



Assessing spatial thermal comfort and adaptation measures for the Antalya basin under climate change scenarios

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Abstract

The concrete damages of climate change are intensifying, and adaptation efforts of actors around the world are increasing, especially in coastal regions. Recommending adaptation measures for specific regions and sectors and determining long-term strategies for mitigating global climate change is essential for reducing vulnerability to climate change. This research aims to estimate the changes in climatic parameters and thermal comfort zones to determine concrete targets and offer suggestions for sectors affected by possible changes. The changes that will occur until 2100 in the Antalya basin, which is located in the southernmost part of Türkiye and is a significant hub for agricultural production and tourism, were monitored spatially using Discomfort Index (DI) and Effective Temperature taking wind velocity (ET_v). The Shared Socioeconomic Pathways (SSP): SSP 245 and SSP 585 predict that the quite cool areas prevailing in the area, according to ET_v, will shrink by 24% and 46%, respectively, and the prevailing cold areas, according to DI, will shrink by 45% and 56%, respectively. By 2100, 5% of the area, according to SSP 245, and 25%, according to SSP 585, will turn into hot areas and move away from the comfort level. The fact that critical regions are areas with high vitality in terms of coastal tourism shows the need to prioritize adaptation policies. These discoveries are discussed in the context of critical issues such as water scarcity and food security, contributing to policy-making for effective management by suggesting specific adaptation measures.

Keywords Urban and Regional planning · Coastal management · Geographic information systems · Global warming · Spatial modeling · Climate change adaptation

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1 Introduction

Governments state that climate conditions are in change, driven by unforeseen extreme weather events and rising temperatures (Barchielli et al. 2022; Cienfuegos 2023; Forzieri et al. 2022; Gao et al. 2022; Lockwood et al. 2024). The climate crisis triggers changes in climate parameters, creating thermal comfort changes requiring urgent climate action (Da et al. 2022). Climate change is a complex and dynamic process associated with many uncertain externalities (Jing et al. 2022; Shen et al. 2023). Global warming and extreme weather events such as storms or heat waves are associated with climate change (Alimonti et al. 2022; Clarke et al. 2022; Amirkhani et al. 2022; Laino and Iglesias 2023a, b). Depending on the level of emissions, the world temperature is expected to increase between 1.4 and 5.8 °C by the end of the twenty-first century, according to different scenarios (Pachauri and Reisinger 2007; IPCC 2014). In particular, heat waves and extreme precipitation are likely to occur more intensely (Skendžić et al. 2021). Climatic conditions have a combined effect on the human body, increasing thermal discomfort and possibly affecting human health (He et al. 2021; Ren et al. 2022; Isinkaralar et al. 2024). These processes increase the need to investigate changes in thermal comfort, especially for outdoor use.

The perception and interpretation of comfort have a relative, subjective, and multivariate structure that varies from person to person. Air temperature, humidity, solar radiation, wind speed, metabolic heat, and clothing conditions are the main factors affecting thermal comfort (Isinkaralar and Isinkaralar 2023). Additionally, it involves a complex physiological and psychological adaptation process (Li et al. 2022). For this reason, many indices have been developed in the literature for evaluation (McLaughlin and Cooper 2010; Rabby et al. 2019; Tasnuva et al. 2021; Pantusa et al. 2022; Kovaleva et al. 2022; Oloyede et al. 2022; Šimac et al. 2023). The developed indices allow us to understand the space by classifying it. In addition to weather conditions and events, there will be corresponding impacts on physical and biological resources providing regional development (Russo et al. 2022). Therefore, global warming threatens socioeconomic structure and economic development and has a comprehensive impact (Lu et al. 2019; Isinkaralar 2024). Therefore, flora/fauna and sectors directly related to climate, such as tourism and agriculture, which have a major place in the world's economic development, will be affected. Although impacts vary depending on the exposure level of the sectors, it is thought that there will be more negative results than positive ones due to the impact of climate change. In the meantime, the world population's demand for agricultural production is also increasing, and it is estimated that current production will need to double by 2050. We need to foresee the risks we face to manage the possible immediate and long-term impacts effectively. Visual mapping is a cutting-edge research method that enables the analysis and presentation of articles in the literature. It has a more advanced calculation logic that provides sound effects and visualization to the programming algorithm on data sets. The general synthesis of the literature in Web of Science big data using the visualization of similarities (VOS) concept of VOSviewer Software Analysis found that most studies focus on vulnerability evidence of the link between sensitivity, adaptive capacity, and climate change such as vulnerability assessment, and conservation planning in Fig. 1.

