



Evaluation of urban topography–biotope–population density relations for Istanbul–Beşiktaş urban landscape using AHP

Gül Aslı Aksu¹  · Nigar Küçük²

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Abstract

The analytical evaluation of urban landscapes is a time-consuming and difficult process as it concerns a large number of components in a complex network of interactions. Studies are either very general and superficial, or unidirectional and in-depth based on certain indicators. For this reason, suitability analyses based on analytic hierarchy process (AHP) create an appropriate framework for evaluating multicomponential urban landscapes systematically. The purpose of this research is to establish an important framework for sustainable landscape planning decisions by comparing it with the artificial topography, population density and biotope characteristics evaluated in the context of microclimatic occurrences in urban landscapes. For this purpose, artificial topography was analyzed by means of AHP according to slope–aspect and elevation criteria. These criteria (slope–aspect–elevation) used to evaluate the artificial topography were preferred for having the potential to represent microclimatic formations such as wind corridor, shading and runoff that affect the decisions on urban landscape planning and management significantly. Artificial topography suitability map obtained was compared to biotope types and population density in research area. In regions with high population density topography compliance is low. In appropriate areas, the building and park biotopes attract attention. These findings indicate that green roof-façade systems should be introduced in such areas and ecological balances should be considered in park design. A balanced distribution of building stock gardens influenced the quality of life positively. It was seen that suitability of topography addressed with regard to life quality and microclimatic comfort is inversely proportional to population density. It was determined by evaluating the relationship of artificial topography with urban biotopes that the predominant biotopes in the areas with high suitability of topography such as garden and grove have high ecological value. Artificial surfaces, such as roads and buildings, gain weight in the areas with high population density and unsuitable urban topography. Considering all of these findings, it was concluded that artificial urban topography is an important indicator for interpreting the relationship with habitat-population density and taking decisions on planning and management of urban landscapes which are in a rapid transformation process.

Keywords Urban landscape planning · Biotope · Artificial urban topography · Analytical hierarchy process (AHP) · Suitability analysis · Population density

1 Introduction

Forman (2008, 2014) states that the people who live within the urban landscape, and who constitute half of the world population, have turned into an urban species—*Homo sapiens* “urbanus”. Forman addresses the significance of urban ecology in parallel with an urban population that continuously increases, tsunami-like. He defines constructed structures as being the key components of urban ecology and mentions that the sphere of interest related to urban ecology will be reached when structure–road interactions are also included in an ecology that already touches on organism–environment interactions

Urbanization can be identified as the process of humans to create a new habitat for themselves. From a different viewpoint, urbanization refers to the process of shaping those spaces which are convenient for basic human needs such as accommodation, food, shopping and production. In this way, human beings cause changes in other living creatures and habitats.

Urbanization is rapidly increasing due to the development of the social economy, changes in living conditions and changes in land use, all of which have a major influence on regional ecologies. Constant increases in the demand for construction sites in cities make the guidance of both urban and national policies very important. The destructive effects of urbanization have gradually become inescapable with increases in economic developments and man-made elements, which are the main driving forces of urban growth and development. As a result of the changes in land use, and the destruction that people have caused in line with their economic interests, the natural structure has been damaged and replaced by one that is artificial (Li et al. 2017; Patowary and Sarma 2017; Jaafari et al. 2016; Kumar et al. 2017).

The lifestyle brought by the modern world causes natural habitats to either rapidly disappear or to become isolated. As a result of urbanization, the water regime of entire regions is being destroyed, their topographical structures are changing, their natural soil characteristics are disappearing, and the formation of urban heat islands is becoming more widespread. Such changes in landscape patterns and functions lead to various consequences, including the degradation of green networks at the regional scale, and the disappearance of specific biotopes.

To slow down or stop the reduction in biodiversity, it is necessary for landscape planners and ecologists to focus on this ongoing process. To help prevent further loss of biodiversity, there is an urgent need for more strategic approaches to conservation planning in urban environments. These approaches should be based on a scientific understanding of landscape patterns, species requirements and development pressures (Darmstad et al. 1996; Gordon et al. 2009). For the future of urban ecosystems, a structure which maintains the balance between sustainable social, economic and ecological systems in a planned manner should be prioritized in any developments (Shi and Yu 2014). However, it is not easy to achieve this requirement. According to Miller et al. (1998), the most complex challenge is to apply adjustments within social and cultural frameworks that enable people to meet their needs at an optimum level without causing any social and environmental problems for the future.

Today’s remote sensing and data processing technologies and geographic information systems continue to make significant contributions to the rapid availability of analytical data, thereby influencing the evaluation of multi-component urban landscapes (Musaoğlu 1999). Multiple criteria analyses which are performed semi-quantitatively can provide considerable support for such an integrated perspective.

Urban landscapes have a multi-component and complex structure. The use of the tools that allow the systematic analysis of this structure raise the quality of landscape evaluations. In addition, diagnosing the destructive effect of rapid urbanization on ecosystems becomes both easier and faster with these tools.

The rising population ratio in urban areas, urban development and concentration tendencies, and the deterioration and change in the natural topography of cities have led to the alteration of their urban topography and land use. Topography is formed by internal dynamics, geo-morphological processes, climatic effects and human and environmental influences. These effects can be both natural and artificial and produce the horizontal and vertical development of a given topography. Such formations reveal the urban character expressed as a natural and artificial topography, based on their means of formation. They shape the structure and the form of a city and create its topography by forming in accordance with its geographical location and landscape structure. Urban morphology can create microclimates in urban areas that have effects both inside and outside their boundaries (Davies et al. 2008; Kitada et al. 1998; Küblü 2015; Yürekli 1993; Cetin et al. 2016).

The artificial topography that emerges in urban environments, particularly in areas with dense housing and developed road networks, is often an indicator for the production of a microclimate. The changes in both the topography and habitats brought by urbanization, and the analytical determination of these structures are crucial for landscape planning and management. From this perspective, the purpose of this research is to evaluate the relationship between habitat and population density in an urban landscape with regard to artificial topography, and to provide suggestions for decisions regarding urban landscape planning, management and design.

By considering slope, aspect and elevation, artificial topography has been chosen as an indicator in the urban environment due to its potential to represent microclimate formations such as wind corridors, solar radiation, shading and runoff. Beam radiation is intercepted by buildings, and, depending on the angle of the sun and building height, a shadow is created. Where buildings are closely spaced, a shadow corridor may form (Marsh 1997).

The Beşiktaş District (Fig. 1) is at the center of the Istanbul metropolis and is undergoing a dense urbanization continuum. For these reasons, it was selected as the research study area. Artificial topography, population density and biotope relationships, which are all indicators of the urbanization process, were discussed and evaluated according to a multi-criteria evaluation approach. The findings obtained from the evaluation were interpreted within the framework of urban landscape planning.

To this end, the artificial topography in the research area that formed due to the influence of urbanization was first evaluated by taking slope, aspect and elevation parameters into account. The topography and its levels of suitability for generating a comfortable microclimate were then determined through the values for slope, aspect and elevation.

In the second step, data regarding population density were converted into spatial information using the administrative borders of 23 neighborhoods in the research area.

Lastly, the research area was separated into eight different biotope classes represented on 1/10,000 scale maps. The suitability of the obtained artificial topography was then construed by overlaying the population density and biotope data.

This evaluation can be used to guide decisions regarding landscape design as well as those regarding the planning and management of the area. In this regard, the evaluation forms an intersection between the planning scale and the design scale.

