Spatial Analysis of Accessibility, Vegetation Density, and Equity of Urban Green Spaces: A Case Study of Esenyurt, Istanbul

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Abstract: *Urban green spaces (UGSs) are essential for sustainable development and improving residents' quality of life. However, urban green space is not always equally accessible to all city residents. This inequality is linked to a broader range of injustices, including disparities in health and well-being, and is a significant environmental justice issue. Accordingly, in this study, the spatial distribution of accessibility, vegetation density, and equity in Esenyurt, Istanbul, which is the most populous district of the city and the country, was analyzed. Using GIS-based network analysis, we found that approximately 813.27 hectares of residential areas are served by green spaces within a 500-meter walking distance, while 650.26 hectares remain unserved. The normalized vegetation density (NDVI) analysis showed moderate overall vegetation density, with significant variations across neighborhoods. Studies have shown that the green space per capita is only 1.01 m², significantly below the 10 m² threshold established by Türkiye's official regulations. Based on the findings of this research, it is evident that urban planners and decision-makers should prioritize the development of new urban green spaces to address accessibility and equity gaps.*

Keywords: Urban green spaces, GIS-based network analysis, Green space accessibility, Vegetation Density, Spatial equity, Urban sustainability

Introduction

Recognized as the "lungs" of cities, urban green spaces (UGSs) are crucial for sustainable development and enhancing the quality of life for local residents. The grass, trees, and shrubs found in city parks, reserves, athletic fields, riparian zones, greenways, public gardens, backyard gardens, and street trees are all included in UGSs (Al-Kofahi & Al-Khlaief, 2025). UGSs offer a variety of environmental services, including mitigating summer temperatures, purifying air and water, and reducing rainwater runoff (Semenzato et al., 2023). They also support urban biodiversity by providing habitats for various wildlife species. Economically, the location and size of UGSs significantly influence both land and property values.

Furthermore, aesthetically appealing UGSs can encourage tourism and make contributions to the local economy. In addition to all these benefits, UGSs can improve the residents' physical and mental health as well as increase their sense of well-being (Li et al., 2021). In this study, public parks and other open-to-the-public green areas managed by the local government are referred to as urban green spaces.

The importance of green spaces in rapidly growing cities is increasing across ecological, aesthetic, sociocultural, and economic dimensions. Assessing their sufficiency, usability, and accessibility is therefore crucial (Adıgüzel & Doğan, 2020). Institutions have set minimum standards for urban green space (UGS): the WHO recommends at least 9 m^2 per person (ideally 50 m^2), the UN suggests 30 m^2, English Nature advises UGS within 300 meters of homes, and the European Environment Agency sets a 1000-meter limit (Al-Kofahi & Al-Khlaief, 2025). Türkiye's Regulation on Spatial Plans (Official Gazette, June 14, 2014, No. 29030) mandates a 500-meter walking distance and a minimum of 10 m^2 per person (Turkish Regulation on Spatial Plans, 2014). However, studies show that green space per capita in Turkish cities falls below these standards (Adıgüzel & Doğan, 2020; Kaya, 2024; Uslu et al., 2024).

The primary objective of this study is to examine the accessibility, vegetation density, and equity of urban green spaces in Esenyurt, the most populous district in Türkiye. Thus, we would like to explain these terms in detail:

In general, spatial accessibility refers to the ease of access to a particular location. Accessibility modeling in the GIS environment is widely used in the literature. The simplest methods of accessibility research are those based on buffer analysis and generating park service areas through network analysis, identifying the population served at various distances (Cracu et al., 2024). However, using the straight-line distance cannot accurately reflect the accessibility of residents under actual travel conditions. When the road network is taken into account, a more realistic measure of accessibility can be achieved (Long et al., 2023).

- The majority of UGS studies analyze the number of green spaces available to residents and ignore the variation in services provided by different types of green spaces. However, according to a study conducted in Tokyo, Japan, the type of green space, rather than its quantity, has the most significant influence on people's well-being (Tsurumi et al., 2018). Furthermore, a survey conducted in New York found that trees are beneficial for people's physical and mental health compared to grass (Reid et al., 2017). The average NDVI value in a given geographic area is frequently used to define greenness. Although objective measures of greenness cannot explain how usable or pleasing the green spaces are, a strong correlation exists between the NDVI and assessments of green spaces made by environmental psychologists (James et al., 2015).

