



Bioclimatic comfort in urban planning and modeling spatial change during 2020–2100 according to climate change scenarios in Kocaeli, Türkiye

O. Isinkaralar¹

Received: 4 October 2022 / Revised: 10 February 2023 / Accepted: 8 May 2023 / Published online: 22 May 2023

© The Author(s) under exclusive licence to Iranian Society of Environmentalists (IRSEN) and Science and Research Branch, Islamic Azad University 2023

Abstract

The concentration of human activities in urban areas, increasing greenhouse gas emissions, and high global temperature values in urban areas have accelerated the research on global warming. They are the most widely used bioclimatic indices to describe the level of thermal sensation experienced by a person due to the changing climatic conditions of an urban area. Thermal comfort is an interdisciplinary spatial issue and a parameter directly affecting urban outdoor land uses. Thom's discomfort index was used to simulate two different climate change scenarios. This study aimed to predict the temporal and spatial changes of surface temperature, relative humidity, and bioclimatic comfort zones of Kocaeli province in terms of climate comfort in the context of SSP 245 and SSP 585 scenarios of IPCC. The current bioclimatic comfort areas throughout the region and their possible situations in 2040, 2060, 2080, and 2100 were modeled using ArcGIS 10.8 software. In the current map, 79.6% of the city consists of cool areas, 18.6% of cold, and 1.8% of comfortable regions. According to the SSP 245 scenario for the year 2100, it is observed that the cool and cold areas warm up, and the comfortable areas increase to 23.5%. According to the SSP 585 scenario, it was determined that comfortable areas reached 82.6%, and hot areas were formed in the province. The geographical structure's effect on the regions' heating draws attention.

Keywords Discomfort index · Geographic information systems · IPCC · Spatial analysis · Urban geography · Urban modeling

Introduction

In the post-industrial period, the employment opportunities (Hoogerbrugge and Burger 2022; Zhao et al. 2022) and social opportunities offered by urban areas, unlike rural areas, initiated the procedure of the migration process from rural to urban and the urbanization process on a global scale gained momentum, especially in developing countries (Ye et al. 2022; Zhang et al. 2022). Global urbanization (Ehrlich et al. 2018; Patra et al. 2018; Yang et al. 2020; Pimonsree et al. 2022), vehicle and population density have increased rapidly in urban areas, and there have been multidimensional

and mutually triggering processes such as environmental pollution (Sulhan et al. 2022; Yayla et al. 2022), socio-spatial problems, land degradation, and global warming in the long term (Cevik and Ghazanchyan 2021; He et al. 2022; Melnikov et al. 2022). The greenhouse gas concentrations such as VOCs, CO₂, CH₄, and N₂O accumulated in the atmosphere (Zhang et al. 2021; Isinkaralar 2022) as a result of increased emissions in urban environments higher than in rural areas (Amani-Beni et al. 2022; Cheval et al. 2022) due to human activities have resulted in global warming. According to WMO (2006), the T_s in the world increased by an average of 0.6–0.7 °C after the 1900s. However, the 0.18 °C increase in temperature in the ten years after 1976 is quite sharp. According to the Intergovernmental Panel on Climate Change (IPCC) Assessment Report, industrialization activities are responsible for an increase of 0.8–1.2 °C depending on the region (Church et al. 2013). If this continues, the gain may reach 1.5 °C before 2052 (Maniatis et al. 2021). Climatic processes emphasizing the distant future have brought emission scenarios, sanctions, and sustainability emphasis

Editorial responsibility: Mohamed F. Yassin.

✉ O. Isinkaralar
obulan@kastamonu.edu.tr

¹ Department of City and Regional Planning, Faculty of Engineering and Architecture, Kastamonu University, Kastamonu 37150, Türkiye



to current research (Kılıkış et al. 2022; Vargas et al. 2022). In addition, many studies showed that mega forest fires have increasingly been seen in recent years, especially those due to the effects of the climate crisis (Ertugrul et al. 2021; Bilgili et al. 2021).

It has been proven in many studies that for most countries, cities are the places most exposed to heat (Hanberry 2022; Jay et al. 2021). After accepting urban growth as a fact that cannot be ignored and the inadequacy of mitigation studies for the factors that will cause climate change, adaptation practices have started to be discussed in addition to mitigation studies in climate change processes (Sharifi 2021). Climate action plans based on strategies and targets have been produced for the change processes experienced (Karhinen et al. 2021). Urban heat island research has become widespread to guide urban design and planning decisions (Park et al. 2021). All these researches emphasize the collective behavior of international organizations, circumstantial authorities, and individuals in seeking solutions to the global temperature change. It is a promising approach in planning to make predictions based on probabilistic scenarios to be prepared for the transformation of climatic conditions, control uncertainties, and minimize possible adverse effects with timely decisions. In this context, the concepts of bioclimatic design (Elaouzy and Fadar 2022), bioclimatic architecture (Widera 2021), and bioclimatic approach (Molina et al. 2021) have begun to take place in current research. In addition, plant species (Wang et al. 2022), models for energy demand at the building scale (Al Huneidi et al. 2022; Salad et al. 2022; Yamaguchi et al. 2022; Salata et al. 2022), surface waters and wetlands (Shah and Lone 2022; Wang et al. 2022a, b), groundwater management (Dehghani et al. 2022; Kumar et al. 2022; Moghadam et al. 2022), basin scale (Abdi and Ayenew 2022; Tarekegn et al. 2022; Naulleau et al. 2022), forest adaption, forest fires (Bilgili et al. 2019; Sevinc et al. 2020) are included in current studies within the framework of the effects of climate change.

The IPCC report reveals that parallel to the increase in emissions in the atmosphere, the increase in T_s and the rise in sea level will continue in the twenty-first century and negatively affect many ecosystems, such as forest and aquatic ecosystems and the biological structures (Church et al. 2013; Kedward et al. 2022; Varol et al. 2022; Tekin et al. 2022). The long-term change of climate indicators is reflected in the comfort parameters of individuals depending on climatic conditions. Thermal comfort is a state of mind that expresses satisfaction with the thermal environment (ISO 2005). However, bioclimatic comfort (BIOC) zones are related to the stress level of individuals and can lead to fatal results by causing thermal stress beyond daily lifestyle (de Freitas and

Grigorieva 2015; Jia et al. 2022; Leng and Han 2022). The space, which moves away from the optimum climate parameters, prepares the environment for hypertension, asthma, and an additional critical public health problem. Sweltering weather can cause many health problems, such as migraine (Chaturvedi et al. 2022), sleeping disorders (Bolton et al. 2022), multiple sclerosis (MS) (Elser et al. 2021), epilepsy (Gulcebi et al. 2021) and infectious diseases (Coates and Norton 2021) by causing water and salt loss from the body due to excessive sweating. The fact that individuals do not feel comfortable affects their psychological health (Matzarakis and Mayer 1997) and their working efficiency. Therefore, individuals try to reach BIOC indoors and outdoors. However, this situation causes an increase in energy demand. It accelerates the growth in the use of fossil fuels, which is supported by many studies that are the leading causes of global warming (Olabii and Abdelkareem 2022). The increase in the CO_2 rate in the atmosphere accelerates the processes, with negative reflections coming to a dead end.

