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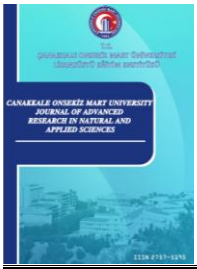

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Analysis of Spatial Distribution of Climatic Comfort Conditions in Diyarbakır City

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Research Article

Abstract − Cities have more adverse thermal comfort conditions than the rural and semi-rural areas around them. In this study, it is aimed to examine the spatial distribution of thermal comfort conditions in Diyarbakir, a historical city in the Southeastern Anatolia Region of Turkey. Thermal comfort can be defined as the state of people feeling comfortable or happy in their environment or thermal environment. Uncomfortable conditions lead to social, economic and physical negativities, especially to human health. Thermal comfort conditions were calculated with the Physiological Equivalent Temperature index obtained from the RayMan model using hourly measurement data for the 2015 – 2021 (7 years) period of four meteorological stations in the field. In the study, while 'cold' and 'cool' stresses are experienced in the winter season in Diyarbakır, 'warm', 'hot' and 'very hot' stresses were determined in the 5-month hot period of the year (May-September). Evaluations revealed that densely built urban areas in the city center (approximately 15%) have more unfavourable thermal conditions than low-density urban areas (approximately 30%) and rural areas (approximately 20%) around them. It is a vital necessity to design and plan with a contemporary smart geographical perspective to reduce the negative thermal conditions of cities and for sustainable healthy cities.

Keywords − *Diyarbakır, physiological equivalent temperature (pet), thermal comfort, urbanization, urban heat island*

1. Introduction

Human life and activities are directly dependent on natural environmental conditions. Climatic conditions in the natural environment are of great importance. Climatic conditions affect people's food-clothing choices, economic activities, psychological and physiological conditions, health, tourism activities, settlement, housing types, etc. directly or indirectly audits (Türkeş, 2010, 2021a). The climate system, which tends to change in all periods, has gained a different dimension since the 19th century with the effect of the industrial revolution. People's industry, energy, agriculture, transportation, heating and waste, construction, wrong land use, etc. In recent years, severe human-induced climate change has been experienced due to increased greenhouse gas emissions in the atmosphere as a result of activities. Changing climatic conditions cause the degradation of ecosystems, loss of habitats, and extinction of approximately 1 million species. Climatic conditions are warming at a rate that nature and humans cannot adapt to, and this causes extremes and disasters (Türkeş, 2020, 2022a). In the reports of the Intergovernmental Panel on Climate Change (IPCC) and many studies, it is stated that cities are at the forefront of climate change and that catastrophic consequences will occur in cities in the coming years (IPCC, 2022a, 2022b; Türkeş, 2022b). In Turkey, almost all cities, large or small, are warming rapidly (Türkeş, 2020). For example, with some exceptions, mean (mean, maximum, and minimum) air temperatures measured in all regions of Turkey and almost all climatology and meteorology stations established in the Southeastern Anatolia Region, the number of summers and tropical day air temperatures, a

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record high air temperatures and hot weather The frequency, duration, frequency and intensities of the waves are increasing rapidly (with statistical significance) (Erlat & Türkeş, 2013, 2017; Türkeş, 2020; Erlat, Türkeş & Aydın, 2021; etc.). Moreover, according to many studies that take into account the changes between the middle and the end of the century, air temperatures in Turkey, along with many other countries in the Mediterranean Basin, in the coming decades will be higher in the warmer part of the year (eg summer), for example towards the end of the century will be 3 to 7 ˚C higher than today (Turp, Öztürk, Türkeş & Kurnaz, 2014; Öztürk, Turp, Türkeş & Kurnaz, 2018; Turkes, Öztaş, Tercan, Erpul, Karagöz, Dengiz, Doğan, Şahin & Avcıoğlu 2020; etc.). All these results show that climatic thermal comfort is deteriorating rapidly even today and this deterioration or negativity may become more severe in the future.

At this point, we find it useful to discuss the concepts of resilience and vulnerability. Resilience is a way of thinking and designing that we need to prepare for the impacts of climate change and how we will achieve this (Türkeş, 2021b). Today, the concept of resilience, psychology and information technology, geography, ecology, public health, agriculture, business, etc. spread rapidly in different and very distant areas such as In terms of climate change, resilience means “strengthening the ability of human and natural systems to withstand and respond to changes in the Earth's climate” and “between prevention and mitigation (climate change combat) approaches to climate change on the one hand and adaptation approaches on the other. It can be considered as a way of closing the conceptual divide” (Türkeş, 2021b, 2022b). In this context, resilience can be considered a positive quality or initiative when it maintains the capacity for adaptability, learning, and/or economic and social transformation. The vulnerability to climate change is defined as “the degree to which a community or system (related to the physical geography and ecological system or socio-economic sector) is affected or vulnerable to climate change stress, the level of meeting or responding to the stress (sensitivity), and the level of adaptation or adaptation to climate change can be defined as the relationship between. In this definition, if the climate is used instead of the term climate change, then we get the concept of climatic vulnerability (Türkeş, 2014). In addition, to reduce the impact of climate change and prevent climate change, anthropogenic greenhouse gas emissions must be reduced very quickly and effectively. Climate change mitigation does not only include mitigation, it also includes all human initiatives and actions to reduce human-induced emissions of major greenhouse gases such as CO2, CH4, and N2O in all socioeconomic sectors and to improve and increase the sinks of greenhouse gases (Türkeş, 2021b, 2022a). On the other hand, considering that it is impossible, but even if greenhouse gas emissions are almost completely stopped at the level of 2015, for example, the accumulation (concentration) of CO2 and other greenhouse gases in the atmosphere will likely remain well above normal levels for the next decades (Türkeş, 2021a, 2022b), the changing climate and effects must be accommodated. But adaptation isn't just about surviving climate change. In addition to "adjustments in natural or human systems" for a new or changing environment, adaptation measures can take advantage of possible "beneficial opportunities" or some "weak-moderate adverse impacts" associated with climate change. According to the IPCC (2022c), adaptation in human systems is the process of adapting to the existing or expected climate and its effects to reduce harm or take advantage of beneficial opportunities. Adaptation in natural systems is the process of adaptation to today's (current) climate and its effects; human initiative can facilitate adaptation to the anticipated (future) climate and its effects. In reality, adaptation is a factor that should be considered at the very beginning and every stage of a sustainable development process. By pre-integrating this into their policies and strategies, governments can accelerate robust economic development while reducing vulnerability to climate change. Adaptation approaches vary by geography, time, sources of funding, levels of political support, and dozens of other factors. There is no one-size-fits-all approach to adaptation (Türkeş, 2021b, 2022b). In this context, it is necessary to determine the temporal and spatial distribution of the thermal comfort conditions of the cities for a climate-resistant sustainable urban development.