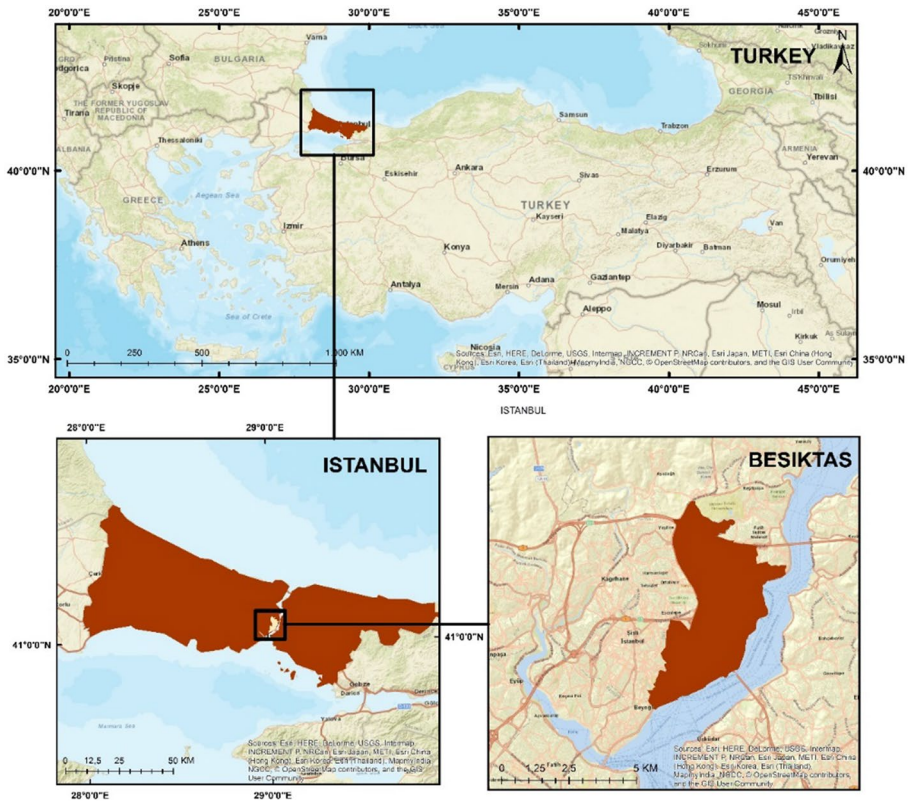


Fig. 1 Beşiktaş is a district of Istanbul, Turkey

2 Materials and methods

2.1 Material

The research area, Beşiktaş, is a district of Istanbul province. It is located on the European side and is under the influence of the 1st and 2nd Bosphorus bridges (Fig. 1). It neighbors Sarıyer to the north and Kağıthane, Şişli and Beyoğlu to the west; Beşiktaş is a small district with a surface area of 37.8 km². However, the features of the district such as its central location, its position as a connection point between Europe and Asia and its easy accessibility make it a center of attraction. The research area has a wide range of educational, historical-cultural and commercial buildings with different typologies. It has a shore line of about 8 km, and there are significant ring roads that close to the research area. The population of the district is almost 15 million (Turkish Statistical Institute-TUIK 2017).

The elevation of the Beşiktaş district starts from sea level and reaches 250 m. The topography of the district has a rugged structure. Its climatic parameters are shaped by its artificial topography, and microclimate formations can also be observed for the same reason. There are major arterial roads running north to south, and these are exposed to wind, thereby creating wind corridors. Beşiktaş has 23 neighborhoods, and the distribution of population density varies accordingly. The highest (620 person/ha) and lowest

population density values (29 person/ha) occur in the Muradiye and Levent neighborhoods, respectively.

This district was chosen as the research area for this study due to its extensive transportation facilities, heterogeneous user profile, and the variety in its topographical structure.

2.2 Methods

The artificial topography was used as an indicator to evaluate the relationship between the biotope and the population density in the research area. Slope–aspect and elevation criteria were then applied to analyze the artificial topography. Such criteria were addressed as part of a suitability analysis, with respect to comfort of use and the potential to generate a microclimate. An artificial topography suitability map obtained through AHP was used to interpret the relationship between biotope and population density.

2.2.1 Suitability analysis of artificial topography

“Multi-criteria decision analysis” allows for the overlaying and interpretation of different criteria in order to make decisions regarding various subjects in a given field. Multi-criteria Analysis also provides a framework that integrates information on effects with values and the preferences of decision makers. It is an ideal way to include the preferences of decision makers in analyses of the distribution of land use and suitability. Furthermore, this method uses mathematical programming techniques and can be used to make analyses for multi-themed decisions (Geneletti 2005, 2007; Collins et al. 2001).

According to Steiner (1991), suitability analysis is considered to be the process of determining the fitness or the appropriateness of a given tract of land for a specified use.

In the “McHarg Suitability Analysis,” McHarg (1992) used matrices to compare the relevant land cover/land use classes and thematic data such as climate, land and topography to ensure that a research area is perceived properly with regard to different uses and that it is also managed well. He assigned suitability degrees such as high, medium and low to the criteria which are compared with these matrices. Consequently, he detected areas which are/are not suitable for different uses, in the suitability map obtained by applying the above rating system to maps through overlay analysis. This stratified suitability analysis model is an important example for multi-criteria analyses performed in many different areas (Steiner 1991; Malczewski 2004; Uy and Nakagoshi 2008).

Ecological risk and suitability analyses that gain qualitative features as the decision maker assigns values are frequently used in landscape analyses and evaluations. For this study, the values that were determined to be consistent through the analytic hierarchy process were designated to the parameters chosen to make the evaluation semi-quantitative, and these were then subjected to overlay analysis (Saaty 1980; Saaty and Vargas 2012; Banai-Kashani 1989).

Multi-criteria suitability and risk analyzes based on AHP are used to bring together many different criteria in an analytical hierarchy, and to formulate important bases for planning and management decisions.

Aksu (2012) and Aksu et al. (2017) have used such analyses to determine levels of ecological risk, and to develop an ecological baseline and sustainable landscape planning strategies for an urban landscape. For their risk analysis, they used vegetation, soil, water and bioclimatic comfort criteria (together with sub-criteria) and systematized them by using AHP. Finally, they interpreted the ecological risk map they obtained

through the use of the framework of urban landscape change with spatial and social components. Feizizadeh and Blaschke (2013) assessed the use of land resources for the purpose of agricultural production in the Tabriz County of Iran by applying an AHP-based suitability analysis. They revealed suitable areas for irrigated and dry farming in the research area by using multiple criteria.

In addition to planning, AHP-based risk analyzes are also widely used to assess various disaster risks and to facilitate management decisions. Duzgun et al. (2011) developed a multi-criteria methodology with the aim of assessing the urban earthquake risk of Eskişehir, Turkey. Later, Bahadori et al. (2017) developed a model that integrates effective parameters for disaster risk-related policy and decision making. This model allowed them to bring technical, structural and social components together in an analytical framework, and to map the seismic damage distribution steps. This model is an important basis for earthquake risk analysis.

In particular, environmental and landscape assessments that involve multi-component complex structures require tools that will allow for the systematic and analytical gathering and interpretation of each component. Therefore, the artificial topography criteria used to evaluate the relationships between habitat and population density in an urban environment were weighted by means of AHP, and their consistency was then tested.

Assigning the suitability values to different criteria in suitability analyses is a subjective evaluation method based on the foresight of the analyst. The analytic hierarchy process was used to make this evaluation semi-quantitative.

The analytic hierarchy process covers the forming of proportional scales with the aim of revealing the components of a problem. The fundamental logic of generating paired comparisons in this method to allow the division of a problem into smaller building blocks, and to develop priorities for each hierarchy (Harker and Vargas 1987). In the analytic hierarchy process, values from 1 to 9 are assigned to the factors subjected to the comparison matrix. The intermediate even numbers are excluded from the evaluation, since they are regarded as intermediate values (Saaty and Vargas 2012).

AHP uses a hierarchical model that consists of purpose, criterion, probable sub-criterion levels and options for every problem. It is established on the basis of three main principles: generation of hierarchies, determination of priorities, and logical and numerical consistency (Özcan 2008).

The criteria specified as appropriate for the analysis should be normalized, weighted and subjected to analysis after being overlaid. Thanks to the normalization process, the values of the criteria decrease and correspond to the acquisition degree of the component evaluated. Thus, the effects of the defined alternatives for the criteria become comparable (Geneletti 2007; Herwijnen and Janssen 2001).

Secondly, the factors should be weighted for the analysis. Accordingly, a numerical value that indicates the importance of the suitability of an activity in the area under discussion is given. In this way, the weighting process is implemented to express and assess the relative significance levels of different criteria. Weighting is intended to reflect the interaction between the factors in the landscape. Lastly, the consistency of the weighting is checked. If the consistency is within an acceptable reference interval, the criteria are weighted, and alternatives are offered as part of a given decision-making rule (Steiner et al. 2000; Geneletti 2007; Herwijnen and Janssen 2001).

An AHP evaluation level enabled the artificial topography of the research area to be subjected to a suitability analysis with a semi-quantitative evaluation considering slope, aspect and elevation criteria.

