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RESEARCH ARTICLE

The effects of climate on land use/cover: a case study in Turkey by using remote sensing data

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Abstract
Economic and industrial development results in worldwide population concentration in cities, leading to increases in impervious surfaces. Thus, the surface temperatures increase and cities are exposed to the urban heat island effect. This study analyzed the changes in the urban heat island effect in the 30 years (from 1990 to 2021) in the central district of Bartin. In this sense, there were two primary goals. Firstly, land use/land cover change, land surface temperature (LST), normalized difference built-up index (NDBI), and normalized difference vegetation index (NDVI) were analyzed by using remote sensing methods between 1990 and 2021. Secondly, a linear regression analysis was conducted to determine the factors associated with LST, NDVI, and NDBI. The study results revealed increases in urban surfaces and the average land surface temperature values in the past 30 years and showed a decline in the vegetation. Regression analysis results indicated a strong negative relationship between LST and NDVI and a strong positive relationship between LST and NDBI. It was also found a robust negative relationship between NDBI and NDVI. In light of the findings, it was stated that the amount of open and green areas should be increased in order to prevent the negative effects of the urban heat island in the central district of Bartin. For this purpose, it has been proposed to encourage green roof systems throughout the city, to create city parks and to create a green belt system. In addition, as a result of the study, the importance of preventing forest destruction caused by over settlement in the Mountains, which is one of the rare habitats of the world with different plant species, was emphasized. In this sense, legal sanctions should be employed to protect those areas and prevent construction.

Keywords Land surface temperature (LST) · Normalized difference built-up index (NDBI) · Normalized difference vegetation index (NDVI)

Introduction

Economic and industrial development and high population rates are closely associated with rapid changes in land uses/land cover change (LULC) in the twenty-first century, leading to the transformation of landscapes into residential areas and the increases in the amount of impervious surface worldwide. Impervious surfaces include buildings, roads, and industrial areas that absorb the short-wave solar radiation and reduce the long-wave solar energy emitted from the earth (Amelung and Viner 2006; Cetin 2020a and b; Amelung et al. 2007; Adiguzel et al. 2022a and b; Amiranashvili et al. 2008; Adiguzel et al. 2020; Amiranashvili et al. 2010; Cetin 2019; Amiranashvili et al. 2018; Varol et al. 2022; Varol et al. 2021; Cetin et al. 2019; Fletcher and Morakabati 2008; Cetin 2018; Zhong and Chen 2019; Cetin et al. 2018; Cetin 2016a, b and c; Bozdogan Sert et al. 2021; Cetin and Sevik 2016a and b; Fielding and Shortland 2011; Kaya et al. 2009; Cetin and Zeren 2016a and b; Kilicoglu

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et al. 2020; Kilicoglu et al. 2021; Clements and Georgiou 1998; Cetin 2015a, b, c and d; Gungor et al. 2021; Cetin et al. 2010a and b; De Freitas 2003; Liu Shaojun et al. 2014) . An increase in impervious surfaces results in warming the urban environment, creating the urban heat island (UHI) effect (Scott and Lemieux 2009; Cetin 2020a and b; Ataei and Hasheminasab 2012; Adiguzel et al. 2022a and b; Adiguzel et al. 2020; Auliciems and Kalma 1979; Cetin 2019; Varol et al. 2022; Varol et al. 2021; Cetin et al. 2019; Cetin 2018; Bakhtiari and Bakhtiari 2013; Cetin et al. 2018; Cetin 2016a, b and c; Bode et al. 2003; Bozdogan Sert et al. 2021; Cetin and Sevik 2016a and b; Kaya et al. 2009; Farajzadeh and AhmadAbadi 2010; Cetin and Zeren 2016a and b; Kilicoglu et al. 2020; Hamilton and Tol 2004; Kilicoglu et al. 2021; Cetin 2015a, b, c and d; Gungor et al. 2021; Cetin et al. 2010a and b; De Freitas 2003).

The UHI effect is generally identified by using two methods. The first method involves the ground-based air temperature measurements in micro studies based on the modeling of meteorological data (Hejazizadeh et al. 2019; Matzarakis 2006; Hernandez and Ryan 2011; Scott and Lemieux 2009; Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020; Grassl 1981; Grassl 2006; Grassl 1976; Grassl 1989; Grassl 2011; Grassl 1979; Cetin 2020a and b; Cetin 2019; Harlfinger 1991; Kovács and Unger 2014a and b; Monteiro et al. 2016). The second method is used in macro studies based on land surface temperature (LST) measurements. LST is measured through remote sensing methods using satellite image data and mapping the thermal energy released to the atmosphere from the earth. The LST measurements from thermal satellite images are easy, fast, continuous, and very reliable as it allows to calculate the energy emitted from the earth to the atmosphere (Matzarakis 2002; Cetin 2020a and b; Cetin 2019; Matzarakis 2007; Maddison 2001; Mieczkowski 1985; Moreno et al. 2008; Scott et al. 2004; Scott et al. 2016; Wang et al. 2016; Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020; De Freitas 2003; Cetin et al. 2019; Cetin 2018; Cetin et al. 2018; Scott and McBoyle 2001; Berrittella et al. 2006: Cetin 2016a, b and c; Cetin and Zeren 2016a and b; De Freitas 2005; Scott and Lemieux 2009; Cetin 2015a and b; Lin and Matzarakis 2008).

Greenhouse gas emissions and LULC changes are the main factors affecting LST values. Industrialization mainly depended on fossil fuels escalates greenhouse gas emissions, increasing the rate of greenhouse gases in the lower atmosphere (troposphere). The solar radiation reflected from the earth is absorbed and re-emitted in the troposphere and increases the surface temperature (Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020; Zhong and Chen 2019; Cetin 2020a and b; Cetin 2019; De Freitas 2003; Cetin et al. 2019; Cetin 2018; Cetin et al. 2018;Lise and Tol 2002; Scott and Lemieux 2009; Lin and Matzarakis 2008; Cetin 2015a and b; De Freitas 2005).

The radiation emissions from the earth's surface depend on the LULC changes. Impervious surfaces such as buildings and roads reflect radiation, but surfaces vegetation or covered with permeable materials absorb most. Therefore, LULC changes affect LST values by changing the radiation absorption rates of the land surface (Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020; Zhong and Chen 2019; Clements and Georgiou 1998; Fletcher and Morakabati 2008; Cetin 2020a and b; Cetin 2019; Fielding and Shortland 2011; De Freitas 2003; Monteiro et al. 2016).

Additionally, many studies emphasized that dense and healthy vegetation also affects the LST and UHI due to evaporation. Thus, remote sensing techniques are applied to measure vegetation indices and to evaluate vegetation. One of those indices, the normalized difference vegetation index (NDVI), is widely used in many studies to describe vegetation patterns (De Freitas 2003; Lise and Tol 2002; Cetin 2020a and b; Cetin 2019; Lin and Matzarakis 2008; Zhong and Chen 2019; Scott and Lemieux 2009; Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020).