Thermal comfort can be defined as the state of feeling comfortable or comfortable/happy in the environment they are in or in the thermal environment (mainly temperature, humidity, and wind climatology) (Olgyay, 1973; Sungur, 1980; Çağlak, 2021). Uncomfortable conditions increase mortality rates (Anderson & Bell, 2009; Nastos & Matzarakis, 2011; Aboubakri, Kahnjani, Jahani & Bakhtiari, 2020), diseases such as circulatory and respiratory system (Nastos, Giaouzaki, Kampani & Matzarakis, 2013; Scherber, Langner & Endlicher, 2014; Huang, Zhao, Chen, Kan & Kuang, 2015; Fallah & Mayvaneh, 2016; Blazejczyk, Baranowski

& Blazejczyk, 2018) cause many social, economic, and physical negativities such as increases in energy use and decrease in work efficiency (Türkeş, 2010; Türkeş & Erlat, 2017).

Mankind, who settled down in the Neolithic period, later established urban settlements depending on factors such as production surplus and trade. In this respect, cities are tangible cultural heritage areas where civilizations, scientific discoveries, and socio-economic advancements occur (Yazar, 2006). However, urbanization movements in the world gained speed with the industrial revolution. With the industrial revolution, the need for labor in the cities, the education, health, and socio-economic attractiveness of urban life, and the mechanized agriculture in the countryside, many unemployed families migrated to the cities. As a result of the rapid and unplanned urbanization movement, many environmental pollutions such as squatting, the conversion of natural areas to impermeable surfaces such as asphalt and concrete, the use of motor vehicles, the use of fossil fuels, the destruction of green areas, domestic and industrial wastes have adversely affected the thermal comfort conditions of the cities. In dense and high-rise urban areas, the number of urban canyons and the areas they affect has increased, and this has led to reduced wind speed and air pollution in cities, transforming cities into suffocating, dull and hot environments (Clarke & Bach, 1971; Tuller, 1980; Mayer, 1993; Svensson & Eliason, 2002; Thorsson, Lindqvist & Lindqvist, 2004; Bulut, Toy, Irmak, Yılmaz & Yılmaz, 2008; Błażejczyk, Kuchcik, Dudek, Kręcisz, Błażejczyk, Milewski, Szmyd & Palczyński, 2016; Toy, Çağlak & Esringü).

With the majority of the population living in cities and the increase in people's awareness, scientific studies have begun to be made on the thermal comfort conditions of urban areas. Oke (1973) in Canada, Karl, Diaz & Puppet (1988) in the USA, Fortuniak, Kłysik & Wibig (2006) in Poland, Bonacquisti, Casale, Palmieri & Siani (2006) in Italy Gulyas, Unger & Matzarakis (2010) investigated the thermal comfort conditions of urban areas in Hungary. In these studies, it has been explained that while negative thermal comfort conditions are experienced in densely built areas in the urban area, more positive thermal conditions are experienced in suburban and rural areas. Algeciras, Tablada & Matzarakis (2018) Afforestation studies are proposed to improve the thermal comfort conditions of pedestrians in Cuba. In the studies carried out in Turkey, negative thermal conditions are experienced due to dense urban areas and air pollution in Erzurum (Bulut et al., 2008) in the cold climate region, in Ankara (Çalışkan & Türkoğlu, 2014) and Eskişehir (Toy et al., 2021) revealed that urban areas have more negative comfort conditions than the surrounding rural areas and that the urban area in Samsun offers more oppressive and negative thermal conditions than the rural area in its immediate vicinity (Çağlak, 2017).

This study, it is aimed to examine the thermal comfort conditions of Diyarbakır, which is a historical city in the Southeastern Anatolia Region of Turkey, which is not very cold in winter and is characterized by very hot and dry conditions in summer. In this context, the aims of the study can be listed as follows:

- Determination of thermal comfort conditions according to the PET index by using hourly data from four meteorology stations with different terrain characteristics,
- Revealing the temporal distribution of the determined thermal comfort conditions according to the seasonal order,
- Demonstrating the spatial distribution of thermal comfort conditions with new methods, taking into account many variables and features of the land,
- As a result of the analysis, examining the comfortable and stressful periods of the city of Diyarbakır in terms of climatic thermal comfort,
- Distribution of thermal comfort conditions in the city according to spatial distribution analysis and determination of the factors affecting the distribution,
- Explaining how urban land use affects thermal comfort conditions and how urbanization affects thermal comfort conditions,
- Developing solutions to negative thermal comfort conditions due to urbanization and

- Redesigning the newly developing or developed districts and neighborhoods of Diyarbakır in terms of in terms of creating climate-resistant cities and adapting to the negative effects of climate change; making necessary physical and ecological geographical improvements and making suggestions on managerial measures.

2.General Physical Geography Features

Diyarbakır is at level 3 (TRC2) in the Şanlıurfa Sub-Region of the Southeastern Anatolia Region according to the statistical regional units classification. Geographically, it is located in the Tigris Section of the South-eastern Anatolia Region, between 38° 02' and 37° 48' north latitudes and 40° 18' and 40° 01' east longitudes. The city of Diyarbakır, which has the status of a metropolitan city, consists of the district centres of Bağlar, Kayapınar, Yenişehir, and Sur. The basalt plateau formed by the basalt lavas emanating from the Karacadağ volcano and the Tigris River was effective in the establishment and development of the city of Diyarbakır. The city was founded on a broad basalt plateau extending horizontally on the eastern edge of the Tigris River valley (Figure 1; Karadoğan, Drahor & Kuzuoğlu, 2020). Diyarbakir is one of the oldest settlements in Anatolia, as it is located on the city trade routes established by the Tigris River, and it is also a city of history, culture, and civilizations.

