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Land Use Change in Türkiye and Determination of Priority Areas for Urban Heat Island Studies

Türkiye'de arazi kullanım değişimi ve kentsel ısı adası çalışmaları için öncelikli alanların belirlenmesi

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Öz

Türkiye gibi gelişmekte olan ülkelerde iklim değişikliği ve çarpık kentleşmenin beraberinde getirdiği Kentsel Isı Adası (KIA) etkisi sıklıkla araştırılmaktadır. KIA çalışmalarına nerede öncelik verileceği önemli bir sorundur. Bu çalışmada CORINE Arazi Kullanımı/Arazi Örtüsü (AK/AÖ), Meteoroloji İstasyonu (Mİ), kentsel AK/AÖ ve il sınırı verilerini CBS kullanılarak Türkiye'de KIA çalışmalarının planlanmasına temel oluşturmayı amaçlanmıştır. Türkiye'de il düzeyinde AK/AÖ'deki değişimin yanı sıra Mİ'nin 10 kilometre yarıçapındaki şehirleşmiş alan oranı ve yoğun kentsel AK/AÖ tiplerinin oranı bulunmuştur. 1990 yılında Türkiye'nin yüzölçümünün %0,91'inin Yapay Yüzeylere (YY) ayrıldığı, 2018 yılında ise bu oranın %1,97'ye yükseldiği tespit edilmiştir. YY'ye en fazla dönüşüm 1041 km^2 ile İstanbul'da ve 949 km^2 ile Ankara'da gerçekleşmiştir. Yarıçapı 10 km olan Mİ'lerin YY'ye dönüşme oranı %23,8 ile %40,8 arasında değişirken, aynı mesafedeki 22 Mİ'nin yoğun kentsel AK/AÖ oranı %38,4 ile %54,4 arasında değişmektedir.

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Abstract

Urban Heat Island (UHI) effect of climate change and unplanned urbanisation in developing countries like Türkiye is frequently investigated. Where to prioritise UHI studies is an important problem. In this study, CORINE Land Use/Land Cover (LU/LC), Meteorological Station (MS), urban LU/LC and provincial boundary data were analysed using GIS to provide a basis for the planning of UHI studies in Türkiye. In addition to the change in the LU/LC at the provincial level in Türkiye, the proportion of urbanised area within a 10 kilometer radius of the MS and the proportion of dense urban LU/LC types were found. In 1990, 0.91% of Türkiye 's surface area was allocated to Artificial Surfaces (AS), while this ratio increased to 1.97% in 2018. The highest amount of conversion to AS was in Istanbul (1041 km^2) and Ankara (949 km^2). The rate of conversion of MS into AS within a radius of 10 km varies between 23.8% and 40.8%, while the rate of dense urban LU/LC of 22 MS at the same distance varies between 38.4% and 54.4%.

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1. Introduction

Cities are generally built according to resource diversity and various geographical advantages. However, with rapid urbanization and climate change, various problems arise in cities. One of these is the urban heat island (UHI) phenomenon (Oke, 1988), which was first recognized in urban microclimates by Luke Howard (Howard, 1833) in 1833 (Kuşçu-Şimşek, 2013). UHI is the higher air and surface temperature in urban areas compared to rural areas (Oke, 1982). The heat absorbed during the day in the built environment, which increases due to urbanization, is released in the first hours of the night, increasing the severity of UHI. In addition to physical factors, the urban canyon, which is found by the ratio of building height (H) to street width (W), the sky view factor (SVF) and the urban geometry created together with other urban data are among the factors that determine the UHI effect. In addition, wind speed and the amount of cloudiness have an important role in determining the intensity of UHI (Arnfield, 2003; Oke, 1988).

It is a known fact that the adverse effects on humans will increase with Heat Waves (HWs) affecting UHI. The frequency, intensity and duration of hot spells and heat waves have increased in cities, which are seen as responsible and solution venues for climate change (Perkins et al., 2012). In relation to this, there have been a large number of deaths associated with hot weather. An association was found between infant mortality from gastrointestinal disorders and extreme heat between 1910 and 1912 (Bleyer, 1913). In the summer of 2003, 40,000 deaths and an economic loss of 10 billion US dollars occurred in Europe (García-Herrera et al., 2010). In the summer of 2015, 6700 premature deaths in 93 European cities of 53 million people were associated with urban heat islands (Iungman et al., 2023). In Spain, 4610 people died in July and August 2022 (Tobías et al., 2023). Most deaths occurred in people over the age of 65 (British Columbia Coroners Service, 2022; Chien et al., 2016) and in individuals with cardiovascular or cerebrovascular disease (Ellis et al., 1980). In addition to deaths, HW has been associated with increased crime rates (Hou et al., 2023; McDowall et al., 2012) and decreased worker productivity (Herbel et al., 2017). In addition, the severity, number, and duration of heat waves are predicted to increase (Hoag, 2015).

Various bibliometric studies on Web of Science (WOS) indexed publications show that studies on UHI have increased. While the number of journals on UHI was 34 in 1990s, this number increased to 331 in 2010s. In parallel, it was found that there were only 4 publications on UHI in 1990 and 378 publications in 2016 (Wu and Ren, 2019). The number of UHI studies using Remote Sensing data and methods has increased significantly, especially after 2018 (Almeida et al., 2021; Huang and Lu, 2018).

Türkiye is one of the critical countries in the Mediterranean Basin with respect to UHI and HW. Türkiye's urbanization and distribution of urban population (Avcı, 1993) is not very balanced. Much research has been carried out on cities in Türkiye, which is a developing country, mostly unplanned and vulnerable to the risks of climate change with its rapid urbanization. During the period 1965-2006, the number of hot days, frequency, and duration of HWs increased in western Türkiye, and extreme temperatures were observed to be more frequent especially after (Sezginer Ünal et al., 2013). It was also found that the amplitude of the extreme HW projected between 2075 and 2094 in Türkiye will vary between 2 °C and 4 °C per heat wave day (Amengual et al., 2014). In Türkiye, 43% of the disasters between 1971 and 2016 were associated with HWs (Gürkan et al., 2017). Similarly, a study conducted with data from 1950-2018 shows that Türkiye is exposed to higher temperatures, longer duration and more frequent HWs (Erlat et al., 2021).

Studies on UHI in Türkiye are mostly conducted using three basic data. The first of these is meteorological data, which has been used since the 1990s. In studies using only meteorological data (Aykır, 2017; Çiçek and Doğan, 2005; Karaca et al., 1995; Kum, 2006; Tayanç and Toros, 1997; Yasdıman, 2021), parameters such as minimum-average-maximum temperature, humidity, wind, precipitation are analyzed. The majority of these studies are conducted over meteorological stations representing urban, semi-urban, and rural areas in a city (Çiçek and Doğan, 2005; Karaca et al., 1995). In addition to these, there are also studies conducted throughout Türkiye. In these studies, stations are selected based on population criteria (Yasdıman, 2021), the arrival directions of air masses affecting Türkiye, or the availability of long-term data (Aykır, 2017). Such studies are usually carried out by researchers in the fields of geography and meteorological engineering. The second basic data is the land surface temperature (LST) data obtained from thermal satellite images. This data started to be used in Türkiye after 2005s (Dihkan et al., 2015; Duman-Yüksel, 2008; Duman-Yüksel and Yılmaz, 2008; Kaya et al., 2012; Kuşçu and Şengezer, 2011; Sarp et al., 2018; Ünal et al., 2020). These studies are generally conducted by researchers in the fields of urban and regional planning, meteorological engineering, landscape architecture, geomatic and geography. Recently, it can be said that UHI studies using only LST data have increased. The third data set is land cover/land use (LU/LC) data. Although the relationship between LU/LC and LST is generally examined in studies (Aksak et al., 2023; Soydan, 2020; Ünsal and Avci, 2023; Ünsal et al., 2023; Yılmaz and Özcanlı, 2021), there are also studies in which meteorological data and LU/LC are examined together (Bilgen, 2016; Erkek et al., 2020). In addition, these three data are frequently used in bioclimatic comfort studies related to UHI (Bozdoğan Sert et al., 2021; Çağlak et al., 2022; Topuz and Geçen, 2024; Türkoğlu et al., 2012).

