DOI:10.5152/forestist.2022.22018
Forestist 2023: 73(1): 85-96

ISTANBUL UNIVERSITY CERRAHPAŞA

Original Article

Evaluation of Artificial Surface—Urban Ecosystem Relations by Using Analytical Hierarchy Process: The Urban Landscape of Istanbul

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ABSTRACT

Especially in urban landscapes under intense urbanization pressure, artificial surfaces affect many components of the urban ecosystem and disrupt the flow of natural cycles. Due to the decrease in the continuity of the green system, population movement is interrupted, biodiversity decreases, the precipitation water infiltration capacity of soils and the transpiration rates decline as a result of sparse and interrupted vegetation cover, and the increase of impermeable surfaces trigger runoff rates and density. The artificial topography created by artificial surfaces, wind-shadow corridors, and urban heat island formations can be counted among further main adverse effects of the unplanned increase in artificial surfaces. Considering all these negative effects, relationships between the artificial surfaces and the green system were evaluated in our research. For this purpose, the criteria of surface cover type, surface flow direction, and slope were overlapped according to the weight ratios determined with the help of the Analytical Hierarchy Process (AHP). A map of priority areas, which enabled us to interpret the disruptions caused by artificial surfaces in the urban ecosystem, was produced. This map has been evaluated with a holistic perception to guide sustainable stormwater management and landscape planning and restoration and management processes related to the urban ecosystem. Artificial surfaces, which dominate the landscape with 62% surface cover in the research area, were assessed in terms of building blocks, transportation networks, and hardscapes, while suggestions were made for sustainable urban landscape planning.

Keywords: Landscape connectivity, landscape ecology, landscape structure, urbanization

Introduction

Urbanization combined with the expansion of artificial surfaces has significantly altered ecosystems, which is strongly linked with climate change in the short- and long term (Olsson et al., 2019). Although the global urban population growth has been in a decreasing trend since the last decade from 2.2% (2010) to 1.80% (2020), today 56% of the world's population is concentrated in urban areas (The World Bank, 2021). Being one of the mega cities, Istanbul has almost reached a population of 15.5 million in 2020 (TÜİK, 2021), which manifests itself as the transformation of green spaces into built-up areas. For instance, artificial surfaces have increased by 8.5% between 1987 and 2001 in the Anatolian Side of Istanbul (Musaoğlu et al., 2004), while the rate of conversion in the Sarıyer district was 13% between 1997 and 2010 (Aksu, 2012). Land cover classification carried out for Istanbul, Beşiktaş District, in 2015 shows that 62% of the total land is covered with artificial surfaces (Aksu & Küçük, 2020).

Such intense and rapid increase of artificial surfaces in both horizontal and vertical axes changes and imbalances micro- and macroclimatic conditions that are mainly the result of artificial topography, urban heat islands, shadow-wind canyon formations, increases in noise-particulate, matter-emission runoff, and deterioration of water regime in urban environments. These transformations having many further effects such as degradation/loss of valuable habitats and biodiversity decline give important clues about the rate at which the disruptions in the ecological processes are reaching the ecological thresholds (Aksu & Küçük, 2020; Chrair et al., 2020; Kırca et al., 2015).

Forman (2014) defined built structures as key components of urban ecology and stated that interactions with structural surfaces should be considered in ecology, which deals with organism–environment relations. In

Cite this article as:
Aksu, G. A., & Kırca, S. (2023). Evaluation of artificial surface—urban ecosystem relations by using analytical hierarchy process: The urban landscape of Istanbul. *Forestist*, 73(1), 85-96.

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Received: February 20, 2022
Accepted: May 25, 2022
Available Online Date: August 13, 2022

this sense, one of the major consequences of the increase of artificial surfaces that suppresses the functioning of urban ecosystems is the fragmentation of the green network since they are the major factors interrupting the integrity of the system.

The spatial transformation process directly affects the landscape structure, which is composed of units, corridors, and the matrix, and occurs as "perforation," "dissection," "fragmentation," "shrinkage," and "attrition" in land cover/land use classes over time (Forman, 1995). Based on this, Bentrup (2008) evaluated the relationships between units and corridors in terms of the integrity of the green system by pointing out the importance of different structural connectors in the landscape such as stepping stones, wedges, corridors, and so on thereby improving the habitat connectivity. Thus, the expansion of artificial surfaces that may occur in weak connections between green units can cause critical and non-recoverable gaps, while the already sensitive flows and relations in the green system are getting interrupted. As the final stage, green units become transformed into island geographies surrounded by artificial surfaces and disconnected from the main system (Haila, 2002).

Such disconnected green units isolated by artificial surfaces naturally lead to a decrease in biological diversity. Yet, being a mega city under intensive urbanization pressure, Istanbul has been facing drastic changes in terms of vegetation composition (Çakir et al., 2008; Güneralp et al., 2013). Located at the crossroads of two phytogeographical regions (Euro-Siberian and Mediterranean) (Davis et al., 1971), Istanbul harbors 5 of Turkey's 122 Important Plant Areas (Özhatay et al., 2005) and the historical Belgrade Forest on the northern part of the European side with high floristic and faunistic diversity (Çolak, 2013). Owing to the varying climatic and topographic conditions, southern parts of the city facing the Marmara Sea are characterized by Mediterranean elements such as Turkish Pine (*Pinus brutia* Ten.), maquis, and garriques formations (Yaltırık et al., 1993), whereas pseudo-maquis, heathlands, broad-leaved forests, and sand dunes gradually seize toward the north, respectively (Avcı, 2014). Thus, implementations aiming to restore habitat connectivity and developing planning schemes for reducing the effects of artificial surfaces should consider that even such a highly degraded urban landscape has the potential to rapidly rehabilitate itself, thanks to its well-established vegetation infrastructure.

Changes in macro-, mezzo-, and microclimatic conditions are another major outcome of uncontrolled and unbalanced urbanization which basically means the increase of artificial surfaces. For example, increase in the concentration of particulate matter (PM) and emissions in the air prevent the sun rays from reflecting off the surfaces and returning to the atmosphere (Batur & Aksu, 2021), a phenomenon known as greenhouse effect. The increased greenhouse effect, especially in urban environments, can cause climate changes on different scales that are reported to be occurring as sea-level rise, flood and overflow problems due to sudden and excessive precipitation, deviations in seasonal climate averages, extreme heat events, and drought due to overheating (UN-Habitat, 2011). Hence, land use/land cover changes in the urban scale have wide-ranging impacts posed by the urban heat island effect originating from the artificial surfaces. First, depending on the density of construction, a large part of the hardscapes and facades of the buildings are covered with materials such as waterproof concrete, asphalt, keystone, brick, and so on. These surfaces reveal the radiation they accumulate during the day, especially at night, and cause the temperature values in the urban environment to increase compared to the rural areas. Second, dark-colored surface materials, which are prevalent in buildings and hardscapes, collect and trap solar energy in large amounts. The temperatures of dark, dry surfaces under direct sunlight can reach up to 88°C during the day, whereas vegetation-covered surfaces with moist soils, can only reach 18°C under the same conditions. Anthropogenic heat (heating–cooling systems used in buildings and the excess of this energy due to insufficient attention to energy efficiency, warming from motor vehicles, etc.) decreases wind speed and air pollution (Forman, 2014; Gartland, 2008; Oke, 1976) whereas the permeability, color, and texture of the pavement materials are other important factors that trigger urban heat island formations (U.S. EPA, 2012).

Being another important driver, urban topography continuously changes urban climate and ecological conditions. An artificial topography begins to take shape in the urban environment with the building layer, which creates a geometrical texture both horizontally and vertically. As the building density increases, the effects of artificial topography begin to intensify. With the change of natural topography, dramatic changes are observed such as the sudden increases in slope degrees and intensified impermeable surfaces which together interrupt natural drainage cycles and generate higher surface runoff rates (Aksu & Küçük, 2020). Furthermore, wind and shadow corridors referred to as urban canyons are formed so that the natural water and wind flows as well as light conditions are highly affected by the height and layout of the buildings (Erell et al., 2011; Forman, 2014; Gartland, 2008). Along with the degradation of urban hydrological systems, biodiversity is also undermined as urban environments have become highly homogenous mainly comprising alien and invasive species but poor in terms of habitat diversity (Hill et al., 2002).

As clearly seen, urban topography is strongly related to the disruption of the water regime. In a natural system, rainfall is intercepted, absorbed, and filtered by plants and the soil throughout the catchment. This infiltration keeps groundwater and soil moisture levels at reasonably stable levels and reduces the incidence of surface flows. Soil and vegetation operate like a sponge—retaining and releasing water, collecting, and attenuating flows. Types of vegetation, soils, topography, and land use all significantly affect the natural hydrological cycle with resulting changes in the frequency, volume, and duration of runoff. Research shows that vegetation can increase water infiltration by up to 60 times compared to bare ground (Heke & Pöneke, 2021). However, impervious surfaces combined with reduced vegetative cover in urban environments alter hydrologic cycles by reducing infiltration, increasing runoff volume and rates, lowering groundwater tables, decreasing evapotranspiration, and creating precipitation anomalies while accelerating the need for municipal services such as waste and water management (Parece et al., 2016). This also causes the city to dry very quickly and heating up. Since the precipitation cannot be kept in the city, the humidity of the air remains lower than in the surrounding natural areas, and the presence of solid particles in the urban atmosphere frequently causes fog (Barner, 1983).