On the other hand, many researchers applied the normalized difference built-up index (NDBI) to investigate the effects of urban impervious surfaces such as roads and building roofs on LST. In addition, the studies on LST and UHI show that determining the factors affecting LST and the relationship between these factors is of great importance in the development of measures to reduce the urban heat island effect (Matzarakis 2006; Zhong and Chen 2019; Clements and Georgiou 1998; Scott and Lemieux 2009; Cetin 2020a and b; Cetin 2019; Fletcher and Morakabati 2008; Hernandez and Ryan 2011; Fielding and Shortland 2011; De Freitas 2003; Hejazizadeh et al. 2019; Zeren Cetin and Sevik 2020; Zeren Cetin et al. 2020).

The study area changed from county status to province status in 1996, and this administrative change led to significant demographic, industrial, and agricultural developments. It also influenced the LULC, especially the increasing urbanization. Forest areas, one of LULC's classes, were not an exception in this process. The forests of the Mountains, which is a very important area not only for Turkey but also for the world in terms of hosting plant species belonging to 3 phytogeographic regions, have been turning into impervious surfaces due to increasing transhumance activities.

In line with all these developments, it is of great importance to investigate the effects of changes in LST, NDVI, and NDBI values in the central district of Bartin. Therefore, in this study, first of all, the effects of changes in LULC, LST, NDVI, and NDBI values between 1990 and 2021 in the central district of Bartin were analyzed and the change in the UHI effect was determined.

Materials and methods

Bartın is in the Western Black Sea Region of Turkey's Black Sea Region. It is surrounded with the Black Sea in the north. Most of the province, which is rich in forests, is located within the borders of Kuree Mountains National Park. Bartın Stream is the only river on which transportation is carried out in Turkey. It is located between 41° 53′ North latitude and 32° 45′ East longitude of the western black sea region. It is surrounded by the Black Sea with its 59 km coastline to the north, Kastamonu to the east, Karabük to the east and south, and Zonguldak to the west. Its area is 2143 km^2. The altitude of the city center is 25 m. It has 6 meteorological stations that get data for evaluations shown in Fig. 1.

In the study, the Landsat 5 Thematic Mapper (TM) and Landsat 8- Operational Land Imager (OLI) satellite images of 1990 and 2021 were used (Table 1).

Both data were acquired from US Geological Survey Explorer (USGS, 2021). The data were inbuilt georeferenced to UTM zone 37 North projection with WGS-84 datum. Before the analysis, radiometric corrections and image enhancement procedures were executed with ArcGIS 10.8 software.

LULC maps were classified using the supervised classification method. The supervised classification was processed by ArcGIS 10.8. Bands 1–5 and 7 were used for preparing LULC maps with Landsat 5–TM images, but the 6 was excluded because it was a thermal band. The bands 1–7 were considered for Landsat 8-OLI images. All the bands were compounded in ArcGIS 10.8 software using the image analyst tool. Landsat 8 imagery with a spatial resolution of 30 m were pan-sharpened using the ESRI method with the 15 m panchromatic bands for better LULC classification. More than 200 training samples were collected randomly using the training sample manager tool.

NDVI describes the vegetation proportion by measuring the difference in the near-infrared portion of the electromagnetic spectrum and red portion of the spectrum. Healthy and lush vegetation absorbs visible light and reflects most of the near-infrared light. On the contrary, unhealthy vegetation condition reflects more visible light and less near-infrared light. NDVI has values ranging from + 1 to − 1 (+ 1 for the healthy vegetation and − 1 for areas with no vegetation). NDVI was calculated in ArcGIS 10.8 by using the following equation

$$NDVI = \frac{NIR - R}{NIR + R}$$

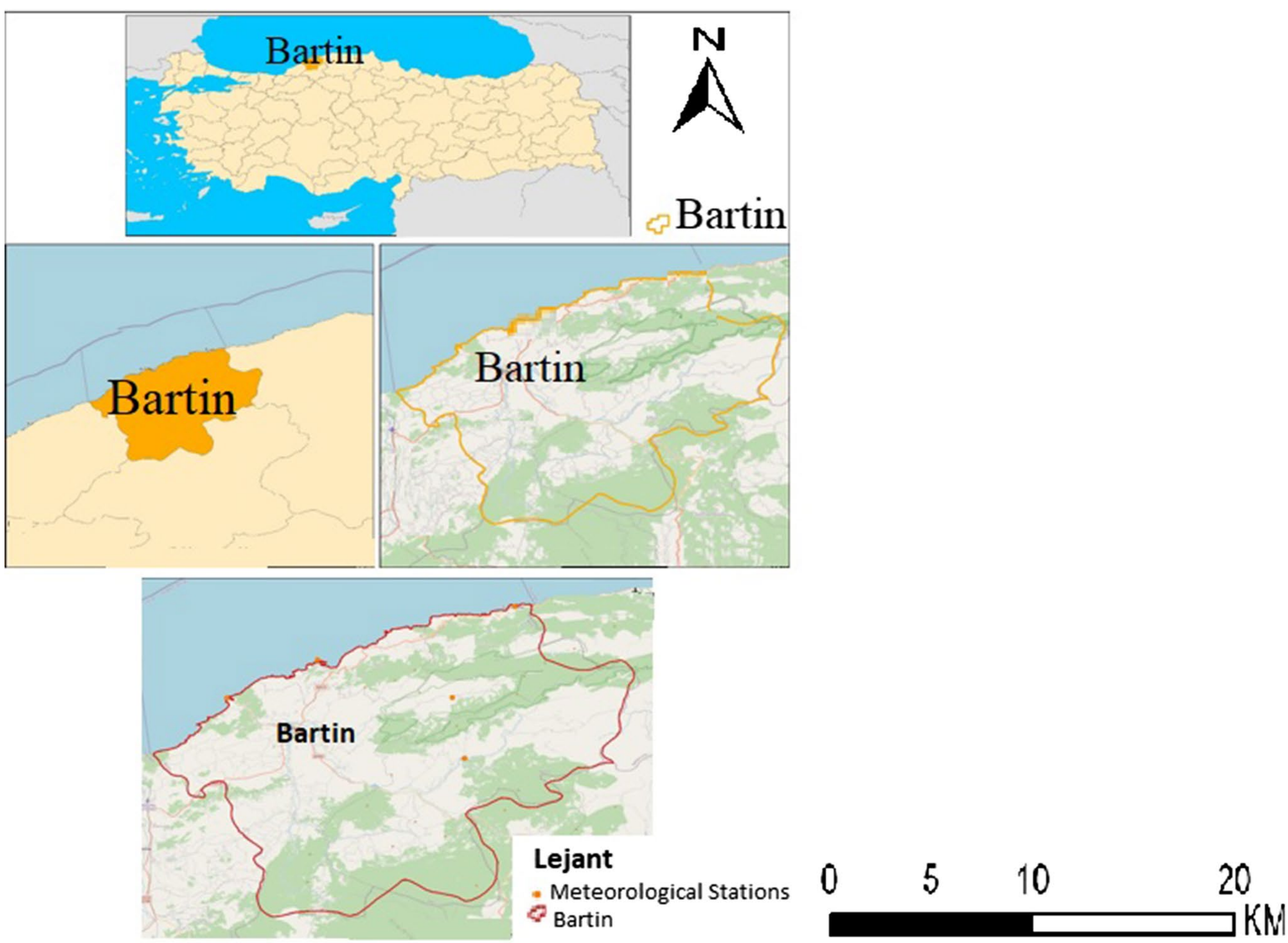

Fig. 1 Location of study area with spatial distribution of meteorological stations and elevations in the study area

Table 1 The characteristics of the images

Acquired date	Acquired time	Satellite	Sensor	Cloud cover	Sun elevation (degree)	Sun azimuth (degree)
15.07.1990	06:25:25	Landsat 5	TM	1.98	61.45	124.73
15.07.2021	07:35:33	Landsat 8	OLI	2.01	63.25	123.12

NDBI ranges from − 1 to + 1 and distinguishes built-up territory from other land uses/land surfaces. Built-up lands have higher reflectance in MIR than in NIR. Therefore, the high NDBI values show the built-up areas. NDBI was calculated in ArcGIS 10.8 software using MIR band 6 and NIR band 5 of the Landsat-8 data and MIR band 5 and NIR band 4 of Landsat-5 data as shown in the equation below.

$$NDBI = \frac{MIR - NIR}{MIR + NIR}$$

LST refers to the temperature measured by the remote sensor. As the LST provides essential data about a climate system, the procedure has been addressed and clarified in many studies.

