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Determining Residential Areas Based on Bioclimatic Conditions in Kahramanmaraş, Türkiye

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Biyoklimatik Koşullara Dayalı Yerleşim Alanlarının Belirlenmesi Kahramanmaraş, Türkiye

Ahmet Doğan DOĞRULUK[1*], Semih EKERCİN[2], Abdullah VARLIK[3]

[1] *Hatay Mustafa Kemal Üniversitesi, Antakya Meslek Yüksekokulu, Mimarlık ve Şehir Planlama Bölümü, Hatay, Türkiye*
[2] *Antalya Bilim Üniversitesi, Rektörlük, Antalya, Türkiye*
[3] *Necmettin Erbakan Üniversitesi, Mühendislik Fakültesi, Harita Mühendisliği Bölümü, Konya, Türkiye*

**This study is derived from a section of the doctoral thesis titled "Determination of Suitable Settlement Areas with Multi-Hazard and Bioclimatic Assessments" which is prepared by Ahmet Doğan Doğruluk under the supervision of Assist. Prof. Dr. Abdullah Varlık and Prof. Dr. Semih Ekercin.

Abstract

Bioclimatic comfort refers to the climatic conditions that contribute to individuals' physiological and psychological well-being. Criteria such as temperature, relative humidity and wind speed are pivotal in determining bioclimatic comfort. Bioclimatic areas should be taken into consideration in urban planning studies for both human well-being and energy saving. This study endeavors to identify bioclimatic comfort areas tailored for Kahramanmaraş. 57 years of climate data obtained from 32 meteorological stations were used. These data were imported into ArcGIS 10.8 geographic information systems (GIS) software. Bioclimatic comfort levels were analyzed on a monthly, seasonal, and annual basis, employing the Discomfort Index (DI), Heat Index (HI), and Wind Chill Index (WCI). The findings revealed that the optimal bioclimatic conditions fell within specific ranges: a temperature range of 18-25°C, relative humidity between 32-48%, and a wind speed of 1.25 – 2.75 m/s. Ten classes were generated based on bioclimatic suitability. The areas characterized by almost unsuitable bioclimatic comfort cover are 426 km^2 and 2.93%, less suitable areas encompass 9106 km^2 and 62.69%, and moderately suitable bioclimatic comfort areas span 4993 km^2 and 34.38%.

Keywords: *Geographic information systems; Bioclimatic comfort; Discomfort index; Landscape planning; Climatic parameters.*

Öz

Biyoklimatik konfor insanlar için hem fizyolojik hem de psikolojik olarak kendilerini sağlıklı hissettikleri iklim koşullarıdır. Biyoklimatik konforun belirlenmesinde sıcaklık, bağıl nem ve rüzgâr hızı gibi kriterler kullanılmaktadır. Hem insan sağlığı hem de enerji tasarrufu için biyoklimatik alanlar şehir planlama çalışmalarında dikkat edilmelidir. Bu çalışmada Kahramanmaraş ili için biyoklimatik konfor alanlarının belirlenmesi amaçlanmıştır. 32 meteoroloji istasyonundan 57 yıllık iklim verileri kullanılmıştır. Bu veriler ArcGIS 10.8 coğrafi bilgi sistemleri (CBS) yazılımına aktarılmıştır. Discomfort Index (DI), Heat Index (HI) ve Wind Chill Index (WCI) kullanılarak biyoklimatik konfor aylık, mevsimlik ve yıllık olarak belirlenmiştir. Bu araştırma ile biyoklimatik koşulların en uygun olduğu zamanlarda sıcaklık 18-25°C, nispi nem %32-48 ve rüzgâr hızı ise 1.25-2.75 m/s olarak hesaplanmıştır. Biyoklimatik açıdan uygunluk durumuna göre on sınıf oluşturulmuştur. Biyoklimatik konforun neredeyse uygun olmadığı alanlar 426 km^2 ve %2.93, biyoklimatik konforun az uygun olduğu alanlar 9106 km^2 ve %62.69, biyoklimatik konforun orta uygun olduğu alanlar 4993 km^2 ve %34.38 oranındadır.

Anahtar Kelimeler: *Coğrafi bilgi sistemleri; Biyoklimatik konfor; Rahatsızlık indeksi, Yerleşim alanı belirleme; İklim parametreleri.*

1. Introduction

Throughout history, the climate has been a significant and intriguing concern for humanity. It directly influences fundamental human needs such as shelter and nutrition. Optimal climatic conditions contribute to both physiological and psychological well-being, promoting a sense of health. Today, the notion of bioclimatic comfort is defined as the suitability of natural climatic conditions for human health. Parameters affecting human well-being, such as temperature, humidity, wind speed and radiation, are evaluated in the assessment of bioclimatic comfort status (Ekercin and Örmeci 2010, Orhan et *al.* 2014). The energy people use today is predominantly derived from non-renewable sources, particularly coal, oil and natural gas. A substantial part of this energy is consumed for heating in cold climates and cooling in hot climates. Bioclimatic conditions play a direct or indirect role in various aspects of human life, such as well-being, habitat selection and nutrition (Roshan et *al.* 2019). In a world with finite settlement possibilities, bioclimatic evaluations must be considered in the planning phase of the cities for sustainable human living (Cetin et *al.* 2018, Nouri et *al.* 2023, Oliveira and Andrade 2007, Toy et *al.* 2007). Research on bioclimatic conditions and their effects on humans has been a focal point for researchers

*Sorumlu Yazar/Corresponding Author: Ahmet Doğan Doğruluk e-posta/e-mail: addogruluk91@gmail.com

over many years. In the early stages, Haldane (1905) examined the psychological states of people working in extreme temperatures, exploring the effects of bioclimatic conditions on human well-being. Today, one of the most widely used indices for gauging bioclimatic comfort is the Bioclimatic Comfort Chart developed by Olgyay (1963). Olgyay notes that optimal bioclimatic comfort conditions outdoors entail a temperature range of 21 - 27.5°C, relative humidity between 30% and 65%, and wind speed less than 5 m/s. Some of the indices developed to calculate bioclimatic comfort are as following; Effective Temperature (ET), Temperature Humidity Index (THI), Discomfort Index (DI) (Thom 1959), Wind Chill Index (WCI) (Osczevski 1995), Physiological Equivalent Temperature (PET) (Mayer and Höppe 1987) and Heat Index (HI) (Steadman 1979).