While one aspect of the UHI phenomenon is based on urbanization and how urbanization occurs (Erdem Okumus and Terzi, 2021; Erdem Okumus and Terzi, 2022; Demircioğlu Yıldız et al., 2023; Ünal Çilek, 2022), another aspect is based on the analysis of long-term meteorological data. In studies using only meteorological data, it is possible to find out which station exhibits UHI characteristics, but it is not possible to answer the question of where in the city UHI is strengthened. Similarly, in studies using only LST data, the climatic characteristics of the city are ignored. Therefore, in UHI studies, it is important to analyze only meteorological data or to examine the relationship between LST and LU/LC, instead of analyzing only meteorological data or examining only the relationship between LST and LU/LC, it is important to consider LU/LC, LST and meteorological data together. In this context, this study is important and unique in terms of addressing these gaps and prioritizing UHI studies. In addition, the findings of the study are noteworthy as they will pave the way for interdisciplinary studies.

The data and approach used in the study are similar to the studies conducted by Kahraman and Doğan (2021) and Yılmaz (2020). In the study conducted by Yılmaz (2020), LU/LC data (CORINE 1990, 2012) of meteorological stations within a 10 km radius were used to explain the urbanisation relationship in climate indices obtained from the stations. Kahraman and Doğan (2021) explained CORINE 1990, 2000, 2006, 2012 and 2018 data and explained them at the provincial level using hot spot analysis. In this study, these approaches used by different researchers from the fields of physical and human geography were combined in a way, focusing on UHI and Surface Urban Heat Island (SUHI), and by analysing CORINE LU/LC, Urban Atlas LU/LC and meteorological stations data together, the mentioned literature gap and the following four research objectives were tried to be achieved. In addition, all datasets obtained in the research were provided transparently in the research supplement[1] with the understanding of open science and open data, providing background information for different researches.

One of the physical reflections of urbanization is the change in land use. By identifying the regions where the transition from other types of LU/LC to urban land use is the highest, the location of the research site for UHI studies will be on solid ground. The extraction of this LU/LC change in relation to the meteorological station will enable the analysis of meteorological data, which has been mostly ignored in recent years in UHI studies. In this context, the research has four objectives that go from general to specific. The first one is to determine the change in LU/LC from 1990 to 2018 at the provincial level. With this aim, the big picture of the overall LU/LC change in Türkiye will be seen. The second is to determine the proportion of urbanized areas within a 10-kilometer radius of all meteorological stations in Türkiye. This will provide helpful and guiding information for future UHI studies. The third objective is to provide information on urban LU/LC types within this radius. With this objective, the stations to be used for UHI studies can be prioritized. The last objective is to determine the relationship between the rate (%) of conversion of meteorological stations into artificial surfaces within a radius of 10 km and the rate (%) of dense urban LU/LC. In this way, it will be proved whether the dense urban LU/LC ratio increases as the rate of conversion to artificial surfaces around the stations increases.

2. Material and Method

The research area is the borders of the Republic of Türkiye. In order to achieve the study objective, 4 basic geographical data were analyzed in an 9-stage process. The first of these data is the location of meteorological stations[2]. This data obtained from the General Directorate of Meteorology includes attributes such as the name, identification number, province, district, X, and Y coordinates of the stations (General Directorate of Meteorology, 2023). The second data is the provincial border data obtained from the General Directorate of Mapping (GDM) (General Directorate of Mapping, 2023). The third data is the European Union's CORINE (Coordination of Information on the Environment) data for the years 1990 and 2018 (Copernicus, European Union, 2023). In the study conducted by Özür and Ataol (2018), it was revealed that there are inadequacies in the literature on CORINE LU/LC data in terms of "resolution, classification area, naming and accuracy analysis". However, CORINE LU/LC was preferred in this study since a dataset with a similar scope (temporal and class diversity) at the national level cannot be easily produced. The CORINE LU/LC data produced for the 39 member countries of the European Environment Agency includes 5 classes at the top level (Level 1), 15 Level 2 classes and 44 Level 3 classes (Supplement). CORINE LU/LC, which was produced in 1990, 2000, 2006, 2012 and 2018, started to be produced every 6 years after 2000. The next data is planned for 2024 and will be published in the last quarter of 2025. While the temporal range of the 1990 data is 1986-1998, this range for 2018 is 2017-2018. The minimum mapping unit for both data is 25 hectares for spatial data, while the minimum mapping width for linear data (highways, etc.) is 100 meters. In addition to UHI studies, this data is preferred in different disciplines and studies (Alan et al., 2020; Ateşoğlu, 2016; Bayrak et al., 2022; Başayiğit, 2004; İkiel et al., 2019; Karakuş and Demiroğlu, 2022; Siyavuş, 2021; Ustaoğlu and Aydınoğlu, 2019). In addition, Köppen-Geiger climate classes data were used to determine the climate types overlapping the meteorological stations with the most artificial surfaces around them (Taşoğlu et al., 2024).

Finally, the Urban Atlas data of 2019, which expresses urban land use types, was used in the study. The term urban atlas will be used hereafter as urban LU/LC. Urban Atlas data, which is produced in the member countries of the European Environment Agency, such as CORINE LU/LC, has been produced since 2006. The minimum mapping unit is 0.25 hectares. The urban LU/LC produced in 2006, 2012 and 2018 are produced for settlements with a population over 50,000 and a population density of 1500 people/km^2 (Copernicus, 2016). Some settlements in Türkiye that do not meet this criterion did not produce data. In addition, Türkiye only has data for the years 2012 and 2018. In this context, the Ministry of Environment, Urbanization and Climate Change (MoEUCC) has produced a new urban LU/LC data for 2019, covering all provincial and district centers in Türkiye and detailing some urban LU/LC types (MoEUCC, 2019). The types that are not included in the urban LU/LC data produced by the European Union and detailed by the MoEUCC are public, education, health, worship, commerce and greenhouse, cemetery, active and passive green areas. For this reason, we have used the urban LU/LC data produced by the MoEUCC in our study. Apart from these, it would be appropriate to explain the classes that give the quantity of the built environment. The first of these is the class named "Continuous Urban Area (> 80%)". It indicates that the amount of impervious surfaces in the area assigned to this class is more than 80%. In other words, it means that 1600 square meters of a 2000 square meter parcel consists of impervious surfaces. Other density-indicating classes can be proportioned with the same information. Very Low Density Discontinuous Urban Area (<10%) means that at most 10% of a 1000 square meter parcel consists of impervious surfaces. As can be understood from this, the expression "density" in the names of the classes refers to the area covered by impervious surfaces in the relevant area instead of high-rise dense construction (Supplement).

