Quantitative Assessment of Urban Sprawl Dynamics During the COVID-19 Pandemic Using AI-Supported Satellite Data

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Abstract: This study aims to quantitatively assess the effects of socioeconomic changes experienced during the COVID-19 pandemic on urban sprawl dynamics. The research was conducted in the Döşemealtı District of Antalya Province, located in the Mediterranean Region of Türkiye, which stands out with its semi-rural urban characteristics and is part of one of the country's most important tourism destinations. Settlement dynamics, expansion patterns of built-up areas, and their spatiotemporal changes in the study area were analyzed for the pre- and post-pandemic periods using artificial intelligence–supported land use/land cover (LULC) data. In this context, the Built-up class filtered from the ArcGIS Living Atlas LULC dataset was compared between 2017 (pre-pandemic) and 2023 (post-pandemic), and thematic maps of built-up surfaces were produced for each reference year. These maps were analyzed using geographic information system (GIS) technologies to evaluate the magnitude, spatial direction, and temporal trends of changes in impervious surfaces.The findings indicate that the spatial restructuring tendencies triggered by the pandemic reached a remarkable scale in the Döşemealtı District, with an increase in construction clusters within rural belts and a rapid conversion of vacant lands into built-up areas. Impervious surfaces, which covered 4146,94 km^2 in 2017, increased to 4412,74 km^2 in 2020, reached 5426,62 km^2 in 2023. Accordingly, a short-term increase of 30,9% in impervious surfaces was observed, largely attributable to the pandemic period. By providing a rapid, low-cost, and objective analytical framework, this study demonstrates strong potential for application in remote sensing–based urban planning and spatial change monitoring during crisis periods. The results are expected to serve as an important data source for regional and local authorities in defining urban growth strategies, supporting sustainable planning decisions, and evaluating spatial transformations in future disaster or crisis scenarios.

Keywords: Urban sprawl, Impervious surfaces, AI supported LULC, COVID-19 pandemic, Remote sensing, Spatial statistics.

1. INTRODUCTION

The spatial transformation of urban areas over time plays a crucial role in shaping contemporary urban planning policies. Monitoring this transformation is of great importance for sustainable urbanization strategies, infrastructure planning, environmental impact assessment, disaster risk management, and sustainable urban growth [1]. Urban sprawl, in particular, has been increasing in an uncontrolled manner in developing countries, leading directly to problems such as environmental degradation, loss of natural areas, and imbalances in resource use [2]. In addition, migration driven by various economic, social, and cultural factors exerts significant pressure on urban expansion strategies [3]. Consequently, scientific studies addressing the causes of urban sprawl, its economic impacts, expansion strategies, pressures on urban systems and natural resources, as well as its social and cultural implications, have increased considerably in recent years [4-6]. Within this context, analyzing urban growth processes both temporally and spatially has become a necessity for effective urban planning and the promotion of sustainable urban living [7, 8].

The COVID-19 pandemic has had significant impacts on settlement systems and population movements. In particular, during the initial phase of the pandemic, the high population density of large cities and heightened health risks triggered a tendency among some individuals to relocate to less dense rural or peri-urban areas [9] . In many countries, mobility restrictions and the widespread adoption of remote working reduced the attractiveness of city centers while increasing the relative appeal of rural areas. Media narratives and several academic studies reported a migration trend from urban cores toward rural and more open spaces; this shift led to a reduction in net out-migration or even an increase in in-migration in certain rural regions [10]. In Europe, evidence suggests that migration to rural areas intensified during the COVID-19 period, with an increase in internal migration toward rural regions in 2020, particularly those located near urban centers and characterized by second-home ownership [11]. Similarly, studies conducted in

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countries such as China indicate that pandemic-related uncertainty and health concerns influenced temporary or permanent migration decisions from urban to rural areas [12]. In the Türkiye context, research shows that especially the elderly population tended to move from large metropolitan areas to smaller towns and rural settlements during the pandemic; this trend has been associated with regional differences in the implementation of COVID-19 measures [13]. Such tendencies demonstrate that migration toward rural areas has the potential to transform not only demographic structures but also land use patterns, economic activities, and settlement dynamics in rural regions [14]. To manage this transformation sustainably and to prevent potential adverse spatial, environmental, and socio-economic impacts, land use changes and settlement dynamics in rural areas need to be monitored regularly using systematic and quantitative methods [15]. Such monitoring processes can support evidence-based planning and policy-making, thereby contributing to the development of healthy, balanced, and resilient spatial development strategies.

Remote sensing technologies, satellite imagery, and particularly high-accuracy Land Use/Land Cover (LULC) data constitute core components of contemporary spatial analysis for monitoring and analyzing urban sprawl [16-18]. With the COVID-19 pandemic, shifts in lifestyle preferences, the widespread adoption of remote working, and changes in health risk perception have led to pronounced spatial restructuring in urban development processes, making the careful and systematic monitoring of urban sprawl increasingly necessary [19]. Tracking LULC changes over a defined time period, especially when focusing on the built-up class, provides highly accurate quantitative information on the direction, rate, and intensity of urban growth. Revealing the spatiotemporal patterns of increases in built-up areas enables an assessment of the relationships between pandemic-induced settlement preferences and urban expansion. Moreover, satellite image classifications supported by artificial intelligence and machine learning algorithms enhance the accuracy of LULC data, allowing for more precise quantitative analyses of the impacts of urban sprawl on agricultural lands, natural ecosystems, and open spaces [20]. The integrated use of remote sensing and geographic information systems (GIS) yields quantitative outputs that not only characterize existing urban sprawl trends but also support the development of future spatial growth scenarios. In this respect, LULC-based analyses represent an indispensable tool for monitoring urban sprawl dynamics during and after the pandemic, contributing to sustainable land management, balanced spatial development, and evidence-based planning decisions.