When analyzing the research on the determination of bioclimatic comfort in recent years Adiguzel et *al.* (2020), Çalışkan et *al.* (2012), Cetin (2015, 2020), Cetin et *al*. (2018, 2019), Evrendilek and Berberoglu (2008), Gungor et *al.* (2021), Kargıoğlu et *al.* (2009), Mansuroğlu et *al.* (2021), Metin and Çağlak (2022), Ozyavuz et *al.* (2018), Topay (2007), Toy et *al.* (2007, 2022), it becomes evident that comfort zones are identified through a single index, with the results not converted into an annual format.

This study employed DI, HI and WCI to delineate bioclimatic comfort areas in Kahramanmaraş. Detailed information regarding the indices is presented in the material and methods section. Hence, the study seeks to;

- Produce temperature, relative humidity and wind speed maps for Kahramanmaraş.
- Compare the results for DI and HI, which depend on temperature and humidity variables.
- Evaluate the effect of cold conditions on bioclimatic comfort areas using WCI.
- Compare DI, HI and WCI maps with those derived from DI+HI+WCI.
- Determine monthly and seasonal bioclimatic comfort areas for sectors like tourism.
- Identify new bioclimatically suitable residential areas to minimize energy consumption for heating and cooling purposes.

2. Materials and Methods

2.1 Study Area

Kahramanmaraş was chosen as the study area due to its status as a growing city characterized by diverse climate characteristics. Located in the southern region of Turkey, the city center is situated at coordinates 37° 34′ 59″ North and 36° 55′ 59″ East (Figure 1). With an average altitude of 568 meters above sea level, the city encompasses northern regions involving mountainous terrain. The altitude of the land varies between 350 and 3000 meters. Due to its geographical location, Kahramanmaraş exhibits both Mediterranean and continental climate characteristics. The city experiences an average annual temperature of 17.2°C, with an average of 76.4 rainy days and a monthly total precipitation averaging 750.9 mm. Over the period from 1930 to 2022, the highest recorded temperature in the city reached 45.2°C, while the lowest temperature was -9.6°C.

The city has a surface area of 14525 km^2, 59.7% of which is covered with mountains, 24% plateaus and 16.3% plains. Besides, it sustains a growing population of 1,178,619 people. It continues to receive immigration due to factors such as the economy, climate and transportation (Int. Ref. 1, Meteorology 2022).

2.2 Field study and modeling of bioclimatic variables

This study used data obtained from 32 meteorological stations and field studies administered by the State Meteorology Affairs General Directorate (SMAGD) covering the entire city (Meteorology 2022). The observations (temperature, relative humidity and wind speed) and environmental data carried out by these stations from 1965 to 2022 were organized in a computerized environment. Meteorological parameters for the entire city were derived from the measured stations using Kriging Interpolation in ArcGIS 10.8 software. Monthly average temperature distributions (Figure 3), monthly average relative humidity distributions (Figure 4) and monthly average wind speed distributions (Figure 5) were modeled for all months.

2.3 Selection and calculation of bioclimatic comfort indices

The use of a single index in determining bioclimatic comfort zones in cities with diverse climate characteristics, like Kahramanmaraş, is both uncontrolled and insufficient. Therefore, it is essential to employ multiple bioclimatic comfort indices to systematically assess various climate effects in a controlled and nuanced manner. This study utilized DI and HI indices based on temperature and relative humidity variables and WCI indices to account for the coldness effect (Thom 1959, Steadman 1979, Osczevski 1995). The formulas for these indices and their bioclimatic classifications (Table 1), (Table 2), (Table 3) are displayed as follows:

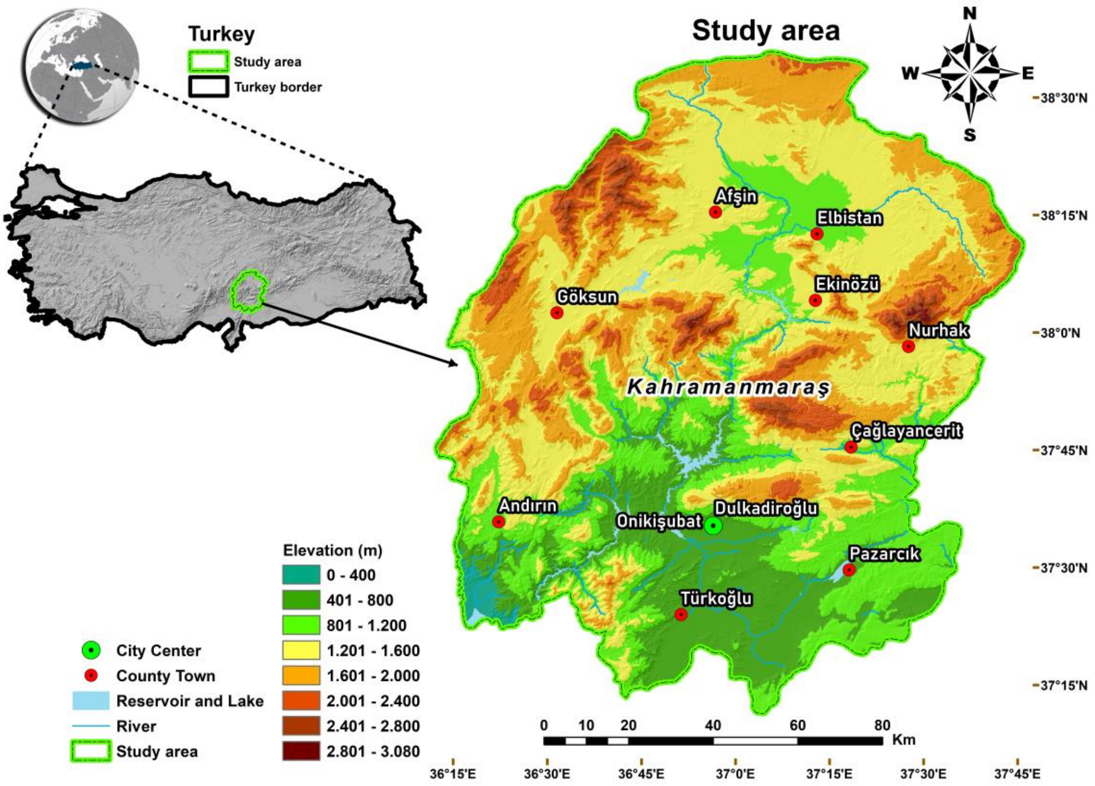

Figure 1. Location of study area

Table 1. Classes of the discomfort index (Thom 1959).

DI	Comfort sensation	Point
Less than 10	Discomfort feeling	0
10 – 18	Moderate discomfort feeling	1
18 – 21	No discomfort feeling	2
21 – 27	Moderate discomfort feeling	1
More than 27	Discomfort feeling	0

$$DI = T - (0{,}55 - 0{,}0055RH)(T - 14{,}5) \qquad (1)$$

Here, DI represents the discomfort index, T signifies the temperature (°C) and RH (%) refers to the relative humidity.

Table 2. Classes of the heat index (Fotso-Nguemo et *al.* 2023).

HI	Comfort sensation	Point
Less than 15	Discomfort feeling	0
15 – 17	Moderate discomfort feeling	1
17 – 25	No discomfort feeling	2
25 – 28	Moderate discomfort feeling	1
More than 28	Discomfort feeling	0

$$HI = 0{,}5 * \begin{Bmatrix} T + 61 + [(T - 68) * 1.2] \\ +(R * 0.0094) \end{Bmatrix} \qquad (2)$$

Here, HI represents temperature index, T signifies the temperature (°F) and RH (%) refers to the relative humidity.

Table 3. Classes of wind chill index (Blazejczyk et *al.* 2012).

WCI	Comfort sensation	Point
Less than (-10)	Discomfort feeling	0
0 – (-10)	Moderate discomfort feeling	1
More than 0	No discomfort feeling	2

$$WCI = 13.12 + 0.6215T - 11.37V^{0.16} + (0.3965T * V^{0.16}) \qquad (3)$$

Here, WCI refers to the Wind Chill index, T points the temperature (°C) and V (km/h) is the wind speed.

Monthly thematic maps for DI, HI and WCI were generated from the monthly average temperature (Figure 3), monthly average relative humidity (Figure 4) and monthly average wind speed (Figure 5) maps using the raster calculator function, which facilitates pixel-based calculations. These maps were classified through the reclassify function. In this process, bioclimatically unsuitable areas were assigned 0 points, moderately suitable areas 1 point, and very suitable areas 2 points. Thus, maps were created for monthly and seasonal evaluations (Figure 6), (Figure 7), (Figure 8).

2.4 Determining suitable settlement areas on a monthly and annual basis from a bioclimatic perspective

The cell statics function can calculate across the same pixels in various layers. Using this function, a monthly bioclimatic comfort zones map, represented as DI + HI + WCI, was generated by averaging the monthly maps produced for DI, HI and WCI (Figure 9). In this comprehensive city-wide modeling study, the monthly DI + HI + WCI map was divided into 10 classes, prioritizing more suitable areas over unsuitable ones to make a thorough analysis of bioclimatic comfort areas.

Monthly bioclimatic comfort zone maps may be insufficient for a comprehensive assessment of suitable settlement areas. Thus, annual DI, HI and WCI bioclimatic comfort zone maps were generated by averaging the respective monthly maps, using the cell statics function. Besides, an annual DI+HI+WCI bioclimatic comfort zone map (Figure 10) was produced by averaging these maps through the same cell statics function. This resulting map was categorized into 10 distinct classes, ranging from unsuitable to very suitable areas, for more detailed analysis. In this way, bioclimatically suitable areas for settlement were determined by combining three different indices for Kahramanmaraş.