A nine-stage process was applied in the study. The first three processes were carried out to fulfil the first objective of the study and the others to fulfil two objectives. First, all geographic data were converted to the WGS 1984 Web Mercator (EPSG 3857) projection system. In the second stage, CORINE LU/LC data were combined in the union tool to extract land use change between 1990 and 2018 in ArcGIS for Desktop 10.8 software. Then, this data was processed again with the provincial boundaries in the union tool and it was possible to find out how much LU/LC change of what type and in which province. In the third stage, the combined CORINE LU/LC data were processed in the summary statistics tool to extract land use change across Türkiye. In this way, the change according to CORINE LU/LC classes at the province level was extracted. In the fourth stage, a buffer area was generated according to the 10-kilometer radius of all meteorological stations. In the fifth stage, the merged CORINE LU/LC data within this buffer area was cut with the clip tool and the amount of land use change in which buffer area was determined using the tool called spatial join. Since this calculation was made for each station in this process, an area was replicated as many times as how many different stations are in the buffer area. This is necessary to reach a station-based result. In the sixth stage, using the Level 1 information in the CORINE LU/LC data, the amount of area transferred from other species to artificial surfaces was collected with the summary statistics tool. In the seventh stage, the percentage of area converted to artificial surface in the 10-kilometer buffer area of the meteorological stations using station ID numbers was transferred to the station layer with the tool called Join. In this way, the percentage of area converted into artificial surface within a 10 km radius[3] of the meteorological stations was found. Using this ratio and the Optimised Hot Spot Analysis (OHSA) method (ESRI, 2024; Getis and Ord, 1992; Ord and Getis, 1995), the hot spots formed by the most urbanised stations were found. Hot spot analysis was developed by Art Getis and Keith Ord in 1995. This analysis creates a statistically significant hot and cold spot map using the Getis-Ord Gi* statistic in Equation 1 (ESRI, 2024a; Getis and Ord, 1992; Ord and Getis, 1995). In Equation 1, x_j is the value of the j_{th} feature in the dataset, $w_{i,j}$ is the spatial weight value between the i_{th} and j_{th} data points, n is the total number of objects and S is the standard deviation (ESRI, 2024c, 2024e; Getis and Ord, 1992; Ord and Getis, 1995). As the Gi* value calculated in the equation approaches zero, it is understood that there are no high or low values in the neighbourhood of the calculated object. The z-score is also calculated with this equation. As the z-score increases, it is understood that the objects with high values in the geographic data are co-located or clustered. In this way, hot spots are found. As the z-score decreases, it is understood that objects with low values are located together. Accordingly, cold spots emerge. OHSA is preferred to produce the most appropriate results compared to the classical Hot Spot analysis (Getis-Ord Gi*) method. Compared to the Hot Spot Analysis (Getis-Ord Gi*) method, OHSA generally reduces statistically insignificant results. It calculates the optimum distance band used in the classical Hot Spot Analysis (Getis-Ord Gi*) method. In addition, this method calculates how many of its objects have less than how many neighbours based on how many meters of distance band according to the geographical objects given as input.

$$G_{\text{i}} = \frac{\sum_{j=1}^{n} W_{i,j}\, x_j - \underline{\underline{x}} \sum_{j=1}^{n} w_{i,j}}{\sqrt{\frac{\left[n \sum_{j-1}^{n} w_{i,j}^{2} - \left(\sum_{j=1}^{n} w_{i,j}\right)^{2}\right]}{n-1}}} \qquad (1)$$

After the OHSA step, maps and graphs were created by overlapping the hot spots with Köppen-Geiger climate classes so that researchers can identify priority areas. In the last stage, urban LU/LC types within a 10 km radius of the stations were identified using tools such as spatial merging and summary extraction. In this way, it was possible to evaluate the urban LU/LC types around the stations with the most artificial surfaces in their immediate surroundings. In this step, the dense urban LU/LC types within a 10 km radius of the stations were collected and mapped separately. With this map, the stations with the most dense urban land use around them were revealed.

ArcGIS for Desktop 10.8 software and Esri maps were used in these processes. In addition, the Natural Breaks (Jenks) method was used in the classifications of all maps. In this way, an objective visuality was provided by colouring the maps according to the natural breaks of the data. Also, The amount of conversion from other land use types to artificial surfaces between 1990-2018 in Turkey can vary considerably. In order to show the most (head) and least (tail) urbanised provinces and stations in two separate groups, and to classify the other provinces and stations that changed in between into 5 different groups, all relevant maps are divided into 7 classes.

In the study, the buffer areas showing the 10 km radius area of the meteorological stations were not cut according to the land surface. Therefore, the ratio of the artificial surface within the 10 km radius of the stations located close to the sea is lower.

3. Findings

The first of the main findings of the research is the LU/LC change in Türkiye. According to the LU/LC change between 1990 and 2018 obtained using CORINE data, 87.9% of Türkiye remained in agriculture and forest and semi-natural areas. The proportion of artificial areas increased from 0.91% to 1.97%. More than doubling in 28 years, artificial surfaces were mostly formed by the conversion of agricultural areas (0.78%). This was followed by the conversion of forest and semi-natural areas into artificial surfaces at 0.26% (Table 1).

Table 1. Changes in CORINE LU/LC classes in Türkiye between 1990-2018 CORINE LU/LC[4]

LU/LC Changes	Ratio (%)
1990: Forest and Semi-Natural Areas-2018: Forest and Semi-Natural Areas	49.530
1990: Forest and Semi-Natural Areas-2018: Water Bodies	0.107
1990: Forest and Semi-Natural Areas-2018: Wetlands	0.212
1990: Forest and Semi-Natural Areas-2018: Agricultural Areas	4.266
1990: Forest and Semi-Natural Areas-2018: Artificial Surfaces	0.265
1990: Water Bodies-2018: Forest and Semi-Natural Areas	0.027
1990: Water Bodies-2018: Water Bodies	1.786
1990: Water Bodies-2018: Wetlands	0.037
1990: Water Bodies-2018: Agricultural Areas	0.030
1990: Water Bodies-2018: Artificial Surfaces	0.007
1990: Wetlands-2018: Forest and Semi-Natural Areas	0.018
1990: Wetlands-2018: Water Bodies	0.030
1990: Wetlands-2018: Wetlands	0.219
1990: Wetlands-2018: Agricultural Areas	0.049
1990: Wetlands-2018: Artificial Surfaces	0.003
1990: Agricultural Areas-2018: Forest and Semi-Natural Areas	2.781
1990: Agricultural Areas-2018: Water Bodies	0.214
1990: Agricultural Areas-2018: Wetlands	0.046
1990: Agricultural Areas-2018: Agricultural Areas	38.376
1990: Agricultural Areas-2018: Artificial Surfaces	0.782

Source: CORINE LU/LC Datasets (Copernicus, 2023)

When analyzed according to the amount of transition from other LU/LC species to the artificial surface, it was found that Istanbul and Ankara were in the first group (590.5-1041.1 km^2), while Izmir, Bursa, Antalya and Konya were in the second group. Kocaeli, Tekirdağ, Balıkesir, Manisa, Muğla, Mersin, Adana, Gaziantep, Şanlıurfa and Diyarbakır are in the third group. Other metropolitan cities are in the fourth (Sakarya, Eskişehir, Aydın, Denizli, Kayseri, Kayseri, Kahramanmaraş, Hatay, Van, Samsun) and fifth (Erzurum, Ordu, Trabzon, Mardin, Malatya) groups. In addition to metropolitan cities, the fourth group includes provinces such as Çanakkale, Kütahya, Afyonkarahisar, Aksaray, Yozgat, Sivas and Kars (Figure 1).

