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Assessing ecosystem services of urban blue-green infrastructure in Karşıyaka, Izmir *

Kentsel mavi-yeşil altyapıda ekosistem servislerinin hesaplanması: Karşıyaka, İzmir

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ABSTRACT

Objective: This study aimed to calculate the regulating ecosystem services such as carbon storage, air pollution, runoff retention, and urban heat island reduction provided by the blue-green infrastructure of Karşıyaka, Izmir (Türkiye).

Material and Method: Regulating ecosystem services provided by urban blue-green infrastructure were calculated with remote sensing techniques and geographic information system. Data preparation and analyzes were performed in ArcGIS 10.8 software.

Results: The findings showed that the carbon storage potential of blue-green infrastructure was 2.45 kg C m^2 while the particulate matter removal potential was 4.73 g/m^2. The total rate of runoff in the BGI has been calculated to be 0.008 m^3/m^2. The urban heat island intensity index showed that the hot islands were located in the middle and north, and the cool islands were located in the south of the city.

Conclusion: It has been determined that the blue-green infrastructure in Karşıyaka has predominantly low values in terms of the regulating ecosystem services evaluated. It has been concluded that the blue-green infrastructure needs to be improved to boost ecosystem services and urban resilience.

Keywords: Blue infrastructure, GIS, green infrastructure, urban areas, urban ecosystem services

ÖZ

Amaç: Bu çalışmada İzmir Karşıyaka'daki kentsel mavi-yeşil altyapının sağladığı karbon depolama, hava kalitesi, yüzey akış düzenleme ve kentsel ısı adasının azaltılmasını kapsayan düzenleyici ekosistem servislerinin değerlendirilmesi amaçlanmıştır.

Materyal ve Yöntem: Kentsel mavi-yeşil altyapının sağladığı düzenleyici ekosistem servisleri uzaktan algılama teknikleri ve coğrafi bilgi sistemleriyle hesaplanmıştır. Veri üretimi ve analizler ArcGIS 10.8 yazılımında gerçekleştirilmiştir.

Bulgular: Mavi-yeşil altyapının karbon depolama kapasitesi 2.45 kg C m^2, partikül madde tutma kapasitesi 4.73 g/m^2'dir. Mavi-yeşil altyapıdaki toplam yüzey akışı tutma oranı 0.008 m^3/m^2 olarak hesaplanmıştır. Kentsel ısı adası yoğunluğu ise sıcak adaların kentin merkezi ve kuzeyinde, serin adaların ise güneyinde yer aldığını göstermektedir.

Sonuç: Karşıyaka'daki mavi-yeşil altyapının değerlendirmeye alınan düzenleyici ekosistem servisleri açısından ağırlıklı olarak düşük değerlere sahip olduğu belirlenmiştir. Kentsel dayanıklılığı artırmak için mavi-yeşil altyapının iyileştirilmesi gerekmektedir.

Anahtar sözcükler: Mavi altyapı, CBS, yeşil altyapı, kentsel alanlar, kentsel ekosistem servisleri

INTRODUCTION

Urban areas cover a small part of the earth, but they account for a large ratio portion of the global carbon emissions in energy and resource consumption and cause climate change, ecosystem degradation, and biodiversity losses on global scale (Seto et al., 2012). However, people living in cities are directly facing the consequences of global warming, such as extreme weather events, ecosystem, and land losses (IPCC, 2019). IPCC (2021) reports stated that various sustainable strategies, including physical and social infrastructure, are needed to reduce the cities' fragility and increase their resilience. In this context, maintaining and enhancing ecosystem services (ES) therefore urban ecosystems are essential to developing the adaptive capacities of cities and societies (IPCC, 2023).

Urban green areas increase the resilience of cities through the multi-ecosystem services (Caneva et al., 2020). ES are classified as provisioning, regulating, supporting and cultural services according to the benefits they provide. Regulating ES include many ecosystem services, such as regulating air quality and microclimate, soil quality, erosion control, pollination, carbon storage and sequestration, reducing noise pollution, and natural disaster control (Smith et al., 2013; Rupprecht et al., 2015; Ghorbani et al., 2022; Orta-Ortiz & Geneletti, 2022). ES are derived from ecosystem functions, and the benefits they provide represent the actual flow of services (Vihervaara et al., 2017). The processes that lead to providing ES are spatial, and the ecosystem functions and processes responsible for the production of services vary in time, space and scale (Ruskule et al., 2018). Therefore, ES maps are needed to identify and evaluate the provision of ES as a function of ecosystem processes, land use cover, climate and environmental diversity (Maes et al., 2013).

