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ORIGINAL PAPER

Thermal comfort modeling, aspects of land use in urban planning and spatial exposition under future climate parameters

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Abstract

Global urbanization and climate change have brought about crucial climatic pattern variations between urban areas and rural surroundings. The impact of global heating is influencing the climatological variables in the surrounding urban environment. Thermal comfort in an environment is an influential location choice for urban living quality and facilities. This study models the change in the spatial pattern of comfort zones in the Kastamonu province sample. Simulation plots were generated, and comfort requirements were investigated based on global climate models in the Coupled Model Intercomparison Project Phase 6. The spatio-temporal shifts in temperature, humidity, and ThC fields were optimized by Thom's discomfort index. To assess the synergies of extreme hot weather events throughout the province, the current status of ThC areas and their potential concerns in 2040, 2060, 2080, and 2100 were modeled based on the Shared Socioeconomic Pathways scenarios: SSP2-4.5 and SSP5-8.5 using ArcMap 10.8 software. The research determined that cold, cool, and comfortable areas are predicted in the site based on SSP2-4.5 until 2100. According to the SSP5-8.5, coastal regions will dominate 15.3% of the area with marine characteristics above the comfort values (hot and very hot). According to the SSP5-8.5 climate projections, the 5 °C increase in the highest temperature value in the area and the 9.7% decrease in the relative humidity are remarkable for describing impreciseness in complex interacting human and environmental mechanisms. The research provides guiding and concrete spatial indicators for many interacting disciplines and decision-makers.

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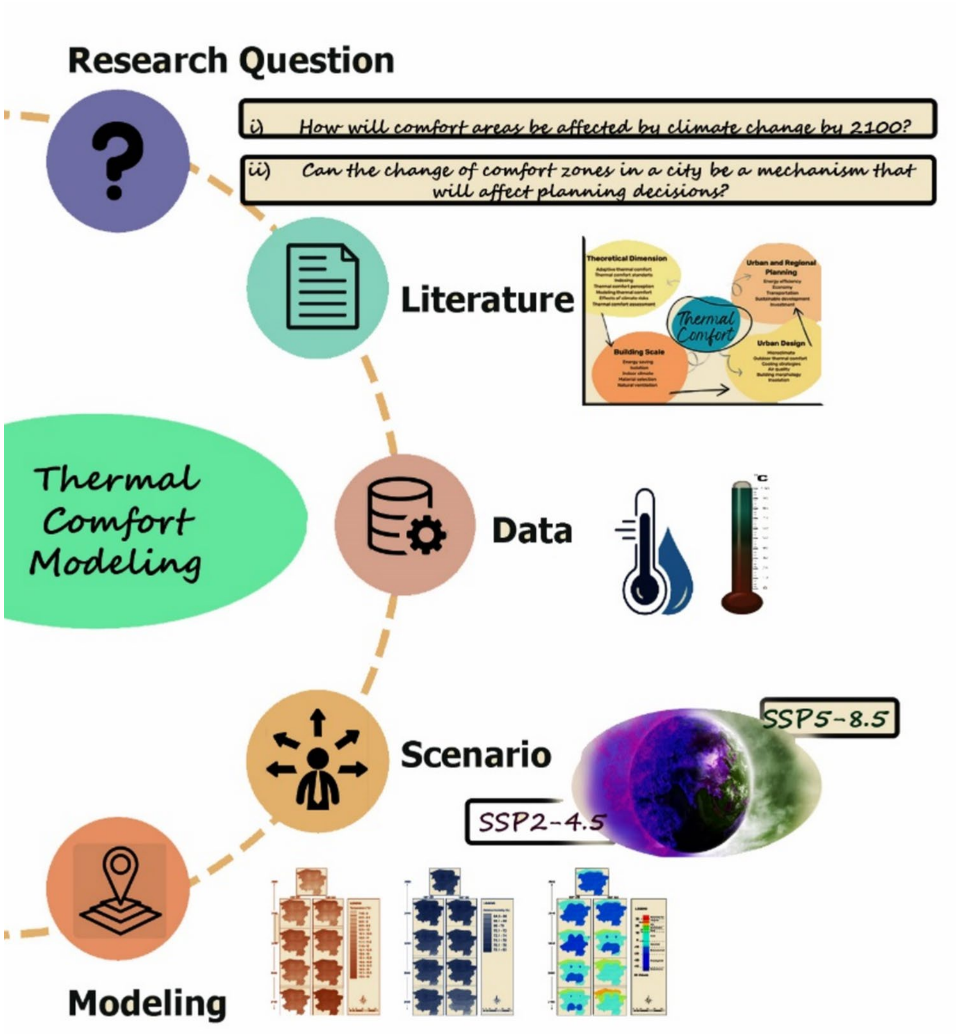
Graphical abstract



Keywords Adaptation strategies · Climate comfort · Global warming · Environmental risks · Spatial modeling · Urban policy

Abbreviations

CMIP6	Coupled model intercomparison project phase 6
DI	Discomfort index
GCMs	Global climate models
GIS	Geographic information system
IDW	Inverse distance weighted
IPCC	Intergovernmental panel on climate change
RCP	Representative concentration pathway
RH	Relative humidity
SSPs	Shared socioeconomic pathways
T	Ambient dry bulb temperature
ThC	Thermal comfort
THI	Temperature-humidity index
UHI	Urban heat island
UN	United Nations

Introduction

Governments now know global warming with concrete indicators based on reports (Martinez-Villalobos and Neelin 2023; Supran et al. 2023; Piwowarczyk and Kolanowska 2023). Policy-makers made efforts to control greenhouse gas emissions after the Kyoto Protocol, which was concluded in 1997 (Mesquita et al. 2023; Tan et al. 2023; Wang and Luo 2023). The search for clean and renewable energy, environmentally friendly urban planning approaches, and sustainable urban design concerns have emerged (Razmjoo et al. 2022; Hunjra et al. 2023). Current Intergovernmental Panel on Climate Change (IPCC 2021) reports define cities as the areas where global warming will be most effective due to the urban heat island (UHI) effect and will be rise to 1.5 °C and 2 °C than normal levels. However, it is stated that the impact and loss of extreme weather events resulting from climate change, depending on population density, will be high in cities. The United Nations (UN) (2019) emphasizes that the process will affect the urban population, especially in low- and middle-income countries. Projected high risks require interventions within the framework of climate-sensitive urban planning. It is possible to reduce the harmful effects of changes through urban planning and design interventions (Creutzig et al. 2022; Shin et al. 2022; Maiurova et al. 2022; Pande and Moharir 2023). When aiming for healthier and more livable cities, it is crucial to investigate how much the climate affects the city.