Coastal regions are exposed to extreme impacts triggered by sea level rise and other climate change impacts, such as heat waves, storms, floods, and erosion (Seneviratne et al. 2021; Laino and Iglesias 2023a, b). These events could directly or indirectly threaten human life. The future uncertainty of these disasters necessitates taking action to enhance disaster resilience. Due to the warming of the oceans and the atmosphere, the coastline will have a new

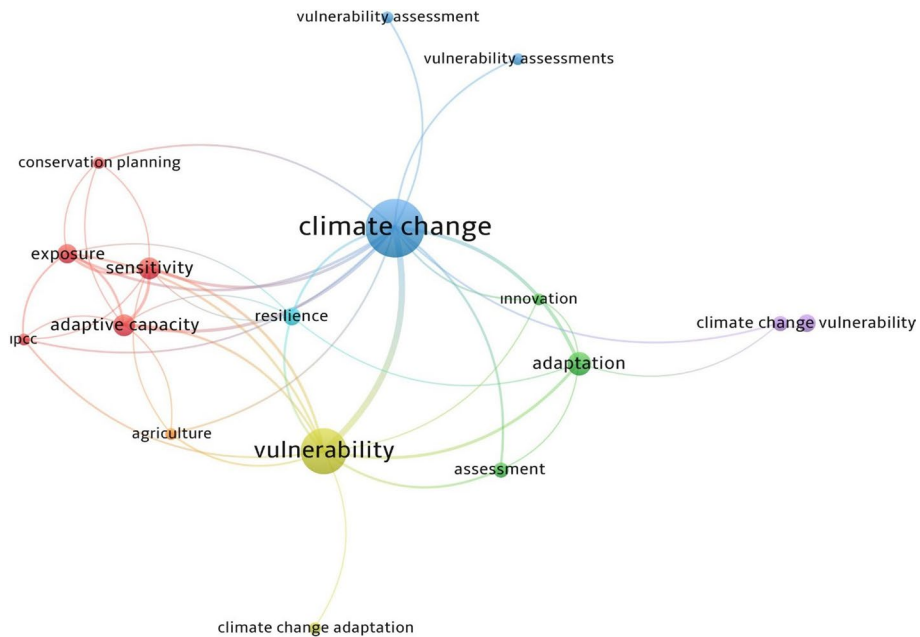


Fig. 1 Aggregation of principle variables contributing to climate change and vulnerability between 1991 and 2024 based on VOSviewer software bibliographic analysis

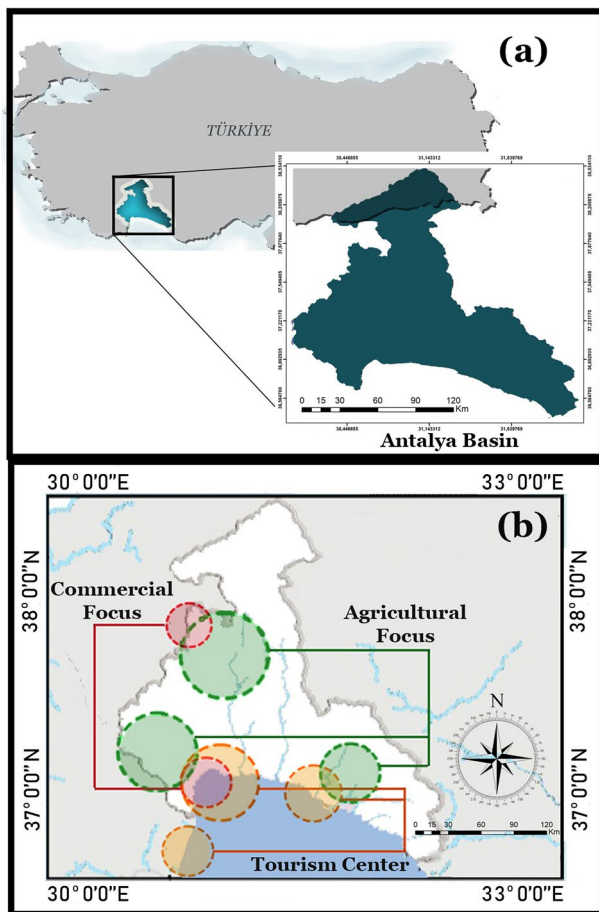
form, and the settled system must also adapt to this. Many tools aim to measure coasts' vulnerability to climate change (Koroglu et al. 2019). However, this article focuses on the changes in the climatic parameters of a region that is the locomotive of agriculture and tourism and its long-term thermal predictions. The uncertain and complex adaptive nature of the changes experienced is known. This paper overviews the impact of climate change on the regional vulnerability of the Antalya basin of Türkiye on the seashore of the Mediterranean Sea. It aims to guide local public decisions based on the concretely presented spatial pattern by concretely evaluating possible risks with scenario approaches from a deterministic perspective. Therefore, the fundamental objectives of this paper are detailed below:

- To ensure that raw climatic data are handled in a way that allows spatial evaluation from a thermal perspective.
- To draw attention to the thermal spatial structure of the region.
- To determine the regions that will be affected by thermal change under different climate scenarios.
- To create adaptation strategies by identifying sectors affected by the climate crisis.