ES mapping is crucial to determine the extent to which ecological processes occur in order to understand how ecosystems contribute to human well-being (Vihervaara et al., 2017; Rendon et al., 2019). Many scientific studies have been conducted to assess and map the ES provided by urban green areas (Derkzen et al., 2015; Xiao & Xiao, 2018; Marando et al., 2019; Hepcan & Coşkun Hepcan, 2021; Ma et al., 2021; Codemo et al., 2022). Recent ES mapping studies highlight the importance the sustainability of ecosystems and they provide a new perspective by providing strong information to improve existing urban planning decisions and practices (Sun et al., 2022; Liu et al., 2023).

ES mapping is an essential tool to support decision-making in policies related to urban sustainability, climate adaptation, and sustainable management of natural sources and to guide investments in green infrastructure and ecosystem restoration (Vihervaara et al., 2017).

Like other cities the effects of climate change are felt intensely in Karşıyaka. In recent years, high temperatures, urban floods, and increasing air pollution have adversely affected the functioning of the city. Therefore, this study aims to:

i) calculate carbon storage, air purification, reduced urban heat island effect, and runoff retention potentials of BGI in Karşıyaka in order to determine the effectiveness of regulating ES provided by these areas that would increase urban resilience.

ii) present a framework for quantitative assessment of regulating ES of urban BGI at the local scale (especially in cities with limited data) to provide data for urban management strategies to increase urban resilience in the short and long term for the decision makers to close the knowledge gap to integration of ES assessments into urban development and urban green area management plans in Türkiye.

MATERIAL and METHOD

Study area

The coastal district of the city of Izmir, Karşıyaka (Türkiye) located on the north side of Izmir Bay (38°34'- 38°26' N and 27°03-27°11 E) is defined as the study area. It encompasses about 51 km^2 area with a population of 346,264 inhabitants (Figure 1). The urban area of this Metropolitan district is located on the lowlands (coastal plain) in the South and expands to hilly areas in the North. In the urban development zone, the urban pattern is composed of a high building density. The city has a Mediterranean climate, and the average minimum and maximum temperature values are 13.6 and 22.7°C. Most of the precipitation is seen in the spring and autumn (October - March) period, while the average total annual rainfall is 713.8 mm (TSMS, 2023).

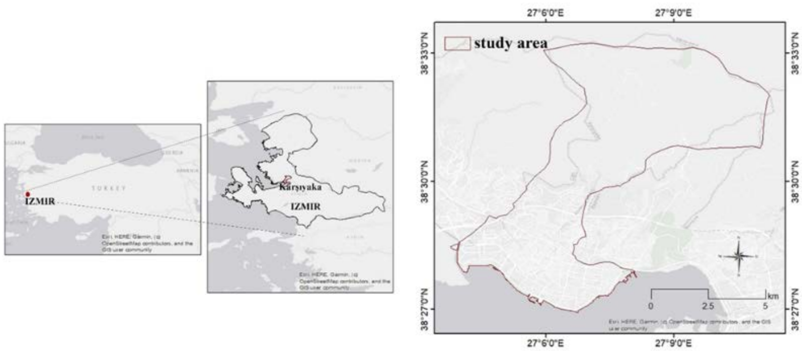

Figure 1. The location of the study area.

Şekil 1. *Çalışma alanı.*

Method

The methodology of this research has five steps: (1) determining the blue-green infrastructure (BGI), calculating and mapping the (2) carbon storage, (3) PM10 deposition, (4) heat island effect, and (5) runoff retention by the BGI.

In this research USGS Landsat-8 (30 m resolution) satellite images were used for land surface temperature and urban heat island intensity maps. ESA Sentinel-2 (10 m resolution) satellite images were used in Normalized Difference Vegetation Index (NDVI), carbon storage and PM10 removal maps. The land use/cover map was derived from the high spatial resolution WorldView-2 (0.5 m resolution) satellite image of 2014. ERDAS Imagine 14.01 was used for image processing, and ArcGIS 10.7.1 was used for database creation and geographic information system (GIS) analysis.

Blue-green infrastructure

The BGI map was derived from WorldView-2 (PAN+MS bundle 0.5 m resolution) by screen digitizing using ArcGIS based on CORINE (Coordination of Information on the Environment) land cover nomenclature (Bossard et al., 2000). Elements of BGI in the study area were defined in six classes as natural areas (forest and scrub vegetation), open space with little or no vegetation, gardens (public and private gardens), urban sparks, blue corridors (canal) and green corridors (roadside vegetation, green streets).

