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Assessing ecosystem services provided by cemeteries in urban landscapes

Kentsel peyzajlarda mezarlıkların sağladığı ekosistem hizmetlerinin değerlendirilmesi

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ABSTRACT

Objective: The objective of this study is to quantify the regulating ecosystem services provided by cemeteries, which have an important place in the urban green space system, in sample areas in Isparta city.

Material and Methods: The Gülcü Cemetery, Isparta Garrison Martyrs' Cemetery-Karaağaç Cemetery and Akyol Cemetery, which were selected as the main study material, were evaluated in terms of their capacity to provide four regulating ecosystem services (air pollution removal, carbon sequestration and storage, oxygen production, avoided surface runoff) using the i-Tree Eco model. Data on land use type and various tree characteristics (tree species, trunk diameter (DBH) (cm), tree height (m), live crown height (m), etc.) were used in the analysis.

Results: According to the research findings, the trees in the examined cemeteries collectively store approximately 47.22 tons of carbon and sequester 6,770 tons of carbon per year in gross terms. Additionally, plants in cemeteries intercept approximately 373.6 cubic meters of surface runoff per year and remove 35.55 kilograms of air pollutants. Moreover, the trees in the cemeteries generate an estimated 125.89 tons of oxygen annually.

Conclusion: To enhance regulatory ecosystem services, it is suggested to utilize suitable plant species in cemetery designs and increase plant species diversity.

Keywords: Cemeteries, ecosystem services, Isparta, i-tree eco model, urban landscape

ÖZ

Amaç: Bu çalışmanın amacı kentsel yeşil alan sistemi içerisinde önemli bir yer tutan mezarlıkların sağladığı düzenleyici ekosistem hizmetlerini Isparta kenti örneğinde belirlenen alanlarda ölçmektir.

Materyal ve Yöntem: Ana çalışma materyali olarak seçilen Gülcü Mezarlığı, Isparta Garnizon Şehitliği-Karaağaç Mezarlığı ve Akyol Mezarlığı, i-Tree Eco modeli kullanılarak dört düzenleyici ekosistem hizmeti (hava kirliliğini giderme, karbon tutma ve depolama, oksijen üretimi, yüzey akışını önleme) sağlama kapasiteleri açısından değerlendirilmiştir. Analizlerde; arazi kullanım türü ve çeşitli ağaç özellikleri (ağaç türleri, ağacın göğüs yüksekliğindeki çapı-DBH (cm), ağaç yüksekliği (m), canlı taç yüksekliği (m), vb.) verilerinden yararlanılmıştır.

Araştırma Bulguları: Araştırma bulgularına göre incelenen mezarlıklardaki ağaçlar brüt olarak yılda yaklaşık 47,22 ton karbonu tutmakta ve 6.770 ton karbonu depolamaktadır. Ayrıca mezarlıklardaki bitkiler yılda yaklaşık 373,6 m³ bir yüzey akışı engellemekte ve 35,55 kg hava kirleticisini ortadan kaldırmaktadır. Son olarak mezarlıklardaki ağaçların yıllık 125,89 ton oksijen ürettiği hesaplanmıştır.

Sonuç: Sonuç olarak daha iyi düzenleyici ekosistem hizmeti üretebilmek için, mezarlık tasarımlarında uygun bitki türlerinin kullanılması ve kullanılan bitki türlerinin çeşitliliğinin artırılması önerilmiştir.

Anahtar sözcükler: Mezarlıklar, ekosistem hizmetleri, Isparta, i-tree eco modeli, kentsel peyzaj

INTRODUCTION

When discussing urban green areas, our initial thoughts typically gravitate towards urban parks, recreational spaces, urban forests, street tree planting and similar features. Unfortunately, cemeteries have often been overlooked in these conversations (Sallay et al., 2022, 2023). As a relatively understated component of the urban green space system, cemeteries possess significant potential for developing ecosystem services (ES) due to their expansive areas and high proportion of green surfaces resulting from their functions. They can therefore play a prominent role in shaping the urban landscape. Additionally, cemeteries hold considerable significance as historical and cultural landscapes, serving as sacred burial sites imbued with profound social meanings. Cemeteries represent complex ecosystems that harbor diverse meanings and serve various purposes (Özmen, 2016; Rae, 2021).

