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ORIGINAL PAPER

Discovery of spatial climate parameters and bioclimatic comfort change simulation in Türkiye under socioeconomic pathway scenarios: A basin-scale case study for urban environments

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Abstract

Heat waves and extreme weather events caused by climate change increase people's need for predictable, healthy, and appropriate thermal thresholds in urban areas. The Mediterranean region, where alarming effects are expected, poses a danger to many species and threatens the quality of human life. In the research, predictions were made according to SSP 245 and SSP 585 scenarios from CNRM-CM6-1 climate models using the data of meteorological stations for 2020 in the Eastern Mediterranean region via CMIP6 and WorldClim database. The study aims to predict the change in the bioclimatic comfort situation of the region at 20-year intervals until 2100, depending on the periods. The highest annual temperatures seen in the area are 18–20 °C. In the 2100 estimations, areas with a value of 22–24 °C according to SSP 245 and 24–26 °C according to SSP 585 are modeled spatially. While the largest area in the basin today is the area with a humidity range of 62–64%, according to SSP 245, in 2100 predictions, the largest area will be 23% with a humidity level of 56–58%. While the wind speed in the area is currently 0.5–1 m/s, it decreases to 0–0.5 m/s in 36% of the area, according to SSP 585. According to the ET*v* index, quite cool areas are effective on a 36% area surface. However, in the 2100, compared to the SSP 245, the most comprehensive range is the slightly cool areas with 40%. According to SSP 585, mild areas will have a share of 42%. Warm areas, the most critical class of the index, will begin to form. According to DI, the field has a 58% share in the cold class. According to SSP 585, hot areas have a rate of 26%, and comfortable areas have a rate of 52%. Findings of thermal disturbance variation can help develop solutions to conditions in the context of the climatic values of the region.

Keywords Disaster response · Natural hazards · Risk management · Spatial planning · Urban modeling

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1 Introduction

In addition to the social and economic adverse effects of urbanization, such as food security (Hu et al. 2023), traffic, and noise (Popek et al. 2023; Guha and Gokhale 2023), it also has effects such as environmental emissions (Jiang et al. 2022; Isinkaralar 2023a, b), land degradation (Seifollahi-Aghmiuni et al. 2022) and damage to natural systems (Shang et al. 2023). Land use plans are tools to manage the possible damage that urbanization and urban growth will cause to the ecological structure and natural land cover. However, it is stated that the climate change under the influence of dynamic and complex processes in today's world. It is known that this differentiation of climate parameters will continue for centuries (Lyon et al. 2022). They are investigating whether changing conditions suit humans and other living species, a vital analysis in urban planning processes.

Determining bioclimatic comfort conditions based on the suitability of climatic conditions for life is a critical analysis in designing sustainable cities, especially in terms of optimum use of heating and cooling-based energy, in order to bring the microclimate to the desired ranges (Pisello et al. 2015; Istanbullu et al. 2023). However, extreme climatic conditions effectively reduce productivity in working life and decrease social life quality (Chatzidimitriou and Yannas 2016; Ragheb et al. 2016). Serious changes can affect psychology and lead to respiratory and circulatory diseases and early death; all socio-economic segments are threatened by global warming (Zhao et al. 2022). However, healthy ecosystems and comfortable biodiversity depend on the environment, providing living species with climatic values suitable for living conditions. However, the changing climatic parameters require urgent intervention for the sustainability of species on our planet. Therefore, people's ability to stay healthy, perform at high levels, and feel comfortable depends on living in areas suitable for bioclimatic comfort.

A suitable outdoor environment for bioclimatic comfort is related to the optimum temperature, humidity, and wind parameters due to climate (Oliveira and Andrade 2007). However, it is possible to carry out mitigation and adaptation studies against climate change through urban planning interventions. Urban microclimate influences urban planning and design decisions (Abdollahzadeh and Biloria 2022; Wang et al. 2023). In climates warmer than a bioclimatically comfortable area, interventions such as cold pavements, green patterns, widespread water surfaces, and energy-efficient construction are possible. Thus, determining whether the outdoor environment is hotter or colder than a suitable area in terms of bioclimatic comfort is necessary to determine the type of intervention needed and ensure sustainable development for comfort areas.