The rates of immigration and urbanization of cities for employment purposes are different from each other. The growth process of some cities is faster than in the country in general. Greenhouse gas emissions brought about by urban growth are considered to be responsible for the increase in T_s . In this context, this study that was carried out in 2021 aims to make future predictions of the BIOC areas of an industrial city for the Kocaeli, where people migrate heavily, in terms of T_s and RH , through the thermal scale developed in this framework. It is also targeted to draw attention to the point that can direct urban growth in the spatial decision mechanism of the obtained urban models.

Materials and methods

Study area of simulation

This research was carried out in Kocaeli province, where coordinates at latitude 40.852°N , and longitude 29.878°E . The area is located in the Marmara region and borders Marmara and the Black Sea. It creates a transition between the Mediterranean and the Black Sea climate. In the ranking prepared according to the socio-economic development index (SEDI) of Türkiye, Kocaeli comes after Istanbul, Ankara, and Izmir. Although it is smaller than Türkiye's metropolitan cities in terms of surface area, it is a city where industrial activities are intense in the Marmara region. It ranks first in terms of income per capita in the country (Fig. 1).

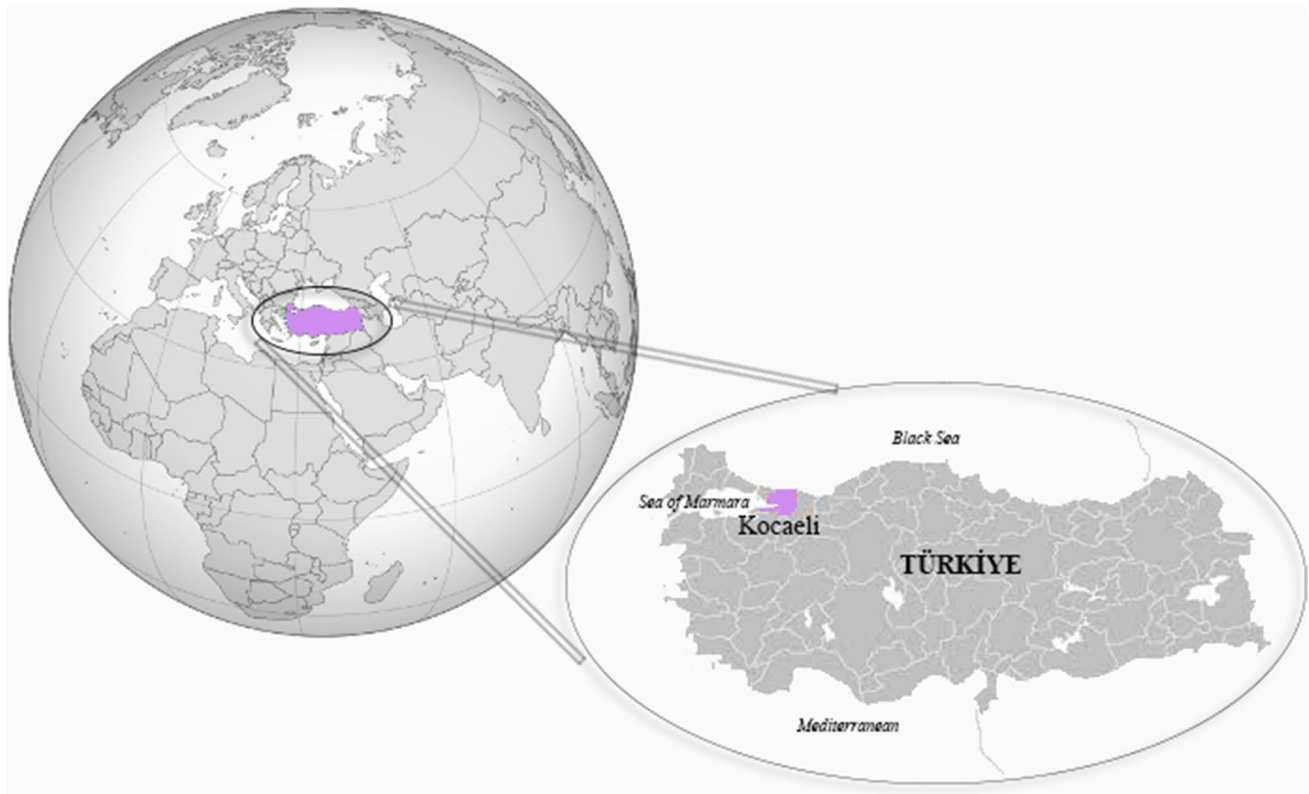


Fig. 1 Research area determined for BIOC analyses

Database, methodology of analyses, and prediction

The National Department of Energy Lawrence Livermore National Laboratory produces high-resolution (50 km resolution) climate projections for regional or local areas. In this context, SSP 245 (an intermediate radiative force is 4.5 W/m^2) and SSP 585 (the most extreme—radiative pressure is 8.5 W/m^2) scenarios of the CNRM-CM6-1 model were selected as some studies built on these scenarios (Varol et al. 2022). After the climate data was downloaded in NetCDF file format, these data were processed in ArcGIS 10.8 program. Many studies about spatial networks that affect decision-making processes have demonstrated using ArcGIS in spatiotemporal analyses (Sağlam et al. 2008; Aljoufie et al. 2013; Hussain et al. 2022; Liu et al. 2022; Isinkaralar and Varol 2023; Wei et al. 2023). Maps for simulation were created using the "inverse distance weighted (IDW)" method from the climate data obtained after the transformation process was applied with the software's section. The simple formula of the IDW, which is proceeding with the principle of estimating unknown points by interpolation from known values, is as follows:

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

The location X_0 where the estimations are made is a function of neighbor measurements $n [z(X_{0i})$ and $i = 1, 2, \dots, n$]; r is the top that determines the assigned range of each of the observations, and d is the distance separating the observation location X_i from the prediction location X_0 . The larger the exponent, the lower the assigned weight of statements far from the forecast location. An increase in the exponent indicates how closely the predictions are similar to the closest observations. Calculations were made using these data and the above formulas in Eq. 1 via the ArcGIS program.

Thermal comfort is essentially a type of analysis based on perception. As the temperature sensation of each individual is variable, their tolerance levels also differ. In this context, it is possible to say that it has a subjective aspect. However, there are indexes on which comfort feel ranges developed so far are based on certain assumptions. It is possible to determine the

Table 1 DI classification in this study

Interpretation of DI	Meaning of DI
< -40.0	Extremely ice
-39.9 to -20	Freezing cold
-19.9 to -10	Extremely cold
-9.9 to -1.8	Very cold
-1.7 to +12.9	Cold
13.0 to +14.9	Cool
15.0 to +19.9	Comfortable
20.0 to +26.4	Hot
26.5 to +29.9	Very hot
> +30.0	Extremely hot

suitability of the index values in terms of the perception of comfortable feeling in the human body, with the calculations carried out based on numerical data based on these indexes. These numerical operations and BIOC index formulas were applied to the climate maps of each scenario, and BIOC maps were produced for the study area. There are indexes, such as DI (Thom 1959), Climate Index (CLIM) (Becker 2000), and Cold Strain Index (Moran et al. 2003; Rissanen and Rintamäki 2007), which are widely used in the creation of BIOC maps. These indices are based on average temperature, and surface air temperature and subsequent water vapors are critical components of climate change and the hydrological cycle (Sein et al. 2022). All layers were in 1×1 km spatial resolution, and DI was covered by the temperature-humidity index (THI) and made by the implementation of its index in Eq. 2:

$$DI = T - (0.55 - 0.0055 \times RH) \times (T - 14.5) \quad (2)$$

where;

DI: discomfort index;

T : monthly average temperature ($^{\circ}\text{C}$);

RH: relative humidity (%).