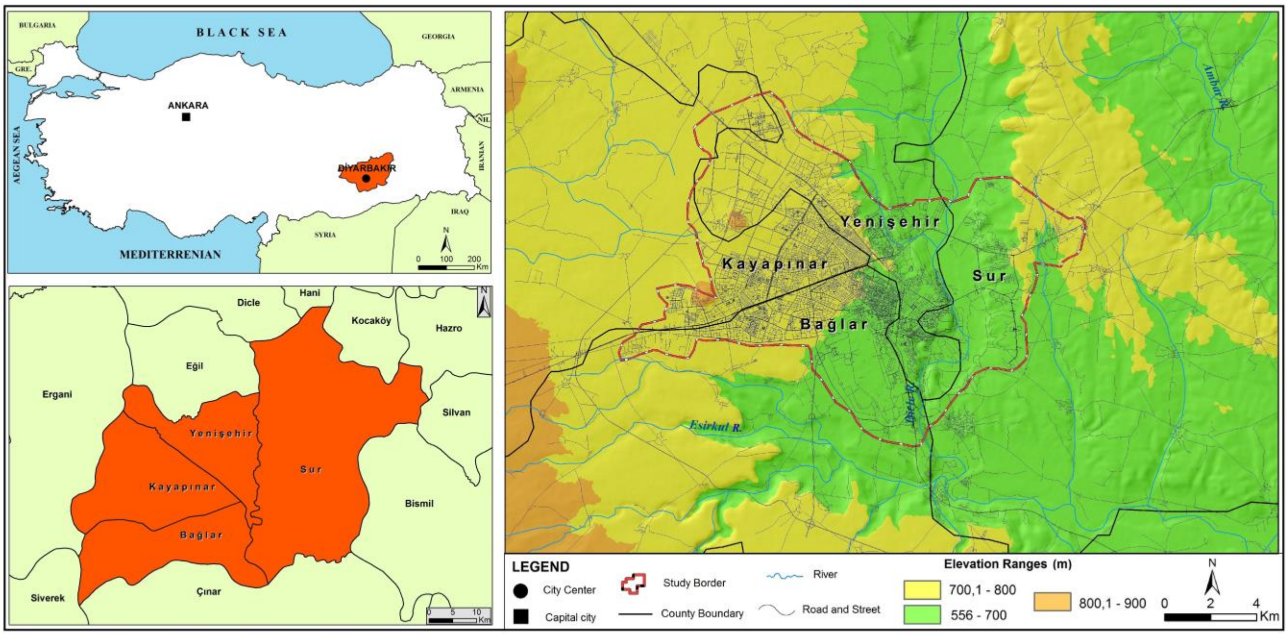

Figure 1. Location map of Diyarbakir city

In the city of Diyarbakir, according to De Martonne steppe – is humid, according to Aridite Index and Erinç Precipitation Efficiency Index, steppe – is semi-arid, according to Thornthwaite semi-arid – less humid (C1, B'3,s2,b'2) and Köppen –Geiger' according to this, climate conditions with mild-hot dry summer (Csa) are experienced (Bölük, 2016; Yılmaz & Çiçek, 2018). The climate features that can be expressed as the degraded Mediterranean with hot and dry summers and rainy winters are observed.

According to long annual means, the annual mean temperature is 15.9 °C, rising to 38.4 °C in summer and falling to -2.2 °C in winter. Mean relative humidity is 55.2%, and annual total precipitation is 498.4 mm. Precipitation falls mostly in winter and spring seasons, and drought occurs in summer. The wind speed has been measured as 1.1 m/s on mean and it is understood that the wind speed is low. The mean and extreme values for the city of Diyarbakir are given in Table 1.

Table 1
Mean and extreme meteorological values of Diyarbakır city (1929 – 2021) (Url 1)

Parameters	Value	Date/Period
Mean air temperature for many years	15.9 °C	Annual
Mean high air temperature	38.4	July
Mean low air temperature	-2.2	January
Mean relative humidity	% 55.2	Annual
Mean wind speed	1.1 m/s	Annual
Mean annual total precipitation	498.4 mm	Annual
Mean number of rainy days	93.9 days	Annual
Extreme high temperature	46.2 °C	21.07.1937
Extreme lowest temperature	-24.2 °C	11.01.1933
Highest rainfall in a day	71.6 mm	26.03.1976
The highest snow thickness	65 cm	16.01.1973
Fastest wind	35 m/s	01.06.1987

3. Materials and Methods

In the study, the data of Diyarbakır Regional Meteorology Station with national code 17281 representing the urban area, Sur/Ünal Erkan Heliport with national code 17283 and Eşref Bitlis Heliport with national code 18166 representing the semi-urban area, and the measurement data of Diyarbakır Airport meteorology station with national code 17280 representing the rural area were used. From 2015 to 2021 (7 years), which are the years when these stations in the city make common measurements, hourly; air temperature (˚C), relative humidity (%), wind speed (m/s), and cloudiness (octa) measurement data were considered appropriate (Figure 2).

Figure 2. Selected meteorological stations with hourly measurements and different terrain textures in the city of Diyarbakir

The meteorology stations used in the study are located at altitudes close to each other and on different terrains. Some information about the stations is given in Table 2. The land features were determined by considering the building and settlement densities in the area where the stations are located (Figure 2).

Table 2
Altitude and terrain characteristics of meteorology stations used in the study (Url 2)

Represented Area	Code	Location	Altitude (m)	Surface
U	17281	37°54'33.01"N; 40°12'52.89"E	680	Dense structured
SU	18166	37°55'27.48"N; 40°13'58.43"E	679	Loosely structured
SU	17283	37°56'19.57"N; 40°17'48.37"E	701	Loosely structured
R	17280	37°54'0.49"N; 40°12'21.16"E	674	No structure

Thermal comfort conditions were tried to be determined by using the data measured in meteorology stations. The Physiological Equivalent Temperature (PET) index obtained from the RayMan model, which is a radiation model and calculates both personal and atmospheric factors, was used to determine thermal comfort conditions. PET index, body heat energy by taking into account human thermal comfort, all effects of the thermal environment (short and long wavelength solar radiation, air temperature, relative humidity, wind speed, etc.), and thermo-physiological conditions of the human body (clothing type and activity). (Höppe, 1999; Matzarakis, Mayer & Iziomon, 1999; Gulyas, Unger & Matzarakis, 2006). After creating station information (altitude, latitude, longitude, time zone) in RayMan software, hourly; Air temperature, relative humidity, wind speed, and cloudiness data are loaded, and the software calculates the short and long-wavelength solar radiation according to the day and time of the year. The formula (Equation 3.1) developed by Höppe (1984) is used to calculate the index (Türkoğlu & Çalışkan, 2011).

$$M+W+Q^*(Tmrt,v)+QH(Ta,v)+QL(e,v)+QSW(e,v)+QRe(Ta,e)+S=0 \quad (3.1)$$

In the equation, M is the metabolic rate (activity), W mechanical power (type of activity), Q* radiation budget, QH change in sensed temperature, QL change in latent heat (evaporation), QSW distribution of latent heat through perspiration, QRe heat exchange through respiration (sensed and latent heat exchange). temperature), S is storage, Ta is air temperature, e is vapor pressure, v is wind speed, and Tmrt is mean radiant temperature. Since thermal comfort conditions are felt subjectively, a 35-year-old, 175 cm tall, 75 kg, 0.9 clo clothing load, and 80W workload is taken into consideration in determining the comfort ranges of the PET index (Table 3).