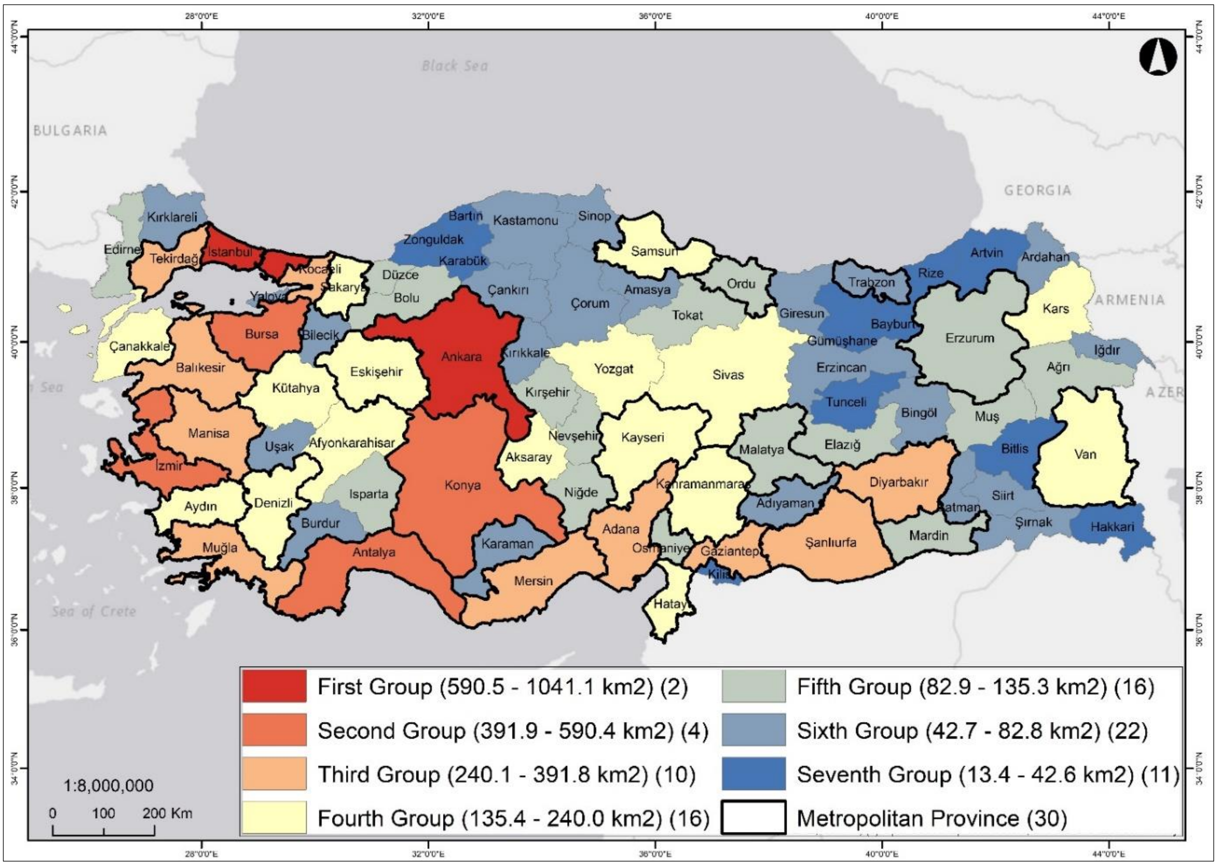

Figure 1. From 1990 to 2018, the amount of transition from other LU/LC types to artificial surface (km^2)[5]

When analyzed according to the rate of transition from other LU/LC types to artificial surface, Istanbul was found to be in the first group alone (10.8%). Kocaeli alone (5.6%) is in the second group. In the third group (1.9% - 3.5%), there were seven metropolitan cities (Bursa, Tekirdağ, Sakarya, İzmir, Ankara, Hatay, Gaziantep) and two non-metropolitan cities (Düzce, Yalova). Erzurum, Van and Malatya are in the sixth and seventh groups due to their area (Figure 2).

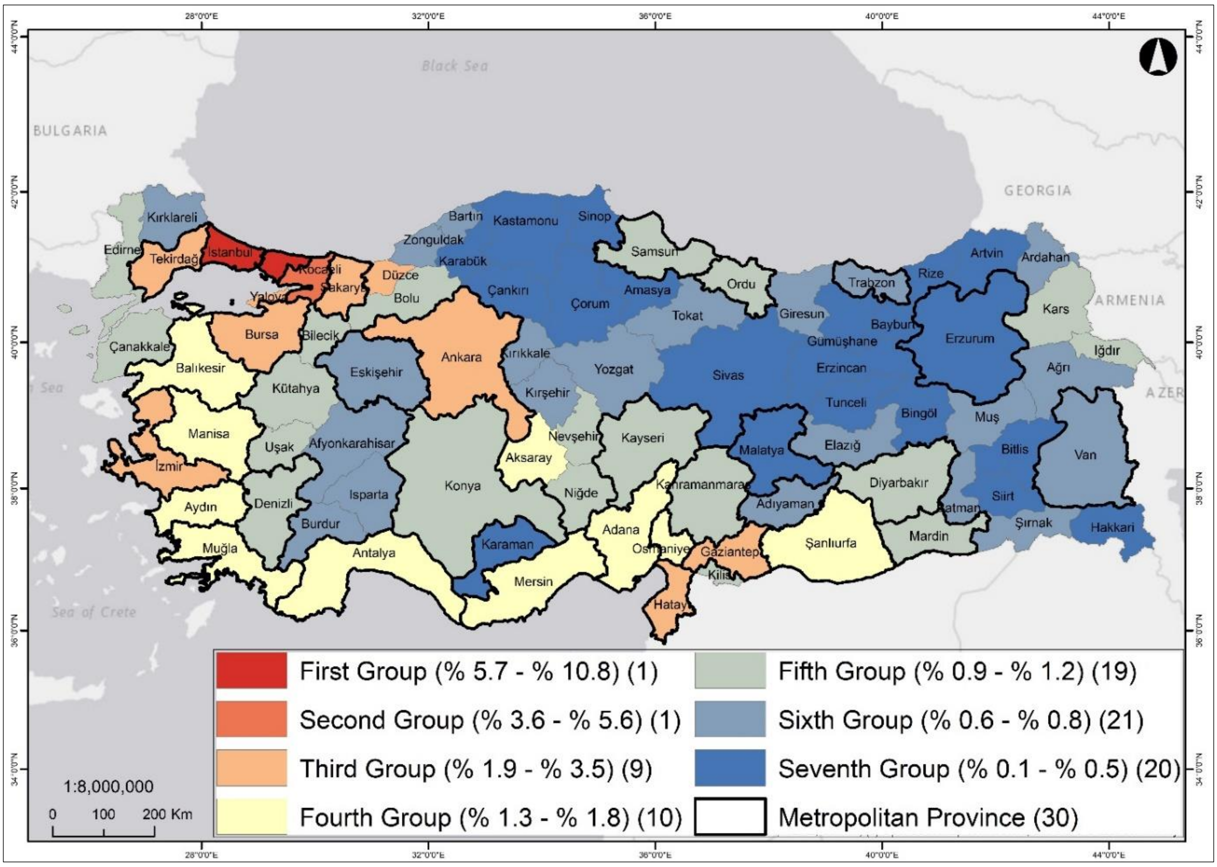

Figure 2. From 1990 to 2018, the rate of transition from other LU/LC types to artificial surface (%)

Another finding obtained within the scope of the research is the ratio of the area transformed into an artificial surface within a radius of 10 kilometers of the meteorological stations. In most of the stations (52.3%), the rate of conversion into artificial surfaces was found to be less than 1.1%. In 15 stations, the rate of conversion into artificial surfaces within a radius of 10 km varies between 23.8% and 40.8%. Of the 15 stations, 6 are located in Istanbul, 4 in Ankara, 2 in Kocaeli and one each in Bursa, Gaziantep and Konya. Izmir has no stations in this group. In Izmir, it was determined that the majority of the stations in the city center varied between 10% and 17%. It is expected that 61 of the 63 stations with an artificial surface conversion rate of more than 15.3% are located in the 10 most populated provinces of Türkiye. The other two stations are Sakarya (17069) and Serdivan (19120) in Sakarya province. Both stations were found to have around 15.5% conversion to artificial surfaces within a radius of 10 km[6] (Figure 3).