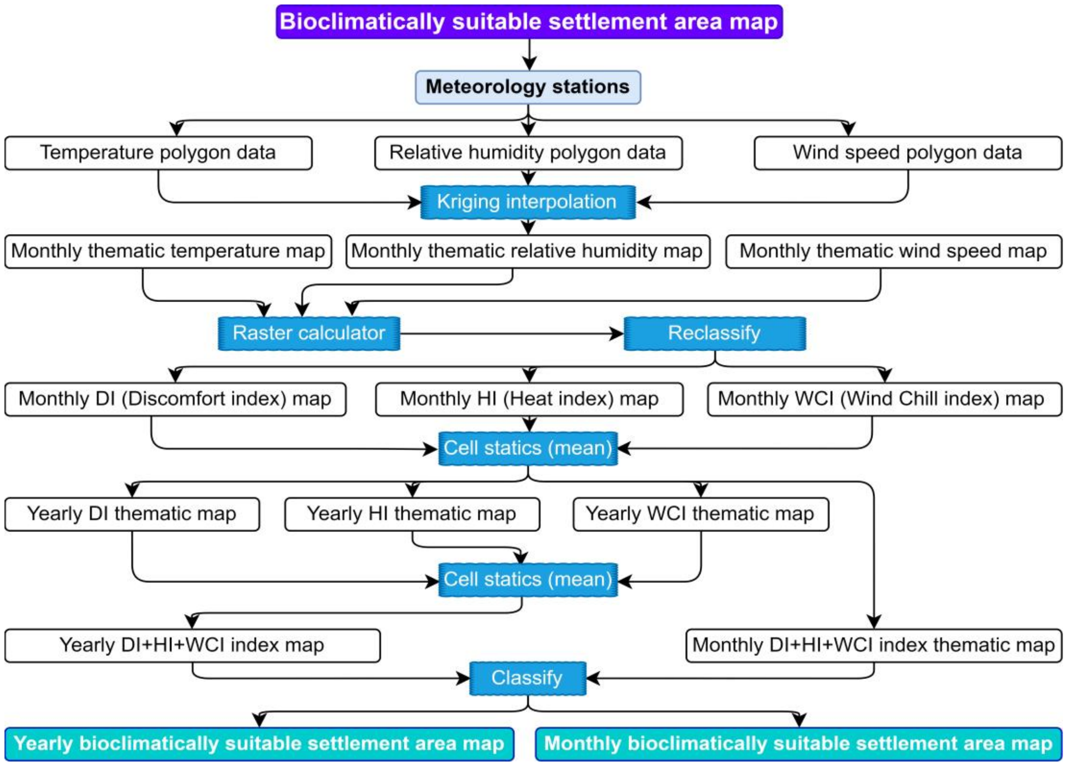

Figure 2. Study flow diagram

3. Results and Discussions

The findings revealed that the optimal bioclimatic conditions for Kahramanmaraş fell within specific ranges: a temperature range of 18-25°C, relative humidity between 32-48%, and a wind speed of 1.25 – 2.75 m/s. The value ranges of bioclimatic variables (temperature, relative humidity and wind speed) were calculated through analyzing the monthly average temperature (Figure 3), monthly average relative humidity (Figure 4) and monthly average wind speed (Figure 5) maps for Kahramanmaraş.

The coldest season in Kahramanmaraş is winter and the hottest season is summer. Winter is characterized by increased humidity levels, which subsequently decrease during the summer months. In addition, the annual temperature average is calculated at 10.75°C, with an annual relative humidity average of 57.83% and an annual wind speed average of 2.31 m/s. The average temperature increases from January to August, with August being the hottest month and January the coldest. The highest humidity is observed in January, while the lowest humidity in September. Humidity is quite high in winter and lowest in summer. Considering wind speed, the months display general similarities despite an increase during the summer months. The effect of high temperatures in summer is lessened by winds coming from the north.

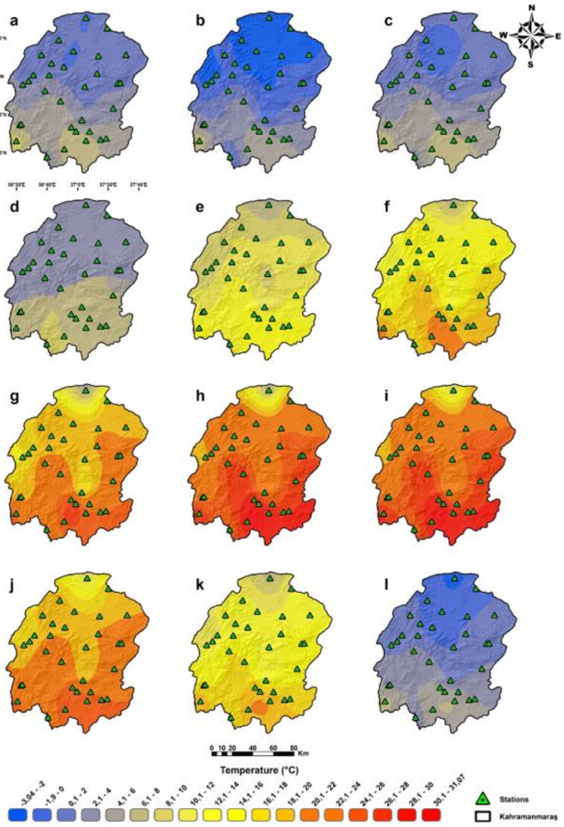

Figure 3. Average monthly temperature (from 1965 to 2022): **a** December, **b** January, **c** February, **d** March, **e** April, **f** May, **g** June, **h** July, **i** August, **j** September, **k** October, **l** November.