Carbon storage capacity

Different methodologies have been used to estimate the amount of carbon stored by plants. Some studies focused on the carbon storage capacity of above below-ground biomass (Tolunay, 2011) while other models developed for the calculation of carbon storage capacities in different plant species (Lee et al., 2016) and communities (Sivrikaya & Bozali, 2012; Durkaya et al., 2019).

Carbon storage capacity of plants in BGI was calculated by using a model (Eq.1), that calculates carbon storage per pixel based on the Normalized Difference Vegetation Index-NDVI (Myeong et al., 2006; Dobbs et al., 2018). The average NDVI values from Sentinel-2 satellite images (10 m resolution) from June, July, August, and September 2019 were obtained using the equation below (Eq.2) (Fung & Siu, 2000).

$$\text{Carbon (tons/pixel)} = 0.10702 * e^{(\text{NDVI}*0.0194)} \quad (1)$$

$$\text{NDVI} = \text{NIR} - \text{RED} / \text{NIR} + \text{RED} \quad (2)$$

NIR= Near-Infrared band, RED= RED band.

Urban heat island intensity

The urban heat island intensity index (HFI) defines the intensity of the heat island effect in an area. In this study the HFI calculation was based on the land surface temperature (LST) of June, July and August in 2019 (Eq.3) (Gao et al., 2019; Khorrami & Gündüz, 2019).

$$\text{HFI} = \frac{\text{Ti}-\text{Tmin}}{\text{Tmax}-\text{Tmin}} \quad (3)$$

Ti=Surface temperature, Tmax=Maximum effective surface temperature in area, Tmin=Minimum effective surface temperature in area.

PM_{10} deposition

Urban trees can improve air quality by keeping airborne particles on leaf surfaces through dry deposition (Nowak et al., 2013; Marando et al., 2016). Dry deposition on leaf surfaces is controlled by stomata and it has a higher rate when the stomata are open (Wang & Zhou, 2000). PM10 deposition capacity of BGI was calculated using the equation below (Marando et al., 2016) (Eq.4).

$$\text{Q} = \text{F} * \text{L} * \text{T} \quad (4)$$

$$\text{F} = \text{Vd} * \text{C}$$

Where Q=Amount of PM10 retained by 1 m^2 surface land cover (mg/m^2), F=deposition flux of pollutant (mg/m^2/day), Vd=was set at a median value (cm/sec), C=concentration in the air (mg/m^3), L=leaf area index, T=period of time considered.

The dry deposition rate value for PM10 is accepted as 0.064 cm/s from the relevant literature (Nowak, 1994; Lovett, 1994). Climate data was obtained from the Ministry of Agriculture and Forestry General Directorate of Meteorology (TSMS, 2019). Pollutant concentration data was obtained from the "Ministry of Environment Urbanization and Climate Change & National Air Quality Monitoring Network Karşıyaka station air pollution data from 2019" (MoEU, 2019).

An important biophysical determinant for estimating the photosynthesis, respiration and transpiration of a vegetation canopy is known as LAI, which is defined as half of the all-sided leaf area per unit ground area (Jin et al., 2015). In this study, LAI was obtained by using the equation (Eq.5) (Saito et al., 2001).

$$\text{LAI} = 0.57 * \exp(2.33 * \text{NDVI}) \quad (5)$$

Runoff retention

Some of the precipitation is retained by the soil and some of it becomes surface flow. Permeable surfaces and vegetation allow rainwater to drain into the lower layers of the soil. Soil sealing reduces rainwater infiltration, disrupts the natural water cycle and increases surface runoff and flood risk.

The surface runoff was calculated using the SCS-CN (Soil Conservation Service Curve Number) method (Eq.6) developed by USDA-NRCS (United States Department of Agriculture, A Natural Resources Conservation Service). It helps to estimate surface runoff based on land use/cover data, soil type and precipitation (Strom et al., 2013; Yao et al., 2018).

$$Q = \frac{(\text{P} - 0.2\text{S})^2}{(\text{P} + 0.8\text{S})}$$

$$S = 2540/CN - 25{,}4$$

$$V_r = Q * A/1000 \quad (6)$$

Where Q=surface flow depth (mm), P=rainfall (mm), S=Maximum accumulation potential after the surface flow begins (cm), CN=Curve Number, A=Area (m^2), Vr=surface flow volume (m^3).

