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Environmental impacts of urban development and sustainable landscape management: the case of Muratpaşa, Antalya

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ABSTRACT

Problem statement. Intensive urbanization stands out as a phenomenon that significantly affects environmental change and raises serious concerns about the sustainability of cities. The pressure of human activities on ecological areas causes regional ecological networks to shrink and become less connected, leads to increased pollution, deterioration of ecological functions and poses serious threats to the sustainable development of cities. This study comprehensively examines the environmental impacts of urbanization and its consequences on urban landscapes in the Muratpaşa district of Antalya. The research focuses specifically on green space distribution, carbon emissions, and land use changes, assessing how these factors influence sustainable urban development. Muratpaşa, characterized by rapid urbanization and population growth, represents a critical area for environmental and ecological sustainability.

Purpose. The primary aim of the research is to analyze the environmental impacts of urban development in Muratpaşa, to reveal the effects on the urban landscape by using the variables affected in this process, identify land use changes, and make future projections. The study seeks to address inequalities in green space distribution, carbon emissions, and the evolving dynamics of urban landscapes, providing recommendations for sustainable urban planning.

Research methods. The study employed CORINE land cover data, Landsat satellite imagery, the GHG Protocol, artificial neural networks, and Geographic Information Systems (ArcGIS). Analyses included green space evaluation, land use classification, carbon emission calculations, and projections for land use in 2040. Additionally, the distribution of green spaces was analyzed at the neighborhood level based on population density.

Research results. The research reveals a dramatic increase in motor vehicle numbers and carbon emissions in Muratpaşa between 1994 and 2023. During the same period, green spaces declined, while urbanization accelerated. Coastal neighborhoods had higher proportions of green spaces, whereas inland areas showed significantly lower levels. Projections for 2040 indicate further reductions in green spaces and increased urbanization. CORINE data demonstrated that agricultural lands and natural habitats are under significant pressure from urban development.

Conclusion. The Muratpaşa district is at a critical juncture in terms of environmental sustainability. Reducing land use changes, carbon emissions, and inequalities in green space distribution requires the adoption of sustainable urban planning strategies. Preserving green spaces, supporting biodiversity, and minimizing the carbon footprint are essential for achieving comprehensive sustainability policies.

Keywords*: sustainability, urban development, urban green areas, land use estimation, carbon emission, ArcGIS, artificial neural network, Muratpaşa, Antalya.*

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Introduction. In parallel with the rapid increase in the world population and the development of the global economy, the process of urbanization is also progressing rapidly, and urban populations and the size of urban areas are gradually increasing. Every year, more and more people migrate from rural areas to cities, contributing to the increase in the urban population. By 2023, the population of cities and towns was 4.6 billion, and it is projected to reach 5 billion by 2030 [1]. This intensive urbanization stands out as a phenomenon that significantly affects environmental change and raises serious concerns about the sustainability of cities [2]. Urbanization is a complex process shaped by the expansion of urban areas, economic use of land, transfer of rural labor to cities, and economic growth [3]. However, the growth of cities and the expansion of urban impervious surfaces have negative impacts on air quality, land use, water resources, biodiversity and climate [4-9]. In particular, the pressure of human activities on ecological areas causes regional ecological networks to shrink and become less connected [10]. This leads to increased pollution, deterioration of ecological functions and poses serious threats to the sustainable development of cities [11, 1]. In this context, the pressures of urbanization on the natural environment have led to the concept of *resilient cities*, which requires increasing the resilience capacity of cities [12], including new relevance for the study of emerging urban resilience in Ukraine [49]. However, for a long time, the science has paid limited attention to the environmental problems of cities and therefore has not been able to contribute sufficiently to the environmental impacts on urban landscapes [13, 14]. The rapidly increasing number and area size of cities has increased the need for urban ecology studies since the 2000s [15, 16]. Nevertheless, studies that address the impacts of urbanization on the natural environment in a holistic manner are still limited.

Many studies in the literature have generally addressed the environmental impacts of urbanization independently of each other and have examined the interrelationship of these impacts in a limited way. For example, one study emphasized that urbanization strengthens dependence on fossil fuels by increasing the number of automobiles and as a result, the carbon footprint grows, focusing on the difficulties in the recovery of natural resources [17, 3]. In another study, it was stated that 16% of carbon emissions worldwide originate from the transportation sector [18, 5]. In another study, they analyzed black carbon and particle number concentrations between different years according to vehicle types in Stockholm in order to measure the effectiveness of European Carbon Emission Reduction policies [19]. A similar study examined the effects of smart transportation policies on carbon emission reduction in 258 cities in China using a quasi-natural experimental method [20]; they evaluated the impact of coal use in transportation on carbon emissions and found that efficient use of coal has a strong relationship with emissions [21, 22].

The effects of urbanization on green spaces have also been widely discussed. In one study, it was stated that the reduction and fragmentation of green areas is inevitable with urbanization [23], while in Paris, changes in vegetation cover were shaped by social policies [24]. The original integrated approach using urban remote sensing (URS) and GIS for changes detection to evaluate the current state and monitor spatial transformations of the urban green spaces in Kharkiv (Ukraine) represented [51]. Some methodical issues of geoinformation approach to the urban geographic system research [50] and features of using GIS & remote sensing for sustainable land use [52] developed from the perspective of geographical science and tested on different case studies. In China, it was also emphasized that increasing urban population density and non-agricultural working population significantly affect the distribution of green areas [25]. In addition, a study conducted in the Nanjing metropolitan area using Landsat imagery between 2000 and 2020 determined that the distribution of green areas is affected by a combination of physical geography, socio-economic structures and management policies [3]. It has also been shown that economic development and vegetation improvement can be possible simultaneously with sustainable policies [8]. The effects of urbanization on climate have been associated with the increase in the areal extent of impervious surfaces and surface temperatures. A study analyzed the impact of urban expansion on climate change through surface temperatures, NDVI, NDBI and MNDWI indices using Landsat 5 TM and Landsat 8 OLI data between 1992-2021 and found a positive correlation between the size of impervious surfaces and surface temperatures [26]. In addition, a similar study revealed a strong negative correlation between NDVI and surface temperatures [27].

These studies reveal the importance of addressing the environmental and climatic impacts of urbanization in a more holistic manner. In this context, this research has been applied in Muratpaşa district, the central district of Antalya city, which is a rapidly growing and especially an important tourism center. Evaluated in 4 different categories, Muratpaşa district is based on the impact of ecology on the urban landscape. The aim of the research is to comprehensively analyze the environmental impacts of urban development in Muratpaşa district and to reveal the effects on the urban landscape by using the variables affected in this process. In this context, Antalya/Muratpaşa district's vehicle carbon emissions by years, the distribution of green areas at the neighborhood scale, land use analysis, future situation estimation and Corine analysis were conducted. The study aims to identify the unique characteristics of Muratpaşa district by analyzing the pressures on the urban environment in detail and to provide new findings to the literature.