From the earliest epochs of human history, the concepts of graveyards and tombs have constituted integral facets of human existence, spanning from the inception of life to its culmination. From the smallest settlements in villages to the largest urban centers in cities, people have established cemeteries to honor and commemorate their lost relatives at every stage of life. These cemeteries can be found situated at elevated points within villages, as well as integrated within the verdant landscapes of urban areas (Özhancı & Aklıbaşında, 2017). Cemeteries serve as cultural landscapes that encapsulate people's post-mortem beliefs and rituals. They function as spaces where individuals honor their ancestors and commemorate their past through memorial ceremonies. Additionally, cemeteries serve as sites where people connect with nature, leveraging the symbolic significance of plants. Additionally, cemeteries serve as sites where people connect with nature, leveraging the symbolic significance of plants. Moreover, these spaces harbor species-rich environments, including algae and mature trees, thereby providing vital habitats for wildlife amidst semi-natural landscapes (Evensen et al., 2017). Furthermore, cemeteries contribute to public health like many other green spaces, offering recreational amenities and opportunities (WHO, 2016).

The shortage of green spaces in urban environments, particularly in recent years in our country, has prompted a reassessment of cemeteries. While studies on this subject were quite limited in the past, today cemeteries are recognized as areas that require careful planning and management (Özhancı & Aklıbaşı, 2017). As green spaces diminish at an alarming rate, cemeteries remain largely untouched due to their inherent function and sacred significance compared to other types of green areas. It is crucial for cemeteries to persist as enduring green spaces. In this regard, cemeteries can be viewed as significant ecosystems that offer both natural and cultural benefits to people (Barrett & Barrett, 2002; Harvey, 2006; Andersson et al., 2007). Safeguarding and enhancing cemeteries is essential for sustaining ecosystem services. The capacity of cemeteries to deliver ecosystem services depends on factors such as tree and plant species diversity, green space design and maintenance practices. Through reforestation and landscape design, cemeteries contribute to ecosystem services such as air pollution removal, carbon storage and oxygen production (Özkan et al., 1996; Karaoğlu, 2007).

Understanding the composition, diversity and structure of tree species within cemeteries is essential for grasping the dynamics of these green spaces and formulating effective management strategies (Martinez-Trinidad et al., 2021). Nevertheless, information regarding cemeteries in Türkiye remains relatively scarce. In recent years, specialized computer programs like I-Tree have been developed to estimate the ecosystem services provided by trees. I-Tree tools are tailored software programs designed for assessing the ecosystem services of green spaces. For instance, I-Tree Eco is utilized to conduct structural assessments of green spaces, quantify carbon sequestration and storage, assess air pollution removal, estimate avoided runoff, and assign economic values to these services (Martinez-Trinidad et al., 2021).

The main objective of this study is to quantify the levels of four regulatory ecosystem services (air pollution removal, carbon sequestration and storage, oxygen production and runoff prevention) that cemeteries, which are important components of Isparta's green space system, can provide using i-Tree Eco software. Gülcü Cemetery, Isparta Garrison Martyrdom-Karaağaç Cemetery and Akyol Cemetery, which were determined as research material, were studied because they include large trees that can provide important contributions in terms of ES. It is also aimed to discern the disparities in the ecosystem services provided by trees and plants within cemeteries and to underscore the significance of these services for both environmental sustainability and human health.

MATERIALS and METHODS

Materials

This study, investigating the ecosystem services offered by urban cemeteries, was conducted in three designated cemeteries situated in the city center of Isparta, Türkiye (Figure 1). As part of the study, the selected cemeteries from Isparta Province include Gülcü Cemetery, Isparta Garrison Martyrdom, Karaağaç Cemetery and Akyol Cemetery (Figure 1). Isparta Garrison Martyrdom and Karaağaç Cemetery were considered as a single area for evaluation within the study due to their adjacency. All of the designated cemeteries for the research are situated in the southeastern part of Isparta central district.