Thom's Discomfort Index, later refined by Giles et al. (1990), to evaluate human comfort and inform urban management. The Discomfort Index, developed in the 1920s, combines dry bulb and wet bulb temperatures to assess discomfort in hot, humid climates. Subsequent indices, such as Steadman's Temperature-Humidity Index, incorporated additional factors like wind chill to provide a more comprehensive measure of apparent temperature. They proposed an alternative version of Thom's Discomfort Index, defined using temperature and relative humidity. Thom of the National Weather Service developed the Discomfort Index in 1959, also known as the Temperature-Humidity Index, which quantifies the impact of hot, humid summer conditions on human discomfort (Thom 1959). This index combines dry bulb temperature and wet bulb temperature, and is utilized in forecasting summer comfort and working hours in the United States. The index was empirically derived by subjecting multiple samples of individuals to varying temperature and humidity conditions. As a concept intertwined with climate conditions, research on thermal comfort (ThC) literature within the framework of risks is quite limited. The issue of ThC covers building scale (Arowoiya et al. 2023; Babich et al. 2023; Ouanes and Sriti 2024), urban design (Darbani et al. 2023; Deng et al. 2023), and urban and regional planning strategies (Cárdenas-Jirón et al. 2023; Isinkaralar and Isinkaralar 2023; Yuan et al. 2023) that comply with the comfort standards of individuals against changing climatic conditions indoors and outdoors. In the theoretical context, adaptive ThC (Lamsal et al. 2023; López-Pérez and Flores-Prieto 2023), ThC assessment (Abd Rahman et al. 2022; Elnabawi and Hamza 2020), and indexing (Kim et al. 2022; Tang et al. 2021) literature dominates. ArcGIS and other GIS tools have become valuable for analyzing urban environments and supporting sustainable development decisions. ThC studies have demonstrated how these tools can assess housing demand and its impact on zoning, as well as aid sustainable tourism planning. The increasing use of GIS in urban planning is due to its spatial analysis and manipulation capabilities that align with planner needs. As GIS technology evolves, its integration with urban comfort design has enhanced functionality and accessibility, allowing planners to more effectively address complex urban issues. Overall, GIS has significant potential to support strategic urban planning for sustainable development, such as evaluating urban growth suitability, managing facilities and services, and mitigating urbanization impacts.

Environmental conditions at the urban scale are the main factors that affect the quality of life of individuals (Leng and Han 2022; Iamtrakul et al. 2023; Kang 2023), their activities, and, therefore, the socioeconomic capital of cities. In cities in different geographies, solutions are produced to make parameters such as temperature, humidity, and precipitation biologically suitable. The city's climatic conditions seriously affect the city's economy and green innovation by affecting forestry, agriculture, industry, trade, and tourism activities. Effective land use management, both at the local and regional scale, is critical for sustainable economic development. Therefore, thanks to ThC modeling, efficiency can be achieved in many sectors such as energy and transportation. The potential for preference increases when climatic indicators are in the ThC range (Isinkaralar 2023; Pashkov et al. 2023; Hunjra et al. 2024a). The climate affects the entire urban pattern, including urban land uses such as commerce, housing, industry, tourism, administrative facilities, open-green areas, and other areas (Hunjra et al. 2024b; Zhang et al. 2024). Therefore, the climate structure of the city can be defined as a natural resource value that can be transformed into capital in terms of creating the unique identity of the cities and branding them (Shao et al. 2023; Wang and Liao 2023). Types of tourism are affected multidimensional by climate change, while the world's attention is on dealing with the discomfort urban environment (Cevik and Ghazanchyan 2021). However, areas with a high potential for winter tourism are considered more vulnerable to climatic conditions.

We aim to provide future predictions of the ThC areas over Kastamonu using different ThC scenarios based on global climate models (GCMs) in the Coupled Model Intercomparison Project Phase 6 (CMIP6). The proposed method, which offers the possibility of being applied to different areas, allows us to see the change in the space with the most pessimistic and more moderate perspectives in the light of two scenario frameworks.The primary focuses of this study are i) to identify future scenarios obtained from variables meteorological parameters, ii) to analyze the variance of thermal conditioning alternatives for the period 2020–2100 on the SSP framework, iii) to evaluate the factors using the geographic information system (GIS) application for development maps of thermal changes of the rapid growth of urbanization, iv) to encourage the notion of variability in future climate and societal conditions by describing a wide range of credible futures. The results of this examination should offer data to assist in comprehending future changes in ThC over Kastamonu under different climate change scenarios by providing a data set of climate change and societal futures for use in research groups.

Materials and methods

Ensuring specific standards that fall outside the subjective thermal perception of individuals depends on managing the bottom-up and top-down effects of all these components in Fig. 1. These findings allow the decision-makers to forecast better mitigation and adaptation in the Kastamonu plan towards sustainable urban development policy, such as water availability, sustainable environmental conditions, and climate-related diseases. The research area also includes tourism centers based on water resources such as Valla Canyon, the second deepest canyon in the world, and waterfalls. Identifying the effects of the region, which is fragile in terms of climate change due to its intense nature, fills an essential gap in the literature on the subject of the study. The questions of the research conducted for the province of Kastamonu with the data collected in 2023 were designed as follows:

(i) How will comfort areas be affected by climate change by 2100?
(ii) Can the change of comfort zones in a city be a mechanism that will affect planning decisions?