2 Materials and methods

This research spatially models the temporal-spatial change under different climate scenarios in the Antalya basin. While analyzing the region, i) data on the current values of climate-related parameters and the structure of the region were collected, ii) a database was

Fig. 2 The location of case area
(a): Antalya basin in Türkiye; (b)
focus on regional economy



created for the selected scenarios, and iii) regional vulnerability was presented spatially by producing forecast maps.

2.1 Study region

Antalya Basin is one of the twenty-five basins in Türkiye and is on the northern border of the Mediterranean between latitudes and longitudes of $36^{\circ} 30' 38'' 28'$ north and $30^{\circ} 10' 32'' 22'$ east. The basin covers 2.56% of the country, with a surface area of 2,235,036 hectares. Afyonkarahisar, Antalya, Burdur, Isparta, and Konya provinces are partially located within the Antalya Basin, as shown in Fig. 2. Tourism, agriculture, and trade are crucial in the region's economy. Due to its geographical features and climatic conditions, tourism and agriculture sectors have come to the fore. It is one of the basins that contribute the most to the country's economy in both sectors. Antalya has recently gained significant momentum with the developments in industrial and construction activities. The region, which offers alternative tourism options thanks to its climatic conditions, nature, and cultural and historical heritage, is rich in culture, sports, health, winter, congress, plateau, cave, camping, and religious tourism, especially sea, sand, and sun. Since increasing temperatures in

the summer months may cause more energy demand, insufficient water supply, infectious diseases, stress, and inferior weather conditions, it is crucial to carry out the necessary adaptation practices, especially for the tourism sector. Increasing temperatures due to the intensification of anthropogenic activities on the earth and natural processes cause extreme weather events and severely pressure physical and human systems. Noticeable changes in the severity and frequency of extreme weather phenomena require us to take steps to adapt and mitigate Fig. 3.

2.2 Data and shared socioeconomic pathways

The climate parameters of temperature, humidity, and wind speed required when performing spatial modeling were collected as an annual average from 15 stations belonging to the General Directorate of Meteorology Institution. Geographic information systems were used to organize the data obtained. ArcGIS 10.8 software was chosen as a tool, and the data obtained from the WorldClim v2.1 project was reclassified during the simulation phase. Based on the IPCC scenario and data, predictions have been made for 2021–2040, 2041–2060, 2061–2080 and 2081–2100. Within shared socioeconomic pathways (SSP), approaches have been defined depending on different developments. Within the uncertain, complex structure of the climate, SSP scenarios benefit from certain assumptions and assumptions. If we do not start from these assumptions, reaching the prediction probabilities is impossible. Only two of the most commonly chosen in the literature (HamadAmin and Khwarahm 2023), fossil fuel-based development (SSP585) and middle-of-the-road development (SSP245), were applied in this study, and the selected scenarios are presented in Fig. 4. SSP 245 is a medium-emission scenario, while SSP 585 is a very high-emission scenario (Liu et al. 2023). Thus, the effect of average and extreme values can be monitored spatially in Fig. 3.

2.3 Indexing

Studies that make spatial patterns measurable and comparable based on indices are essential in facilitating our understanding of space. Some indexes reflect the change in thermal comfort zones depending on climatic values. In this study, the Thom Discomfort Index (DI) (Thom

