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Spatial Strategies in Reducing Anthropogenic Urban Heat Island Impacts: The Case of Bolu City Center

Antropojen Kaynaklı Kentsel Isı Adası Etkisini Azaltmada Mekânsal Stratejiler; Bolu Kent Merkezi Örneği

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ÖZ

Dünyada ve Türkiye'de kentlerin büyümesi ve kentleşme hareketleri ile mikro iklim yapısında değişimler yaşanmakta ve kentler ısınmaktadır. Özellikle antropojenik aktivitelerin yoğunlaşmasıyla kentsel alanlarda, iklim değişikliğinin etkilerinden biri olan "kentsel ısı adası" (KIA) etkisi ortaya çıkmaktadır. KIA etkisi; sıcaklık, nem, güneş ışınımı, rüzgar gibi meteorolojik faktörlere ek olarak morfo-tipolojik faktörleri oluşturan; bina yükseklikleri, bina tipolojisi, coğrafi konum, kent geometrisi, yüzey ve döşeme malzemesi seçimi vb. antropojen etkiler sonucunda meydana gelmektedir. Bu çalışmada, Türkiye'de yer alan Bolu kentinde kontrolsüz kentsel gelişme sebebiyle meydana gelen KIA etkisi tanımlanarak mevcut durum ortaya koyulmakta ve mekânsal öneriler geliştirilmektedir. Araştırma yöntemi olarak öncelikle literatür değerlendirmesi yapılmış ve KIA'yı etkileyen faktörler irdelenmiştir. Literatürden çıkarılan ana başlıklar çerçevesinde CBS (GIS) kullanılarak kentteki mevcut durum ve KIA etkisi tartışılmaktadır. Son olarak, KIA etkisini azaltmaya yönelik mekansal stratejiler, kentsel tasarım önerisi olarak şematik çerçevede verilmekte ve kentin gelecek yıllardaki gelişim eğilimini yönlendirecek bir yol haritası oluşturmaktadır. Ayrıca, bu çalışma Bolu kent merkezi planlanma ve tasarımında akademi, meslek odaları, yerel yönetimler ve yerel halkın katılımıyla bütüncül, çevreye duyarlı stratejiler üretilmesine ve yeşil altyapı önerileriyle kentteki KIA etkisinin azaltılmasına rehberlik etmektedir.

Anahtar Kelimeler: Kentsel Isı Adası (KIA), İklim Değişikliği, Bolu, Mekansal Strateji, Kentsel Tasarım

ABSTRACT

The growth and urbanization of cities in the world and in Turkey have resulted in changes in the micro-climate structure, and cities are heating up. The "urban heat island" (UHI) effect, which is one of the effects of climate change in urban areas, is emerging especially with the concentration of anthropogenic activities. UHI effect, in addition to meteorological factors such as temperature, humidity, solar radiation, wind, morphological factors like building heights, building typology, geographic location, urban geometry, surface material selection, etc. is caused by anthropogenic effects. In this study, UHI effect which is caused by uncontrolled urban development in Bolu/ Turkey is identified and spatial strategies are developed. As a research method, the literature assessment was first taken and the factors affecting the UHI were investigated. Finally, the spatial strategies for reducing the UHI impact are given in the conceptual framework as a proposal for urban design and a roadmap that will guide the city's development trend in the coming years. In addition, this study guides the development of holistic, environmental-conscious strategies and the reduction of the UHI impact in the Bolu city center with green infrastructure proposals with academic, non-governmental organizations (NGOs), local governments and the participation of local people.

Keywords: Urban Heat Island (UHI), Climate Change, Bolu, Spatial Strategy, Urban Design

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INTRODUCTION:

Starting from the 20th century, contemporary urban areas have been constructed by focusing on technological progress while neglecting the limitations of the natural surroundings. In recent times, a shared global challenge has emerged, characterized by adverse environmental conditions resulting from haphazard urban expansion and rising temperatures. These conditions lead to heightened energy consumption, excessive utilization of resources, pollution, and increased waste generation (Zupancic et al., 2015; Bhargava et al., 2017; Wang & Banzhaf, 2018). Therefore, the process of urban development is causing changes in the micro-climate structure, which is warm up cities (Kuşçu Şimşek, 2013). The "Urban Heat Island" (UHI) effect, which is a climatic environmental problem in urban areas, is emerging especially with the concentration of anthropogenic activities (Shahmohamadi et al., 2011). UHI effect in cities can occur due to meteorological factors (temperature, humidity, solar radiation, wind, cloudy days, etc.) and anthropogenic factors like building heights, building typology, geographical location, urban geometry, surface material selection, surface water insulation, ventilation, etc. Especially, anthropogenic factors include many structural components that form micro-conditioning spatial solutions such as structural elements, quality of the structure, material, surface and color selection (Makvandi, 2016; Li et al., 2020).

Oke stated that (1981) the spread of anthropogenic heat is related to the increase in population and the energy consumption per capita. According to Oke (1981), urban areas are high carbon dioxide emission areas where many complex systems are seen, from burning fossil fuels for heating and cooling processes to industry and transport. Therefore, uncontrollable human activities in the urban environment are damaging the natural environment unless appropriate infrastructure is formed, which negatively affects the urban climate (Makvandi, 2016; Shahmohamadi et al., 2011). The holistic structure of the city shows a strong relationship between anthropogenic heat, structural factors and UHI. Construction plays an active role in the density and formation of the urban micro-climate. UHI effect is linked to the surface-atmosphere relationship like radiation in short and long branches, evaporation, heat storage, anthropogenic heat, conventional heat, etc. Especially, the albedo effect denotes the capacity of a surface or entity to reflect solar radiation back into the atmosphere. It serves as a quantitative gauge of surface reflectivity, conventionally represented as a percentage. Surfaces exhibiting high albedo properties exhibit a greater propensity to reflect incoming solar radiation, whereas surfaces characterized by low albedo values tend to absorb a larger portion of solar energy (Xu et al., 2015; Yao et al., 2022). In short, dark surfaces increase the UHI effect due to low reflective or low albedo effect. Therefore, structures and land covers with dark and dry surfaces are known to directly absorb sunlight, creating an environment for the warmer surface (Mobaraki, 2012). The albedo effect is between in asphalt, etc. 0.05-0.20, on light white surfaces is 0.50-0.90, brown emulsion (on roof materials) is 0.10-0.35, on grass surfaces 0.25-0.30, on shrub and trees 0.15 and 0.18 (Donner et al., 2015).

The UHI effect which has a dynamic structure will also change temporal and spatial (Alvarez, 2013). Today, it is known that most urban areas are 2°C hotter than the countryside/periphery, while in high-density residential areas there is a 5-6°C temperature difference (Kuşçu Şimşek, 2013; Bhargava et al., 2017; Li et al., 2020). Similarly, it is emphasized that the night temperature in high building density city center is 4°C in higher than in the open/green areas (Bayraktar & Truth, 2014). Therefore, the effect of morphological construction on the UHI density is considerable (International Bank for Reconstruction and Development, 2020). The variables in the morphology and UHI relationship can be listed as carbon density for heating, compact urban form, energy usage demand, external shell heat performance of the structure (Živković, 2020). Nichol (2005) observed that by the GIS method in Hong Kong, on the differences in neighborhood temperatures was less than 10 ˚C in windy areas and 8 ˚C in urban parking areas (Kuscu Simsek, 2013). Urban climate is affected by the physical structure of city (building layout geometry, material selection, building orientation, structure openness - closed etc.) and the UHI has changed the intensity of its influence (Pacheco-Torgal, 2015).

The main reason for the UHI formation is the heat imprisoned by city geometry, the characteristic of the city surface, and the fact that the surface of the structure is replaced by vegetation (Shishegar, 2013). More than ¼ of the urban areas are made up of streets stressing that the aspect ratio of the street width and height of the buildings creating the canyon effect has changed the city's microclimate due to urban ventilation and thermal comfort. Shishegar (2013) emphasized the importance of the urban shaded layer and the urban boundary layer as the main layers of air on urban areas. The urban shadow layer forms the top layer of rooftop in places between structures, and the structure changes with the drop of solar energy on the foreads and floors. The urban boundary layer affects the temperature of the air by factors such as heat transfer, polluted emissions, evaporation, sweating, etc. in relation to the average heights of buildings. According to Oke (1987), the structure creates radiation on the road and building surfaces that form the canyon creating an environment for eliminating long wave emissions from the internal change between canyon geometry and sky vision. At this point, the increase of green surfaces in urban patterns is one of the radiation reduction solutions in the surrounding area, which is made by shadow and evapotranspration effect (Mobaraki, 2012).

