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Assessment of the effect of land use change on bioclimatic comfort conditions in Uşak Province

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Abstract: Bioclimatic comfort is the state of people in which they feel comfortable, happy, and fit in the atmospheric environment they are. The bioclimatic comfort conditions of cities have changed depending on anthropogenic factors. The aim of this study is to compare the bioclimatic comfort conditions of Uşak city between 1990 and 2018. In the first stage, the bioclimatic comfort conditions of the city centre between 1990 and 2018 were determined according to the Physiological Equivalent Temperature (PET) index obtained from the RayMan model by using hourly data of the meteorological station in the city centre; air temperature (°C), relative humidity (%), wind velocity(m/s) and cloudiness (octa). By using Geographic Information Systems in the spatial distribution of bioclimatic comfort conditions, calculations were made with base maps of elevation, land use, solar radiation, mean radiant temperature (MRT), and wind speed. In the second stage, the land cover was classified according to the general appearance for the period covering 28 years (from 1990 to 2018), and the rates of change were calculated. As a result, it was determined that the most comfortable areas are the agricultural areas, followed by the forest and natural areas, and the most uncomfortable conditions are in the artificial areas. Intense urbanization and construction have increased the uncomfortable conditions in the city. It is thought that the plans to be made by prioritizing bioclimatic comfort conditions will contribute to decelerating the climate change caused by global warming, as well as improving the existing problems.

Key words: Bioclimatic comfort, GIS (Geographic information system), land use change, PET (Physiological Equivalent Temperature), urban climate, Uşak

1. Introduction

Bioclimatic comfort is the state of people in which they feel comfortable, happy, and fit in the atmospheric environment they are. Uncomfortable conditions cause many problems such as a decrease in people's work efficiency, health conditions, and an increase in energy consumption.

Because of the industrialization of the cities that started with the industrial revolution, the intense migration of people from rural areas to urban areas has led to an increase in settlement areas in cities. In this context, in line with the dense and irregular housing seen in cities, differences in the urban climate compared to the rural climate have been observed, due to natural areas covered with impermeable surfaces, environmental pollution experienced by industrial production, and other anthropogenic factors. The first determination of the mentioned difference was made by Howard in London in 1833 (Toy et al., 2021).

It is observed that urban areas have different climates than rural areas due to anthropogenic effects as well as different microclimate conditions within the cities themselves. Compared to open areas, the complex surface structures of urban areas create an environment with special microclimatic properties that have a dominant effect on the energy balance of the human body (Gulyas et al., 2006). Balık and Yüksel stated in their study in 2014 that surfaces with high heat capacity, especially in summer, negatively affect people's bioclimatic comfort conditions (Toy et al., 2021). Mayer (1987) reports that all air temperature parameters increase in residential areas according to the results of the Stadtklima Bayern research project. It was reported that solar radiation values in street canyons where trees are located decrease because of tree crowns on solar radiation, and PET values are low in tree-covered areas (Mayer and Matzarakis, 1997; Mayer and Matzarakis, 1998). It was also determined that solar radiation in street canyons with trees decreases because of tree crowns on solar radiation (Mayer and Matzarakis, 1997). Svensson and Eliason (2002), revealed that the temperature deviation is always 8 °C higher in urban areas

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compared to open areas, and the temperature difference between apartments and detached areas is 4 **°C more than** in open areas. Toy et al., (2007) concluded in their study that the most suitable areas in terms of bioclimatic comfort in Erzurum, Turkey, are urban forests. Turkogluet. al (2012) analysed the PET values in Ankara, Turkey over 10 years in their study and found out that there was a 0.4–1.2 °C daily mean PET difference between urban areas with high buildings and open areas in forests, and 2.2–3 °C between parks and 1.7–2.5 °C between the suburbs. According to the PET analysis of Gulyas et al. (2006), which was conducted in two different areas with densely built city centres where radiation flows and trees of 20–30 m tall are factors, they say that the difference in PET indexes between these two places may be up to 15–20 °C. Kestane and Ulgen (2013) evaluated the coastal city of İzmir, located on Turkey's Aegean coast, in terms of bioclimatic comfort in their study. They determined the bioclimatic comfort zones by creating apparent temperature maps for 12 months. As a result of the study, it was determined that the areas of the city far from the settlement areas are more suitable in terms of bioclimatic comfort compared to the densely populated areas. Erkek et al. (2020) examined the association between land use and bioclimatic comfort in the city of İzmir, where dense housing is common in Turkey. In the study, bioclimatic comfort maps of five different years (1990, 2000, 2006, 2012, and 2018) were associated with land use maps according to the same years. It has been determined that comfort zones are formed primarily in agricultural areas, followed by natural and seminatural areas and settlements, respectively. Toy et al. (2019) calculated bioclimatic comfort values in Eskişehir, Turkey, and evaluated them according to the PET index. In the study, they determined that densely populated areas are hotter compared to their surroundings, causing the formation of heat islands in areas where there is excessively dense housing in the city. Blazecjyk et al. (2016) have revealed a difference of 4–5 °C UTCI between the city centre, where the buildings are dense, and the surrounding areas, where the building density is less and covered with plants.