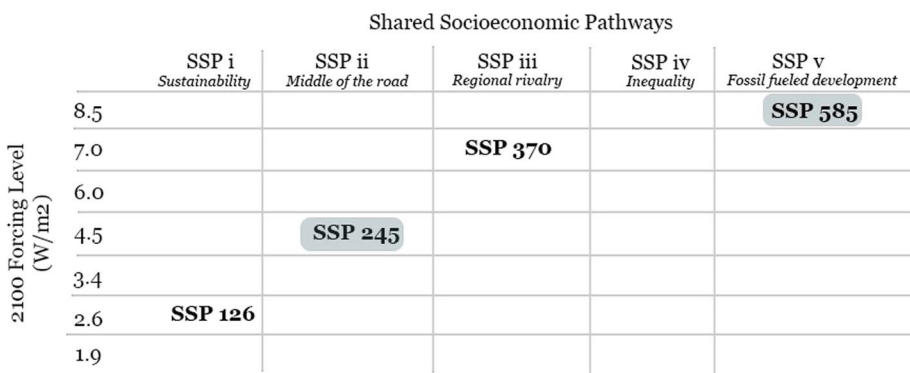


Fig. 3 Selected Shared Socioeconomic Pathways

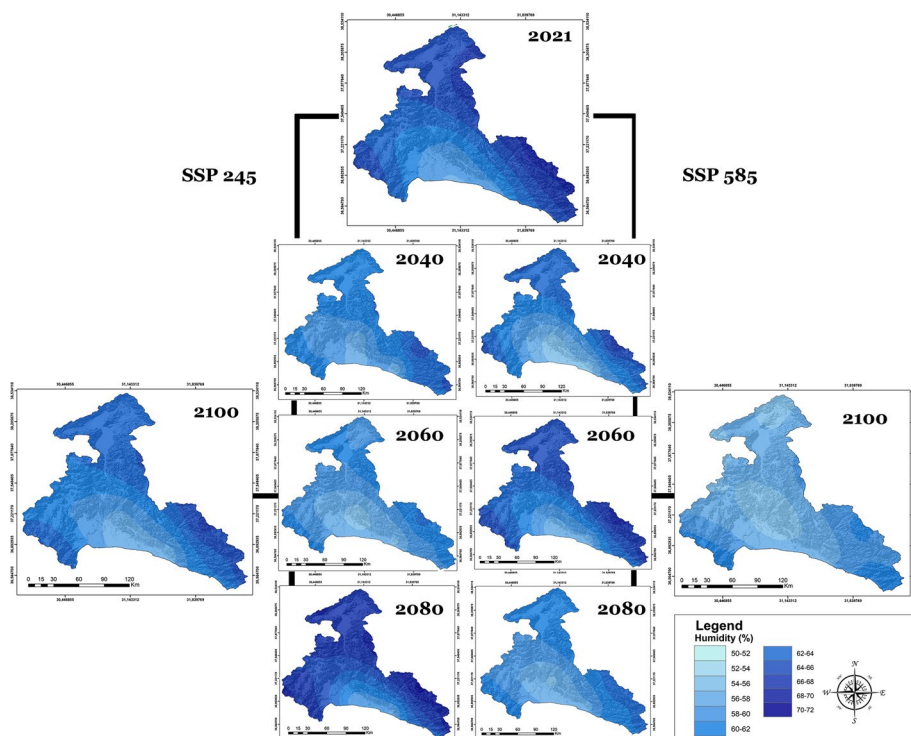


Fig. 4 The humidity transformed by climate change until 2100

1959) and ET_v were applied. The calculation was made according to the formula in Eq. 1 (Giles et al. 1990) :

$$DI = (T_{dbt}) - 0.55[1 - (0.01)(RH)] * [T_{dbt} - 14.5] \quad (1)$$

where; DI : Temperature-humidity index (discomfort empirical index); T_{dbt} : dry bulb temperature ($^{\circ}\text{C}$); and RH : Relative humidity (%) and v is wind speed (m/s).

The following formula in Eq. 2 is used for effective temperature-taking wind velocity (ET_v) (Lucena et al. 2016):

$$ET_v = 37 - \left[\frac{(37 - T_{dbt}) * (1.76 + 1.05v)}{(0.68 - 0.0014RH + 1)} \right] - (0.29) * (T_{dbt}) * \left[1 - \frac{RH}{100} \right] \quad (2)$$

The interpretation of the index value obtained after the calculations was made according to Fig. 5. Evaluation of the indexes has been classified in an advanced manner in various studies. There are four categories in the field according to DI and six categories according to ET_v .

The predictions were made using ArcGIS 10.8 software as in Eq. 3:

$$z(x_o) = \frac{\sum_{i=1}^n z(x_i) \cdot d_{i0}^{-r}}{\sum_{i=1}^n d_{i0}^{-r}} \quad (3)$$