Oke (1981-1992) addresses increasing UHI impact and issues with urbanization in the following 5 headings (Table 1).

- Anthropogenic heat
- Air pollution
- Surface permeability
- Structure thermal quality
- Surface geometry

Table 1: Factors affecting the UHI (Mobaraki, 2012; Shahmohamadi et al., 2011; Santamouris, 2014)

Anthropogenic heat	**Air pollution**	**Surface permeability**	**Structure thermal quality**	**Surface geometry**
- It is caused by high energy demand uses in the city center such as anthropogenic activities, industrial growth, and vehicle density. - Dependence on fossil fuels increases due to the need for heating in the winter months and cooling in the summer months. Pollution caused by energy emissions increases the absorption of radiation in the boundary layer, which prepares the situation for the inversion layer to arrive. The inversion layer prevents the cooling of the rising air and slows the dispersion of pollutants. With the increase of ozone in the air and the increase in the temperature felt, the quality of the air deteriorates.	It is the phenomenon of increasing emissions of particulates such as carbon dioxide from domestic, industrial and automobile use. As a result of this; - Infrared (electromagnetic) waves accumulate on the surface and increase the temperature felt. - The long-wave radiation absorbed on the urban surface increases the air temperature. - Depending on the urban population, rural-urban temperature differences occur as a result of 10% long wave radiation.	- Evaporation effect of asphalt and concrete covered surfaces decreases. - Latent heat is reduced as a result of increased sensitive heat transfer with urban surface cover. - In areas with dense vegetation, latent heat increases and the felt temperature decreases.	- It is the thermal feature of the urban structure. - It is the phenomenon that impermeable materials such as asphalt surface and concrete increase the thermal heat effect. - The albedo effect in cities is 5-10% less than in rural areas. While the surface of a high albedo (light colored) object reflects 80% of the incident light, the reflection rate is around 10% on dark colored surfaces.	- A rough urban surface with a high friction effect reduces the horizontal air flow compared to the rural area. For this reason, the annual average wind speed in cities is lower than in rural areas. - In urban canyons, the hot air becomes stagnant unless it is ventilated by the cold rural air effect.

According to Oke (1992), antropogenic heat release is related to energy consumed per person and per population. Therefore, the main cause of antropogenic heat generation is the release of carbon dioxide (Aksay et al., 2005; Büyükşahin, 2018). Anthropogenic factors are the main cause of the increase in global temperatures from 1951 to 2010 (WWF, 2013), especially it has been defined in the last years human activities are primarily responsible for the observed rise in average global temperatures (IPCC, 2021). The most important issue about anthropogenic factors is that global climate change on a macro scale is the rise in temperature that can reach the threaten human health on a microscale. The transportation modals of cities, geographical location, building density, population, urban geometry, surface material, vegetation status, field use, carbon emissions, etc. are the basis factors for antropogenic-induced warming (Shahmohamadi et al., 2011).

The environmental and societal ramifications of UHI phenomenon have been extensively documented (EPA, 2003; Xu et al., 2015; Bhargava et al., 2017; Li et al., 2020). Among these repercussions, the impact of elevated greenhouse gas concentrations within the atmosphere, culminating in the warming of the Earth's biosphere (i.e., global warming), holds paramount importance due to its consequential influence on ecosystem equilibrium. In addition, the CO2-source greenhouse gas effect in the cities is reported to have caused 0.7°C heating at earth temperature over the past 100 years (Akkurt et al., 2019; IPCC, 2021; UN, 2020). In our country (Turkey), emissions have increased 2.25 times as much as in 1990. This is particularly an indication of the UHI effect in city centers and how the perceived air temperature has an effect (Akkurt et al., 2019). For this reason, it is necessary to take measures to minimize the effects of anthropogenic influences on the climate and to develop strategic planning-design proposals. Extensive literature is available on current strategies to reduce the UHI impact (Aflaki et al., 2017; Rosenfeld et al., 1998; Azevedo & Leal, 2017; Wang et al., 2016;Orhan, 2021). The UHI effect-mitigating strategies called urban green systems (UGS), use of different scales of vegetation (Gago et al., 2013; Selim et al., 2023), presence of wetlands (Daniel et al., 2018) and use of materials with a high albedo ratio for pavements, roads and other ground surfaces (Pacheco-Torgal, 2015). Extensive research on green infrastructure in related literature is emphasized like small local parks (Aram et al., 2019), large urban parks (Buyadi et al., 2015), urban forests (Brandt et al., 2016), urban gardens (Mazhar et al., 2015 2015), green roofs (Besir & Cuce, 2018), green/permeable surfaces (Manso & Castro - Gomes, 2015), trees in different shapes and scales (Wang & Banzhaf, 2018). For example, in the study conducted in 2010, it was observed that large parks called urban green systems (UGI) and urban forests have reduced the daytime temperature by up to 0.94 0C (Bowler et al., 2010). For this reason, the thermal and aerodynamic properties of the surface change when green areas are placed instead of urban uses, buildings and roads, and the UHI effect can be reduced by creating a cooling effect in the area (GLA, 2016).

Much more than esthetically or luxurious appearance in urban green systems is an important part of spatial planning (James et al., 2009). An example is the goal of increasing the shadowing by road-side trees in London to reduce the surface temperature between 5 and 20°C (GLA, 2016). Green systems emphasize the significance of carefully selecting tree canopies as a preventive measure to hinder the dispersal of pollutants from residential areas and thoroughfares. In other words, the choice of tree species and vegetation in urban environments plays a crucial role in mitigating the movement of pollutants, thus helping to maintain cleaner and healthier neighborhoods and streets (Zupancic et al., 2015; Yao et al., 2022). There are studies on the creation of permeable facades, green walls and green roofs to help reduce the UHI effect by affecting building insulation (Bianco et al., 2017; Bass et al., 2002). In many studies, it is expressed that the urban temperature is reduced by areas or permeated pavements that will store high solar reflectance materials and rainwater (Leal Filho et al., 2018). Green walls and roofs to develop urban green systems are constructed in some cities such as Birmingham and Manchester. These strategies are important for improving microclimate and are aimed at reducing the impact of the UHI by establishing a green infrastructure system in cities.

Another important point in mitigating the UHI effect is to reduce carbon emissions by creating the green infrastructure. The green belt (parks, overhead trees, shrubs, etc.), created in urban centers/busy areas is intended to reduce greenhouse gas emissions, called carbon zero or low carbon zones (He, 2019). In addition to sustainable transport strategies (Demirtürk, 2021), green building systems are very important (building isolation) in addition to green road network, intelligent transportation systems, renewable energy-driven vehicles, energy-generating roads, traffic calming, personal vehicle use prevention, etc. It is emphasized that factors that have an impact on the UHI such as energy use must be controlled. The objective of carbon emissions reduction is to establish areas characterized by low emission levels, thereby inhibiting the accumulation of greenhouse gases and the subsequent warming of the atmosphere (He, 2019; Lehmann, 2014).

In this study, factors specified by the Oke (1981) and causing the UHI are covered in two main indicators and the current situation in the Bolu city center is examined. While under the title of **physical/natural properties** in the city, the ***population, topography and climate*** are evaluated as the first indicator, under the title of **artificial properties**; ***transportation, land use change, surface permeability, blue-green infrastructure, surface geometry and air pollution*** are examined. The effects of both indicators on climate change and UHI are studied in the city, especially in the context with the construction of the Bolu province in the last 25 years (1994-2019). Finally, urban design proposals and interventions associated with green infrastructure are developed in a conceptual way.

1. Material, Method & Limitations

1.1. Material

The Bolu city is 262 km from Istanbul on the D-100 highway and 191 km from Ankara. There are Zonguldak and Karabük in the north of Bolu, in the east of Çankırı, in the Southeast and in the south, Ankara, in the southwest, Eskisehir and Bilecik, in the west are the provinces of Düzce and Sakarya. It is located in the West Black Sea region of Turkey and is located between the 30° 32"-32° 36" and the 40° 06"-41° 01" north latitudes. It consists of 9 districts including central district (Dörtdivan, Gerede, Göynük, Kıbrıscık, Mengen, Mudurnu, Seben, Yeniçağ (ÇŞB, 2021). There are one national park (Yedigöller), three nature conservation areas (Kökez-Göknar Forest, Akdoğan-Ebe Protection Area, Bolu Castle Protection Area) and nine nature parks (Abant, Gölcük, Sünnet Lake, Sülüklü Lake, Beşpınarlar, Göksu, Karagöl, Ayıkayası, Kargalı). The scope of the study is based on the limits set out in the Bolu Urban Development Sub-region, the Bolu City Center, Karacasu Municipality, where the UHI effect in the city center of Bolu is determined and the areas that are clearly visible in 1/25,000-scale Development Plan (Figure 1).