Curve number values were interpreted based on literature related to soil type, slope characteristics, and geomorphology structure (USDA, 1986). Calculations were made for 192 mm rainfall based on a 10 year-24-hour rainfall event in Karşıyaka.

RESULTS

Blue-green infrastructure

BGI covers 65% of Karşıyaka. The urban area shows a continuous pattern in the south of the city. Natural vegetation (forest and shrub), the dominant component of BGI, constitutes 56.41% of the city and 88% of the BGI. A large intact natural vegetation patch is located to the north of the urban development zone and extends in a northeast to southwest direction.

Open spaces with little or no vegetation cover 4.2% of BGI. They are mostly located between building lots and around transportation corridors in the north and west of the city (Figure 2). Private and institutional gardens occupy 3.5% of BGI. Private gardens are mostly apartment and single-family house gardens irregularly distributed within the district. Single family house gardens with dense vegetation are mainly located in the southern part of Karşıyaka. They are the remnants of the traditional urban structure. Apartment gardens in the new development area in west and north are relatively larger. School and public buildings' gardens represent institutional gardens. They show scattered distribution in the city.

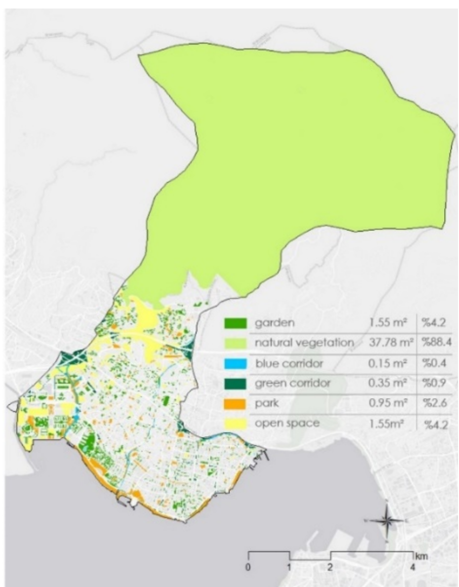

Figure 2. Blue-green infrastructure map.

Şekil 2. *Mavi-yeşil altyapı haritası.*

Urban parks constituted a small portion of the BGI with 2.6%. They show irregular distribution throughout the city with smaller patches in the north and larger patches in the south. Many of them are small size neighborhood parks located between building blocks. The coastal park that lies along the coastline is the larger park among them (Figure 2).

Blue and green corridors cover only 1.3% of the BGI. Blue corridors are in the form of engineered rivers of which only some segments have linear parks. Only some streets that are perpendicular and parallel to sea have tree cover.

Carbon storage capacity

The total carbon storage rate of GI was estimated to be 2.45 kg C m^2. Natural areas had the highest carbon storage potential with 2.92 kg C m^2. Urban parks followed the natural areas with 2.39 kg C m^2. The carbon storage capacity of green corridors was calculated to be 2.0 kg C m^2. The carbon storage potential of gardens and open spaces was estimated at 1.73 kg C m^2 and 1.61 kg C m^2, respectively (Figure 3; Table 1).

Table 1. Carbon storage, PM_{10} deposition and Runoff values

Çizelge 1*. Karbon depolama, PM_{10} depolama ve Yüzey akışı değerleri*

	Carbon storage kg/m^2	PM deposition g/m^2	Runoff value m^3/m^2
Open space	1.61	2.64	0.008
Garden	1.73	4.18	0.009
Park	2.39	4.24	0.009
Green corridors	2.0	3.35	0.009
Natural vegetation	2.92	5.86	0.008
Total	**2.45**	**4.73**	**0.009**

Potential of PM_{10} deposition

The PM10 retention potential of the green areas in Karşıyaka was estimated to be 4.73 g/m^2. Natural vegetation located in the north of the city provided the highest contribution for pollutant uptake with 5.86 g/m^2 (Figure 3) that is higher than the overall potential of BGI. It was observed that the amount of PM10 that could be retained by the urban parks and gardens were in close range with 4.24 g/m^2 and 4.18 g/m^2, respectively. Green corridors followed them with 3.35 g/m^2. The lowest contribution for the ecosystem services was calculated for open spaces with to be 2.64 g/m^2 (Figure 3; Table 1).