Material and methods. The methods used in this study were selected to comprehensively analyze the environmental impacts of urban development in Muratpaşa district. The GHG Protocol was chosen for carbon emission calculations in accordance with international standards [28-32]; CORINE land cover data was chosen to monitor long-term and detailed land use changes [33-35]; Landsat 8 OLI-TIRS satellite imagery was chosen to provide high-resolution spatial analysis; and the green space analysis method was chosen to understand the relationship between population density and environmental equity [36-39]. For the future land use prediction in Muratpaşa, the Artificial Neural Network method, the accuracy of which has been proven in many studies, was applied and the estimated land use map of 2040 was made [40, 41]. These methods increase the scientific reliability of the study and allow both local and international comparisons.

Calculating carbon emissions. Within the scope of the purpose of the study and the variables obtained, the method was carried out in 4 stages. The first stage of the study was conducted to understand the relationship between the number of motorized land vehicles in Muratpaşa district of Antalya and their environmental impacts. During the research process, the Turkish Statistical Institute (TUIK) collected the motorized land vehicle data of Antalya between 1994 and 2023. This data was used to determine the change in the number of vehicles in the district over time. Then, the population ratios of Muratpaşa district with other districts were calculated and these ratios were divided by the number of vehicles to determine the average number of vehicles in the district between 1994 and 2023. Then, the average carbon dioxide emission of vehicles in Muratpaşa district was calculated by formulating the number of vehicles with the most up-to-date 2023 carbon emission rates of the GHG Protocol. The main reason for choosing the GHG Protocol is that it enables greenhouse gas emissions to be calculated within the framework of a global standard. In this way, the carbon footprint data of the district was analyzed in accordance with international comparisons [42-44, 6]. These steps are an appropriate method to analyze how the number of vehicles is related to population and environmental factors and to understand the environmental impacts of transportation in the district. The main reason for using the GHG Protocol in this process is to measure environmental impacts in a standardized way and to obtain comparable data [45]. The GHG Protocol is recognized as a global standard for calculating and reporting greenhouse gas emissions. This protocol provides a comprehensive framework for calculating and reporting GHG emissions according to a specific process and methodology. Therefore, the use of the GHG Protocol has enabled the identification of carbon dioxide emissions of vehicles in Muratpaşa district and a clear measurement of environmental impacts. Thus, calculating GHG emissions and relating these emissions to population and vehicle numbers will contribute to understanding the environmental impacts of the district and guide future landscaping sustainability efforts. The detection of carbon dioxide emissions from vehicles is an important element that increases the reliability and comparability of the research [46, 24].

Calculation of parks and green areas. Another stage of the study is the collection and analysis of park and green area data in the neighborhoods within the borders of Muratpaşa district. First, neighborhood-based park and green area data were obtained from Muratpaşa Municipality. This data includes the square meters of parks and green areas in each neighborhood. Then, the total square meters of parks and green areas in each neighborhood were divided by the number of population in that neighborhood to determine the average park and green area per capita. The purpose of this step is to determine how the area of parks and green spaces, which have psychological effects on people and environmental aesthetic value, is distributed according to the population density in each neighborhood [12, 14, 18]. In terms of landscape architecture, the amount and distribution of green spaces in neighborhoods can directly affect the quality of the urban environment and people's quality of life. Therefore, determining the amount of parks and green spaces per capita can provide important data to be used in urban planning and landscape design. The determined data will provide a basis for analyzing and improving the urban landscape in Muratpaşa district, and the ratio of the amount of green space to the population will also guide the sustainability efforts of the district and the determination of green space policies [47].

Digitization of land cover data. In another phase of the study, CORINE data for the years 1990, 2000, 2006, 2012 and 2018 published by Copernicus Land Monitoring Service were used [24, 34]. The use of CORINE data was preferred because it provides reliable land cover data based on European Union standards [8]. CORINE data is a detailed and reliable source covering land cover over various periods. These data are an important basis for understanding and monitoring land use in and around Muratpaşa district of Antalya province. CORINE land cover classes were used to classify the study area according to the characteristics of each year and the legends were prepared accordingly. This classification defines various land types and plays an important role in determining the changes that have occurred over the years [2, 45]. Using the Geographic Information Systems software ArcGIS 10.8.1, the 1990, 2000, 2006, 2012 and 2018 land cover data of Muratpaşa district and its surroundings were digitized and mapped. Thanks to this digitization process, the land use of each year can be analyzed in detail. The data obtained will contribute to the understanding of landscape changes in the region by calculating and tabulating the area covered in square kilometers for each year. The use of CORINE data can provide urban planners and environmental experts with an important basis for improving various aspects of the landscape, such as urban regeneration projects and the protection of green spaces [2, 8].

Land use classification and future forecasting. In another stage of the study, Landsat 8 OLI-TIRS (Operational Land Imager and Thermal Infrared Sensor) satellite images of 2013 and 2023, which have low cloudiness, were preferred by the United States Geological Survey (USGS) to classify the land use of Muratpaşa and its surroundings in detail and to predict future land use (Table 1) [16, 31, 33, 40]. In order to clearly reveal the change between the two years, a 10-year period was determined between the image acquisition dates and Landsat 8 OLI-TIRS satellite image was preferred because the image quality should be good in the analysis to be performed. In order to obtain the natural appearance of Muratpaşa and its surroundings, a combination of Red, Green and Blue bands was made using ArcGIS 10.8.1. In the natural view formed with the Classification tool, a sample group was formed in 4 classes. These are Forest, Plant-Agriculture Land, Build Up Area and Bare Land. For each sample, 50 samples were taken from the study area and detailed land use maps of 2013 and 2023 were created with the Interactive Supervised Classification analysis in the Classification tool [16].

In addition to the land use data for the years 2013 and 2023 obtained as a result of the analyzes made with ArcGIS 10.8.1, Digital Elevation Model (DEM), road data and river data of Muratpaşa and its surroundings were integrated into QGIS 2.18 software, another Geographic Information Systems software, by installing Molusce plug-in. Finally, by applying the Artificial Neural Network method, the estimated land use map of Muratpaşa and its surroundings for the year 2040 was created. The accuracy of this map was compared with TerrSet Geospatial Monitoring and Modeling Software, another Geographic Information Systems software, and positive results were obtained [44, 46-48].

The findings from these four phases will provide important information in a wide range of perspectives, from the environmental impacts of motor vehicles in Muratpaşa district to the distribution of green space, from land use changes to future land use projections. This information will shed light on the development of a district's environmental sustainability policies, the improvement of urban planning processes and the formulation of long-term environmental management strategies.