The high amount of artificial surfaces is also directly linked with reduced air quality and entangled health problems. Increased vehicle traffic and industrial use as well as domestic activities have a boosting effect on the most common physical and chemical pollutants in the urban atmosphere such as PM, NO, NO^2, CO, NMVOV (non-methane volatile organic compounds), O^3, and SO^2 (Çepel, 2003). Depending on the level of these pollutants in the urban atmosphere, they may have adverse effects on the health system of urban residents in different ways and at different levels. Besides diseases caused by the pollutants originating from artificial surfaces, Dadvand and Nieuwenhuijsen (2019) suggest that a decrease in green areas may also trigger psychological disorders. Rising noise levels can negatively impact human health as well.

In this research, artificial surfaces that have such vital impacts on the urban ecosystems and accordingly on urban life quality are discussed from a bio-integrated perspective. Hence, Beşiktaş, a highly urbanized part of Istanbul was selected as the study area and "Urban Landscape Plan and Implementation Strategy" (Aksu, 2017) was used as a supporting document. It was aimed to determine priority areas for connectivity restoration by using multi-criteria analysis based on three main parameters: (1) surface cover, (2) flow direction, and (3) slope. It is believed that such an approach would help define realistic ecological design proposals that could eliminate the problems in the urban landscape structure.

Methods

Material

The research area Beşiktaş is located in the European side of Istanbul between 41°02′31″ north latitudes and 29°00′26″ east longitudes by the Bosphorus. Beşiktaş is administratively a district of the Istanbul Metropolitan Municipality. The neighboring districts are Sarıyer in the north and Kağıthane, Şişli, and Beyoğlu in the west (Figure 1). Today, the district covers an area of 18.22 km^2 with 23 neighborhoods. According to TÜİK (2021), the total population is 178.938. Being settled since the Byzantine Empire, Beşiktaş has been known as one of the most elegant districts of Istanbul and favored by the Ottoman sultans mainly because of the abundant greenery (i.e., groves and palace gardens) and picturesque views it provides (Koçu, 1961).

Method

Based on the premise that there is a close link between ecological pattern, ecological function, and process, the spatial heterogeneity of landscapes has become one of the key issues in understanding the considerable complexity and diversity in time and space (Forman, 1995). Acknowledging the interaction of bio-physical and sociocultural processes that lead to the spatial change of interacting ecosystems (Ndubisi, 2002), efforts for finding ways of creating "multifunctional landscapes" that are completely perfect and self-regulating "Gestalt systems" of the entire ecosphere (Naveh, 2001) have escalated in the last decades. To address this goal, the concept of ecological planning was proposed as a key method that examines biophysical and sociocultural information to suggest opportunities and limitations for making decisions on where specific land uses can best be applied (Steiner, 1991). Due to its multi-criteria nature, AHP, which increases the consistency and quantification of multi-criteria analysis, is widely used effectively as a supportive approach in ecological planning (Aksu et al., 2017a; Aksu & Küçük, 2020; Harker & Vargas, 1987). Thus, AHP was preferred in this study to optimize land use and the benefits of enhancing the quality and quantity of the green network in the Beşiktaş district.

In the urban environment, artificial or urban topography, which is formed by the effect of the floor heights of the buildings, causes changes in the slope, aspect, and elevation values. These changes affect

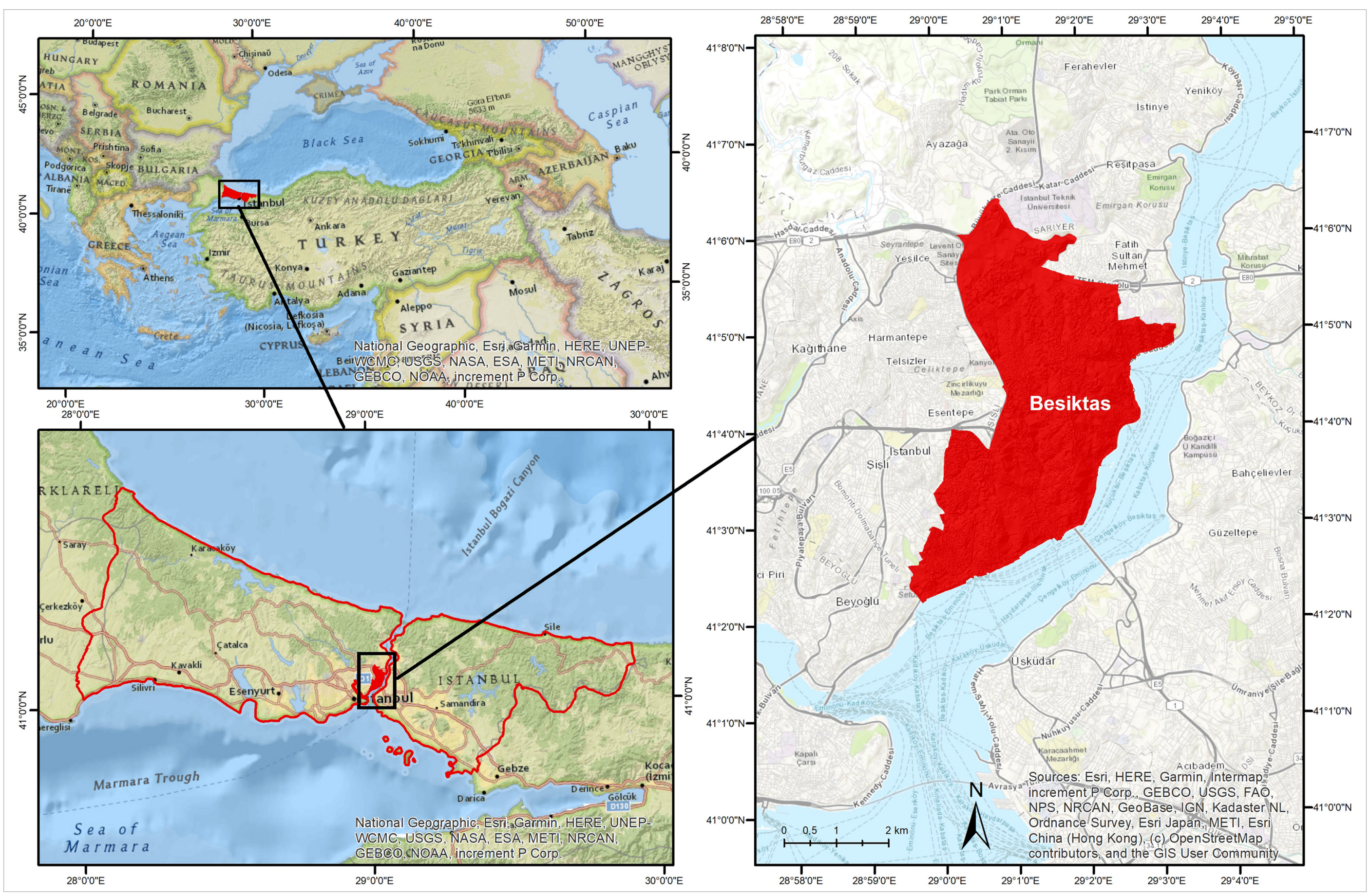

Figure 1.
The Research Area Beşiktaş Is a Central District of Istanbul. Source: ArcGIS 10 Basemap.

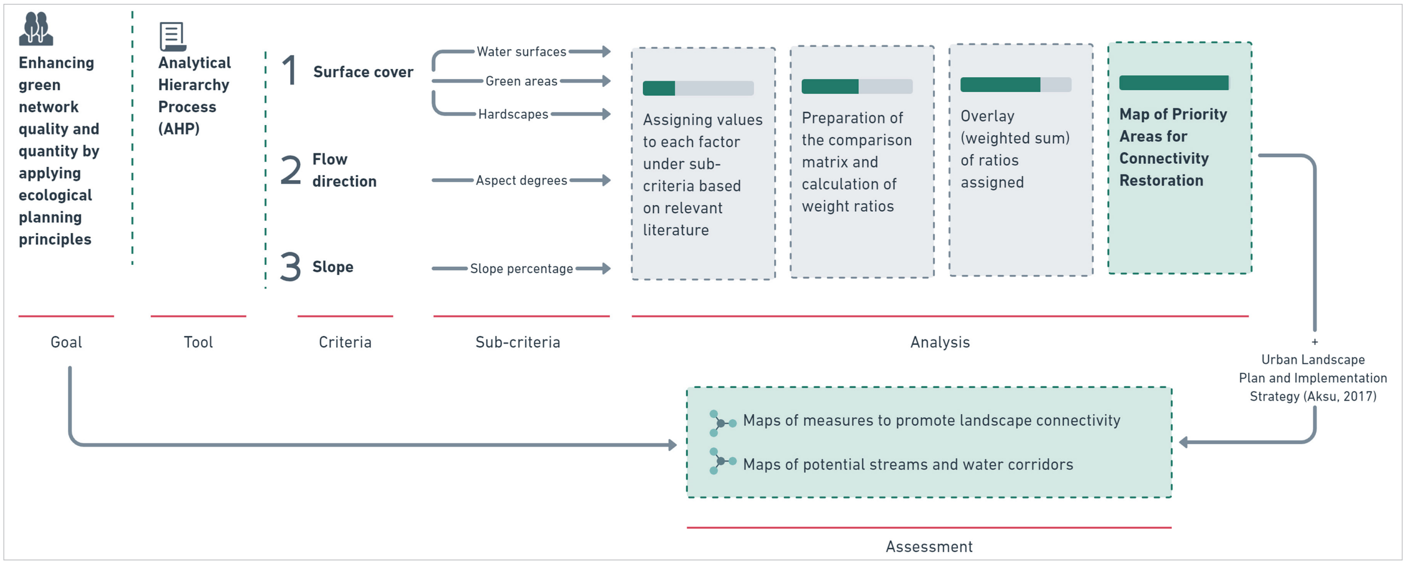

Figure 2.
Main Steps of the Methodology.