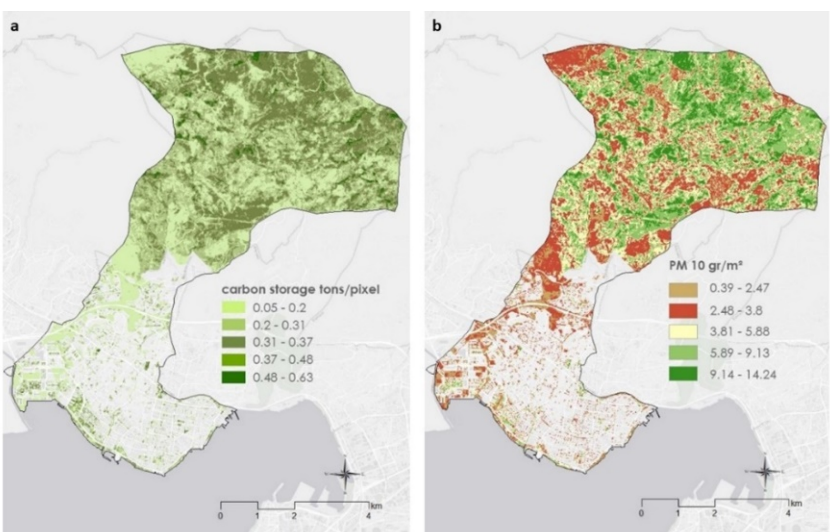

Figure 3. Carbon storage (a) and PM10 (b) maps.

Şekil 3. *Karbon depolama (a) ve PM10 (b) haritaları.*

Urban heat field intensity

The Karşıyaka heat island intensity map shows that high numbered classes (5, 6 and 7) are weighted. To the south of the city and along the coastline are cool islands with low numbers formed by the classes (1, 2, 3 and 4). In the northern part of the city and in the region with natural vegetation outside the development area, it is observed that there are larger cool islands (Figure 4).

Runoff retention

The amount of surface runoff in the BGI is calculated to be 328328.58 m^3, (0.008 m^3/m^2). The natural areas located north of the urban area have the highest runoff potential in the city with 289700.75 m^3 (0.008 m^3/m^2). The total runoff retention potential of gardens is 11893.66 m^3 (0.009 m^3/m^2). Parks follow behind with 8378.30 m^3 (0.009 m^3/m^2) while the determined runoff retention of the green corridors is about half of this value 3256.55 m^3 (0.009 m^3/m^2) (Table 1). Results indicated that natural areas and open spaces with little or no vegetation showed similar runoff values per unit area are slightly lower than the runoff value of parks, gardens, and green corridors.

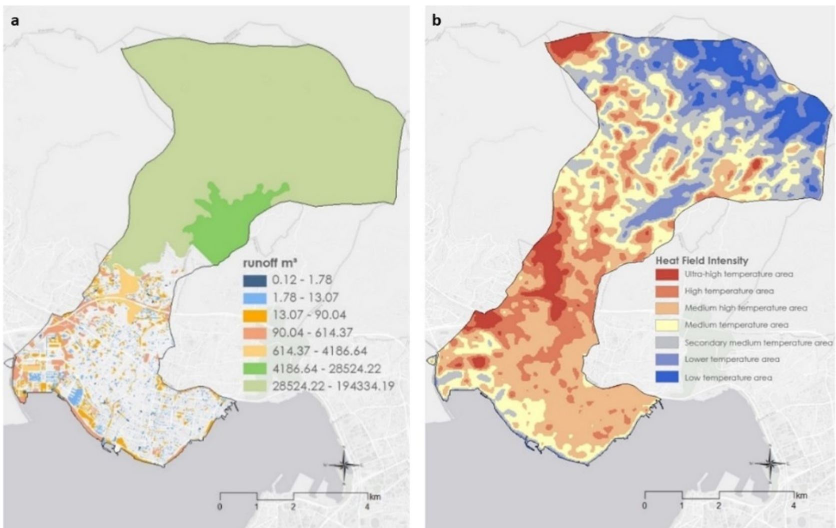

Figure 4. Runoff (a) and HFI (b) maps.

***Şekil 4**. Yüzey akışı (a) ve HFI (b) haritaları.*

DISCUSSION

Blue-green infrastructure

Urban green areas in Karşıyaka show irregular distribution. The BGI is composed of small-sized patches between dense construction. Relatively large urban parks, gardens, and green corridors are clustered in the southern part of the city. As stated in Hepcan & Coşkun Hepcan (2017), it is not possible to mention the well-connected BGI in the city.