Study area and data

The sample area of the research is Kastamonu province. It is located at 41°22′35.85″N, longitude 33°46′35.39″E in the western Black Sea region of Türkiye and has a 170 km coastline in Fig. 2. However, it was established with elevations around 780 m above sea level that developed north–south due to its central east–west slope and is 245 km from the coast. As a result, it has poor natural

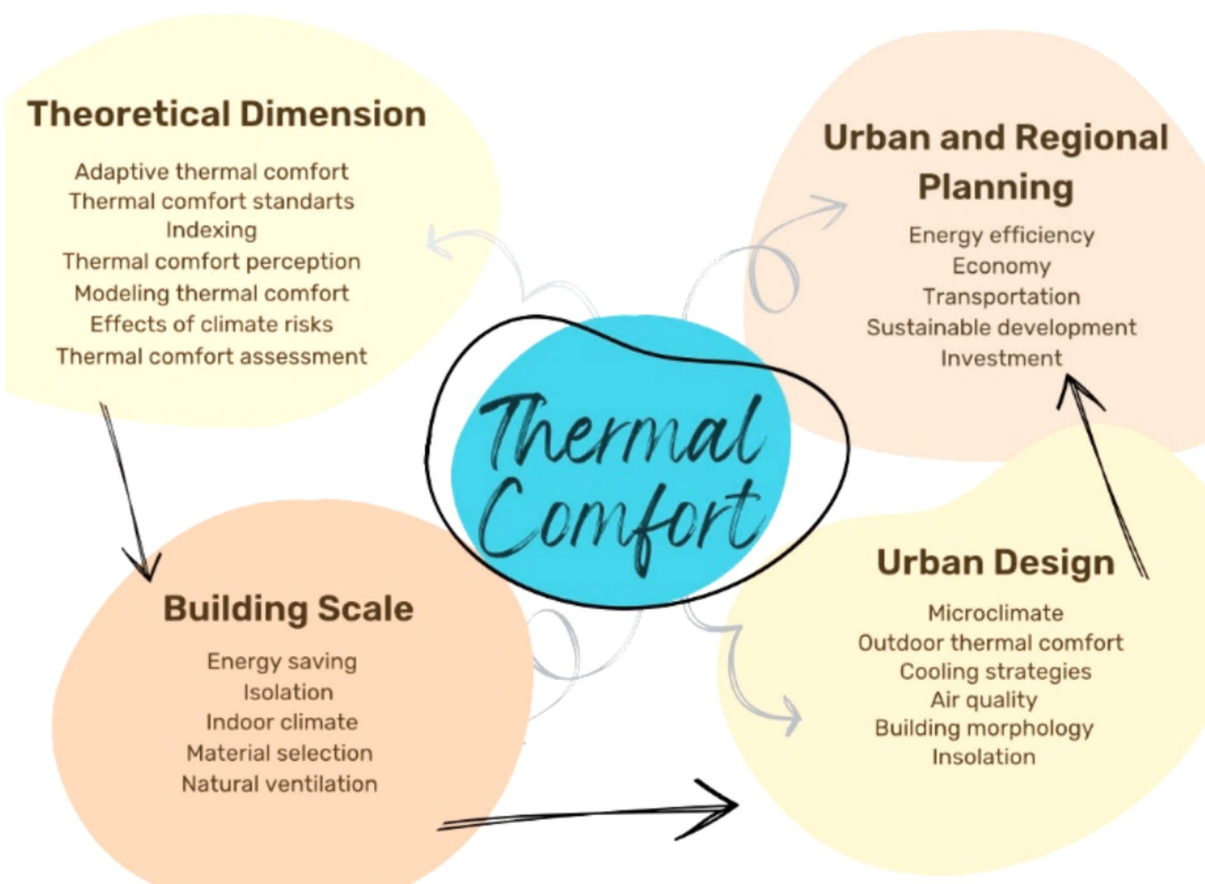


Fig. 1 The concept of ThC is discussed in different dimensions in the literature

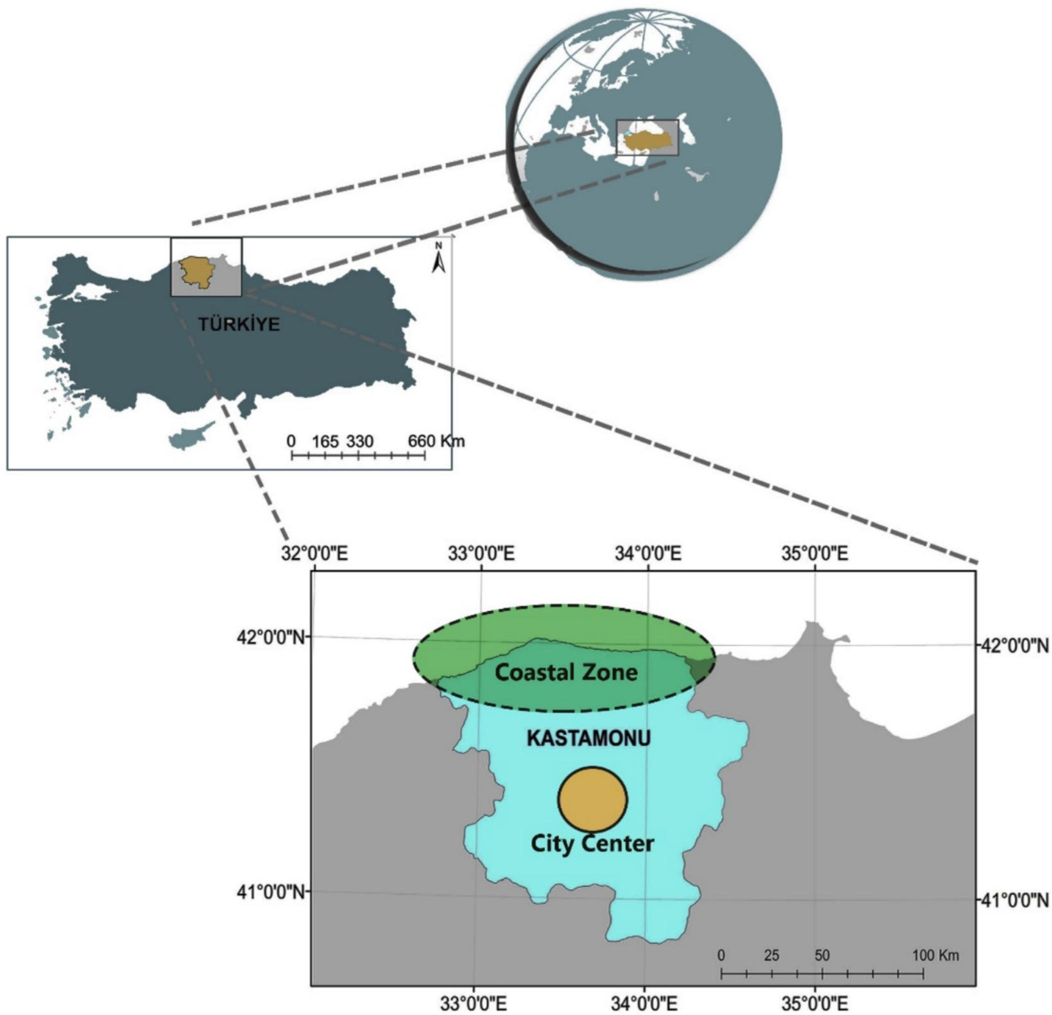


Fig. 2 The research area determined for ThC analysis

ventilation due to being surrounded by mountainous terrain. The Küre Mountains, located at the area's boundaries, form a barrier in front of the coast, causing the climatic elements to differ between the beach and the interior and the formation of microclimate areas. There are canyons, waterfalls, old natural forests, and caves within the province's borders, and it is rich in natural resources. There is a wide variety of tourism potentials in the region, such as winter tourism, ecotourism, adventure tourism, plateau tourism, and faith tourism. The area's attractiveness to visitors is related to the level of satisfaction. Outdoor temperature analysis is becoming an essential requirement for people to feel comfortable. During the last two decades, Kastamonu City has witnessed a fast urban expansion and development of severe commercial activities. The meteorological data exercised in this study were mainly collected from only one state-run weather station.

Methodology

The National Department of Energy's Lawrence Livermore National Laboratory produces high-resolution (50 km grid resolution) climate projections for local or regional areas. Accordingly, the future projections of impacts, adaptation, and vulnerability following the Shared Socioeconomic Pathways (SSPs): S_I (moderate radiation forcing 4.5 W/m^2, SSP2-4.5 update of representative concentration pathway (RCP) RCP4.5 in CMIP5) and S_{II} (peak—radiation pressure 8.5 W/m^2, SSP5-8.5 is renovating of RCP8.5 in CMIP5) models of the CNRM-CM6-1 model were chosen to implement the scenarios. For this, we utilize the results from the climate data exported to Microsoft Excel in NetCDF format (to create charts and perform calculations). These data were then integrated and analyzed in ArcGIS 10.8 software. Numerous projects have illustrated the use of ArcGIS in spatio-temporal modeling. After the software applied the conversion process, maps were created for simulation using the "Inverse Distance Weighted (IDW)" method from the climate data obtained. The current forecast point X_0 is a function of n [$z(X_{0i})$ and $i = 1,2,\ldots,n$] neighbor measurements, where r is the upper part that determines the assigned range of each of the observations and d is the distance separating the observation location X_i from the forecast point X_0. The greater the size of the exponent, the less the associated weight of the expressions away from the prediction position. It shows that an increase in the exponent represents how close the predictions are to the closest available observations. Our measurements were performed via ArcGIS 10.8 software using these data and the formulas mentioned above in Eq. (1).

$$z(x_o) = \frac{\sum_{i=1}^{n} z(x_i) \cdot d_{i0}^{-r}}{\sum_{i=1}^{n} d_{i0}^{-r}} \quad (1)$$

ThC index formulas and numerical processes were carried out on the climate plans for each scenario, and ThC maps were generated for the studied area. Includes indexes like the Thom's Discomfort Index (DI) (Thom 1959) in Eq. (2), Climate Index (CLIM) (Becker 2000), and Cold Strain Index (Moran et al. 2003; Rissanen and Rintamäki 2007), which are commonly used in creating ThC charts. In particular, DI is one of the most widely used indices for outdoor ThC, and it uses atmospheric temperature and relative humidity. For this reason, DI was selected for the disturbance levels in the Kastamonu region in this study. ThC for DI is predicated on mean temperature, and surface air temperature and ensuing water vapors are critical ingredients of climate change and the hydrological cycle (Sein et al. 2022). Whole layers were at 1 × 1 km spatial resolution, and DI was spanned by the temperature-humidity index (THI), with the index applied as described below (Giles et al. 1990):