In this study, the Landsat 5 images for 1990 and Landsat 8 images for 2021 were used to perform the LST analysis described below: Step 1: Conversion to top of atmosphere (TOA) radiance: we applied the formula in Eq. 3 to convert thermal infra-red numbers (DN) to TOA values for Landsat-8 data.

$$TOA = ML * band\ 10 + F - Oj$$

ML = the band-specific multiplicative rescaling factor = 0.0003342; F = re-scaling factor = 0.1; Oj = correction value = 0.29.

The formula in the equation below was applied to the Landsat-5 TM data.

$$TOA = \left(\frac{LMAX\lambda - LMIN\lambda}{QCALMAX - QCALMIN}\right) * (band6 - QCALMIN) + LMIN\lambda$$

$LMAX\lambda$ = is the radiance that is scaled to $QCAL$MAX, $LMIN\lambda$ is the radiance that is scaled to $QCAL$MIN, $QCAL$MIN is the lowest calibrated value, and LMIN is the highest calibrated value LMAX λ

Step 2: Brightness temperature: radiance values were converted to brightness temperature using the equation below

$$T = \frac{K2}{\left(\frac{K1}{TOA}\right) + 1} - 273.15$$

T = brightness temperature (0 C); K1 = calibration constant 1 (Table 2); K2 = calibration constant 2 (Table 2)

Step 3: Calculation of LST applying the equation

$$LST = \frac{T}{\left[1 + \left\{\left(\frac{\lambda * \mathrm{T}}{c}\right) * InE\right\}\right]}$$

Table 2 Thermal constant of Landsat TM and OLI thermal imageries

Sensor	Year	Band	K1	K2
Landsat 5	1990	Band 6	702.34	1380.45
Landsat 8	2021	Band 10	792.93	1523.23

T = brightness temperature (°C), λ = wavelength of emitted radiance = 10.8 for band, 10E = emissivity of land surface, C = 14,388mK

It is necessary to obtain the Land surface emissivity (E) to calculate the LST. It refers to the radiating and absorbing power of a surface in the long-wave radiation spectrum and generally differs by the land cover. The equation is shown below

$$E = 0.004 * Pv + 0.986$$

E = land surface emissivity; Pv = proportion of vegetation; 0.986 is the correction value

To determine the land surface emissivity (E) value, the vegetation proportion (Pv) parameter equation proposed is shown below

$$Pv = (((NDVI - NDVImin))/((NDVImax - NDVImin)))^2$$

Pv is vegetation proportion; NDVImin is the lowest value of NDVI; NDVImax is the highest value of NDVI

Statistical analysis

In the study, linear regression analysis was performed to reveal the relationship between LST and NDVI, LST and NDBI, and NDVI and NDBI, as in many other studies (Fielding and Shortland 2011; Zhong and Chen 2019; Clements and Georgiou 1998; De Freitas 2003; Fletcher and Morakabati 2008). Therefore, all pixels were converted to points. Then, the parameter values of these points were obtained from the LST, NDVI and NDBI maps and shown in graphics.

Results and discussion

The land use of Bartin central district was categorized into five: water surface, vegetation, bare lands, agricultural lands, and built-up. Figure 2 shows the spatial distribution of land use in Bartin in 1990 and 2021.

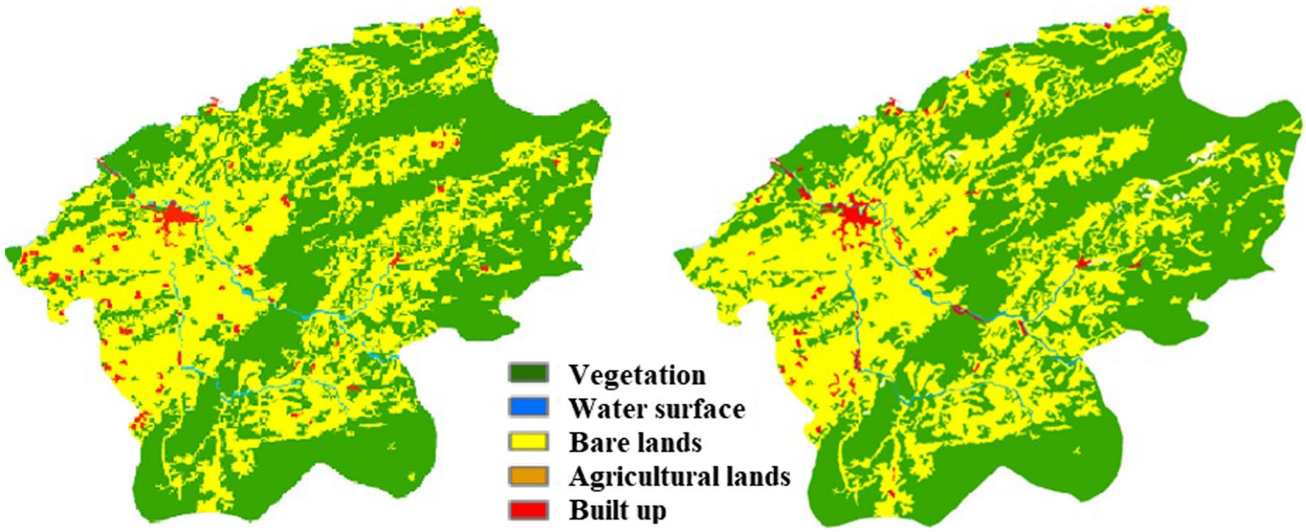

Fig. 2 Spatial distribution of LULC in 1990 and 2021

Table 3 below presents the LULC and change statics. The (−) minus sign indicates that it has decreased compared to the previous period, and the (+) plus sign indicates the opposite.

The analysis results showed that between 1990 and 2021, built-up areas increased significantly from 1674.98 to 5657.34 ha by 5.63%, but bare lands and vegetation decreased. Land use maps provide essential information about the spatial change in urban regions. In the 1990s, single or two-story buildings with gardens were mainly located very close to agricultural lands. However, after the 2000s, the rate of multi-story construction increased, and the city center was spatially separated from agricultural areas. As seen in Fig. 2, the built-up area has spatially expanded to the east of Bartin between 1990 and 2021. Although the number of agricultural lands in the city increased, it indirectly led to a decrease in vegetation cover. The primary reason for the reduction in vegetation is the destruction of green areas to open up new agricultural areas. Another reason was the increase in the upland settlement around densely covered vegetation.