Table 1

Metadata of Landsat 8 OLI-TIRS satellite imagery

Satellite Image	Image Number	Shooting Date	Path/Row	Format
LANDSAT 8 OLI-TIRS	LC81780342013117LGN02	2013.04.27	178-034	GeoTiff
LANDSAT 8 OLI-TIRS	LC81780342023257LGN00	2023.09.19	178-034	GeoTiff

Findings. Table 2 shows that the number of cars has increased dramatically in Antalya Muratpaşa district since 1994. The increase in the mobility needs of individuals and businesses in parallel with population growth is the most important reason for the number of cars. The rise in income levels due to population growth and economic development, which are especially characteristic of developing countries, has enabled more people to own cars. For this reason, the number of vehicles, which has a significant impact on urban ecology, affects the urban landscape depending on air and environmental quality. The carbon dioxide emissions in Muratpaşa District between 1994 (33084585.83 KG) and 2023 (247515903.57 KG) showed an increase every year in parallel with the increase in the number of vehicles (Table 2). Although there is a decreasing trend in carbon emissions per vehicle, the total carbon emissions increasing every year is a major threat to future generations and the urban landscape. The number of Minibuses, another transportation node, has generally increased over the years observed between 1994 (704) and 2023 (3844). This increase can be attributed to factors such as increased need for public transportation, urbanization and population growth. Increasing population density and transportation needs in cities, especially in developing countries, have increased the demand for minibuses. However, it is noteworthy that carbon emissions per minibus fluctuate between 1994 (1551852.95 KG) and 2023 (8473569.83 KG). The reason for these fluctuations is that older and less efficient van models are still in use in certain years. However, there has been a general upward trend in the carbon emissions of minibuses in recent years. This increase is due to the fact that minibuses usually have diesel engines and less efficient technologies. The number of buses in Muratpaşa district increased dramatically between 1994 (496) and 2023 (2277). This can be attributed to the increase in the district's population and transportation demand. Especially in a touristic region like Antalya, the development of transportation infrastructure and the expansion of public transportation services lead to more widespread use of buses. There is a significant increase in the average carbon emissions of buses in Muratpaşa district between 1994 (1092836.48 KG) and 2023 (5018580.09 KG) (Table 1).

This increase is a result of the transportation demand in the district and the growth of bus fleets. Between 1994 (3094) and 2023 (43557), there is a significant increase in the number of pickup trucks in

Table 2

The amount of carbon emitted by cars, minibuses, buses, vans, trucks, trucks and motorcycles in Muratpaşa district between 1994-2023

Avg. Carbon (KG)	Motorcycle	Avg. Carbon (KG)	Truck	Avg. Carbon (KG)	Van	Avg. Carbon (KG)	Bus	Avg. Carbon (KG)	Minibus	Avg. Carbon (KG)	Car	Years
14732994.97	11836	12893934.92	1833	15320454.18	3094	1092836.48	496	1551852.95	704	33084585.83	16956	**1994**
15422709.13	12390	13322082.60	1893	17510570.12	3536	1229912.63	558	1679706.85	762	37687458.61	19315	**1995**
16319526.88	13111	13976345.77	1986	20207256.30	4081	1388786.82	630	1858702.32	843	42085157.40	21569	**1996**
17480017.10	14043	14587794.18	2073	24681646.21	4984	1494842.68	678	2102253.52	954	46787463.51	23979	**1997**
18316242.26	14715	15385219.23	2187	29206881.46	5898	1587065.17	720	2322329.91	1053	50396374.00	25829	**1998**
19064655.49	15316	15307617.46	2176	30988351.52	6258	1561075.20	708	2415809.98	1096	51840012.40	26569	**1999**
20061119.67	16117	16047510.17	2281	34584246.95	6984	1701924.09	772	2684931.97	1218	56438061.93	28925	**2000**
20903972.14	16794	16345875.58	2323	37328953.72	7539	1825166.87	828	2823265.70	1281	59389525.17	30438	**2001**
21594159.68	17348	16961337.87	2411	41147062.12	8310	1972303.65	895	2985912.63	1354	63087480.44	32333	**2002**
22613109.38	18167	17586165.89	2499	46762647.44	9444	2071233.23	940	3154428.26	1431	67131968.28	34406	**2003**
27090334.15	21764	23204266.20	3298	57658615.47	11644	2410779.66	1094	3939157.79	1787	74044439.89	37949	**2004**
33815402.20	27167	24358926.97	3462	67106432.89	13552	2615765.10	1187	4435901.65	2012	81240741.72	41637	**2005**
40977399.68	32921	25465421.13	3619	76390415.33	15427	2656846.03	1205	4705023.63	2134	86755581.40	44463	**2006**
44531534.12	35776	26458188.56	3760	85696054.11	17306	2857639.53	1296	4954862.74	2248	91997721.46	47150	**2007**
48133243.22	38670	26792678.93	3808	93078985.78	18797	3342226.78	1516	5058822.63	2295	97517013.37	49979	**2008**
50347949.93	40449	25620624.66	3641	98476124.46	19887	3301145.86	1497	5018999.28	2277	101752947.48	52150	**2009**
51799568.64	41615	25628652.43	3642	106385399.56	21485	3522899.02	1598	5031155.89	2282	107959368.24	55331	**2010**
53818532.86	43237	25438661.90	3615	115435870.06	23312	3811723.08	1729	5181646.22	2350	117563218.15	60253	**2011**
55938563.64	44940	26420725.64	3755	123986361.39	25039	4134082.60	1875	5318722.37	2413	126479939.22	64823	**2012**
57235623.89	45982	26290943.37	3737	130882496.01	26432	4114380.52	1866	5476338.98	2484	136333114.50	69873	**2013**
59183344.48	47547	27442928.22	3900	139164636.94	28104	4220017.19	1914	5204282.65	2361	146095018.88	74876	**2014**
61161834.74	49137	29091296.78	4134	150535161.47	30401	4328588.21	1964	5470889.47	2482	157477909.18	80710	**2015**
62142204.01	49924	30098781.79	4278	158764573.89	32063	4310562.90	1955	5503586.54	2497	166430990.20	85298	**2016**
63879744.03	51320	30921628.11	4395	166685147.96	33662	4453088.57	2020	5764324.66	2615	177101151.28	90767	**2017**
65960484.30	52992	31319002.67	4451	172233881.07	34783	4546149.44	2062	6141598.47	2786	185146717.64	94890	**2018**
68571646.47	55089	31872918.73	4530	177132923.73	35772	4655558.85	2112	6611094.77	2999	193004176.92	98917	**2019**
71525535.51	57463	33247005.18	4725	185418830.98	37446	4652624.49	2111	6830751.97	3099	205021511.23	105076	**2020**
75426183.86	60596	34972975.51	4970	194234847.97	39226	4645079.02	2107	6912913.82	3136	216344296.30	110880	**2021**
84802651.35	68129	37176598.09	5284	205583716.16	41518	4787604.68	2172	7481339.70	3394	230962109.03	118371	**2022**
100969513.30	81117	38992211.84	5542	215681224.03	43557	5018580.09	2277	8473569.83	3844	247515903.57	126855	**2023**