$$DI : T - (0.55) * (1 - 0.01 * RH) * (T - 14.5) \quad (2)$$

where DI is the temperature-humidity index (discomfort indices); T is ambient dry bulb temperature (°C); and RH is relative humidity (%). According to the latest developments, the DI index is evaluated by classifying the data according to the context of the analysis and finding the values obtained. In order to explain the DI values, $DI \le 14.9$ is the uncomfortable, $15.0 \le DI \le 19.9$ is the comfortable, $20.0 \le DI \le 26.4$ is partially comfortable, and $DI \ge 26.5$ is uncomfortable are commonly accepted (Thom 1959). Din et al. (2014) suggested that the partially comfortable range is $20 \le DI \le 30$, and the uncomfortable range is $DI \ge 30.1$. Discomfort Index (DI) illustrates the range of classes for the chosen approach in this work. Values < -40 are considered extremely cold, and $> +30$ extremely hot.

Results and discussion

ThC modeling

The change in the annual average temperature of Kastamonu province in 2040, 2060, 2080, and 2100, according to S_I and S_{II} scenarios within the existing and projection intervals, is depicted in Fig. 3. On interannual timescales, the temperature change in the province is examined, and the average temperature varies between 7.5 and 13.9 °C. The results of S_I show the lowest temperature rises to 10.2 °C, while the recorded maximum temperature is 16 °C in the 2100 forecast. As seen from the S_{II} scenario, the highest value of today's map, 13.9 °C, is the lowest temperature value of the province. This simulation also indicates that the highest temperature value in the area is modeled as 18.9 °C, and a temperature of 5 °C in the highest temperature value of the province is possible. The analysis of climate parameters is presented in Table 1.

Figure 4 indicates the annual average relative humidity in the area by a value between 68 and 80%. According to S_I, the lowest relative humidity drops to 65.4% in the 2100 forecast. The highest relative humidity is 75.3%. According to the S_{II} scenario, the lowest relative humidity is estimated at 61.3%, and the highest is 70.3%. According to the S_I climate change scenario, the highest relative humidity will undergo a range decline of 4.7%, and according to the S_{II} climate change scenario, there will be a 9.7% decrease in the highest relative humidity in the area.

The spatial reflection of the estimates of ThC zones according to the DI formulation is shown in Fig. 5. Currently, there are extremely cold and very cold areas in the research area. According to Table 2, the annual average calculations of the area in today's conditions show that 86.9% is cold, and 13.1% is cool among the classifications. It has been determined that ThC is uncomfortable. According to the S_I scenario, extremely cold areas are decreasing, and comfortable regions are emerging in the forecasts for the 2100s. Accordingly, 75.5% of the site is cold, 23.4% is cool, and 1.1% is comfortable. Cold spots decreased to 62.8% in the 2060s, 24.2% in the 2080s, and 14.4% in the 2100s. Comfortable areas that do not exist today will reach 13% by the 2100s. Also, this increases the water-holding capacity of the atmosphere, erosion, and sediment transportation, resulting in global increases in precipitation and evapotranspiration. According to the S_{II} scenario, it is predicted that cold regions, which have a share of 86.9% today, will not take place after the 2080s.