Due to the high temperatures, especially in summer, a significant proportion of the urban population lives in upland settlements in the Mountains, where the weather is colder than the city center between May and October. There are many upland settlements in the vegetation of the Mountains in the south of Bartin. Therefore, the increasing population in such settlements has destroyed the rich and unique vegetation of the Mountains.

Figure 3 shows the LST maps of the study area in 1990 and 2021. As seen in the figure, the average temperature in the southern part of Bartin was 20–25 °C in the 1990s; it rose to 30–35 °C in this region in 2021. Similarly, there is a significant increase in urban settlements' LST values.

Table 4 shows a statistical overview of LST values. In general, there has been an increase in the maximum and average temperature values of the study area over the 30 years. The average temperature rose from 25.72 to 27.00 °C. Findings

Table 3 LULC and change statistics of Bartin

Land type	Year 1990		Year 2021		Change in the period of 1990 and 2021	
	Ha	%	Ha	%	Ha	%
Water surface	534.3	0.68	576.72	0.69	+ 42.42	+ 0.01
Built-up	1674.98	1.29	5657.34	6.92	+ 3982.36	+ 5.63
Vegetation	67,643.45	56.34	54,754.12	51.93	− 12889.33	− 4.41
Agricultural lands	12,435.23	14.34	11,534.43	15.23	− 900.8	+ 0.89
Bare lands	31,345.25	27.35	28,493.10	25.23	− 2852.15	− 2.12
total	11,3633.2	100	10,1015.7	100		

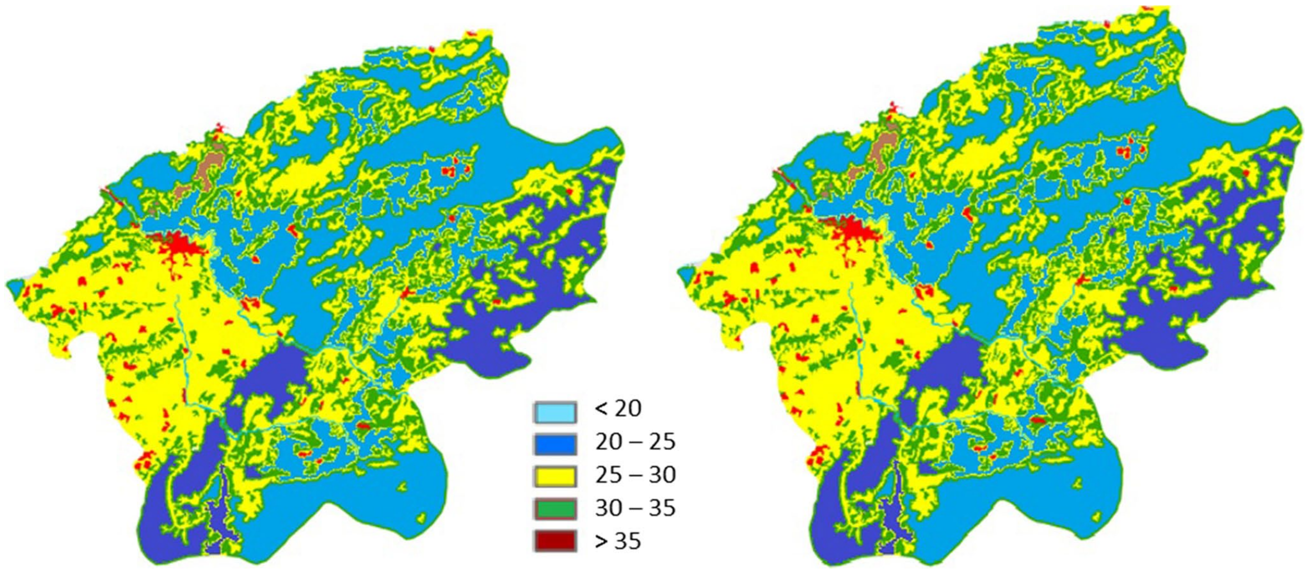

Fig. 3 LST maps for the years 1990 and 2021

Table 4 A statistical overview of the LST values for Bartin City

	Min	Max	Average	Standard deviation
1990	18.29	43.48	40.03	0.40
2021	18.80	48.34	42.97	0.42

from this study show similar results with other studies (Scott and Lemieux 2009; Lise and Tol 2002; Lin and Matzarakis 2008; Zhong and Chen 2019; De Freitas 2003).

NDVI

The normalized difference vegetation index (NDVI) identifies and monitors vegetation. Several studies also investigate the effects of NDVI on the urban heat island (UHI) (Zhong and Chen 2019; De Freitas 2003; Clements and Georgiou 1998; Scott and Lemieux 2009; Fletcher and Morakabati 2008). The values between 0.1 and 0.75 generally indicate vegetation cover.

NDVI maps are shown in Fig. 4. The lowest values showed bare lands and buildings. However, as emphasized by Scott and McBoyle 2001, De Freitas 2003, De Freitas 2005, Berrittella et al. 2006, Lin and Matzarakis 2008, and Scott and Lemieux 2009, it is tough to distinguish bare lands and built-up areas by using NDVI values. The NDVI value of above 0.1 corresponds to the vegetation cover. Similarly, in this study, the values of NDVI were categorized as low (0.1–0.2), medium (0.2–0.3), high (0.3–0.4), and very high (0.4–…).

As shown in Fig. 4, the most drastic changes mainly occurred in three regions. The first region was the Bartin city center, where NDVI values decreased significantly. The changes in the agricultural lands in the north and the highland settlements in the south were also evident. Especially the upland settlements in the Mountains, which have rich vegetation cover, led to a decline in vegetation across the study area.

Table 5 shows the NDVI density classes in 1990 and 2021, and Table 6 gives a statistical summary of NDVI values. As shown in Table 5, there were decreases in low, medium, and high-density classes, but a very high increase occurred in built-up areas.

NDBI has been applied in many studies as it helps distinguish the built-up areas from other land uses and land cover. The NDBI density maps are given in Fig. 5 and statistical data are shown in Table 7.

The negative NDBI values correspond to vegetation, small positive values to bare lands, and significant positive values to built-up areas. However, the NDBI values indicating residential differed in some studies (Zhong and Chen 2019; Lin and Matzarakis 2008; Lise and Tol 2002; Scott and Lemieux 2009; De Freitas 2003). NDBI value