In this research, the suitability of the artificial topography was addressed as part of the criteria for the generation of comfortable physical and microclimatic conditions for human use. In line with this approach, slope, aspect and elevation criteria were evaluated according to reference intervals determined according to their potential to influence the microclimatic structure through effects such as wind corridors, shading, solar radiation and runoff. Geneletti (2007) emphasizes that the criteria which are independent of each other should be used in multi-criteria decision analyses. He mentions that repetition of interrelated criteria under different titles will lead to double counting and negative consequences. For this reason, the climatic parameters that have the greatest importance in the intersection between habitat, topography and utilization were not separately evaluated. Compared to macro-climatic conditions, microclimate formations gain significance in the evaluation of urban landscapes. The artificial topography of the study area was included in the research as the primary factor in the formation of such conditions.

The artificial topography was assessed using a digital elevation model which was generated from stereo images taken from the ASTER satellite (ASTER DEM-2014, 15 m, URL-1). Slope, aspect and elevation analyses were performed using DEM data by means of the spatial analyst module of the ArcGIS 10.3 software. A digital elevation model was created from the satellite image. This contains components such as building height that also promote the development of an artificial topography. Thus, building heights could be incorporated into the slope–aspect and elevation analyses. Ultimately, they became the main factor in the creation of microclimatic conditions.

The consistency of the weight ratios obtained through AHP was analyzed, and the layers were overlaid according to weight ratios which were determined to have an acceptable consistency. This artificial topography suitability map covers the effects of microclimatic formations and was construed through comparisons with maps for population density and biotope types of the research area.

2.2.2 Population density analysis

The population data of the neighborhoods in the research area for 2015 (TUIK 2017) were compared to the surface area of each neighborhood (ha) and total surface area (ha) to establish the population density (person/ha). The 2015 population density data of the neighborhoods based on the surface area were assigned to neighborhood polygons, thereby making them spatial. Ultimately, a population density map at a scale of 1:10,000 was obtained (Fig. 5).

2.2.3 Biotope mapping

The biotope map of the research area was generated by dividing green areas and artificial surface layers into sublayers which were taken with UA from the Pléiades satellite image (2015) at a spatial resolution of 50 cm × 50 cm (Fig. 4a).

Indicator animal groups, especially mammals, birds, small butterflies, amphibians and reptiles were classed as priority biotopes. However, when the structure of the landscape pattern that they make up as biotope types was considered, the findings were not consistent. For example, the roadsides which run alongside the roads were referred to as linear barriers. Such issues were addressed by giving priority to such linear and connective characteristics.

The findings from an Urban Topography Suitability Map based on AHP were interpreted by overlaying them on the 1:10,000-scale biotope map and the population density map of the neighborhoods. From this, strategies were then designated.

3 Findings

3.1 Artificial topography suitability map

Slope, aspect and elevation criteria were used to evaluate the topography with a suitability analysis based on the analytical hierarchy process.

3.1.1 Slope criterion

With regard to the effect of slope criteria on the artificial topography, significant high slope percentages are observed when considering the housing rate in Istanbul. This produces a rugged topography as the building height rises and slope parameter is triggered. While the areas with a slope ratio $> 20\%$ constitute 62.48% of the total area, 37.52% of the total research area is made up by relatively flat areas (slope ratio $< 20\%$).

The slopes formed by the artificial topography in the research area were evaluated within the following four reference intervals: 0–20; 21–50; 51–100 and 101% $<$. The values assigned to the reference intervals in the suitability analysis are shown in Table 1.

Relatively flat areas with a low slope of 0–20% are regarded as comfortable with respect to utilization and microclimatic formation (runoff, corridor generation etc.) in the research area, therefore a high suitability value was assigned to those areas with such slopes. The research area is located in Istanbul, which has a rough structure, and for this reason, slope values of up to 50% are usually seen in the natural topography of the city. Considering this point, a limit of 100% was first set as the slope value, and as an indicator of the artificial topography which depends on building height. The lowest suitability value was assigned to the areas with a slope ratio $> 101\%$ (Table 1).

3.1.2 Aspect criterion

The predominant wind direction in Istanbul is N–NE, which makes the city vulnerable to cold winter winds. The wind corridor formations that run in this direction adversely influence the bioclimatic comfort of the city. Hence, the lowest (3) suitability value was assigned to areas with N–NE aspects (Table 2). On the other hand, the mean relative humidity values of Istanbul are 74–79%. The impact of this high relative humidity was neutralized particularly, in summer by chilly and aerating winds from the W–NW. Thus,

Table 1 Reference intervals determined to evaluate the slope criterion, and the suitability values assigned in AHP

Reference interval (% slope)	Suitability value
0–20	9
21–50	7
51–100	5
101 $<$	3

Table 2 Reference intervals determined to evaluate the aspect criterion, and the suitability values assigned in AHP

Reference interval (aspect direction)	Suitability value
S–SW	9
W–NW	7
E–SE	5
F	5
N–NE	3

the areas with W–NW aspects received a high suitability value (7) with regard to their comfort.

In Istanbul, the high relative humidity creates a negative effect, especially in summer. Winds from the S–SW directions produce warm sea breezes and refresh the city and make it comfortable in terms of air current. The south and southwest also aspects gain importance with respect to insulation, particularly in winter. Consequently, the highest suitability value was assigned to areas with S–SW aspects (Table 2). The E–SE aspects provide the optimum level of solar radiation under Istanbul conditions, but they are weak in terms of shading and ventilation to neutralize the muggy influence of the high humidity, especially in the summer. This dilemma produces a moderate (5) suitability value for the E–SE aspects. Even though flat areas (F) have a negative effect by keeping the air currents, they present positive conditions, because they can delay the runoff effect. Due to their positive and negative characteristics, they were assigned a moderate suitability value.

In addition to all above, the S–SW aspects are of significance for having aesthetic sea views. This feature was considered to raise their suitability values.

3.1.3 Elevation criterion

The maximum elevation in the research area starts at 0 m altitude by the sea and reaches 254 m. When elevation is evaluated as a criterion of suitability analysis, the areas with elevation < 100 m. and the areas with elevation > 101 m. were assigned high and low suitability values, respectively (Table 3).

Values were assigned to comparison matrix by taking the relationship between the criteria into account (Table 4). The consistency ratios of the values that were assigned to a normalized matrix were tested and calculated according to the analytical hierarchy process.

In order to render the effects of the defined criteria alternatives comparable, normalized comparison matrices were attained (Table 5).

Thanks to these matrices, the weight ratio of each criteria could be established. Finally, the consistency of the each weight ratios was checked.

Table 3 Reference intervals determined to evaluate the elevation criterion, and the suitability values assigned in AHP

Reference interval (elevation m.)	Suitability value
0–50	9
51–100	7
101–150	5
151–200	3
201 <	1

Table 4 Comparison matrix of the suitability of topography

Suitability of topography	Slope	Aspect	Elevation
Slope	1.00	3.00	5.00
Aspect	0.33	1.00	3.00
Elevation	0.20	0.33	1.00
Sum column	1.53	4.33	9.00

Table 5 Normalized comparison matrix of the suitability of the topography

Criteria	Slope	Aspect	Elevation	Sum row
Slope	0.65	0.69	0.56	1.90
Aspect	0.22	0.23	0.33	0.78
Elevation	0.13	0.08	0.11	0.32

$n = 3$

Weight ratios

$$W = \begin{vmatrix} 0.63 \\ 0.26 \\ 0.11 \end{vmatrix}$$

When the weight ratios are evaluated, it can be seen that slope is the most influential criterion of artificial topography with a ratio of 0.63. Aspect has a ratio of 0.26, and elevation is the criterion with the lowest weight (0.11 ratio).

These weight ratios were used, and their consistency was analyzed prior to the generation of the topography suitability map.

Weighted total vector

$$A \times W = \begin{vmatrix} 1.95 \\ 0.79 \\ 0.32 \end{vmatrix}$$

Consistency vector

$$E = \begin{vmatrix} 3.07 \\ 3.03 \\ 3.01 \end{vmatrix}$$

Average value of the consistency vector

$$\lambda = \Sigma E_i / n = 3.04$$

Consistency index

$$CI = \lambda - n / n - 1 = 0.02$$

Randomness index

$$RI = 0.58 \text{ (The value read from the table for } n = 3 \text{)}$$

Consistency ratio

$$CR = CI/RI = 0.03$$

$CR < 0.10$ the performed comparisons may be deemed as consistent.