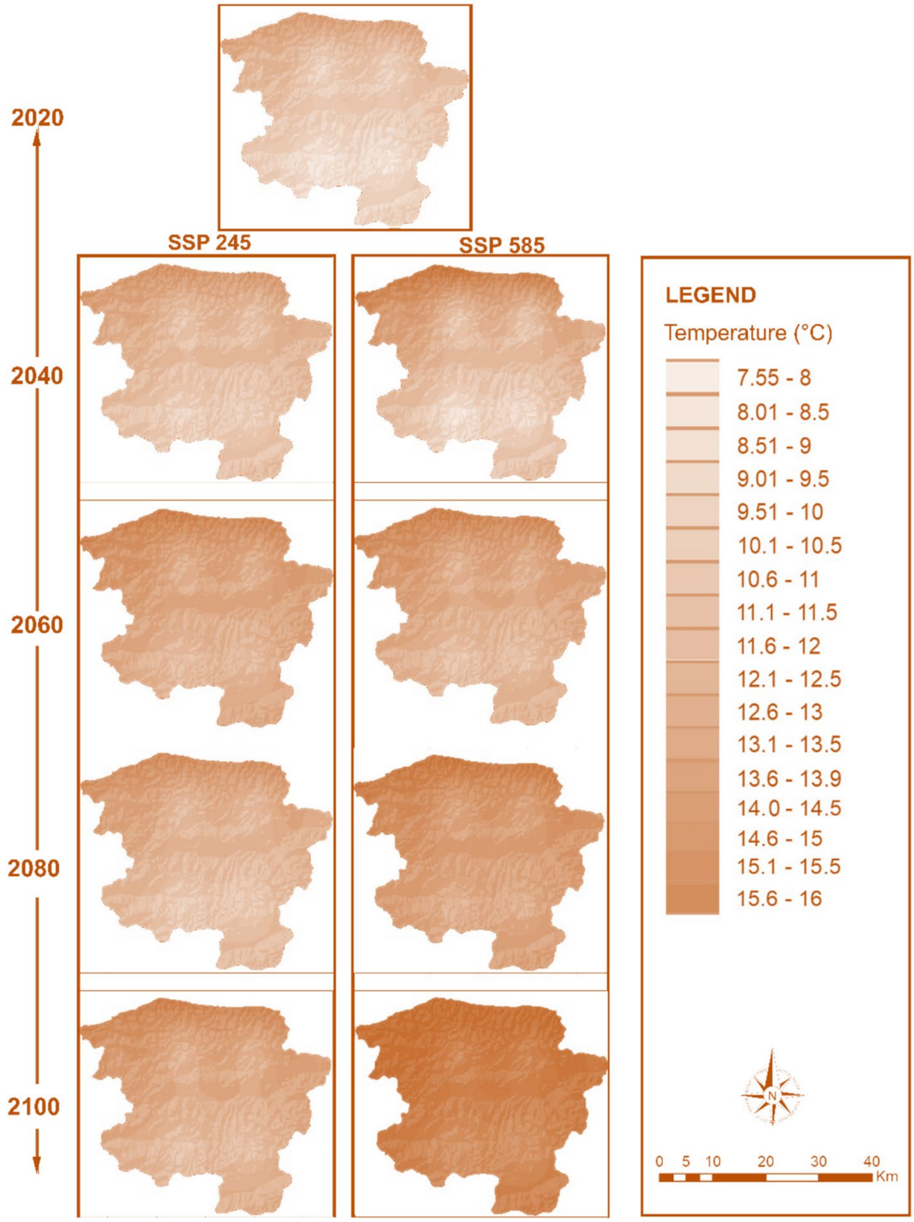


Fig. 3 Spatial temperature simulations for S_I and S_{II} climate scenarios

Table 1 Characterization of the climate scenarios based on the outdoor temperature and outdoor relative humidity

Climate Scenario	Mean OT	Min OT	Max OT	Mean ORH	Min ORH	Max ORH
Current situation of 2020	9.6	7.55	11.6	77.25	76.2	78.3
A moderate scenario of S_I projection at 2100	12.8	12.4	13.1	72.6	70.7	74.5
A pessimistic scenario of S_{II} projection at 2100	15.4	14.8	16	67.3	64.3	70.3

OT outdoor temperature (°C) and *ORH* outdoor relative humidity (%)

On average, global surface temperatures have increased until the 2060s. The area will be mostly (60%) cool, and 12.1% of the comfortable regions will be formed in regions with strong variability. In the S_{II} scenario, hot (15.2%) and very hot (0.1%) areas are modeled with a more pessimistic result regarding ThC in the 2100s and enhanced diffusive sources of large amounts of pollutants from agricultural land to river systems.