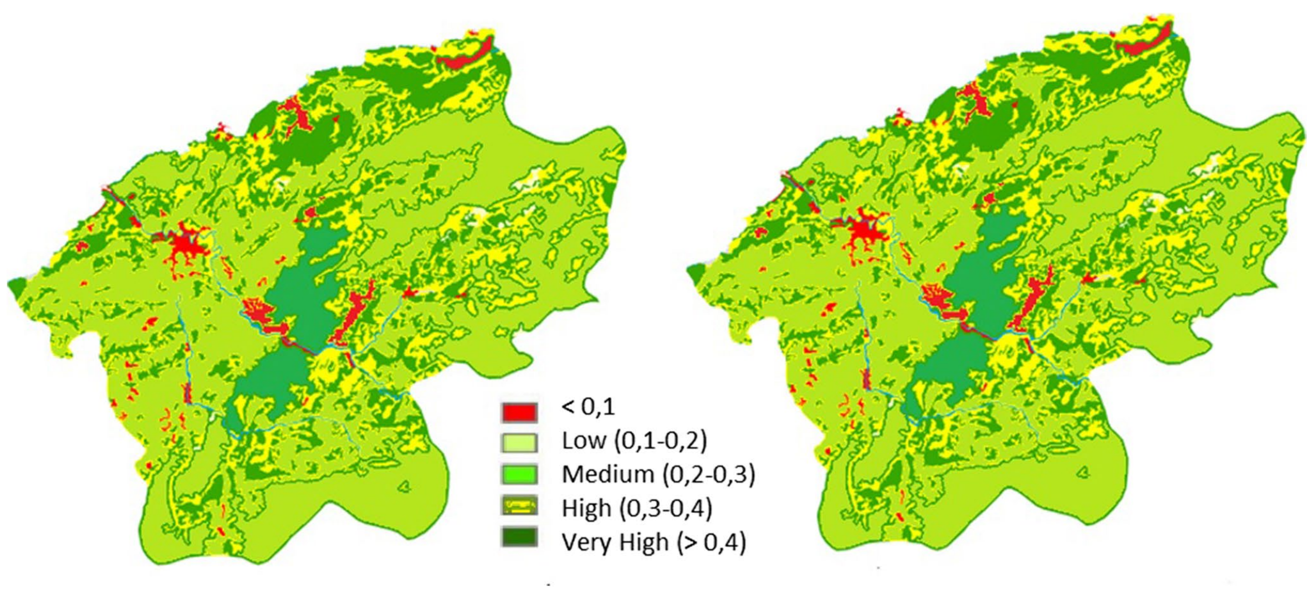

Fig. 4 NDVI density map of 1990 and 2021

Table 5 The NDVI density classes between 1990 and 2021

	Year 1990		Year 2021		From the year 1990 to year 2021	
	Ha	%	Ha	%	Ha	%
< 0.1	1895.37	2.31	3895.23	6.65	+ 1999.86	+ 4.34
Low (0.1–0.2)	21,3476.23	26.47	19,867.24	24.49	− 193609	− 1.98
Medium (0.2–0.3)	21,345.35	24.36	19,856.29	23.47	− 1489.06	− 0.89
High (0.3–0.4)	29,765.12	33.44	30,345.23	32.12	+ 580.11	− 1.32
Very high (> 0.4)	17,345.23	13.42	17,312.96	13.27	− 32.27	− 0.15
total	17,345.23	100	17,312.96	100		

representing the residential areas was 0.07 for the year 1990 and, 0.16 for the year 2021.

The correlations between LST and NDVI, LST and NDBI, and NDBI and NDVI are shown in Fig. 6, and the value matrix is presented in Table 8 below. As seen in the figure above, there is a negative relationship between NDVI and LST values between 1990 and 2021.

Table 6 The statistical summary of NDVI values for Bartin City

	Min	Max	Average	Standard deviation
1990	− 0.36	0.58	0.07	0.11
2021	− 0.23	0.72	1.13	0.16

Conclusion

In this study, LST values of 1990 and 2021 were analyzed in order to determine the change in the urban heat effect in Bartin over 30 years. The study results showed that the average temperature of Bartin city was 25 °C in 1990, but it rose to 27 °C in 30 years. In order to determine the spatial changes in the LST values, LULCC maps for 1990 and 2021 were formed.

As a result of the LULCC maps, it was found that the land use of Bartin district had changed rapidly from 1990 to 2021 due to urbanization and agricultural and industrial practices. It mainly stemmed from the administrative change in Bartin, which used to be a district of Adana until 1996. It was governed as a province after 1996. The governance shift has led to the construction of multi-story

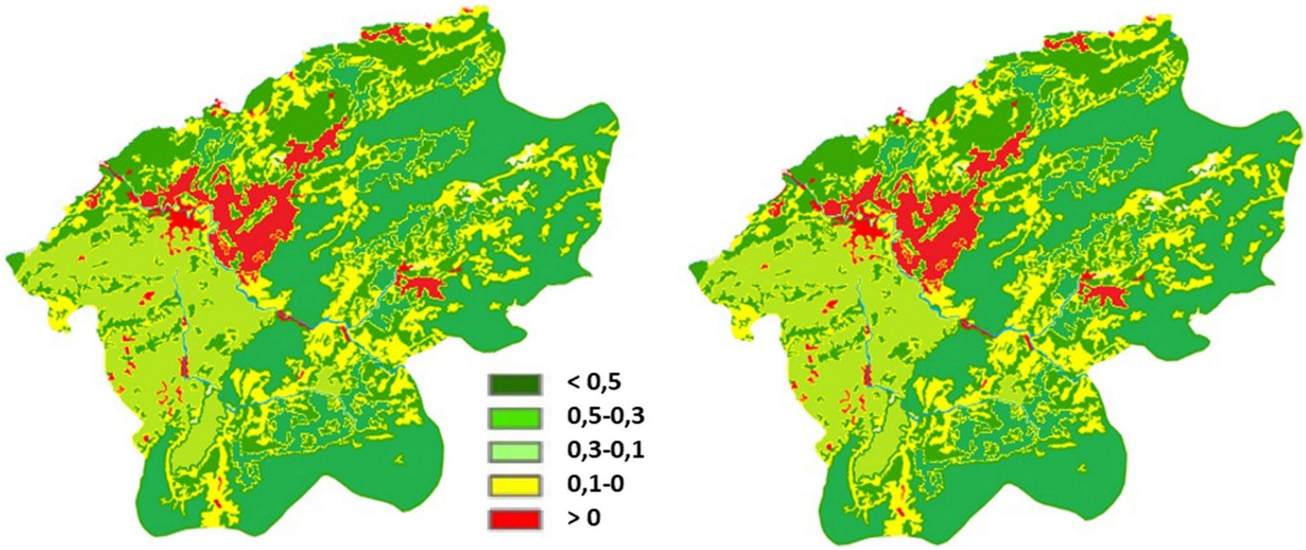

Fig. 5 NDBI density map in 1990 and 2021

Table 7 A statistical summary of NDBI values for Bartin City

	Min	Max	Average	Standard deviation
1990	− 0.32	0.61	0.01	0.15
2021	− 0.48	0.42	− 0.27	0.18

buildings in the city center, where there used to be single or two-story structures closely located near agricultural lands. The residential areas have been completely separated from the agricultural lands and expanded toward the east of our study area, which resulted in a 92% increase in impervious surfaces. Besides, the increasing population in upland areas has destroyed the forests in the Mountains, which have rich flora.

When considering the LULCC and the increasing LST in Bartin, it was found that the highest temperature increases experienced in impermeable surfaces such as urban areas and bare lands. It showed that LST was correlated with LULC. A description of the correlations between LST and ground surface characteristics allows us to take effective measures to reduce the UHI effect. Therefore, it was also aimed to determine the factors related to the LST.

The study results showed a negative relationship between LST and NDVI, implying that the land surface temperature was lower in surfaces with dense vegetation. The significant negative correlation between NDVI and LST indicates that healthy vegetation lowers the surface temperature.