the organisms and their habitats in the urban ecosystem positively or negatively. However, expansion of artificial surfaces with increasing slope and elevation values due to buildings are the main reasons for high surface flow causing environmental catastrophes, that is, floods. Thus, we used three main criteria as (1) surface cover, (2) flow direction, and (3) slope based on urban topography in order to provide a holistic perspective for guiding through the landscape planning, restoration, and management processes of artificial surfaces in urban ecosystems. As shown in Figure 2, AHP was applied to the selected criteria and values from 1–9 were assigned to the factors under each sub-criteria (see Table 1 for summarized values).

Surface Cover

Pléiades satellite image from 2015 with 50 × 50 cm spatial resolution was used to derive data on the surface cover of the study area. Green and artificial areas were distinguished by creating the Normalized Vegetation Index (NDVI), whereas the 1/25.000 scaled vector base map of the area was used to mask some layers while determining subclasses under artificial surfaces. Additionally, the subclasses were elaborated as buildings, roads, and hardscapes by using the manual digitization method in ArcMap 10.8.2 (see Aksu et al., 2017b, for more information).

Land cover type is one of the important components of determining landscape connectivity, while hard and impermeable surfaces create a barrier effect for the continuity of the ecosystem and change the natural flow of stormwater. On the contrary, green areas directly affect the quality and quantity of biological diversity and living conditions. Land cover ratios of green areas and artificial surfaces are given in Figure 3. As shown in the map of "Surface Cover" in Figure 4, 38% of the study area is covered with green areas, whereas groves play crucial roles in providing connectivity to the green network. Their well-structured woody vegetation supports the ecosystem services and provides habitat for many species. Roadside green areas, on the other hand, are important for balancing the negative effects of the road network that creates a barrier effect between habitats. Although cemeteries have a small part in the green network of the study area, they are important habitats for timid species mainly because of their well-developed tree cover and low visitor activity. Residential gardens are small, but important since they are considered stepping stones within the landscape matrix. Finally, parks and water surfaces are of vital importance and are considered either as major habitats or stepping stones depending on their

Table 1.
Assigned Values in the AHP Process

1	Surface Cover		Value
	Water surfaces	Waterbody	9
	Green areas	Cemetery	9
		Grove	9
		Roadside green	9
		Garden	7
		Park	7
	Hardscapes	Building	3
		Road	1
		Impermeable surface	3
2	**Flow direction (°)**		**Value**
	N, NE,		3
	NW		5
	SE, W, E		7
	S, SW		9
3	**Slope (%)**		**Value**
	> 100.1		1
	50.1–100		3
	20.1–50		5
	5.1–20		7
	0–5		9

Note: AHP = Analytical Hierarchy Process.

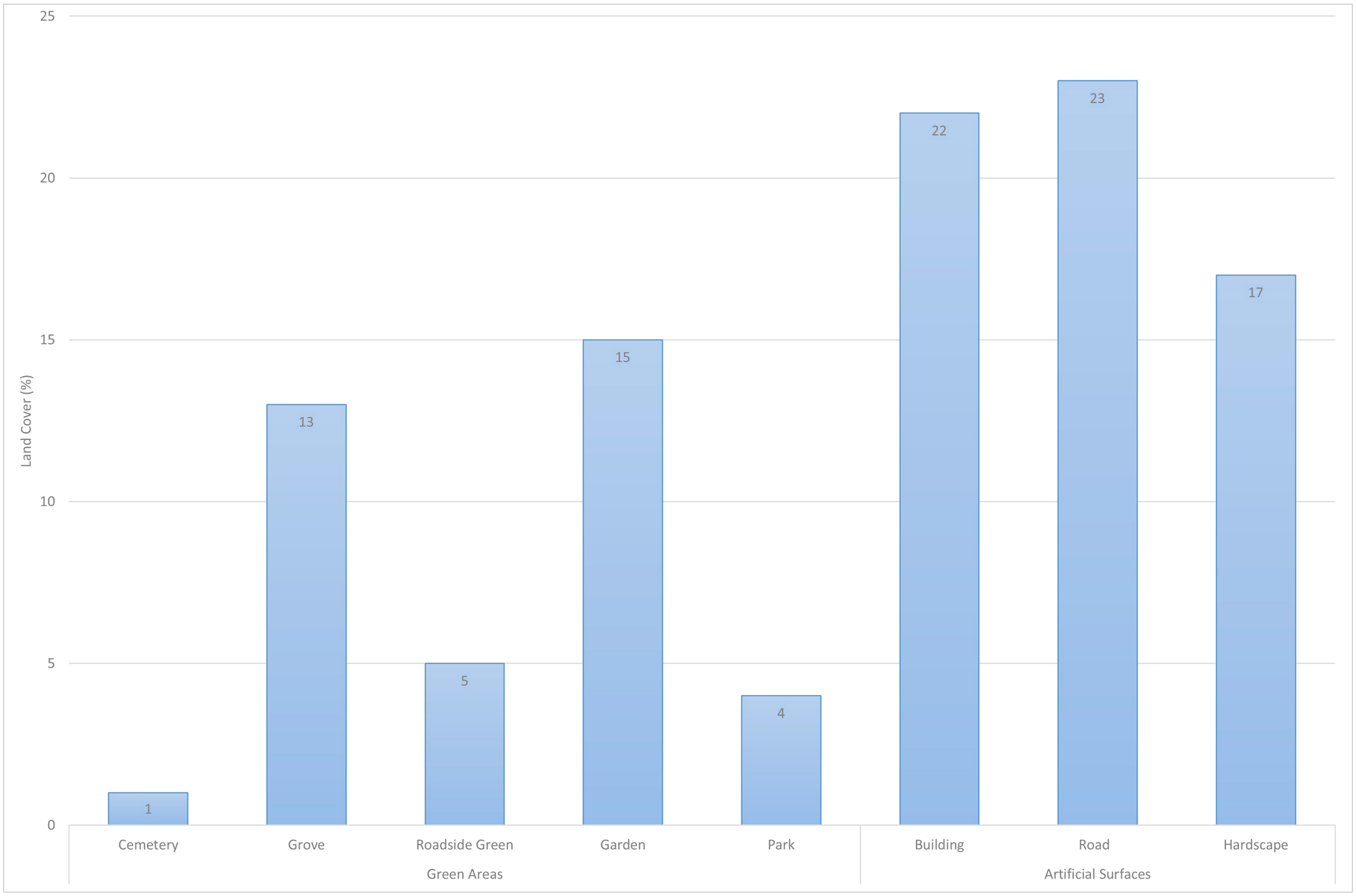

Figure 3.
Land Cover Ratios in Besiktas District.