Irregular distribution of BGI also results in uneven equitable benefit sharing in the city. This situation leads to ecosystem services being of different grades in different parts of the city. The high-density neighborhoods with limited green areas located in the Northeast are especially faced with this challenge more. New developing neighborhoods in the west and Northwest have the advantage to receive better ecosystem services because of their urbanization pattern. Only the main watercourses are left as the remnants of the blue network as natural drainage pattern almost disappeared during urbanization.

Carbon storage

It is observed that the carbon storage potential of BGI is low in the western part of the city while it is high in the south and southwest of the city where larger patches with healthy vegetation are located (Figure 3). In this study the carbon storage capacity of urban vegetation is calculated based on the NDVI and thus on the photosynthetic capacity of the vegetation. Different plant species have different degrees of carbon storage potential, but species differences were not considered in this study. The predominantly low level of carbon storage of urban green areas in Karşıyaka can be explained by the current state of vegetation depending on NDVI values.

The amount of carbon stored by BGI in Karşıyaka has been calculated to be 24 tons/ha (2.45 kg C m^2). This is lower than Efeler/Aydın with 41.63 tons/ha (Ersoy Tonyaloğlu & Kesgin Atak, 2020) but higher than Bogota/Colombia with 699 mg/ha, and Santiago/Chile with 110 mg/ha where the same methodology was used (Dobbs et al., 2018). This could be explained by the dense vegetation of Efeler.

Total carbon storage capacity of urban areas changes based on several factors such as type and age and physical characteristics of tree, length of growth period and environmental factors (Nowak et al., 2013). Carbon storage rate was predicted to be 11 tons/ha for Oakland, 31.4 tons/ha for south Dakota, 43.7 tons/ha for New Jersey, and 45.9 tons/ha for Los Angeles (Nowak et al., 2013).

The intact natural areas located on the north provide the highest contribution for carbon storage with 2.92 kg C m^2. Urban parks followed the natural areas with 2.39 kg C m^2. The carbon storage capacity of green corridors was calculated to be 2.03 kg C m^2. The carbon storage potential of gardens and open spaces was estimated at 1.73 kg C m^2 and 1.61 kg C m^2, respectively. Although green corridors occupy less than one percent of the area in the city, they provide a larger contribution to carbon uptake than gardens.

PM_{10} deposition

Pollution removal capacity of plants varies according to plant diversity, leaf characteristics, length of the in-leaf season, climatic conditions and pollution concentration in the atmosphere (Nowak et al., 2006; Tallis et al., 2011). Considering these effects when comparing urban air quality studies will lead to more accurate inferences.

The amount of PM10 deposition by the BGI in Karşıyaka was calculated to be 4.73 g/m^2. This is almost three times higher than the PM10 removal capacity of urban green areas in the Balçova district with 1.62 g/m^2 in Izmir (Berberoğlu et al., 2019). But this is lower than the results of the prior studies that used the same method with 16.7 g/m^2 for Rome (Manes et al., 2014), with 7.79 g/m^2 for Florence (Bottalico et al., 2016), and 13.1 g/m^2 for the middle-income sub-region of Santiago (Escobedo & Nowak, 2009).

The PM10 removal capacity of the urban parks was estimated to be 4.24 g/m^2. That is also higher than the PM10 removal capacity of park trees in the Balçova districts with 1.19 g/m^2/year (Berberoğlu et al., 2019) and the Aşık Veysel Recreation Area with 0.03 g/m^2, the largest urban park of Bornova (Coşkun Hepcan & Hepcan, 2020). This can be explained by the vegetation characteristics of the parks and the methodology of the studies.

Green corridors provided a lower contribution for PM10 uptake per unit area than urban parks and gardens. This supported the fact that the lack of corridors in the city. Trees tend to take pollution when they are close the pollutant source (Freer-Smith et al., 2005). Vehicle exhausts are one of the main sources of PM10 particles. Therefore, introducing new green corridors by planting trees in the streets would enhance the pollutant removal service in the city.

While the green areas with the highest pollutant removal potential in Karşıyaka are the natural areas covered with forest vegetation in the north of the city, the pollutant deposition values decrease with the decrease in the vegetation towards the city center (Figure 3). It shows a linear relationship between vegetation, leaf area index and pollutant removal values (Nowak et al., 2006; Litschike & Kuttler, 2008; Manes et al., 2014). The green areas in the study area have low pollutant removal potential related to the leaf area index of the vegetation in these areas. The vegetation cover that consists of trees with large canopies are more effective in removing air pollutants (Yang et al., 2005). In addition, it is argued that they are an important component in improving air quality, as the presence of more tree canopy cover in cities can increase the pollutant holding capacity in different environmental conditions (Pugh et al., 2012; Silli et al., 2015).