A strong positive correlation between LST and NDBI was determined, which justifies higher temperature values in dense urban areas and bare lands. Also strong negative correlation between NDBI and NDVI was determined in this study.

The attempts to increase the vegetation cover would be simple but effective measures to limit the UHI effect and prevent the harmful consequences of climate change. Hence, in order to reduce the negative effects of UHI in the central district of Bartin, urban green areas should be increased, green roof systems should be encouraged, and the green belt approach should be adopted throughout the city.

Mountains are one of the rare regions in the world rich in plant species and diversity in addition to the relict and endemic species such as Pinus brutia and Fagus orientalis, which have significantly different ecological demands. Therefore, forest destruction due to the increasing upland settlements in the Mountains should be prevented. The wildlife protection area status is not legally sufficient to prevent excessive construction in the region. Thus, a protected area status that would not allow construction or limit construction in such areas should be declared to protect the area.

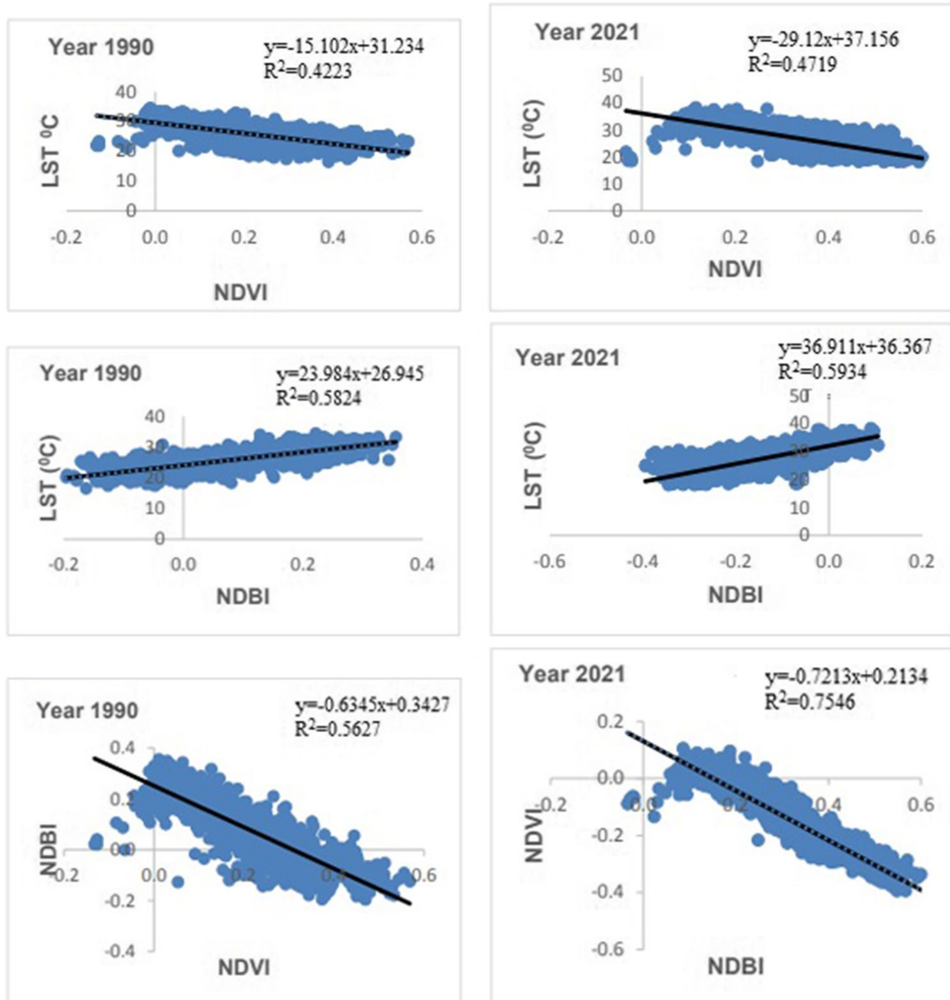

Fig. 6 Relationship of LST vs. NDVI, LST vs NDBI and NDVI vs. NDBI

Table 8 Correlation matrix of the parameters

	The year 1990			The year 2021		
	LST	NDVI	NDBI	LST	NDVI	NDBI
LST	1	− 0.3225	0.3523	1	− 0.33.45	0.3843
NDVI	− 0.4235	1	− 0.4623	− 0.4823	1	− 0.4923
NDBI	0.7223	− 0.8323	1	0.7012	− 0.7123	1

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Author contribution IZC: materials, data collection and/or processing; literature search; TV: literature search; design, resources, HBO: design, resources, design, resources; HS: design, resources, design, resources; IZC: writing; materials, analysis and/or interpretation.

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Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable

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References

Adiguzel F, Cetin M, Kaya E, Simsek M, Gungor S, Bozdogan Sert E (2020) Defining suitable areas for bioclimatic comfort for landscape planning and landscape management in Hatay. Turkey. Theor Appl Climatol 139(3):1493–1503. https://doi.org/10.1007/s00704-019-03065-7

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):519. https://doi.org/10.1007/s10661-022-10172-y

Adiguzel F, Bozdogan Sert E, Dinc Y, Cetin M, Gungor S, Yuka P, Sertkaya Dogan O, Kaya E, Karakaya K, Vural E (2022) Determining the relationships between climatic elements and thermal comfort and tourism activities using the tourism climate index for urban planning: a case study of Izmir Province. Theor Appl Climatol 147(3):1105–1120. https://doi.org/10.1007/s00704-021-03874-9

Amelung B, Viner D (2006) Mediterranean tourism: exploring the future with the tourism climate index. J Sustai Tour 14(4):349–366. (https://doi.org/10.2167/jost549.0)

Amelung B, Nicholls S, Viner D (2007) Implications of global climate change for tourism flows and seasonality. J Travel Res 45:285–296. (https://journals.sagepub.com/doi/abs/10.1177/0047287506295937)

Amiranashvili A, Matzarakis A, Kartvelishvili L (2008) Tourism climate index in Tbilisi. Transactions of the Georgian Institute of Hydrometeorology 115:27–30. (http://dspace.gela.org.ge/bitstream/123456789/744/1/TCI-Tb-Konf08En.pdf)

Amiranashvili A, Matzarakis A, Kartvelishvili L (2010) Tourism Climate Index in Batumi, Modern Problems of Using of Health Resort Resources, Collection of Scientific Works of International Conference, Sairme, Georgia, June 10-13, 2010, ISBN 978-9941-0-2529-7, Tbilisi, 2010, pp. 116-121. http://dspace.gela.org.ge/bitstream/123456789/660/1/TCI-Batumi-Konf-2010-En.pdf

Amiranashvili AG, Japaridze ND, Kartvelishvili LG, Khazaradze KR, Kurdashvili LR (2018) Tourism Climate Index in Kutaisi (Georgia), International Scientific Conference, ISSN 1512-1976, v. 6, Kutaisi, Georgia. http://www.openlibrary.ge/handle/123456789/7330

Ataei H, Hasheminasab F (2012) Comparative assessment of human bioclimatic in Isfahan City using Terjunde, TCI, PET. PMV. Urban Reg Stud Res 4(14):17–19