An assessment of the effect of land use change on bioclimatic comfort conditions was carried out in Uşak. The textile and leather industries that developed in Uşak after 1970 caused the migration from rural to urban areas to accelerate, resulting in the expansion of the urban area (Yasak, 2014).

Located on the threshold between the Aegean Region and the Central Anatolia region, Uşak has a Mediterranean transitional climate between the Mediterranean climate and the continental climate (Turkes et al., 2002). According to Köppen-Geiger climate classification (Csa), the climate is mild in winter, very hot in summer, and arid, according to De Martonne; semiarid to humid, and according to Thornthwaite; (C1) semiarid– less humid climatic conditions were determined (Bölük, 2016). Due to its location, the city is under the influence of the frontal systems affecting the Mediterranean basin and the anticyclone anomalies coming from the Balkans (Yilmaz, 2004). The annual average temperature in the city, which has transitional climate characteristics, is 12.5 °C (extreme minimum –19.9 °C in January and an extreme maximum of 40.2 °C in July). The annual rainfall is 557.6 mm, and the relative humidity is 65%. The annual average wind speed is 1,9 m/s (Table 1).

2. Materials and methods

This study was carried out in the Uşak province, which has a Mediterranean transition climate between the Mediterranean climate and the continental climate in

Table 1. Long-term means of some climatic parameters (1939–2020).

Uşak	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean
Mean temperature (°C)	2.3	3.3	6.2	10.9	15.6	19.9	23.4	23.4	19.1	13.7	8.3	4.2	12.5
Mean maximumtemperature (°C)	6.8	8.3	11.8	16.8	21.8	26.5	30.3	30.5	26.3	20.3	14.1	8.8	18.5
Mean minimum temperature (°C)	-1.3	-0.6	1.4	5.2	9.2	12.6	15.5	15.6	11.9	7.9	3.8	0.7	6.8
Mean sunshine duration (h)	3.9	4.6	5.5	6.8	8.8	10.9	11.8	11.3	9.7	7.3	5.3	3.8	7.5
Mean number of rainy days	12.2	10.7	10.8	11.0	10.1	6.0	3.1	2.4	3.4	7.1	8.5	12.7	98.0
Mean monthly rainfall (kg/m^2)	73.4	66.7	58.0	50.9	48.0	27.2	16.5	12.6	18.6	42.2	58.9	84.6	557.6 (total)
Extremely high temperature (°C)	18.3	23.6	27.0	30.0	34.5	36.6	40.2	38.2	36.6	32.6	26.0	21.8	30.5
Extremely low temperature (°C)	-19.9	-15.0	-12.5	-6.2	-1.0	2.9	7.4	6.8	2.0	-4.8	-11.8	-18.9	-5.9
Mean wind speed (m/s)	1.8	1.9	1.9	1.9	1.8	2.0	2.2	2.1	1.8	1.7	1.7	1.7	1.9
Mean relative humidity (%)	76	72	69	67	63	57	54	54	57	64	71	77	65

Turkey. Uşak city was established on a plateau in the inner west Anatolian part of the Aegean Region. The city is located at an altitude of 800–1100 m. Its establishment on the plateau caused the city to have a clustered settlement. The city has hosted many civilizations from past to present due to its important location on the line stretching from the Aegean Region to the east and interior regions (Figure 1). The İzmir-Ankara Road, built-in 1966, had an impact on the spread of the city (Bilgen, 1999).

In the study, the bioclimatic comfort conditions of the Uşak city centre over a 28-year period were evaluated together with the land cover change maps of the city. In the determination of bioclimatic comfort conditions, hourly data for the years 1990 and 2018 of the Uşak meteorology directorate station number 17,188, located at an altitude of 916 m in the city centre, were used. Meteorological data used are air temperature (Ta; °C), relative humidity (RH; %), wind velocity (Wv; m/s), and cloudiness (octa; skyview/10). The characteristics of the meteorology station and the terrain features are shown in Table 2 and Figure 2. Widely used PET index (Höppe, 1999) and RayMan software (Matzarakis et al., 2010) were used in the study to determine bioclimatic comfort conditions as calculation models.

The PET (Physiological Equivalent Temperature; VDI, 1998; Höppe, 1999; Matzarakis, 2007) index was used through the radiation model RayMan software for the calculation of bioclimatic comfort values. A 35-year-old, 175 cm tall, 75 kg, male, healthy individual with a 0.9 clothing load and an 80 W workload was considered in the calculation (Matzarakis et al., 1999). The values obtained as a result of the calculation determine the human temperature sensation levels and physiological stress levels in humans for each value range given in Table 3 (Fanger, 1970; Mayer, 1993; Matzarakis and Mayer, 1996).