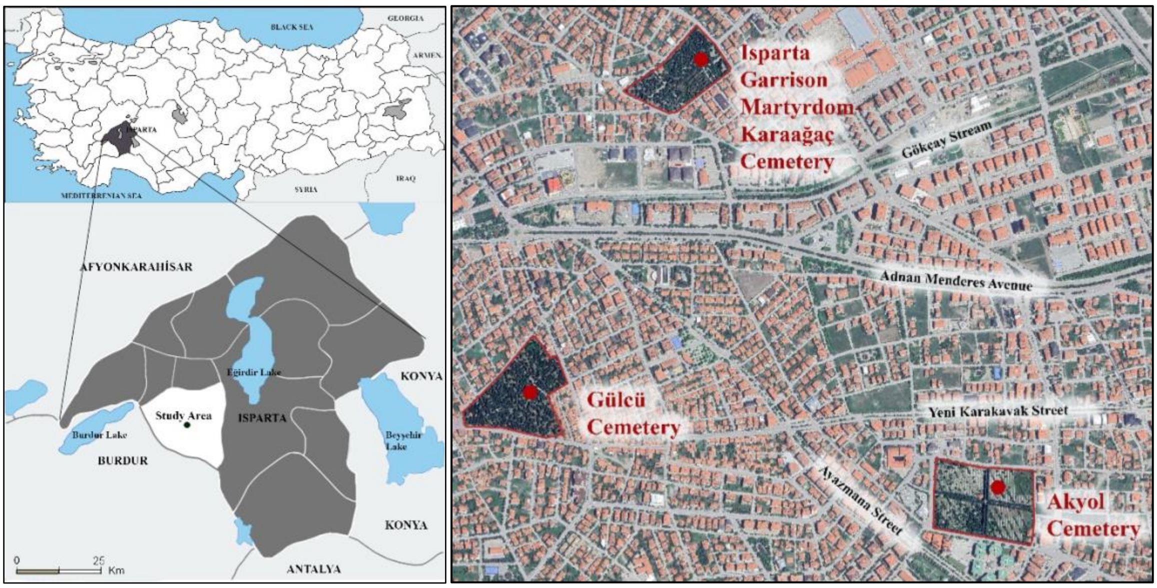

Figure 1. Location of the study area.

Şekil 1. *Çalışma alanının konumu.*

Isparta Garrison Martyrdom and Karaağaç Cemetery collectively cover an area of 41,505 m². Situated within an urban landscape predominantly characterized by three-story buildings, this cemetery is intersected by the Gökçay creek flowing from the south. Gülcü Cemetery, boasting the highest vegetation density among the selected cemeteries, spans across an area of 55,127 m². It is situated within an urban environment primarily comprised of two to three-story buildings. Akyol Cemetery covers an area of 45,880 m². This cemetery, bordered by two-lane streets on three sides, is located in an urban setting where buildings range from three to six stories in height. It is adjacent to Yeni Karakavak Street to the north, Ayazmana Street to the northwest, and Şevket Savlu street to the east. Furthermore, Akyol Cemetery exhibits a lower vegetation density compared to the other cemeteries (Table 1).

In addition to the study areas, which constitute the primary focus of the research, the supplementary materials include photographs captured to gather information about the research sites, the field observation form utilized for the inventory study, and the i-Tree Eco software (i-Tree, 2020) employed for measuring ecosystem services. The photographs were captured to assess the physical attributes of the cemeteries and the condition of the green spaces. The field observation form was utilized to identify the quantitative, spatial, and physical characteristics of the cemeteries. This form facilitated the collection of data pertaining to various aspects such as the dimensions of the cemeteries, types of plant species present, distribution of green areas and components of the ecosystem.

Table 1. Some quantitative and qualitative information about the study areas

Çizelge 1. *Çalışma alanları ile ilgili nicel ve nitel bazı bilgiler*

	Quantitative information		Qualitative information	
	The total area (m^2)	Building heights (close vicinity) (m)	Plant cover type	Vegetation density
Isparta Garrison Martyrdom + Karaağaç Cemetery	41,505	6-9	Coniferous + Deciduous Mixed (Mostly Coniferous)	Dense
Gülcü Cemetery	55,127	6-9	Mostly Coniferous	Medium dense
Akyol Cemetery	45,880	9-18	Coniferous + Deciduous Mixed (Mostly Coniferous)	Poor dense

Methodology

The study methodology comprises four main stages. The first stage involved selecting the study areas. Factors such as geographical location, vegetation density, distribution and suitability for applying the chosen model influenced the selection process. The city center of Isparta was chosen due to the specific characteristics of cemeteries within an urban context.

The second stage involved measuring ecosystem services. I-Tree Eco software was utilized for this purpose, allowing for the measurement and evaluation of ecosystem services provided by the cemeteries. This software enables the analysis of key ecosystem services such as carbon storage capacity, oxygen production, air pollution removal and surface runoff. The extensive data obtained through the use of I-Tree Eco contributed to a scientific understanding of the ecological significance and potential benefits of cemeteries. In this context, we define the evaluation criteria to be employed in the I-Tree Eco software for determining the ecosystem services rendered by plants. The criteria encompass the plant type (tree/shrub) and its scientific name, height (m), trunk diameter (DBH) (cm), crown diameter (m), height of the trunk from the ground (m), and physical attributes such as mortality rate (%). Furthermore, an inventory form was devised to document the observations to be conducted in the field and field research was executed accordingly.

During the third phase, the data amassed from the field research was digitally transcribed for utilization in the subsequent analysis phase. The outcomes derived from the analysis conducted via the I-Tree Eco module were meticulously scrutinized and assessed in depth. The findings generated by the model illuminate the cemeteries' capacity to deliver ecosystem services. Through these analyses, a deeper comprehension and assessment of the environmental merits and ecosystem services rendered by cemeteries were achieved.