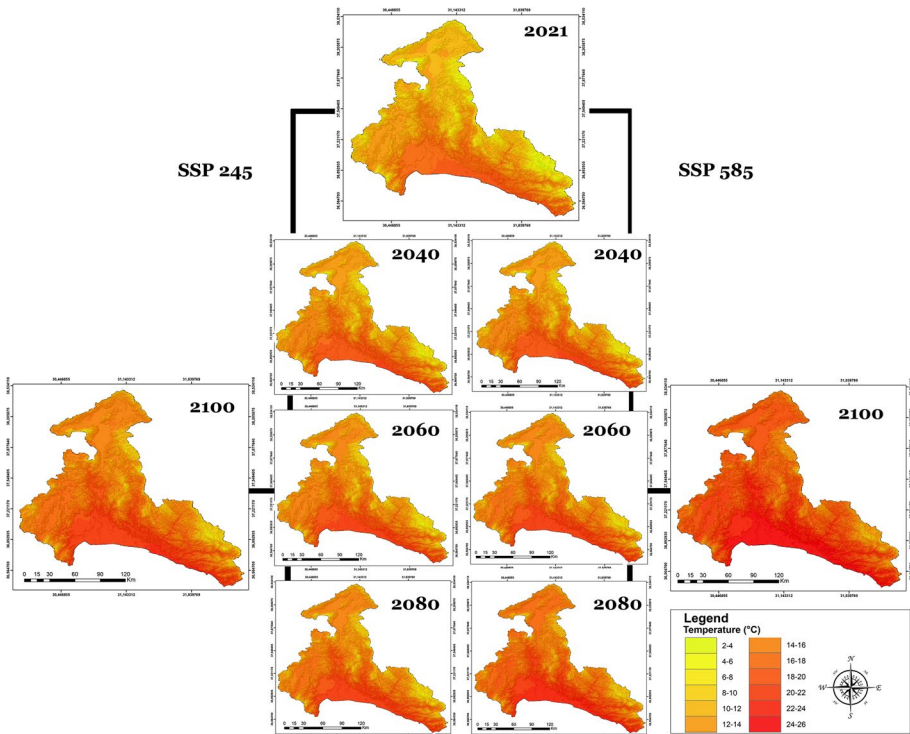


Fig. 5 The temperature transformed by climate change until 2100

where; 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 : the top that determines the assigned range of each of the observations, d : the distance separating the observation location X_i from the prediction location X_0 .

3 Results

Humidity values in the area are presented in Fig. 4 and are concentrated in the range of 60–66%. Humidity decreases from coastal regions to higher elevations in the north. The region's broadest range is the 64–66% slice, which covers 33% of the area. According to SSP 245, 38% of the area will have 62–64% humidity values by 2100. Temperature change in the region is one of the most critical issues, and the spatial process is spatialized in Fig. 6. While today 29% of the area is in the 10–12 °C range, according to SSP 245, 30% will reach 14–16 °C, and according to SSP 585, 29% will reach 18–20 °C. The figures achieved in terms of annual average values are remarkable. The fluctuating movement in wind speed in the area is in Fig. 7. While the current wind speed is 0.5–1 m/s in 95% of the area, it will be in this range by 2100, according to SSP 245, and by 2080, according to SSP 585. The effect of 1–1.5 m/s wind speed, effective in 5% of the area, will disappear.

ETv and DI included in the study have different thermal classification ranges. According to ETv, the area has five different comfort classes, from moderately cold

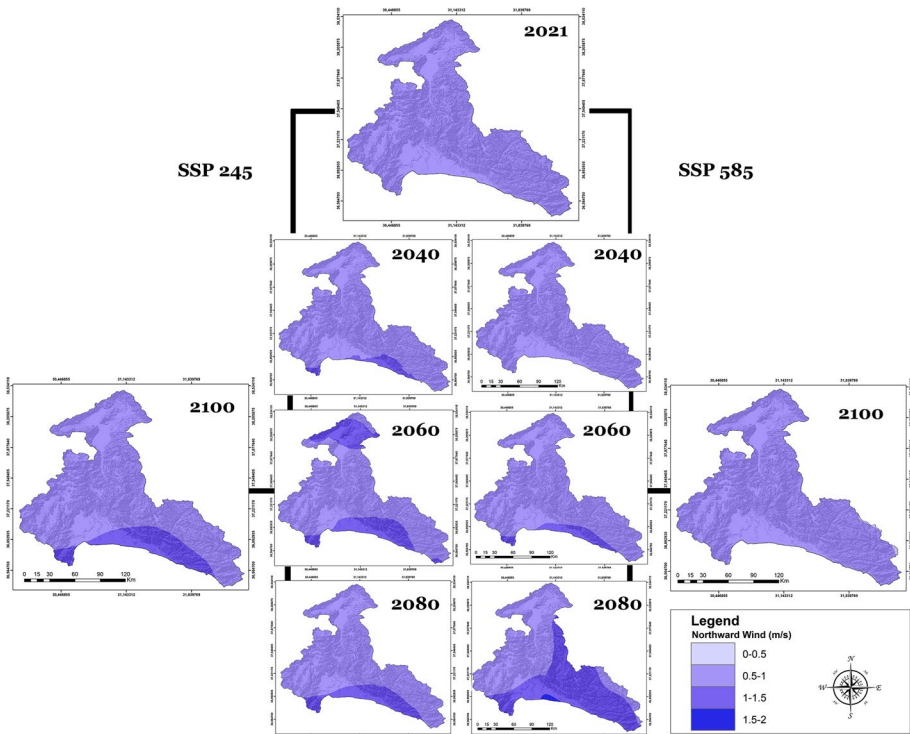


Fig. 6 The northward wind transformed by climate change until 2100

(10 to 12.9) to comfortable (22 to 24.9) areas. According to DI, there are four different class ranges, from cold (-1.7 to 12.9) areas to hot (20 to 26.4) areas. Today, according to ETv, 46% of the area consists of quite cool areas, and according to DI, 58% consists of cold areas. However, it has been determined that these areas are inland areas above sea level. Today, in flatter coastal areas with high agricultural and tourism potential, there are mild areas, according to ETv, and comfortable areas, according to DI. It is estimated that by 2100, according to SSP 585, mild areas will have an area ratio of 33% according to the ETv classification, and hot areas will have an area ratio of 25% according to the DI classification in Fig. 8.