Some studies conducted in recent years focus on whether the perception of comfort arises from climate or individual preferences (Andrade et al. 2011; Aghamolaei et al. 2022; Manavvi and Rajasekar 2022). Research on indoor conditions and thermal perception is common (Larriva et al. 2022; Elraouf et al. 2022; Zhou et al. 2023). For outdoor spaces, some studies research tourists' thermal preferences (Rutty and Scott 2015). Manavvi and Rajasekar (2023) used structural equation modeling in squares for the thermal comfort perception of urban residents in India. Studies on the spatial pattern of bioclimatic comfort zones are limited (Isinkaralar 2023a, b). Many indexes are used to determine whether an outdoor space is bioclimatically suitable. These indexes are based on the classification of values obtained with different formulations of climate parameters. The research used the Discomfort Index (DI) and Effective Temperature Taking Wind Velocity (ET*v*) indexes. Comfort zones were determined based on the version of Thom's Discomfort Index developed by Giles et al. (1990), which defines it in terms of temperature (degrees Celsius) and relative humidity (percentage). An attempt is made to fill the gap in outdoor research by determining the temporal-spatial change of comfort zones in the Eastern Mediterranean basin, one of the south coasts of Türkiye, which is critically affected by changing climatic conditions.

2 Materials and methods

2.1 Study region and data

The Eastern Mediterranean Basin is located in the south of our country between 36°00’ and 37°28’ northern latitudes and 32°06–35°09’ eastern longitudes in Fig. 1. The Eastern Mediterranean Basin consists of 10 sub-basins: Tarsus, Kızıldere, Alata, Lamas, Göksu, Ermenek, Kayraktepe, Delice, Dragon, and Sipahili. In the basin, where the altitude varies between 0 and 2000 m, the elevation exceeds 3500 m on the ridges and peaks. Approximately 92% of Mersin Province, 7% of Antalya Province, 35% of Karaman Province, and 6% of Konya Province are located within its borders.

This research includes simulations for the 2020–2100 times: 2021–2040, 2041–2060, 2061–2080, and 2081–2100. In future predictions, CMIP6 is a part of the Coupled Model Intercomparison Project. Modeling was done based on Socio-economic Pathways (SSP) future climate change scenarios: SSP 245 and SSP 585. The models were produced in two stages. First of all, the temporal-spatial variation of the climate parameters was estimated. Then, the temporal variation of the bioclimatic comfort classification within the scope of different indices was predicted by 2100.

Climate projection data used to determine the change in bioclimatic comfort zones are based on meteorological stations defined by the General Directorate of Meteorology. In addition, the Combined Model Intercomparison Project Phase 6 (CMIP6) global data WorldClim database sets are beneficial for guiding spatial analyses and the climate scenarios developed by the 2021 IPCC sixth assessment report (AR6).

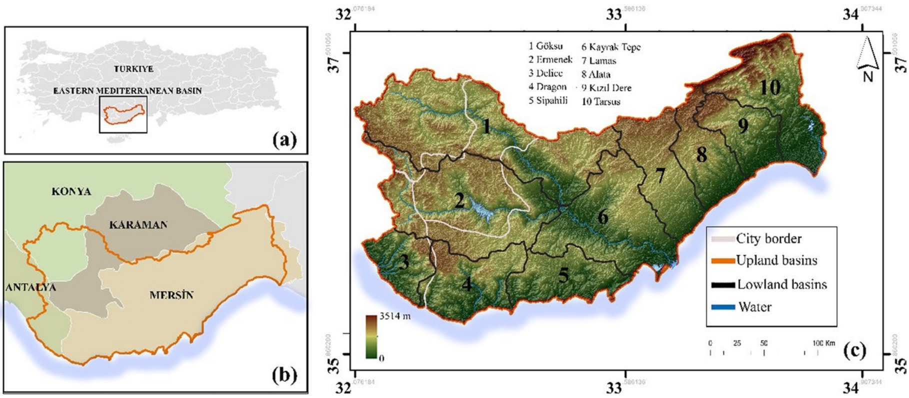

Fig. 1 **a** Geographic location of Eastern Mediterranean basin in Türkiye, **b** The cities in the basin, **c** Elevation distribution and sub-basin boundaries in the basin