In the concluding phase, the recommendations have been formulated based on the study findings and acquired data. These recommendations offer evidence-based directives for the sustainable oversight and preservation of cemeteries. This study highlights the potential of cemeteries to offer ecosystem services in urban landscapes, aiming to ensure more effective evaluation and sustainability of cemeteries. This study underscores the capacity of cemeteries to provide ecosystem services within urban landscapes, with the aim of fostering more efficient assessment and sustainable management of these burial grounds.

RESULTS

The parameters examined in this study, which explores the ecosystem services offered by cemeteries in urban settings through the application of the I-Tree Eco model, encompass tree attributes, urban forest coverage and leaf area, air pollution mitigation, carbon sequestration, oxygen generation and surface runoff mitigation. Hence, the findings are elucidated based on these criteria in sequential order.

Tree features

To assess the tree characteristics in Gülcü Cemetery, inventory studies were conducted on 1,000 cemetery trees, representing 8 different species from 4 families. The total tree cover is 20.3%. The three most common species are *Pinus nigra* (60.4%), *Cupressus sempervirens* (12.1%) and *Pinus pinea* (10.0%), respectively (Figure 2a). Based on the data from Gülcü Cemetery, the overall tree density is recorded at 66 trees per decare.

When examining the distribution of trees in Gülcü Cemetery based on diameter classes, it is observed that the majority fall within the range of 76 to 121.9+ cm. Based on the diameter classes, it can be inferred that the trees in this cemetery typically range from medium-sized to mature. Additionally, a small proportion (12.1%) of larger trees exceeding 121.9 cm in diameter were also found in the cemetery (Figure 2b).

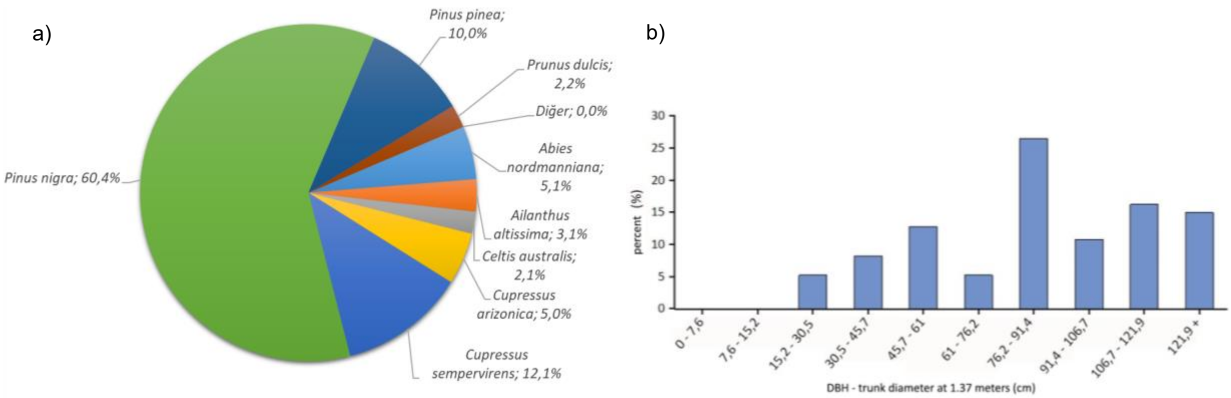

Figure 2. a. Tree species composition in Gülcü Cemetery. **b.** Percent of tree population by diameter class of Gülcü Cemetery trees.

Şekil 2. a. *Gülcü Mezarlığı ağaç türleri dağılımı.* ***b.*** *Gülcü Mezarlığı ağaçlarının çap sınıfına göre ağaç popülasyon yüzdesi*

To assess the tree characteristics at Isparta Garrison Martyrdom-Karaağaç Cemetery, inventory studies were conducted on 1,166 cemetery trees. These trees represent a diversity of 17 species originating from 6 different families. The total tree cover in this area is 24.0%. The three most common species are *Pinus nigra* (30.1%), *Cupressus arizonica* (22.8%) and *Pinus pinea* (21.2%), respectively (Figure 3a). According to the data from Isparta Garrison Martyrdom-Karaağaç Cemetery, the overall tree density is recorded at 118 trees per decar.