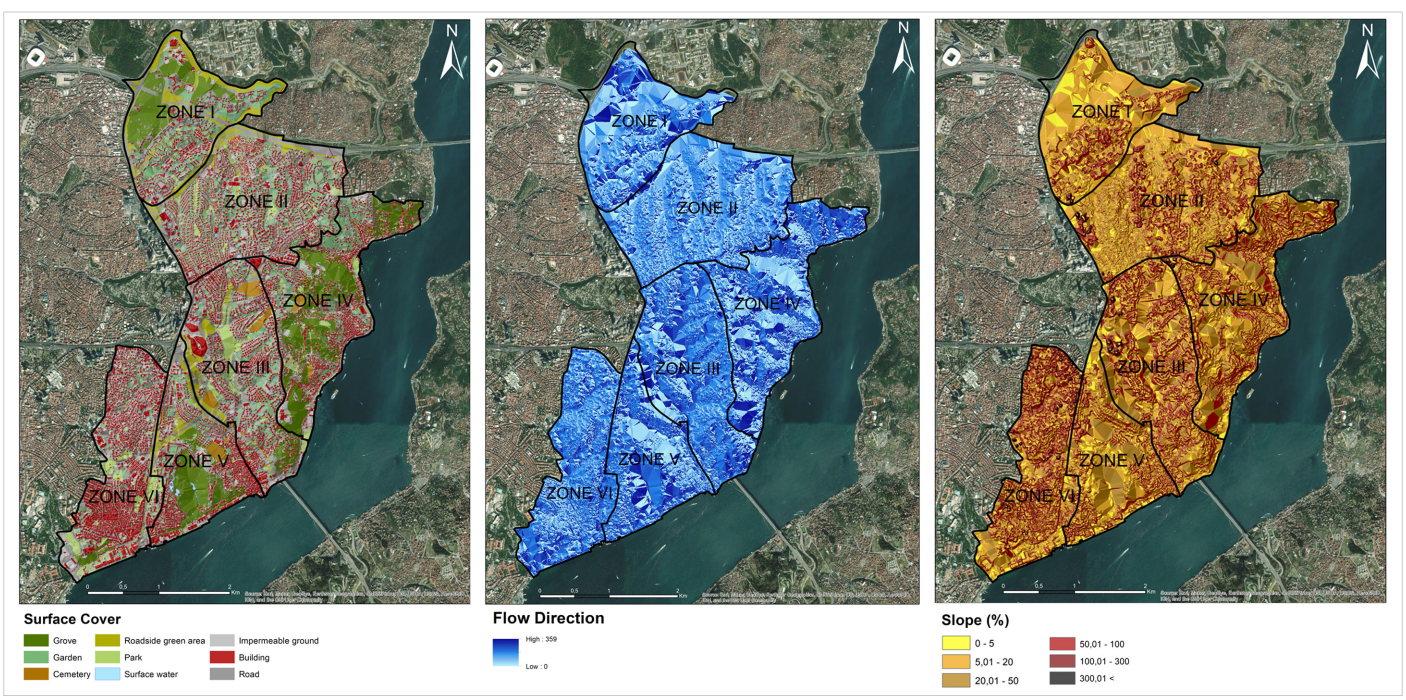

Figure 4.
Map of Surface Cover, Source: Pleiades (2015), Aksu et al. (2017b); Flow Direction and Slope (%) of the Study Area.

size. Almost 40% of the study area is covered with hardscapes and, on the contrary to green areas, their potential for providing habitat is low (Aksu, 2017b; Aksu & Küçük, 2020). Considering these main ecological characteristics, scores between 1 and 9 were assigned to the types of surface cover (Table 1).

Flow Direction and Slope

Flow direction and slope were determined by using the Digital Elevation Model (DEM), which was based on the 1/25.000 scaled vector base map containing z values, especially the building heights. Vector data was converted into the raster data with a 5 × 5 m spatial resolution in the Spatial Analyst Module in ArcMap 10.8.2. Thus, slope, aspect, elevation, and flow direction analyses were applied based on the artificial topography.

Flow direction is one of the major indicators of artificial topography shaped due to the intensity of built-up areas in urban areas. Thus, determining flow direction is mainly important for stormwater management. Flow direction values are shown in degrees (0˚ to 360˚; both indicating the East) and based on the variation of aspects in the urban topography (Figure 4). This criterion was evaluated under four sub-criteria with the assigned values ranging from 3 to 9. The north and northeast areas are prone to main northern winds and having a major impact, these winds trigger the severity and directions of precipitation. Therefore, the lowest value (3) was assigned to these areas. Warmer winds blowing from the Bosphorus increase the air quality and bioclimatic comfort in the study area, so that maximum value (9) was assigned to the south- and southwest-facing areas. Lower frequency winds from the west and east relative to south and southwest do also increase air quality by supporting fresh air circulation and precipitation from the Bosphorus in dry periods, yet do not have negative impacts on the surface flow combined with higher insolation periods. This brings assigning a high value (7) to these aspects. Lastly, northwest areas have medium effects on the air and water circulation potential in the study area with a value of 5 (Table 1).

As another prominent indicator, slope defines the surface flow speed and density. Combined with the surface cover, it leads to further findings on the urban ecosystem. In this study, the slope map was produced by using an urban topography map and slope degrees reaching over 300 (max. 1600 caused by high-storey buildings) were determined by the close environs of the buildings (Figure 4). The barrier effect created mainly by the buildings not only changes the wind direction and force but also increases the precipitation flow rates. The accelerated stormwater joined with the expansion of the impermeable surfaces causes its accumulation and flow at higher rates. Therefore, slope degrees based on urban topography were included in the AHP, whereas lower values were assigned to the higher slope degrees and vice versa (Table 1).

After the preparation of the comparison matrix, the assigned values to each factor were normalized, and finally the weight ratios for each factor were calculated. As a result, the map of priority areas for connectivity restoration was derived by overlaying assigned weight ratios to each category by using ArcMap 10.8.2. For the ease of representing neighborhoods with explicit characteristics in terms of building typology, density, and green area structure, the study area was divided into 6 zones as follows: Zone 1—Konaklar neighborhood, Zone 2—Levent, Akat and Etiler neighborhoods, Zone 3—Nisbetiye, Levazım, Ulus and Ortaköy neighborhoods, Zone 4—Kültür, Bebek, Arnavutköy and Kuruçeşme neighborhoods, Zone 5—Balmumcu, Yıldız and Mecidiye neighborhoods, Zone 6—Gayrettepe, Dikilitaş, Muradiye, Türkali, Abbasağa, Vişnezade, Cihannüma, and Sinanpaşa neighborhoods. These zones were reflected in all maps (Figures 4–7).

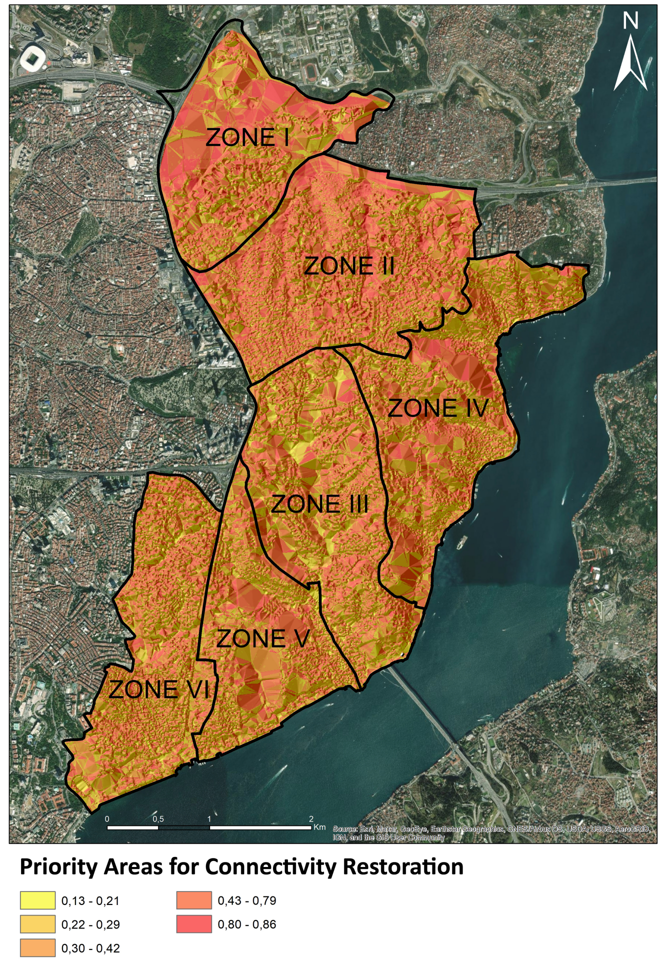

Figure 5.
The Map of Priority Areas for Connectivity Restoration.

The results were compared and overlaid with the "Urban Landscape Plan and Implementation Strategy" that was developed by Aksu (2017) for the research area and relations between priority areas for restoration and artificial surfaces were discussed while suggestions were made within the framework.

Results

An increase in surface flow due to the expansion of artificial surfaces and transformation of topography parallel to the dense urban texture of buildings cause dramatic changes in variables such as temperature, wind speed and direction, radiation level, and intensity. These have direct effects on the natural cycles in urban ecosystems. Therefore, developing strategies for landscape planning, restoration, and management focusing on the sustainability of ecosystems require highly qualified data. However, ecosystem functions and their components cannot be distinguished with strict boundaries, since the elements ensuring healthy functioning of ecosystems are intertwined with each other. This highlights the importance of the methodological construction and parameter selection so that the most relevant ecological parameters to the research topic are selected to ensure a holistic approach that avoids multiple uses of some parameters providing the same inputs. Focusing on the effects of artificial surfaces on ecosystem cycles, criteria that were found most suitable to reveal such