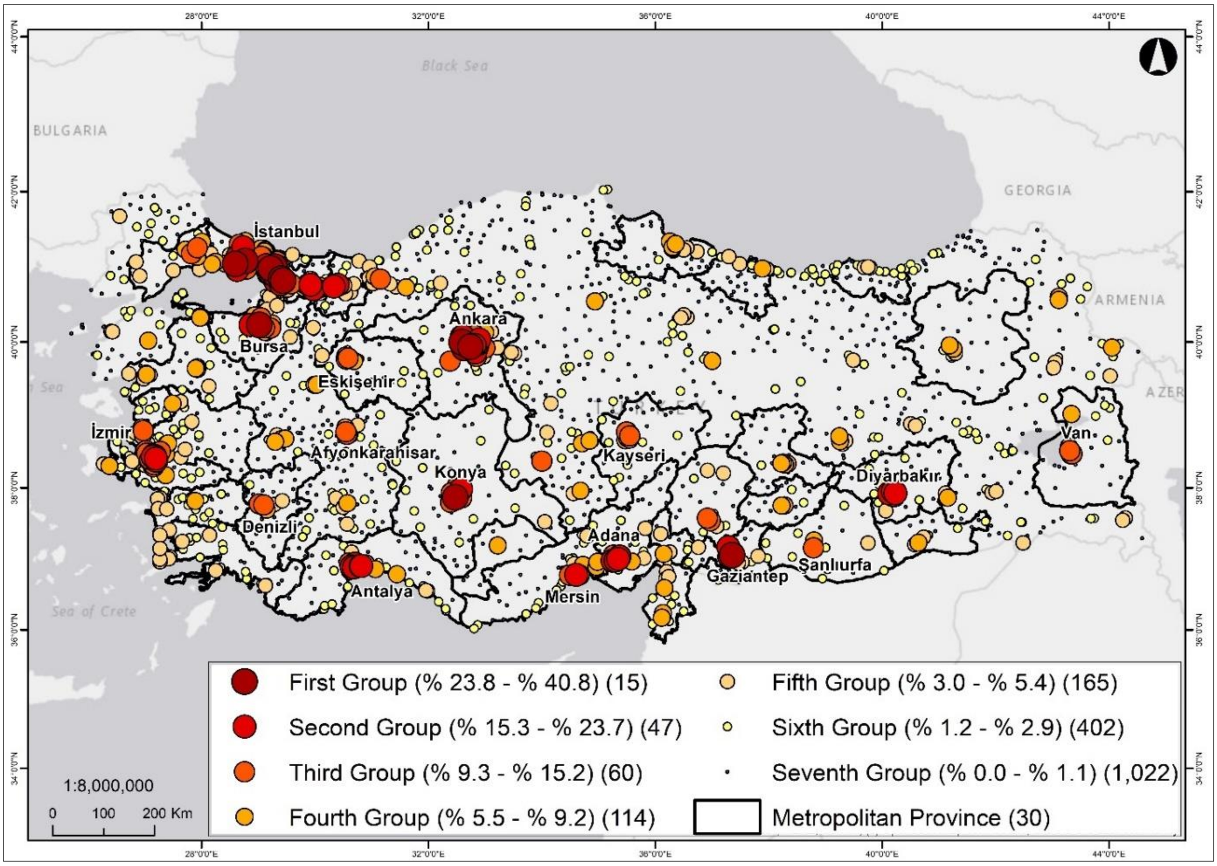

Figure 3. Proportion of the area of meteorological stations transformed into artificial surfaces within a radius of 10 kilometers from 1990 to 2018[7]

To elaborate on an example; it was found that 32.8% of the area within a 10 km radius of the Gebze station (17639) in Kocaeli, which was established in 1930, was transformed into artificial surface from 1990 to 2018. 73.4% was agricultural, 26.3% was forests and semi-natural areas, and 0.3% was water bodies of this area (Figure 4).

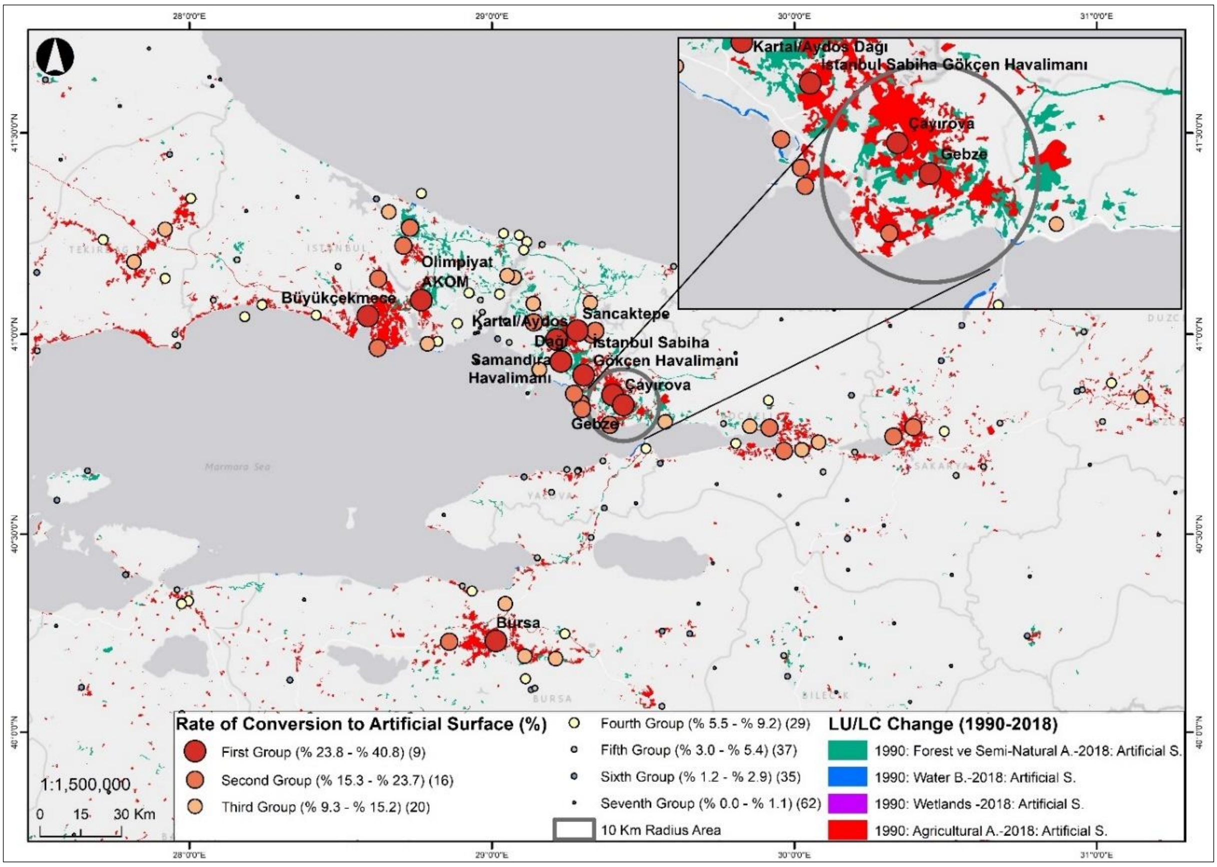

Figure 4. Proportion of area transformed into artificial surface and LU/LC change within a 10 kilometer radius of meteorological stations in and around Istanbul

In the map created according to the proportion of dense urban LU/LC species within a 10 km radius of meteorological stations, there are 22 stations from Istanbul (12) and Ankara (10) in the first group. In other words, at least 38.4% of the area within a 10 km radius of these stations has dense urban LU/LC species. In the second group, there are thirteen stations from Istanbul, five each from Izmir and Adana, two each from Ankara and Kocaeli, and one each from Bursa and Konya, totaling 30 stations. In the third group, there are 45 stations, six each from Izmir and Istanbul, five from Eskişehir, four each from Kocaeli, Kayseri, Antalya and Ankara, two each from Mersin, Sakarya, Konya and Gaziantep, and one each from Bursa, Denizli, Tekirdağ and Adana. In the fourth group, in addition to several metropolitan cities (77), there are 97 stations in total, including three each from Uşak and Afyonkarahisar, two each from Düzce, Elazığ, Sivas, Kırıkkale, Çorum and Batman, and one each from Yalova and Aksaray (Figure 5).