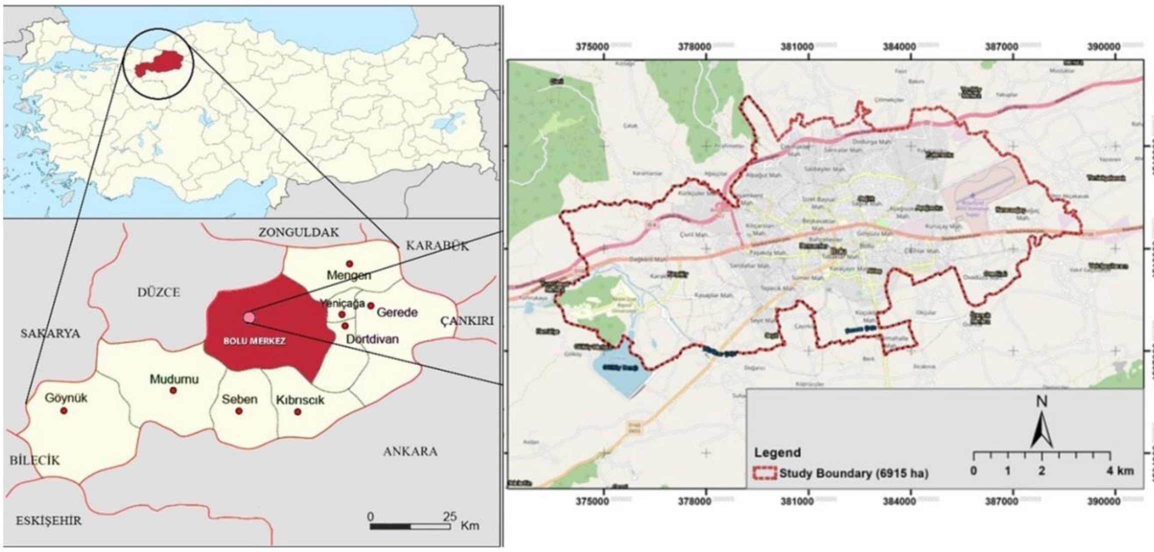


Figure 1: Geographical location and borders of Bolu city (indicated at 1/25.000 scale)

Urban growth which began in the historic city center continued with particular expansion in the north and west direction after the 1999 earthquake (Taner, 2014). Büyükcami, Gölyüzü, Akpınar, Semerkant, Karamanlı, Karaçayır, Tabaklar, İhsaniye and Aktaş neighborhoods form the historic core of the city. With a 1955 Development Plan, Akpınar, İhsaniye, Karamanlı, Karaçayır, Gölyüzü, Büyükcami, Aktaş, Semerkant and Tabaklar neighborhoods have been added to the city. In 1959, the city grew southwest and the neighborhoods of Sümer, Çıkınlar, Borazanlar and Aşağısoku Neighborhoods developed. From 1970 onwards, Beşkavaklar, Kültür and Sağlık neighborhoods, which formed the north of E-5, developed and spread in the northwest direction of the city due to an earthquake in 1999 (Yaşamkent, Umutkent Karaköy, Dağkent, Kürkçüler neighborhoods). In 2004, the Kuruçay neighborhood and Karacağaç, Çakmaklar, Alpağut, Dodurga, Kasaplar, Kılıçarslan, Küçükberk, Çivril, Ovadüzü, Paşaköy, Salıbeyler, Sandallar, Sarıcalar, Seyit and Yukarısoku have become a neighborhood status (Taner, 2014; Bayar & Doğandor, 2017). While Bolu has seen a growth movement from center to periphery, the D100 road connection has created a driving force in the development of the city.

1.2. Methodology

The UHI effect is evaluated in the Bolu city center in terms of quantitative and qualitative. The study follows the urban development process through orthophotos of 1994 (28.07.1994) and 2019 (10.08.2019). Literature review, data collection (current population data, active green area information, Bolu Municipality Park and Garden Directorate, etc.) to develop dissolution-oriented spatial strategies in the city center by researching the factors that have caused UHI impacts analysis, evaluation and synthesis has been conducted. The work is covered in a wide range of tools and programs, such as GIS, Photoshop, Google Maps. The methods followed in this context are as follows.

I. A differential map of the constructed parcels has been manually detected using orthophoto images in 1994 and 2019.

II. Address neighborhoods are printed on the layers of parcels created by the year of construction with the Spatial Join tool. This allows the construction of the parcel areas of the neighborhood to be removed. In addition, building base areas have been removed in closed space geometry using 1/1000 scale current maps from the Bolu Municipality. The floor heights are then printed from the font to the building layer with the Spatial Join tool, and the urban topography and floor heights are visualized in 3-dimensions in ArcGIS Pro software.

III. In order to map the presence of blue and green infrastructure in the city, streams and channels from 1/25000 scale maps produced by the General Directorate of Maps were used. Species were selected to represent water surfaces and open and green areas in the Urban Atlas (2019) data created by the Ministry of Environment, Urbanization and Climate Change in order to determine the urban land cover, the mentioned urban atlas data has been generalized into 4 classes.

IV. The plots (red spots) that were not built according to the 1994 orthophoto image and were built according to the 2019 orthophoto image were mapped. In addition, buildings (turquoise spots) in areas of increasing land surface temperature were shown. Landsat 5 TM images from 1994 (28.07.1994) and Landsat 7 ETM+ images from 2019 (10.08.2019) were downloaded from USGS (URL-1). Land Surface Temperature (LST) maps for both years were produced. Then, the differences between 2019 and 1994 were removed and it was classified into 10 classes according to the raster Natural Breaks (Jenks) method, which includes LST differences. The raster was reclassified and converted to vector data in closed area geometry. Indoor areas with a temperature between 3.7-12.8 degrees Celsius, which is the highest class, and structures (black spots) at a distance of 100 m from the bird's flight were detected (Figure 5). Buildings are mapped with the LST map. While these buildings correspond to 8.7% of the total buildings, they correspond to 12% when proportioned as floor area. In addition, the 2019 LST map and the map showing the floor heights produced from the current map were also prepared.

V. The construction in the city center of Bolu has been shown with a collage work to show the surface materials.

1.3. Limitations

The limitations and difficulties encountered within the scope of the study are stated below.

I. Since the last orthophoto of Bolu city center made available in the General Directorate of Maps of the Ministry of National Defense belongs to 2019, the study was limited to 2019.

II. The absence of 1/1000 scaled map and Urban Atlas data for the year 1994, the absence of demolished and newly constructed buildings (such as active-passive) according to the construction times of the buildings, the fact that the current map is older than 2019 and there are deficiencies in the number of floors and building information.

III. The extraction of automatically structured areas is prevented due to the coordinate system inconsistencies of the provided data, the unknown in which system it was produced, the relative shift in the 1994 orthophoto image and its single band.

IV. The plan changes until 2019 are not included in the current master plan, accordingly, the blue infrastructure is drawn at the upper scale (1/25000) and there is no underground line data.

V. Since the orthophoto image of the year 1994 is smaller than today's adjacent area border, the southern part is not included in the study border.

VI. Limiting making various inferences in terms of wind and temperature due to the lack of meteorology station in the city center of Bolu.

VII. Inability to access the number of vehicles registered to traffic at district and neighborhood level and energy consumption data from the Turkish Statistical Institute (TURKSTAT) and the Energy Market Regulatory Authority (EPDK).