Auliciems A, Kalma JD (1979) A climatic classification of human thermal stress in Australia. J Appl Meteorol 18:616–626. https://journals.ametsoc.org/view/journals/apme/18/5/1520-0450_1979_018_0616_accoht_2_0_co_2.xml

Bakhtiari B, Bakhtiari A (2013) Determination of tourism climate index in Kerman province. Desert 18(2):113–126. (https://jdesert.ut.ac.ir/article_50003_e04a9ca8e1009d1a9602927aa991decb.pdf)

Berrittella M, Bigano A, Roson R, Richard SJT (2006) A general equilibrium analysis of climate change impacts on tourism. Tour Manage 27:913–924. (https://www.sciencedirect.com/science/article/abs/pii/S0261517705000518)

Bode S, Hapke J, Zisler S (2003) Need and options for a regenerative energy supply in holiday facilities. Tour Manag 24:257–266. (https://www.sciencedirect.com/science/article/abs/pii/S0261517702000675)

Bozdogan Sert E, Kaya E, Adiguzel F, Cetin M, Gungor S, Zeren Cetin I, Dinc Y (2021) Effect of the surface temperature of surface materials on thermal comfort: a case study of Iskenderun (Hatay, Turkey). Theor Appl Climatol 144(1):103–113. https://doi.org/10.1007/s00704-021-03524-0

Cetin M (2015) Evaluation of the sustainable tourism potential of a protected area for landscape planning: a case study of the ancient city of Pompeipolis in Kastamonu. Int J Sustain Dev & World Ecol 22(6):490–495. https://doi.org/10.1080/13504509.2015.1081651

Cetin M (2015) Determining the bioclimatic comfort in Kastamonu City. Environ Monit Assess 187(10):640. https://doi.org/10.1007/s10661-015-4861-3

Cetin M (2015) Using GIS analysis to assess urban green space in terms of accessibility: case study in Kutahya. Int J Sustain Dev World Ecol 22(5):420–424. https://doi.org/10.1080/13504509.2015.1061066

Cetin M (2015) Consideration of permeable pavement in landscape architecture. J Environ Protection Ecol 16(1):385–392

Cetin M (2016) Determination of bioclimatic comfort areas in landscape planning: A case study of Cide Coastline. Turkish J Agricult-Food Sci Technol 4(9):800–804

Cetin M (2016) A Change in the Amount of CO2 at the Center of the Examination Halls: Case Study of Turkey. Studies on Ethno-Medicine 10(2):146–155

Cetin M (2016) Peyzaj planlamada biyoklimatik konfor alanların belirlenmesi: Cide kıyı şeridi örneği. Türk Tarım-Gıda Bilim ve Teknoloji Dergisi 4(9):800–804

Cetin M (2019) The effect of urban planning on urban formations determining bioclimatic comfort area's effect using satellitia imagines on air quality: a case study of Bursa city. Air Qual Atmos Health 12(10):1237–1249. https://doi.org/10.1007/s11869-019-00742-4

Cetin M (2020) The changing of important factors in the landscape planning occur due to global climate change in temperature, Rain and climate types: a case study of Mersin City. Turkish J Agricult-Food Sci Technol 8(12):2695–2701. https://doi.org/10.24925/turjaf.v8i12.2695-2701.3891

Cetin M (2020) Climate comfort depending on different altitudes and land use in the urban areas in Kahramanmaras City. Air Qual Atmos Health 13(8):991–999. https://doi.org/10.1007/s11869-020-00858-y

Cetin M, Sevik H (2016) Evaluating the recreation potential of Ilgaz mountain national park in Turkey. Environ Monit Assess 188(1):1–10

Cetin M, Topay M, Kaya L, Yilmaz B (2010) Biyoiklimsel konforun peyzaj planlama sürecindeki etkinliği: Kütahya örneği. Turkish J Forestry 11(1):83–95

Cetin M, Topay M, Kaya LG, Yılmaz B (2010) Efficiency of bioclimatic comfort in landscape planning process: case of Kutahya. Süleyman Demirel Üniversitesi Orman Fakültesi Dergisi Seri A 11(1):83–95