Table 3
Human thermal sensation and stress ranges for PET (Matzarakis et al. 1999)

PET (°C)	Thermal sensation	Level of thermal stress
< 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	Slightly cold stress
18.1–23.0	**Comfortable**	**No thermal stress**
23.1–29.0	Slightly warm	Slightly 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

Mean, Maximum, and Minimum PET values were obtained from the mean, maximum, and minimum hourly data. A newly developed model approach was used to obtain the spatial distribution of thermal comfort conditions from the values obtained from the PET index. It has been determined that this developed method is more than 95% reliable by testing it in three different climatic regions (Çağlak, 2021). In this model approach, ArcGIS 10.5 version of Geographic Information Systems software was used, taking into account the effects of many variables of the field on the PET index. Through the ArcGIS 10.5 program; Altitude, land use, solar radiation, and mean wind speed base maps were prepared. The land use map was obtained from Corine and urban atlas data. The distribution of solar radiation in the field was obtained by using the digital elevation model according to the day and time of the year in the ArcGIS 10.5 program. In addition, the mean radiant temperature (MRT) values according to the land cover were calculated according to the land feature using the Mr. T software. The software calculates according to the following formula (Equation 3.2).

$$T_{MRT} = \left[\frac{K*abs+L*abs}{\varepsilon.\sigma}\right]^{0.25} - 273.15 \quad (3.2)$$

TMRT: mean radiant temperature (°C)

K*abs: Sum of all absorbed shortwave radiant flux densities (W·m^2)

L*abs: Sum of all absorbed long wave radiant flux densities (W·m^2)

ε: Emission power of the human body (0.97)

σ: Stefan-Boltzman constant (5.67 • 10-8 W·m^2·K4) (Cohen, Palatchi, Palatchi, Bar, Lukyanov, Yaakov, Matzarakis, Tanny & Potcher, 2020).

The distribution of radiant temperature (MRT) values was obtained with the ArcGıs 10.5 program (Figure 3).

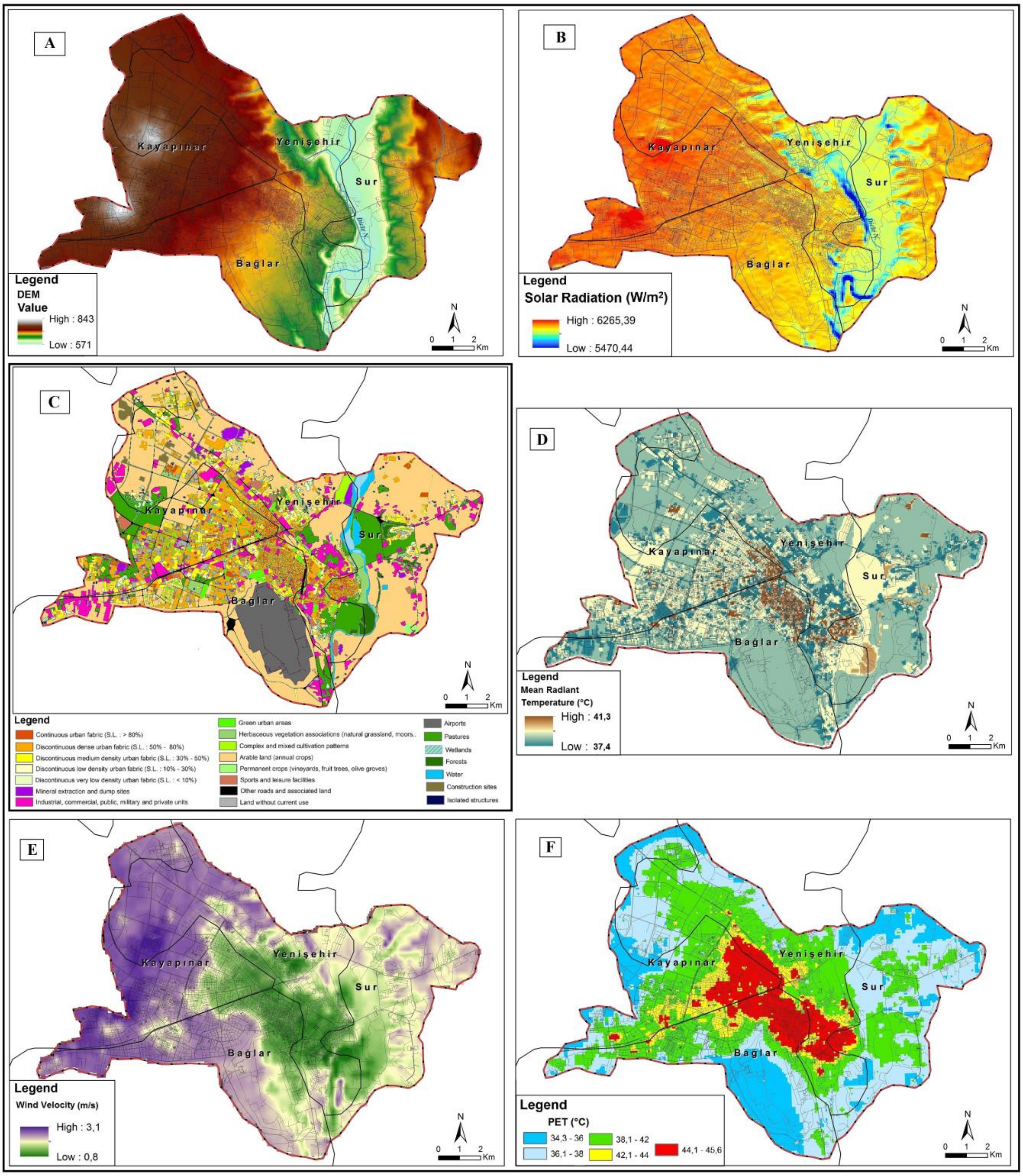

Figure 3. Base maps containing the variables of the terrain used in the spatial distribution of thermal comfort conditions (**A**: Elevation, **B**: Solar Radiation, **C**: Land Use, **D**: Mean Radiant Temperature, **E**: Wind Speed, **F**: Distribution of PET Values by Stations)

Using all these base maps, the spatial distribution of thermal comfort conditions was prepared by calculating with the Raster Calculator tool in the ArcGIS 10.5 program. In addition, how much of the area covered by the thermal gaps were calculated in the ArcGIS 10.5 program. The effects of field variables on the PET index were determined according to the coefficients in Table 4.