Upon gathering the criteria, and their being weighted and checked as having consistency within an acceptable value range, the suitability levels of the urban topography were established. After each weighted criterion (slope, aspect and elevation) was calculated, the urban topography suitability map was created (Fig. 2a, b).

Various refractive values were tested to express significant spatial distributions in the artificial topography suitability map that was produced after the analytical hierarchy process. Those with lower suitability values of between 0.278 and 0.856 have multiple parts, so their interpretation did not make sense. In consequence, 0.6 (which provided the most significant result in the research areas as a spatial distribution) was used as reference (Fig. 3). The areas marked in red on the topography suitability map are those with suitability values > 0.6 . Such areas represent regions that have high suitability in terms of topography. The areas with suitability levels ≥ 0.6 were filtered and overlaid with biotope types, and population density. 0.6 is also the median. The areas with suitability values above the median are those where artificial topography provides a convenient structure depending on slope, aspect and elevation.

3.2 Biotope map

One of the most important indicators of an urban landscape is a biotope map showing important habitats. In the research area of this study, the habitats that can meet reproduction, aliment and sheltering needs of significant species within the indicator animal groups (mammals, reptiles, amphibians, birds and small butterflies) were evaluated. Eight types of biotope were then determined on a 1/10,000 scale biotope map for the Beşiktaş district which was based on both the field survey and scans of the literature (Fig. 4a). These biotopes were buildings, gardens of the buildings, groves, cemeteries, parks, roadsides, water surfaces and artificial surfaces. Road networks that have a dominant influence on landscape structure due to their linear patterns were evaluated as artificial barriers. The percentage distributions of biotopes according to whole area are indicated in Fig. 4b. The green area layer used as a base for biotope map was obtained by using remote sensing and the Normalized Difference Vegetation Index (NDVI). Therefore, the biotope types included in green areas are polygons that exclude artificial surfaces.

- *Buildings* Urban artificial topography is predominantly comprised of buildings. Buildings create vertical layers in the urban topography and bring a new dimension to the perception of slope–aspect–elevation. The artificial topography generated by masses of building has a significant influence on the direction and velocity of wind, noise insulation, shading, heating and runoff. In addition to their effects on topography and microclimates, buildings also constitute habitats for specific species within the indicator groups due to the variety in the materials used for fronts and roofs, forms and structure. In an urban ecosystem, the buildings do not only form habitats but also allow for transitions between green areas and artificial surfaces.
- *Gardens of buildings* This biotope class covers herbaceous and woody vegetation in the immediate vicinity of the buildings. Existing green roof surfaces were also evaluated under this biotope type. Gardens are generally shaped by the artificial topography

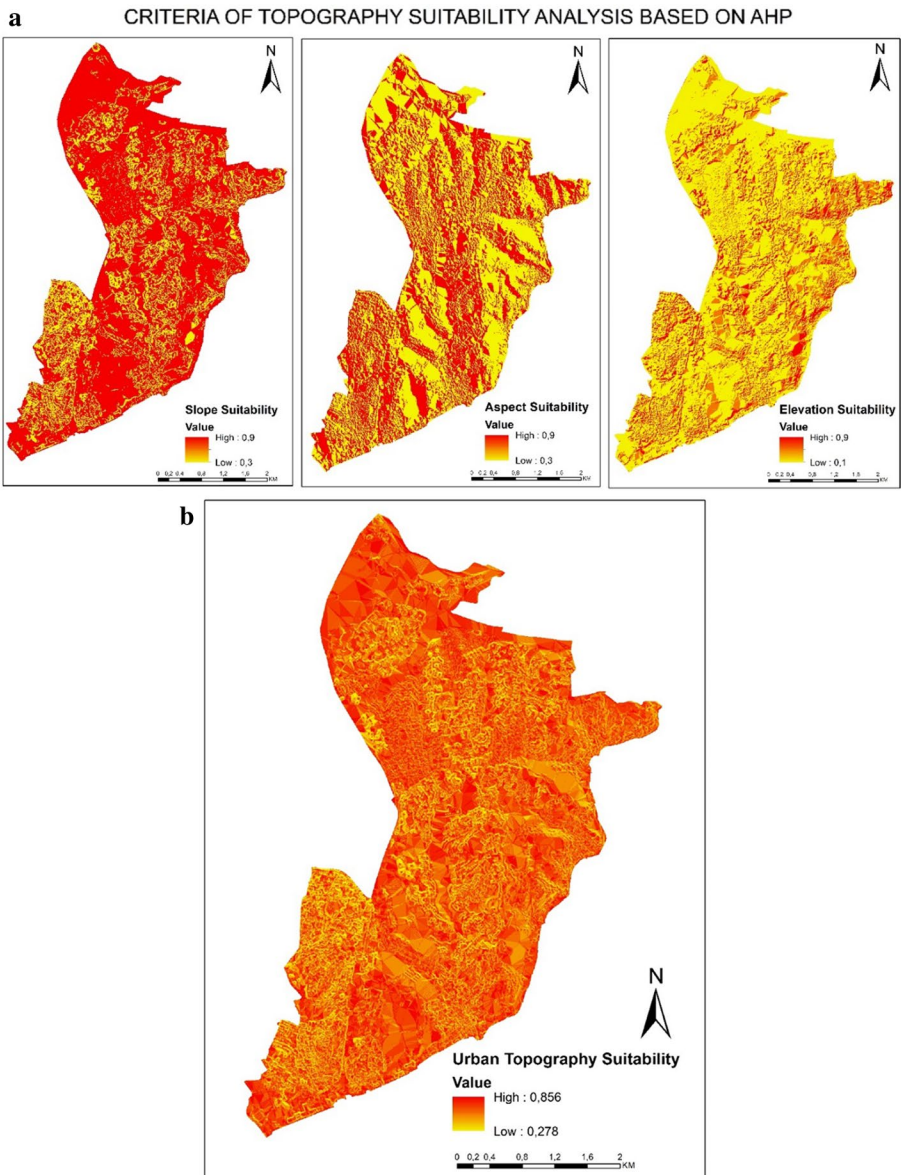


Fig. 2 **a** Suitability maps of slope, aspect and elevation used for the topography suitability analysis. **b** Artificial topography suitability map produced by overlaying the slope, aspect and elevation criteria with assigned suitability values according to their weights

created during or after the construction of buildings. These gardens can also be shaped by the natural topography when it extends away from leveling areas. Similar to other areas covered by vegetation, the gardens of buildings provide shelter for birds, butterflies, reptiles and some mammals. Such biotopes allow transitions between buildings and other artificial surfaces, thereby mitigating the stiffness and coldness of artificial