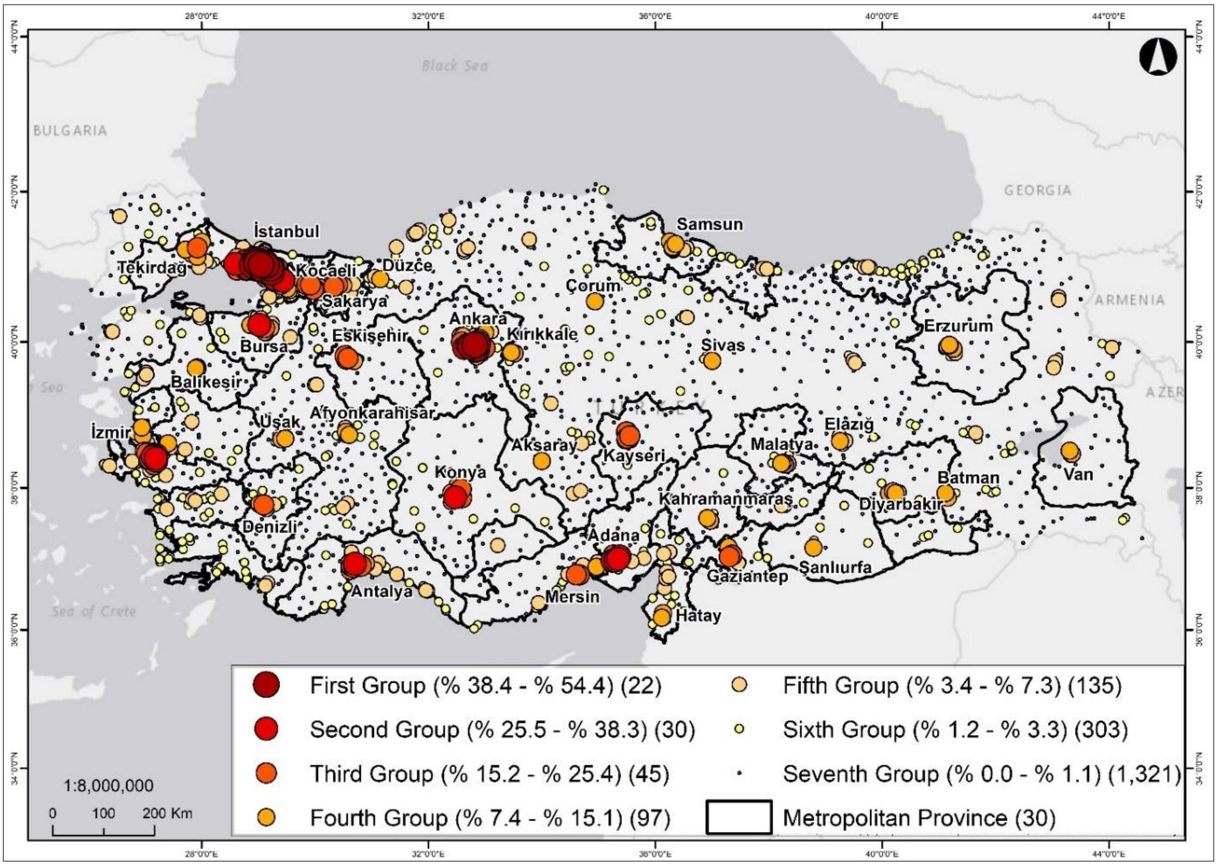

Figure 5. Dense urban LU/LC ratio within a 10 kilometer radius of meteorological stations[8]

The relationship between the rate (%) of conversion of meteorological stations into artificial surfaces within a radius of 10 km and dense urban LU/LC ratio (%) is positive with an R2 value of 0.65. In other words, it proved that as the rate of conversion to artificial surface around the stations increases, the rate of dense urban LU/LC also increases (Figure 6).

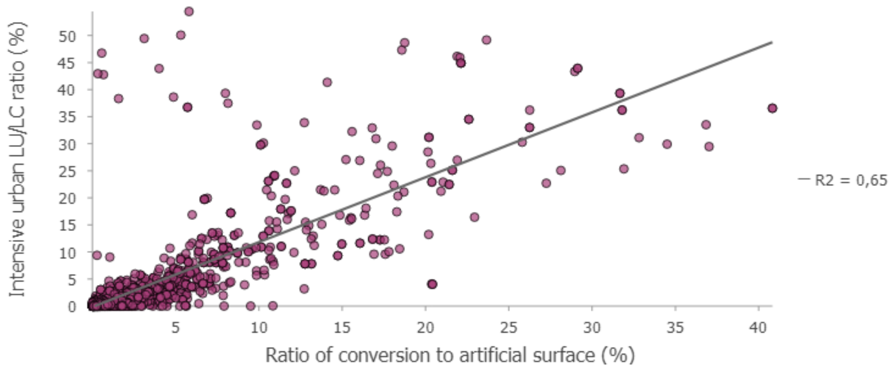

Figure 6. The relationship between the rate (%) of conversion of meteorological stations into artificial surfaces within a 10 km radius and the rate (%) of dense urban LU/LC

When OHSA is applied to the proportion of meteorological stations that turn into artificial zones within a 10 km radius, there are stations classified at 99% confidence level in Istanbul and its surrounding provinces (Kocaeli, Sakarya, Tekirdağ), Bursa, Ankara, Izmir, Konya, Antalya, Adana and

Diyarbakır. Most of these stations (72%) are located in the Csa climate type and in the populous cities of Türkiye. On the other hand, 40.6 % of the stations classified as cold spots at 95% confidence level are located in Cfb climate type (Figure 7 and 8).