- Urban green space is unfortunately not always equally accessible to all city residents. This inequality is linked to a broader range of injustices, including disparities in health and well-being, and is a significant environmental justice issue (Hsu et al., 2022). The availability of UGS is commonly assessed by the green space ratio, which involves calculating the amount of UGS within a city or neighborhood per capita (Iraegui et al., 2020). Many studies have also employed spatial statistics to evaluate distributions of green spaces based on different criteria such as sociodemographic features (Elderbrock et al., 2024; Guo et al., 2024; Iraegui et al., 2020; Song et al., 2024).
- Most of the studies have analyzed either green space accessibility, vegetation density, or equity. However, there is a lack of research integrating all these dimensions. We believe that our multi-modal approach will provide more comprehensive results about the green spaces in the selected study area.

This study aimed to answer the following questions:

- Which residential areas are underserved in terms of urban green space accessibility?
- How does vegetation density vary across parks within different neighborhoods?
- How equitably are the urban parks distributed in terms of vegetation density, green space per capita, and urban park density?

Data and Methodology

In this study, the Esenyurt district, located in the western part of Istanbul, Türkiye, was selected as the study area. It has an area of 43 km² with a population of around 1 million (Turkish Statistical Institute, 2023). The district has 43 neighborhoods, which are analyzed in this research. The rapid urbanization and high density of residential, commercial, and industrial areas (Urban Atlas Land Cover/Land Use 2018) make the district an ideal case for spatial analysis of urban green spaces. The study area is presented in Figure 1.

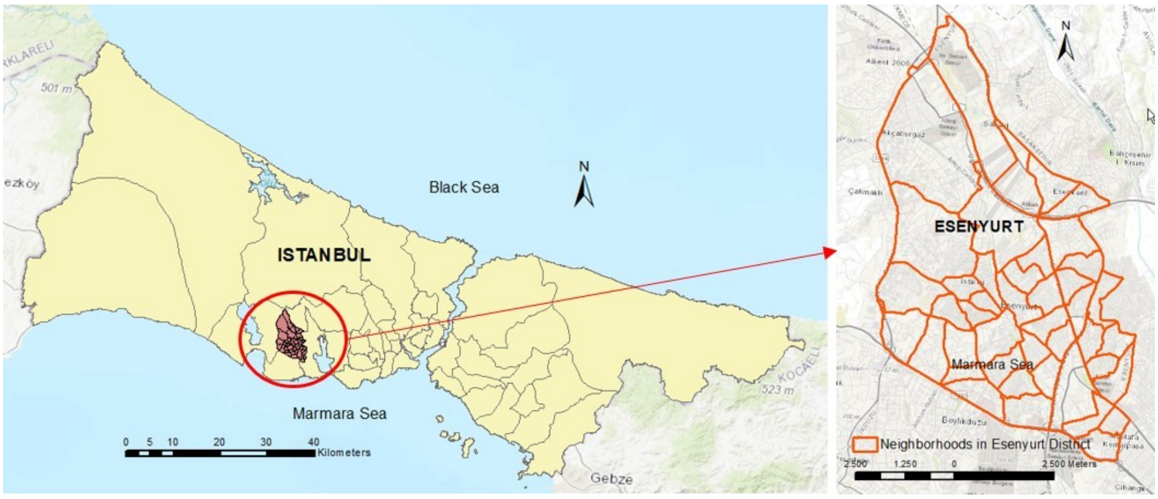

Figure 1: The Study Area.

The data used in this study includes neighborhood boundaries, parks, road network, population information for neighborhoods, and a high-resolution PlanetScope satellite image. A summary of data sources and types is presented in Table 1.

Table 1: Type and source information for the data used.

Name	Type	Source
Neighborhood Borders	Shapefile (Polygon)	OpenStreetMap
Parks	Shapefile (Polygon)	OpenStreetMap
Roads	Shapefile (Polygon)	OpenStreetMap
Population	CSV	Turkish Statistical Institute
Satellite Image	Raster	Planet Labs
Residential Areas	Shapefile (Polygon)	European Environment Agency

All geographic data were clipped to the study area and re-projected to WGS 84 UTM Zone 35N. Neighborhood population data were added to the boundary shapefile's attribute table. To focus solely on public green spaces, automatic satellite-based detection was avoided; instead, park polygons from OpenStreetMap (OSM) were used and verified via Google Satellite and Street View. Private or outdated green spaces were excluded. Park entrances were identified and marked, forming a new point layer, *Park Entrances*, which was used to enhance the accuracy of the accessibility analysis. This process is illustrated in Figure 2, and the overall data processing workflow is shown in Figure 3.