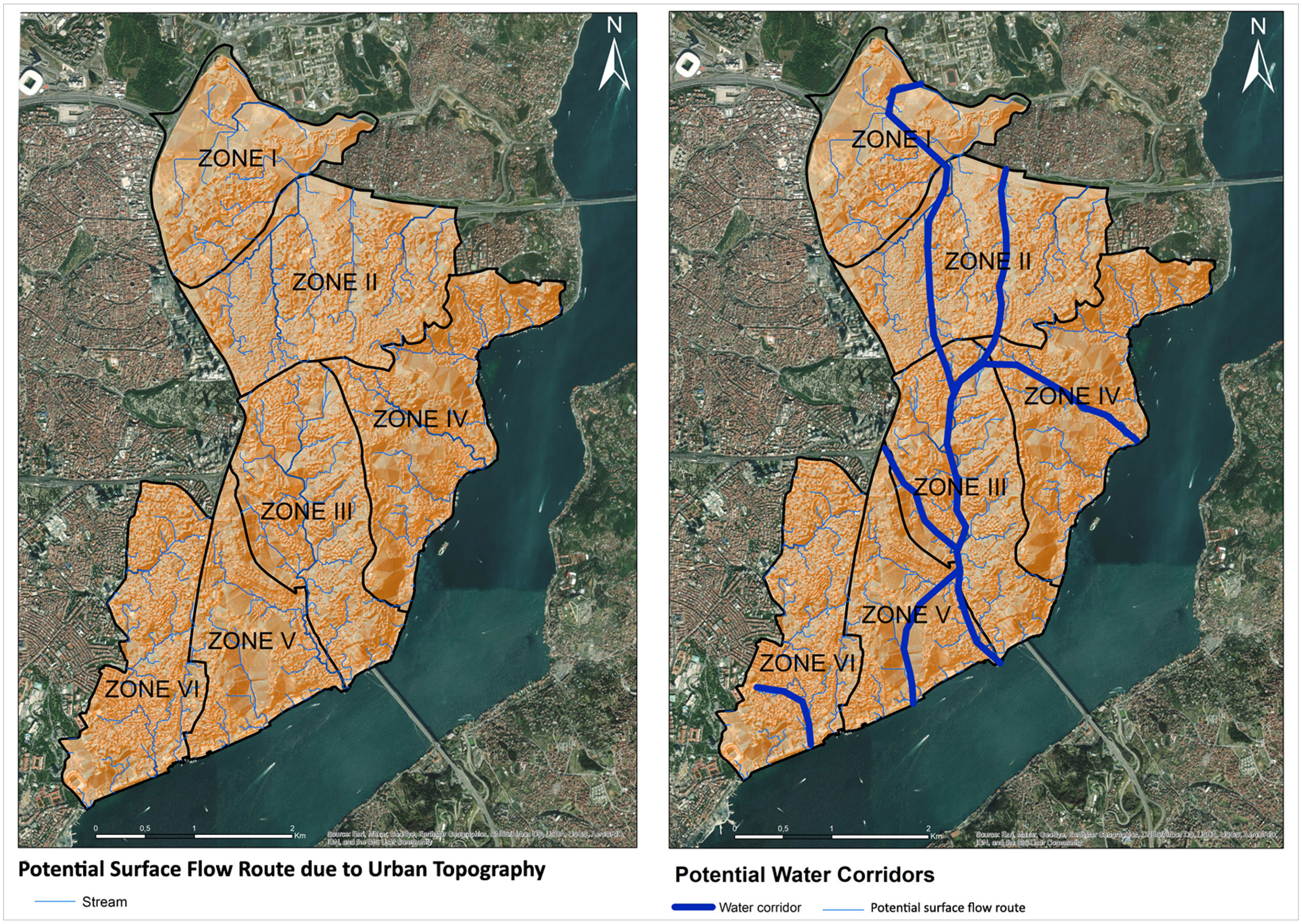

Figure 6.
Maps Showing Potential Surface Flow Routes Due to Urban Topography and Potential Water Corridors.

relationships were selected for the analysis in this study. Based on the idea that ecosystem connectivity is crucial to alleviating the negative effects of artificial surfaces, AHP was applied to the selected criteria (e.g., surface cover, flow direction, and slope) to determine priority areas for connectivity restoration.

After assigning values as explained in the methods, surface cover type, flow direction, and slope criteria were evaluated with the help of a comparison matrix. In order to make the values assigned to the defined criteria comparable, a normalized comparison matrix was created. It is followed by calculating the weight ratios of the criteria and checking their consistency. Consistency ratio (CR) was found .070811 as $CR < 0.10$ means that the assigned values and weight ratios are consistent (Table 2). As a result, the map of priority areas for connectivity restoration was obtained by applying the calculated weight ratios to the criteria of surface cover, flow direction, and slope (Figure 5).

The priority value of an area has an inversely proportional relationship with the restoration need so that lower values mean higher priority and vice versa (Figure 5). This assessment helped to decide which regions should be supported primarily in terms of green systems, as well as the regions that are critical and suitable for re-establishing ecological connections, which have been broken by artificial surfaces.

Available water surfaces serving multi-functional purposes are indispensable for the continuity of ecosystems. Therefore, we analyzed the basins by taking the urban topography in Beşiktaş as a reference. To develop water surfaces with high ecological value, which are an indispensable part of the ecosystem, potential surface flow routes, and water corridors were determined based on the relationship between topography and priority areas (Figure 6). These corridors may guide restoration efforts while developing strategies for rebuilding a blue infrastructure for the research area.

The priority map provided valuable information on finding ways to compensate for the disruptions caused by artificial surfaces. Thus, some measures were acknowledged in the research area to shed light on the most crucial spots for rebuilding connectivity (Figure 7). Thus, potential green corridors, potential water corridors, green connectivity points, and areas that need to be supported by green roof-facade systems, roadside plantings, and/or noise barriers were evaluated by associating them with each other. Areas with high priority were compared according to hardscape—green area distribution. Aksu (2017)'s Urban Landscape Plan and Implementation Strategy was also used to determine corridors with the potential to strengthen the connectivity of the green network. As in Figure 7, these corridors are divided into two types "primary green corridors" and "secondary green corridors" according to their priority levels. These corridors are extremely

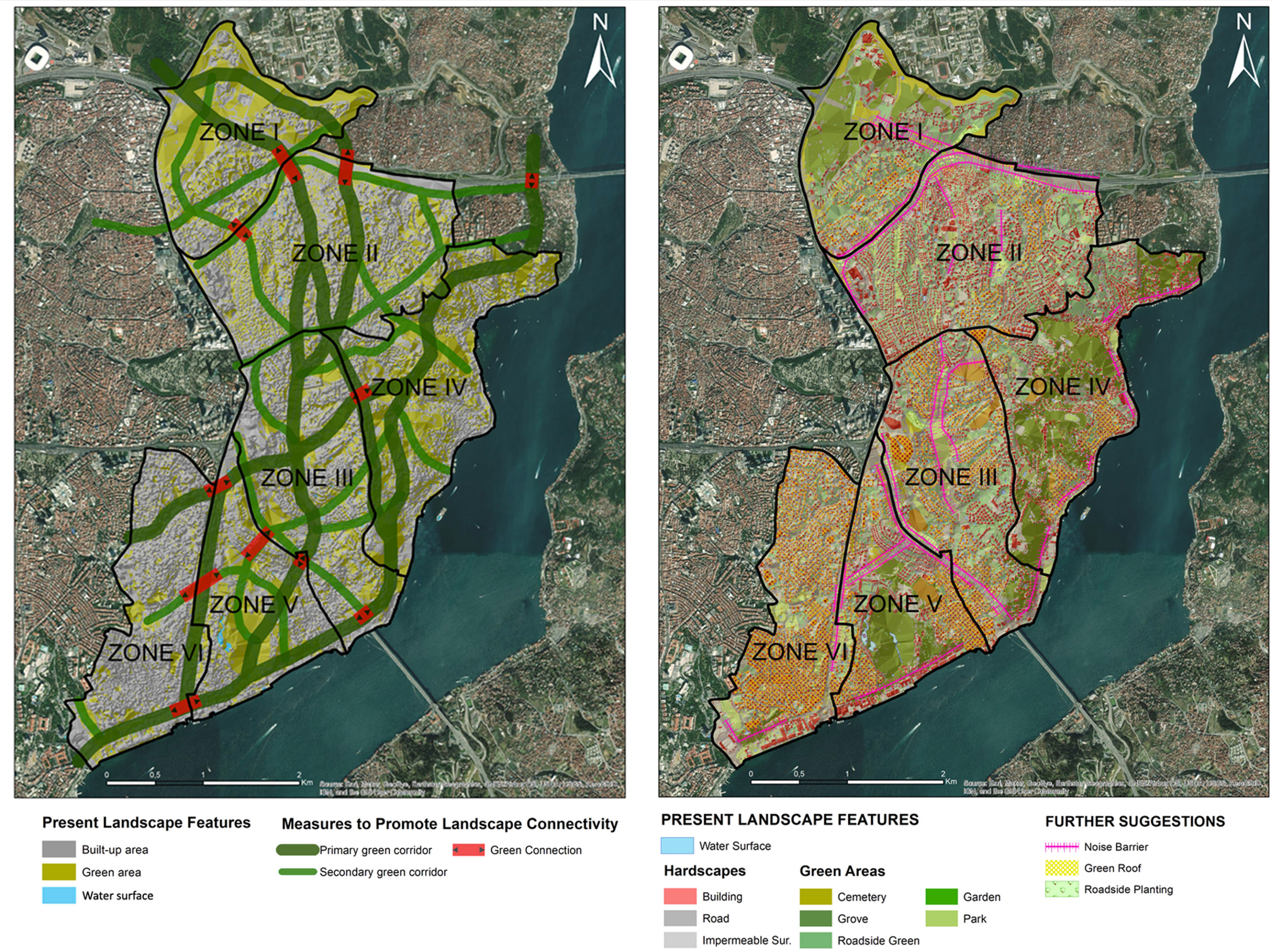

Figure 7.
Maps of Some Measures to Promote Landscape Connectivity; Green Corridors and Connection Points (Left) and Further Suggestions (Right).

important in terms of ensuring the continuity of the green system but also need to be safeguarded with the "green connections." These points have been evaluated as green systems that have the quality of connecting green units.