Many studies have been conducted to define the effectiveness of tree species for PM10 capture. For instance, many studies have confirmed that coniferous trees are the best candidate for PM10 uptake (Beckett et al., 2000; Letter & Jager, 2020). Manes et al. (2014) determined the high efficiency of broadleaf evergreen trees for PM10 removal in Rome. Conversely in some locations they also found that deciduous species showed a higher inter annual variability with a higher abatement level than evergreen broadleaves. Therefore, in order to enhance air purification functions of urban trees, local (site specific) studies should be conducted to identify the best tree species.

Areas with high PM10 removal within the Karşıyaka urban development boundaries are large gardens with dense vegetation located in the west and south of the city. In the eastern and northeastern parts of the city, there are small parks with high pollutant retention potential. In the western and northern parts of the city, there are large areas with low pollutant retention potential. These areas are also located in areas where there is newer construction than in other parts of the city. Large open spaces on both sides of the main road in the north of the city have a low potential to keep pollutants. Although these open areas are close to pollutant sources due to heavy vehicle traffic, their low pollutant holding potential creates a negative situation for the city and its residents. The assessment of these areas should be considered for the improvement of urban ecosystem services.

Air pollution is among the important factors affecting the quality of life in the city. The air quality monitoring index of Karşıyaka shows that the pollutant concentration reaches moderate to high levels frequently during the year (MoEU, 2019). Therefore, it is important to take precautions in this regard.

Urban heat island

Karşıyaka's land surface temperature and heat island intensity calculations reflected the solar radiation obtained from the land surface of the city. High values indicated that the ratio of building density and impermeable ground is high in the Karşıyaka urban topology.

An urban heat island depends on various factors which in its physical expression are categorized as external (location, climate, proximity to water surfaces) and internal (urban-specific, city size, land cover, anthropogenic heat releases) (Imhoff et al., 2010; Schwarz et al., 2011; Zhou et al., 2017). The land surface temperature and heat island intensity index of this study is based on Landsat-8 satellite data.

In this research there were questions on the mitigating effects of the green areas in Karşıyaka on the urban heat islands. In the study area it compared regions with different spatial compositions. It has been observed that in regions where there are green areas with dense vegetation, the land surface temperature is lower than in regions where there is no green area (Figure 5). Similarly, areas with high land surface temperatures include open areas with poor vegetation (Figure 5b). This supports the negative correlation between surface temperature and vegetation cover as mentioned in previous studies (Huang & Ye, 2015; Zhao et al., 2020; Khan et al., 2021).

The size of green areas, ratio, their location, leaf area index and plant diversity significantly affect the cooling potential of green areas (Xiao et al., 2018). Urban green areas have a significant mitigating effect on the urban thermal environment. It has been observed that while the large green areas in the north of Karşıyaka create a cold island effect, the small green areas in the inner parts of the city are under the impact of a hot island (Figure 5a, b). It is comprehended that the cooling effects of different types of urban green areas also have different capacities. In figure 5a, there are large green areas on both sides of the ring road, but the cooling effects are also weak because the vegetation cover in these areas is sparse. A similar situation applies to the green areas in the western part of Figure 5b. The surface of the areas in this region is largely made up of soils without vegetation cover.

The cooling effects of tree canopy cover in urban areas have been determined in many research (Wang et al., 2018; Marando et al., 2019). Similarly, Şentürk & Çubukçu (2022) determined that the cooling intensity of the urban cold areas is related to the size of the green area and the cooling capacity of the cold areas in the urban area of İzmir increases as the size of the green area increases. The results of this research are compatible with these studies. Figure 5b shows the high cooling effects of the large urban green areas with dense vegetation.

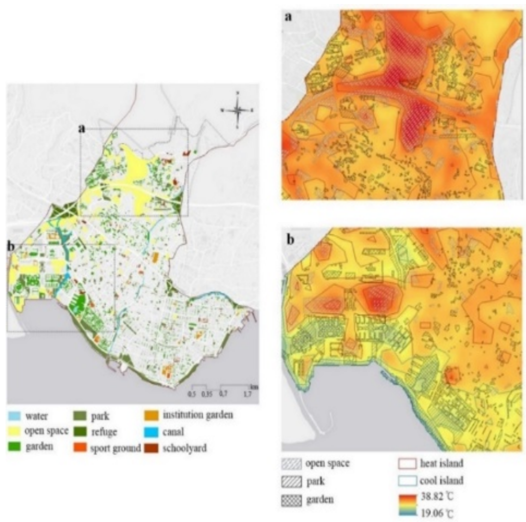

Figure 5. Example of urban heat islands and cold islands in Karşıyaka.