In recent studies, the DI parameters have been interpreted by finding the obtained values and classifying them according to the scope of the research. When interpreting DI values, the classification of *uncomfortable* ($DI \leq 14.9$), *comfortable* ($15.0 \leq DI \leq 19.9$), *partially comfortable* ($20.0 \leq DI \leq 26.4$), and *uncomfortable* ($DI \geq 26.5$) is widely preferred (Thom 1959). According to Din et al. (2014), it was suggested that the *partially comfortable* range is $20.0 \leq DI \leq 30$, and the *uncomfortable* range is $DI \geq 30.1$. The Physiological equivalent temperature (PET) classification ranges generated by Basansenot were preferred for analysis in the study in Table 1 (Güçlü, 2010; Toroğlu et al. 2015; Cetin et al. 2019).

Results and discussion

BIOC simulation results

In the research, firstly, surface temperature (T_s) and relative humidity (RH) were modeled according to SSP 245 and SSP 585 scenarios for the years 2040, 2060, 2080, and 2100. In the next step, the change of BIOC areas for these years was simulated using the DI. The current situation of the annual average temperature of Kocaeli province and the change in 2040, 2060, 2080, and 2100 according to SSP 245 and SSP 585 scenarios within the scope of projection periods are given in Fig. 2. According to SSP 245, in 2040, 45.8% of the area constitutes the majority of the site at $14\text{--}15$ $^{\circ}\text{C}$, and in 2100, 56.4% of the area is $16\text{--}17$ $^{\circ}\text{C}$. According to SSP 585, $15\text{--}16$ $^{\circ}\text{C}$ covered 44.8% of the site in 2040. According to this scenario, $19\text{--}20$ $^{\circ}\text{C}$ areas will take place in 2100 to a large extent.

The maps in which RH changes are determined and simulated in terms of DI values according to the SSP 245 and SSP 585 climate scenarios are given in Fig. 3. According to the map showing the present RH, the values are dominant in the range of 68–69% level. However, according to SSP 245, the RH values decrease to 66–67% in 2100 and 62–63% according to SSP 585.

While the BIOC zone simulation models the increase in comfortable areas in 2100 according to SSP 245, it models the possibility that hot regions will be formed in 2080 and that this rate may reach 11.4% in 2100 according to this increase according to SSP 585 (Table 2). Kocaeli city center has chosen a place in the formation of a bay. According to the BIOC model, the spatial distribution of hot areas in 2100 is primarily in areas where settlements are located and without vegetation in Figs. 3 and 4.

Discussion

It is indisputable that the change of BIOC zones is a multi-parameter (Adiguzel et al. 2022; Roshan et al. 2022) and self-organizing complex system in the dilemma of human activities and climate response (Isinkaralar et al. 2022). However, to achieve this, measures are taken at different levels, from the macro-scale (Mansuroglu et al. 2021; Calama-González et al. 2022; Faragallah and Ragheb 2022; Labdaoui et al. 2021a) to the street (Acero et al. 2022; Labdaoui et al. 2021b; Narimani et al. 2022; Ren et al. 2022; Sun et al. 2022) and building design (Razmi et al. 2022; Sathiparan et al. 2022), to keep body temperature at 37 $^{\circ}\text{C}$ following

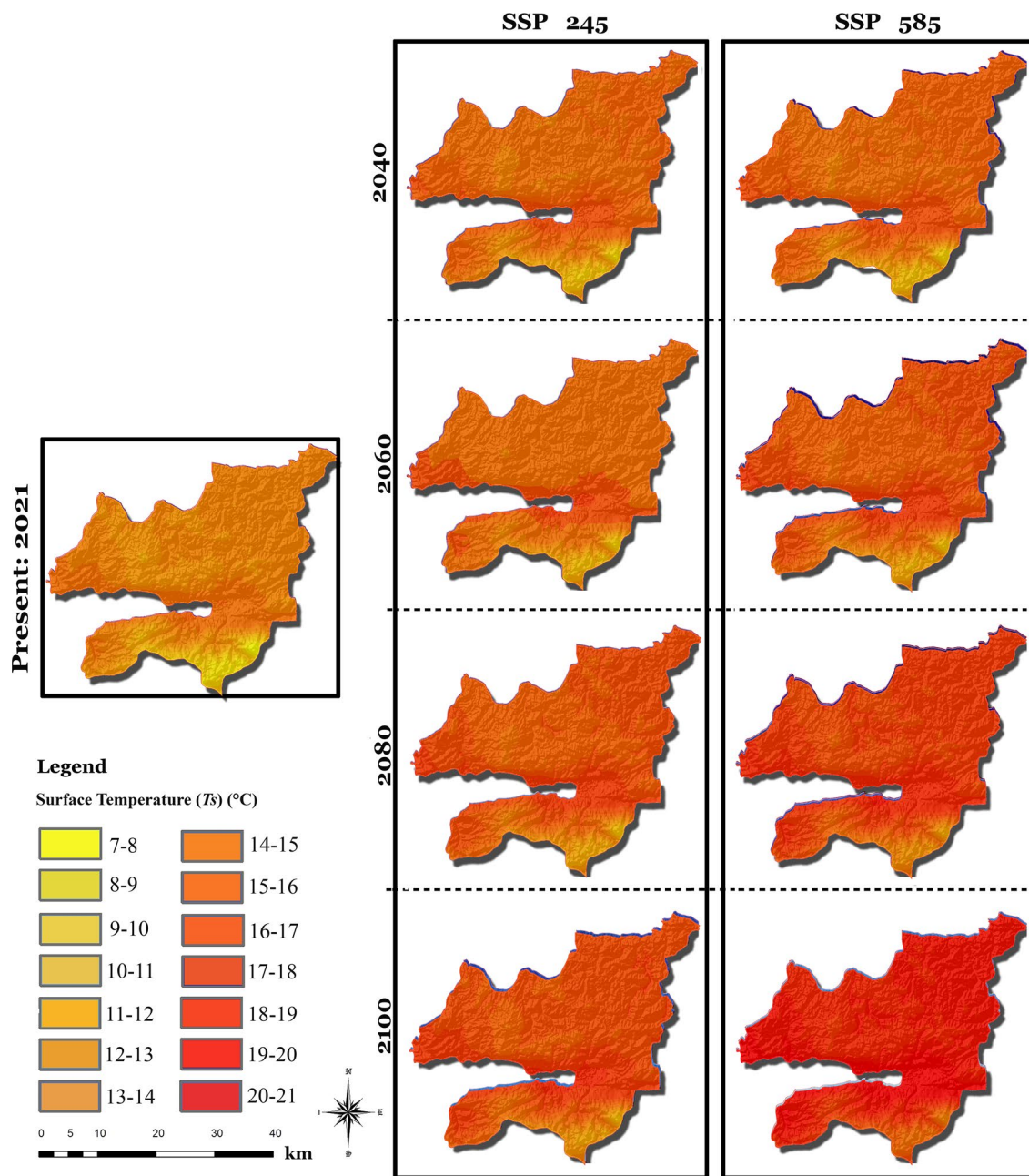


Fig. 2 T_s simulations for SSP 245 and SSP 585 climate scenarios

conventional comfort theory (Jie et al. 2022; Xie et al. 2022). The fact that a maximum monthly temperature of 36 °C for cities cannot develop a human civilization and may indicate the beginning of an inevitable collapse (Hanberry 2022) shows the necessity of predictions and logical analysis. Precautions such as guiding investment decisions at the regional scale, planning urban ventilation corridors at the urban scale (Öztürk 2015; Liu et al. 2021), setting up open green spaces (Yang et al. 2022), and planting design

at the micro-scale (Sayad et al. 2021), creating shadow spaces with structural materials and modeling specific to building energy is for BIOC (Yang et al. 2022). In addition, bioclimatic design strategies are being developed against the effects of global warming. Bienvenido-Huertas et al. (2021) revealed a decrease in thermal comfort hours, especially in hot climates, with 450 case studies selected in six countries (France, Portugal, Spain, Argentina, Brazil, and Chile). Research indicates that the future effectiveness of