Land use of the study area was used to reveal the relationship between bioclimatic comfort conditions and land use characteristics between 1990 and 2018. Land use data were obtained from the Coordination of Information on the Environment program (CORINE) and coordinated by the European Union (CORINE, 2021). Land cover was generally classified as artificial areas (continuous urban fabric, discontinuous urban fabric, industrial or commercial units, public facilities, road and rail networks and associated land, airports, mineral extraction sites), agricultural areas (arable land, permanent crops, heterogeneous agricultural areas), forest and natural areas (broad leaved forest, coniferous forest, mixed forest, scrubland herbaceous vegetation associations, natural grassland, open spaces with little or no vegetation) and pasture areas (natural herbaceous species, unimproved or lightly improved meadows and grazed or mechanically harvested meadows).

The total area of the study area is 3652 ha. Of this area, 38.9% (1422 ha) consisted artificial areas, 59.4% (2168 ha) of agricultural areas, and 1.7% (62 ha) of forest, and natural areas in 1990 (Figure 3). Of the field, 76.8% of it consisted artificial areas, 21.3% of agricultural areas, and 1.8% of forest and natural areas in 2018 (Figure 4).

A newly developed model, raster calculation, is used in the spatial distribution of bioclimatic comfort conditions. This method was tested in three different climatic regions and found to be 95% reliable (**Çağlak**, 2021). In this method, through the ArcGIS 10.5 program from the

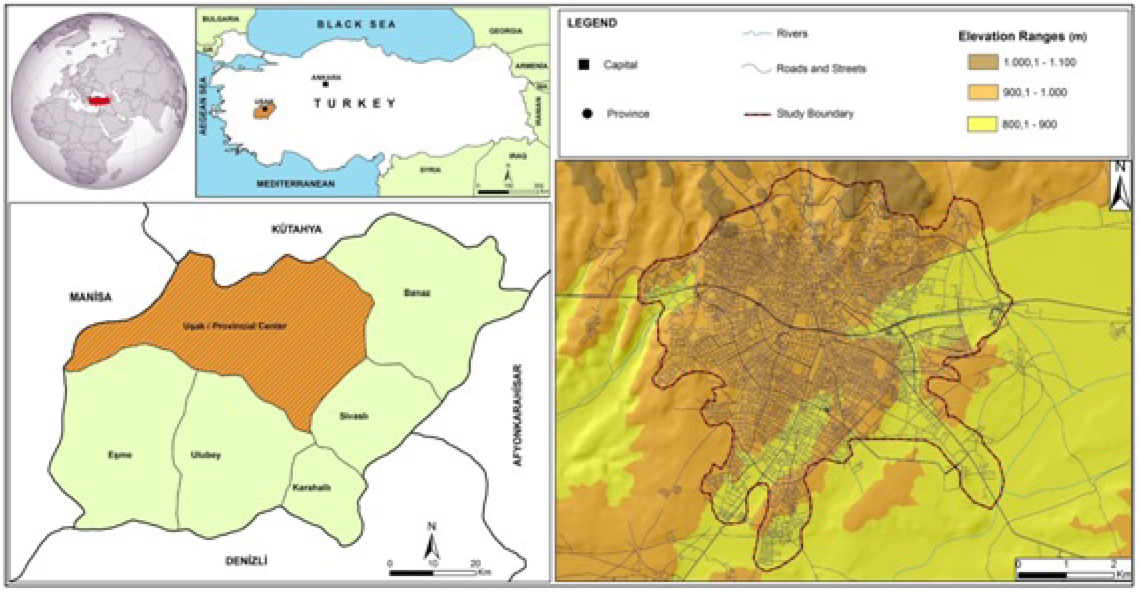

Figure 1. Location map of the study area.

Table 2. Meteorological stations used in the study and their features.

Name and code	Longitude (East)	Latitude (North)	Altitude (m)	Surface
Uşak Meteorological Station – 17,188	29°24’	38°39’	916	Dense structure

Figure 2. The location of the meteorological station in the city.

Table 3. Thermal sensation and stress ranges (edited from Matzarakis et al. 1999; Höppe, 1999; Toy, 2010; Çağlak, 2021).

PET (°C)	ThermalSensation	Level of ThermalStress	Colors
<–4	Extreme Cold	FreezingColdStress	
°–3.9– 4.0	VeryCold	Extreme ColdStress	
4.1–8.0	Cold	StrongColdStress	
8.1–13.0	Cool	ModerateColdStress	
13.1–18.0	SlightlyCool	SlightlyColdStress	
18.1–23.0	**Comfortable**	**No ThermalStress**	
23.1–29.0	SlightlyWarm	SlightlyHeatStress	
29.1–35.0	Warm	ModerateHeatStress	
35.1–41.0	Hot	StrongHeatStress	
>41.0	Very Hot	Extreme HeatStress	

Geographical Information Systems software, calculations were made with base maps of altitude, land use, solar radiation, mean radiant temperature (MRT) and wind speed.