2.2 Methods

In conducting this research, a data set related to the study area was first compiled. The maps produced were organized using geographic information systems (GIS). The data obtained is not based on fieldwork or experiments. Big data provided by WorldClim and meteorological data obtained from institutional stations were used for modeling. The parameters obtained depending on the climate were arranged using the ArcGIS 10.8 software program. The "Inverse Distance Weighted (IDW)" analysis was used to map the climate data. The basic equation of the analysis is as follows in Eq. (1):

$$z\left(x_o\right) = \frac{\sum_{i=1}^{n} z\left(x_i\right).d_{i0}^{-r}}{\sum_{i=1}^{n} d_{i0}^{-r}} \tag{1}$$

where x_0: a function of neighbor measurements n [$z(X_{0i})$ and $i=1,2,\ldots,n$];r: the exponent determining the assigned range of each of the observations;d: the distance separating the observation location X_i from the prediction location X_0.

Comparable research on outdoor comfort is based on indices. In the study, the change in bioclimatic comfort zones for the Eastern Mediterranean basin was modeled by using Thom's Discomfort Index (DI) (1959) and Effective Temperature Taking Wind Velocity (ETv) indexes (Suping et al. 1992). Spatial maps predict future spatial changes in the temporal process.

The first of the indexes applied in the study is DI, and it is formulated as follows in Eqs. (2) and (3) (Giles and Balafoutis 1990):

$$\mathrm{DI} = \left(T_{\mathrm{dbt}}\right) - 0.55[1 - (0.01)(\mathrm{RH})] * \left[T_{\mathrm{dbt}} - 14.5\right] \tag{2}$$

$$\mathrm{ET}_v = 37 - \left[\frac{\left(37 - T_{\mathrm{dbt}}\right) * (1.76 + 1.05v)}{(0.68 - 0.0014\mathrm{RH} + 1)}\right] - (0.29) * \left(T_{\mathrm{dbt}}\right) * \left[1 - \frac{\mathrm{RH}}{100}\right] \tag{3}$$

where DI: Temperature–humidity index (discomfort empirical index); T_{dbt}: dry bulb temperature (°C) and RH: Relative humidity (%), v is wind speed (m/s)

According to the intervals of the index values, the feeling of thermal comfort is interpreted according to specific intervals. This classification ranges from extremely cold to extremely hot. DI has ten primary classifications. Three are warmer than comfortable, and six are colder. According to ETv, the $22 \le \mathrm{ET} \le 25$ range is considered comfortable. Four classifications are warmer, and six classifications are colder, making eleven categories.

3 Results and discussion

3.1 Simulation of climate components

Some climate parameters are temperature, relative humidity, and northward wind. The temperature change reflects climate change as a parameter directly reflecting the urban heat island (UHI). Today, 19% of the study area has the largest area of 8–10 ℃, and 18% has the largest area of 10–12 ℃. According to the SSP 245 scenario predictions in the research area, by 2100, there will be no 0–4 ℃ zones, which today have an area of 2%. Areas in the

20–24 ℃ range, which do not exist today, will have a share of 18%. According to SSP 585, the 24–26 ℃ range, which we do not see today, will have a share of 11%, there will be no areas in the 0–8 ℃ range, and areas in the 20–26 ℃ range will dominate 36% of the region.

While temperature values increase, the temporal decrease in humidity is remarkable. Today, the 62–66% humidity range accounts for 51% of the area. According to SSP 245, by 2100, areas in the 56–58% range, which do not exist today, will start to be observed with 23% of the area in Fig. 2. According to SSP 585, humidity values in the 50–52% range will be observed, which not the case is today. There is a fluctuating course in wind parameters. While 0.5–1 m/s wind speed is observed in the entire area today, according to SSP 585, 36% of the area will have 0–0.5 m/s, and 3% will have 1–1.5 m/s by 2100.