The south of the region shows a different climatic structure from the inner parts due to the influence of the maritime. The fact that the Western Taurus Mountains extend parallel to the coast prevents moisture and temperature transitions between the coast, the interior, and the highlands and can change the climate in short distances by acting like a barrier. When the change in thermal comfort areas is examined, the critical change significantly in the coastal region is striking. Since these regions are areas where large hotels are located and mainly visited by foreign tourists, the tourism sector's exposure to change is relatively high. However, even areas in the interior classified as cold today tend to turn into hot areas in 2100, according to SSP 585. This situation will significantly affect tourism on the coast and the sectors that have chosen a location for it.

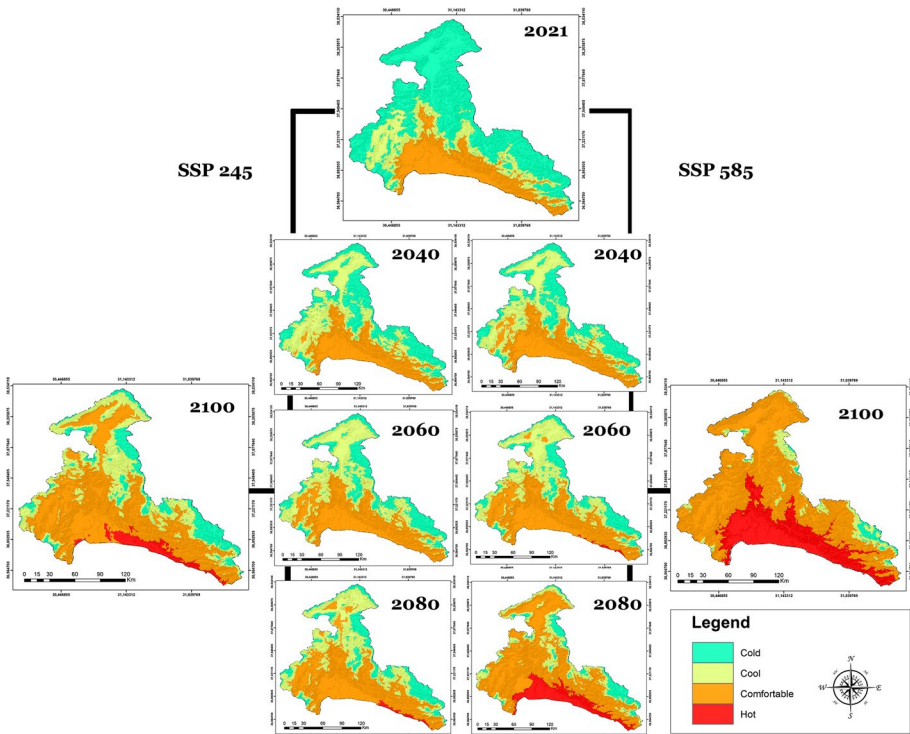


Fig. 7 Simulations of thermal areas according to DI

4 Discussion

The governments are critical partners in climate change mitigation and adaptation endeavors. Climatologists believe that in the next century, climates in various parts of the world will change rapidly, and unprecedented events will occur one after the other (Torda et al. 2017; Malhi et al. 2020). Throughout Türkiye, the economic importance of the leading sectors in the region is well known, with tourism and agricultural productivity accounting for most of the Gross Domestic Product. The necessity of developing policies for economic development due to the climate crisis is indisputable (Fankhauser and Stern 2016). Due to tourism's extreme dependence on climatic factors, fast anthropogenic climate change is directly linked to economic impacts. This process is especially the case in intensive tourism and agricultural production areas. However, how and why tourism and agriculture are involved in the climate policy of economies is a current topic of debate. It is unknown to what extent the agriculture and tourism sectors may be affected by climate change (Fei and McCarl 2023). However, there will be a change in local dynamics (Li et al. 2023). As temperatures reach predicted levels, the decline in certain tourism and agricultural markets and reductions in demand will also increase the current account deficit in this area. The adversely affected sectors, combined with broader impacts on society and economic development, will lead to problems of different dimensions (Grimm et al. 2018; Yalew et al. 2020; Yang et al. 2023). The measures