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(9):1103–1112. https://doi.org/10.1007/s11869-019-00727-3
Cetin M (2018) The finding of suitable biocomfort area mapping for Karabük City Center. In International Agricultural, Biological & Life Science Conference (pp. 295–299). Edirne
Cetin M, Sevik H (2016a) Assessing potential areas of ecotourism through a case study in Ilgaz Mountain National Park, InTech, Chapter 5, Eds: Leszek Butowski, 190
Cetin M, Zeren I (2016b) Bioclimatic mapping of rural areas in Bozkurt, Turkey, for recreation. In VII International Scientific Agriculture Symposium, "Agrosym 2016b", 6–9 October 2016b, Jahorina, Bosnia and Herzegovina. Proceedings (pp. 2924–2931). University of East Sarajevo, Faculty of Agriculture
Cetin M, Zeren I (2016a) Evaluation of the value of biocomfort for Kastamonu-Inebolu. In International conference GREDIT (pp. 4–35)
Cetin M, Yildirim E, Canturk U, Sevik H (2018) Investigation of bioclimatic comfort area of Elazig city centre. Recent Res Sci Landsc Manag 324–333
Clements M, Georgiou A (1998) The Impact of Political Instability on A Fragile Tourism Product. Tour Manage 19(3):283–288. (https://www.sciencedirect.com/science/article/abs/pii/S0261517798000120)
De Freitas CR (2003) Tourism climatology: evaluating environmental information for decision making and business planning in the recreation and tourism sector. Int J Biometeorol 48(1):45–54. (https://link.springer.com/article/10.1007/s00484-003-0177-z)
De Freitas CR (2005) The climate-tourism relationship and its relevance to climate change impact assessment, in: Hall, M.C. and Higham, J. (eds.) Tourism, Recreation and Climate Change, Channel View Publications, Clevedon, 29–43. https://books.google.com.tr/books?hl=en&lr=&id=7nNEFApnJAcC&oi=fnd&pg=PA29&dq=The+Climate-Tourism+Relationship+and+its+Relevance+to+Climate+Change+Impact+Assessment,+in:+Hall,+M.C.+and+Higham&ots=MhY3tQ4FNq&sig=A9SeB_suGGmZ9jIEIuWnrazWPw4&redir_esc=y#v=onepage&q&f=false
Farajzadeh M, AhmadAbadi A (2010) Assessment and zoning of tourism climate of Iran using tourism climate index (TCI). Physical Geography Research Quarterly 71:42–31. https://jphgr.ut.ac.ir/m/article_21546.html?lang=en
Fielding D, Shortland A (2011) How do tourists react to political violence? An empirical analaysis of tourism In Egypt. Defence Peace Econ 22(2):217–243. (https://www.tandfonline.com/doi/abs/10.1080/10242694.2011.542340)
Fletcher J, Morakabati Y (2008) Tourism activity, terrorism and political instability within the Commonwealth: the cases of Fiji and Kenya. Int J Tourism Res 10:537–556. (https://onlinelibrary.wiley.com/doi/abs/10.1002/jtr.699)
Grassl H (1976) The dependence of the measured cool skin of the ocean on wind stress and total heat flux. Boundary-Layer Meteorol 10(4):465–474
Grassl H (1981) The climate at maximum entropy production by meridional atmospheric and oceanic heat fluxes. Quarterly J Royal Meteorol Soc 107(451):153–166
Grassl H (2011) Climate change challenges. Surveys in Geophysics 32(4–5):319
Grassl H (1979) Possible changes of planetary albedo due to aerosol particles. In Developments in Atmospheric Science (Vol. 10, pp. 229–241). Elsevier
Grassl, H. (1989). Extraction of surface temperature from satellite data. In Applications of Remote Sensing to Agrometeorology (pp. 199–220). Springer, Dordrecht
Grassl, H. (2006). Climate change, new weather extremes and climate policy. In Earth System Science in the Anthropocene (pp. 41–50). Springer, Berlin, Heidelberg
Gungor S, Cetin M, Adiguzel F (2021) Calculation of comfortable thermal conditions for Mersin urban city planning in Turkey. Air Qual Atmos Health 14(4):515–522. https://doi.org/10.1007/s11869-020-00955-y
Hamilton JM, Tol RSJ (2004) The impacts of climate change on tourism and recreation. Working paper FNU-52, Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg
Harlfinger O (1991) Holiday bioclimatology: a study of Palma de Majorca. Spain GeoJournal 25(4):377–381
Hejazizadeh Z, Karbalaee A, Hosseini SA, Tabatabaei SA (2019) Comparison of the holiday climate index (HCI) and the tourism climate index (TCI) in desert regions and Makran coasts of Iran. Arab J Geosci 12:803. (https://link.springer.com/article/10.1007/s12517-019-4997-5)
Hernandez AB, Ryan G (2011) Coping with climate change in the tourism industry: a review and agenda for future research. Tourism and Hospitality Management 17(1):79–90. (https://hrcak.srce.hr/69285)
Kaya LG, Cetin M, Doygun H (2009) A holistic approach in analyzing the landscape potential: Porsuk Dam Lake and its environs. Turkey Fresen Environ Bull 18(8):1525–1533
Kilicoglu C, Cetin M, Aricak B, Sevik H (2020) Site selection by using the multi-criteria technique—a case study of Bafra. Turkey. Environ Monit Assess 192(9):608. https://doi.org/10.1007/s10661-020-08562-1
Kilicoglu C, Cetin M, Aricak B, Sevik H (2021) Integrating multicriteria decision-making analysis for a GIS-based settlement area in the district of Atakum, Samsun. Turkey Theor Appl Climatol 143(1):379–388. https://doi.org/10.1007/s00704-020-03439-2
Kovács A, Unger J (2014a) Modification of the Tourism Climatic Index to Central European climatic conditions–examples időjárás/quarterly. J Hungarian Meteorol Service 118(2):147–166
Kovács A, Unger J (2014) Analysis of tourism climatic conditions in Hungary considering the subjective thermal sensation characteristics of the South-Hungarian residents. Acta Climatologica et Chorologica 47:77–84
Lin T-P, Matzarakis A (2008) Tourism climate and thermal comfort in Sun Moon Lake. Taiwan. Int J Biometeorol 52:281–290. (https://link.springer.com/article/10.1007/s00484-007-0122-7)
Lise W, Tol RSJ (2002) Impact of climate on tourist demand. Clim Change 55(4):429–449. (https://link.springer.com/article/10.1023/A:1020728021446)
Liu Shaojun J, Zhang JH, Wu SA, Zhang MJ, Che XF (2014) Possible impact of global climate changes on climate comfort degree and tourist flow in Hainan island. J Trop Meteorol 30:977–982
Maddison D (2001) In search of warmer climates? The impact of climate change on flows of British tourists. Clim Change 49:193–2208. (https://link.springer.com/article/10.1023/A:1010742511380)
Matzarakis A (2002) Examples of climate and tourism research for tourism demands, Proceedings of the 15th Conference on Biometeorology and Aerobiology joint with the International Congress on Biometeorology, Kansas City 2002, 391–392
Matzarakis A (2006) Weather and climate related information for tourism. Tourism Hospitality Planning Dev 3(99):115 (https://www.tandfonline.com/doi/abs/10.1080/14790530600938279)
Matzarakis A (2007) Climate change and tourism: Assessment and coping strategies. (Eds: Amelung, B. and Blazejczyk, K. and Matzarakis, A.), Climate, Thermal Comfort and Tourism, 139–154
Mieczkowski Z (1985) The tourism climatic index: a method of evaluating world climates for tourism. Canadian Geographer 29(3):220–233. (https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1541-0064.1985.tb00365.x)
Monteiro MV, Doick KJ, Handley P, Peace A (2016) The impact of greenspace size on the extent of local nocturnal air temperature cooling in London. Urban Forestry Urban Greening 16:160–169

Moreno A, Amelung B, Santamarta L (2008) Linking beach recreation to weather conditions: a case study in Zandvoort. Netherlands Tour Mar Environ 5(2–1):111–119. (https://www.ingentaconnect.com/content/cog/tme/2008/00000005/F0020002/art00004)

Scott D, McBoyle G, Schwartzentruber M (2004) Climate change and the distribution of climatic resources for tourism in North America. Clim Res 27(2):105–117. (https://www.int-res.com/abstracts/cr/v27/n2/p105-117)

Scott D, Rutty M, Amelung B, Tang M (2016) An Inter-Comparison of the Holiday Climate Index (HCI) and the Tourism Climate Index (TCI) in Europe 2016. Atmosphere 7(6):80. (https://www.mdpi.com/2073-4433/7/6/80)

Scott D, Lemieux C (2009) Weather and climate information for tourism. Commissioned White Paper for the World Climate Conference 3 World Meteorological Organization: Geneva and United Nations World Tourism Organization: Madrid

Scott D, McBoyle G (2001) Using a 'tourism climate index' to examine the implications of climate change for climate as a natural resource for tourism. A. Matzarakis and C. de Freitas (Eds.). Proceedings of the First International Workshop on Climate, Tourism and Recreation. 5-10 October 2001: International Society of Biometeorology, Commission on Climate, Tourism and Recreation, Greece

Varol T, Canturk U, Cetin M, Ozel HB, Sevik H (2021) Impacts of climate change scenarios on European ash tree (Fraxinus excelsior L) in Turkey. Forest Ecol Manag 491:119199

Varol T, Cetin M, Ozel HB, Sevik H, Zeren Cetin I (2022) The effects of climate change scenarios on Carpinus betulus and Carpinus orientalis in Europe. Water Air Soil Pollut 233(2):45. https://doi.org/10.1007/s11270-022-05516-w

Wang YF, Yin XM, Cheng XP (2016) Analysis of the tourism climate comfortable index in Panzhuhua region based on Fuzzy analysis hierarchy process. Environ Eng 34(1083–1086):1107

Zeren Cetin I, Sevik H (2020) Investigation of the relationship between bioclimatic comfort and land use by using GIS and RS techniques in Trabzon. Environ Monit Assess 192:71. https://doi.org/10.1007/s10661-019-8029-4

Zeren Cetin I, Ozel HB, Varol T (2020) Integrating of settlement area in urban and forest area of Bartin with climatic conditions decision for managements. Air Qual Atmos Health 13:1013–1022. https://doi.org/10.1007/s11869-020-00871-1

Zhong L, Chen D (2019) Progress and prospects of tourism climate research in China. Atmosphere 10:701. (https://www.mdpi.com/2073-4433/10/11/701)