In this context, Döşemealtı District, located within Antalya Province, has emerged as an area that has been experiencing rapid population growth and increasing urbanization pressure in recent years, while still largely preserving its natural and rural character. Especially following the COVID-19 pandemic, settlement preferences have shifted in Türkiye, as in many other parts of the world, with individuals increasingly favoring less dense living environments closer to natural settings [21, 22]. The pandemic has represented a critical turning point that directly influenced spatial settlement behaviors, manifesting in many regions as a movement from urban centers toward rural and peri-urban areas [23, 24]. This trend has intensified construction pressure in districts surrounding metropolitan areas and accelerated urban sprawl processes [25, 26]. However, how these transformations have materialized geographically, which specific areas have experienced concentrated increases in built-up development, and the measurable magnitude of these changes remain insufficiently documented in the existing literature, and research on these issues is still ongoing [27, 28]. While most academic studies primarily focus on urban growth in major city centers, the present study seeks to make an original contribution by concentrating on the pandemic-driven transformation of rural–urban transition zones.

The primary objective of this study is to analyze the urban sprawl process in the Döşemealtı District during the pandemic period (2017–2023) by using artificial intelligence–supported LULC data, to reveal the spatial dimension and trends of this change, and to concretely evaluate the impacts of the pandemic on built-up areas. To monitor temporal change, a seven-year period between 2017, representing the pre-pandemic baseline, and 2023, corresponding to the post-pandemic recovery phase, was considered. This temporal delimitation was adopted to ensure data consistency and to enable a focused assessment of the direct effects of the pandemic.

In the study, freely accessible, AI-generated LULC datasets, whose usability and adoption have increased significantly in recent years, were employed, and thematic maps for the relevant years were produced and analyzed within a GIS environment. Through this approach, the changes and expansion patterns of built-up areas in Döşemealtı District, one of the closest districts to the Antalya city center and an area that has experienced rapid construction growth particularly after the pandemic, were quantitatively identified. The findings are expected to contribute to decision-support mechanisms aimed at preventing unplanned development and promoting sustainable settlement policies. Moreover, the proposed methodology offers a replicable model that can be applied to other regions with similar demographic and geographic characteristics, thereby providing a foundation for large-scale spatial analyses. Overall, this study constitutes a comprehensive investigation that spatially examines the effects of the COVID-19 pandemic on urban sprawl and presents an original case study focused on medium-scale settlement units. Both in terms of its methodology and its thematic focus, the study offers a timely, measurable, and meaningful contribution to sustainable urbanization policies.

The originality of this study arises from several interrelated and innovative approaches. First, the use of artificial intelligence–supported annual LULC data provided by the ESRI ArcGIS Living Atlas for the 2017–2023 period enables the monitoring of spatial changes with high temporal resolution, allowing a clear comparison of pre- and post-pandemic dynamics. Second, rather than conducting a generalized evaluation of all LULC classes, the analysis specifically focuses on the "Built Area" class, which most effectively reflects the dynamic characteristics of the study area, thereby enabling a more in-depth examination of the urbanization process. Through this approach, urban expansion is analyzed not only as a quantitative increase in area but also in terms of its spatial patterns, development trends, and directional growth. Moreover, the study reveals the impacts of an abrupt and unexpected global shock, such as the COVID-19 pandemic, on urban transformation and migration dynamics in Döşemealtı District, an area characterized by a predominantly rural structure. In this respect, the study differs from the existing literature, which predominantly examines pandemic effects in major metropolitan areas, and contributes a novel perspective by addressing urban expansion and population movements within the context of rural–peri-urban settlements.

2. MATERIAL AND METHODS

2.1. Study Area

The study area was selected as Döşemealtı District, located in the southern part of Türkiye and characterized by prominent tourism and agricultural activities, within Antalya Province at approximately 37°01′22.89″ N and 30°36′04.35″ E. Döşemealtı is situated in the mediterranean region of Türkiye, approximately 20 km north of the Antalya city center (Figure **1**). The district occupies a strategic position along the northward development axis of the Antalya metropolitan area and was therefore selected as the study area due to the pronounced concentration of settlement tendencies driven by its climatic conditions, vegetation characteristics, and social and cultural structure. Although the mediterranean climate generally prevails in the district, its higher elevation and inland location result in cooler winters and more pronounced temperature variations compared to coastal areas [29]. Summers are typically hot and dry, while winters are mild and rainy [30].

2.2. Data sets

In this study, global LULC data provided within the Esri-ArcGIS Living Atlas of the World were used to

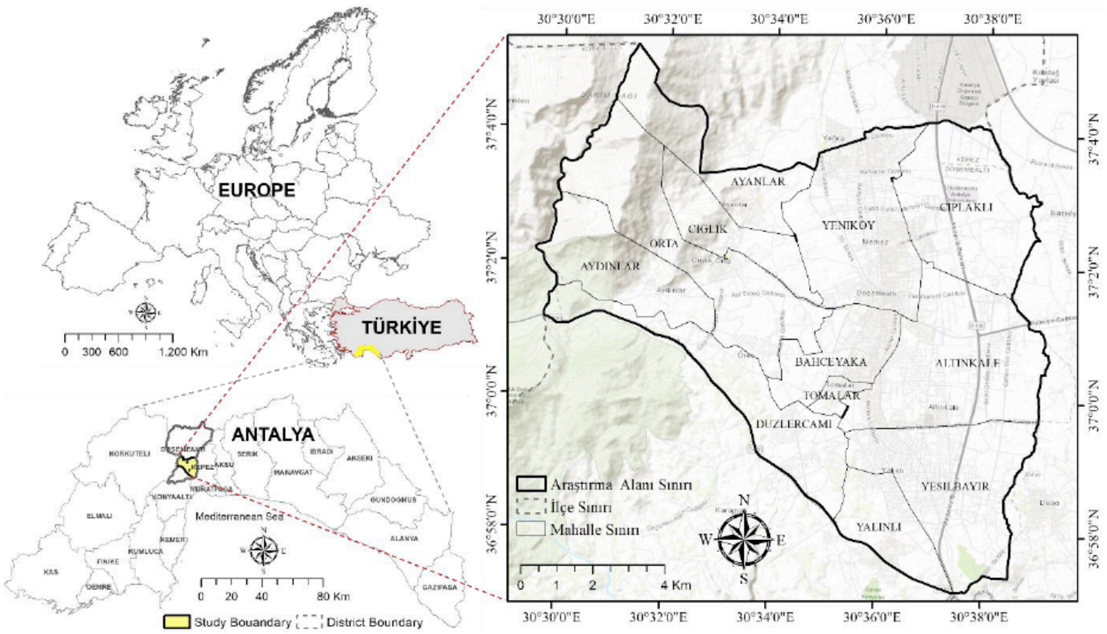

Figure 1: Study area location.