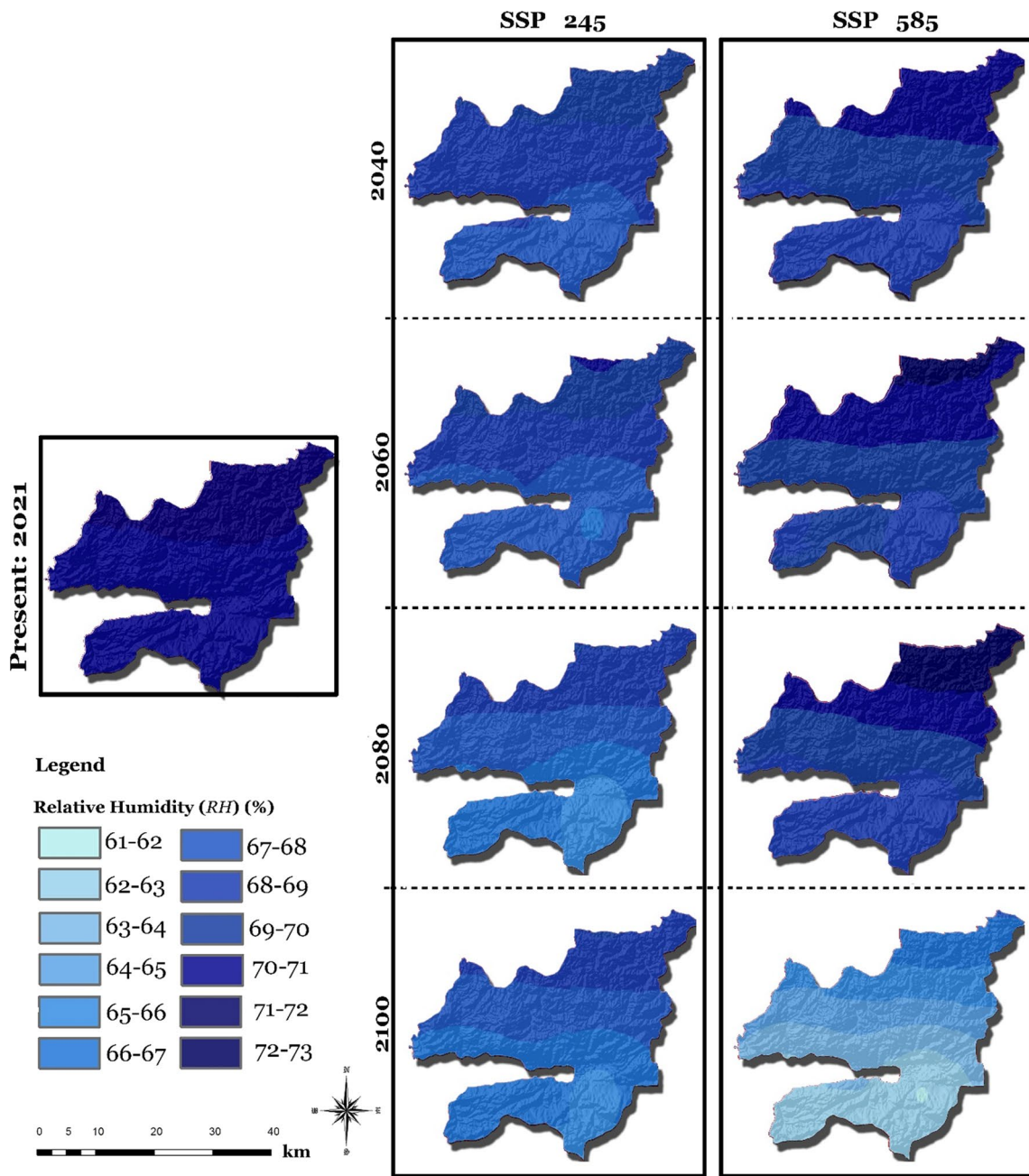


Fig. 3 RH simulations for SSP 245 and SSP 585 climate scenarios

Table 2 The percentages of the current and future status of BIOC maps under the SSP 245 and SSP 585 scenarios

Scenario	Class	Years				
		Present (2020) (%)	2040 (%)	2060 (%)	2080 (%)	2100 (%)
SSP 245	Cold	18.6	6.5	5	3.5	2.6
	Cool	79.6	91.5	84.1	73	72.4
	Comfortable	1.8	1.9	10.9	23.5	25
SSP 585	Cold	18.6	5.8	3.9	0.9	–
	Cool	79.6	88.9	71.9	27.3	0.6
	Comfortable	1.8	5.2	24.2	71.8	82.6
	Hot	–	–	–	1	11.4