Şekil 5. *Karşıyaka kentsel serin ve ısı adaları örneği.*

The sea also has a mitigating effect on land surface temperature and urban heat islands in coastal cities (Sasaki et al., 2018; Lin et al., 2020; Morabito et al., 2021). The cold island formations on the coastal zone of the city could be explained by the cooling effects of the sea and sea breezes (Figure 5b).

The results show that the effects of high temperatures are clearly felt in the city. Additionally, increases in the frequency and duration of heat waves have been experienced since the beginning of the 2000s (TSMS, 2023). It is crucial to take action to mitigate the effects of high temperatures.

Runoff retention

The BGI has 328328.58 m^3 runoff retention potential. Natural areas at the north of the district have the highest runoff retention potential (289700.75 m^3). This area is suitable to build retention and detention basins and terraces to reduce surface runoff and recharge the aquifers. Özeren Alkan & Hepcan (2022) also emphasize the value of natural vegetation for rainwater infiltration in cities. Rainwater infiltration and recharging of aquifers are especially important in Mediterranean cities not only for drought but also for flood protection.

Parks, gardens and green corridors have the same runoff value in unit area with 0.009 m^3/m^2. This is slightly better than the runoff values of parks and gardens in the other districts in Izmir like Balçova with 0.10 m^3/m^2 (Berberoglu et al., 2019). High runoff values of urban parks and gardens can be associated with the large impervious surfaces and less dense vegetation cover.

Land cover type, soil and vegetation characteristics, size and inclination of the components of BGI affect the amount of stormwater runoff and water quality (Zhou et al., 2021; Huang et al., 2022). Urban vegetation, especially urban trees help to reduce surface runoff. The results indicated that parks, gardens, and green corridors could hold 13508.51 m^3 of surface runoff.

It is clear that BGI has potential to hold and infiltrate surface runoff. The urban floods in 1995, 2020, 2021 and 2022 prove that both grey and BGI in the district are not sufficient for flood protection in extreme rainfall. Therefore, it is necessary to improve the water retention capacity of BGI by replacing impervious materials with previous ones, and designing rain gardens, sponge parks and swales.

CONCLUSIONS

The intent of this study was to define the regulating ES provided by BGI in Karşıyaka. The results revealed that BGI is unevenly distributed in the city. The heart of the city lacks large green areas with high ecological quality. This spatial distribution of BGI has led to inequity in ES delivery. ES provided by BGI reduce the effects of high temperatures, air pollution and heavy rain but they are not enough to protect the city from these threats. The city is constantly expanding to the natural areas. Coastal wetlands have been transforming to urban areas. Therefore, many ES are currently at risk of disappearing.

BGI increases urban resilience by providing many ES that are strongly related to the ecological quality of these areas. It is critical to increase the amount of BGI to enhance the ES by improving the quality of the green areas of the BGI and the equity of ES in the city. Various strategies and regulations can be developed to reach this goal. Enhancing the ES of BGI and the equity of ES delivery is necessary to enhance the quality of life. The ES quantitative values of BGI obtained in this study provide valuable data for urban planning and management of BGI. Ultimately, it is hoped these changes will create sustainable cities that are resilient to global climate change and environmental problems.

Karşıyaka would be both denser and greener. The city needs strategies and actions to improve the ecological quality of the existing BGI. The outputs of this study provide valuable quantitative spatial data for the city administration. In order to increase urban resilience and reach the SDG11-Sustainable Cities and Communities Goals in the district, BGI needs to be enhanced and action and regulations mentioned above should be taken. That will boost the ecosystem services of BGI and quality of life for the residents.

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Data Availability

Data will be made available upon reasonable request.

Author Contributions

Conception and design of the study: ATY, ÇCH; sample collection: ATY, ÇCH; analysis and interpretation of data: ATY, ÇCH; statistical analysis: ATY, ÇCH; visualization: ATY, ÇCH; writing manuscript: ATY, ÇCH. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

There is no conflict of interest between the authors in this study.

Ethical Statement

We declare that there is no need for an ethics committee for this research.

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