reveal the spatiotemporal changes in impervious surfaces in Döşemealtı District. The ArcGIS Living Atlas and the integrated Earth Observatory/Esri global LULC datasets generate high-resolution (10 m) annual global LULC maps using Sentinel-2 satellite imagery from the European Space Agency. In this production process, state-of-the-art artificial intelligence (deep learning) models are employed; for example, UNet-based deep learning architectures are used to predict a land-cover class for each Sentinel-2 pixel, and these predictions are composited from dozens of images acquired throughout the year to produce the final map. This global model typically includes nine main classes. The LULC classification models are trained on Sentinel-2 multispectral reflectance data and optimized using deep learning algorithms with billions of human-labeled samples collected from diverse biomes worldwide. Overall classification accuracy is generally around or above 85%, varying by class and region, and is considered reliable for global-scale change analyses.

These AI-supported LULC datasets available through the ArcGIS Living Atlas are provided as time series that support monitoring land-cover changes over time and form a basis for sustainability and planning analyses [31-33]. The nine primary classes include: Water, representing rivers, lakes, and seas with dominant water presence throughout the year; Trees, areas covered by tall and dense vegetation; Flooded Vegetation, wetlands with abundant vegetation mixed with water; Crops, human-planted cereals and field crops; Rangeland, natural grasslands and open areas; Bare Ground, rock and soil surfaces with little or no vegetation; Snow/Ice, persistent snow and ice in mountainous and high-latitude regions; Clouds, pixels where land information cannot be retrieved due to cloud cover; and Built up, representing urban and settled regions with associated infrastructure where human activities are dominant. Within this classification scheme, the “Built up” class specifically defines the human-made environment, including residential buildings, commercial and industrial structures, as well as homogeneous impervious surfaces such as wide asphalt roads, parking lots, and railway lines. These surfaces are spectrally distinguished from surrounding vegetation and bare ground in satellite imagery. The built-up class is particularly critical for tracking urbanization, infrastructure development, and the spatial expansion of human activity. The model training relies on deep learning algorithms optimized with billions of human-labeled pixel samples, enabling the production of global LULC outputs [32]. In this study, annual LULC data for the period from 2017 to 2023 were used, and the interannual change, trend, direction, and magnitude of the built-up class were quantitatively determined.

The primary reason for selecting Sentinel-2–based and artificial intelligence–supported LULC data in this study is their ability to capture spatial changes occurring before and after the pandemic with high temporal continuity and adequate spatial resolution. Sentinel-2 imagery, with its multispectral structure and 10 m spatial resolution, is widely recognized as a reliable data source for analyzing urban development dynamics and spatial expansion patterns. In addition, the artificial intelligence–supported annual LULC datasets provided by the ESRI ArcGIS Living Atlas offer a consistent and standardized time series covering the 2017–2023 period, thereby enabling a comparative assessment of the spatial impacts of sudden and unexpected events such as the COVID-19 pandemic.

2.3. Methods

In this study, a multi-stage spatial analysis approach was applied to examine the effects of the COVID-19 pandemic on urban sprawl in the Döşemealtı District. The methodological framework consists of four main stages: data acquisition, data preprocessing, thematic map production, and spatial statistical analyses.

Data Acquisition: As the primary data source, LULC datasets freely provided through the ArcGIS Living Atlas [32] were used. LULC data for the years 2017, 2018, 2019, 2020, 2021, 2022, and 2023 were selected for analysis. Particular emphasis was placed on the “built-up” (impervious surface) class. The main objective of the data acquisition stage was to obtain high-resolution, up-to-date, and reliable spatial data to enable an accurate analysis of temporal changes in urban areas.

Data Preprocessing:The acquired LULC datasets were processed within the ArcGIS Pro environment. First, the coordinate systems and projections of all datasets were standardized (UTM Zone 36, WGS 84). The data were checked for missing or erroneous values; NoData cells in raster datasets were identified and, where necessary, filled or excluded. In addition, to ensure interannual comparability, all datasets were resampled to a consistent spatial resolution and extent. This stage is critical for ensuring the consistency and accuracy of the analysis results.

Thematic Map Production: Following preprocessing, thematic maps representing the built-up class were generated from the LULC raster datasets. Using the “Reclassify” tool in ArcGIS Pro, the built-up class was separated from other land-cover classes, resulting in raster layers representing only impervious surfaces.

These layers were symbolized by year to visualize the spatial distribution of urban sprawl. Furthermore, built-up surfaces were converted into vector format using the “Raster to Polygon” tool to facilitate subsequent analyses. This class includes buildings, roads, parking areas, and other hardened surfaces and is considered a reliable indicator for monitoring urban sprawl and land-use change [34]. The thematic maps constitute the core data source for the comparative assessment of the spatial and temporal dimensions of urban expansion.

Spatial Statistical Analyses and Comparative Assessment: Changes in built-up areas over time were analyzed using the “Zonal Statistics as Table” tool in ArcGIS Pro. Based on the resulting statistical outputs (*e.g.*, total area, mean size, magnitude of increase), the extent, direction, and trend of urban sprawl were quantitatively evaluated. Interannual comparisons were conducted using both absolute area changes and percentage change rates calculated with 2017 as the reference year. These analyses were performed to identify pre- and post-pandemic trends in urban expansion, changes in spatial intensity, and potential directions of sprawl.

In order to support the accuracy of urban expansion detection and the reliability of the classification results, official population growth statistics and building permit data issued by municipalities for the corresponding years were utilized in this study. As these official datasets directly reflect increases in population density and new construction trends within the study area, they were spatially compared with the LULC classification results. The analyses indicate a high degree of consistency between the spatial expansion patterns of the Built Area class and both official population growth figures and the number of issued building permits. This consistency confirms that the classification is reliable both spatially and temporally and accurately represents urbanization dynamics during the pre- and post-pandemic periods.

Overall, this methodological approach aims to objectively examine the spatiotemporal dimensions of urban sprawl in the Döşemealtı District and to reliably assess the impacts of the pandemic on urban development processes.