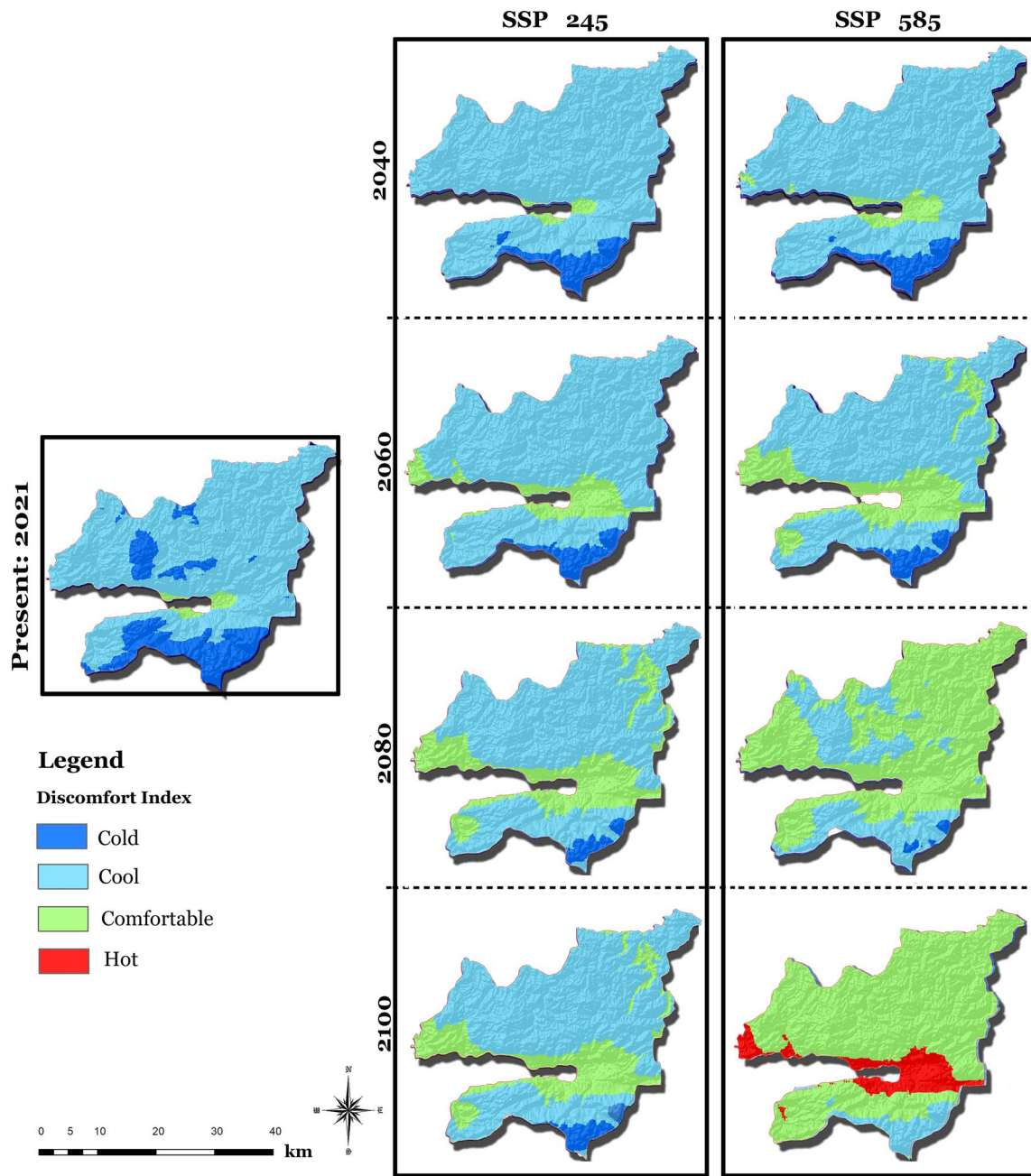


Fig. 4 BIOC zone simulations according to SSP 245 and SSP 585 climate scenarios

passive design strategies will decline. Cetin (2015) examined the compatibility of the annual data related to the Kastamonu with the ArcGIS program and BIOC analysis. In addition to the existing literature, this paper presents the

BIOC model of an industrial city with a methodology that includes integrated climate change scenarios and DI.

Conclusion

The spatial model produced is an essential guide for site selection in urban planning because the location of an urban land use provides a high quality of life for society and maximum profitability for the companies. The social, economic, cultural, political, and spatial consequences of the location decision/selection are revealed. Therefore, investigating the time-dependent change of residential areas with the effect of climate change, one of the most fundamental global problems of today's world is a crucial issue in the context of innovative approaches to making urban areas more resistant to climate change. Combating climate change is a multi-actor and multi-level phenomenon. Experienced parameter changes necessitate considering the comfort perception of the society in the built environment against the changing climate parameters as one of its spatial dimensions.

It is modeled with the DI index, which is most commonly used in urban climate research to describe the thermal sensation a person experiences due to the changing climatic conditions of a metropolitan area. T_s , RH, and BIOC changes that occur at intervals of twenty years are monitored considering the climate scenarios. The spatiotemporal warming process in the research area is quite remarkable. In the emergence of this situation, automotive, machinery, chemistry, etc., in the province. The density of industrial facilities is effective. In addition, according to the findings obtained from the model, the warming in the coastal region of the province to the Marmara Sea is a striking result. Climatic comfort indicators are effective in many areas of people's social life. In addition, the change in temperature values confirms the use of energy with heating–cooling systems. This situation drives the global energy demand. The energy requirement, on the other hand, primarily affects the use of fossil fuels and causes an increase in greenhouse gas emissions, which is responsible for global warming in the future. This research, in which the changes in outdoor comfort values are monitored, is significantly guiding decision authorities in addition to the methodological approach it offers that can be applied to many cities. In future studies, a model can be produced at the regional level by creating a framework for the region.

Limitations and future research directions

This research focuses on the temporal change process of thermal conditions in outdoor use in an urban context from the climate change perspective. While drawing attention to the

change in climatic conditions, it is aimed to spatially determine the areas that will be comfortable in the future depending on the scenarios based on the current measurements by making future predictions. The research was carried out by choosing the primary data available throughout the province as an indicator. However, the study can be developed by modeling climate variables in some areas of the region and producing local spatial models, considering the mobile measurements that can be carried out via several methods.

This study is limited to defending the necessity of considering the thermal comfort of urban development in determining suitability in terms of location selection. Socio-economic growth and development are not just about the growth and expansion of the metropolitan area. The fact that subjective perceptions are included in studies evaluated in terms of the tourism sector, where outdoor use is a very decisive and critical factor in terms of thermal comfort, especially when considered in the context of economic growth and the fact that this is different from actual observations has been demonstrated by previous studies (Lopes et al. 2021). Further studies are needed to clarify the differences between thermal comfort, thermal sensation, and thermal preference in future research, primarily based on changes in anthropogenic heat and air circulation produced by cities, and to fill in research gaps about the thermal comfort of urban areas.

Funding There is no financial support and commercial support.

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.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

References

- Abdi DA, Ayenew T (2022) A scenario-based modeling of climate change impact on the hydrology of Ketar watershed, Central Rift Valley Basin. *Ethiopia Model Earth Syst Environ* 8(3):3473–3486. <https://doi.org/10.1007/s40808-021-01314-1>
- Acero JA, Ruefenacht LA, Koh EJ, Tan YS, Norford LK (2022) Measuring and comparing thermal comfort in outdoor and semi-outdoor spaces in tropical Singapore. *Urban Clim* 42:101122. <https://doi.org/10.1016/j.uclim.2022.101122>