Land use, altitude, mean radiant temperature, wind speed, and solar radiation maps were prepared and calculated considering their effects on the PET index in the spatial distribution of bioclimatic comfort conditions (Lee and Mayer, 2016; Perkhurova et al., 2019; Koopmans et al., 2020). Mean radiant temperature (mrt) was calculated by mr. T. software and mapped by ArcGIS 10.5 software (Cohen et al., 2020). Solar radiation maps were obtained spatially with the “Area Solar Radiation” tool in ArcGIS10.5 software (Caglak, 2021). Wind speed maps are arranged at 1.1 m, which constitutes the reference level of the centre of gravity of the human body (Nastos et al., 2013; Nastos and Matzarakis, 2019). Since the anemometer at the meteorology station is at an altitude of 10 m, the wind speed was edited according to the level of 1.1 m using the formula below. The wind speed data obtained from the meteorology station were evaluated according to 1.1 m using the formula below.

Formula: $WS1.1 = WSh \times (1.1/h)a$

$a = 0.12 \times z0 + 0.18$

WSh: Windspeed value measured at altitude (m/s) (usually 10 m),

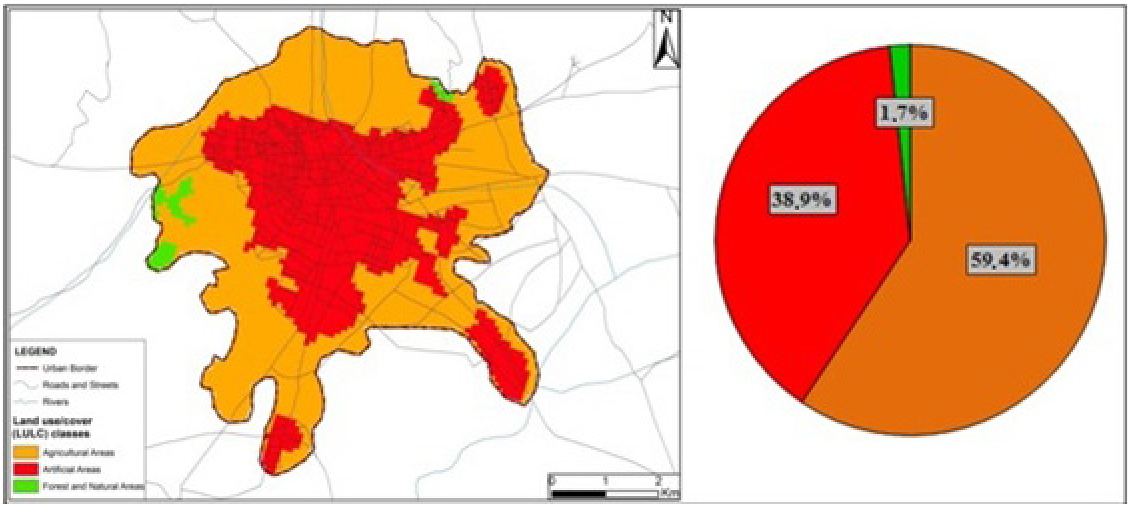

Figure 3. Spatial and percentage distribution of land use/cover in 1990.