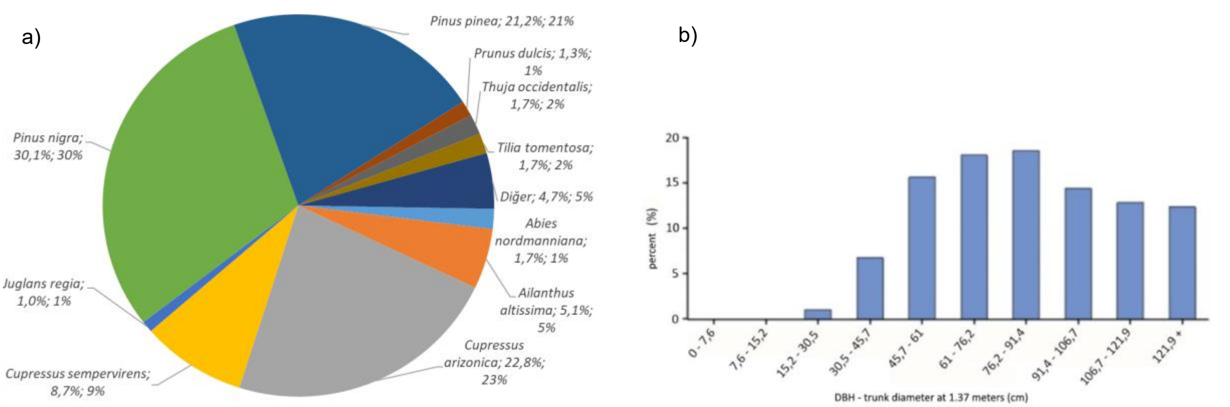

Figure 3. a. Tree species composition in Isparta Garrison Martyrdom-Karaağaç Cemetery. **b.** Percent of tree population by diameter class of Isparta Garrison Martyrdom-Karaağaç Cemetery trees.

Şekil 3. a. *Isparta Garnizon Şehitliği-Karaağaç Mezarlığı ağaç türleri dağılımı.* ***b.*** *Isparta Garnizon Şehitliği-Karaağaç Mezarlığı ağaçlarının çap sınıfına göre ağaç popülasyon yüzdesi.*

When examining the distribution of trees in the Isparta Garrison Martyrdom-Karaağaç Cemetery according to diameter classes, it is observed that the majority fall within the following ranges: 76, 61-76.2, 91.4, 2, and 45.7-61 cm, respectively. Based on the data, it appears that trees within the range of 76 to 91.4 cm generally represent mature and large specimens, whereas those in the 45.7-61 cm range indicate younger and smaller trees. The trees within the range of 61 to 76.2 cm are considered to be in the category of young and mature trees (Figure 3b).

Inventory studies were conducted for 900 cemetery trees belonging to 13 different species from 6 different families in Akyol Cemetery to evaluate the tree features. The total tree cover is 21.3%. The three most common species are *Cupressus arizonica* (30.7%), *Pinus nigra* (26.8%) and *Pinus pinea* (7.9%), respectively (Figure 4a). According to Akyol Cemetery data, the overall tree density is 77 trees per decar.

When examining the distribution of trees in Akyol Cemetery based on diameter class, the majority fall within the range of 76, 121.9-91.4 -106.7, 91.4+, and 91.4 cm, respectively. According to the data, Akyol Cemetery predominantly features medium-sized trees (ranging from 76.2 to 91.4 cm) and large, mature trees (ranging from 91.4 to 106.7 cm and 121.9 cm and above) (Figure 4b).

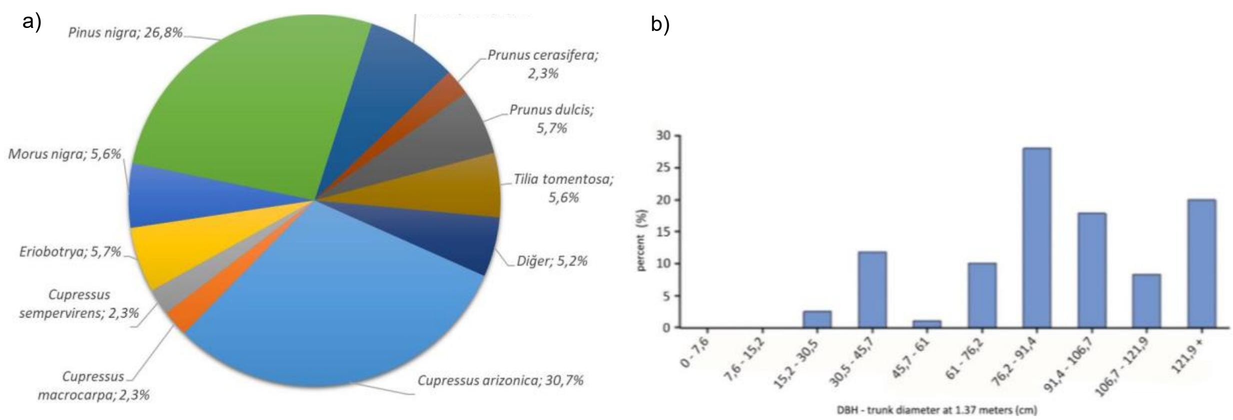

Figure 4a. Tree species composition in Akyol Cemetery. **b.** Percent of tree population by diameter class of Akyol Cemetery tress.