Figure 2: Park entrance identification process.

In the next step, the road network was processed. Using the OSMnx and NetworkX libraries in Python, we ensured that the road network is fully connected. Later, we manually checked the network to delete road classes that represent roads unsuitable for walking. Thus, busway, cycleway, motorway, motorway_link, primary, primary_link, trunk, and trunk_link classes were deleted. Additionally, we have checked other road classes using Google Street View to assess their suitability. We considered the availability of sidewalks during this check. Based on this, some of the link roads and unclassified roads were deleted from the network.

Residential areas were extracted from the EU Urban Atlas, which shows different land use classes for the urban and suburban areas. In addition to the classes indicated as residential, construction sites were also taken into consideration since the data shows land use classes for 2018. Construction sites were manually identified using the Google Satellite Basemap, and some of them were converted to residential areas, considering their situation. Finally, the PlanetScope satellite image of the study area, captured on August 13, 2024, was used for vegetation density analysis. The image has a spatial resolution of 3 meters, with Red, Green, Blue (RGB), and Near-Infrared (NIR) bands.

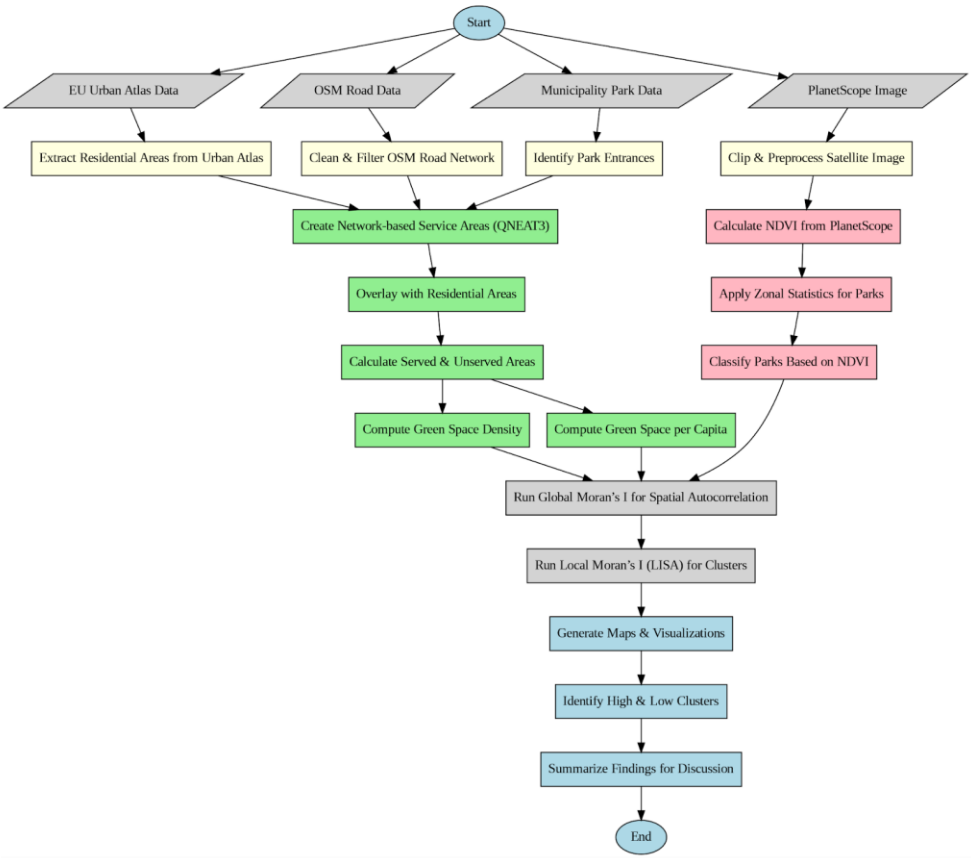

Figure 3: Flowchart of the methodology.