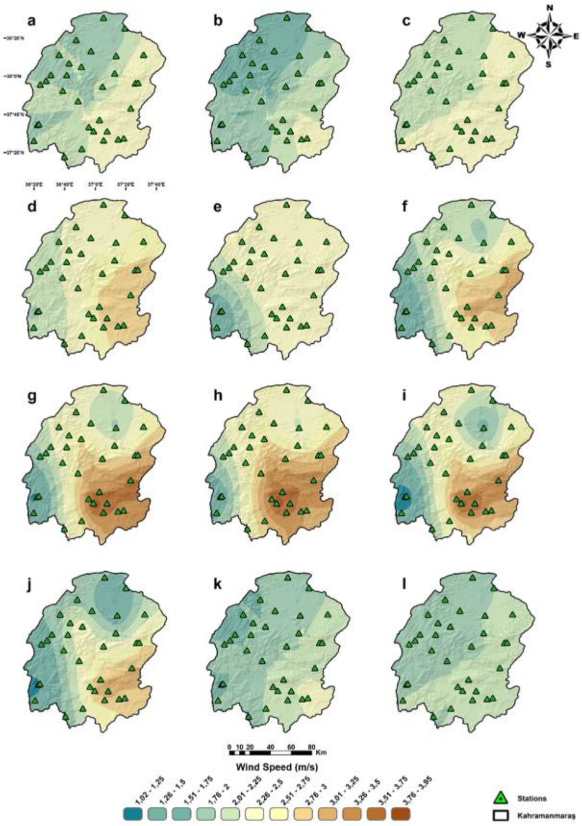

Figure 5. Average monthly wind speed (from 1965 to 2022): **a** December, **b** January, **c** February, **d** March, **e** April, **f** May, **g** June, **h** July, **i** August, **j** September, **k** October, **l** November.

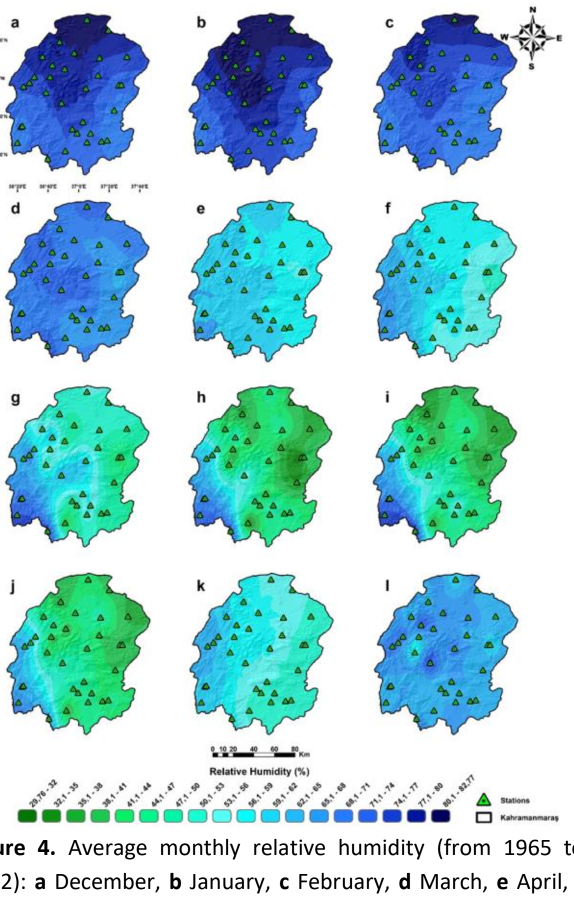

Figure 4. Average monthly relative humidity (from 1965 to 2022): **a** December, **b** January, **c** February, **d** March, **e** April, **f** May, **g** June, **h** July, **i** August, **j** September, **k** October **l** November.

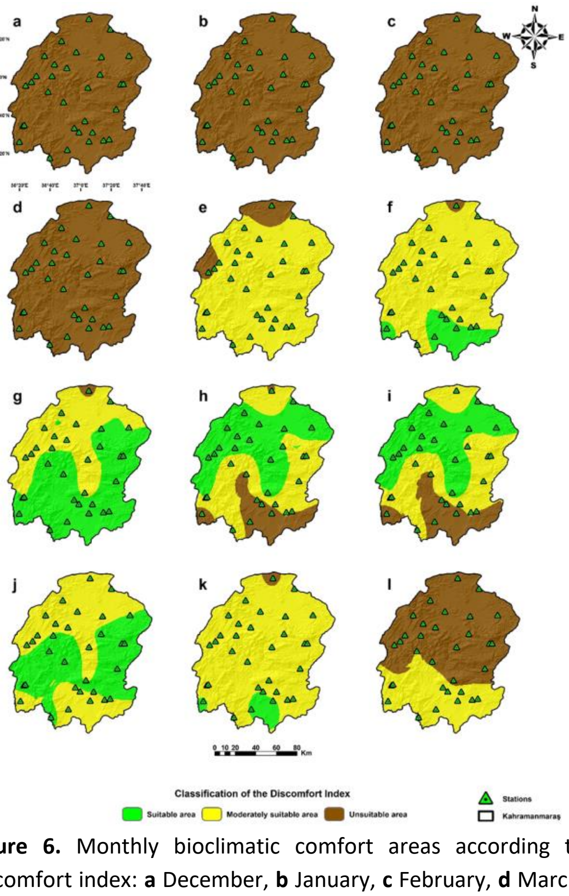

Figure 6. Monthly bioclimatic comfort areas according to discomfort index: **a** December, **b** January, **c** February, **d** March, **e** April, **f** May, **g** June, **h** July, **i** August, **j** September, **k** October, **l** November.