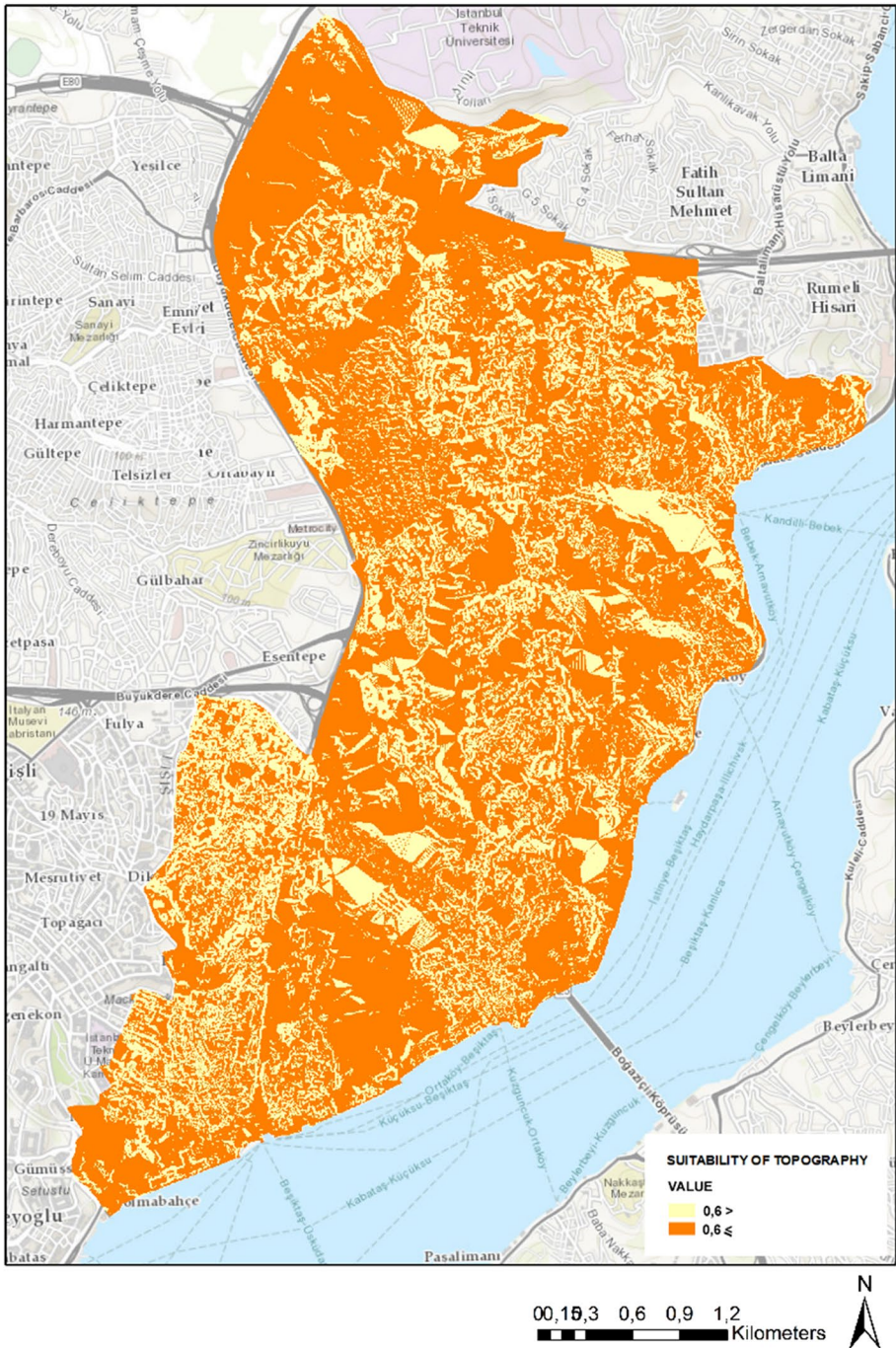


Fig. 3 Urban topography suitability map based on a 0.6 suitability value

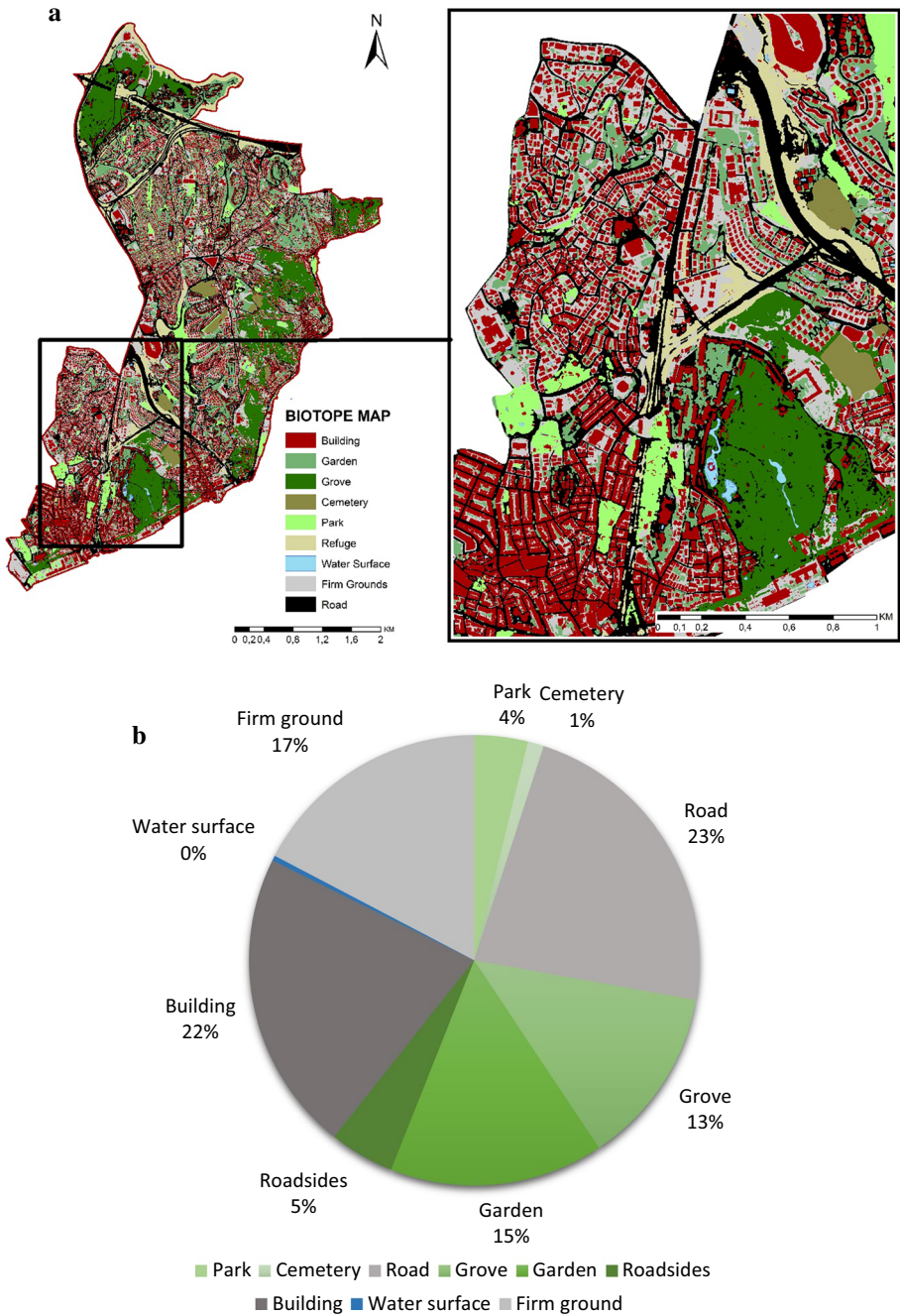


Fig. 4 **a** Biotope map of the research area. **b** The percent distributions of biotopes in research area

surfaces. They also have other functions such as absorbing sun rays, shading, protecting the environment from the negative influences of wind and slowing down the passage of rain water to runoff.

- *Groves* In areas such as Beşiktaş where there is high level of urbanization, groves are the lifelines of the urban ecosystem. Such areas are important biotopes and often have a great biological variety. Groves can be created either through the protection of forest sections left after urbanization or through planning. In both situations, they are likely to be located within the natural topography. A total of 177.04 ha of grove area exists in the Beşiktaş district. Due to their contribution to biodiversity in the urban ecosystem and as their structure is similar to natural green zone systems, groves are crucial for the continuity of urban green zone systems.
- *Cemeteries* Cemeteries are biotopes with high-density vegetation. They are often within the natural topography, and active human usage is minimum. They receive limited physical intervention, such as pruning and disinfection, so they offer a habitat for more sensitive species when they are compared to other urban biotopes. Such characteristics make cemeteries a transition point and a buffer between different biotopes. These areas can show microclimatic differences because of their ecological features.
- *Water surfaces* When the water surfaces that are vital for all of the indicator types and urban biotopes are examined, it is clear that the research area does not contain sufficient water surfaces. The total water surface (4.81 ha) makes up only 0.26% of the whole research area (Fig. 4b). Considering that most of the water surfaces are swimming pools with added chemicals, the research area can be said to be inadequate in terms of water surface.
- *Firm ground* Firm ground provides aliment and sheltering for species, especially at connecting points between materials. In addition, firm ground with material structures that ensure permeability are ecologically important since they allow for contact with the soil. Due to these characteristics, areas of firm ground have the potential to generate biotopes. Any evaluation of their biotopes will vary depending on criteria such as permeability, structure and material.
- *Roadsides* The roadsides which accompany road networks are significant biotopes, because their linear patterns create connecting features. Moreover, they soften the structural effect of road networks and act as a buffer between roads and other biotopes. These characteristics raise the importance of roadsides for the continuity of green networks in urban ecosystems. The central location of the research area, namely being located in the transition area between Europe and Asia, and also being by the Bosphorus, have resulted in Beşiktaş having main arteries for both maritime and terrestrial transport. The orbit roads of two Bosphorus bridges, several main arteries which connect the sea to the land, and the presence of basic transportation services such as a coast road make the roadsides that accompany these arteries much more significant.
- *Roads* Roads with the highest spatial percent in the research area are important for creating artificial barriers for biotopes through the imposition of their linear character. In particular, broad and continuous main arteries break up green zones and limit the biotopes.