3. RESULTS

In this study, the impacts of the COVID-19 pandemic on urban sprawl in the Döşemealtı District were analyzed using LULC data covering the period from 2017 to 2023. Thematic maps generated for the built-up class, together with spatial statistical assessments, enabled a quantitative evaluation of changes in the temporal and spatial distribution of urban areas. The analyses focused on identifying differences in the magnitude, direction, and trends of urban sprawl between the pre-pandemic and post-pandemic periods. Within this framework, thematic maps of the built-up class corresponding to the pandemic period are presented in Figure **2**.

According to the 2017 thematic map of the Döşemealtı city center and its surroundings, impervious surfaces were predominantly concentrated around core urban areas and on the left side of the main highway. In particular, clusters of impervious surfaces were observed in the neighborhoods of Altınkale, Yeşilbayır, Yeniköy, and Çıplaklı, whereas areas such as Yalınlı, Aydınlar, and partly Orta Mahalle exhibited a more fragmented and lower-density distribution. In 2018, the spatial pattern largely resembled that of the previous year; however, limited retreats and increased spatial fragmentation of impervious surfaces were observed in the neighborhoods of Düzlerçamı, Altınkale, Yeşilbayır, Yalınlı, Yeniköy, and Ayanlar. The reduction of impervious surface areas along the peripheries of these neighborhoods suggests that land-use transformation processes were influential during 2018. Despite this, the core settlement structures of Altınkale and Yeşilbayır, as well as the neighborhoods of Çıplaklı and Tomalar, largely preserved their spatial continuity, indicating ongoing development.

The 2019 map reveals a more pronounced increasing trend in impervious surfaces, particularly in Altınkale, Yeşilbayır, Çıplaklı, and Yeniköy, where expansion occurred in more continuous and consolidated spatial forms. In contrast, Yalınlı and Aydınlar continued to display fragmented impervious patterns, while Ayanlar showed limited year-to-year fluctuations. The concentration of impervious surface growth mainly around existing settlement areas in 2019 indicates a contiguous and gradual pattern of urban sprawl in the Döşemealtı city center. By 2020, a decrease or weakening in the spatial continuity of impervious surfaces was observed in several neighborhoods. Notably, Düzlerçamı, Yalınlı, Ayanlar, and partly Yeşilbayır exhibited increased fragmentation and land-use changes at the parcel scale, whereas Altınkale, Çıplaklı, and Yeniköy maintained their growth trend and spatial coherence. This spatial pattern suggests a slowdown in the overall rate of impervious surface expansion in Döşemealtı during 2020, accompanied by land-cover transition processes in certain areas, which can be interpreted as a preparatory phase for construction driven by pandemic-related dynamics.

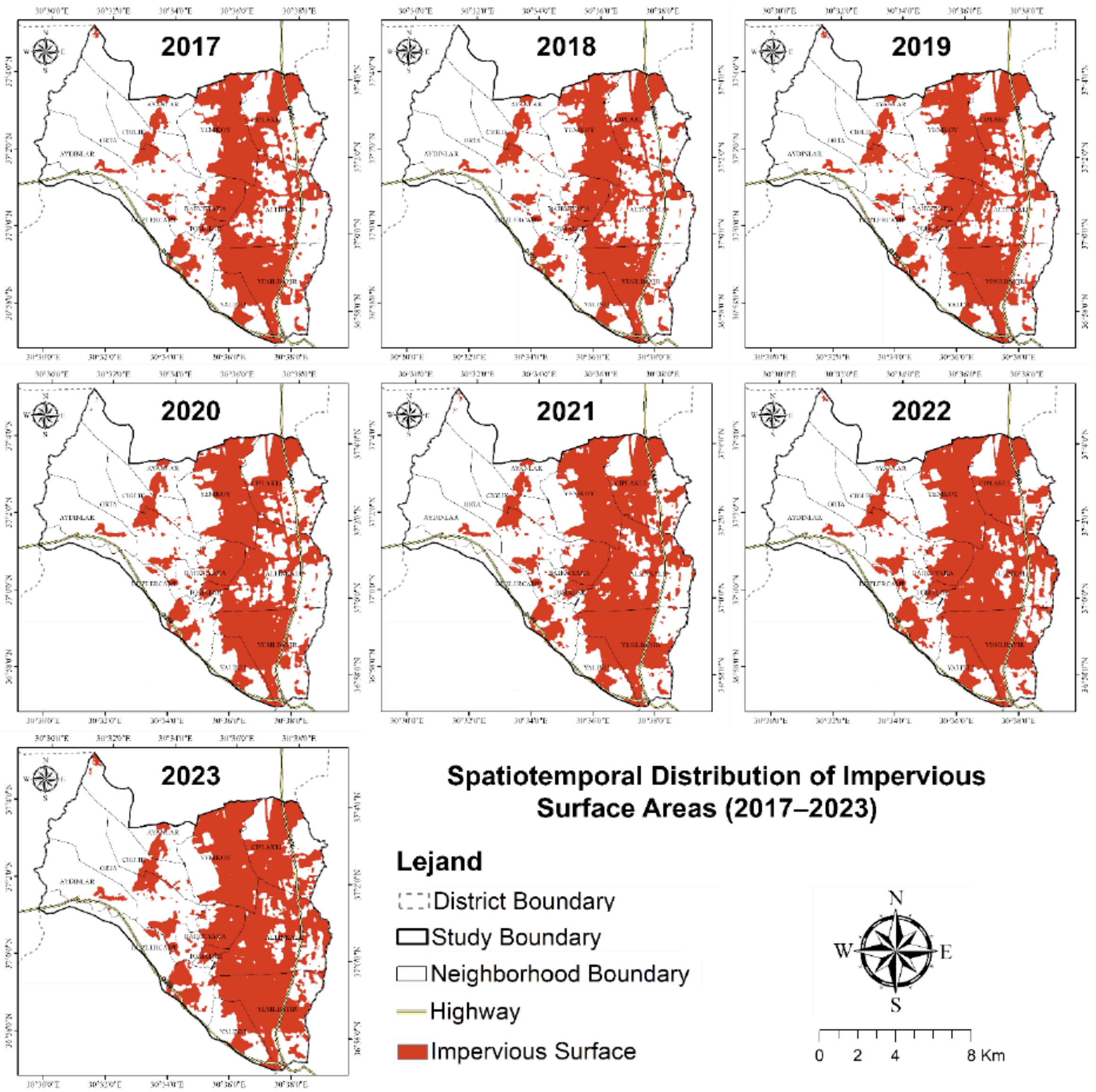

Figure 2: Thematic maps of the built-up class for the period 2017–2023.