3.2 Spatial modeling of bioclimatic comfort areas

The change of the areas according to the scenarios depending on the indices is presented in Table 1. In the analysis made using DI, it is observed that the surfaces in the cold class, which dominate the area, decreased to 27% within the scope of SSP 245 and to 4% within the scope of SSP 585 in the 2100 predictions. According to SSP 585, in the 2040–2060 period, hot areas will begin to form, moving away from bioclimatically comfortable areas. By 2100, 52% of the area will be in the comfortable class, while the rate of hot areas will reach 26%. According to ET*v*, there are no comfortable areas today. Comfortable areas will begin to form in the 2040–2060 period within the scope of SSP 245 and the 2020–2040 period according to SSP 585. According to SSP 585, warm areas will begin to form by 2100.

The spatial change model of comfort zones gives very guiding clues in decision-making processes (Fig. 3). According to SSP 245, there continue to be ET*v*/quite cool, DI/cold areas in bioclimatic terms in the inner parts of the north of the basin in Fig. 3. In the coastal part in the south, ET*v*/comfortable and DI/hot areas are observed due to the marine effect. According to SSP 585, it is estimated that ET*v*/quite cool areas in the inland areas will turn into slightly cool and mild areas. In contrast, DI/cold areas will gradually decrease, and cool and comfortable areas will dominate. It is predicted that ET*v*/comfortable areas will dominate in the coastal area; while, DI/hot areas will occupy a large area along the coasts.

Significantly, the transformation of coastal regions into hot areas in terms of comfort between 2040 and 2060, according to the pessimistic scenario, and between 2060 and 2080, according to the moderate scenario, will cause the region to be affected sectorally. The UHI phenomenon, which expresses that the temperature level in cities is higher than in the surrounding regions, is in a more critical position, especially in hot climates (Piselli et al. 2018; Isinkaralar et al. 2023). The UHI effect may worsen in regions with high air temperature and high humidity, such as the research area (Abdollahzadeh and Biloria 2021). According to Sharmin and Steemers (2020), three factors affect thermal perception: weather, health status, and psychological factors. The climate crisis's most perceived impact is temperature change (Mansuroğlu et al. 2021). However, air temperature is the most substantial microclimatic component affecting thermal sensation (Tan et al. 2019). Tourism is one of the sectors most affected by outdoor temperature.

The region, which has significant income from coastal tourism, is at economic risk. In addition, Mersin province, located on the coast, contains agriculturally productive lands, and approximately 25% comprises agricultural areas. Many industrial enterprises and mining activities are carried out. As a port city, nearly three thousand ships participate in active trade annually. It is a rich country geography regarding forestry and animal husbandry