Table 4
Parameters affecting the spatial distribution of the PET index (Steenveld, Koopmans, Heusinkveld, Hove & Holstlag, 2011; Koopmans, Ronda, Steeneveld, Holstlag & Tank, 2018; Perkhurova, Konstantinov, Varentsov, Shartova, Samsonov & Krainov, 2019; Koopmans, Heusinkveld & Steenveld, 2020)

Parameters	**Alteration**	**PET (˚C)**
Wind velocity	1 (m/s)	2.50
Mean radiant temperature (MRT)	1 ˚C	0.6
Elevation	100 (m)	0.5
Solar radiaton (saat 14:00)	100 (w/m^2)	0.4
Solar radiaton (saat 07:00)	100 (w/m^2)	1.2

Anemometer device, which measures wind speed at synoptic meteorology stations, makes measurements at 10 meters above the ground. Therefore, wind speed maps are arranged according to 1.1 meters, which is the reference level of the human body's centre of gravity (Nastos, et al., 2013; Nastos & Matzarakis, 2019). The wind speed data obtained from the meteorology station making observations for synoptic purposes were evaluated according to 1.1 meters using the following formula (Equation 3.3).

$$WS_{1.1} = WS_h \cdot (1.1/h)^a \qquad (3.3)$$

In the equation, a = 0.12 • z0 + 0.18; WSh: wind speed value measured at altitude (m/s) (at 10 meters);

H is the height of the Station (10 meters); an empirical exponent of surface roughness; z0 is the surface roughness length (Troen & Petersen, 1989).

The roughness length (z0) value was obtained from the European Wind Atlas.

4. Results and Discussion

The thermal comfort conditions of Diyarbakir city are mapped monthly as mean, maximum, and minimum. According to the mean PET values, 'cool' stress in dense and high-built areas (11.4%, and 4.1% of the field, respectively) in the city center in December and January, in medium and low-density urban areas (65.7% of the field, 67.0%, respectively) 'cold' stress and 'very cold' stress were determined in rural areas (22.9% and 28.2% of the area, respectively) on the urban periphery. In February, 'slightly cool' stress is experienced in the over-built and dense urban canyons (2.8%), 'cool' stress in medium-density urban areas (13.5%), and 'cold' stress in other areas (83.7%). While 'comfortable' conditions are perceived in densely built areas (4.8%, 4.2%, respectively) in March and November, 'slightly cool' stress in medium-density urban areas (29.8%, 21.1%, respectively) and low-density urban areas and urban peripheries (65.4%, respectively), 74.7% perceived 'cool' stress. 'Slightly warm' stress in April, 'warm' stress in May and October (10.1%, 15.9%, respectively), and 'hot' stress in June and September (15.9%) in dense and highly built areas (6.3% of the area) in Diyarbakır city, 'very hot' stress was determined in July and August (13.0%, 17.2%, respectively). In a medium-density urban area (about 36.4% to 75.5% of the area) 'comfortable' conditions in April, 'slightly warm' stress in May and October, 'warm' stress in June and September, 'hot' stress in July and August heat stress is experienced. 'Slightly cool' stress in April, 'comfortable' conditions in May and October, 'slightly warm' stress in June and September, in low-density urban areas and rural areas on the periphery (about 7.3% to 47.7%), July and August 'warm' stress was detected in the months of the year (Figure 4; Table 5).