In 2021, impervious surfaces increased markedly and displayed a wider spatial spread. Significant expansions in both area and spatial continuity were observed in Altınkale, Çıplaklı, Yeşilbayır, and Orta Mahalle. New impervious surfaces also emerged in Bahçekaya and Tomalar, while growth remained relatively limited and fragmented in Yalınlı and Aydınlar. The 2021 map indicates an acceleration of construction and infrastructure pressure in Döşemealtı and the onset of a major land-use transformation process. This trend intensified further in 2022, during which impervious surfaces reached their highest levels of density and continuity across the district. Particularly in Çıplaklı, Altınkale, and Yeşilbayır, impervious surfaces became more integrated and uninterrupted, while Bahçekaya, Orta Mahalle, and Tomalar experienced notable expansion that filled gaps between settlement areas. In contrast, increases in Yalınlı and Aydınlar, which are located farther from the city center, remained relatively limited. Accordingly, 2022 can be considered the period when urban sprawl and construction pressure were most intense in Döşemealtı.

In 2023, a general stabilization and, in some areas, limited retreat of impervious surfaces were observed compared to 2022. Peripheral reductions and increased spatial fragmentation occurred particularly in Düzlerçamı, Yeşilbayır, and Bahçekaya. Conversely, Altınkale, Çıplaklı, and Yeniköy largely preserved their impervious surface extent and spatial integrity. Overall, the 2023 patterns suggest a slowdown in new construction activity or a temporary stagnation in land-cover transformation and land-use change processes in certain parts of the study area.

To quantitatively evaluate the urban sprawl observed in the maps above, neighborhood-based expansion graphs are presented in Figure **3**.

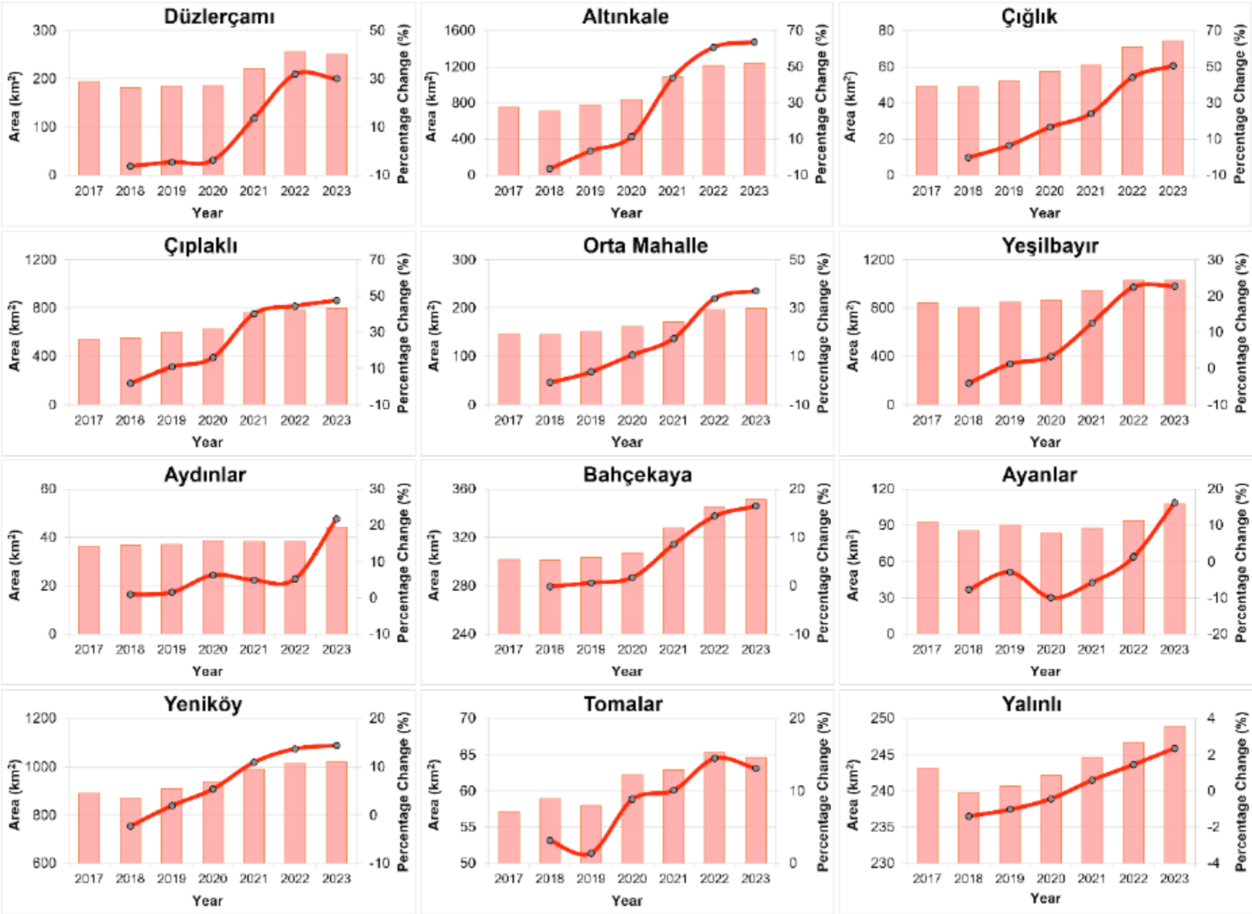

Figure 3: Temporal changes in the extent of impervious surfaces.

Altınkale Neighborhood exhibits the highest increase in impervious surfaces within the Döşemealtı District. The impervious surface area in the neighborhood increased from 754.05 km² in 2017 to 1234.19 km² in 2023, corresponding to a 63.7% increase. When changes in impervious surfaces are examined with 2017 as the reference year, land-use transformation remained limited during the 2017–2020 period due to the relatively low rate of increase. In 2021, a critical turning point was identified, marked by an acceleration in impervious surface growth, which continued with a similar momentum in 2022. In 2023, although the growth rate slowed, impervious surfaces reached their highest recorded extent. Overall, the expansion of impervious surfaces in Altınkale in recent years is closely associated with intensive construction activity and infrastructure investments.