- Adiguzel F, Cetin M, Dogan M, Gungor S, Kose M, Bozdogan Sert E, Kaya E (2022) The assessment of the thermal behavior of an urban park surface in a dense urban area for planning decisions. *Environ Monit Assess* 194(7):1–13
- Al Huneidi DI, Tahir F, Al-Ghamdi SG (2022) Energy modeling and photovoltaics integration as a mitigation measure for climate change impacts on energy demand. *Energy Rep* 8:166–171. <https://doi.org/10.1016/j.egy.2022.01.105>
- Aljoufie M, Zuidgeest M, Brussel M, van Maarseveen M (2013) Spatial–temporal analysis of urban growth and transportation in Jeddah City, Saudi Arabia. *Cities* 31:57–68. <https://doi.org/10.1016/j.cities.2012.04.008>
- Amani-Beni M, Chen Y, Vasileva M, Zhang B (2022) Quantitative-spatial relationships between air and surface temperature, a proxy for microclimate studies in fine-scale intra-urban areas? *Sustain Cities Soc* 77:103584. <https://doi.org/10.1016/j.scs.2021.103584>
- Becker S (2000) Bioclimatological rating of cities and resorts in South Africa according to the climate index. *Int J Climatol A J R Meteorol Soc* 20(12):1403–1414. [https://doi.org/10.1002/1097-0088\(200010\)20:12%3c1403::AID-JOC539%3e3.0.CO;2-V](https://doi.org/10.1002/1097-0088(200010)20:12%3c1403::AID-JOC539%3e3.0.CO;2-V)
- Bienvenido-Huertas D, Rubio-Bellido C, Marin-Garcia D, Canivell J (2021) Influence of the representative concentration pathways (RCP) scenarios on the bioclimatic design strategies of the built environment. *Sustain Cities Soc* 72:103042. <https://doi.org/10.1016/j.scs.2021.103042>
- Bilgili E, Coskuner KA, Usta Y, Saglam B, Kucuk O, Berber T, Goltas M (2019). Diurnal surface fuel moisture prediction model for Calabrian pine stands in Türkiye. *iForest*, 12, 262–271. <https://doi.org/10.3832/ifor2870-012>
- Bilgili E, Kucuk O, Saglam B, Kucuk O, Coskuner KA (2021) Mega forest fires: causes, organization and management. Book Chapter, Kavzoglu T., TUBA- Turkish Acad Sciences, vol. 33, pp1–23, Ankara, 2021. ISBN: 978-605-2249-79-6
- Calama-González CM, Suárez R, León-Rodríguez ÁL (2022) Thermal comfort prediction of the existing housing stock in southern Spain through calibrated and validated parameterized simulation models. *Energy Build* 254:111562. <https://doi.org/10.1016/j.enbuild.2021.111562>
- Cetin M, Adiguzel F, Gungor S, Kaya E, Sancar MC (2019) Evaluation of thermal climatic region areas in terms of building density in urban management and planning for Burdur, Turkey. *Air Qual Atmos Health* 12:1103–1112. <https://doi.org/10.1007/s11869-019-00727-3>
- Cevik S, Ghazanchyan M (2021) Perfect storm: climate change and tourism. *J Global Dev* 12(1):47–61. <https://doi.org/10.1515/jgd-2020-0015>
- Chaturvedi P, Khan R, Sahu P, Ludhiadch A, Singh G, Munshi A (2022) Role of omics in migraine research and management: a narrative review. *Mol Neurobiol*. <https://doi.org/10.1007/s12035-022-02930-3>
- Cheval S, Dumitrescu A, Iraşoc A, Paraschiv MG, Perry M, Ghent D (2022) MODIS-based climatology of the surface urban heat island at country scale (Romania). *Urban Clim* 41:101056. <https://doi.org/10.1016/j.uclim.2021.101056>
- Church JA, Clark PU, Cazenave A, Gregory JM, Jevrejeva S, Levermann A et al (2013). Sea level change. *Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, pp 1137–1216
- Coates SJ, Norton SA (2021) The effects of climate change on infectious diseases with cutaneous manifestations. *Int J Women’s Dermatol* 7(1):8–16. <https://doi.org/10.1016/j.ijwd.2020.07.005>
- de Freitas CR, Grigorieva EA (2015) A comprehensive catalogue and classification of human thermal climate indices. *Int J Biometeorol* 59(1):109–120. <https://doi.org/10.1080/14693062.2022.2107475>
- Dehghani R, Poudeh HT, Izadi Z (2022) The effect of climate change on groundwater level and its prediction using modern meta-heuristic model. *Groundw Sustain Dev* 16:100702. <https://doi.org/10.1016/j.gsd.2021.100702>
- Din MFM, Lee YY, Ponraj M, Ossen DR, Iwao K, Chelliapan S (2014) Thermal comfort of various building layouts with a proposed discomfort index range for tropical climate. *J Therm Biol* 41:6–15. <https://doi.org/10.1016/j.jtherbio.2014.01.004>
- Ehrlich D, Kemper T, Pesaresi M, Corbane C (2018) Built-up area and population density: two essential societal variables to address climate hazard impact. *Environ Sci Policy* 90:73–82. <https://doi.org/10.1016/j.envsci.2018.10.001>
- Elaouzy Y, ElFadar A (2022) A multi-level evaluation of bioclimatic design in Mediterranean climates. *Sustain Energy Technol Assess* 52:102124. <https://doi.org/10.1016/j.seta.2022.102124>
- Elser H, Parks RM, Moghavem N, Kiang MV, Bozinov N, Henderson VW et al (2021) Anomalously warm weather and acute care visits in patients with multiple sclerosis: a retrospective study of privately insured individuals in the US. *PLoS Med* 18(4):e1003580. <https://doi.org/10.1371/journal.pmed.1003580>
- Ertugrul M, Varol T, Ozel HB, Cetin M, Sevik H (2021) Influence of climatic factor of changes in forest fire danger and fire season length in Türkiye. *Environ Monit Assess* 193(1):1–17
- Faragallah RN, Ragheb RA (2022) Evaluation of thermal comfort and urban heat island through cool paving materials using ENVI-Met. *Ain Shams Eng J* 13(3):101609. <https://doi.org/10.1016/j.asej.2021.10.004>
- Gulcebi MI, Bartolini E, Lee O, Lisgaras CP, Onat F, Mifsud J et al (2021) Climate change and epilepsy: Insights from clinical and basic science studies. *Epilepsy Behav* 116:107791. <https://doi.org/10.1016/j.yebeh.2021.107791>
- Hanberry BB (2022) Global population densities, climate change, and the maximum monthly temperature threshold as a potential tipping point for high urban densities. *Ecol Indic* 135:108512. <https://doi.org/10.1016/j.ecolind.2021.108512>
- He W, Zhang L, Yuan C (2022) Future air temperature projection in high-density tropical cities based on global climate change and urbanization—a study in Singapore. *Urban Clim* 42:101115. <https://doi.org/10.1016/j.uclim.2022.101115>
- Hoogerbrugge M, Burger M (2022) Selective migration and urban–rural differences in subjective well-being: evidence from the United Kingdom. *Urban Stud* 59(10):2092–2109. <https://doi.org/10.1177/00420980211023052>
- Hussain MS, Goswami AK, Gupta A (2022) Predicting pedestrian crash locations in urban India: an integrated GIS-based spatiotemporal HSID technique. *J Transp Saf Secur*. <https://doi.org/10.1080/19439962.2022.2048759>
- Isinkaralar O, Varol C (2023) A cellular automata-based approach for spatio-temporal modeling of the city center as a complex system: the case of Kastamonu Türkiye. *Cities* 132:104073. <https://doi.org/10.1016/j.cities.2022.104073>
- Isinkaralar O, Varol C, Yilmaz D (2022) Digital mapping and predicting the urban growth: integrating scenarios into cellular automata—Markov chain modeling. *Appl Geomat*. <https://doi.org/10.1007/s12518-022-00464-w>