In Figs. 4a, b, it can be seen that the roads included in the study as artificial barriers have the highest ratio (23%). Artificial Surfaces dominate the research area with 62%, as buildings (22%) and firm ground (17%) are added to the ratio of roads. The Garden biotope is the Green Area with the highest ratio of 15%. Followed by Grove (13%), Roadside (5%), Park (4%) and Cemetery (1%) are added to this ratio, the total ratio of Green Areas reaches

38%. On the other side, the amount of Water Surface in the research area is so insufficient it cannot be included in the percentage ratios.

3.3 Population density

The population density is shown in total number of people per hectare and was calculated by considering the 2015 population data (TUIK 2017) of the neighborhoods within the research area. The Muradiye neighborhood was found to have the highest population density with 620 person/ha. The lowest population density (29 people/ha) was observed in the Levent neighborhood. Figure 5 shows the distribution of population density. This was calculated by using total number of people per hectare in the research area and was based on the figures for the neighborhoods. It stands out that the neighborhoods with the highest population density are concentrated in the southwest of the research area. This area has dense housing and is remarkable for its low suitability value, as observed in artificial topography suitability map (Fig. 3).

3.4 Artificial topography, biotope, population relations

There is a significant inverse proportion between two criteria when the findings of population density (person/ha) are evaluated together with areas that have a high suitability level in terms of their artificial topography (≥ 0.6) (Fig. 6).

A moderate negative correlation ($r = -0.565$) was found between the population density and suitability of topography values.

The distributions of biotope types according to neighborhoods were then investigated (Fig. 7a). This evaluation is considered as an ecological indicator of the urbanization process. To be able to see the distributions, the graph was more generalized and evaluated at the level of artificial surface/green area, according to the neighborhoods (Fig. 7b).

After the criteria were examined, the maps obtained from the suitability of topography analyses (≥ 0.6), type of biotope (%) and population density (person/ha) were superimposed and evaluated collectively. This evaluation was based on the neighborhood polygons (Fig. 8; Table 6).

Within the artificial topography, the areas with low suitability values have high population density. In such areas, the biotope types mainly consist of artificial surfaces. In particular, the southwest of research area reflects this feature. When the area in Fig. 2a is evaluated according to the sub-criteria, it becomes clear that the suitability values of this area are also low.

Table 6 shows the distributions of biotope type in the areas with high suitability of topography. Buildings have the greatest percentage (21.68%). Buildings are followed by roads (21.65%) and areas of firm ground (17.06%). According to these values, 60.39% of the areas with high suitability of topography are comprised of artificial surfaces. The remaining surfaces (39.60%), consist of gardens (14.87%), grove areas (14.38%) and other biotope types (10.35%). These values demonstrate that buildings and areas of firm ground should be of primary concern during the planning of biotope types with high suitability of topography.

In terms of suitable topography, the Muradiye neighborhood areas have the lowest value (4.21 ha) and also have the highest level of population density (620 person/ha). When suitable areas are assessed with respect to biotope type, it is seen that the biotopes of buildings (43.94%) and parks (30.88%) have the highest levels, and roads have a ratio of 15.44%. It

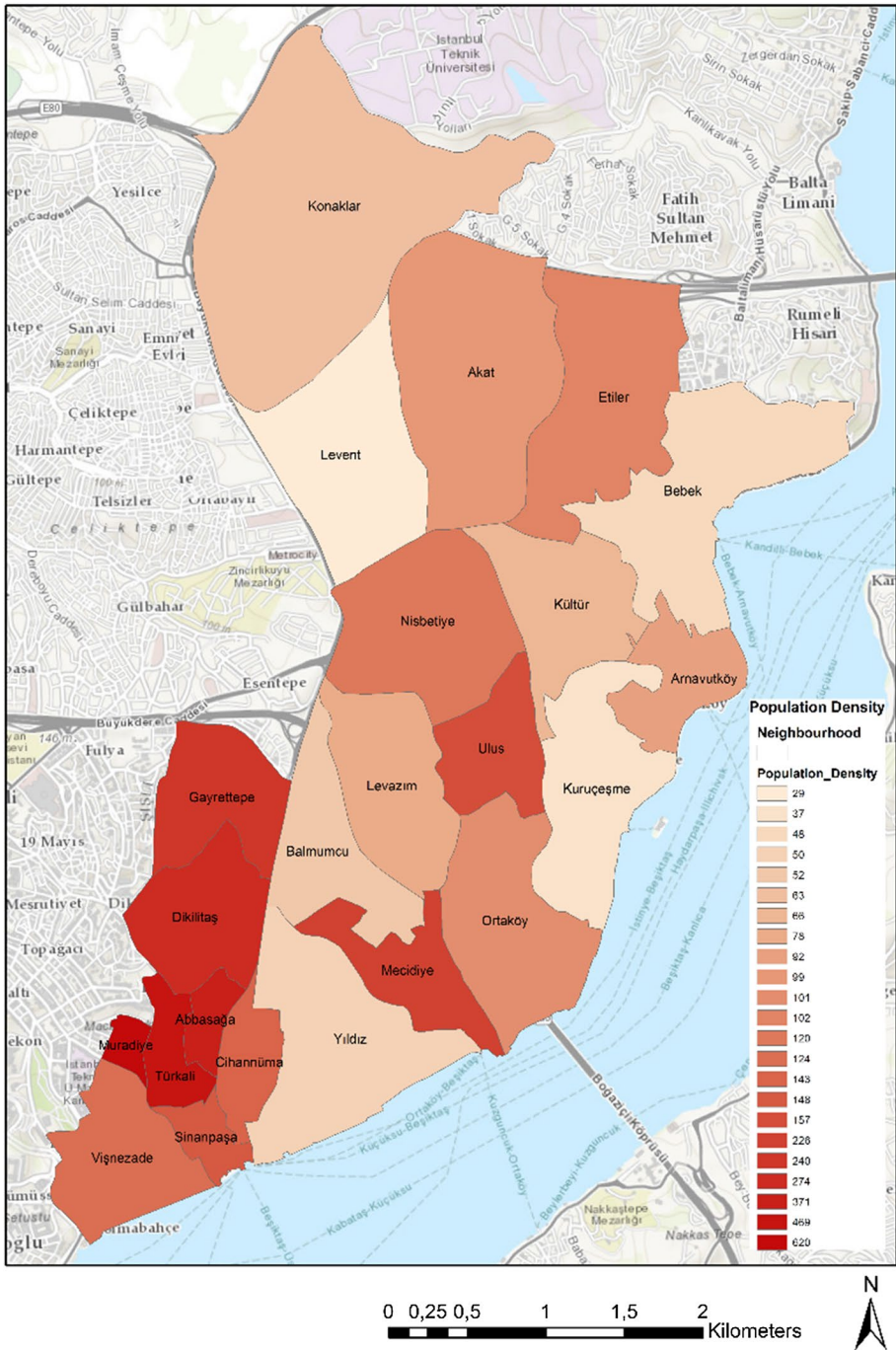


Fig. 5 Population density map shows the distribution of population density based on neighborhoods in the research area

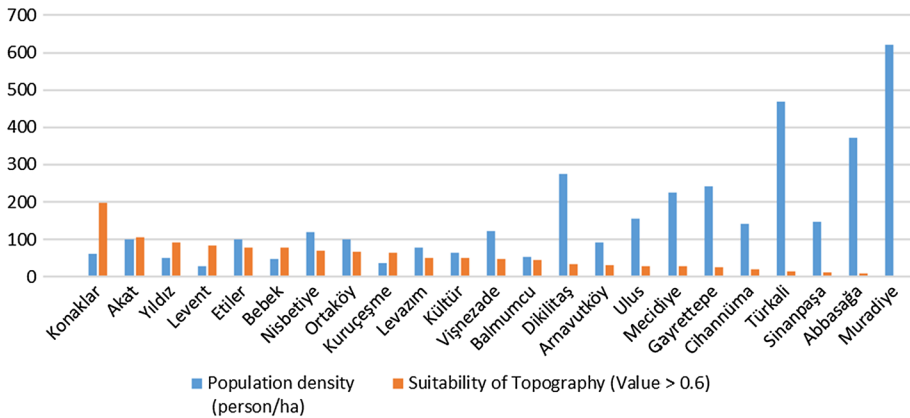


Fig. 6 Population density/suitability of artificial topography relationship based on the neighborhoods

can be concluded that the buildings in the Muradiye neighborhood will require sensitivity during any further design, planning and/or management processes. Furthermore, a significant ratio of park areas in this neighborhood have high ratios for artificial surfaces. This indicates that the ecological balance should be taken into account for the selection of plant species when these areas are redesigned and renewed.