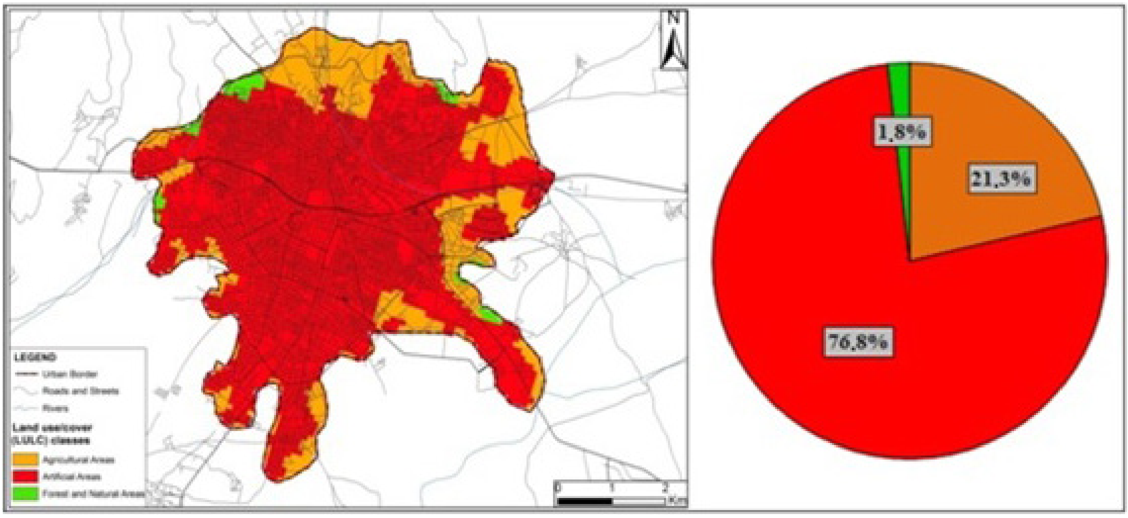

Figure 4. Spatial and percentage distribution of land use/cover in 2018.

h: Height of the station (usually 10 m)

a: An empirical exponent based on surface roughness.

z0: Surface roughness length (Troen and Petersen, 1989).

Bioclimatic comfort conditions were prepared monthly between 1990 and 2018. In order to explain the similar conditions one after the other, the distribution of bioclimatic comfort conditions throughout the year, the astronomical season order, was followed. In the astronomical context, starting with December, which is the beginning of the winter season, the spring, summer, and autumn seasons were explained respectively. Besides, the percentages of spatial distributions were explained with graphics.

3. Results

3.1. Bioclimatic comfort conditions distribution in 1990

According to the distribution of bioclimatic comfort conditions in 1990, "very cold" stress which was effective during the winter season, was perceived in the whole area in December and January, "cold" stress was perceived in the urban area in February. In the spring season, "cool" stress was experienced in the majority of the fields in March, "slightly cool" stress in the urban area in April, "cool" stress in the whole rural area, "comfortable" perceptions in the urban area, and "slightly cool" stress in the rural area in May. In June, "slightly warm" stress in urban areas and their surroundings, "comfortable" conditions in rural areas, "hot" stress in the city centre, and "slightly warm"

stress in rural areas in July and August were observed. In the autumn season, "slightly warm" stress in the urban area and its surroundings in September and "comfortable" conditions in the rural areas, "comfortable" perceptions in the city centre in October, "slightly cool" stress in the rural areas, and "cool" stress in the urban area and its immediate vicinity, "cold" stress in rural areas was perceived in November (Figure 5).

In 1990, comfortable perceptions at the beginning of summer and at the end of summer, "hot" stresses in mid-summer, and "very cold" stresses in winter season dominated.

3.2. Distribution of bioclimatic comfort conditions in 2018

Depending on the change in land use, the "very cold" stress in the urban area in the winter season was replaced by the "cold" stress, and, "cool" stress began to be experienced in the urban area and its immediate surroundings in February 2018. In June of the summer season, the majority of the field experiences "slightly warm" stress, "hot" stress with scorching effects in urban areas in July and August, and "slightly warm" stress in rural areas. In the spring and autumn seasons, which are the transitional seasons, "slightly cool" stress was observed in the densely built