VIII. Inability to obtain long-term, seasonal averages for air quality monitoring and the limited number of stations.

IX. The lack of address neighborhoods belonging to 1994, the state of construction and the construction and green areas per capita were followed one by one.,

2. Findings

There are many problems with anthropogenic sources that result in lack of green infrastructure due to unplanned urbanization movements in the cities (Mobaraki, 2012). In particular, the thermal properties of building materials during the day in urban centers where construction is dense store more energy than green space and vegetation-covered areas, spreading high levels of heat energy to the city's surface, and at night it oscillates to urban areas. Therefore, anthropogenic activity creates thermal changes in the surface energy balance, creating a sense of heat balance instead of hidden heat (Stone & Rodgers, 2001). As mentioned above, the UHI effect in Bolu city center is considered as firstly; physical/natural properties of the city (population, topography and climate), and secondly; for land use-change; transportation, construction, blue-green infrastructure, the structure-thermal relationship, air pollution, energy consumption, surface permeability, surface geometry, etc. are examined under the title of artificial properties. Both indicators coming from literature review are investigated for the effects of UHI and climate change in the city, and urban design proposals with the spatial strategies is highlighted.

2.1. Physical/Natural Properties Affecting UHI

2.1.1. Population

The ratio of the population living in the city center of Bolu to the total population is 72%. The ratio of the population living in rural areas to the total population is 28% (MEU, 2020). It is known that the population of Bolu, which decreased after the 1999 earthquake increased after 2015. While the population in 1994 was 270,654 in the last 25 years, it increased to 291,095 people in 2015 and it was determined as 314,802 people in 2019 (Şahin & Taşlıgil, 2019).

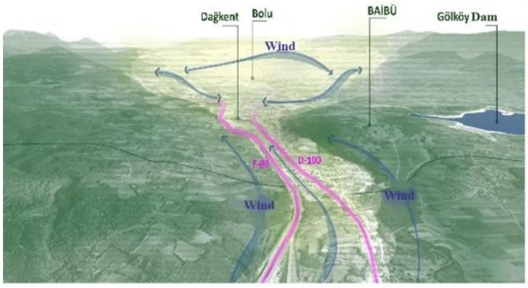
2.1.2. Topography

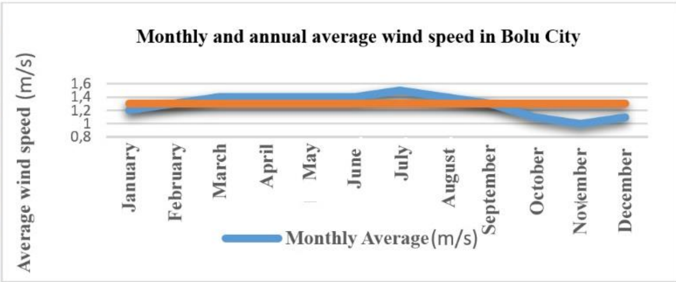
In the rural area of Bolu, the elevation is 1460 m and it decreases to 690 m in the city center. The city stays between the mountain masses in the north and south, and develops on a plain between narrow straits that can be expressed as the threshold in the east and west. Since this situation makes it difficult to form wind corridors, it has an increasing effect on the UHI effect.

2.1.3. Climate

There are temperature differences between the city and the periphery in Bolu. In the average of the data obtained from 17070 Bolu Central Meteorology Station and 17637 Bolu Mountain Meteorology Station between 2009-2019 the temperature felt in the city is 30 °C in August, the hottest month of summer, while the temperature felt in the countryside is 19 °C, and the temperature differences between urban and rural areas are 11 °C. was measured. In winter, the coldest months are January and February, and the temperature difference between the city and the countryside is 6°C. Considering the 2010-2019 data, the average relative humidity was 73.4% and the annual total precipitation was

549.8 mm (Çağlak et al., 2021). Since the average wind speed at these two stations is 1.3 m/s it is understood that the wind speed is low. The highest wind speed was measured as 1.5 m/sec in July and the lowest as 1 m/s in November (Figure 2).





(a) (b)

Figure 2: Wind direction (a) and average wind speed (b) in Bolu city

2.2. Artificial Properties Affecting UHI

2.2.1. Transportation

It is seen that there is a linear growth along the D-100 highway in the city center of Bolu. Boulevards and avenues developing from the city center to the peripheries and connection axes have developed. While the street widths are 50 m in the main artery (D-100), it varies between 25-30 m in the connecting axes with boulevard characteristics, and 10-15 m in the intermediate arteries. There is a 520 ha road network in the city. Traffic density in the city is at 08.30 in the morning and 18.30 in the evening at Hürriyet Avenue, Ali Rıza Tekmen Avenue, Atatürk Boulevard, Şemşi Paşa, İzzet Baysal, Cumhuriyet and İsmet Paşa Streets in the city center (URL-2).

2.2.2. Land-use Change

The expanding road transportation system in Bolu has also caused structural growth from the center to the peripheries. The first master development plan was made in 1985 and an unplanned urban texture is observed with the effect of urbanization in the city. When the 1994-2019 dates are compared, among the neighborhoods that make up the historical city center due to its proximity to Aktaş (17ha) and Karaçayır (15ha) neighborhoods and the city center, it is seen that the impermeable surfaces have increased due to the increase in the built areas in the Borazanlar (22ha) neighborhood. The highest increase in impermeable surface in 1994-2019 orthophoto changes, Sağlık (67ha), Karaköy (53ha), Karaağaç (49ha), Küçükberk (42ha), Kültür (23ha), Kılıarslan (27ha), Aşağısoku (30ha), Dağkent (26ha) , Kürkçüler (26ha), Çivril (30ha), Çıkınlar (46ha), Ovadüzü (32ha), Kuruçay (30ha), Yaşamkent (22ha), Dağkent (26ha), Kürkçüler (26ha), Alpagut (35ha), Yukarısoku (36ha), Borazanlar (22ha) neighborhoods (Figure 3). A structural increase of 80% has been observed in approximately 25 years.

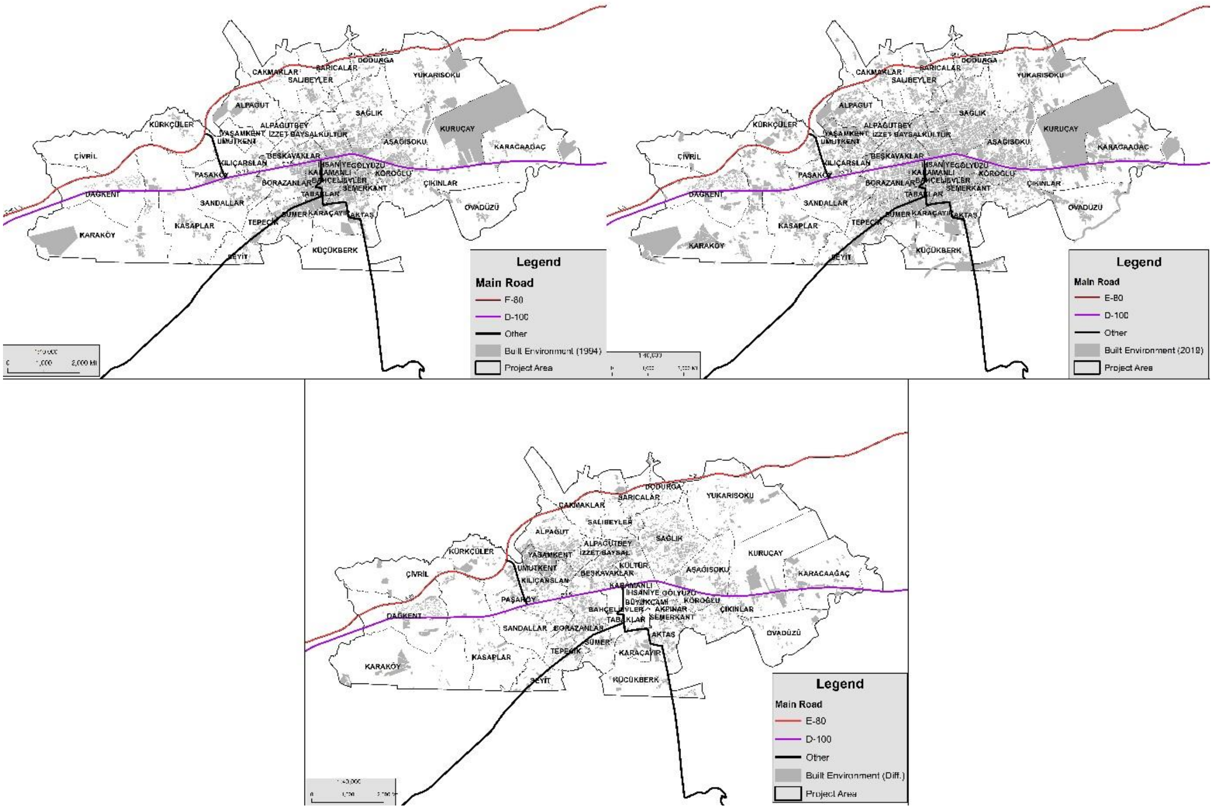


Figure 3: Development of built up environment between 1994-2019 years

In the LST temperature map for the years 2019-1994, the number of buildings (indicated by black spots) remaining in the hottest region and at a distance of 100 meters from this region by a bird's flight is 1789 (Figure 4). These structures constitute approximately 9% of the buildings in the city center. It has been determined that the temperatures in the city center increase in the summer months due to the building density and population growth in 25 years. In the orthophoto images of 2019, it is seen that the surface temperature differences are more in the neighborhoods with low housing rates and less in neighborhoods with high housing rates (such as Borazanlar, İhsaniye, Bahçelievler).