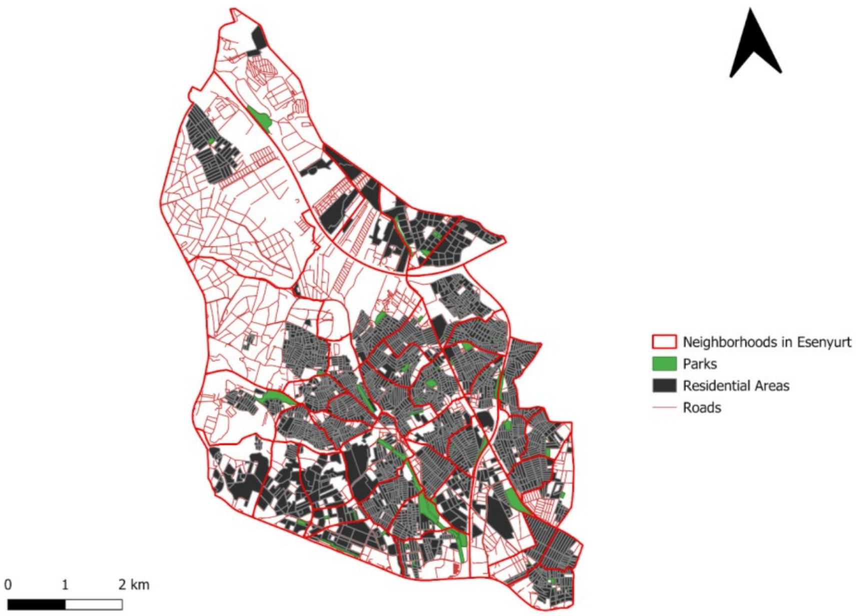

Figure 4: Parks, residential areas, and roads in the study area.

The study includes three main parts to analyze urban green spaces: accessibility, equity, and vegetation density analyses. Table 2 summarizes the analysis processes used in the study.

Table 2: Analyses, data, and tools used, and anticipated results were described.

Method	Input Data	Tool	Output
Accessibility Analysis	Road network, park entrances	QNEAT3 Plugin (QGIS)	Served and unserved areas
Vegetation Density Analysis	NDVI raster, park polygons	Zonal Statistics (QGIS)	Mean NDVI for each park
Equity Analysis	Neighborhood polygons, park polygons	Moran's I, LISA (Python)	High/low green space clusters

Accessibility analysis was performed using the QNEAT3 plugin in QGIS to evaluate park access within the study area. Residential zones with access to parks within the 500-meter threshold—based on Türkiye's official regulation (Turkish Regulation on Spatial Plans, 2014)—were identified. Service area polygons were generated accordingly and intersected with residential polygons to assess accessibility. This resulted in two new categories: "*Served Areas*" and "*Unserved Areas*".

Vegetation density is a key indicator of park quality, assessed using the Normalized Difference Vegetation Index (NDVI), which effectively evaluates urban green spaces (Moreno et al., 2020). NDVI measures vegetation's photosynthetic activity by comparing the absorption of red light and the reflectance of near-infrared light, with values ranging from -1 to +1. Values near 1 indicate vigorous vegetation, while those between -1 and 0 reflect non-vegetated areas. NDVI also helps assess vegetation density, cover fraction, and chlorophyll quality (Moreno et al., 2020). The following formula is used for NDVI calculation:

$$NDVI = (NIR - Red)/(NIR + Red)$$

Where "Red" is the red band and "NIR" is the near-IR band.

We have used the "Raster Calculator" tool in QGIS 3.40 software to apply this formula and create the NDVI map of the study area. The resulting raster map shows related NDVI values in pixels. Since mean NDVI values can be used as an indicator of green space coverage for each park, we have used the NDVI map and park polygons to calculate mean NDVI values for each park using the "Zonal Statistics" tool.

The most critical analysis of the study is the Equity Analysis. This metric involves computations and statistical analyses used to examine the distribution of urban green space in greater detail. These are: Urban Green Space Metrics and Spatial Autocorrelation. The green spaces were quantitatively analyzed using two metrics, which are urban green space density and urban green space per capita. Spatially intersecting neighborhood and park polygons were used to compute both metrics. The intersection was done by using the "intersect" function of the Geopandas library in Python. The following formulas were used following the intersection:

$$\text{Green Space per Capita} = (\text{Total green space } (m^2))/(\text{Neighborhood population})$$

$$\text{Green Space Density} = (\text{Total green space } (m^2))/(\text{Total neighborhood size } (m^2))$$