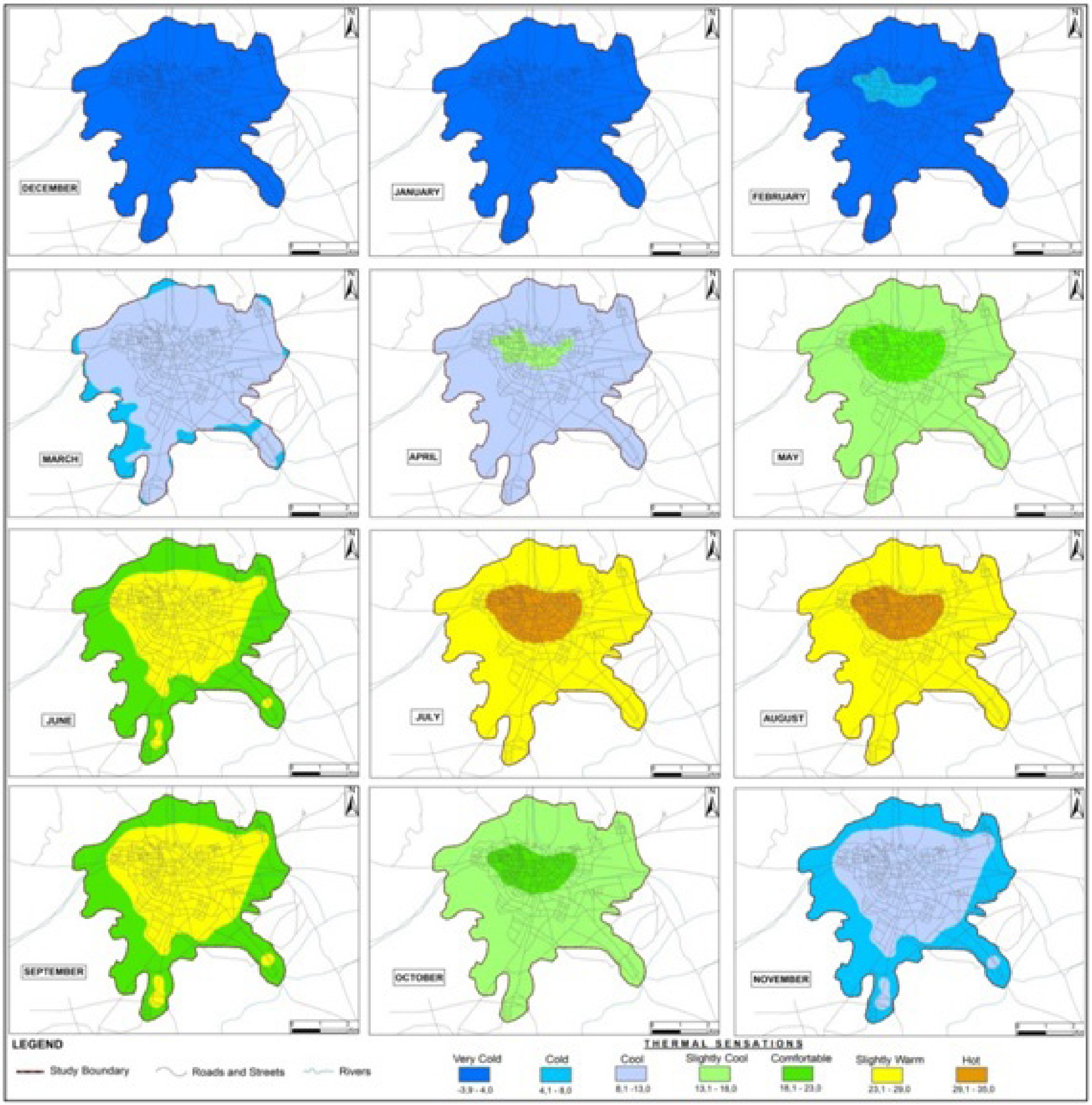

Figure 5. Spatial distribution of monthly average PET values in 1990.