Muratpaşa district (Table 2). This increase is due to the need for commercial transportation and logistics requirements, along with the increase in the population and commercial activities of the district. Especially in the Muratpaşa district of Antalya, which is a touristic region, the increase in touristic activities and the expansion of the service sector have increased the demand for pickup trucks. Between 1994 (15320454.18 KG) and 2023 (215681224.03 KG), the average carbon emissions of pickup trucks in Muratpaşa district also increased (Table 2). This increase can be attributed to the fact that pickup trucks usually run on fossil fuels, increasing the carbon footprint of commercial transportation activities. Especially in the district, which is a touristic destination, intensive tourist and material transportation causes carbon emissions to increase. The number of trucks in Muratpaşa district increased significantly between 1994 (1833) and 2023 (5542), as did the number of vans (Table 2). In this period, with the increase in commercial activities and logistics needs, it is seen that the demand for trucks has increased in addition to vans. The fact that the district is a touristic region and the increase in activities in the construction sector also create an additional demand for trucks. Between 1994 (12893934.92 KG) and 2023 (38992211.84 KG), the average carbon emissions of trucks in Muratpaşa district also increased (Table 2). This increase can be attributed to the fact that trucks generally run on fossil fuels, increasing the carbon footprint of commercial transportation activities. Construction activities, material transportation and logistics requirements in the district have also increased carbon emissions, but the continued use of old trucks also contributes to the increase in carbon emissions. The number of motorcycles in Muratpaşa district increased significantly between 1994 (11836) and 2023 (81117). In this period, it is observed that the use of motorcycles increased as a result of the effects of individuals' personal transportation preferences, changes in transportation infrastructure and the city's climate being suitable for motorcycling. In particular, the intensity of urban transportation and traffic problems can also affect individuals' preference for motorcycles. The average carbon emission of motorcycles in Muratpaşa district has shown an increasing trend between 1994 (14732994.97 KG) and 2023 (100969513.30 KG) (Table 2). This increase is accompanied by an increase in the use of motorcycles, and it is inevitable that carbon emissions will increase as more motorized vehicles circulate on the roads.

Table 2 shows that the increase in the number of vehicles and the related increase in carbon emissions is an important trend that should be taken into account in terms of transportation and environmental policies of Muratpaşa district. These increases are likely to have emerged with the growth of the population and economy of the district. However, the increasing number of vehicles and carbon emissions are a major concern in terms of environmental sustainability and urban landscape.

There are 55 neighborhoods in the Muratpaşa district of Antalya province. When we look at Fig. 1, we see the distribution of green areas (park areas) at the neighborhood scale of Antalya Muratpaşa district. When Fig. 1 is examined, it is seen that green areas are concentrated close to the coast. The 10 neighborhoods that do not have green areas are located in neighborhoods far from the coast of Muratpaşa district (Fig. 1).

One of the most important dynamics in urban landscape is the green area per capita in the city. In this context, the square meter area per capita was found by proportioning the green areas to the neighborhood population at the neighborhood scale of Muratpaşa district. Fig. 2 shows the square meter green area per capita at the neighborhood scale. According to the analysis, the ratio of green space per capita is high in the neighborhoods close to the sea, while this ratio is low in the neighborhoods in the inner parts of the district. There are no green areas in 10 neighborhoods in Muratpaşa district. Neighborhoods with no data are shown in white on Fig. 2. The 5 neighborhoods with the least park area per capita are Yıldız (0.24 m^2), Güvenlik (0.26 m^2), Yüksekalan (0.45 m^2), Gebizli (0.46 m^2) and Varlık (0.55 m^2). The 5 neighborhoods with the highest park area per capita are Selçuk (256.19 m^2), Kılınçarslan (190.96 m^2), Meltem (58.40 m^2), Bahçelievler (18.31 m^2) and Şirinyalı (12.93 m^2) (Fig. 2). According to the Spatial Plans Construction Regulation of the Zoning Law No. 3194, the average green area per capita in Turkey is 10 $m^{(2)}$. Accordingly, 6 neighborhoods were observed in Antalya-Muratpaşa district that comply with the regulation (Selçuk, Kılınçarslan, Meltem, Bahçelievler, Şirinyalı and Çağlayan).

CORINE (Coordinated Information on the Environment) is a program developed by the European Union that aims to collect, process and share environmental information. CORINE enables the use of a database covering various environmental topics such as land use, land cover and natural habitats to reveal the status of the region in 1990, 2000, 2006, 2012 and 2018. Looking at the distribution of artificial surface and urban structure of Antalya/Muratpaşa district in 1990 using the Corine Land Cover Classes program, agricultural lands irrigated by irrigation canals and irrigation ponds are concentrated in the center and east of the district. Dryland agricultural lands are generally located in the east and north of Muratpaşa district. In these lands, mostly cereals and legumes are grown. Lands with fruit trees are located in the north of Muratpaşa. In these areas, citrus fruits, grapes and figs are generally grown. Broad-leaved forests are