Çığlık Neighborhood ranks second in terms of impervious surface growth in the district. The impervious surface area increased from 49.27 km² in 2017 to 74.13 km² in 2023, representing a 50.5% increase. Although a gradual transformation has been ongoing since 2017, impervious surfaces expanded more rapidly after 2021, driven by intensified construction and infrastructure development. Due to its proximity to the city center, Çığlık has become one of the neighborhoods under the strongest development pressure.

In Çıplaklı Neighborhood, impervious surface area increased from 541.14 km² in 2017 to 798.18 km² in 2023, corresponding to a 47.5% increase. During the 2017–2020 period, land-use change remained limited due to low and fluctuating growth rates; however, after 2020, impervious surfaces expanded more rapidly as a result of intensified construction and infrastructure investments.

In Orta Mahalle Neighborhood, impervious surfaces increased from 145.81 km² in 2017 to 199.86 km² in 2023, reflecting a 37.1% increase. Since 2021, accelerated expansion of impervious surfaces has been observed, largely attributable to intensive construction activities and the neighborhood's proximity to the city center, which has increased development pressure.

In Düzlerçamı Neighborhood, impervious surface area grew from 193.53 km² in 2017 to 251.51 km² in 2023, representing a 30.0% increase. Following the 2019–2020 pandemic period, construction and infrastructure pressure intensified. In 2023, a slight decrease compared to 2022 was observed, suggesting the initiation of land-cover transformation or redevelopment processes in certain areas.

In Yeşilbayır Neighborhood, impervious surfaces increased from 840.59 km² in 2017 to 1031.46 km² in 2023, corresponding to a 22.7% increase. Due to the low and fluctuating growth rate, land-use transformation remained relatively limited. In the post-pandemic period, impervious surfaces continued to increase at a moderate pace. Yeşilbayır was designated as part of the Cittaslow (Slow City) network in 2019, a status that emphasizes the protection of cultural and natural values, enhancement of quality of life, and control of unplanned urbanization pressures. The findings of this study confirm that the Cittaslow designation has partially contributed to slowing uncontrolled urban sprawl in the neighborhood.

In Aydınlar Neighborhood, impervious surface area increased from 36.34 km² in 2017 to 44.24 km² in 2023, corresponding to a 21.7% increase. In Bahçekaya Neighborhood, impervious surfaces expanded from 301.71 km² to 351.38 km², reflecting a 16.5% increase, while in Ayanlar Neighborhood, the area increased from 92.60 km² to 107.62 km², corresponding to a 16.2% increase. In Yeniköy Neighborhood, impervious surfaces increased from 891.54 km² to 1020.43 km², representing a 14.5% increase. Tomalar Neighborhood experienced a 13.2% increase, whereas Yalınlı Neighborhood exhibited only a 2.4% increase.

As distance from the Döşemealtı city center and the main highway increases, the intensity of urban sprawl decreases. In these peripheral neighborhoods, urban expansion has occurred at relatively low growth rates. This pattern is closely associated with the availability of transportation and infrastructure facilities; consequently, both the magnitude and direction of urban sprawl have remained more limited compared to neighborhoods closer to the urban core.

This urban growth has also had a significant impact on the increase in the resident population of the region and is corroborated by official data from the Turkish Statistical Institute [35]. According to these official records, the number of buildings issued occupancy permits in the Döşemealtı District between 2017 and 2023 is presented in Table **1**.

The overall trend observed in the table indicates a pronounced decline at both spatial scales during the 2019–2020 period. This downturn can be directly associated with the uncertainty caused by the COVID-19 pandemic, disruptions in construction supply chains, and broader economic contraction. In particular, the sharp decrease in the number of buildings issued permits across Antalya Province in 2020 demonstrates that the pandemic significantly constrained construction activity at the urban scale. In contrast, a notable recovery and upward trend emerged in the post-pandemic period, especially in 2021 and 2022. This increase can be explained by the tendency to avoid high-density urban living, a shift toward lower-density environments, and a growing demand for detached housing. Accordingly, the substantial rise in building permits observed in the Döşemealtı District in 2021, and particularly in 2022, indicates a strengthening trend of urban-to-rural migration and the expansion of rural and peri-urban development. Factors such as larger parcel sizes, lower land costs, and proximity to natural environments have rendered Döşemealtı increasingly attractive for residential preferences in the post-pandemic period. In 2023, however, a partial decline is observed at both scales, likely reflecting the constraining effects of rising construction costs, limited access to financing, and prevailing macroeconomic conditions on building permit demand. Overall, the table clearly illustrates that while the pandemic suppressed construction activity in the short term, it accelerated development in peripheral districts in the medium term through increased urban-to-rural orientation. This pattern is also clearly reflected in the thematic maps produced within the scope of the study, where both the increase in housing units and the expansion of impervious surface areas have predominantly exerted pressure on agricultural lands and vacant parcels. The differences in built-up surface areas between 2017 and 2023 indicate that the rapid expansion of impervious surfaces over this seven-year period, driven by pandemic-related dynamics, has significantly influenced other land-use categories (Figure **4**).