- Isinkaralar K (2022) High-efficiency removal of benzene vapor using activated carbon from *Althaea officinalis* L biomass as a lignocellulosic precursor. *Environ Sci Pollut Res*. <https://doi.org/10.1007/s11356-022-20579-2>
- ISO (2005) International Standard 7730, Ergonomic of the thermal environment—analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD Indices and local thermal comfort criteria, Geneva
- Jay O, Capon A, Berry P, Broderick C, de Dear R, Havenith G et al (2021) Reducing the health effects of hot weather and heat extremes: from personal cooling strategies to green cities. *The Lancet* 398(10301):709–724. [https://doi.org/10.1016/S0140-6736\(21\)01209-5](https://doi.org/10.1016/S0140-6736(21)01209-5)
- Jia M, Choi JH, Liu H, Susman G (2022) Development of facial-skin temperature driven thermal comfort and sensation modeling for a futuristic application. *Build Environ* 207:108479. <https://doi.org/10.1016/j.buildenv.2021.108479>
- Karhinen S, Peltomaa J, Riekkinen V, Saikku L (2021) Impact of a climate network: the role of intermediaries in local level climate action. *Global Environ Change* 67:102225. <https://doi.org/10.1016/j.gloenvcha.2021.102225>
- Kedward K, Ryan-Collins J, Chenet H (2022) Biodiversity loss and climate change interactions: financial stability implications for central banks and financial supervisors. *Clim Policy*, pp 1–19.
- Kılıç Ş, Krajačić G, Duić N, Rosen MA (2022) Effective mitigation of climate change with sustainable development of energy, water and environment systems. *Energy Convers Manage* 269:116146. <https://doi.org/10.1016/j.enconman.2022.116146>
- Kumar S, Narjary B, Islam A, Yadav RK, Kamra SK (2022) Modeling climate change impact on groundwater and adaptation strategies for its sustainable management in the Karnal district of North-west India. *Clim Change* 173(1):1–30. <https://doi.org/10.1007/s10584-022-03393-0>
- Labdaoui K, Mazouz S, Acidi A, Cools M, Moeinaddini M, Teller J (2021a) Utilizing thermal comfort and walking facilities to propose a comfort walkability index (CWI) at the neighbourhood level. *Build Environ* 193:107627. <https://doi.org/10.1016/j.buildenv.2021.107627>
- Labdaoui K, Mazouz S, Moeinaddini M, Cools M, Teller J (2021b) The street walkability and thermal comfort Index (SWTCI): a new assessment tool combining street design measurements and thermal comfort. *Sci Total Environ* 795:148663. <https://doi.org/10.1016/j.scitotenv.2021.148663>
- Leng H, Han B (2022) Effect of environmental planning on elderly individual quality of life in severe cold regions: a case study in Northeastern China. *Sustainability* 14(6):3522. <https://doi.org/10.3390/su14063522>
- Liu W, Zhang G, Jiang Y, Wang J (2021) Effective range and driving factors of the urban ventilation corridor effect on urban thermal comfort at unified scale with multisource data. *Remote Sensing* 13(9):1783. <https://doi.org/10.3390/rs13091783>
- Liu Y, Song L, Wang W, Jian X, Chen WQ (2022) Developing a GIS-based model to quantify spatiotemporal pattern of home appliances and e-waste generation—a case study in Xiamen, China. *Waste Manage* 137:150–157. <https://doi.org/10.1016/j.wasman.2021.10.039>
- Lopes HS, Remoaldo PC, Ribeiro V, Martin-Vide J (2021) Perceptions of human thermal comfort in an urban tourism destination—a case study of Porto (Portugal). *Build Environ* 205:108246. <https://doi.org/10.1016/j.buildenv.2021.108246>
- Maniatis K, Chiaramonti D, van den Heuvel E (2021) Post COVID-19 recovery and 2050 climate change targets: changing the emphasis from promotion of renewables to mandated curtailment of fossil fuels in the EU policies. *Energies* 14(5):1347. <https://doi.org/10.3390/en14051347>
- Mansuroglu S, Dag V, Kalayci Onac A (2021) Attitudes of people toward climate change regarding the bioclimatic comfort level in tourism cities; evidence from Antalya Türkiye. *Environ Monit Assess* 193(7):1–16. <https://doi.org/10.1007/s10661-021-09205-9>
- Matzarakis A, Mayer H (1997) Heat stress in Greece. *Int J Biometeorol* 41(1):34–39. <https://doi.org/10.1007/s004840050051>
- Melnikov VP, Osipov VI, Brouchkov AV, Falaleeva AA, Badina SV, Zheleznyak MN et al (2022) Climate warming and permafrost thaw in the Russian Arctic: potential economic impacts on public infrastructure by 2050. *Nat Hazards* 112(1):231–251. <https://doi.org/10.1007/s11069-021-05179-6>
- Moghadam SH, Ashofteh PS, Loáiciga HA (2022) Optimal water allocation of surface and ground water resources under climate change with WEAP and IWOA Modeling. *Water Resour Manage*. <https://doi.org/10.1007/s11269-022-03195-0>
- Molina JR, Lefebvre G, Espinoza R, Horn M, Gómez MM (2021) Bioclimatic approach for rural dwellings in the cold, high Andean region: a case study of a Peruvian house. *Energy Build* 231:110605. <https://doi.org/10.1016/j.enbuild.2020.110605>
- Moran DS, Pandolf KB, Laor A, Heled Y, Matthew WT, Gonzalez RR (2003) Evaluation and refinement of the environmental stress index for different climatic conditions. *J Basic Clin Physiol Pharmacol* 14(1):1–16. <https://doi.org/10.1515/JBCPP.2003.14.1.1>
- Narimani N, Karimi A, Brown RD (2022) Effects of street orientation and tree species thermal comfort within urban canyons in a hot, dry climate. *Ecol Inf* 69:101671. <https://doi.org/10.1016/j.ecoinf.2022.101671>
- Naulleau A, Gary C, Prévot L, Berteloot V, Fabre JC, Crevoisier D et al (2022) Participatory modeling to assess the impacts of climate change in a Mediterranean vineyard watershed. *Environ Model Softw* 150:105342. <https://doi.org/10.1016/j.envsoft.2022.105342>
- Olabi AG, Abdelkareem MA (2022) Renewable energy and climate change. *Renew Sustain Energy Rev* 158:112111. <https://doi.org/10.1016/j.rser.2022.112111>
- Öztürk S (2015) Determining management strategies for the Sarikum Nature Protection Area. *Environ Monitor Assess*. <https://doi.org/10.1007/s10661-015-4302-3>
- Park Y, Guldmann JM, Liu D (2021) Impacts of tree and building shades on the urban heat island: combining remote sensing, 3D digital city and spatial regression approaches. *Comput Environ Urban Syst* 88:101655. <https://doi.org/10.1016/j.compenvurbysys.2021.101655>
- Patra S, Sahoo S, Mishra P, Mahapatra SC (2018) Impacts of urbanization on land use/cover changes and its probable implications on local climate and groundwater level. *J Urban Manage* 7(2):70–84. <https://doi.org/10.1016/j.jum.2018.04.006>
- Pimonsree S, Limsakul A, Kammuang A, Kachenchart B, Kamlangkula C (2022) Urbanization-induced changes in extreme climate indices in Thailand during 1970–2019. *Atmos Res* 265:105882. <https://doi.org/10.1016/j.atmosres.2021.105882>
- Razmi A, Rahbar M, Bemanian M (2022) PCA-ANN integrated NSGA-III framework for dormitory building design optimization: energy efficiency, daylight, and thermal comfort. *Appl Energy* 305:117828. <https://doi.org/10.1016/j.apenergy.2021.117828>
- Ren Z, Zhao H, Fu Y, Xiao L, Dong Y (2022) Effects of urban street trees on human thermal comfort and physiological indices: a case