Şekil 4a. *Akyol Mezarlığı ağaç türleri dağılımı.* ***b.*** *Akyol Mezarlığı ağaçlarının çap sınıfına göre ağaç popülasyon yüzdesi.*

When collectively evaluating the tree characteristics of the three cemeteries, data was gathered from a total of 3,066 cemetery trees representing 24 different species from 15 distinct families. The total tree cover is 21.1%. The three most common species are *Pinus nigra* (37.9%), *Cupressus arizonica* (19.6%) and *Pinus pinea* (13.9%), respectively. According to the values obtained, the majority of the tree density comprises coniferous species (Table 2).

Table 2. Comparison of the cemeteries in terms of tree characteristics

Çizelge 2. *Mezarlıkların ağaç özellikleri bakımından karşılaştırılması*

Cemetery	Total number of trees	Tree cover (%)	Tree density (per decar)	The 3 most common species	Range of the 3 most common DBH (%)
Gülcü Cemetery	1000	20.3%	66	*Pinus nigra* *Cupressus sempervirens* *Pinus pinea*	76.2 to 91.4 (60.4%) 106.7 to 121.9 (12.1%) 121.9+ (10.0%)
Garrison Martyrdom + Karaağaç Cemetery	1166	24.0%	118	-*Pinus nigra* -*Cupressus arizonica* -*Pinus pinea*	-76.2 to 91.4 (30.1%) -61 to 76.2 (22.8%) -45.7 to 61 (21.2%)
Akyol Cemetery	900	21.3%	77	-*Cupressus arizonica* -*Pinus nigra* -*Pinus pinea*	-76.2 to 91.4 (26.8%) - 121.9+ (30.7%) - 91.4 to 106.7 (7.9%)

Urban forest cover and leaf area

When examining the trees in the cemeteries in terms of leaf area, it is determined that the trees in Gülcü Cemetery provide a leaf area of 27.65 decare. In terms of leaf area, the most dominant species have been identified as *Pinus nigra, Pinus pinea* and *Cupressus sempervirens*. It was determined that the trees in Isparta Garrison Martyrdom-Karaağaç Cemetery provide a leaf area of 18.03 decare. In terms of leaf area, the most dominant species have been identified as *Cupressus arizonica, Pinus nigra* and *Pinus pinea* species. At Akyol Cemetery, analysis revealed that the collective leaf area of the trees amounted to 28.61 decare. In terms of leaf area, the most dominant species have been identified as *Pinus nigra, Cupressus arizonica* and *Pinus pinea*. When considering all three cemeteries collectively, the total leaf area amounts to 74.29 decar (Table 3).

In the context of urban forest cover, the Garrison Martyrdom of Isparta-Karaağaç Cemetery exhibits the highest urban forest cover ratio at 24.0%, distinguishing itself as the cemetery with the densest tree population. The urban forest cover rates of other cemeteries, specifically Gülcü Cemetery and Akyol Cemetery, are closely matched, with percentages of 20.3% and 21.3%, respectively (Table 3). The significance values (IV) were computed by summing the population percentage and leaf area. In Gülcü Cemetery, *Pinus nigra* (42.7%) has the highest significance, meaning it is the dominant species in terms of both the percentage of population and the percentage of leaf area. The highest value in the Garrison Martyrdom-Karaağaç Cemetery of Isparta belongs to the species *Cupressus arizonica* (61.0%). In Akyol Cemetery, the highest value belongs to the species *Pinus nigra* (90.4%) (Table 3).

Table 3. Comparison of the cemetery areas in terms of urban forest cover and leaf area

Çizelge 3. *Mezarlıkların kentsel orman örtüsü ve yaprak alanı bakımından karşılaştırılması*

Cemetery	Tree cover (%)	Leaf area (decar)	The 3 most common types and leaf areas (%)	IV
Gülcü Cemetery	20.3%	27.65	*-Pinus nigra (60.4%)* *-Cupressus sempervirens(12.1%)* *- Pinus pinea (10.0%)*	*-Pinus nigra* (42.7%) *-Pinus pinea* (18.4%)
The Garden of Eden – Cemetery	24.0%	18.03	*-Pinus nigra (30.1%)* *- Cupressus arizonica (22.8%)* *- Pinus pinea (21.2%)*	*-Cupressus arizonica* (61.0%) *-Pinus pinea* (53.6%)
The Akyol Cemetery	21.3%	28.61	*-Cupressus arizonica (30.7%)* *-Pinus nigra (26.8%)* *-Pinus pinea (7.9%)*	*- Pinus nigra* (90.4%) *- Cupressus arizonica* (50.6%)

Air pollution removal

Air pollution removal in the research areas was estimated through the integration of field data with current pollution and meteorological data sourced from the Directorate General of Meteorology. It is estimated that all cemeteries remove ozone (O_3), carbon monoxide (CO), nitrogen dioxide (NO_2), sub 2.5 micron particulate matter (PM2.5) smaller than 10 micron and greater than 2.5 micron particulate matter (PM10*2) and sulphur dioxide (SO_2) at different rates.