Table 1: Number of Buildings by Occupancy Permit Status [35]

Regions / Years	2017	2018	2019	2020	2021	2022	2023
Döşemealti District	665	576	420	438	819	1,361	1,007
Antalya Province	5,529	5,398	3,576	3,122	4,164	5,178	4,693

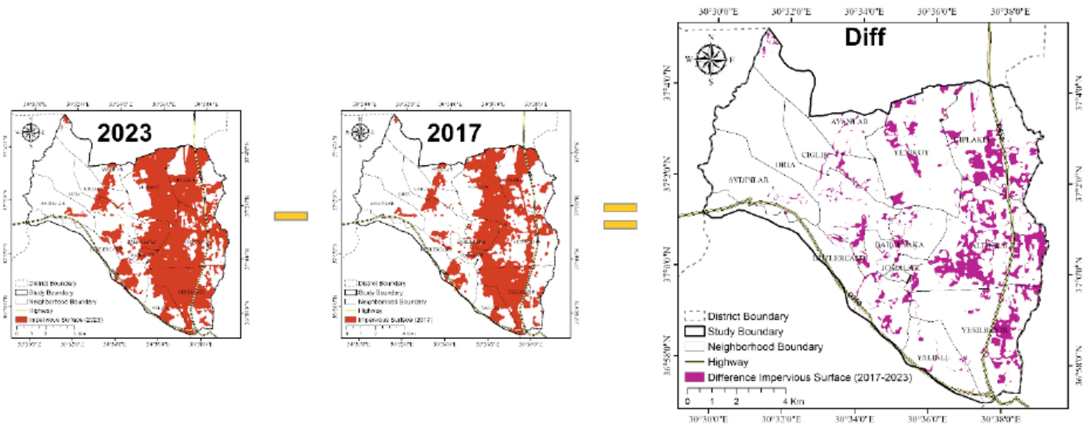

Figure 4: Differences in built-up surface areas between 2017 and 2023.

As shown in the difference map above, built-up surfaces are predominantly concentrated along the main transportation corridor in a north–south direction. Based on the 2017 LULC map as a reference, 76.52% of the Crops class, 19.03% of the Rangeland class, 4.43% of the Trees class, and 0.01% of the Water and Bare Ground classes were converted into impervious surfaces by 2023. This finding indicates that existing land-use patterns can be significantly affected by sudden events such as pandemics.

When evaluated together with national statistical data, the findings of this study clearly demonstrate that the COVID-19 pandemic triggered a pronounced population movement from urban centers toward semi-urban and rural areas in the Döşemealtı District. During the pandemic, demand increased for areas offering alternatives to dense urban fabrics, characterized by lower building density, larger parcel sizes, and closer connections to the natural environment; this tendency became evident through the accelerated housing production observed in Döşemealtı. Growing population pressure directly increased housing demand and, in turn, intensified the spatial expansion of construction activities. This process led to a substantial rise in the proportion of impervious surfaces within the study area, particularly through the enlargement of building footprints and the expansion of road and infrastructure networks. Consequently, the results indicate that pandemic-induced socio-spatial transformation rapidly converted areas with predominantly rural characteristics in Döşemealtı into a semi-urban structure, significantly altering land-cover dynamics.

The spatial and temporal dynamics of artificial surface expansion observed in Döşemealtı District reveal not only quantitative increases but also distinct spatial patterns and trends that reflect the underlying driving forces of urban sprawl. In particular, the concentration of growth along existing urban cores and major transportation corridors indicates a contiguous and infrastructure-dependent expansion pattern, whereas slower and more fragmented development is observed in peripheral neighborhoods due to accessibility constraints and lower development pressure. A comparison of the pre- and post-pandemic periods demonstrates a marked acceleration in built-up area growth after 2020, which can be associated with increased housing demand, urban-to-rural migration, and pandemic-induced shifts in housing preferences. Furthermore, the integration of official population statistics and building permit data confirms that these spatial patterns are closely linked to socio-economic and policy-related factors, thereby reinforcing the reliability of the observed trends. These findings suggest that sudden global events such as COVID-19 can influence not only the rate of urban expansion but also its direction, continuity, and degree of fragmentation, reshaping land-use dynamics and offering important implications for spatial planning, infrastructure provision, and sustainable urban development.

4. DISCUSSION

The findings obtained in this study indicate that the impacts of the COVID-19 pandemic on urban dynamics have extended beyond the public health domain, leaving profound and lasting effects on spatial development processes and land-use change. The pandemic has compelled a critical re-evaluation of urban structures, urbanization patterns, and planning priorities [36]. In particular, social distancing measures and quarantine policies implemented during the pandemic restricted intra-urban mobility and triggered transformations in local-scale living patterns and economic activities [37]. These changes altered the degree of dependence on city centers and led to the emergence of new trends in urban sprawl processes. Moreover, the contraction of economic activities and the widespread adoption of remote working models during the pandemic produced previously unanticipated impacts on the physical structure of cities. The vulnerabilities exposed by COVID-19, related to infrastructure capacity, availability of open spaces, access to green areas, and overall quality of life, have highlighted the need for these elements to be given greater priority in contemporary urban planning processes [36].

The COVID-19 pandemic has also generated pronounced impacts on settlement preferences and internal migration dynamics. The literature indicates that, during the pandemic, migration trends shifted from urban centers toward less densely populated rural areas [10]. Rowe *et al*. further report that, in the post-pandemic period, rural areas were able to reduce previous population losses and achieve net in-migration gains [38]. Consistent with these findings, the results of the present study conducted in Döşemealtı indicate the presence of a population movement oriented from urban to rural and semi-urban areas. In addition, the emergence of remote working arrangements, heightened health risk perceptions, aspirations for improved quality of life, and economic uncertainty during the pandemic reshaped individuals' spatial preferences [39]. These preferences elevated the relative importance of rural attributes, such as larger living spaces, access to nature, and lower population density, alongside the traditional employment and social opportunities offered by city centers [40]. Collectively, these trends suggest that the pandemic may have temporarily or permanently altered internal migration patterns, creating new dynamics in the physical and socio-economic structures of cities. This interpretation is corroborated by the substantial physical transformation observed in Döşemealtı, a settlement that previously exhibited rural characteristics and limited growth tendencies. From a broader perspective, post-pandemic debates on urban resilience and urban form emphasize the need for cities to develop more flexible and sustainable spatial strategies in response to public health crises [41]. In this regard, the LULC analyses conducted for Döşemealtı demonstrate that urban sprawl gained momentum in the post-pandemic period and became concentrated particularly in areas proximate to infrastructure and transportation networks. These findings align with the concepts of "healthy cities" and "resilient cities" widely discussed in the urban resilience and sustainability literature [42]. However, increasing population mobility, shifting settlement preferences, and growing spatial demand have placed Döşemealtı under considerable urbanization pressure, leading not only to an expansion of impervious surfaces but also to substantial transformations in other land-use categories, particularly agricultural land and vacant parcels. Pandemic-driven housing demand and spatial expansion trends have accelerated unplanned or insufficiently guided development processes, resulting in the conversion of natural and agricultural areas into built environments [43]. The lack of parallel progress in infrastructure capacity and urban service provision has, in turn, adversely affected urban quality, as deficiencies in transportation, technical infrastructure, social facilities, and green spaces have intensified the pressures generated by spatial growth and produced negative social and environmental outcomes for local residents. Accordingly, rapid urbanization processes should be evaluated not only in terms of physical expansion but also through the lenses of social sustainability and quality of life [44]. Particularly during sudden and unpredictable crises such as pandemics, it is essential for local governments and planning authorities to adopt cautious, evidence-based decision-making approaches. In this context, the effective use of decision-support systems plays a critical role in monitoring spatial change and identifying potential risks at early stages [45]. As demonstrated in this study, remote sensing and geographic information systems (GIS) technologies provide rapid and reliable data, enabling the monitoring of urban sprawl, the analysis of land-use change, and the early detection of potentially unplanned or undesirable development trends [46]. Integrating these technologies into planning and urbanization policies can therefore support the healthier management of rapid post-pandemic growth processes and contribute to achieving long-term sustainable urban development goals.