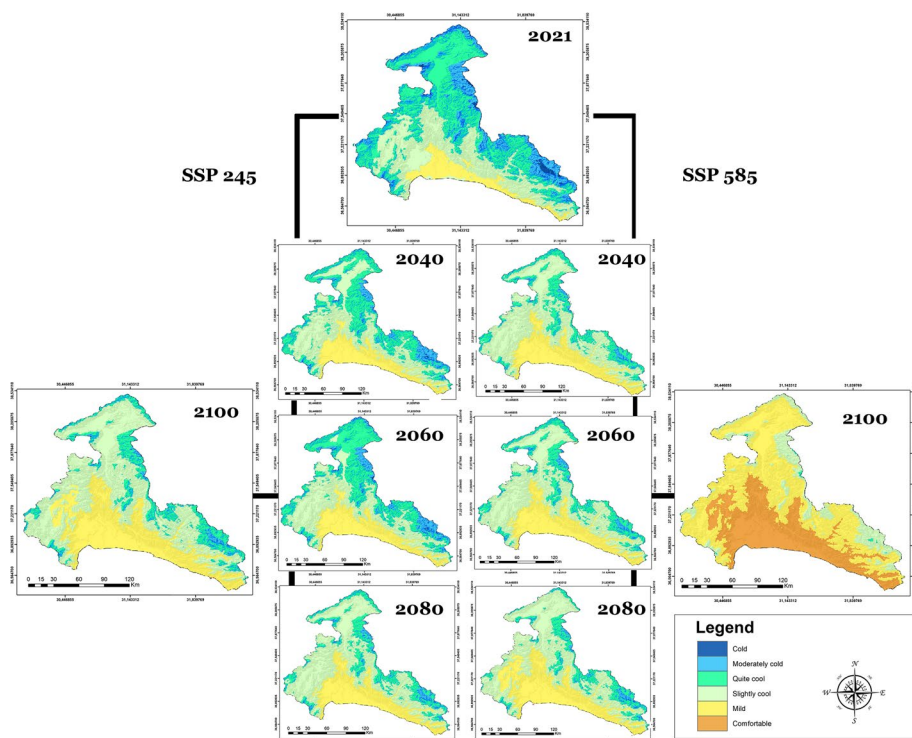


Fig. 8 Simulations of thermal areas according to ETv

that countries should take in response, as well as their adaptive capacity and alternative coping methods, should be explored in different regions (Koop and van Leeuwen 2017; Reckien et al. 2018).

Going forward, it is imperative that tourism and agricultural activities anticipate the consequences of climate change on future demand and that various models are built to predict scenarios against them. New infrastructures and medium- and long-term problem-solving packages will provide relief through strategic planning for the affected sectors. Current evidence that the climate change study results of tourism, agriculture, and public health need to be contextualized in the regions, which means that all determinants of tourism demand—except climate, whose impact is analyzed—should be held constant by Weatherdon et al. (2016) and Bocchiola et al. (2019). Steps should be taken to eliminate the uncertainty of the plans and obligations to be made in the near term and the practices planned to be carried out in the medium and long term. The idea of resilience within the uncertain, complex, dynamic climate structure is a critical issue for ecological systems (Folke et al. 2010). By measuring the expected climate changes, the future situation of the agricultural and tourism sectors can become apparent; this will indirectly determine the impact and existence of adverse conditions in these sectors (Pröbstl-Haider et al. 2016). In addition to tourism and agriculture, measures to be taken in nature conservation areas will help ensure optimal conditions and minimize

vulnerabilities to the effects of future climatic conditions (Tzanopoulos et al. 2011; Noor and Abdul Maulud 2022; Zhang et al. 2022; Peng et al. 2023).

The unprecedented rate of climatic determinants (such as temperature, precipitation, and wind) in the studies of climate projections and even evaluating the contribution of the remaining variables (species in the region, urbanization, and urbanization plans, population growth, emissions) will provide more realistic results (Köberl et al. 2016; Dellink et al. 2019). However, when defining all these factors in the models, the fact that the conditions that profoundly change in regular times are accelerated and the speed of their negative contribution is high shows the speed of climate change and sea acidification. This projection predicts that temperatures will rise above projected current temperatures and could become even more incredible than global emissions allowances by 2100 if not constrained by anthropogenic greenhouse gas emissions. It has been shown that the development of the current tourism and agricultural sectors is unsustainable due to climate change (Arabadzhyan et al. 2021). Both industry and governments must evaluate the risks and opportunities associated with future climate change and climate policies (Fuhrer et al. 2014).