It has been determined that the trees within Gülcü Cemetery contribute to a reduction in air pollution by an estimated 136.35 kilograms per year. In 2023, the trees within this cemetery emitted an estimated 100.70 kilograms of volatile organic compounds. Emissions vary among species due to their distinct characteristics and leaf biomass. 94% of VOC emissions are caused by *Pinus nigra* and *Pinus pinea*. The trees in the Isparta Garrison Martyrdom-Karaağaç Cemetery have been found to reduce air pollution by 96.21 kilograms per year. In 2023, the trees in this cemetery emitted an estimated 52.68 kilograms of volatile organic compounds. 63% of VOC emissions are caused by *Cupressus arizonica* and *Pinus nigra.* Trees in Akyol Cemetery have been found to reduce air pollution by 121.99 kilograms per year. In 2023, the trees in this cemetery emitted an estimated 92.81 kilograms of volatile organic compounds. 89% of VOC emissions are caused by *Pinus nigra* and *Cupressus arizonica* (Table 4).

Upon evaluating all three cemeteries collectively, they were observed to contribute to a total air pollution removal of 354.55 kilograms per year. The combined emission of volatile organic compounds from all three cemeteries amounts to 246.19 kilograms. Based on these findings, it is evident that the trees within Gülcü Cemetery make the highest contribution to pollution removal among the three cemeteries. The lowest pollution removal is provided by the Garrison Martyrdom-Karaağaç Cemetery (Table 4). Based on the data collected from all cemeteries, it was determined that they exhibit notable effectiveness in the removal of ozone.

Table 4. Comparison of the cemeteries in terms of air pollution

Çizelge 4. *Mezarlıkların hava kirliliği giderimi bakımından karşılaştırılması*

Cemetery	Pollution removal (kg/year)	VOC (kg/year)	VOC emissions sources and percentages (%)
Gülcü Cemetery	136.35	100.70	*Pinus nigra* and *Pinus pinea* (94%)
Garrison Martyrdom – Karaağaç Cemetery	96.21	52.68	*Cupressus arizonica* and *Pinus nigra* (63%)
Akyol Cemetery	121.99	92.81	*Pinus nigra* and *Cupressus arizonica* (89%)

Carbon sequestration and storage

The gross carbon sequestration of the trees in Gülcü Cemetery is about 15.7 tons per year (Table 5). Due to the high density of trees, *Pinus nigra* sequesters more carbon than other species. However, the broad-leaf species *Ailanthus altissima*, comprising 31 trees, sequesters more carbon compared to the coniferous species *Cupressus arizonica*, with 50 trees, and *Cupressus sempervirens*, with 121 trees. The broad-leaf species *Ailanthus altissima* has a much better carbon sequestration potential than other tree species (Table 6). The amount of carbon storage of the trees in this cemetery is calculated as 1980 tons. Due to the excess of tree density among the sampled species*, Pinus nigra* stores the most carbon and accounts for about 59.9% of the total stored carbon and 64.7% of the entire carbon sequestration process (Table 5).

The gross carbon sequestration of the trees in the Isparta Garrison Martyrdom-Karaağaç Cemetery is about 18.47 tons per year (Table 5). As mentioned above, the amount of carbon sequestration is directly proportional to the health and size of the trees. As the trees grow, the amount of gross carbon sequestration will increase. According to the following data, the broad-leaf species *Ailanthus altissima*, similar to the one found in Gülcü Cemetery, has been found to sequester more carbon than coniferous species *Cupressus arizonica* and *Cupressus sempervirens* (Table 7). The carbon storage capacity of the trees within this cemetery is calculated to be 2430 tons. Of the species sampled, *Cupressus arizonica* stores the most carbon (about 34.9% of the total carbon stored), while *Pinus nigra* sequesters the most carbon (about 34.9% of all carbon sequestered) (Table 5).

The gross carbon sequestration of the trees in Akyol Cemetery is about 13.05 tons per year. The amount of carbon storage of the trees in this cemetery is calculated as 2360 tons. Among the species sampled, *Pinus nigra* stores the most carbon and accounts for about 32.6% of the stored carbon and 27.6% of the entire carbon sequestration process (Table 5).

Upon evaluating all three cemeteries collectively, they are found to collectively sequester 47.22 tons of gross carbon. The total carbon storage of these three cemeteries is 6770 tons. The trees in the cemeteries differ in terms of gross carbon sequestration. Isparta Garrison Martyrdom-Karaağaç Cemetery has the highest gross carbon sequestration amount with 18.47 tons, while Akyol Cemetery has the lowest sequestration amount with 13.05 tons. (Table 5). This variance is attributed to factors such as the size of the cemeteries, tree density, types of trees, and the respective management policies implemented within each cemetery. In terms of carbon sequestration potential, it is seen that Isparta Garrison Martyrdom-Karaağaç Cemetery is more advantageous than others.