The Levent neighborhood has the lowest population density (29 person/ha). The significant biotopes in terms of suitability of topography are buildings (24.20%) and gardens (24.02%). Roads in this neighborhood have a ratio of 23.21%. Such values that indicate that distribution of the buildings is balanced when compared to gardens, which is a sign of low population density.

Compared with other areas, the Konaklar neighborhood has a high ratio of Groves (26.88%) and the highest suitability of topography (197.13 ha). The low population density (63 person/ha) in this neighborhood can be attributed on the total ratio of green zone (58.47%), which is higher than the ratio of artificial surfaces (41.44%).

4 Discussion

Findings have concentrated the research on some Concluding Remarks:

- Buildings tend to artificialize the topography according to their height. However, they are calculated as the dominant biotope for suitability of topography due to the scarcity of green zones.
- 60.4% of the areas with high suitability of topography are artificial surfaces, mainly buildings. Gardens and groves also stand out with a ratio of 39.6%.
- The suitability of topography values was found to be low in neighborhoods with high population density. As biotope types, buildings and park areas are prominent in such areas.
- In areas with low population density, buildings and gardens gain weight as biotope types. This data demonstrates that the areas where the building-garden ratios are proportionate have a more balanced population density.

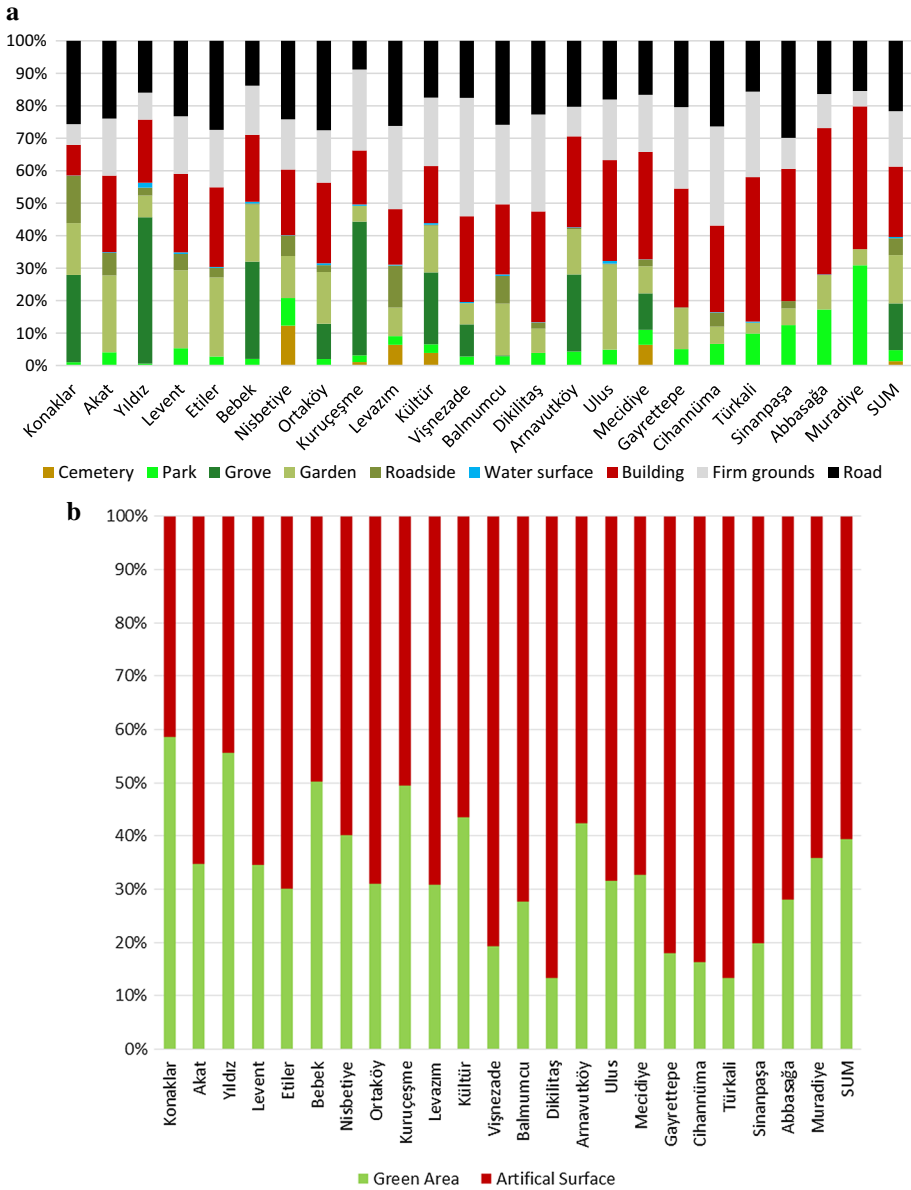


Fig. 7 **a** Distribution of biotope types based on neighborhood. **b** Distribution of artificial surface/green area based on neighborhood

- In areas with high suitability of topography and relatively low population density, groves and roads have the highest ratios. Based on this finding, it can be said that groves constitute a green zone type which provides high suitability of topography.
- In general, the most important biotope in terms of balancing the dividing effect of the dominant road networks in the research area are the linear roadsides. However, the

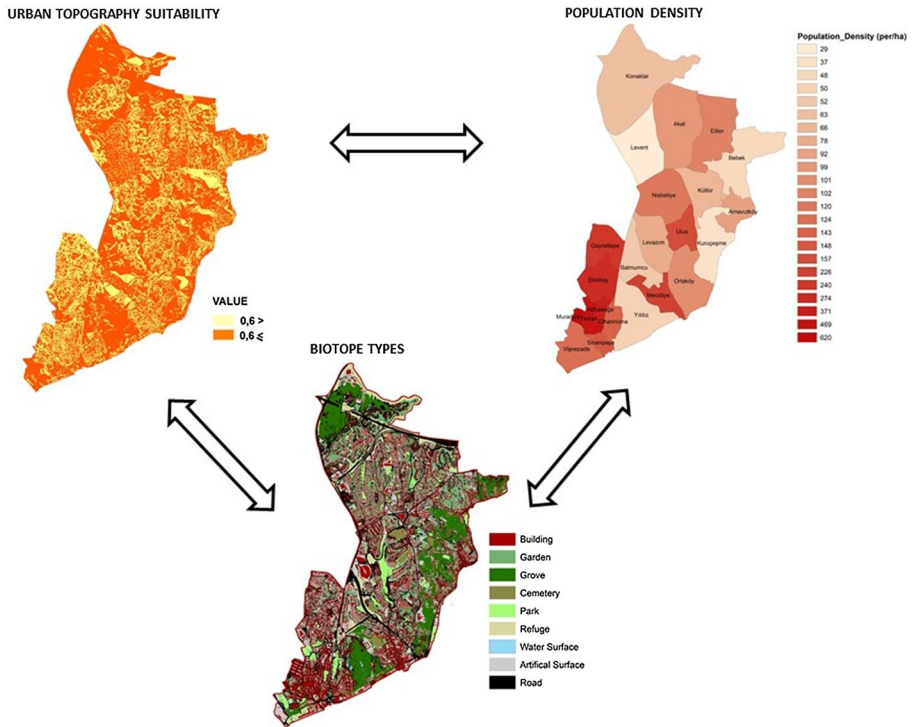


Fig. 8 Correlation of the layers used to evaluate the research area

roadsides account for only 5% of the research area and are not sufficient for balancing the roads, which have a ratio of 21%. This finding shows the significance of roadsides in urban ecosystems, since they do not only connect the green zones but also balance the artificial effects of the roads.