For this reason, comprehensive studies on the future of climates have been examined by Scott et al. (2012) and Karimi et al. (2018). Day et al. (2021) examined climate change scenarios on tourism and recreation in Indiana. It will adversely affect the tourism sector. They reveal direct and indirect impacts on the tourism system. Zamani et al. (2020) noted that six adaptation scenarios to climate change on agriculture and water allocation in southwest Iran were proposed based on decision-making methods. Their future climate conditions indicated increased system vulnerability (Watson et al. 2013; Liu et al. 2022). Mereu et al. (2016) presented future projections using SSP 245 and SSP 585 models for the Pedra e' Othoni reservoir (Sardinia, Italy), which supplies water to tourism, domestic, and agricultural sectors. They focussed on a specific study site for water-demand forecasting models (using temperature and precipitation values) due to increasing their vulnerability to climate change. Food safety is another alarming global concern, as reviewed by Abbas et al. (2022), who synthesized current mitigation and adaptation approaches in sectorial assessment. They reveal that climate extremes and food shortages interact. Similarly, Fang et al. (2018) presented a revealing analysis of the profound impact of increasing climate change on tourism research.

Recent experiments indicate that food and tourism security based on climate change and its adverse impacts have been demonstrated for changes in different regions to the detriment of tourism and agricultural outputs, either wholly or to a large extent. This thematic issue is especially true in cities like Antalya, where water resources are dwindling and inter-annual climatic variability is high. The strong dependence on reservoirs as the primary water source (e.g., agricultural irrigation, drinking water) has posed challenges arising from future changes that require a balance between climate change and its impacts on water availability and the development of water demand (Anik et al. 2023; Asif et al. 2023). In the studied area, the water required for additional agricultural irrigation and tourism demands may be taken from the hydroelectric sector, thus reducing some of the potential for renewable energy production. For this purpose, there may be potential competition between the agriculture and tourism sectors. According to the projections for the coming years, the tourism and agriculture sector is expected to decrease further. Although clean energy facilities (wind turbines and solar energy) have been implemented in Antalya in the last decade, the tendency for irrigation and tourism to consume more will have negative results regarding water resources. From this perspective, it aims to use all kinds of reusable resources in the agriculture and tourism sector more effectively with the help of

new technologies. Recent developments in environmentally friendly recycling systems mean that water used in more efficient agriculture and tourism can be used effectively and efficiently.

5 Conclusion and study limitations

A simulation model for the likely realizable projection up to 2100 for the Antalya region is presented to recognize global themes and trends better. The model is run with the climate scenario for SSP 245 and SSP 585 to assess its resilience to meteorological parameters in the region. The impacts on tourism and agricultural production, which are among the leading sectors in the region, are taken into account, and the situation of local climatic conditions is assessed. The results that can be obtained by revealing the climatic changes in tourism regions and their dimensions are essential. However, water management is a fundamental need at the intersection of agriculture and tourism. Plans that can be produced as the output of our study with implications for water resources by negatively changing the supply variability and hydrological regime should come to the fore. First, rather than increasing the amount of precipitation, studies can be carried out to achieve regular and stable amounts, and technologies that can reduce evaporation losses can be developed. In addition to technologies, it is crucial to disseminate social programs to increase climate change awareness among people. The ability of the social structure to cope with external stresses and disturbances that arise due to social, political, and environmental change needs to be improved by increasing social resilience (Adger 2000). Governments and local governments need to include the climate change factor in their calculations when planning population growth and urbanization. In addition, local governments need to create more water retention structures to meet the needs and changes in urbanization styles, as the increases in water demand caused by socioeconomic changes pose a significant challenge. Regarding the sustainability of tourism and agricultural activities, long-term protection programs affected by seasonal stresses and changes should be made with urgent support and precaution packages. While water resources in the region are resilient to future changes, they are forecasted to decline, primarily due to the large basin that supplies them. Hence, in times of stress, regional development plans in Antalya should carefully consider trade-offs and potential conflicts between sectors. Reservoirs at risk of future changes should be identified, and mitigation measures accounted for sustainable resource utilization. The need for governance systems to effectively address these challenges is indisputable.

Although this study has made valuable contributions with its ideas about the region's current and future spatial structure in terms of thermal comfort, it is also essential to acknowledge its limitations. Regions that must be ready to adapt to climate risk have come to the fore. On the other hand, the methodological approach used in the research can be applied to many social-economic-environmentally critical regions. However, it should not be forgotten that the findings are based on certain assumptions. First, the evaluation is based on available data and selected indices. Since the ranges of different indexes vary, data gaps may exist, although they provide concrete indicators about the region. Future research can be tried with different indices. However, these trials will not change the fact that coastal areas are at risk. In addition, future studies can be improved by enriching the dataset based on local measurements. However, it has been observed that the region's summer temperatures exceed 45 °C. Further research may provide analyses of seasonal details.

Urban uses that may be affected spatially can be identified through sub-scale studies, and pinpoint decisions can be made. Strategies for the climate crisis can be diversified by analyzing the region's resilience to change through comprehensive analysis in future studies. In addition, studies expressing satisfaction with the thermal environment in the region and evaluated with subjective appraisal can be carried out to define the change.

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Data availability Not applicable.

Declarations

Ethics 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.

Consent to publish Not applicable.

Competing interest The authors declare that they have no competing interests.

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