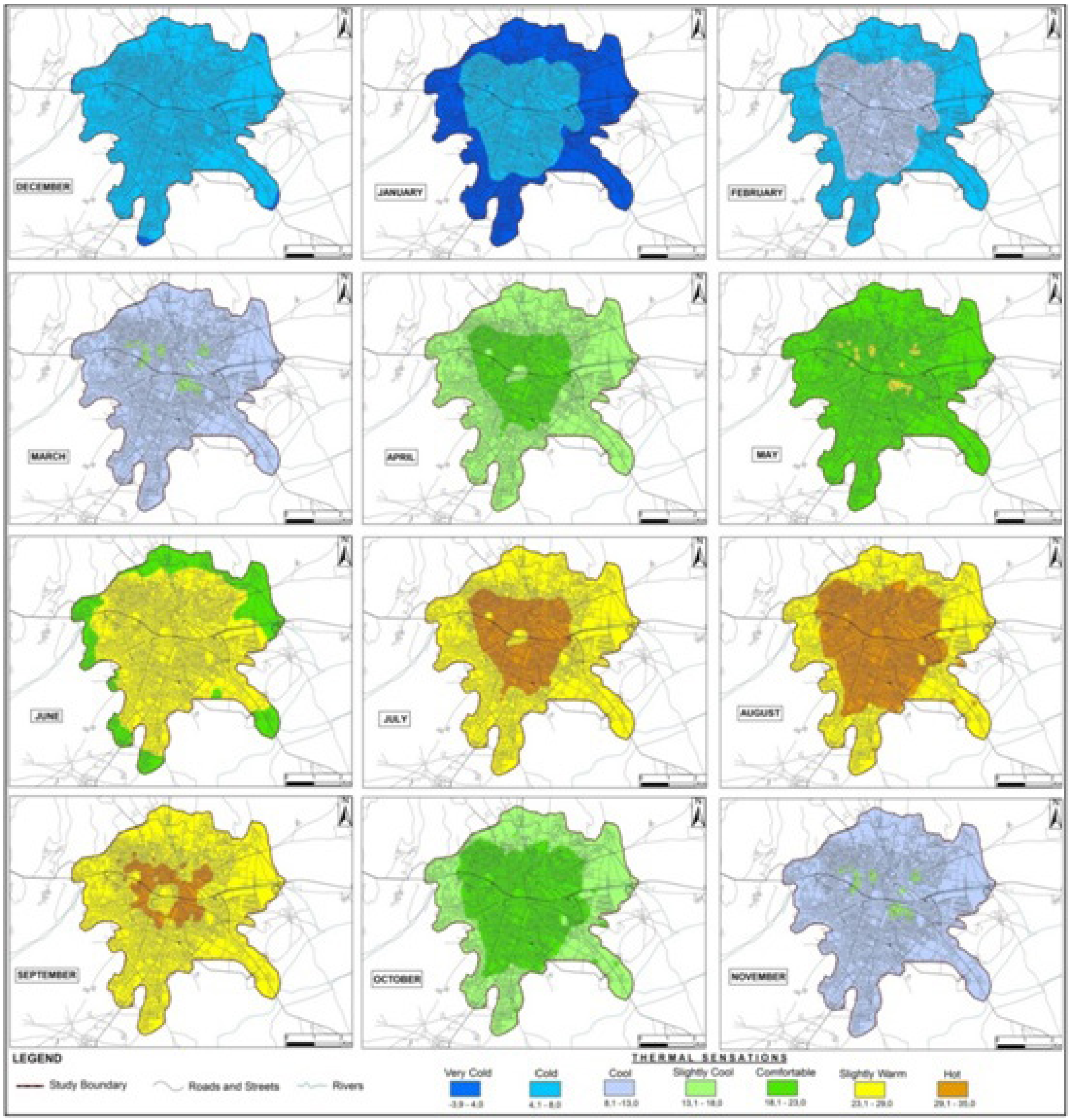

Figure 6. Spatial distribution of monthly average PET values in 2018.

and high-rise buildings in the urban areas in March and November, while “cool” stress was observed in the vast majority of the fields. In April and October, “comfortable” perceptions were perceived in urban areas, and “slightly cool” stress was perceived in rural areas. While “slightly warm” stress was effective in the majority of the field in September, the scorching “hot” stress was effective in densely built areas in the urban area, “comfortable” perceptions were dominant in the field, and “slightly warm” stress was effective in high-rise building areas in the urban areas in May (Figure 6).

In 2018, comfortable perceptions started to be experienced in April, May, and October. The scorching heat stresses became more effective in the field in the summer season and “cold” stress started to be experienced instead of “very cold” stresses in the winter season.

With urbanization changing the climatic conditions, human bioclimatic comfort conditions have also changed. This situation has led to hotter suffocating thermal conditions in the city.

3.3. Spatial distribution of land use/cover

In the study area, urbanization became effective very quickly, and many agricultural areas transformed into urban areas. High-rise buildings and mass housing organizations have increased since the 1990s in the Uşak city. The establishment of 1 Eylül Industrial Estate, **Çanlı** Leather Industrial Estate, and Uşak Organized Industrial Zones, which have great importance for Uşak city and its

surroundings, was effective in this situation. Besides, Uşak University, established in 2006, was effective in attracting migration to the city (Bilgen, 1999). The migration from rural to urban areas, which has increased due to the increasing industrial activities in the city for the last 20 years, has led to the emergence of new business centres. Thus, it is observed that the agricultural areas in the study area are transformed into urban areas, and the urban areas are expanding day-by-day (Yasak, 2014).

3.3. Assessing the relationship between bioclimatic comfort and land use

Migration from rural to urban areas, started in Uşak after 1970, accelerated due to industrialization after the 1990s. As a result of increasing housing needs and the opening of new service and trade centres, agricultural areas were turned into urban areas. Thus, artificial areas constituting 38.9% of the field in 1990 increased to 76.8% in 2018.

In the winter season, depending on the increase in artificial areas, "very cold" stress was observed in the whole field in December and January in 1990, and in 93.6% of the field in February, in 1.1% of the field in the agricultural areas in December 2018 and in 58.2% of the area, which constitutes all of the agricultural, forest and natural areas and a small part of artificial fields in January 2018. The "slightly warm" stress perceived in the artificial areas and surrounding agricultural areas that constitute 46.7% of the area in June 1990 in the summer season, was perceived in the artificial areas that constitute 75.8% of the area in 2018.

While the "hot" stress with scorching effects was seen in 15.3% of the field in July and 13.2% in August in the artificial areas in 1990, it was seen in 26.2% of the field in July and it was observed in 48% of the artificial areas in August with the increase in the artificial areas in 2018. In the transition seasons, "cold" stress was perceived (March: 11.4%; November: 47.6%) in agricultural areas, forests, and natural areas, while "cool" stress was perceived in artificial and agricultural areas in their immediate vicinity (March: 88.6; November: 52.4%). In March and November of 2018, 97.4% of the field experienced "cool" stress, while 2.6% experienced "artificial areas" stress. 93.6% of the field experienced "cool" stress, and "slightly cool" in 6.4% (artificial areas) in April 1990, while 73.8% of the field experienced "slightly cool" stress, and "comfortable" perceptions were experienced in 26.2% of them (artificial areas) in April 2018. Besides, all agricultural, forest and natural areas were "slightly cool" (84.7% in May; 89% in October), and some artificial areas were "comfortable" (May: 15.3%; 11% in October) in May and October 1990; and "comfortable" conditions were detected in 98.2% of the field and 48.1% (artificial areas) in May and October in 2018. While 52.3% of the field (artificial areas and their immediate surroundings) experienced "slightly warm" stress in September 1990, and 47.7% (agricultural areas, forest, and natural areas) experienced "comfortable" conditions, only 11% of the field (artificial areas) experienced "hot" stress in 2018, and 89% experienced "slightly warm" stress (Figure 7). The increase in artificial areas has worsened the uncomfortable conditions in Uşak city.

