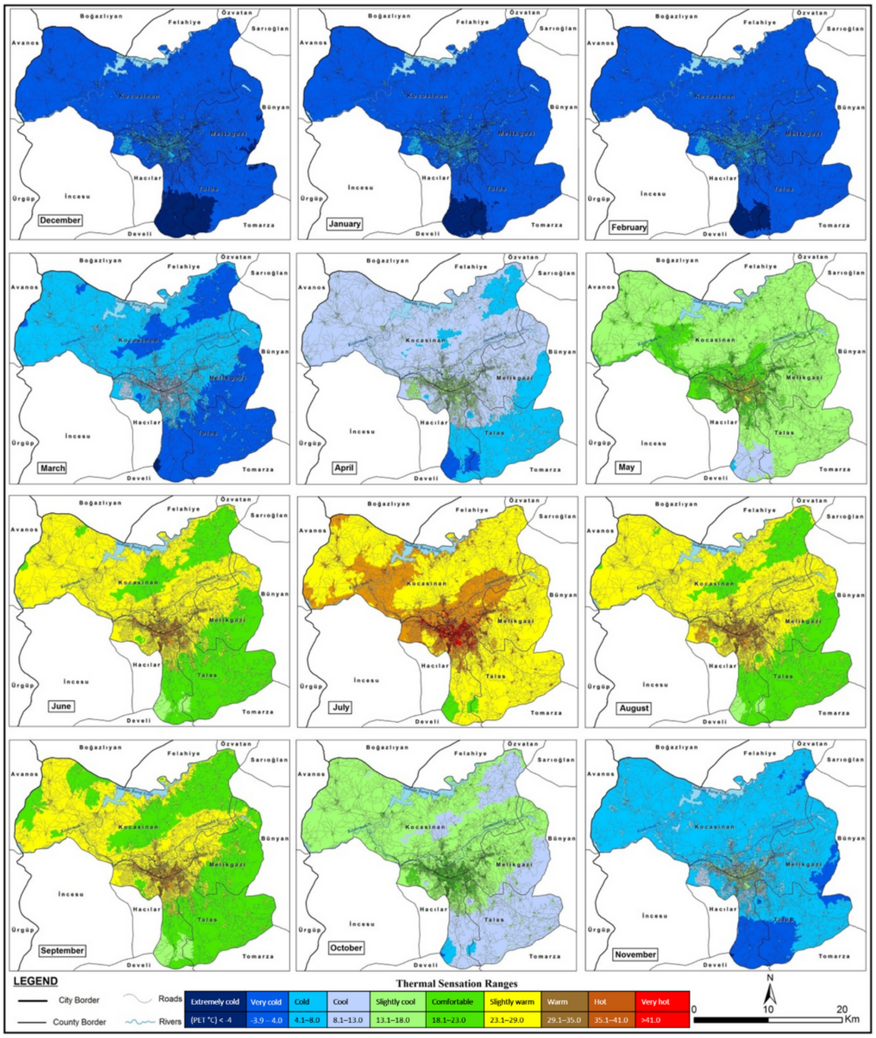

## Figure 5

*Kayseri's monthly distribution of thermal comfort conditions in the near future (2021 - 2050) according to RCP8.5 scenario*




## Figure 6

*Kayseri's monthly distribution of thermal comfort conditions in the far future (2069 - 2098) according to RCP4.5 scenario*




## Figure 7

*Kayseri's monthly distribution of thermal comfort conditions in the far future (2069 - 2098) according to RCP8.5 scenario*