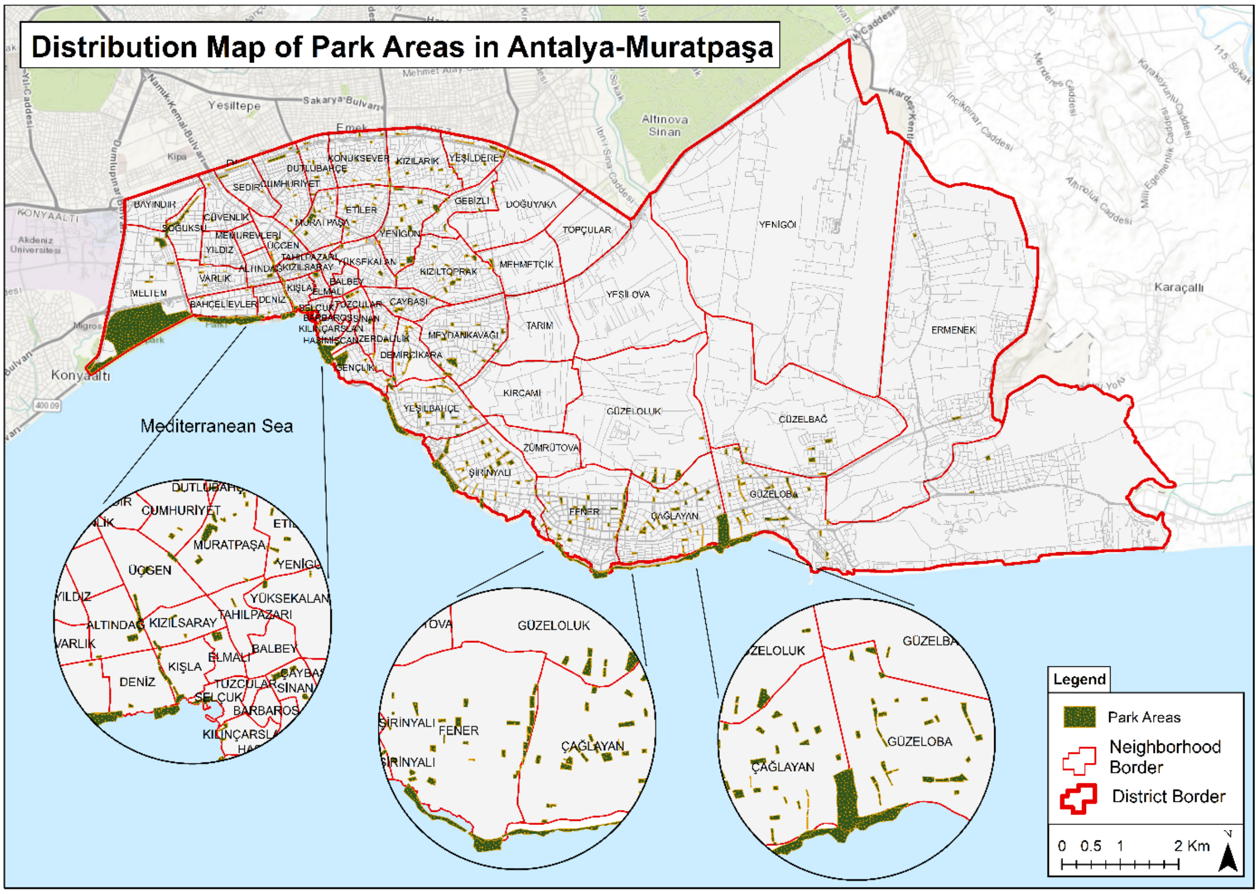

Fig. 1. Antalya/Muratpaşa district Green Area Distribution

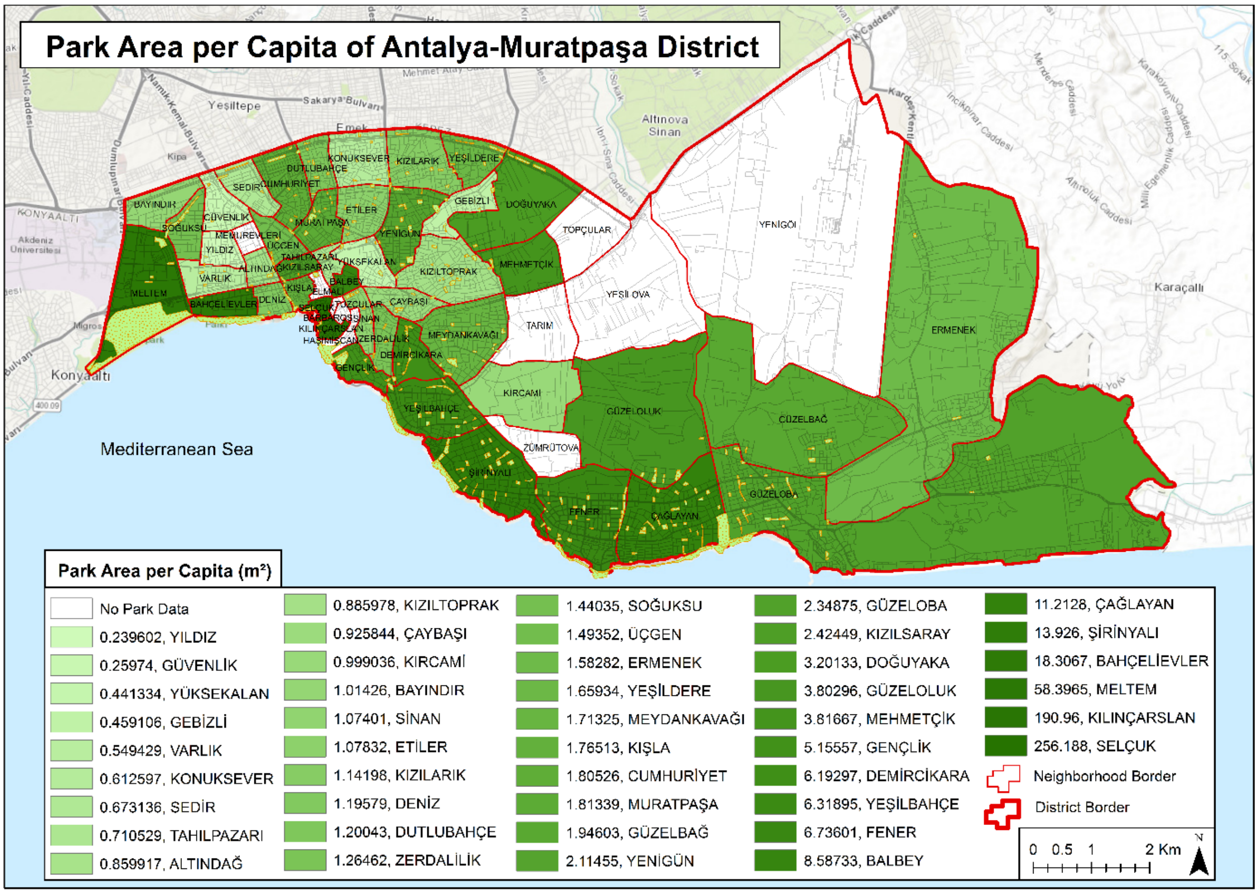

Fig. 2. Per capita green area (m^2) at the neighborhood scale in Antalya Muratpaşa district