In urban landscapes, the topography changes according to the urbanization process. The primary factor which changes an area's natural topography is the buildings within it. In particular, the height of the buildings affects the elevation and slope values of the topography. However, microclimatic formations such as wind corridors, shade corridors, solar radiation and sunshine duration are triggered depending on building type and the organization of the buildings in the adjacent parcels. Sudden changes in wind direction and eddy formations may occur within an artificial topography, which is unlike natural topography in that it has rigid geometric lines and steep angles. The southwest part of the research area is the weakest, regarding its suitability of topography. It can be said that the buildings which are concentrate in this area have resulted in the formation of shade corridors and urban heat islands. This area has a predominance of artificial surfaces and only low spatial ratios for parks.

When the relationship between population density and biotope type is considered, the balancing influence of the gardens of the buildings was revealed. The areas with a balanced ratio between buildings and gardens were determined to have a high topographical suitability (e.g., the Levent neighborhood). According to this finding, it can be stated that

Table 6 Population density – suitability of topography – biotope type relations

	Population density (person/ha)	Suitability of topography (ha) (value ≥ 0.6)	Biotope Type (%)									
			Building	Cemetery	Park	Grove	Garden	Roadsides	Water surface	Firm grounds	Road	
Konaklar	63	197.13 (max.)	9.41	0.00	1.02	26.88	15.95	14.62	0.08	6.38	25.65	
Akat	99	105.41	23.60	0.00	4.09	0.00	23.67	6.92	0.22	17.57	23.94	
Yıldız	50	91.64	19.43	0.00	0.61	45.07	6.68	2.42	1.53	8.33	15.93	
Levent	29 (min.)	83.31	24.20	0.00	5.32	0.00	24.02	5.03	0.49	17.73	23.21	
Etiler	102	78.91	24.55	0.00	2.78	0.00	24.34	2.99	0.27	17.68	27.40	
Bebek	48	76.96	20.63	0.00	2.04	29.98	17.57	0.32	0.53	15.11	13.81	
Nispetiye	120	69.82	20.24	12.29	8.49	0.00	12.96	6.29	0.11	15.47	24.15	
Ortaköy	101	65.98	24.84	0.00	2.00	10.90	15.90	2.11	0.61	16.10	27.55	
Kuruçeşme	37	63.53	16.62	1.07	2.09	41.18	4.82	0.03	0.42	24.93	8.83	
Levazım	78	50.14	17.07	6.40	2.65	0.00	8.80	12.96	0.28	25.65	26.19	
Kültür	66	49.51	17.55	3.88	2.69	22.14	14.38	0.28	0.50	21.11	17.47	
Vişnezade	124	47.42	26.38	0.00	2.80	9.89	6.50	0.02	0.38	36.46	17.57	
Balmumcu	52	46.34	21.60	0.00	2.87	0.28	15.93	8.52	0.45	24.51	25.83	
Dikilitaş	274	34.25	34.13	0.00	3.88	0.00	7.47	1.90	0.09	29.87	22.66	
Arnavutköy	92	30.73	28.02	0.00	4.33	23.76	13.93	0.39	0.16	9.11	20.31	
Ulus	157	28.85	31.06	0.31	4.61	0.00	26.20	0.28	0.83	18.65	18.06	
Mecidiye	226	28.64	33.07	6.39	4.64	11.21	8.34	2.06	0.07	17.60	16.62	
Gayrettepe	240	26.3	36.58	0.00	5.06	0.00	12.59	0.30	0.00	25.06	20.42	
Cihannüma	143	19.96	26.70	0.00	6.66	0.00	5.31	4.31	0.15	30.51	26.35	
Türkali	469	13.49	44.47	0.00	9.86	0.00	3.33	0.00	0.37	26.32	15.64	
Sinanpaşa	148	10.68	40.73	0.00	12.45	0.00	5.15	2.25	0.00	9.55	29.87	
Abbasağa	371	7.7	45.06	0.00	17.27	0.00	10.65	0.00	0.13	10.52	16.36	
Muradiye	620 (max.)	4.21 (min.)	43.94	0.00	30.88	0.00	4.99	0.00	0.00	4.75	15.44	

Table 6 (continued)

Population density (person/ha)	Suitability of topography (ha) (value ≥ 0.6)	Biotope Type (%)									
		Building	Cemetery	Park	Grove	Garden	Roadsides	Water surface	Firm grounds	Road	
SUM	1230.91	21.68	1.33	3.43	14.38	14.87	5.21	0.39	17.06	21.65	

microclimatic effects are relatively small in areas with a balanced building–garden ratio, and it should be taken into consideration in future urban transformation projects.

Groves are the dominant biotope type in the areas with low population density and high of topography. This finding indicates that high quality woody vegetation balances the topography and microclimate. Grove areas are the lungs of urban landscapes. Their functionality should be maintained by associating them with green structures, which may form stepping stones and/or connecting corridors. In this sense, the roadsides that accompany roads, are of importance due to their linear structure. The current roadsides should be boosted by woody plants and the interrupted areas should be supported by forestations.

5 Conclusion

The fact that buildings are the dominant elements of urban landscapes, illustrates the requirement for supporting buildings with green systems to mitigate their negative microclimatic effects. The surfaces of green roofs and façades should be increased, and woody green tissue should be introduced into the artificial surface through the forestation of roads and gardens.

The spatial increase in the artificial surfaces and their concentration in definite areas in urban environments lead to the formation of urban heat islands and raise the quantity and rate of runoff because they prevent the rain water from accessing the soil. The runoff ratio should be controlled with interventions to raise the permeability of open area firm ground.

Concrete and asphalt are the predominant building materials of artificial surfaces, and these cause black ice in winter and increase nocturnal radiation in summer as a result of their capacity for sudden heating and cooling. Ecological solutions to balance microclimatic problems should be prioritized as part of the design studies related to the research area. The selection of plant species and the sustainability of the artificial surfaces should also be considered.

Evaluating the landscape in a multifaceted way by using complementary indicators is also important for decision making in terms of landscape management and planning. The negative correlation between population density and the suitability of the artificial topography was also associated with biotope types. As can be seen in the Levent Neighborhood example, especially in regions with high population density, it is important to ensure the building–green area balance. It is necessary to deal with this issue sensitively in reconstruction and development plans.

The artificial topography that is a result of the urbanization process is an important indicator of many formations in cities. Artificial topography research is an important component of landscape analysis in terms of determining suitability values and the microclimatic formations that arise due to slope, aspect and elevation parameters. In this study, artificial topography was evaluated together with the population density and biotope characteristics of a specific urban landscape. The suitability of the artificial topography was assessed with the help of the AHP method. This assessment also ensured that the consistency of the suitability values assigned to such criteria could be tested. In this respect, the relativity in the research is reduced.

One important issue in urban landscape analysis and evaluation is the availability of meaningful and interpretable data that can be obtained within a short time. The artificial topography suitability map obtained through AHP is an important base data for urban landscape research, and such data can be evaluated together with many other parameters.

It was concluded from the research area with high urbanization rate that important and collimating findings regarding decisions on planning, design and management in an urban landscape can be obtained by analyzing the relationships between artificial topography, population density and biotopes. Due to the fact that urban landscapes are often undergoing a rapid transformation process, if such evaluations can be performed swiftly it will become easier to intervene in the disruption and destruction that result from urbanization.

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Affiliations

Gül Aslı Aksu¹  · Nigar Küçük²

✉ Gül Aslı Aksu
gaksu@ticaret.edu.tr; aslibozbay@yahoo.de

¹ Department of Architecture, Faculty of Architecture and Design, Istanbul Commerce University, Kucukyali E5 Kavsagi Inonu Street No: 4, Kucukyali, 34840 Istanbul, Turkey

² Department of Landscape Architecture, Institute of Sciences, Istanbul University, Bozdogan Kemerli Caddesi No:8 Vezneciler Hamami Sokagi Vezneciler, 34452 Istanbul, Turkey