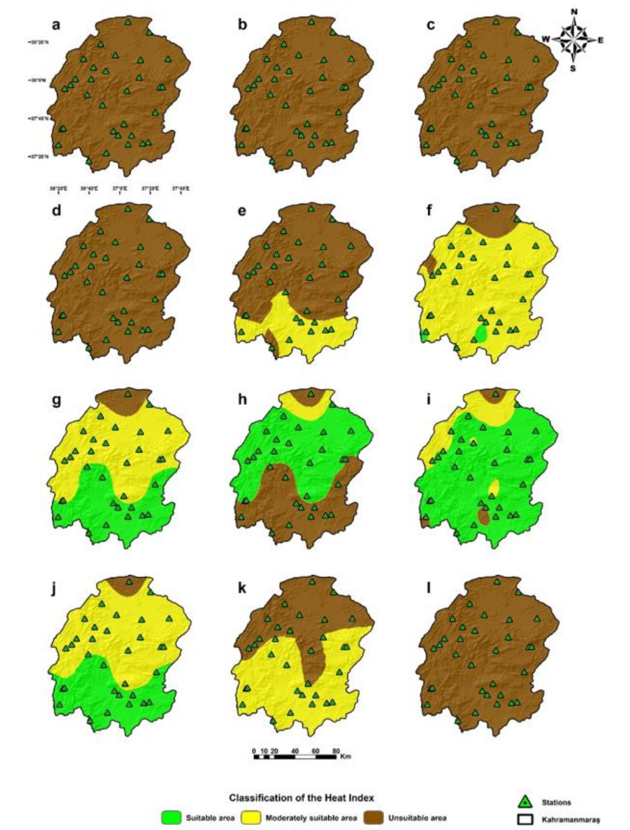

Figure 7. Monthly bioclimatic comfort areas according to heat index: **a** December, **b** January, **c** February, **d** March, **e** April, **f** May, **g** June, **h** July, **i** August, **j** September, **k** October, **l** November.

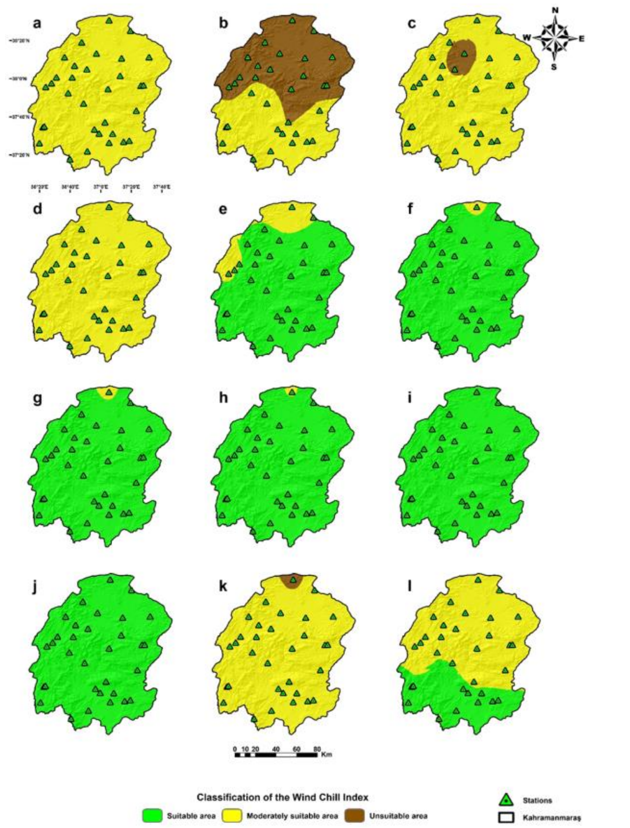

Figure 8. Monthly bioclimatic comfort areas according to wind chill index: **a** December, **b** January, **c** February, **d** March, **e** April, **f** May, **g** June, **h** July, **i** August, **j** September, **k** October, **l** November.

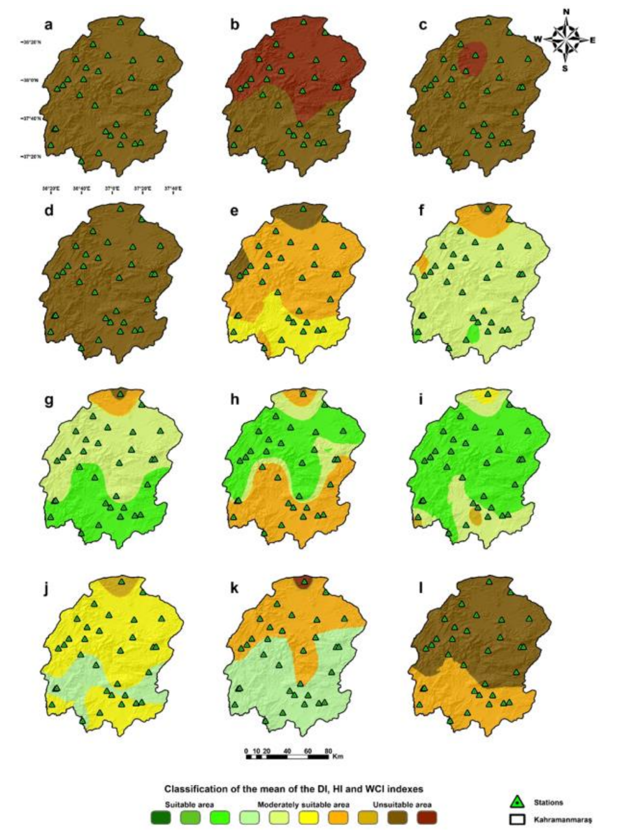

Figure 9. Monthly DI+HI+WCI bioclimatic comfort areas: **a** December, **b** January, **c** February, **d** March, **e** April, **f** May, **g** June, **h** July, **i** August, **j** September, **k** October, **l** November.

Table 4. Seasonal and regional classification of bioclimatic comfort areas for Kahramanmaraş.