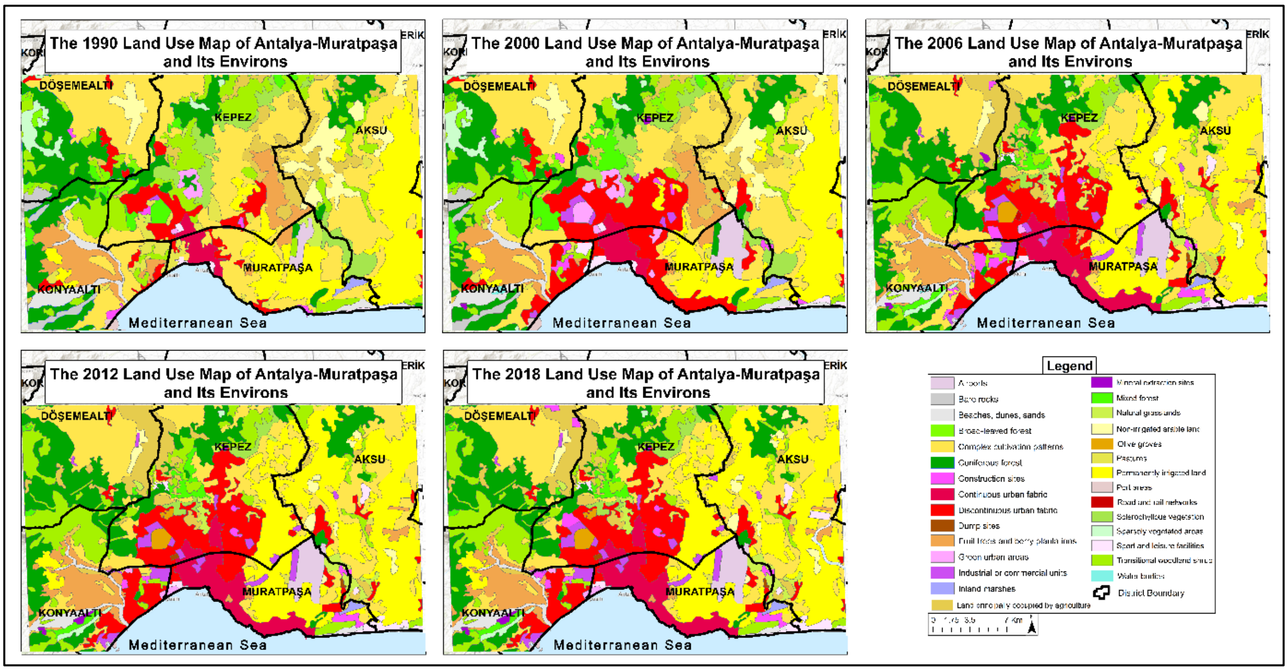

Fig. 3. CORINE land use maps of Antalya Muratpaşa district and its immediate surroundings by years

seen in the coastal area in the southeast of Muratpaşa district, while coniferous forests are seen in the northeastern part of the district. In 1990, continuous urban construction is located in the center of the district.

Looking at the 2000 land use map, it is seen that there is an increase in continuous urbanization in Muratpaşa district. Around the continuous urbanization, the area of discontinuous urbanization has expanded and moved inland from the south of Kepez district. However, discontinuous urban development has increased along the coastal area of Muratpaşa district. No change was observed in the broad-leaved trees in the southeast of Antalya, while the area of coniferous forest in the northeast expanded. Some of the continuously irrigated agricultural land has been degraded and used as an airport.

By 2006, there was an increase in the area of permanently irrigated agricultural land. Although there is not much change in Muratpaşa district, there are increases in Aksu district in general and in the intersection of Muratpaşa district in the southeast of Kepez district. In contrast to 2000, the area of continuous urbanization continues to expand along the coast. Discontinuous urbanization, on the other hand, has moved to the east of Muratpaşa district, towards the outskirts of the city, and has continued to expand north towards Kepez district. The coniferous forest area in the northeast of Muratpaşa district has been converted into a mining area.

In 2012, there was not much change in the area of permanent urban development, but discontinuous urban development continued to expand. Although it increased in the north of Muratpaşa district, it moved from the south to the center of Kepez district and started to gain a foothold in the southeast of Konyaaltı district. There is a slight increase in permanently irrigated agricultural areas north of Aksu district and east of Kepez district. However, in the surrounding districts, mixed forest areas and broad-leaved forest areas have been destroyed with the expansion of construction.

In 2018 (Fig. 3), no change was observed in Muratpaşa district. An increase in construction sites was observed in Kepez, Döşemealtı and Konyaaltı. Coniferous forests in the north of Aksu and continuously irrigated agricultural areas in the east have been destroyed.

The anthropological impact of urban greenery in the Muratpaşa district of Antalya and its immediate surroundings in 2013 is divided into 4 main categories: Forest, Plant-Agricultural Area, Building Area, Bare Land. It is seen that Muratpaşa district, located in the north of the Gulf of Antalya, is densely urbanized. Built-up areas, shown in gray, constitute the largest part of the city. Built-up areas contain urban functions such as housing, workplaces and infrastructure. Plant-agricultural areas, shown in light green, are concentrated in the north and east of Muratpaşa district. These areas provide food and agricultural products to the city. They also function as green areas. Forested areas, shown in dark green, are located in the north and southeast of the district. Forests help to improve the district's air quality, reduce noise pollution and protect biodiversity. Bare land, shown in white, is located in the northeast of the district. Looking at the immediate surroundings of Muratpaşa district, Döşemealtı district has the most forests and plant-agricultural areas. In Aksu district to the east, there are more plant-agricultural areas (Fig. 4).