After the spatial intersection, the total park size values for each neighborhood were integrated into the attribute table of neighborhood polygon data. Metric calculations were completed by using the "total park size," "population," and "total neighborhood size" columns of the neighborhood polygon data. New columns were added to the attribute table to store information related to urban green space metrics. Spatial autocorrelation is a method for evaluating the degree of spatial agglomeration, which refers to the mutual dependency of spatial element qualities on their spatial location (Zhang et al., 2020). The benefit of spatial autocorrelation over other approaches is that it can account for both local and global autocorrelation, revealing both local and overall patterns in the spatial data and providing more valuable information for urban planning and decision-making (Song et al., 2024). Global spatial autocorrelation describes the spatial characteristics of attribute values across the entire region and is used to assess the spatial correlation of the entire area. It is commonly measured using Moran's I index.

Results and Discussion

Accessibility analysis results show that each neighborhood has a certain percentage of residential areas that are unserved, except for Cumhuriyet, which is relatively small (34 ha) and has two parks. The neighborhood's residential area makes up the majority of the remaining space. Additionally, there are minimal unserved residential areas in some neighborhoods. For instance, in comparison to the served areas, the size of the unserved residential area in the southernmost neighborhood, “Turgut Özal”, is relatively small. The area is home to three parks. Overall, the proportion of served versus unserved residential areas is higher in the eastern and southern neighborhoods. Clusters of unserved areas can be seen in the southwest. “Pinar” has a sizable served residential area encircling a moderately sized unserved residential area. In the first part of Figure 5, a service area was created based on a 500-meter threshold. In this figure, the served and unserved residential areas are derived from the spatial intersection of residential areas and service areas, as presented in the middle of Figure 5. In the figure, the NDVI map was also presented.

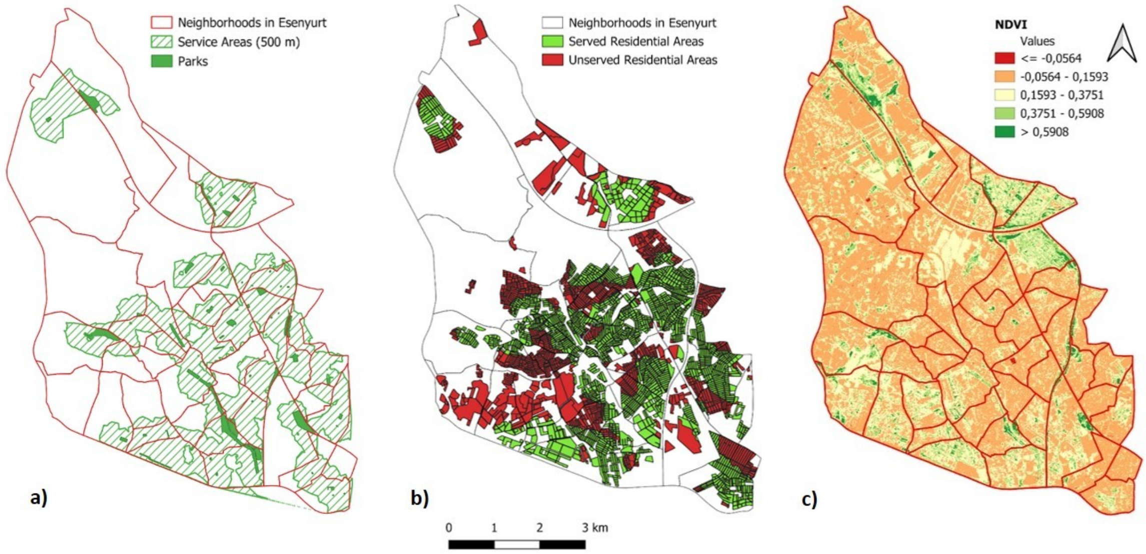

Figure 5. a) Service areas created based on a 500-meter threshold, b) Served and unserved residential areas, c) NDVI map of the study area

The study area's parks have an average NDVI of 0.41, which denotes a moderate level of vegetation density. "Hasbahçe" in the Aşık Veysel neighborhood had the highest mean NDVI value (0.635). The neighborhood of Orhan Gazi's "Esenyurt Recreation Area" has the second-highest mean NDVI value (0.622). The other three neighborhoods in the Aşık Veysel neighborhood come next. Therefore, the Aşık Veysel neighborhood is home to four out of five parks with the highest NDVI values. The NDVI values of smaller parks are typically low to moderate. An exception to this rule is Battalgazi's "19 May Youth Park," which spans 2.6 hectares and has an NDVI of 0.33. “Yonca Park,” located in the Sultaniye neighborhood, has the lowest NDVI value (0.126). Next in line are "Defne Park," located in Süleymaniye, with an NDVI of 0.176, and "Sarmaşık Park," situated in Ardıçlı, with an NDVI of 0.196. When comparing neighborhoods, Balıkyolu comes in third place because it only has one park, which is 1.4 hectares in size and has an average NDVI of 0.59. 52 of the 59 parks in the study area have an NDVI value between 0.2 and 0.6, although the NDVI values range from 0.125 to 0.635.