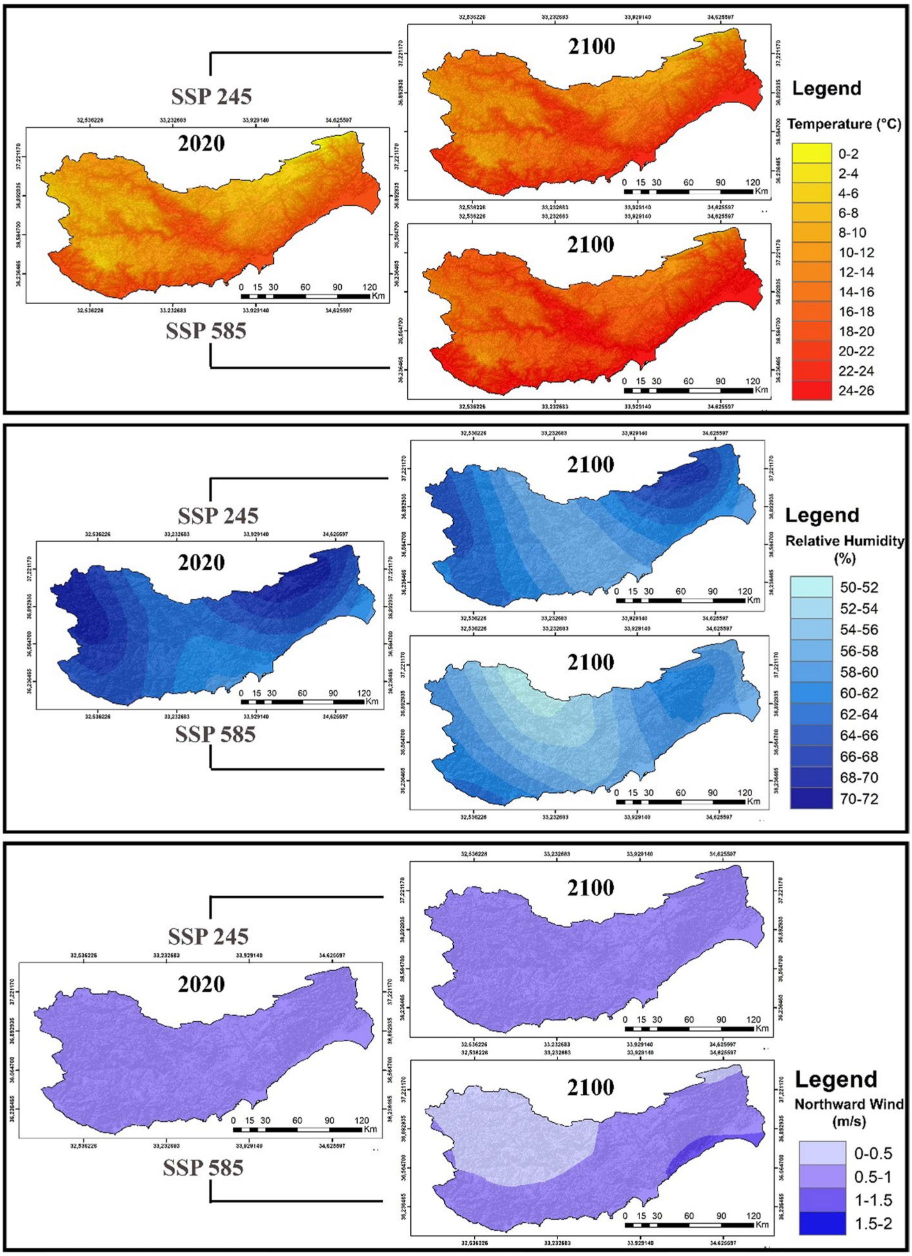

Fig. 2 2100 maps of climate parameters (temperature, relative humidity, and northward wind) depending on scenarios

activities. In this context, the efficiency of the activities carried out may decrease. However, the city center is located on the south coast. In this location with a high population density, risks arise regarding quality of life and public health. Many studies reveal the effects of changing thermal comfort values (Acero and Herranz-Pascual 2015; Antonini

Table 1 Spatial simulation results of bioclimatic comfort analysis based on scenarios

Index	Scenario	Determination	Years				
			Present (2020) (%)	2040 (%)	2060 (%)	2080 (%)	2100 (%)
Discomfort index	SSP 245	Cold	58	48	39	33	27
		Cool	15	17	21	22	25
		Comfortable	27	35	40	39	40
		Hot	0	0	0	6	9
	SSP 585	Cold	58	45	34	18	4
		Cool	15	18	22	25	17
		Comfortable	27	37	39	43	52
		Hot	0	0	5	14	26
ET*v*	SSP 245	Cold	1	0	1	0	0
		Moderately cold	14	6	6	2	1
		Quite cool	36	32	31	21	17
		Slightly cool	30	36	32	38	40
		Mild	19	25	28	31	31
		Comfortable	0	0	2	7	12
		Warm	0	0	0	0	0
	SSP 585	Cold	1	0	0	0	0
		Moderately cold	14	1	3	3	0
		Quite cool	36	18	19	23	0
		Slightly cool	30	41	38	38	17
		Mild	19	34	31	31	42
		Comfortable	0	5	10	4	39
		Warm	0	0	0	0	1

et al. 2020; Santos et al. 2023). When considered from an economic perspective, the cooling energy requirement of buildings may increase.

In summary, bioclimatic comfort is effective in urban processes with its social, environmental, and economic aspects. Predicting urban development in physical and socio-economic terms is a critical guide in spatial planning. Creating new attraction points by withdrawing the significant investments planned to be carried out in the region from coastal to inland areas could be an essential strategy.