Critical gaps in the continuity of the green system affect population mobility and biodiversity negatively. In the exact parallel, depending on the increase in impermeable surfaces and the decrease in vegetation density; transpiration declines the infiltration capacity of stormwater by the soil and the amount of water in the subsurface water tables decreases, the surface flow rate and density increase (Suri, 2020).

Discussion, Conclusion, and Recommendations

The priority maps developed for the conservation and restoration efforts in urban landscapes are found highly efficient in terms of focusing on crucial areas for the fight against climate change and biodiversity loss, as well as channeling limited financial resources to the most beneficial planning strategies (Norton et al., 2015; Soga & Koike, 2013).

The research area is located at the heart of Istanbul, under the influence of two bridges and highways. The Bosphorus consisting of the eastern border of the district, on the other hand, is the source of maritime effects which increases climate comfort. However, the high accessibility together with milder climatic conditions resulted in high urban sprawl.

Although studies indicate that transport infrastructure elements are known as barriers dissecting the habitats on the regional and wider scale (Li et al., 2010), these artificial surfaces have similar effects in the urban landscape matrix as well. This phenomenon can be observed in Beşiktaş through the main transport axes in Büyükdere Street and Barbaros Boulevard with north–east direction, which divides the area and largest green patches (i.e., groves and parks) almost into two halves. The connection roads of the two bridges are more directed toward west–east direction. The coastal road lies parallel to the sea cutting the transition zone between the coastal and marine ecosystems (Aksu, 2021). These high-intensity roads dissect the area vertically and horizontally while disrupting the continuity of the green network. As emphasized by Rusche et al. (2019), connectivity of green infrastructure elements is as important as their multi-functionality. Therefore, we proposed green connections that build links between primary and secondary green corridors (Figure 7). However, such green systems need to be designed with a multidimensional perspective addressing

Table 2.
The Results of AHP Process by Developing Comparison Matrix and Calculating Consistency Rate

Comparison matrix			
	Flow Direction	Surface Cover	Slope
Flow direction	1.00	7.00	9.00
Surface cover	0.14	1.00	3.00
Slope	0.11	0.33	1.00
Column sum	**1.25**	**8.33**	**13.00**

Normalized comparison matrix				
	Flow direction	Surface cover	Slope	Row sum
Flow direction	.80	.84	0,69	**2.33**
Surface cover	.11	.12	0,23	**.46**
Slope	.09	.04	0,08	**.21**
n = 3				

Calculations based on normalized comparison matrix		
Weight Ratios:		*Average Value of the Consistency Vector:* $\lambda = \Sigma E_i / n = 3.0821$ *Consistency Index:* $CI = \lambda - n / n-1 = .041071$ *Randomness Index:* RI = .58 (value read from the table for *n* = 3) *Consistency Rate:* CR = CI/RI = .070811
W =	.7766	
	.1549	
	.0685	
Weighted Total Vector:		
AxW =	2.48	
	.47	
	.21	
Consistency Vector:		
E =	3.19	
	3.04	
	3.01	

Note: AHP = Analytical Hierarchy Process.

both ecological quality and societal needs on fine scales (Akpınar, 2014; Daniels et al., 2018). In this context, the use of indicator species or species groups is considered a highly practical and efficient strategy (Łopucki & Kiersztyn, 2015). As Beşiktaş is under diverse effects of climate, the procedure of designing the structure of green corridors and selecting plant species should be based on the indicator fauna with different habitat preferences and movement patterns. The suggested noise barriers and roadside plantings are generally along these corridors to serve the purpose of ensuring habitat quality. It is important to select trees, shrubs, and herbaceous species that would provide shelter and food to the target fauna, whereas their tolerance to dust and emission, extreme winds, drought, and salinization should be considered. As emphasized by Aksu (2021) and Kırca and Sevinç (2020), roadsides in Istanbul are generally designed with esthetic and practical concerns, neglecting the benefits of forming plant communities meeting ecosystem services and sustainability principles. Such poorly designed roadsides weaken the high ecological and esthetic potential of these areas (Erdem, 2004).

The dense urban fabric was found as another major problem, as 62% of the study area is covered with artificial surfaces, although green areas (i.e., parks and groves) supporting the green network exist mainly in the neighborhoods of Konaklar, Yıldız, Bebek, and Kuruçeşme in zones 1, 4, and 5, respectively. As means of building roofs and facades, building density was found highest in zone 6, which contributes to the extreme pressure of high-density buildings on green areas. Yet, tiny green patches and narrow streets without enough space for tree planting indicate green roof systems as the most relevant solution to serve as urban stepping stones in the system. Although there is still a knowledge gap on whether green roofs are effective stepping stones, Lynch (2019) pointed out the increasing number of studies on how different green roof types in the last decade promote habitat diversity for wildlife (i.e., bats, butterflies, bees, and arthropods). Apart from being a habitat, their high potential for storing carbon, mitigating heat-island effect, and stormwater retention make them crucial in high-density urban landscapes (Ekşi, 2021; Ekşi & Uzun, 2016).

Zones 1, 4, and 5 contain groves as rather large and unfragmented units in a continuous urban fabric. These groves rich in biomass and species diversity owe their current relatively intact structure to being in the Bosphorus front view area. This balance was due to residential gardens in zones 2 and 3, which are dominated by neighborhoods composed of villas. It is suggested by Rudd et al. (2002) that creating backyard habitats is the best approach for creating large and intact ecosystem areas in urban landscapes. Wildlife-friendly gardening contributes highly to the connectivity and availability of habitats, however, their value is generally underestimated (Mimet et al., 2020). Thus, not only maintaining such settlements but also developing programs for raising their habitat quality would be highly beneficial for an efficient strategy to mitigate the negative effects of artificial surfaces.

The findings on the green network as a whole suggest that groves constitute the foundation of the system in terms of connectivity. Structurally, residential gardens and roadside green areas have the second-degree importance. Thus, their complementary role in strengthening the connectivity between green units should be considered through the suggested primary and secondary green corridors and green connections. As emphasized by Kowarik (2011), preserving semi-natural habitats in cities should be combined with strategies acknowledging the contribution of novel urban ecosystems that emerge in such highly transformed environments. All kinds of landscape planning, design, and restoration implementations need to be developed carefully within a holistic framework that would serve to enrich both habitat quality and quantity. On the other hand, the proposed green corridor along the coast would not only help rebuilding connections between the groves but also reconnect coastal and marine ecosystems that were dissected by the coastal road. Such issues highlight the importance of developing tree planting schemes that would enrich habitat diversity, encouraging the allocation of space for gardens particularly in urban transformation projects, and promoting landscape plans focusing on plant use that prescribes mainly the use of native woody vegetation and species assemblages associated with the novel urban ecosystems. Parks should also be handled with the same awareness and knowledge, while suggested priorities and principles should be reflected in the landscape design projects as well.

Land-use change due to urbanization resulted in dramatic changes in physical structure of streams as well as green areas. Most of them either lost their natural structure and/or are totally covered (Dinç & Bölen, 2014). Ortaköy Stream and Ihlamurdere are among the vital but long-vanished streams that are big losses in terms of urban ecosystem functionality. The findings of Aksu and Küçük (2020) also reveal the severity of this issue by indicating that water bodies cover less than 1% of the study area.

In urban landscapes with such high amount of impervious surfaces and rugged topography, one of the major problems is extreme surface runoff due to the dramatic decrease of infiltration capacity. According to (Koç et al., 2020) urbanization and steep topography were found as one of the six aggravating mechanisms of floods in Turkey between 1960 and 2014. Yet, the proposed water corridors would help preventing flooding events which are likely to occur more frequently due to the changing climate. Water harvesting might be implemented in these corridors for creating surface water systems, which would also enrich habitat diversity and serve as reservoirs in case of drought. Artificial surfaces are among the most critical factors affecting the landscape structure. It results in dramatic changes in the functioning of ecosystems especially in highly urbanized centers. With the disruption of the ecosystem services (i.e., regulating, cultural, and supporting services) provided by green areas, the decline in the quality of life along the city's rich natural and cultural background is inevitable in metropoles like Istanbul.