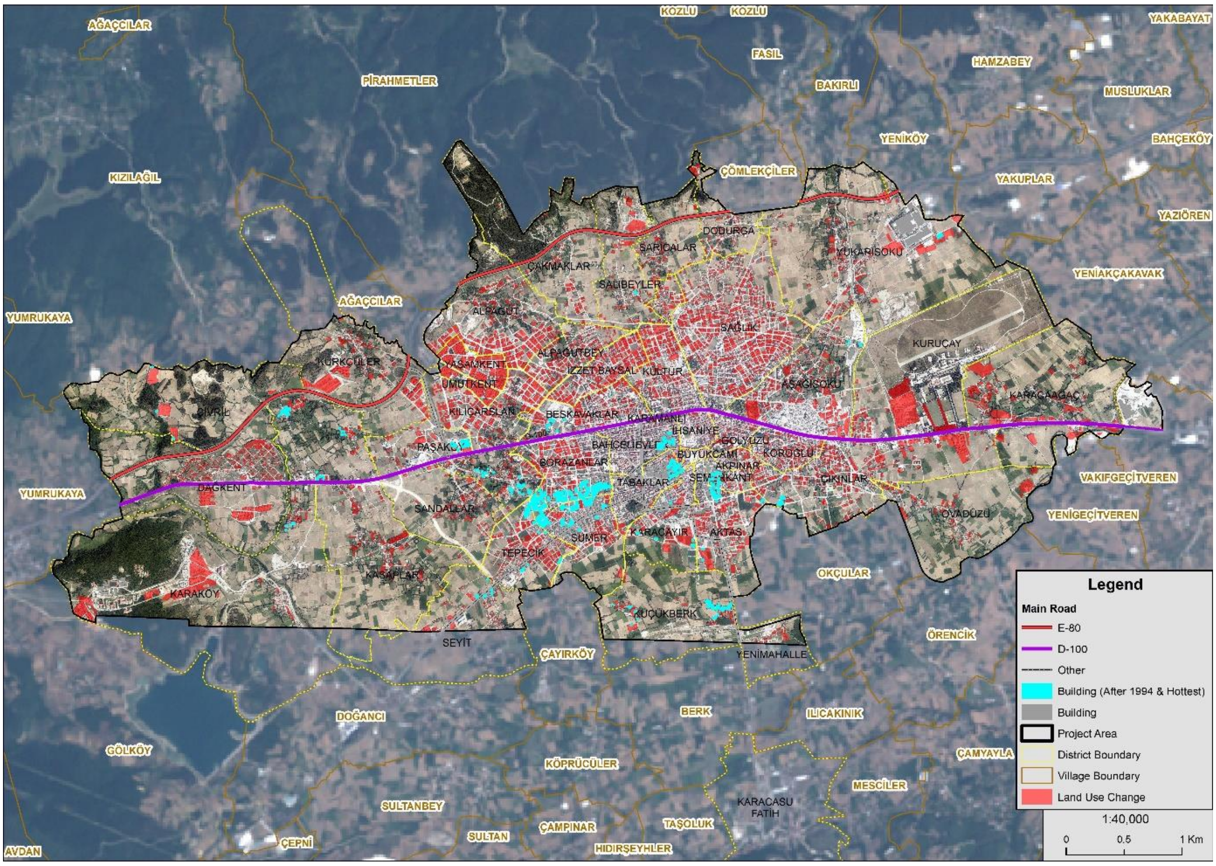


Figure 4: Areas with increasing building density in the city center in 2019

When the parcels (red spots) built after 1994 are examined, it is seen that the city has generally developed towards the north and west. 549 of the buildings seen in Figure 5 were built after 1994. It has been revealed that the structures built after 1994 and remaining in the warmest region in the 2019-1994 LST difference map (the clusters indicated in turquoise color) are concentrated in the urban core and in the westernized areas (Tabaklar, Borazanlar and Sümer neighborhoods) (Figure 5). The reason why the turquoise clusters are in this part of the city is that the D-100 highway is relatively flat (between O-4 and D-100 has a slight slope from north to south), and is mostly located between high and medium density residential and commercial areas. The northern development zone, on the other hand, is more sloping, closer to the mountainous and forested area, and contains relatively less dense residential areas and public buildings with open space.

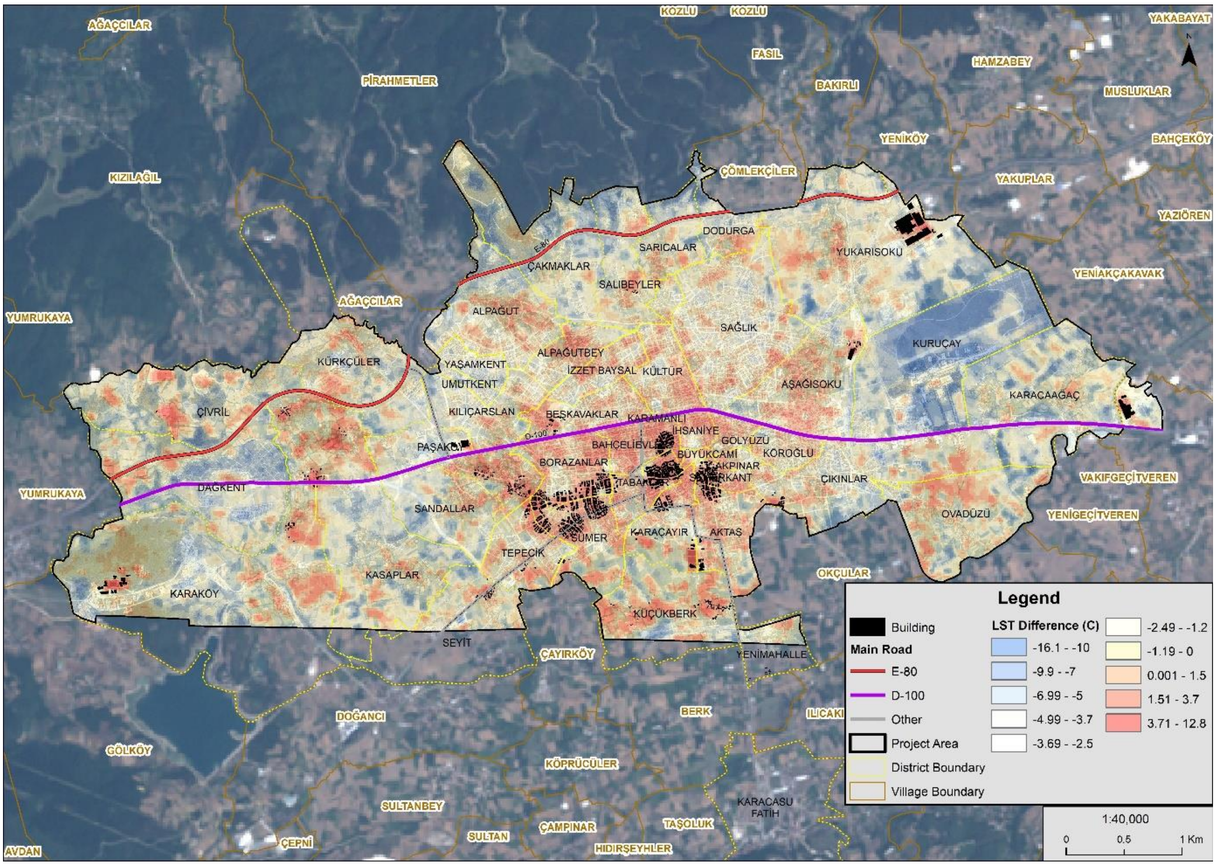


Figure 5: Buildings with increasing land surface temperature differences

In the 25-year period, the most construction is in Dağkent neighborhood. The neighborhoods where the impermeable surface is tried to be reduced are Bahçelievler and Büyükcami Neighborhoods. In addition, the built-up parcel area was 1074 hectares in 1994, while it was 1938 hectares in 2019. It is seen that the floor heights vary between 4-6 floors in the city and in some regions it reaches up to 7-9 floors (Taner, 2014) (Figure 6). When the building density in the whole city and the LST of 2019 are correlated, it is understood that the surface temperature effect, which varies between 25 and 32 °C, is 32-43 °C in some regions. It is noteworthy that the floor heights of the buildings vary between 5-6 floors and the surface temperature is above 30 °C (Figure 6).