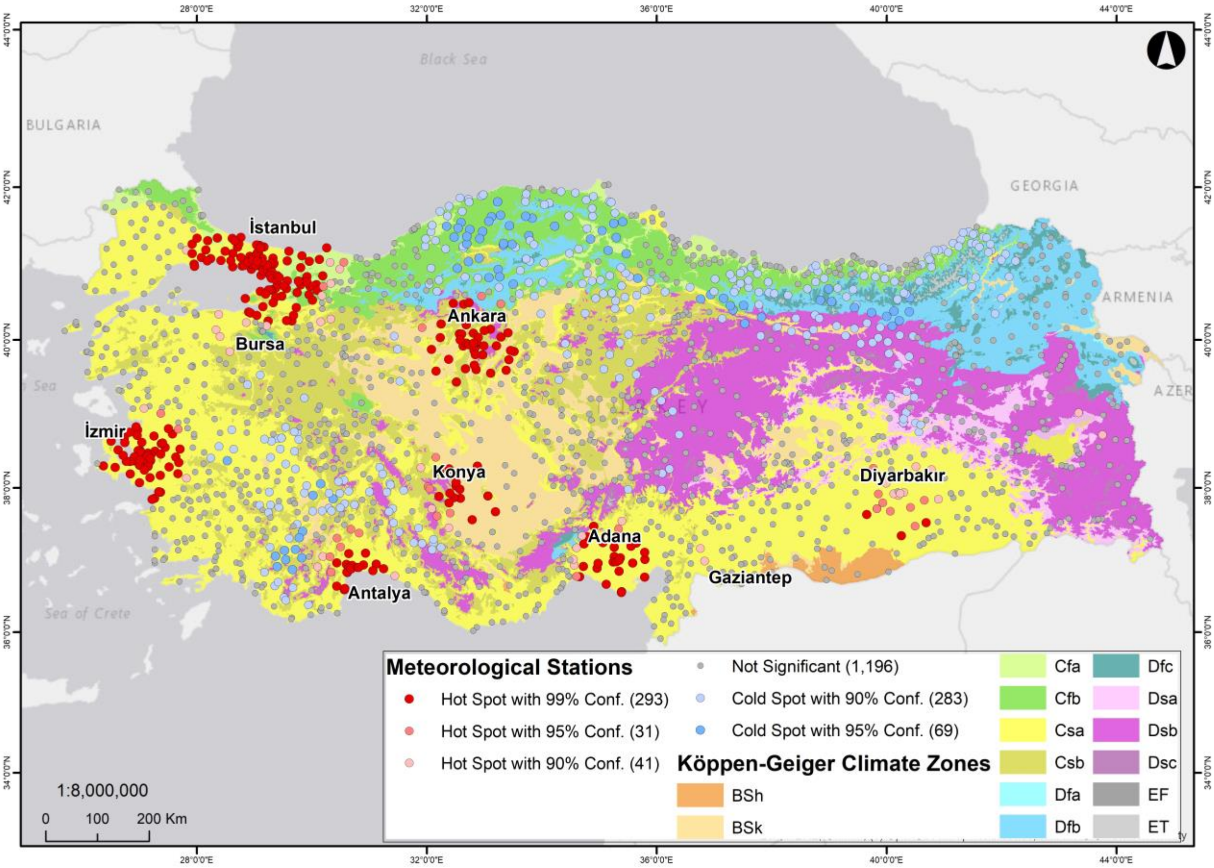

Figure 7. Köppen-Geiger Climate Zones and OHSA result of proportion of the area of meteorological stations transformed into artificial surfaces within a radius of 10 kilometers from 1990 to 2018

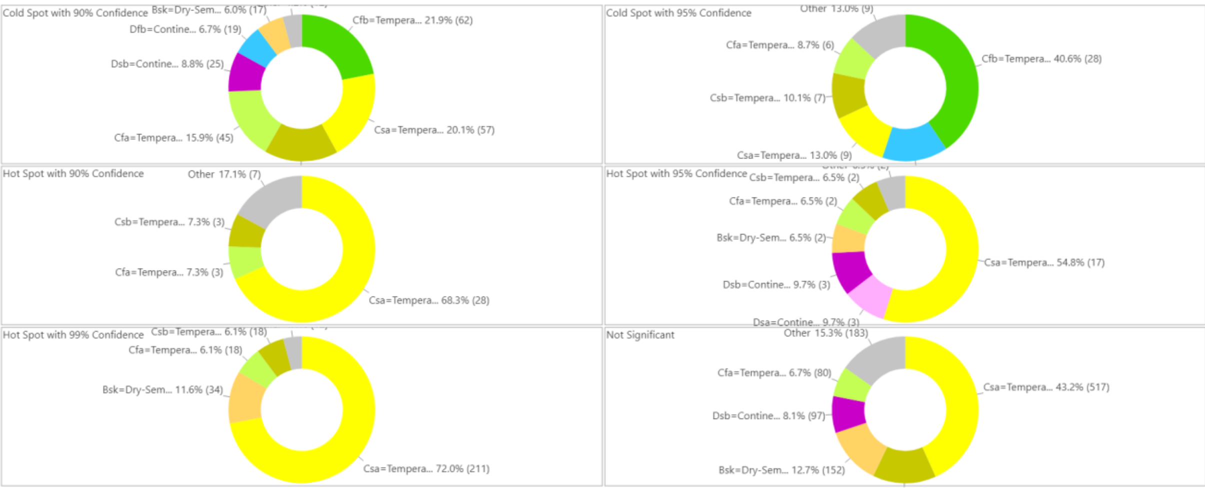

Figure 8. Intersection graphic of Köppen-Geiger Climate Zones and OHSA result of proportion of the area of meteorological stations transformed into artificial surfaces within a radius of 10 kilometers from 1990 to 2018

In addition to these findings, some detailed information is presented as geographic data (WGS 1984 Web Mercator EPSG: 3857) and tables in Supplement. One of these is the change in CORINE LU/LC between 1990-2018 at the provincial level. In addition, there are maps of the amount and proportional change of the area from Forest and Semi-Natural Areas and Agricultural Areas to Artificial Surfaces at the provincial level according to CORINE LU/LC. Finally, the metadata of meteorological stations are presented together with the conversion rate to artificial surfaces within a radius of 10 km, the ratio of dense urban areas and the area information according to urban LU/LC types. In this way, the data can be used more efficiently in future studies (Supplement).

4. Discussion and Conclusion

Türkiye's population increased by 45.4% from 1990 (56.4 million) to 2018 (82 million) (TURKSTAT, 2023). On the other hand, as a result of this research, it was determined that the ratio of artificial regions (according to Türkiye's surface area) increased from 0.91% to 1.97%. In this case, the rate of increase in artificial regions from 1990 to 2018 is 116.5%. The rate of conversion to artificial territory is almost twice as high as the rate of increase in population. This is due to the large share of areas allocated to industry, trade and transportation units (Ustaoğlu and Aydınoğlu, 2019).

The urbanisation process in Turkey can be roughly divided into four different periods: 1923-1950, 1950-1980, 1985-2000 (Işık, 2005) and 2000 and after. In the 1950-1980 period, Istanbul, Ankara and Izmir were first granted metropolitan status in 1984 as a result of the problematic urbanisation resulting in rapid urbanisation from rural to urban areas. Adana, Bursa, Gaziantep, Konya and Kayseri were made metropolitan in 1986-1988, Antalya, Diyarbakır, Erzurum, Eskişehir, Kocaeli, Mersin and Samsun in 1993, and Sakarya after the 1999 earthquakes. Finally, 14 new metropolises (Aydın, Balıkesir, Denizli, Hatay, Malatya, Manisa, Kahramanmaraş, Mardin, Muğla, Ordu, Tekirdağ, Trabzon, Şanlıurfa and Van) were established in 2012 and 2013 (Bekdemir et al., 2014). The groups formed according to the amount of urbanised area in the map in Figure 1 and Figure 3 are relatively consistent with the order of metropolitanisation. It was observed that the stations in the first metropolitan cities such as Istanbul, Ankara, Izmir, Bursa, Konya, Antalya, Adana and Diyarbakır formed hot spots in Figure 7.

There are compatibilities and incompatibilities between some of the findings of this study and some of the studies that serve as a basis for UHI research conducted across Türkiye (Aykır, 2017; Yasdıman, 2021). Some of the main indices used to distinguish the urban heat island are the increases in the maximum of maximum temperatures, the minimum of minimum temperatures and the daily temperature amplitude. The maxima of minimum temperatures of some stations[9] in Türkiye tend to increase by at least at 5% significance level. This finding is generally consistent with the proportion of the area of meteorological stations transformed into artificial surfaces within a radius of 10 kilometers from 1990 to 2018, shown in Figure 3 (Aykır, 2017). On the other hand, an increasing trend in maximum temperatures was observed only in Şanlıurfa and Mersin[10] (significant at 1% level) (Aykır, 2017). This finding is not generally consistent with the proportion of the area transformed into an artificial surface within a radius of 10 kilometers from 1990 to 2018 of the meteorological stations shown in Figure 3.

UHI is closely related to the fact that impermeable surfaces absorb heat during the day and release it at night. Therefore, temperature differences between day and night tend to decrease depending on the UHI.