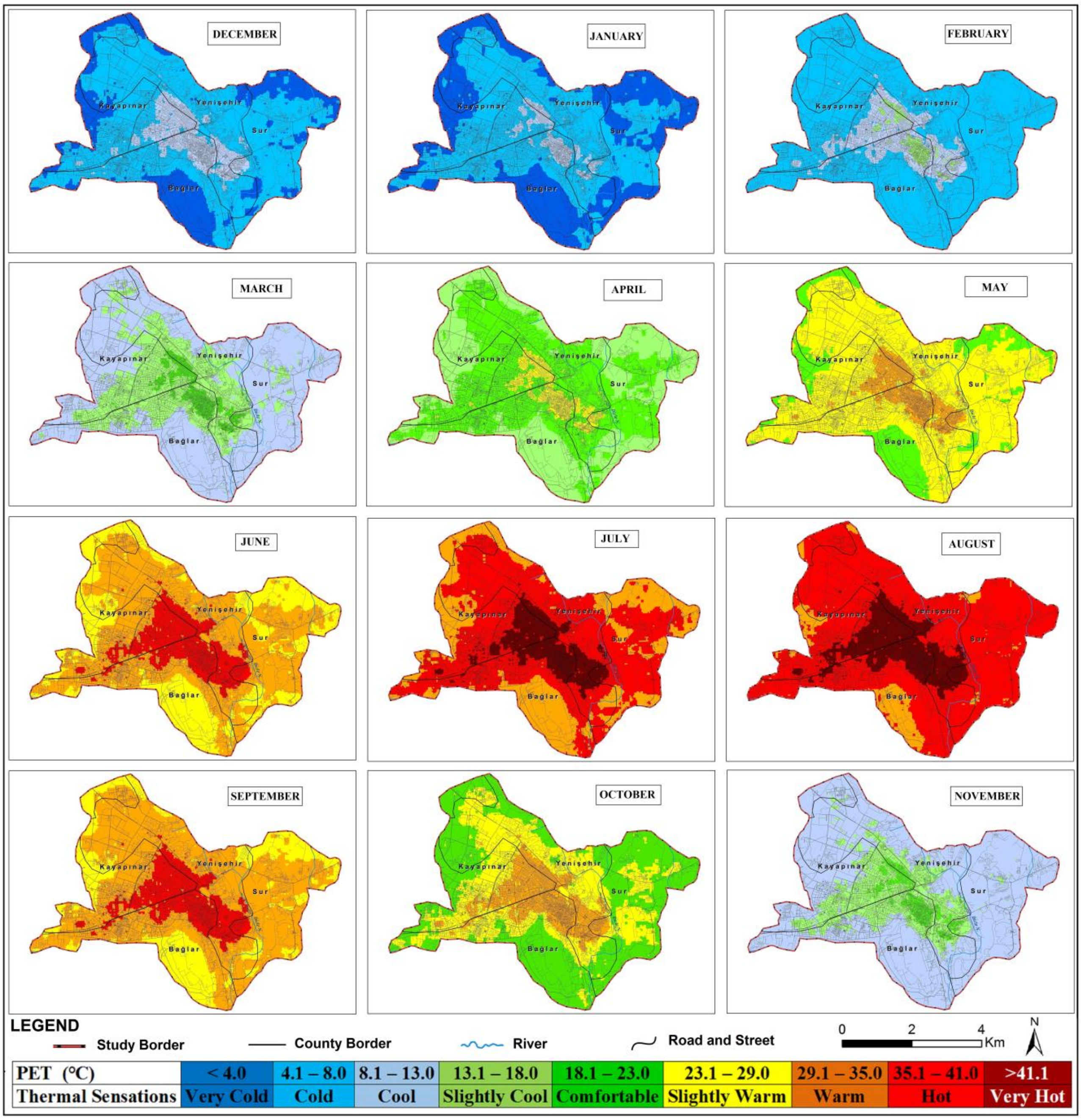

Figure 4. Spatial distribution of the mean thermal comfort conditions of the city of Diyarbakir by months in the year

Table 5
Percentages of spatial distribution of monthly mean thermal comfort conditions in Diyarbakir city (%)

Months/Ranges	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Very cold	28.2											22.9
Cold	67.0	83.7										65.7
Cool	4.8	13.5	65.4								74.7	11.4
Slightly cool		2.8	29.8	40.2							21.1	
Comfortable			4.8	53.5	17.2					47.7	4.2	
Slightly warm				6.3	72.7	29.8			22.9	36.4		
Warm					10.1	55.3	29.8	7.3	61.2	15.9		
Hot						15.9	57.2	75.5	15.9			
Very Hot							13.0	17.2				

According to the maximum PET values, 'slightly cool' stress in the dense urban area (13.3% and 10.3% of the field, respectively) in Diyarbakir in December and January, 'cool' stress in the medium-density urban area (39.4%, 27.8%, respectively) and low-density 'cold' stress is perceived in urban areas (47.3% and 61.9%, respectively). In February, 'slightly warm' stress in the city center (1.4%), 'comfortable' conditions in dense and medium-density urban areas (11.9%), 'slightly cool' stress in low-density urban areas (59.8%), and 'slightly cool' stress in rural areas (26.9% are experiencing 'cool' stress. In March and November, 'slightly warm' stress in densely built areas (13.3%), 'comfortable' conditions in medium-density urban areas (39.4%, 39.0%, respectively), and 'comfortable' conditions in low-density urban areas and urban peripheries (47.3%, 47.7%, respectively). slightly cool' stress is perceived. In April, 'very hot' stress in urban areas where urban canyons are concentrated (3.3% of the area), 'warm' stress in dense and medium-density urban areas (19.6%), 'slightly warm' stress in low-density urban areas (70.0%) and urban 'Comfortable' conditions were determined in the areas open to the wind (7.1%) on the periphery. 'Very hot' stress in densely built areas where the wind speed decreases in May and October (3.4%, 3.3%, respectively), 'hot' stress in dense and medium-density urban areas (10.2%, 19.6%), low-density urban area (approximately 70%).) 'warm' stress and 'slightly warm' stress were determined in rural areas (approximately 7.0%) on the urban periphery. During the hot period of the year from June to September, 'very hot' stress is dominant in the dense and medium-density urban areas (more than half of the site), while 'hot' stress is dominant in other areas (approximately 40.0% of the area) (Figure 5; Table 6).