4 Conclusion

This article focuses on spatial modeling of the impact of climate scenarios on bioclimatic comfort areas in the Eastern Mediterranean basin, one of the hottest regions of Türkiye. Modeling bioclimatic comfort zones is valuable research for many disciplines, including climate scientists, urban planners, ecologists, architects, and engineers. Comfort areas should be determined to ensure that urban microclimatic features can reach optimum conditions through decisions and interventions and to ensure urban sustainable development. Research findings reveal severe changes in temperature and humidity

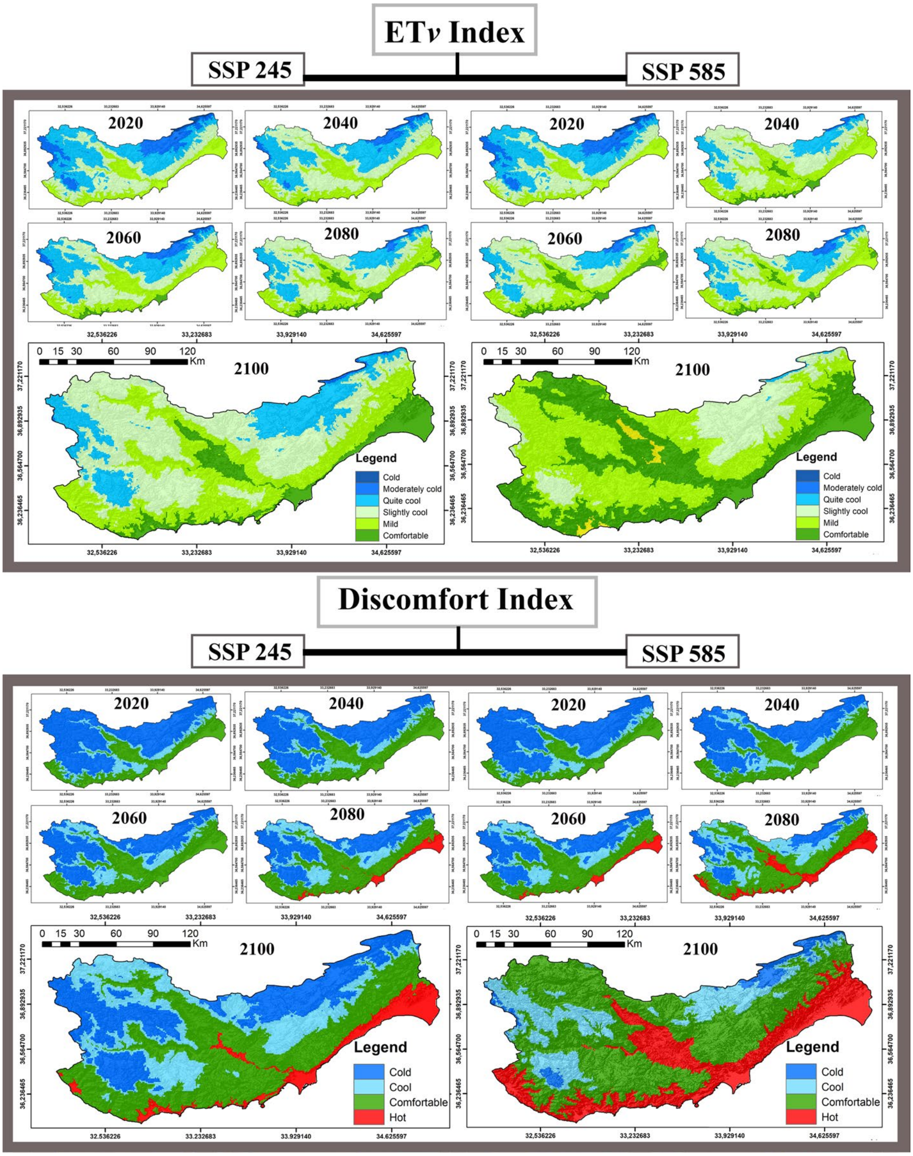

Fig. 3 Changes in bioclimatic areas depending on scenarios until 2100

values and the tendency for coastal areas to change toward warmer areas in the research region. The analyses carried out have multidimensional benefits such as energy savings in buildings, public health, quality of life, and sustainable urban environments.

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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 Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

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