For this reason, the provinces[11] where the daily temperature difference width decreased significantly by at least 5% (Aykır, 2017) were compared with the research findings. Accordingly, the decrease in the width of the daily temperature difference in Istanbul, Ankara, Bursa, Denizli, Düzce, Van provinces is consistent with the ratio of the area transformed into an artificial surface within a radius of 10 kilometers from 1990 to 2018 of the meteorological stations shown in Figure 3. Yasdıman (2021) selected 17 station pairs (urban and rural) from settlements with a population of more than 500,000 in Türkiye to investigate the presence of UHI (Yasdıman, 2021). At the end of this research, there is general agreement between 10 station pairs[12] and the urban LU/LC ratio and the conversion of meteorological stations in Figures 3 and 5 into artificial surfaces within a 10 km radius.

5. Limitations and Assumptions

The limitations of the study are mainly related to the data used. The first one is due to the discrepancy between CORINE LU/LC and the provincial boundary of GDM. Due to the discrepancy between the CORINE LU/LC data and the provincial boundary of GDM, records without a province name or without a CORINE LU/LC class were ignored. There are three limitations related to urban LU/LC data. The first one is that the data is only produced in provincial and district centers. The second one is that the data usually ends before reaching the periphery of the cities (as if it was cut at a plot boundary). Urban LU/LC data was produced by the MoEUCC for the first time in 2019. There is no data from 1990 like CORINE LU/LC. Therefore, a comparison of two different years such as CORINE LU/LC could not be made.

Depending on the focus and scale of the study, the following assumptions and limitations were made while conducting this research, and accordingly, there are several recommendations for future research:

CORINE was used as LU/LC data and it should be noted that the smallest mapping unit of this data is 25 ha. Although this data has been used in many studies, there are reservations about its accuracy in many studies. Since this research was conducted at a higher scale, this problem was ignored. Researchers who conduct research at more detailed scales can use remote sensing and deep learning methods with satellite images.

The location of the meteorological stations used in the research is assumed to remain constant. Although it is known that the locations of stations such as Göztepe (İstanbul) and Kozan (Adana) have changed, these changes have been ignored. Such situations can be taken into account in more detailed studies with fewer stations.

The location of the meteorological stations in the city is very important for this study. Since the LU/LC variation around the station is used, some stations are left in the background. For example, the stations in the eastern and western periphery of Istanbul come to the forefront, while the stations in the area close to the urbanized area before 1990 remain in the background. Stations in such regions can be considered separately by researchers.

In future studies, LST maps for 1990 and 2018 at the national level, soil temperature and other related parameters at different depths, and the final data produced in this study can be used as a basis for different researches.

The most important results of the research can be summarised as follows;

1. LU/LC change at the provincial level from 1990 to 2018 was found. Accordingly, the provinces with the highest amount of conversion from other LU/LC types to artificial surfaces are İstanbul (1041 km^2), Ankara (949 km^2), Konya (590 km^2), İzmir (581 km^2), Bursa (456 km^2), Antalya (440 km^2), Şanlıurfa (391 km^2), Balıkesir (378 km^2), Adana (346 km^2), Gaziantep (333 km^2).

2. The rate of urbanized area within a radius of 10 kilometers of all meteorological stations in Türkiye was determined. Accordingly, it was found that the rate of urbanisation of the area within a 10 km radius of 15 stations varied between 23.8% and 40.8%. 6 of the 15 stations are located in İstanbul, 4 in Ankara, 2 in Kocaeli and one each in Bursa, Gaziantep and Konya. İzmir has no stations in this group. In partial agreement with this result, the mentioned ratio creates hotspots in İstanbul and its surrounding provinces (Kocaeli, Sakarya, Tekirdağ), Bursa, Ankara, İzmir, Konya, Antalya, Adana and Diyarbakır, which are mostly located in the Csa climate type.

3. The proportion of dense urban LU/LC species within a 10-kilometer radius of meteorological stations was determined. Accordingly, the first group includes 22 stations from İstanbul (12) and Ankara (10). In the second group, there are thirteen stations from İstanbul, five each from Izmir and Adana, two each from Ankara and Kocaeli, and one each from Bursa and Konya, totaling 30 stations.

4. Finally, the direction of the relationship between the rate (%) of conversion of meteorological stations into artificial surfaces within a radius of 10 km and dense urban LU/LC ratio (%) was found to be positive with an R^2 value of 0.65. Accordingly, it proved that as the rate of conversion of the stations into artificial surfaces within a radius of 10 km increases, the dense urban LU/LC ratio also increases.

As a result, the information presented in this study and its supplement can be used to plan UHI studies in Türkiye. In this way, research can be conducted with more efficient results. In addition, a few suggestions have been made for future research. The first one is related to the findings at the province level. Various syntheses can be made by comparing the findings at the provincial level with socioeconomic development, Gross Domestic Product, production and other economic outputs in addition to population. With a population size constraint (lower threshold), Türkiye-wide studies can be conducted with various data such as meteorology, land surface temperature (LST), LU/LC. The findings produced in this research can be integrated with the data and results used by Acar (2013), Aykır (2017), Aykır et al. (2022), Yılmaz (2020), and Taşoğlu et al. (2024) and more detailed research can be carried out. In this way, new approaches and findings can be produced in the focus of climate classes, climate change and urbanisation. In addition, research can be deepened by using urbanization projections, digital twin, fluid dynamics and various simulations. In this way, the question "what will happen?" can be answered. In addition, it is suggested that urban LU/LC data should be generated according to the city boundary. Finally, if new data (especially urban LU/LC) is produced after 30 years, a comprehensive research on Türkiye's recent history can be carried out by improving the research.

Notes

[1] Supplement: https://doi.org/10.5281/zenodo.14680382
[2] All stations that were open from the day they were established until 2023, such as those that were open and closed or those that measured at certain periods, were used.
[3] Krähenmann et al. (2018) determined that an effect of 3 km occurred as a result of some calculations to remove the UHI effect from the values measured at the meteorological station in Germany. However, Yılmaz (2020) used 10 km diameter areas while determining the urbanisation rate around the station in Türkiye. In this study, various experiments were carried out using 3, 5, 10, 15 km areas, and in the end, it was thought that 10 km diameter impact areas were sufficient and better reflected the reality.
[4] The expression "1990: Forest and Semi-Natural Areas-2018: Artificial Surfaces" in the table indicates that 0.26% of the provincial boundary of GDM was in the Forest and Semi-Natural Areas type in 1990 and changed to Artificial Surfaces type in 2018.
[5] Since Karaman, Osmaniye and Adıyaman are completely surrounded by metropolitan cities, they appear as in Figure 1. It should be kept in mind that these two provinces are not metropolitan cities.
[6] This was frequently observed at stations located close to each other.
[7] The names of the provinces in the first three groups are written.
[8] The names of the provinces in the first four groups are written.
[9] In the study of Aykır (2017), station pairs were selected to represent each province, urban and rural. The provinces mentioned here are Istanbul (Istanbul and Şile), Sakarya (Sakarya-Geyve), Edirne (Edirne-Uzunköprü), İzmir (İzmir-Seferihisar), Denizli (Denizli-Güney), Isparta (Isparta-Eğirdir), Van (Van-Başkale).
[10] The fact that such a situation occurred only in Şanlıurfa and Mersin by Aykır (2017) can be associated with the geographical location of the stations. The fact that the sunshine duration is more in the south and Turkey is exposed to heat waves coming from the south may be the reason for this.
[11] These stations are Ankara (Ankara-Esenboğa), Sakarya (Sakarya-Geyve), İstanbul (İstanbul-Şile), Bursa (Bursa-Keleş), Edirne (Edirne-Uzunköprü), Denizli (Denizli-Güney), Isparta (Isparta-Eğirdir), Van (Van-Başkale) and Düzce (Düzce-Akçakoca).
[12] These stations are Afyon-Bolvadin, Muğla-Yatağan, Tekirdağ-Çorlu, Aydın-Sultanhisar, Mersin-Silifke, Şanlıurfa-Bozova, Konya-Karapınar, Bursa-M.Kemalpaşa, Ankara-Akyurt and İstanbul-Şile.

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