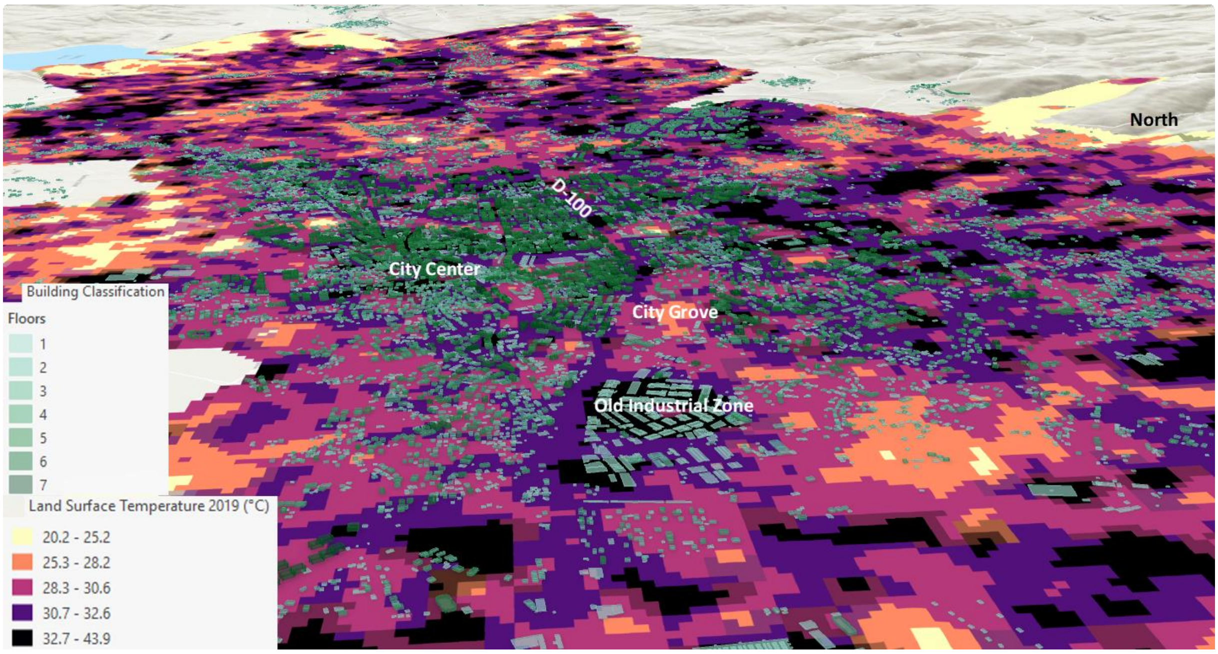


Figure 6: Effect of building heights and surface temperature in Bolu city

On the other hand, there is an Organized Industrial Zone in the east of the city. There are 56 factories-manufacturing shops in it, engaged in food (white meat), woodworking and forestry products, hardware and metal industry, heat glass and tempered glass industry, electrical equipment production, weaving, clothing and leather manufacturing (MEU, 2020). Poultry and some food companies are located in the northwest of the city. In the districts of Aşağısoku and Çıkınlar located in the Bolu city center, there is the Old Industrial Site, which is described as small industry. Metal production, auto maintenance, auto electricity, marble, machinery, steel, iron-jointing, cement etc. production units are located in small industrial site, located close to the center, creates an impermeable and detached surface from its surroundings, and has a surface temperature effect of 32 °C and above.

2.2.3. Surface Permeability

The use of artificial materials such as concrete and asphalt is high with the increase in the parcel area and floor heights built in the city center. The thermal inertia of these materials is greater than the vegetation and natural materials in rural environments. Therefore, more solar radiation eclipse takes place (Figure 7). For this reason, the albedo effect of surface materials in cities is lower than in rural areas. According to the Bolu Municipality Parks and Gardens Directorate Report (2019) (was taken in 2021) there are 96 ha of active green areas (park + recreation area). There are only some partial afforestations on the D-100 highway with high connectivity, Hospital Street, Hürriyet Street, Calligrapher Emin Barın Street in the city.

As is known, trees and plants help cooling through evaporation. Plants take the water from the soil with their roots and give some of this water out from their leaves and stems in the form of dripping and transpiration (Alexandri & Jones, 2010). Meanwhile, evaporation takes place, so the air temperature decreases. In addition, since the surface materials show reflective properties the temperature effect varies according to the type and location of tree area, grass area, artificial area and wetland. It is emphasized that increasing green areas in urban areas reduces the temperature in many studies (Cao et al., 2010, Maimaitiyiming et al., 2014, Li et al., 2017, Zhang et al., 2016; Şentürk et al., 2022). In Bolu city center, the increase in construction in the last 25 years the use of artificial materials and the effect of impermeable surface absorbs the sun's rays more than the vegetation and soil, and the energy stored on the surface is released at night. Therefore, there is a decrease in evaporation and cooling on the surfaces in the city center compared to the rural areas.

Figure 7: Structural silhouette view of Bolu city center

2.2.4. Blue-Green Infrastructure

The total size of the wetlands which are important in terms of blue and green infrastructure, which will reduce the albedo effect in the city is 11 ha. Bolu city center is also rich in terms of underground water resources. Wetlands provide a carbon storage function, increase the humidity of the environment, and provide a healing effect on the microclimate such as precipitation and temperature (WWF, 2008). In this context, Büyüksu Stream and Gölkoy Dam are important in the formation of the microclimatic climate structure (MEU, 2020). In the study, it has been determined that there are studies for bicycle paths on some canal edges where several canals and streams are covered and joined to the road connection in the city.

While the sum of active (parks, children's playgrounds, recreation areas, etc.) and passive green (cemeteries, maquis and grassland, grassland, pasture, greenhouse, forest) areas in the city is 1105 ha (Figure 8), arable agricultural areas in the city center are 2568 ha (MEU, 2020). However, since there are no trees and vegetation around the agricultural areas, it is among the areas with the highest surface temperature effect (Yılmaz, 2015; Alkan et al., 2017; Oke, 1992). The surface temperature in the agricultural areas of the city is 32 °C. Considering the spatial distribution in the city, the agricultural area is 40%, the built area is 37%, the active and passive green area is 17%, the wetland is 0.1% and the undefined area is 5.7% (Figure 8).