- study in Changchun city, China. *J for Res* 33(3):911–922. <https://doi.org/10.1007/s11676-021-01361-5>
- Rissanen S, Rintamäki H (2007) Cold and heat strain during cold-weather field training with nuclear, biological, and chemical protective clothing. *Mil Med* 172(2):128–132. <https://doi.org/10.7205/MILMED.172.2.128>
- Roshan G, Moghbel M, Taleghani M (2022) Spatial analysis of bioclimatic patterns over Iranian cities as an important step in sustainable development. *Sustain Cities Soc* 83. <https://doi.org/10.1016/j.scs.2022.103939>
- Sağlam B, Bilgili E, Durmaz BD, Kadioğulları AI, Küçük Ö (2008) Spatio-temporal analysis of forest fire risk and danger using LANDSAT imagery. *Sensors* 8(6):3970–3987
- Salata F, Falasca S, Ciancio V, Curci G, Grignaffini S, de Wilde P (2022) Estimating building cooling energy demand through the Cooling Degree Hours in a changing climate: a modeling study. *Sustain Cities Soc* 76:103518. <https://doi.org/10.3390/s8063970>
- Sathiparan N, Subramaniam DN, Malsara KGN, Akmal MSM (2022) Thermal comfort analysis of fired-clay brick, cement-sand block and cement stabilized earth block masonry house models. *Innov Infrastruct Solut* 7(2):1–16. <https://doi.org/10.1007/s41062-022-00744-9>
- Sayad B, Alkama D, Ahmad H, Baili J, Aljahdaly NH, Menni Y (2021) Nature-based solutions to improve the summer thermal comfort outdoors. *Case Stud Therm Eng* 28:101399. <https://doi.org/10.1016/j.csite.2021.101399>
- Sein ZMM, Ullah I, Iyakaremye V, Azam K, Ma X, Syed S, Zhi X (2022) Observed spatiotemporal changes in air temperature, dew point temperature and relative humidity over Myanmar during 2001–2019. *Meteorol Atmos Phys* 134(1):1–17. <https://doi.org/10.1007/s00703-021-00837-7>
- Sevinc V, Kucuk O, Goltas M (2020) A Bayesian network model for prediction and analysis of possible forest fire causes. *For Ecol Manage* 457:117723
- Shah M, Lone MA (2022) Modeling the impact of climate change on the flow regimes of River Sindh of Kashmir Valley. *J Inst Eng (india) Ser A*. <https://doi.org/10.1007/s40030-022-00672-y>
- Sharifi A (2021) Co-benefits and synergies between urban climate change mitigation and adaptation measures: a literature review. *Sci Total Environ* 750:141642. <https://doi.org/10.1016/j.scitotenv.2020.141642>
- Sulhan OF, Sevik H, Isinkaralar K (2022) Assessment of Cr and Zn deposition on *Picea pungens* Engelm. in urban air of Ankara. *Environ Dev Sustain, Türkiye*. <https://doi.org/10.1007/s10668-022-02647-2>
- Sun C, Lian W, Liu L, Dong Q, Han Y (2022) The impact of street geometry on outdoor thermal comfort within three different urban forms in severe cold region of China. *Build Environ* 222:109342. <https://doi.org/10.1016/j.buildenv.2022.109342>
- Tarekegn N, Abate B, Muluneh A, Dile Y (2022) Modeling the impact of climate change on the hydrology of Andasa watershed. *Model Earth Syst Environ* 8(1):103–119. <https://doi.org/10.1007/s40808-020-01063-7>
- Tekin O, Cetin M, Varol T, Ozel HB, Sevik H, ZerenCetin I (2022) Altitudinal migration of species of Fir (*Abies* spp.) in adaptation to climate change. *Water Air Soil Pollut* 233:385. <https://doi.org/10.1007/s11270-022-05851-y>
- Thom EC (1959) The discomfort index. *Weatherwise* 12(2):57–61. <https://doi.org/10.1080/00431672.1959.9926960>
- Vargas C, Gomez-Valencia M, Gonzalez-Perez MA, Cordova M, Casnici CVC, Monje-Cueto F et al (2022) Climate-resilient and regenerative futures for Latin America and the Caribbean. *Futures* 142:103014. <https://doi.org/10.1016/j.futures.2022.103014>
- Yamaguchi Y, Kim B, Kitamura T, Akizawa K, Chen H, Shimoda Y (2022) Building stock energy modeling considering building system composition and long-term change for climate change mitigation of commercial building stocks. *Appl Energy* 306:117907. <https://doi.org/10.1016/j.apenergy.2021.117907>
- Wang Y, Dong P, Hu W, Chen G, Zhang D, Chen B, Lei G (2022b) Modeling the climate suitability of Northernmost Mangroves in China under climate change scenarios. *Forests* 13(1):64. <https://doi.org/10.3390/f13010064>
- Wang H, Lin S, Dai J, Ge Q (2022a) Modeling the effect of adaptation to future climate change on spring phenological trend of European beech (*Fagus sylvatica* L.). *Sci Total Environ* 846:157540. <https://doi.org/10.1016/j.scitotenv.2022.157540>
- Wei W, Nan S, Xie B, Liu C, Zhou J, Liu C (2023) The spatial-temporal changes of supply-demand of ecosystem services and ecological compensation: a case study of Hexi Corridor Northwest China. *Ecol Eng* 187:106861. <https://doi.org/10.1016/j.ecoleng.2022.106861>
- Widera B (2021) Comparative analysis of user comfort and thermal performance of six types of vernacular dwellings as the first step towards climate resilient, sustainable and bioclimatic architecture in western sub-Saharan Africa. *Renew Sustain Energy Rev* 140:110736. <https://doi.org/10.1016/j.rser.2021.110736>
- WMO (World Meteorological Organization) (2006) WMO Statement on the Status of the Global Climate in 2005, WMO-No. 998.
- Xie X, Chen XN, Xu B, Pei G (2022) Investigation of occupied/unoccupied period on thermal comfort in Guangzhou: challenges and opportunities of public buildings with high window-wall ratio. *Energy* 244:123186. <https://doi.org/10.1016/j.energy.2022.123186>
- Yang H, Huang J, Liu D (2020) Linking climate change and socio-economic development to urban land use simulation: analysis of their concurrent effects on carbon storage. *Appl Geogr* 115:102135. <https://doi.org/10.1016/j.apgeog.2019.102135>
- Yang Y, Zhou D, Wang Y, Meng X, Gu Z, Xu D, Han X (2022) Planning method of centralized greening in high-rise residential blocks based on improvement of thermal comfort in summer. *Sustain Cities Soc* 80:103802. <https://doi.org/10.1016/j.scs.2022.103802>
- Yayla EE, Sevik H, Isinkaralar K (2022) Detection of landscape species as a low-cost biomonitoring study: Cr, Mn, and Zn pollution in an urban air quality. *Environ Monit Assess* 194(10):1–10. <https://doi.org/10.1007/s10661-022-10356-6>
- Ye X, Zhu D, He P (2022) Earlier migration, better cognition? the role of urbanization in bridging the urban-rural cognition gaps in middle and older age. *Aging Ment Health* 26(3):477–485. <https://doi.org/10.1080/13607863.2021.1872490>
- Zhang W, Li H, Xiao Q, Li X (2021) Urban rivers are hotspots of riverine greenhouse gas (N₂O, CH₄, CO₂) emissions in the mixed-landscape chaohu lake basin. *Water Res* 189:116624. <https://doi.org/10.1016/j.watres.2020.116624>
- Zhang Y, Wu Y, Yan J, Peng T (2022) How does rural labor migration affect crop diversification for adapting to climate change in the



Hehuang Valley, Tibetan Plateau? *Land Use Policy* 113:105928. <https://doi.org/10.1016/j.landusepol.2021.105928>

Zhao J, Xiao Y, Sun S, Sang W, Axmacher JC (2022) Does China's increasing coupling of 'urban population' and 'urban area' growth indicators reflect a growing social and economic sustainability? *J Environ Manage* 301:113932. <https://doi.org/10.1016/j.jenvman.2021.113932>

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