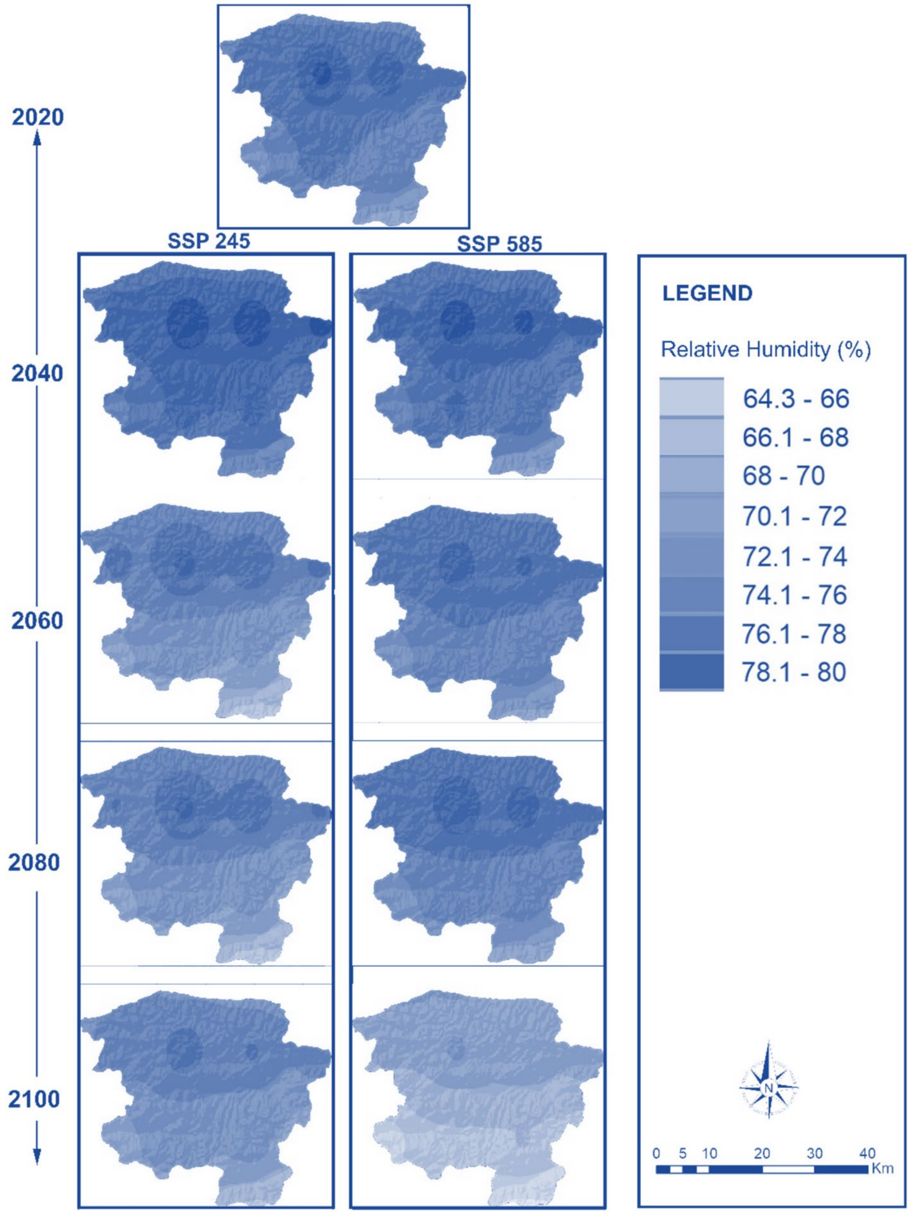


Fig. 4 Spatial relative humidity simulations for S_I and S_{II} climate scenarios

Apart from the worsening of the projection, with increased hot points adversely affecting regional environmental conditions, proper interest in considering this phenomenon as a significant challenge in growing urban sustainability will be increased by the 2100s.

The city center in Fig. 6, which is in the "extremely cold" class today, will warm up to the "cold" class in 2100 in the pessimistic scenario. However, the city center was not affected critically by the changes in 2100. Since the city center and development areas are climatically away from the coastal effect, they have cold ranges even in the pessimistic scenario. Forests, agricultural areas and rural settlements in the city center will be in the hot and very hot class. The possibility of extremely hot areas in Doğanyurt district, located in the northernmost part of the province, is noteworthy. While the temperature drops to 5 degrees in winter, it is around 30 degrees in summer. The elevation continues to increase from the coast to the interior. Summer months are hot and dry. Since the economy and job opportunities are limited, there is a lot of migration to metropolitan cities. The population in the center and villages generally consists of elderly people. Therefore, the possibility of a serious dissolution in the future should be taken into consideration in the planning of this district. In addition, the transformation of the entire coastline into a very hot class requires that land use be shaped accordingly during the hot months of the year.

On the other hand, it is predicted that extremely hot areas will be formed in the İnebolu district, a port settlement with traditional architecture. The country has an essential place in the history of independence. Wood joinery, particle board,