Favored by the Ottoman sultans and officials for many centuries, Beşiktaş has turned from being one of the most elegant and green districts with fresh springs of Istanbul into a highly degraded one with its artificial surface cover of 62%. Overall, this study strengthens the idea that reducing all this damage is only possible with a holistic landscape planning and ecological design approach. The following conclusions can be drawn from the results that aesthetic and functional concerns need to be combined with ecologically minded solutions:

a. Impervious surfaces have a share of 17% in the study area. This brings the importance of considering the structure and permeability of materials used in construction and restoration projects. Selected materials should be environmentally friendly and should not contain chemicals that may cause pollution in the soil or groundwater when washed with rainwater. In addition, the material's carbon footprint should meet the sustainability criteria during the period from production to disposal.
b. For increasing the rainwater retention capacity,materials with a porous structure can be preferred;
    - a permeable pillow such as sand, leaves, natural grass, and groundcover joints between the stones can be used when applying materials such as cobblestone and slab stone;
    - a smooth and impermeable surface is required in areas with heavy public use. In such cases of using a fixed and impermeable cement-reinforced cushion in the infrastructure rather than a movable cushion, it would be appropriate to seek alternative drainage systems where the collected precipitation water can be stored and used. These systems can be included in the water recycling and harvesting systems of the buildings, if any, or they can be integrated with harvesting, retention, detention, and infiltration systems such as rain gardens, rooftop retentions, infiltration zones, trenches, swales, geocellular systems, detention ponds, and soon.
c. Buildings cover 22% of the study area. On the other hand, the facades of the buildings forming a vertical structural layer and dominating the landscape are generally neglected. These rates highlight the importance of putting green roof-facade systems into operation, especially in designated priority areas. In addition, it should not be forgotten that the facades and roofs of buildings also have biotope potential for many organisms. The building stock in the research area mainly consists of reinforced concrete structures due for maintenance and renewal. This situation should be evaluated to consider the biotope-forming properties of buildings, especially during facade renovation works. This initiative can only be realized with an interdisciplinary approach and awareness of biotope patterns in urban areas. Thus, such a holistic and interdisciplinary approach can make buildings part of a sustainable urban system. However, sustainable and energy-efficient building design should not be due to individual efforts of some designers in buildings but need to be carried to the urban scale within a structural framework of planning, design, and management by related municipalities and ministries.
d. Roads occupying 23% of the research area dissect and break up the green system and constitute a barrier for population movement. The results of this study indicate that re-establishing the green system connections can be ensured by green bridges and roadside plantations. However, applying this approach also requires allowing the mechanism of self-restoring of plant cover. It is possible to construct more permanent and holistic green systems by supporting and triggering this self-forming plant tissue with the proper techniques. For this reason, it is vital to make sensitive choices regarding artificial surfaces, especially in urban areas such as Istanbul, which have rich potential in terms of biological diversity. For example, when green areas on the roadside are left to their own devices, this potential manifests itself quickly, and rich herbaceous vegetation can occur spontaneously when the seeds fly in the air, settle, and germinate in the area by carriers such as wind and insects. The suggested noise barriers for the main road arteries should also be designed with a similar approach resembling the natural forest edge structure.

Artificial surfaces, which have become dominant in the urbanization process, should support the functions provided by the green system and adapt as a component of the water cycle in the urban ecosystem. As building different relations between various landscape elements, or making further analyses and assessments is possible, it is crucial to translate these ideas into "urban landscape plans," which are not mandatory yet. Continuous efforts are needed to be made for raising awareness, especially among policymakers and local administrative units, on the importance and benefits of developing urban landscape plans with a holistic and multidisciplinary approach. Thus, introducing and sharing the outcomes of such research is highly beneficial for reaching out to target groups and the general public.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – G.A.A., S.K.; Design – G.A.A., S.K.; Supervision – G.A.A., S.K.; Funding – G.A.A., S.K.; Materials – G.A.A., S.K.; Data Collection and/or Processing – G.A.A., S.K.; Analysis and/or Interpretation – G.A.A., S.K.; Literature Review – G.A.A., S.K.; Writing – G.A.A., S.K.; Critical Review – G.A.A., S.K.

Declaration of Interests: The authors declare that they have no competing interest.

Funding: This study has used data carried out in the scope of the project called "Istanbul-Besiktas District an Ecological Planning Approach for an Urban Landscape Plan and Implementation Strategy (114O 341-T OVAG- TUBITAK)" project funded by The Scientific and Technological Research Council of Turkey (TUBITAK).