In 2023, the plant-agricultural areas in Murat-

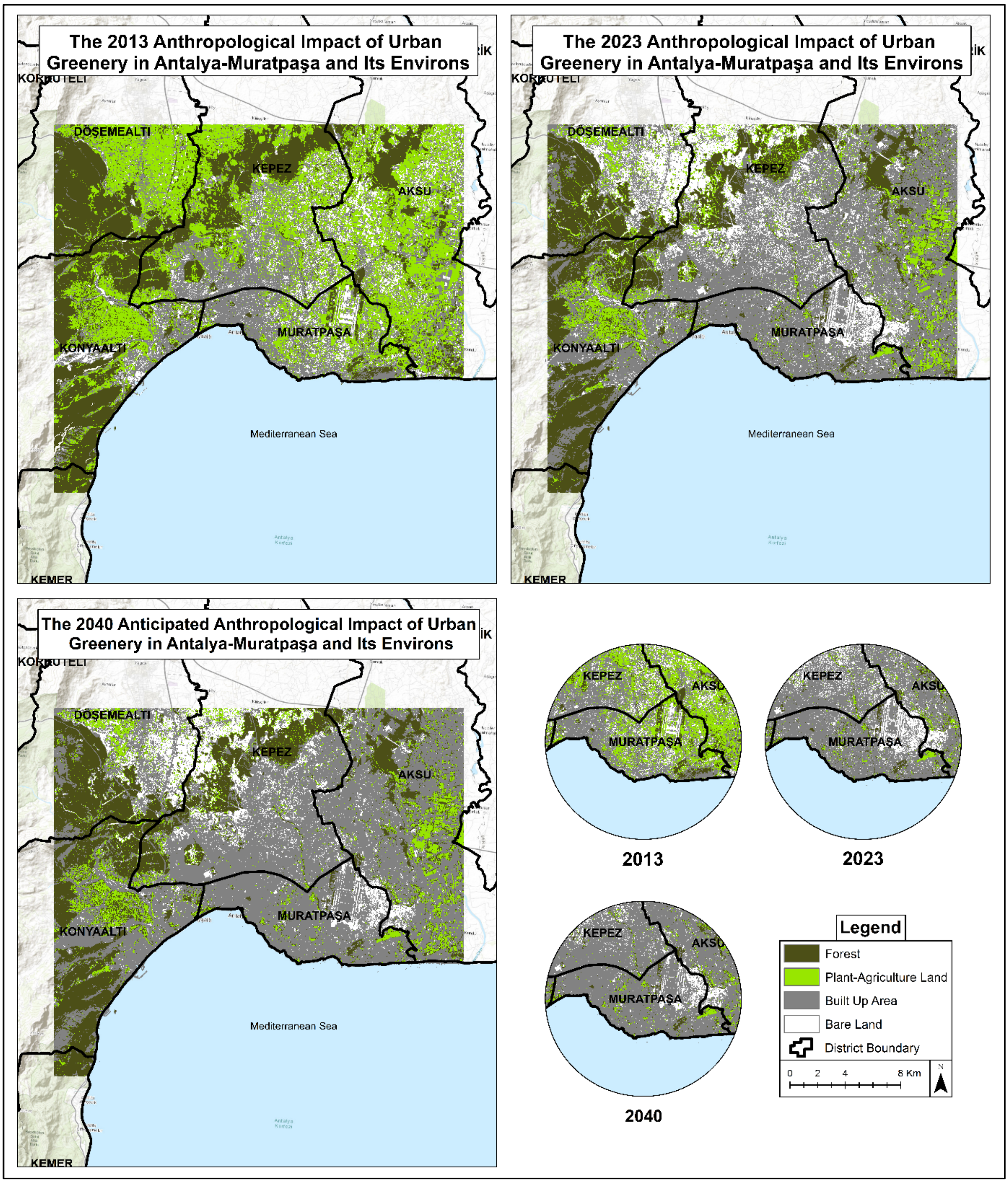

Fig. 4. Land Use Maps of Antalya/Muratpaşa and its immediate surroundings (2013-2023 and 2040)

paşa district have been visibly reduced and transformed into bare land and building areas. The building area has spread dramatically compared to 2013 and increased its density in the center and eastern parts of the district. In 2023, it is seen that forest areas decreased in the southeast of Muratpaşa district. Looking at the neighboring districts of Muratpaşa district, it is observed that plant-agricultural areas in Aksu are mostly converted into building areas, while the northern parts of Kepez district are converted into bare land, while the eastern parts are converted into building areas. In Döşemealtı and Konyaaltı districts, plant-agricultural areas were transformed into construction areas, while no significant change was observed in forested areas.

Looking at the 2040 land use projections, it is seen that the bare land in Muratpaşa district will continue to be converted into building areas (Fig. 4). It is seen that the green areas in the district center will be further destroyed and opened to construction, while the city center will be covered with concrete. By 2040, a significant decrease in forest areas is expected. This reduction will occur due to the expansion of urbanization and the contraction of agricultural activities. It is observed that the remaining forest will be located in a small area in the southeast of Muratpaşa, i.e. outside the district center. The situation is similar in the surrounding districts. With the expansion of building areas, it is estimated that there will be a contraction in bare land and agricultural-vegetation areas.

Discussion. The results of this study, which comprehensively examined the ecological dynamics of the urban landscape in the Muratpaşa district of Antalya, reveal the critical role of ecological elements on sustainable urban development. The findings of the study are in line with some studies with similar content, which emphasize the limits of the potential to reduce carbon emissions [22, 25, 37]. The significant increase in transportation-related carbon dioxide emissions in Muratpaşa in the last 20 years due to the increase in private vehicle use points to a serious problem in terms of carbon management. Analyses of transportation-related carbon dioxide emissions have revealed that the increase in the number of motor vehicles contributes to air pollution and climate change in Muratpaşa [11, 14, 28, 47, 48]. These studies emphasized that motorized vehicle use in urban areas has negative impacts on health and the environment, causing air pollution and greenhouse gas emissions. Sustainable transportation systems, public transport infrastructure and transition to alternative energy sources can contribute to the reduction of transportation-related emissions in Muratpaşa. In addition, this trend can also be associated with the findings of studies on automobile dependency and sustainable transportation . They also emphasized that the increase in private vehicle use not only creates environmental impacts but also negatively affects energy efficiency [28]. Our study supports these findings and shows that emissions from transportation contribute significantly to air pollution and climate change. In this context, it is once again clear that public transportation systems should be improved, bicycle lanes should be encouraged and sustainable transportation strategies should be implemented.

The results obtained from CORINE land cover data reveal that artificial surfaces are increasing in Muratpaşa, while agricultural areas and semi-natural areas are decreasing. These findings can be related to studies on urban landscape ecology; emphasizing the pressure of urban development on natural areas, we can say that sustainable landscape planning plays a critical role to prevent these negative trends [38]. Land use maps in Muratpaşa show that between 2013 and 2023, built-up areas increased while forest and vegetation cover decreased. Projections for 2040 indicate that this trend will continue. These findings are in line with similar studies. In these studies, they emphasized that urban development causes fragmentation of natural areas, habitat loss and reduction in biodiversity. Similarly, they support the idea that the decrease in green areas in Muratpaşa may lead to a threat to biodiversity [21, 24, 30, 41, 42, 47]. Some studies on land use changes show that the impacts of human activities on land cover can lead to loss of ecosystem services and weaken environmental sustainability. The findings of our study, in this respect, concretely demonstrate the pressure of urban development on natural areas and point to the vital importance of sustainable land use planning to reverse this trend [10-12, 15, 32, 48].

The fact that the amount of parks and green areas per capita in Muratpaşa shows significant differences between neighborhoods points to inequalities in the distribution of green areas [9, 42]. The fact that the amount of parks and green spaces per capita differs on a neighborhood basis in Muratpaşa is in line with the studies conducted. These studies emphasized that equal distribution of green spaces is important for human health, welfare and environmental justice. The lack of green areas in some neighborhoods in Muratpaşa can be considered as a deficiency in this sense [5, 7, 12, 29, 34]. Fair distribution and accessibility of green spaces should be taken into consideration in the urban landscape planning process. Similarly, in another study on biodiversity and green space access in urban ecosystems, it was stated that inequalities in access to green spaces may have negative effects on social welfare [43]. Our study showed that access to green space in some neighborhoods in Muratpaşa is quite limited and only six neighborhoods meet the legal per capita green space standard. This clearly demonstrates the need to prioritize green space distribution in planning processes for sustainable urban development and the importance of integrating the principles of social justice and environmental sustainability.