Seasons	Regions	DI	HI	WCI
Winter	North	1	1	2
	East	1	1	2
	South	1	1	2
	West	1	1	2
Spring	North	1	1	2
	East	2	1	3
	South	2	2	3
	West	2	1	3
Summer	North	3	2	3
	East	2	3	3
	South	1	2	3
	West	3	3	3
Autumn	North	1	1	2
	East	2	2	2
	South	2	2	3
	West	2	2	2

*Suitability ranking: 1-Unsuitable-3-Suitable

Monthly DI (Figure 6), monthly HI (Figure 7) and monthly WCI (Figure 8) maps generated from temperature, relative humidity and wind speed maps were examined (Table 5). Bioclimatically, the most favorable season is summer, while the least suitable is winter. A regional analysis of comfort areas reveals that the west and south regions are the most suitable, whereas the east and north regions are identified as the least suitable areas.

Upon comparing DI and HI with the same variables seasonally and regionally, the similarity rate was identified as 69%. In contrast to previous studies Cetin (2015), Oliveira and Andrade (2007), Ozyavuz et *al.* (2018), Toy et *al*. (2007) that employed a single index, this study demonstrated that the use of a single index was not controlled and the results showed significant differences. Moreover, the study's scope was expanded by incorporating the calculation of the coldness effect during winter months with WCI. Areas identified as bioclimatically unsuitable through WCI were found to align with unsuitable areas in both DI and HI maps.

In the initial phase of the study, monthly bioclimatic comfort zone maps for DI, HI and WCI were divided into three categories: unsuitable, moderately suitable and suitable. A similar study divided bioclimatic comfort areas Adiguzel et *al.* (2020) into two classes as suitable and unsuitable areas. Increasing the number of classes in this study offered a notable advantage in determining a more nuanced the order of preference.

Upon analyzing the monthly DI+HI+WCI map (Figure 9), the effects of the continental climate in the northern regions of the province were evident throughout the year. Generally, the city does not exhibit a favorable bioclimatic comfort conditions in December, January, February and March, while the summer months (June, July, August) are more suitable for tourism and nature-related activities. These maps can be used as a foundational tool for settlement planning, and areas can be selected for seasonal residences, holidays and temporary accommodation.

Table 5. The annual and regional suitability for settlement in Kahramanmaraş in terms of bioclimatic conditions.

Regions	DI	HI	WCI	DI+HI+WCI
Northwest	3	2	5	4
North	2	1	4	4
Northeast	3	2	5	4
East	3	2	5	4
Southeast	3	3	5	5
South	3	3	5	5
Southwest	3	3	5	5
West	3	2	5	4

*Suitability ranking: 1-Unsuitable-10-The Most Suitable

Annual maps for DI, HI, WCI and DI+HI+WCI (Figure 10) were generated by averaging monthly produced DI (Figure 6), HI (Figure 7), WCI (Figure 8) and DI+HI+WCI (Figure 9) maps. This annual map was divided into 10 classes and analyzed regionally (Table 5).

The northern regions of Kahramanmaraş exhibit a significantly unfavorable bioclimatic comfort due to the continental climate effect. The southern regions are relatively more suitable areas due to the influence of the Mediterranean climate. No region within the city attains uniform suitability scores across all indexes. Besides, no region in the city is bioclimatically suitable. On the other, the expansion of class categories is advantageous in determining the appropriate settlement area

Considering the suitability classes across regions, notable differences emerged. A substantial difference of 63% was identified between DI and HI, while a complete 100% difference was found between DI and HI, as well as DI and DI+HI+WCI. Similarly, a 100% difference was calculated between HI and WCI, and HI and DI+HI+WCI. A 50% difference was noted between WCI and DI+HI+WCI.

Table 6. Annual classification of bioclimatic comfort areas in Kahramanmaraş based on indices.

Suitability Ranking	DI (km^2)	HI (km^2)	WCI (km^2)	DI+HI+WCI (km^2)
1	144	960	–	–
2	1023	6153	–	426
3	13358	7412	93	9106
4	–	–	217	4993
5	–	–	14215	–
6	–	–	–	–
7	–	–	–	–
8	–	–	–	–
9	–	–	–	–
10	–	–	–	–

*Suitability ranking: 1-Unsuitable-10-The Most Suitable

Bioclimatic comfort areas were analyzed annually using various indices (Table. 6). Generally, categories suitable for settlement could not be conclusively determined for DI, HI and WCI. When comparing DI and HI, it is evident that there is a density in the 2nd and 3rd degree suitability categories. Substantial differences were observed on an area basis between these indices based on the same variables. The WCI is an index mostly related to coldness. Areas in the 5th degree suitability category have been determined due to the absence of very high cold temperatures across the province. The DI index showed the most similarity with the DI+HI+WCI index in terms of appropriate class areas.

Upon the examination of the annual bioclimatic comfort areas for Kahramanmaraş (Figure 10), the bioclimatic conditions are not generally favorable across the city. From a bioclimatic perspective, the southern regions of the province appear to be more suitable in the newly determined settlement areas. The primary limitation of the study is due to the scarcity of meteorological stations in the region and the inadequate number of sensors within these stations.