The average green space per capita across the study area is 1.01 square meters per person, while the average green space density is 2.75%, indicating very little green space availability. More than 25% of all neighborhoods (11 out of 43) lack any public green space. This limits the overall accessibility to the green spaces. The neighborhoods that do not contain any public green space are Esenkent, Koza, Gökevler, İncirtepe, Saadetdere, Piri Reis, Şehitler, Necip Fazıl Kısakürek, Hürriyet, İstiklal, and Fatih. Thus, the ranges of green space per capita and green space density start from 0. When these neighborhoods are excluded, green space per capita ranges from 0.032 m² per person in Namık Kemal to 5.041 m² in Atatürk, while green space density varies from 0.0005% in Ardıçlı to 0.218% in Mehmet Akif Ersoy. There is a high concentration of green space per capita and high green space density in the south, where several large parks are located in proximity to each other. On the contrary, a cluster of neighborhoods that lack parks can be seen in the southwest. In addition to having the highest green space density, Mehmet Akif Ersoy is the neighborhood with the second-highest green space per capita, at 4.52 m². Atatürk, with the highest green space per capita of 5.041 m², has only one park named "Abdullah Gül Park." This park spans an area of 7.8 hectares and serves the 15,527 residents of the Atatürk neighborhood. Within the neighborhood, more than 75% of the residential areas fall within the park's service area.

For the mean NDVI per neighborhood, we observed a slightly negative Moran's I value of -0.01871, indicating no spatial autocorrelation. The z-score of 0.03875 further supports that the values are randomly distributed, while the p-value of 0.46 confirms that the result is not statistically significant. Therefore, there is no strong evidence of spatial clustering for NDVI values. For green space per capita, Moran's I value of 0.18209 suggests moderate positive spatial autocorrelation. The p-value of 0.025 indicates that the result is statistically significant, while the z-score of 2.24023 confirms significance at the 5% level. Finally, for green space density, the analysis revealed a Moran's I value of 0.37916, indicating strong spatial autocorrelation. The p-value of 0.001 demonstrates a highly significant result, while the z-score of 4.89085 confirms significance at the 1% level. These results show a clear pattern of spatial clustering for green space density. After identifying significant positive spatial autocorrelation for both green space per capita and green space density in the Global Moran's I analysis, we conducted a Local Moran's I (LISA) analysis to detect spatial clusters and outliers. The results are shown in Figure 6.