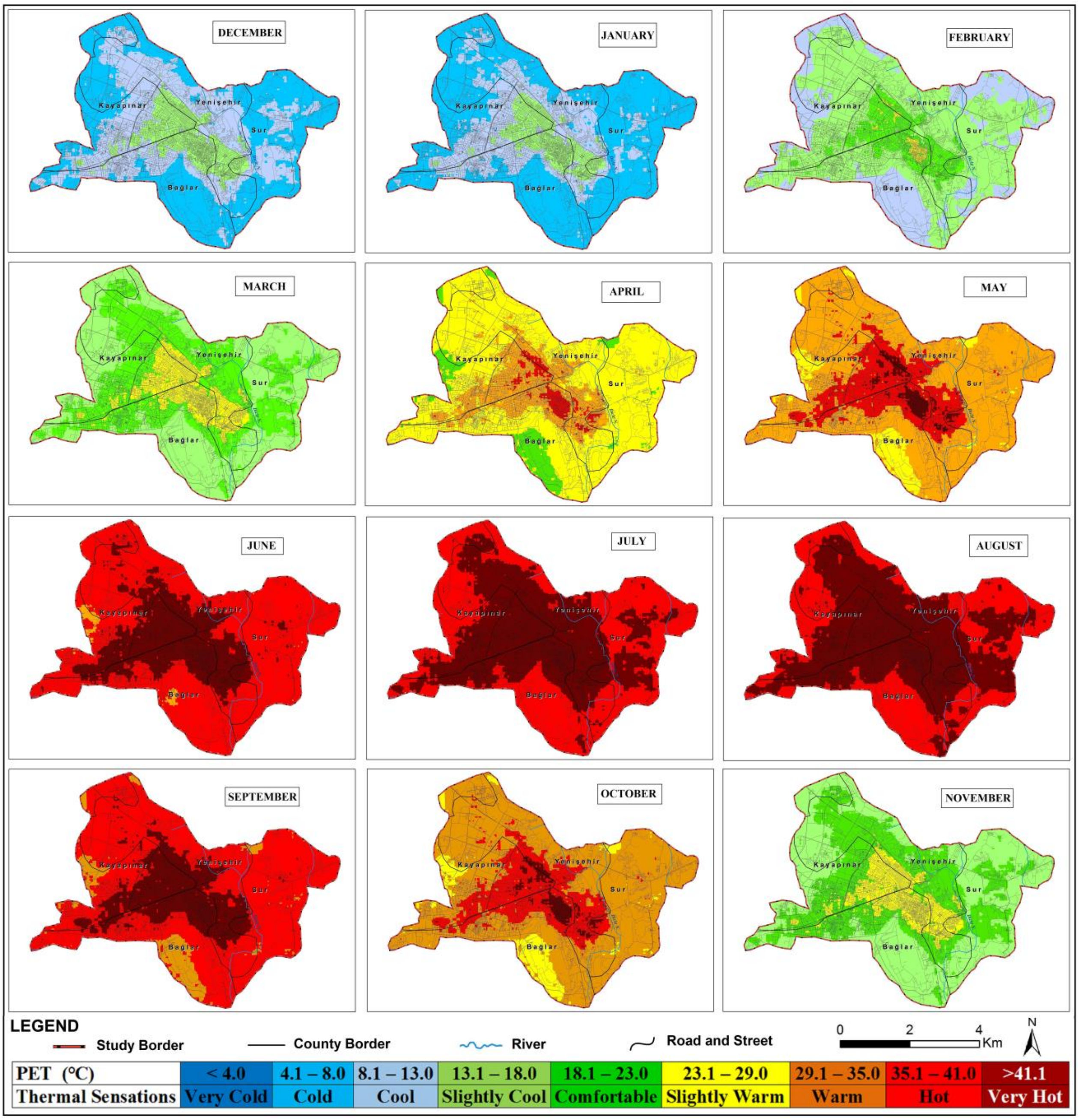

Figure 5. Spatial distribution of the maximum thermal comfort conditions of the city of Diyarbakir by months in the year

Table 6
Percentages of spatial distribution of monthly maximum thermal comfort conditions in Diyarbakir city (%)

Months/Ranges	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Cold	61.9											47.3
Cool	27.8	26.9										39.4
Slightly cool	10.3	59.8	47.3								47.7	13.3
Comfortable		11.9	39.4	7.1							39.0	
Slightly warm		1.4	13.3	70.0	7.0					7.1	13.3	
Warm				19.6	69.8	1.4			7.1	70.0		
Hot				3.3	10.2	69.6	47.2	38.6	70.0	19.6		
Very hot					3.4	29.0	52.8	61.4	22.9	3.3		

According to the minimum PET values, in the city of Diyarbakir; during the winter season (from December to February), 'very cold' stress is effective in the entire field. 'Cool' stress in dense and high-rise urban areas (about 2.2% to 6.5% of the site) in March, April, and November, in dense and medium-density urban areas (about 9.3% to 13.5% of the site)) 'cold' stress and 'very cold' stress in other areas (more than 80.0% of the field) are perceived. In dense and high-rise urban areas (about 10.0% of the area), 'slightly cool' stress in October, 'comfortable' conditions and 'slightly cool' stress in May, 'slightly warm' stress in June and September, 'hot' stress in July and August were determined. 'Cool' stress in October and May, 'comfortable' conditions in June and September, and 'warm' stress in July and August were determined in the medium-density urban area (approximately 15.0% to 30.0% of the area). 'Cold' stress in October and May, 'slightly cool' stress in June and September, 'slightly warm' stress and 'comfortable' conditions in July and August in low-density urban areas and wind-exposed urban fringes (approximately 50.0% of the site) (Figure 6; Table 7).

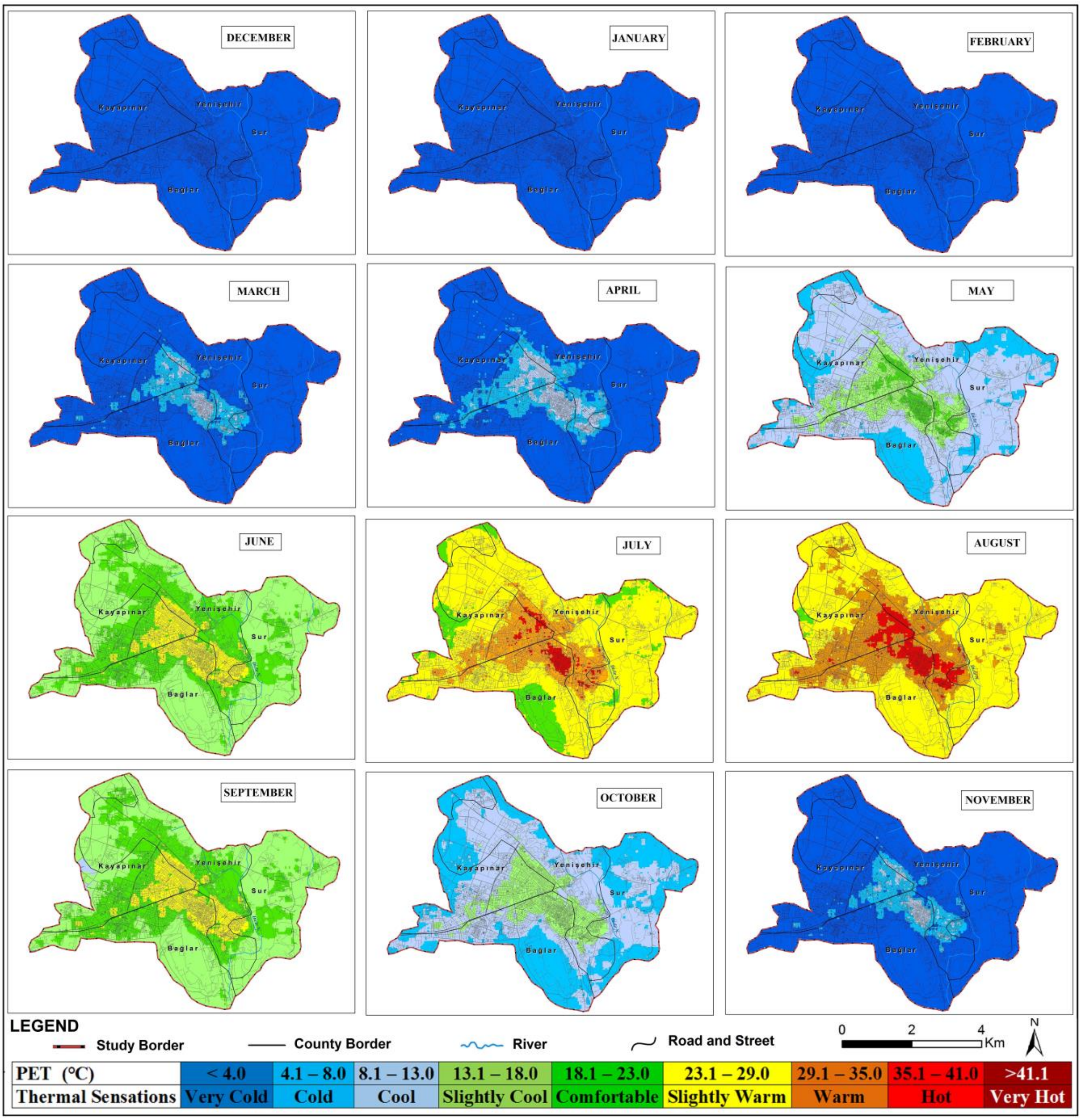

Figure 6. Spatial distribution of the minimum thermal comfort conditions of the city of Diyarbakir by months in the year