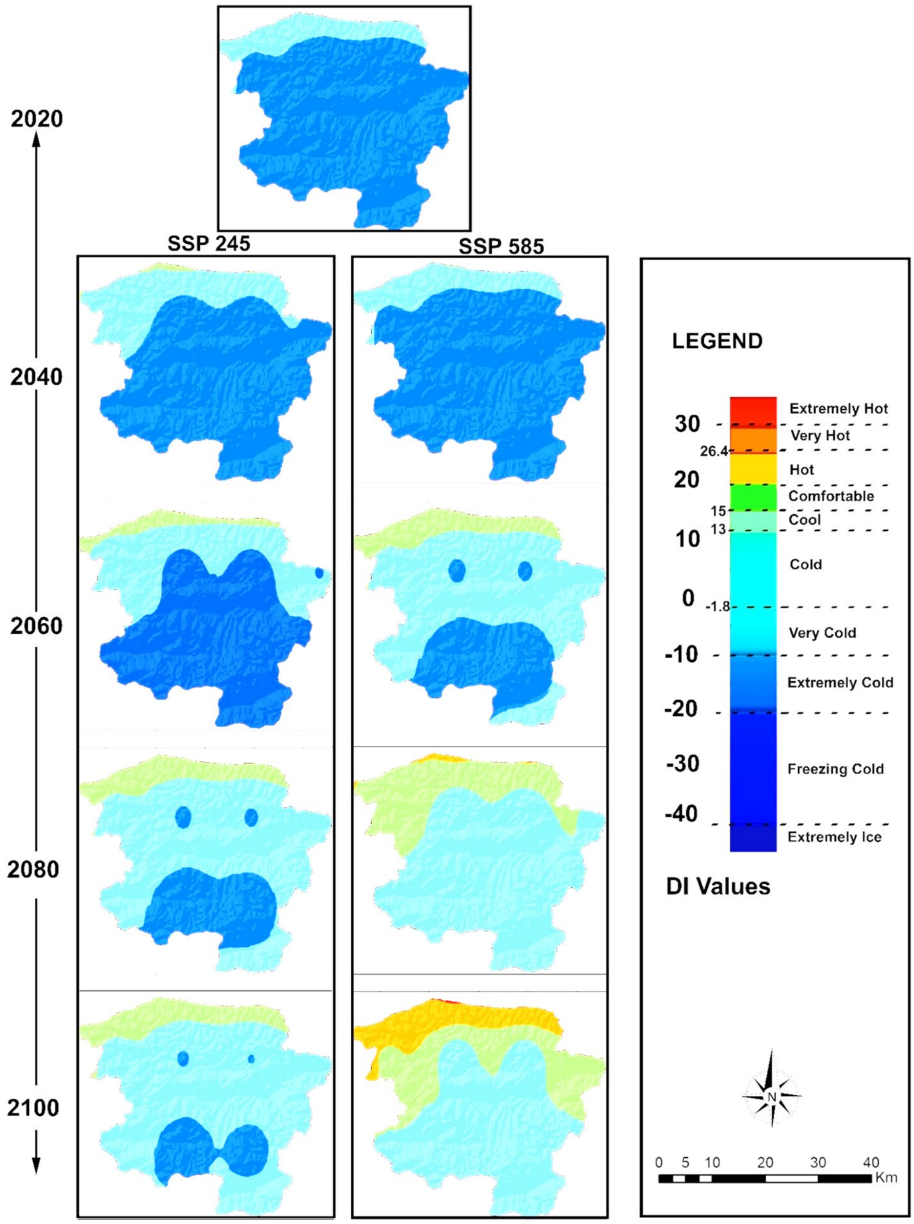


Fig. 5 ThC zone simulations according to S_I and S_{II} climate scenarios

Table 2 The current and future ratio (%) of ThC areas

Scenario	Classification	Years				
		2020	2040	2060	2080	2100
$S_{I€}$	Cold	86.9	75.5	62.8	24.2	14.4
	Cool	13.1	23.4	31.3	63.5	72.6
	Comfortable	–	1.1	5.9	12.3	13
	Hot	–	–	–		
	Very hot	–	–	–		
S_{II}	Cold	86.9	85.8	27.9	–	–
	Cool	13.1	14.2	60	72.5	58.2
	Comfortable	–		12.1	26.5	26.5
	Hot	–			1	15.2
	Very hot	–				0.1

S_I: moderate radiation forcing 4.5 W/m^2, SSP2-4.5, S_{II}: peak—radiation pressure 8.5 W/m^2, SSP5-8.5

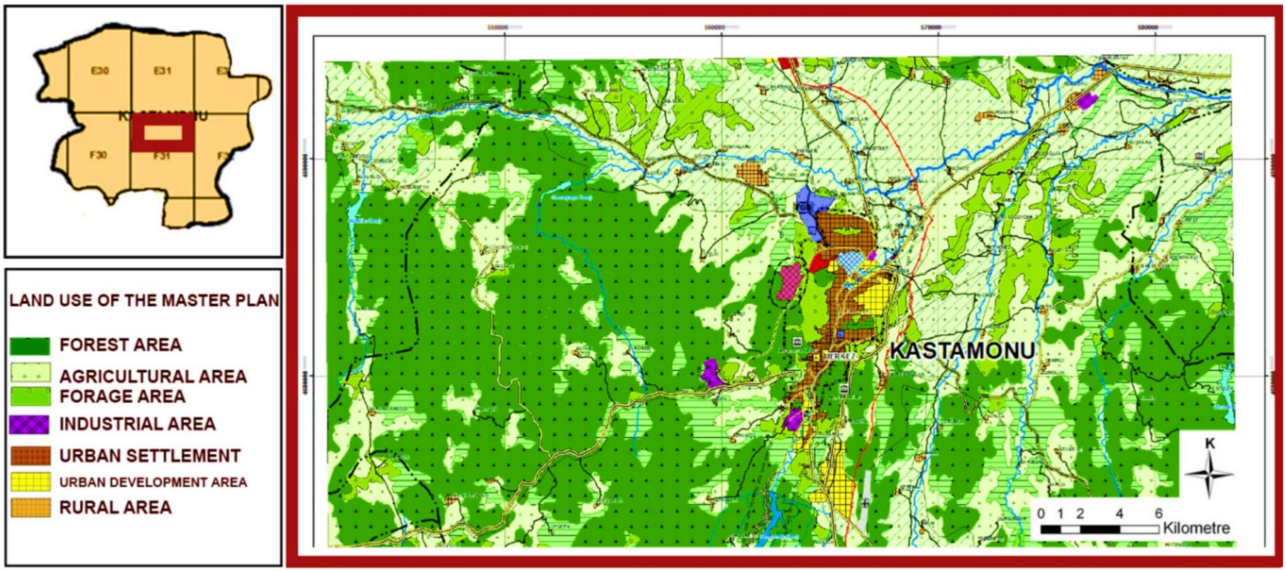


Fig. 6 The master plan of the city

hardwood, copper pyrite, cigarette paper, crystal sugar, fertilizer, etc., can be shipped from the port, including exports and imports of products. It generally has foggy and rainy weather. Pseudomaki, in which some high maquis elements and the more humid species of the Black Sea coexist, are common. It is foreseen that port activities may be at risk depending on the changing climatic conditions. In addition to risks, there is a possibility of displacement of the existing vegetation in the area. Increases in air and water temperature have been indicated to cause biological productivity and decomposition, disruption of the nutrient cycle, untimely eutrophication, and deterioration of the quality of water resources.

Discussion

Our evaluation reflects a significant step forward, including climate impacts on urban land use across climate warming scenarios. Rather than providing a single impact assessment of one location, we offer a Kastamonu province evaluation of today's most relevant ThC zones. Perms (1984) showed the monthly highest DI values for TC conditions on the islands of the Mediterranean Sea in August. A few studies have employed the thermal discomfort research tried to describe in the Campina Grande, Brazil, by Da Silva et al. (2010) and a synergetic effect revealed in three Greek cities by Papanastasiou et al. (2015). It determined it was suitable for ThC, except for four district centers in the province.

On the other hand, this research investigates the impact of ThC zones on settlements by considering climate scenarios in the temporal-spatial process. Concerning the spatial distribution of DI values, the province has extremely cold and very cold areas. It is observed that comfortable regions may occur in the future. The S_{II} simulation shows that by 2100, areas calculated as cold will not take place. In addition, according to the index data, it is predicted that there will be very hot areas that have never been encountered. Sites with complex landscape and elevation differences, which differ from each other, provide better monitoring of the changing pattern. In the temporal change in the area, the temperature increase fluctuates from the coasts to the terrestrial regions modeled. As Mansuroglu et al (2021) stated, the effects of climate change will be highly reflected, especially in tourist cities like Kastamonu. Similarly, climatic analysis is investigated using many techniques and concepts, including TC and heat stress.