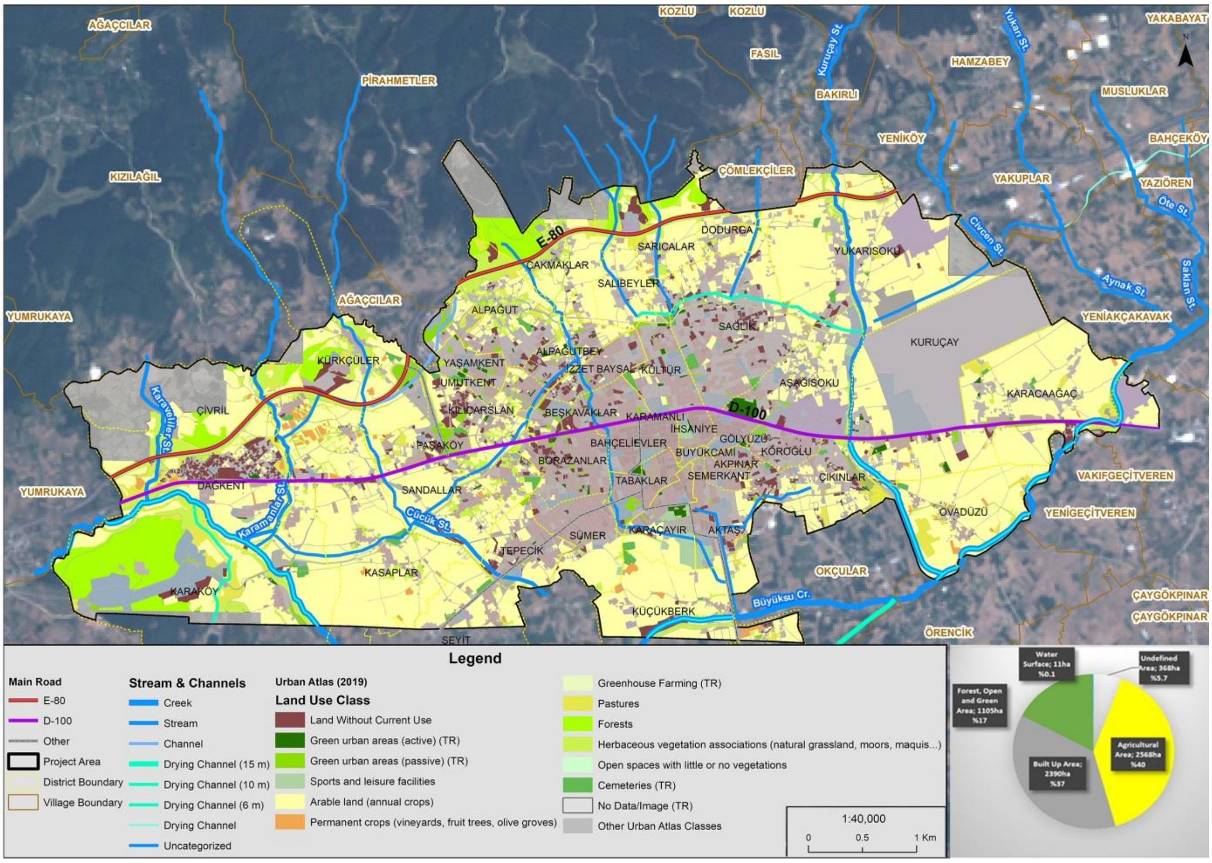


Figure 8: Presence of blue and green infrastructure in the city and distribution of land cover

2.2.5. Surface Geometry

One of the factors that cause the UHI effect in terms of urban space organization is street canyons and wind activity. Street canyons (h/w) known as the ratio of building heights to road width are characterized as narrow and wide. The orientation and geometry of the street canyon is related to many factors such as access to the sun inside and outside the buildings, urban ventilation, air flow, permeability, urban temperature, cooling and evaporation. Therefore, the built environment and especially the street canyon is a key factor in the formation of the urban airflow style. In wide canyons, the wind speed slows down in winter and summer. It is stated that narrow and winding streets reduce cold and hot winds, while straight and parallel streets increase air movement in urban areas (Chan et al., 2001; Shishegar, 2013).

Due to the low wind speed in the city the warm air in the street canyons becomes stagnant, which increases the surface temperature in Bolu (The ratio is between h/w:1 or h/w:2). Although the parallel position of the streets facilitated the air movement, the wind speed is slow due to the bowl-shaped topographic structure of the city. Street afforestation in the city is insufficient in terms of providing shade and cooling effect, especially in summer months. For this reason, afforestation of street canyons is important. For example, Medellin Municipality in Colombia has reduced the temperature by 2 °C in the city with its forestation works on 18 different streets (Ramboll, 2015).

2.2.6. Air Pollution

Air quality standards are concentration units determined by the World Health Organization (WHO) in order to prevent the negative effects of common air pollutants (particulate matter (PM), nitrogen dioxide (NO_2), ozone (O_3) and sulfur dioxide (SO_2) in the atmosphere and to protect human health. There are three stations to measure air quality in Bolu, one of them is Bolu-Abant outside the study area, the other two are the station in Karaçayır park and Atatürk Boulevard-Kızılay Park station in the city center (ÇŞB, 2020). Air pollution is seen in winter due to traffic and domestic heating. According to the data of the Turkish Statistical Institute (TURKSTAT), the number of vehicles registered to traffic in Bolu for March 2021 has been determined as 119,162 (TUIK, 2021). the number of vehicles is 49,602 (MEU, 2020) Exhaust control is important in terms of controlling carbon emissions originating from motor vehicles.

2.2.7. Energy Consumption

Anthropogenic heating is important in terms of energy consumption. Data on input and output variables related to electricity consumption and number of consumers on the basis of consumer type for 2016 in Turkey are available in Bolu (EMRA, 2017; Koçak & Boran, 2019) total consumption is 996.357.60 mwh, with 448.793.60 mwh in industry, 172.724.36 mwh in businesses, and 172,754.36 mwh in residential (housing) areas. It is emphasized that the energy consumption of Bolu for 2016 is higher than the neighboring provinces of Karabük and Çankırı. This situation can be associated with population and industrialization. It is seen that consumption is less than Düzce, Bilecik, Eskişehir, Sakarya and Zonguldak provinces (EMRA, 2017; Koçak & Boran, 2019).

RESULTS AND SUGGESTIONS:

The UHI effect is observed due to settlement density and agricultural areas in Bolu city center. It is evaluated that the temperature increases between 25 - 32 °C in the city reach 32-43 °C in some regions. In the eastern part of the city, the LST effect is higher due to agricultural lands, industrialization and urbanization, while the lower LST effect is detected due to the forests in the northern part of the city. The total forest area, green and open areas in the city constitutes 17% of the entire area. In addition, the total size of wetlands (excluding Gölcük, Abant, Seben dam) is 11ha. However, the trapping of infrared rays, which must be sent to the atmosphere from buildings and various reflective surfaces in densely populated areas, slows down the cooling of urban surfaces. Where rural-urban temperature differences are observed in the city energy consumption due to heating and construction is also high (EPDK, 2017; Koçak & Boran, 2019).

Moreover, while the surface temperature values are low in areas covered with green vegetation, it is observed that the surface temperature increases on pavement surfaces with insufficient green vegetation (street-boulevard, wide asphalt) and in high-density residential areas. This situation negatively affects the health conditions of people living in the city center by reducing their comfort levels. Generally measured in urban areas covered with impermeable surfaces, albedo tar-covered or asphalt surfaces accumulate more heat than natural ground. In this context, many studies have found that urban parks reduce the temperature by 4 °C in dense residential areas (Tonyaloğlu, 2019; McDonald et al. 2016; Santamouris, 2014). It is also known that green roof applications reduce the temperature effect between 0.3-3°C (Santamouris, 2014). The study conducting by Erell et al. (2011) is stated that urban design proposals that reduce the compressed hot air by increasing the natural wind flow reduce the temperature in Singapore by 2°C. For this reason, solution proposals should be developed by considering the UHI impact as multidimensional parameters that affect the climatic comfort, life quality and even the economy in the city.

Green infrastructure applications are important as the sustainable and environmentally friendly approach in establishing a link between the green areas that provide the ecological cycle of the city and the built environment according to their usage areas and purposes. Policies that support green infrastructure in the restructuring and improvement of cities by creating a buffer in the development of the focal points in the important axes and peripheries of the city constitute a great share in ensuring the sustainability of the cities. Prevention of urban sprawl, selection of ecological materials, walkability, widespread use of bicycles, creation of wind corridors, green roof and green building applications, effective use of technology, taking precautions for extra consumed resources (such as water and energy) are mitigation and adaptation measures that are needed in Bolu city center. Similarly, in the creation of a healthy/sustainable city as stated in many studies, it is necessary to control resource consumption, identify sensitive areas, ensure their continuity, and minimize the effects of climate change with the formation of blue-green infrastructure (Katz, 1994; Coşkun Hepcan, 2019). In addition to the issues specified in the Green Certificate Regulation for Buildings and Settlements, the principles that can be developed for Bolu city center are grouped as management and governance, transportation, spatial and environmental. Prevention of urban sprawl, selection of ecological materials, walkability, widespread use of bicycles, creation of wind corridors, green roof and green building applications, effective use of technology can be some of the precautions. The impacts of UHI may be decreased risks with these precautions, which mitigates climate change risks.