Table 7
Percentages of spatial distribution of monthly minimum thermal comfort conditions in Diyarbakir city (%)

Months/Ranges	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Very cold	100	100	88.3	80.0							88.3	100
Cold			9.3	13.5	21.7					38.6	9.4	
Cool			2.4	6.5	58.3				0.6	46.0	2.2	
Slightly cool					15.6	55.3			54.8	15.4		
Comfortable					4.4	33.0	11.1	0.6	32.9			
Slightly warm						11.7	68.9	66.5	11.7			
Warm							17.6	26.4				
Hot							2.4	6.5				

In all evaluations based on average, maximum, and minimum conditions, it has been determined that densely populated areas in the city centre have more unfavourable comfort conditions than low-density areas around them and open areas in the city periphery. Concretization, the increase of asphalt roads and pavements (gardens of school or public buildings, sidewalks, etc.), insufficient green areas, and rapid destruction of natural areas are effective in experiencing these negativities.

When the studies in the literature on the subject are examined; Clarke & Bach (1971) reported that suburbs are more comfortable than the city centre in Cincinnati, Ohio, USA. Tuller (1980) stated that in Christchurch, New Zealand, adverse thermal conditions emerged in areas with the central business district (CBD), light industrial - commercial area, and dense residential areas. Mayer (1993) stated that areas with trees in urban canyons provide a more comfortable living space than areas without trees. These results were found in Sweden (Svensson & Eliason 2002; Thorsson et al., 2004), Poland (Fortuniak et al., 2006; Błażejczyk et al., 2016), Italy (Bonacquisti et al., 2006), It has also been described in studies conducted in Hungary (Gulyas, et al., 2010; Vitt, Gulyas & Matzarakis, 2015). In studies conducted in Turkey, it was found in the cold climate region Erzurum (Bulut et al., 2008), Central Anatolia region Ankara (Çalışkan & Türkoğlu, 2014), Eskişehir (Toy et al., 2021), and Black Sea Climate Region. Similar results emerged in Samsun in Turkey (Çağlak, 2017). The fact that densely built urban areas revealed in this study have more negative thermal conditions than low-density urban areas around them and open areas in the city periphery is similar to the studies in the literature.

5. Conclusion

Thermal comfort conditions, which are the common effects of all climate elements, affect many activities from human health to the economy. In this study, the temporal and spatial distribution of thermal comfort conditions in Diyarbakır, a historical city, were analyzed with new methods. The spatial distribution of thermal comfort conditions in this method; is explained by including geographical variables (land use, altitude, solar radiation, average radiant temperature, wind speed, etc.) in the calculation.

Diyarbakir is a historical city established on the banks of the Tigris River in terms of trade, culture, and tourism. The city had a dense and dense settlement with the migration from rural to urban in Turkey in the 1950s. This situation has caused the climatic conditions of the city to change due to many anthropogenic factors such as the destruction of green areas in the city, the deterioration of natural areas, the increase in air pollution, the increase in the use of motor vehicles, the increase in domestic and industrial wastes.

For sustainable urbanization that is resistant to climate, the temporal and spatial distributions of thermal comfort conditions of Diyarbakir, which has continental climate conditions, were examined as average, maximum and minimum. As a result of the study, according to the averages in the city of Diyarbakir; While 'cold' and 'cool' stresses are experienced in the winter season, 'warm', 'hot', and 'very hot' stresses are experienced from May to September, which is the hot period of the year. In the spring and autumn seasons, which are the transitional seasons, 'slightly warm' stress, 'comfortable' conditions, and 'slightly cool' stress are perceived. In dense and high-rise areas in the urban area, more unfavourable comfort conditions were determined compared to the environment. According to the maximum averages; While 'cool', 'slightly cool', and 'comfortable' conditions were determined in winter, 'warm', 'hot', and 'very hot' stresses were determined from April to October. At maximum averages, more adverse thermal conditions are experienced in densely built urban areas. According to the minimum averages; 'very cold' stress was detected throughout the field in the winter season. In areas with dense urban canyons, 'cool' stress in March, April, and November, 'slightly cool' stress in October, 'comfortable' conditions in May, 'slightly warm' stress in June and September, 'warm' and 'hot' stress in July and August were determined. In low-density urban areas and urban peripheries, 'cold' stress in March, April, and November, 'cool' and 'cold' stresses in October, 'cool' and 'slightly cool' stresses in May, 'slightly cool' stresses in June and September, 'slightly warm' stress is experienced in July and August.

It has been observed that the densely built urban areas in the city center of Diyarbakır experience more adverse thermal conditions than the low-density urban areas around them and the open areas in the city peripheries. In this respect, the study revealed to what extent urban heat islands occur due to urbanization and how land use affects thermal comfort conditions in a city in a continental climate zone. It is necessary to reduce these negative thermal comfort conditions of cities and to adapt to climate-resistant sustainable cities. Environments such as parks, green building designs, and water surfaces should be increased in the city. In addition, when the green areas are distributed evenly in the urban area, a local wind (breeze) effect will occur due to the temperature difference between the built area and the green area, and the 'fresh air' air circulation of the city will also be positively affected. Urban design and planning should be done from a geographical perspective (taking into account human, biotic, and physical environmental conditions) to reduce the negative thermal conditions of cities and for sustainable healthy cities. In this context, the initiatives and scientific-technical touches of architects, landscape architects, geographers, and designers can help us adapt to uncertain future conditions.

Author Contributions

Savaş Çağlak: contributed to data collection, analysis and writing of the article.

Murat Türkeş: designed the work and contributed to the writing of the article.

Conflicts of Interest

The authors declare no conflict of interest.

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