References

- Akpınar, A. (2014). Kullanıcıların Kentsel Yeşil Yolları Kullanım Sebepleri, Algıları ve Tercihlerinin Aydın-Koşuyolu Örneğinde Incelenmesi. *Journal of the Faculty of Forestry Istanbul University*, *64*(2), 41–55.
- Aksu, G. A. (2012). *Peyzaj Değişimlerinin Analizi: İstanbul, Sarıyer Örneği* [*Analysis of landscape changes: A case study in Istanbul Sariyer*] [PhD Thesis]. Istanbul University, Institute of Science.
- Aksu, G. A. (2017). İstanbul-Beşiktaş İlçesi Ekolojik Planlama Yaklaşımlı Kentsel Peyzaj Planı ve uygulama Stratejisi [Final Report of the Research Project: Istanbul-Besiktas District an Ecological Planning Approach for an Urban Landscape Plan and Implementation Strategy. Chapter 5] *ARDEB 3501 Kariyer Geliştirme Programı, proje No: 114-O-341, Proje Sonuç Raporu, 5. Bölüm (Kentsel Peyzaj Planı ve uygulama stratejileri)*. TUBİTAK.
- Aksu, G. A. (2021). Kentsel Peyzajlarda Yol Kenarı Yeşil Alanların, Kent Ekosistemi Çerçevesinde Değerlendirilmesi [Evaluation of roadside green areas in urban landscapes in the framework of urban ecosystem]. *European Journal of Science and Technology*, *25*, 736–748. (in Turkish)
- Aksu, G. A., & Küçük, N. (2020). Evaluation of urban topography–biotope–population density relations for Istanbul–Beşiktaş urban landscape using AHP. *Environment, Development and Sustainability*, *22*(2), 733–758. [CrossRef]
- Aksu, G. A., Musaoğlu, N., & Uzun, A. (2017a). An auxiliary tool for landscape evaluation Ecological risk analysis based on analytic hierarchy process. *Fresenius Environmental Bulletin*, *26*(1), 84–92.
- Aksu, G. A., Tağıl, Ş., Musaoğlu, N., Canatanoğlu, E. S., & Küçük, N. (2017b). İstanbul-Beşiktaş İlçesi Ekolojik Planlama Yaklaşımlı Kentsel Peyzaj Planı ve Uygulama Stratejisi [Final Report of the Research Project: Istanbul-Besiktas District an Ecological Planning Approach for an Urban Landscape Plan and Implementation Strategy. Chapter 4]. *TUBITAK ARDEB 3501 kariyer geliştirme programı, proje No:114-O-341, sonuç raporu, bölüm 4 (Bulgular)*.
- Avcı, M. (2014). Kentsel Biyolojik Çeşitlilik Açısından İstanbul. In Ü. Akkemik (Ed.), *İstanbul Ormanlarının Sorunları ve Çözüm Önerileri* (pp. 87–124). Türkiye Ormancılar Derneği.
- Barner, J. (1983). *Experimentelle Landschaftsökologie* [*Experimental landscape ecology*]. Ferdinant Enke Verlag.
- Batur, A., & Aksu, G. A. (2021). Partikül Madde (PM10) Konsantrasyonunun Kentsel Yeşil Alan Sisteminin Değerlendirilmesinde Ekolojik İndikatör Olarak Kullanımı: İstanbul - Beşiktaş Örneği [The use of particulate matter concentration (PM10) as an ecological indicator by the evaluation of an urban green area system: Istanbul - Besiktas case study]. *European Journal of Science and Technology*, *27*, 125–134.
- Bentrup, G. (2008). *Conservation buffers. Design Guidelines for buffers, Corridors, and greenways. Gen*. Tech. Rep. SRS-109. Department of Agriculture, Forest Service, Southern Research Station.
- Çakir, G., Ün, C., Baskent, E. Z., Köse, S., Sivrikaya, F., & Keleş, S. (2008). Evaluating urbanization, fragmentation and land use/land cover change pattern in Istanbul city, Turkey from 1971 to 2002. *Land Degradation and Development*, *19*(6), 663–675. [CrossRef]
- Çepel, N. (2003). *Ekolojik Sorunlar ve Çözümleri* [*Ecological problems and solutions*]. TÜBİTAK Popüler Bilim Kitapları.
- Chrair, M., Khaldi, A., Hamadouche, M. A., Hamimed, A., Cernesson, F., & Alkan, M. (2020). Evaluation of the effects of land cover changes and urbanization on land surface temperature: A remote sensing study of sub-watershed of Oued Fekan, northwest Algeria. *Sigma Journal of Engineering and Natural Sciences*, *38*(2), 907–926.
- Çolak, A. H. (Ed.). (2013). *Belgrad Ormanı - Bir Doğa ve Kültür Mirası. T. C. Orman ve su İşleri bakanlığı 1*. Bölge Müdürlüğü.
- Dadvand, P., & Nieuwenhuijsen, M. (2019). Green space and health. In M. Nieuwenhuijsen & H. Khreis (Eds.), *Integrating human health into urban and transport planning: A framework* (pp. 409–423). Springer International Publishing. [CrossRef]
- Daniels, B., Zaunbrecher, B. S., Paas, B., Ottermanns, R., Ziefle, M., & Roß-Nickoll, M. (2018). Assessment of urban green space structures and their quality from a multidimensional perspective. *Science of the Total Environment*, *615*, 1364–1378. [CrossRef]
- Davis, P. H., Harper, P. C., & Hedge, I. C. (1971). *Plant life of South-West Asia*. The Botanical Society of Edinburgh.
- Dinç, H., & Bölen, F. (2014). İstanbul Derelerinin Fiziki Yapısı. *Planlama*, *24*, 107–120.
- Ekşi, M. (2021). *Çatı Bahçeleri*. Yeni İnsan Yayınevi.
- Ekşi, M., & Uzun, A. (2016). Yeşil Çatı Sistemlerinin Su ve Enerji Dengesi Açısından Değerlendirilmesi. *İstanbul Üniversitesi Orman Fakültesi Dergisi*, *66*(1), 119–138. [CrossRef]
- Erdem, N. (2004). E-5 Otoyolunda Ekolojik ve Peyzaj Yönünden Bozulmalar [Landscape and ecological degradation on the roadsides of E-5 highway]. *Journal of the Faculty of Forestry Istanbul University*, *54*(1), 89–103.
- Erell, E., Pearlmutter, D., & Williamson, T. (2011). *Urban microclimate. Designing the spaces between buildings*. Earthscan from Routlege, Taylor & Francis.
- Forman, R. T. T. (1995). *Land mosaics*. Cambridge University Press.
- Forman, R. T. T. (2014). *Urban ecology: Science of cities*. Cambridge University Press.
- Gartland, L. (2008). *Heat islands: Understanding and mitigating heat in urban areas*. Earthscan Publications.
- Güneralp, B., Tezer, A., & Albayrak, İ. (2013). Local assessment of Istanbul: Biodiversity and ecosystem services. In T. Elmqvist, et al. (Eds.), *Urbanization, biodiversity and ecosystem services: Challenges and opportunities: A global assessment* (pp. 291–311). Springer Netherlands. [CrossRef]
- Haila, Y. (2002). A conceptual genealogy of fragmentation research: From island biogeography to landscape ecology. *Ecological Applications*, *12*(2), 321–334. [CrossRef]
- Harker, P. T., & Vargas, L. G. (1987). The theory of ratio scale estimation: Saaty's analytic hierarchy process. *Management Science*, *33*(11), 1383–1403. [CrossRef]
- Heke, M., & Pöneke, K. (2021). *Water sensitive urban design. A guide for WSUD stormwater management in Wellington*. Wellington City Council. Retrieved from https://wellington.govt.nz/environment-and-sustainability/water/stormwater/water-sensitive-urban-design-guide
- Hill, M. O., Roy, D. B., & Thompson, K. (2002). Hemeroby, urbanity and ruderality: Bioindicators of disturbance and human impact. *Journal of Applied Ecology*, *39*(5), 708–720. [CrossRef]
- Kırca, S., Altınçekiç, H., & Levin, N. (2015). Landscape continuity analysis as a tool for landscape planning: A case study in Istanbul. *Landscape Research*, *40*(3), 359–376. [CrossRef]
- Kırca, S., & Sevinç, Ş. (2020). Kentlerde Etkin Doğa Koruma için Yol Kenarlarındaki Çim Alanlar Üzerine Bir Araştırma. *Peyzaj Araştırmaları ve Uygulamaları Dergisi*, *2*, 51–60.
- Koç, G., Petrow, T., & Thieken, A. H. (2020). Analysis of the most severe flood events in Turkey (1960–2014): Which triggering mechanisms and aggravating pathways can be identified? *Water*, *12*(6), 1562. [CrossRef]
- Koçu, R. E. (1961). Beşiktaş. In İ. Ansiklopedisi (Ed.), *İstanbul Ansiklopedisi* (pp. 2562–2571). İstanbul Ansiklopedisi ve Neşriyat Kollektif Şirketi.
- Kowarik, I. (2011). Novel urban ecosystems, biodiversity, and conservation. *Environmental Pollution*, *159*(8–9), 1974–1983. [CrossRef]
- Li, T., Shilling, F., Thorne, J., Li, F., Schott, H., Boynton, R., & Berry, A. M. (2010). Fragmentation of China's landscape by roads and urban areas. *Landscape Ecology*, *25*(6), 839–853. [CrossRef]
- Łopucki, R., & Kiersztyn, A. (2015). Urban green space conservation and management based on biodiversity of terrestrial fauna – A decision support tool. *Urban Forestry and Urban Greening*, *14*(3), 508–518. [CrossRef]
- Lynch, A. J. (2019). Creating effective urban greenways and stepping-stones: Four critical gaps in habitat connectivity planning research. *Journal of Planning Literature*, *34*(2), 131–155. [CrossRef]
- Mimet, A., Kerbiriou, C., Simon, L., Julien, J.-F., & Raymond, R. (2020). Contribution of private gardens to habitat availability, connectivity and conservation of the common pipistrelle in Paris. *Landscape and Urban Planning*, *193*, 103671. [CrossRef]
- Musaoğlu, N., Coşkun, M. Z., Göksel, Ç., Kaya, Ş., Bektaş, F., Saroğlu, E., Üstün, B., İpbüker, C., Erden, T., & Karaman, H. (2004). İstanbul Anadolu Yakası Hazine Arazilerinin Uydu Verileri ve Coğrafi Bilgi Sistemleri (CBS) ile İncelenmesi [Examination of public lands in the Anatolian side of Istanbul by using satellite images]. *TÜBİTAK-İnşaat ve çevre Teknolojileri araştırma grubu (IÇTAG-I433) Projesi, proje No: 103I011*.
- Naveh, Z. (2001). Ten major premises for a holistic conception of multifunctional landscapes. *Landscape and Urban Planning*, *57*(3–4), 269–284. [CrossRef]
- Ndubisi, F. (2002). *Ecological Planning*. The Johns Hopkins University Press.
- Norton, B. A., Coutts, A. M., Livesley, S. J., Harris, R. J., Hunter, A. M., & Williams, N. S. G. (2015). Planning for cooler cities: A framework to prioritise green infrastructure to mitigate high temperatures in urban landscapes. *Landscape and Urban Planning*, *134*, 127–138. [CrossRef]
- Oke, T. R. (1976). The distinction between canopy and boundary-layer urban heat islands. *Atmosphere*, *14*(4), 268–277. [CrossRef]
- Olsson, L., Barbosa, H., Bhadwal, S., Cowie, A., Delusca, K., Flores-Renteria, D., Hermans, K., Jobbagy, E., Kurz, W., Li, D., Sonwa, D. J., & Stringer, L. (2019). Land degradation. In P. R. Shukla, et al. (Eds.), *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (pp. 345–436).

- Özhatay, N., Byfield, A., & Atay, S. (2005). *Türkiye'nin 122 önemli bitki alanı*. World Wildlife Fund Türkiye.
- Parece, T. E., Lumpkin, M., & Campbell, J. B. (2016). Irrigating urban agriculture with harvested rainwater: Case study in Roanoke, Virginia, USA. In T. Younos, T. E. Parece (Eds.), *Handbook of Environmental Chemistry*. Springer International Publishing. [CrossRef]
- Rudd, H., Vala, J., & Schaefer, V. (2002). Importance of backyard habitat in a comprehensive biodiversity conservation strategy: A connectivity analysis of urban green spaces. *Restoration Ecology*, *10*(2), 368–375. [CrossRef]
- Rusche, K., Reimer, M., & Stichmann, R. (2019). Mapping and assessing green infrastructure connectivity in European city regions. *Sustainability*, *11*(6), 1819. [CrossRef]
- Soga, M., & Koike, S. (2013). Mapping the potential extinction debt of butterflies in a modern city: Implications for conservation priorities in urban landscapes. *Animal Conservation*, *16*(1), 1–11. [CrossRef]
- Steiner, F. (1991). *The living landscape. An ecological approach to landscape planning*. McGraw-Hill, Inc.
- Suri, L. (2020). Criteria for determining water basin boundary and the importance planning decisions in sustaining water resources. *Fresenius Environmental Bulletin*, *29*(5), 3764–3777.
- The World Bank. (2021). *Urban population growth (annual %) - World Bank staff estimates based on the United Nations Population Division's World Urbanization Prospects: 2018 Revision*. Retrieved from https://data.worldbank.org/indicator/SP.URB.GROW
- TÜİK. (2021). *Population of Beşiktaş District*. Retrieved from https://biruni.tuik.gov.tr/medas/?locale=tr
- UN-Habitat: United Nations Human Settlements Program. (2011). *Global report on human settlements 2011: Cities and climate change*. Earthscan Publications.
- U.S. EPA: Environmental Protection Agency. (2012). Cool pavements. In: *Reducing Urban Heat Islands: Compendium of Strategies*. Retrieved from https://www.epa.gov/heat-islands/heat-island-compendium
- Yaltırık, F., Efe, A., & Uzun, A. (1993). İstanbul Adalarının Doğal ve Egzotik Bitkileri [Natural and exotic plants of Istanbul's islands]. İstanbul Adaları İmar ve Kültür Vakfı Yayınları.