In the **transportation system;** it is important to reduce the use of automobiles by increasing green transportation opportunities, to expand bicycle, pedestrian and public transportation-oriented transportation types, and to increase pedestrian access in organic urban textures. In the **spatial context**; creating mixed-use areas in neighborhood centers, providing compact settlement, controlling all kinds of low-density and vehicle-dependent urban sprawl, transforming public buildings into green buildings, building-street related that take into account the sky view factor in the presence of building-green space, giving importance to the prevailing wind direction/wind corridors/ speed, recalculating the building distances depending on the height of the building are among the spatial measures to reduce the UHI effect. Establishing green infrastructure in the city in terms of **environmental aspects**, creating planted car parks, roadside afforestation and vertical gardens, creating a data entry system network for the species to be used by preparing an inventory of road trees and monitoring them at regular intervals, creating a biodiversity inventory, improving river corridors and water channels and making them green corridors (green streets project), preventing the drying up of wetlands, using permeable surfaces in the city center, creating rain gardens, switching to clean energy and carbon zero policies to reduce air pollution, transforming idle areas into green areas for the establishment of an urban green system and ensuring its continuity, renewable energy sources (solar, wind, geothermal, etc.) should be expanded and restoration should be made in ecosystems that have lost their function. Finally, for the implementation of these principles and suggestions creating a participatory environment at the local level in terms of **management/governance** ensure that local people and experts come together with the politicians, integrating spatial analyzes of UHI areas into the spatial planning process and developing solutions, creating climate change risk maps throughout the city. It is important to create a site-specific settlement scheme by local governments in new development areas, to improve solution proposals in the spatial planning process, to create a rainfall water management plan, to make it available on an open data portal if it has been created.

In order to reduce the UHI effect, while designing urban streets in Bolu, it is necessary to transform concrete and asphalt floors into a sustainable drainage system with rain water-permeable material selections. Wetland assets in the city should be determined and added to the urban drainage. In this way, the effect of absorbing and spreading the heat of the floor will be reduced. In addition, it is important to bring wetlands to the city in the form of landscape design and bicycle application along the canal. Another important point is that plant designs that meet the economic, aesthetic and physiological characteristics that will adapt to the locality in the Bolu city center and take into account the relationship of roads (main, intermediate and secondary road), structure and infrastructure should be proposed. In addition, the ratio of the building heights to the street width (h/w) and the orientation of the buildings (canyon areas) to the sun should be taken into account in the zoning activities of the city. Within the scope of all these mentioned above, an urban design proposal at 1/5000 scale has been developed for the city center of Bolu. A proposal project that supports green infrastructure has been put forward in the design-plan diagram that supports green infrastructure and shows environmental and spatial decisions (Figure 9).

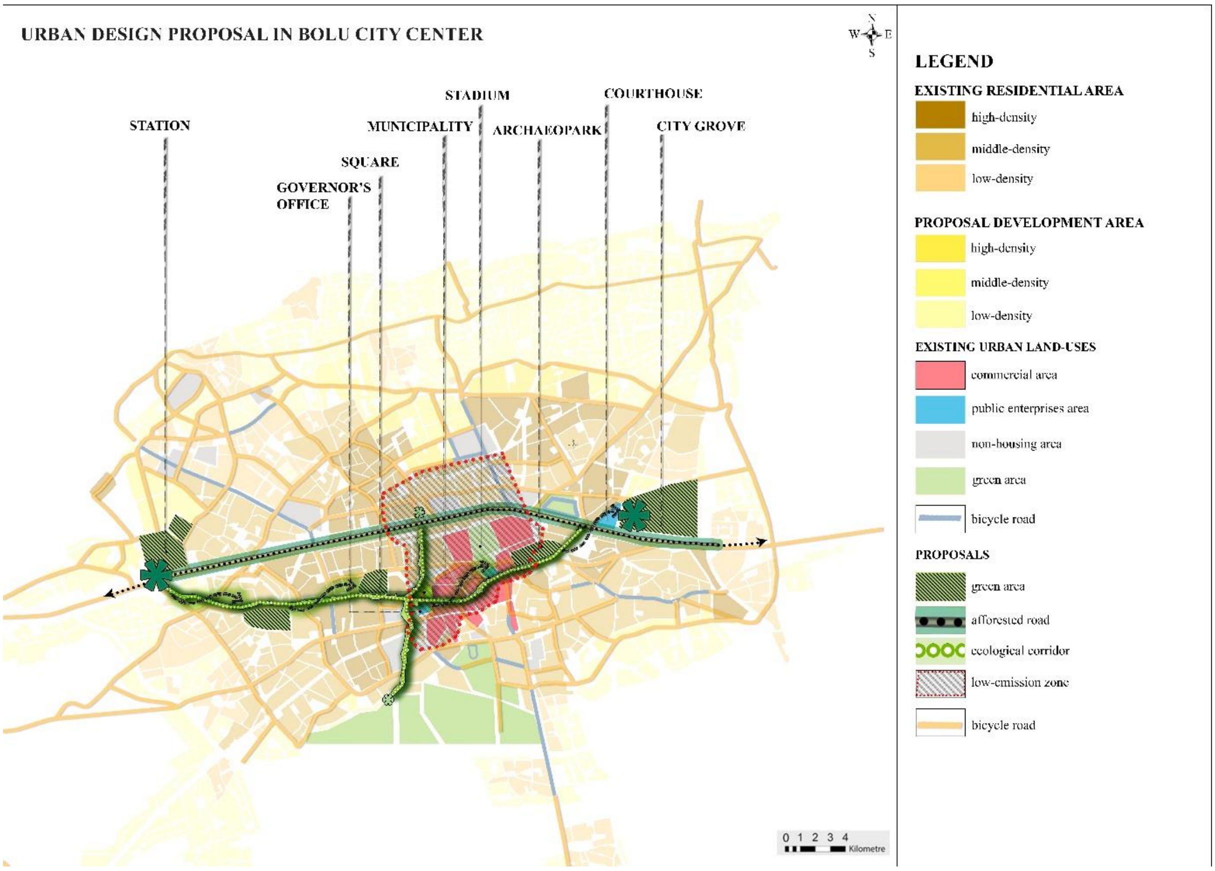


Figure 9: Urban design proposal to reduce the UHI effect in Bolu city center

The urban design proposal in Figure 9 was prepared by taking into account the studies and strategies of Bolu Municipality Directorate of Reconstruction and Urbanization, Park and Garden Directorate and Bolu Governorship, in addition to the findings in the study and literature research. Accordingly, spatial arrangement was envisaged by increasing green areas in existing public areas such as the governor's office, terminal, square and municipality in the city center, which is denser than rural areas and the periphery of Bolu. In addition, proposed bicycle paths have been added for studies on increasing bicycle lanes (the plan is ongoing) in order to support green transportation in the city center, which is one of the goals of Bolu Municipality. In addition, the small industrial site in the east of the city was removed and replaced with a city grove. An ecological corridor proposal has been developed to increase walkability and pedestrian circulation between the terminal entrance in the west of the city and the small industrial site in the east. Old Istanbul Street and Hürriyet Street are planned to be developed as ecological corridors. Moreover, it is proposed that two parcels within the borders of Borazanlar and Bahçelievler Neighborhoods, which were used as a former prison on Hürriyet Street and are now idle, will be used as urban green areas. For the street that starts with the Governor's Office (Ali Rıza Tekemen Street) and reaches the Siteler Mosque in the city center, it is offered to transform into a green/pedestrian priority road. On the other hand, it is envisaged that the central region, where commercial uses are intense, will be a low emission zone and policies aimed at calming traffic will be implemented. The main purpose in the area designated as the low emission zone is to provide controlled slowdown at the vehicle entrance and to support the reduction of greenhouse gas emissions in city center. In addition, it has been suggested that the area determined by the Bolu

Municipality as the 2nd Degree Archaeological Site, where the historical remains of the city (which is still in progress), and which is currently used as an education area, should be an Archeopark. With the proposed area, it is envisaged that 108ha more active green areas will be added to the city.

It has been concluded that the UHI effect due to anthropogenic impacts is high due to the insufficient green space in the Bolu city center, the pressure of urbanization, the excess of agricultural areas with low albedo value and the industrialization effect. It is aimed to reduce the UHI effects in future urban development plans with the developed project and green infrastructure proposals. It is emphasized that there is a need for collaborative work with local government, local people, academia and Non-Governmental Organizations to ensure sustainable development in future.

Complience with Ethical Standart

Conflict of Interest: *There is no conflict of interest between the authors or any third party individuals or institutions.*

Ethics Committee Approval: *Ethics committee approval is not required for this study.*

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