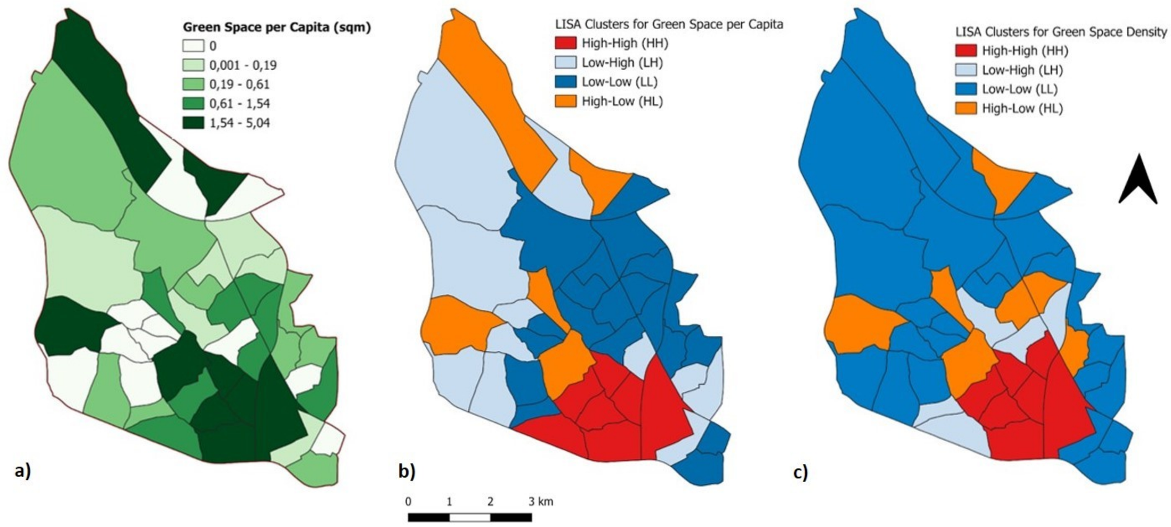

Figure 6. a) Green space density map of the study area based on neighborhood values, b) LISA map for urban green space per capita, c) LISA map for urban green space density

This study analyzed pedestrian accessibility, vegetation density, and equity in Esenyurt, Istanbul. The accessibility analysis indicated that 813.27 hectares of residential areas have access to green spaces, while 650.26 hectares remain unserved. Cumhuriyet is the only neighborhood without any unserved regions; however, all other neighborhoods contain varying amounts of unserved residential space. The vegetation density analysis showed moderate overall density, with the highest NDVI values observed in parks within the Aşık Veysel neighborhood. In terms of equity, the calculated green space per capita is 1.01 m², significantly below the 10 m² threshold established by Türkiye's official regulations (Turkish Regulation on Spatial Plans, 2014). Spatial statistics revealed that green space availability exhibits a non-random pattern, with high and low clusters indicating spatial inequalities throughout the study area.

The primary limitations of this research are associated with the data that we used. We have used OpenStreetMap's road network, park polygons, and neighborhood boundaries. The accuracy of the results may be affected by outdated and improperly mapped polygons. The processing of roads belonging to specific classes, such as "tertiary" and "unclassified," is subjective, despite the road network being prepared for pedestrian-based analysis. Sidewalks were the only factor considered when classifying walkability.

Additionally, informal routes and shortcuts were not included in the accessibility analysis. Plus, despite appearing to be very close to a particular green space, a few residential areas were found to be unserved. The exclusion of specific road classes, like "primary" and "primary_linked," may cause this situation. Besides OSM data, the precision and accuracy of the satellite image utilized for vegetation density analysis can be enhanced. The image had a spatial resolution of 3 meters, and a greater spatial resolution can increase the accuracy of the NDVI computation. Furthermore, temporal variations were ignored. The optimum time of year to collect images and examine vegetation was considered to be summer, although conditions may vary depending on the season. Data on residential areas and populations are likewise limited by time. Population data provided by the Turkish Statistical Institute is for 2023, and the EU Urban Atlas is prepared for 2018. Thus, the changes in land use and population may affect the results. In Urban Atlas, only areas classified as "Construction Sites" were taken into manual investigation; however, other land use changes were neglected.

Private sites were considered the study's most significant limitation, aside from data limitations. Since the population of these private sites is unknown and cannot be excluded from metric calculations, they were included in this study. Therefore, private green spaces have been excluded from the analysis, which may result in an overestimation of the number of unserved residential areas. Even though they often have their own green spaces, these areas cannot be used by people outside of these private sites.

Conclusion and Recommendation

This study aimed to analyze the accessibility of public urban green spaces, vegetation density, and equity in a rapidly urbanizing area. Consequently, we discovered that about half of the district's residential neighborhoods lack access to any green space within a 500-meter radius. Furthermore, we identified that 13 out of 43 neighborhoods in the district do not have any public green space at all. A moderate overall vegetation density was found as a result of NDVI analysis, while the highest NDVI values were observed in the parks of the Asik Veysel neighborhood. The equity analysis showed that the overall green space per capita in the study area is 1.01 m². The highest value is around 5 m², and it was observed in the Mehmet Akif Ersoy neighborhood. These values indicate very poor green space availability compared to the official standard of 10 m². Spatial statistics revealed that the density of green space and the amount of green space per capita do not vary randomly throughout neighborhoods, providing strong evidence of spatial inequality. These findings provide valuable insights by emphasizing spatial inequalities among neighborhoods and identifying areas that require additional green spaces. Improving access to high-quality green spaces is one way to create more sustainable and livable urban environments, especially in regions with high-density commercial and residential areas, such as Esenyurt. Enhancing the quality and availability of public green spaces can help improve public health, climate resilience, and overall well-being.

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