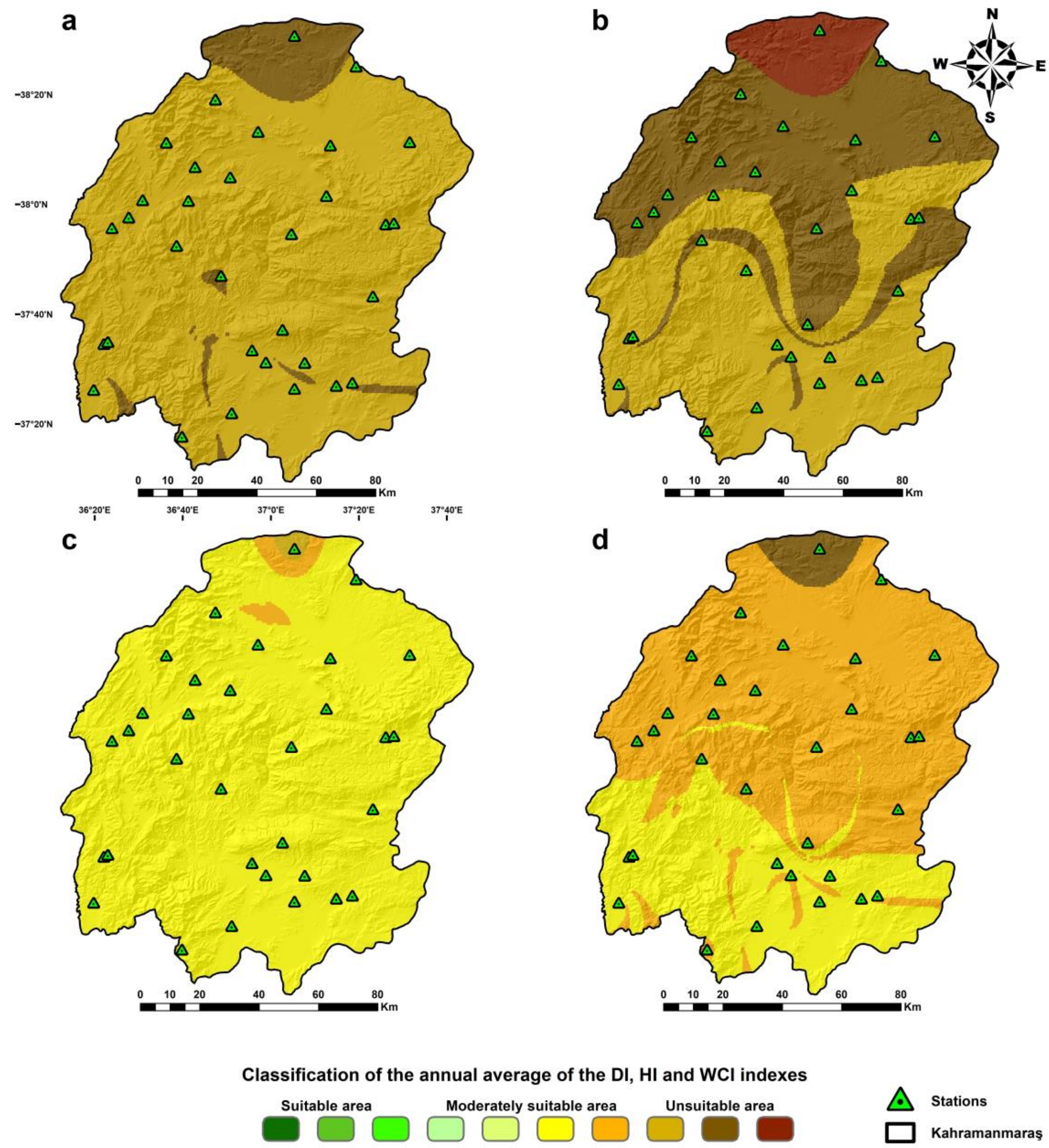

Figure 10. Annual bioclimatic comfort areas for Kahramanmaraş: **a** DI, **b** HI, **c** WCI, **d** DI + HI +WCI

4. Conclusion

This study employed data from 32 meteorological stations to model temperature, relative humidity and wind speed. Bioclimatic comfort areas for Kahramanmaraş were identified in both monthly and annual formats with DI, HI, WCI and DI+HI+WCI.

The western and southern regions of Kahramanmaraş are bioclimatically more comfortable on both a monthly and seasonal basis compared to the eastern and northern regions. The most favorable months for outdoor activities and tourism are June, July and August. On comparing DI and HI results based on temperature and humidity variables in a monthly format, a notable difference of approximately 30% was observed. This suggests that relying on a single index for determining bioclimatic comfort zones is uncontrolled and inaccurate.

This study confirmed the necessity of deploying distinct indices to calculate both the effects of temperature and coldness in cities such as Kahramanmaraş, where four seasons and different climates are experienced.

A bioclimatically very suitable and suitable settlement area was not determined in Kahramanmaraş. It consists of unsuitable areas due to the continental climate effect of the northern regions. However, the southern regions are moderately suitable for settlement due to the Mediterranean climate.

This study conducted specifically for Kahramanmaraş highlights that bioclimatic comfort areas can be determined through the simultaneous application of various indices. To enhance the efficiency of future research, it is recommended to increase sampling points, incorporate more bioclimatic indexes, and expand suitability classes. Besides, criteria such as regional radiation, number of cloudy days, rainy and snowy days may also be included in the calculation process.

Decision makers must take natural climatic conditions into account when determining settlement areas to promote sustainable human living and optimize the accurate use of finite energy resources. Thus, the amount of energy spent for cooling in hot seasons and heating in cold seasons will decrease and energy efficiency will be ensured.

Declaration of Ethical Standards

This study is derived from a section of the doctoral thesis titled "Determination of Suitable Settlement Areas with Multi-Hazard and Bioclimatic Assessments" which is prepared by Ahmet Doğan DOĞRULUK under the supervision of Assist. Prof. Dr. Abdullah VARLIK and Prof. Dr. Semih EKERCİN.

The authors declare that they comply with all ethical standards.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Author-1: Conceptualization, investigation, methodology and software, visualization and writing – original draft.
Author-2: Conceptualization, methodology, supervision and review.
Author-3: Conceptualization, supervision, writing – review and editing.

Data Availability Statement

Datasets are available on request. The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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