Numerous indices have been tried to show climate change in urban areas. The biological variability can show differences in prediction accurately, although the DI recognizes a more straightforward and more easily used index. At the building scale, there are studies on natural ventilation (Izadyar et al. 2020; Gilvaei et al. 2022) and material selection (Nicolalde et al. 2022; Imghoure et al. 2021) for energy-saving purposes (Ma et al. 2021). There is also a research field in urban design that includes building morphology cooling strategies and investigates the impact of microclimate on outdoor comfort (Khraiwesh and Genovese 2023; Sun et al. 2023). On a macro scale, ThC has a dimension that manages comprehensive energy and transportation investments and a sustainable regional economy (Khan et al. 2022). Fotso-Nguemo et al. (2022) analyzed regional heat and discomfort in Central Africa, which is divided into two main types: tropical climate (two seasons) and humid tropical climate (four seasons). The potential changes were determined at 1.5, 2, and 3 °C at Regional Climate Models (RCMs) simulations (a total number of 8). The DI indicates an enhanced grade of pressure to a gradually large proportion of the local population of these countries compared to the reference range. Oleson et al. (2015) searched climate change for four cities by five commonly used heat stress indices: the NWS, HI, AT, SWBGT, Humidex, and DI. They used heat indices for rural and urban areas in future scenarios of a humid subtropical climate for Houston, and a subtropical desert climate for Phoenix, Toronto, and New York. The urban heat stress is higher than in rural areas in daytime and nighttime for all locations as exceedance frequency. Din et al. (2014) performed DI for a thermal sensation questionnaire survey in four kinds of buildings in Putrajaya, Malaysia, using an HOBO data logger (HOBO U12). It is also well known that the TC condition was obtained for better design assessment in the future. DI has also been applied to another research study very close to our result. They positively correlate with confirmed land particulars during heat conditions (Polydoros and Cartalis 2015).

Regarding the health of results, the homogeneity of the data and a large number of samples of air quality (multi-point surface measurements in cities) are essential for the traditional DI applications in cities (Sharafkhani et al. 2019). Another index to consider of urban bioclimatics, Zeroual et al. (2019) explained climate zones and estimated climate zone expansion from 1951 to 2098 in Algeria as defined by the Köppen–Geiger criteria. The RCP8.5 found the most pessimistic scenario averaged between 2045 and 2098 as an aridification trend. Brown et al. (2015) researched the effects of TC using thermal sensation in the parks, including ambient temperature, short wave radiation, prevailing wind, and humidity. Using these parameters, they modeled five climate zones based on the Köppen–Geiger classification. The results show remarkable heat problems and uncomfortable bioclimate in studied areas, while green spaces relate more TC in all climate zones. Mazhar et al. (2015) measured the microclimate in Lahore (Alhamra Art Centre and Shalimar Garden), Pakistan. They identified urban landscape characteristics (air temperature and prevailing) in terms of the thermal discomfort of residents, which were modeled and compared to the TC conditions using COMFA. Also, they express climate-sensitive urban projection implications for lessening thermal discomfort in hot conjuncture. The results show that Shalimar was more thermally comfortable than Alhamra due to its hotter microclimate. Mobolade and Pourvahidi (2020) analyzed thermal analysis with Köppen climate classification for five different climatic regions in Nigeria. Some ThC features highlighted in our study, such as the temperature and humidity over the particular region, were also found in Flannigan et al. (2016), Mora et al. (2017), Chew et al. (2021), and Zhang et al. (2023). Despite many steady features from previous research showing that climate change's effect on cities is seen with drought (Isinkaralar et al. 2024), it also impacts climate-based architecture in cities. As it turns out, DI is a significant indicator of city climate conditions. Nevertheless, it does not reveal the spatial variation of thermal discomfort levels due to the sparsely-spaced measured points (weather stations) being limited data. This finding indicates the importance of measures and policymaking about TC conditions for urban planners. Thus, while emphasizing climate change, the study directs planning strategies regarding energy and ecosystems and proves the index's applicability in ThC analyses.

Conclusion

Climate risk has affected cities and human life in ways such as the choice of residential areas, clothing choices, eating habits, and activity preferences. Regarding ThC, Suitability also brings many advantages and disadvantages in areas where tourism activities occur. Therefore, it is essential to determine the suitable and not suitable for ThC magnitude during the tourism season, especially in areas where tourism activities occur. The rapid increase in size is ideal for ThC, but it will also devastate food and water resources, among people's basic needs. It is also known that due to changing conditions, there can be devastating and irreversible effects like storms, tornadoes, floods, and forest fires. Overall, our analysis indicates that the interannual analysis, the average temperature in the province ranges between 7.5 and 13.9 °C. The S_I scenario projects a minimum temperature rise to 10.2 °C, with a maximum temperature of 16 °C forecasted for 2100. In contrast, the S_{II} scenario suggests that the current maximum temperature of 13.9 °C represents the lowest anticipated temperature for the province. This simulation further indicates that the modeled maximum temperature for the area is 18.9 °C, with the possibility of a 5 °C temperature in the highest temperature zone. The level of thermal discomfort has drastically increased for a multidimensional way will occur in numerous problems related, among other things, to food safety and local population displacement in a short time. We suggest fitting a mechanism for regularly updating the SSPs, land-use scenarios, and emissions based on precipitation and temperature patterns. In conclusion, this is something that must be taken into consideration in future socioeconomic development plans of Kastamonu city. Thus, the behavior and intensity of different climatic variables will ensure that the greenhouse gases responsible for warming will be eliminated by developing climate-appropriate approaches, not only according to the current climate but also considering future evolution. Based on research findings, various economic actors and policy makers at the country and regional levels should produce short, medium and long-term strategies according to different time periods that determine the priorities of risks. While directing these strategies, unfortunately, it seems beneficial to reduce coastal usage to higher and inland areas.

Since the data source is limited in the future estimations of this research, it is calculated over the annual average values. The study can be enriched by strengthening the data set in sample areas where local station data can be provided. However, this study includes pessimistic and milder approaches from the five scenarios in the IPCC report. All scenarios can be preferred in studies aiming to reveal the change more comprehensively in terms of scenarios. Kastamonu City, which belongs to a medium-sized and developing country, was chosen for this study. Extending new perspectives can be gained by applying them in cities with different levels of development. There are various evaluation indices in terms of ThC. This study is based on the classification created by the DI, which is widely preferred in the literature. The study aims to draw attention to the importance of spatial decisions in terms of planning. However, different indices can be compared in studies focusing on the effect of other indices on ThC change. Future studies may be carried out at the regional borders and cover larger areas with similar climate and plant characteristics regarding environmental, managerial, and economic aspects.

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Data availability The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All authors have read, understood, and have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors.

Consent to participate Not applicable.

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