In conclusion, the findings demonstrate that urban sprawl in the post-pandemic period should not be regarded merely as a phenomenon of physical growth, but rather as a multidimensional process situated at the core of debates on spatial justice, sustainability, and urban resilience. Reframing urban policies with explicit consideration of this complex dynamic is essential for building cities that are more resilient to similar crises in the future.

This study has some limitations.The artificial intelligence–supported datasets used in this study are capable of representing complex spatial patterns more effectively than traditional pixel-based classification approaches, owing to deep learning algorithms, and they offer higher accuracy potential, particularly in the detection of built-up areas [47]. Moreover, the open-access nature of these datasets, their continuous updates, and their well-documented methodological framework provide a significant advantage by enhancing the transparency and reproducibility of the study [48]. For these reasons, Sentinel-2–based and AI-driven LULC data were considered the most suitable data source for analyzing the urban development dynamics of the study area within the context of the COVID-19 pandemic. However, despite their high spatial resolution and broad temporal coverage, Sentinel-2–based and AI-supported LULC classifications are subject to certain limitations, including spectral mixing, inter-class similarity, and the quality of training data labels [49]. In addition, artificial intelligence models rely heavily on large and balanced training datasets, and their geographic and temporal generalization performance may vary across regions and time periods [50]. These factors were therefore acknowledged as limitations of the present study and were carefully considered during the analysis process.

CONCLUSION

In this study, the spatiotemporal dynamics of urban sprawl in the Döşemealtı District between 2017 and 2023 were examined using LULC data and spatial statistical analyses. The results indicate that the pandemic period exerted pronounced effects on urban transformation and construction activity. During the pre-pandemic period, the overall magnitude of urban sprawl remained limited, with low and irregular growth rates. From 2021 onward, however, the post-pandemic period was characterized by an acceleration of urban expansion, particularly in neighborhoods located close to infrastructure and transportation networks, with a directional concentration toward the urban core. This finding suggests that the economic and social impacts of the pandemic contributed to increased development pressure and a faster pace of urban sprawl. By evaluating urban sprawl not only in terms of its extent but also its spatial direction and intensity distribution, the study provides critical insights into the underlying drivers of spatial growth. The concentration of expansion near the city center and along major transport corridors highlights the decisive role of urban planning decisions and infrastructure investments in shaping spatial development patterns. Conversely, as illustrated by the case of Yeşilbayır Neighborhood, conservation and sustainability oriented initiatives such as Cittaslow designation have been effective in constraining unplanned and uncontrolled expansion, underscoring their strategic importance in managing urban growth.

This study offers a valuable reference for urban planning, sustainable urbanism, and post-pandemic urban governance at both national and international scales. At the national level, municipalities and planning authorities can benefit from such spatial analyses when assessing neighborhood-scale urban expansion and infrastructure needs. At the international level, the findings provide data and a methodological framework for comparative research on the impacts of sustainable urban development initiatives (*e.g.*, the Cittaslow network), pandemic-induced transformations of urban space, and land-use dynamics. The innovative contribution of the study lies in its quantitative and spatial assessment of pandemic impacts and neighborhood-scale urban sprawl using long-term raster datasets. The adopted methodology enables objective identification of impervious surface change and evaluation of land-use transformations, offering a decision-support approach applicable to both academic research and practical urban management.

This study reveals the spatial and temporal dynamics of LULC changes in the study area before and during the COVID-19 period and provides important insights into the environmental impacts of urbanization and built-up expansion processes, particularly in rural–peri-urban settlements. The results offer valuable information for environmental engineering applications, including urban planning, infrastructure development, water and soil management, and disaster risk management. In addition, as the study is based on Sentinel-2 and artificial intelligence–driven LULC datasets, the classification accuracy and geographic generalization capacity are subject to certain limitations; however, these limitations were largely validated through comparisons with official population statistics and building permit data. Future research directions include integrating LULC change analyses with environmental engineering applications across different geographic regions and longer time series, developing methods to further improve classification accuracy, and employing comprehensive modeling approaches to examine the environmental impacts of sudden events such as pandemics on urban systems. These additions strengthen both the analytical depth and the practical relevance of the study.

Overall, the evidence from the Döşemealtı case demonstrates that the pandemic acted as a catalyst accelerating urban sprawl, and that both the magnitude and direction of expansion are closely linked to infrastructure provision and planning conditions. Accordingly, the findings can inform local governments' strategic decision-making processes and contribute to international scholarship on sustainable and planned urban development. In practice, such spatial analyses can guide municipalities, planning agencies, and local authorities in the post-pandemic period by supporting strategies to limit urban sprawl, direct infrastructure investments, and develop sustainable land-use plans. At the international level, the study provides a methodological benchmark for comparative analyses examining how similar socio-spatial processes manifest across different geographic contexts.

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AUTHORS' CONTRIBUTION

All authors contributed equally to the conception and design of the study, data acquisition, analysis and interpretation of the results, and the writing and revision of the manuscript. All authors have read and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

DECLARATION OF CONFLICTING INTEREST

The Authors declare that there are no relevant financial or non-financial competing interests to report

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