The results obtained from the settlement forecast maps, where the anthropological impact was analyzed, show that the built-up areas in Muratpaşa will increase significantly by 2040 and this increase will create serious pressures on existing green areas and natural habitats. This finding can be related to studies evaluating urbanization and ecological systems; it can be said to confirm the conclusion that rapid and uncontrolled urbanization leads to disruption of ecological balance, loss of biodiversity and transformation of ecosystem processes [41]. The fact that anthropological impacts will limit landscape studies in the future and green areas may disappear is in line with studies on a similar subject. These studies emphasized that urban development leads to fragmentation of natural areas, habitat loss and reduction of biodiversity. The predicted development trend in Muratpaşa may lead to similar results. Sustainable urban planning, preservation of green areas and protection of sensitive natural areas are of great importance in preventing these negative impacts. It is also in line with the findings that dense development threatens the ecological balance by suppressing natural habitats and causes loss of biodiversity [16, 26]. Our study predicts that a similar scenario will occur in Muratpaşa if the current development trends continue and emphasizes once again the importance of sustainable planning policies that take into account ecological dynamics in order to reverse these negative trends.

The findings of this study clearly reveal that ecological factors should be taken into account for the sustainability of urban areas, quality of life and ecological balance. Conservation of green areas, afforestation efforts, sustainable transportation systems and transition to alternative energy sources can be among the strategies that will serve this purpose. However, it is also important to continuously monitor and evaluate the relationship between ecological factors and the urban landscape.

Conclusion. This study has comprehensively examined the ecological dynamics in the urban landscape of the Muratpaşa district of Antalya and has scrutinized the role of ecological factors. The findings clearly demonstrate that ecological factors are vital for sustainable urban development. CORINE land cover data shows that during the 1990-2018 period, artificial surfaces have increased in Muratpaşa, while agricultural areas and semi-natural areas have decreased. This situation concretely reflects the pressure of urban development on natural areas. Protecting green areas, adopting appropriate landscape design strategies and sustainable land use planning can contribute to reversing this negative trend [38]. It has been determined that carbon dioxide emissions from transportation in Muratpaşa have increased significantly in the last 20 years. The main reason for this increase is the high rate of increase in private vehicle use. The results of the analysis show that the increase in the number of motor vehicles directly contributes to air pollution and climate change [22, 25]. Another result of the study revealed that the amount of parks and green spaces per capita in Muratpaşa varies significantly on a neighborhood basis. While some neighborhoods have very limited access to green space (there are only 6 neighborhoods that comply with the green space per capita provision deemed sufficient by law), some other neighborhoods have higher amounts of green space. This points to inequality in the distribution of green space in the region. In addition, the settlement forecast maps, where the anthropological impact is analyzed, show that the built-up areas in Muratpaşa will increase significantly by 2040. This increase is projected to put pressure on existing green areas and natural habitats. If future development continues uncontrolled, there is a risk that the ecological balance of the region will be seriously disrupted [24].

Research findings clearly show that urbanization creates environmental impacts such as loss of natural areas, carbon emissions from transportation and green space inequalities. In particular, the increase in artificial surfaces and the decrease in green areas have led to a deterioration in ecological balance, and projections for 2040 indicate that these negative trends will continue. As a result, adopting sustainable urban planning strategies, protecting natural areas and strengthening green infrastructure in Muratpaşa are of fundamental importance in reducing environmental impacts. In this context, our findings are important for local governments and decision makers to adopt a holistic planning approach that considers environmental, social and economic balances. Local governments, non-governmental organizations, academia and the public working in cooperation to implement these recommendations will make significant contributions to ensuring the ecological sustainability of Muratpaşa. Thus, the environmental quality of the region will be improved, the quality of life will be increased, a healthier urban heritage will be left to future generations and a sustainable urban environment will be created.

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Екологічні наслідки урбаністичного розвитку та стале управління ландшафтами: кейс Муратпаші, Анталія

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Інтенсивна урбанізація є явищем, що суттєво впливає на зміну довкілля та викликає серйозні занепокоєння щодо сталості розвитку міст. Тиск людської діяльності на екологічні території спричиняє скорочення та зменшення зв’язності регіональних екологічних мереж, підвищує рівень забруднення, погіршує екологічні функції та створює загрозу сталому розвитку міських територій. Це дослідження комплексно розглядає екологічні наслідки урбанізації та її вплив на міські ландшафти в районі Муратпаша міста Анталія, що включає аналіз екологічних наслідків урбаністичного розвитку в Муратпаші, виявлення впливу цього процесу на міський ландшафт через аналіз дотичних змінних, виявлення змін у землекористуванні та прогнозування їхньої майбутньої динаміки. Дослідження має на меті подолання просторових нерівностей у розподілі зелених зон, оцінку викидів вуглецю та динаміки трансформацій міського ландшафту, а також формування рекомендацій щодо сталого міського планування. У роботі використано дані CORINE про землекористування, супутникові знімки Landsat, Протокол GHG, штучні нейронні мережі та геоінформаційні системи (ArcGIS). Проведено оцінку зелених зон, класифікацію землекористування, розрахунок викидів вуглецю, а також прогнозування змін у землекористуванні до 2040 року. Крім того, було здійснено аналіз розподілу зелених зон на рівні мікрорайонів залежно від щільності населення. Дослідження виявило різке зростання кількості автотранспорту та викидів вуглецю в Муратпаші в період з 1994 по 2023 рік. У той самий час площі зелених зон скоротилися, а темпи урбанізації зросли. У прибережних районах спостерігалося більше зелених насаджень, тоді як у внутрішніх – значно менше. Прогнози на 2040 рік свідчать про подальше зменшення зелених зон і збільшення щільності забудови. Дані CORINE демонструють, що сільськогосподарські угіддя та природні середовища зазнають суттєвого тиску внаслідок міського розвитку. Район Муратпаша перебуває на критичному етапі в контексті екологічної сталості. Зменшення змін у землекористуванні, викидів вуглецю та просторової нерівності у розподілі зелених зон вимагає впровадження стратегій сталого міського планування. Збереження зелених насаджень, підтримка біорізноманіття та мінімізація вуглецевого сліду є ключовими умовами реалізації ефективної політики сталого розвитку.

Ключові слова*: сталість (стійкість), урбаністичний розвиток, міські зелені зони, прогнозування землекористування, викиди вуглецю, ArcGIS, штучна нейронна мережа, Муратпаша, Анталія.*

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