4. Discussion and conclusion

In the study, the negative effects of anthropogenic land-use changes such as the increase in asphalt and concrete surfaces in the study area, the increase in areas with high buildings, the destruction of natural areas in the comfortable period, and comfortable period lengths were revealed.

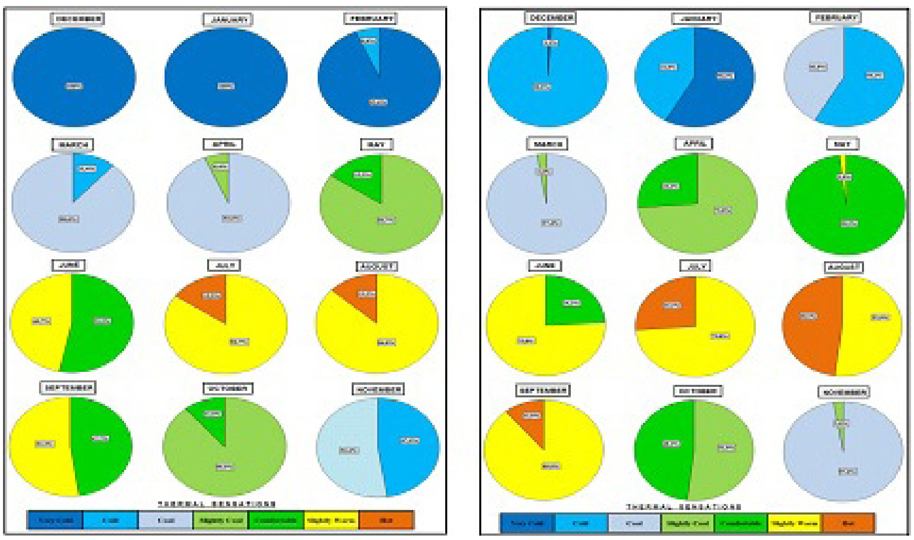

Figure 7. Percentages rates of spatial distribution of bioclimatic comfort conditions 1990–2018.

It was determined that the most comfortable conditions were agricultural areas, forest areas, respectively. The most disturbing conditions were determined to be in artificial areas. Green vegetation in agricultural areas causes low average radiant temperature and high wind speed. In forest areas, both radiant temperature and wind speed are low. In artificial areas, the average radiant temperature is high and the wind speed is low. In addition, fossil fuel use, air pollution, heating systems, etc., are effective in artificial areas. These findings were similar to those found in studies conducted in İzmir located in the Mediterranean climate zone, and Sivas located in the continental climate zone (Erkek et al., 2020; Karakuş and Demiroğlu, 2021). The areas covered with natural vegetation, where heat or cold stress is low, were destroyed by intense urbanization, and natural areas were replaced by built areas. As a result, it is seen that the areas become unsuitable in terms of bioclimatic comfort, and the uncomfortable conditions in the city increase. This situation poses a risk both for the existence of natural areas and for human health and bioclimatic comfort conditions in the future. When these results of the study are compared with the studies in the literature, it is seen that they are similar (Svensson and Eliason, 2002; Gulyas et al., 2006; Türkoğlu et al., 2012).

It is also observed that bioclimatic comfort is related to the land cover in cities. In this context, it is suggested that urban planning should be done by taking into account the bioclimatic comfort conditions for the urban people to lead a healthy life.

The settlements should be planned in accordance with the climate and topography of the region in order to increase the bioclimatic comfort values that have decreased over the years. For existing built-up areas, microclimate conditions can be improved in areas with heat stress by using the predominant wind direction of the city.

According to our results, increasing the agricultural and forest areas in the city will positively affect the microclimate conditions.

In the city, places such as agricultural areas that reduce the average radiant temperature, do not reduce the wind speed, and provide green cover should be created.

Afforestation can be done with deciduous species suitable for the climatic conditions of the city. In this way, it will be beneficial to reduce the heat stress with the shading and moisture-providing characteristics of the plants in the summer and the cold stress in the winter since it will not prevent the sun rays.

It is thought that the plans to be made by prioritizing bioclimatic comfort conditions will contribute to decelerating the climate change caused by global warming, as well as improving the existing problems.

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