In comparing Gülcü Cemetery with the Isparta Garrison Martyrdom-Karaağaç and Akyol cemeteries, significant disparities are observed in terms of carbon storage and the overall carbon sequestration. Gülcü Cemetery emerges as the site with the highest total carbon storage, thereby making the most substantial contribution to the overall carbon capture process among the studied cemeteries. Isparta Garrison Martyrdom-Karaağaç Cemetery stands out with *Cupressus arizonica*, which provides 34.9% of the stored carbon, while Akyol Cemetery stands out with *Pinus nigra*, which stores the most carbon due to its abundance (Table 5).

Table 5. Comparison of the cemeteries in terms of the estimated amount of carbon storage and gross carbon sequestration

Çizelge 5. *Mezarlıkların tahmini karbon depolama ve brüt karbon tutma miktarı bakımından karşılaştırılması*

Cemetery	Total carbon storage (tons)	The most carbon-storing species	% Of total carbon stored (%)	Gross carbon sequestration (tons)	Percentage of all carbon sequestration (%)
Gülcü Cemetery	1980	*Pinus nigra*	59.9%	15.7	64.7%
Isparta Garrison Martyrdom – Karaağaç Cemetery	2430	*Cupressus arizonica*	34.9%	18.47	34.9%
Akyol Cemetery	2360	*Pinus nigra*	32.6%	13.05	27.6%

Oxygen production

The trees within Gülcü Cemetery are estimated to produce approximately 41.86 tons of oxygen per year (Table 9). Among the species observed, *Pinus nigra* stands out as the most prolific oxygen producer, generating a total of 27.08 tons of oxygen. Other species have produced lower amounts of oxygen (Table 6). Examining the table, it is evident that despite *Ailanthus altissima* having a smaller number of trees, its oxygen production surpasses that of *Cupressus arizonica*. This observation suggests that broad-leaf trees may be more efficient in oxygen production compared to coniferous trees.

Table 6. The first 8 species that produce the most oxygen in Gülcü Cemetery

Çizelge 6. *Gülcü Mezarlığı'nda yer alan, en çok oksijen üreten ilk 8 tür*

Type name	Oxygen (tons)	Gross carbon sequestration (tons/year)	Number of trees	Leaf area (decar)
Pinus nigra	27.08	10.16	604	22.76
Pinus pinea	7.36	2.76	100	2.31
Ailanthus altissima	2.22	0.83	31	0.10
Abies nordmanniana	1.85	0.70	51	0.25
Cupressus arizonica	1.73	0.65	50	0.54
Prunus dulcis	1.09	0.41	22	0.09
Cupressus sempervirens	0.32	0.12	121	1.35
Celtis australis	0.20	0.07	21	0.26

It has been calculated that the trees in the Garrison Martyrdom-Karaağaç Cemetery of Isparta produce approximately 49.24 tons of oxygen per year (Table 9). The highest oxygen production is *Pinus nigra* with 17.18 tons of oxygen. The table shows that, similar to the data from Gülcü Cemetery, the family of *Ailanthus altissima* has a small number of trees, but oxygen production is greater than *Cupressus arizonica* (Table 7).

Coniferous trees such as *Pinus nigra* and *Pinus pinea* produce significant amounts of oxygen, depending on tree numbers and leaf areas. *Pinus nigra*, in particular, produces more oxygen than other coniferous trees with a high number of trees and large leaf area (Table 7). When comparing *Cupressus sempervirens* and *Platanus orientalis* species, although *Cupressus sempervirens* has a higher number of trees, its leaf area is lower. Consequently, *Platanus orientalis* has produced more oxygen (Table 7).

Table 7. The first 17 species producing the most oxygen in Isparta Garrison Martyrdom-Karaağaç Cemetery

Çizelge 7. *Isparta Garnizon Şehitliği-Karaağaç Mezarlığı'nda yer alan, en çok oksijen üreten ilk 17 tür*

Type name	Oxygen (tons)	Gross carbon sequestration (tons/year)	Number of trees	Leaf area (decar)
Pinus nigra	17.18	12,888.65	351	4.23
Pinus pinea	13.87	10,398.90	247	4.17
Ailanthus altissima	5.88	4,407.61	60	0.28
Cupressus arizonica	5.49	4,115.02	266	6.88
Robinia hispida	2.04	1,533.53	10	0.04
Thuja occidentalis	0.94	704.77	20	0.12
Tilia tomentosa	0.86	648.03	20	0.26
Cupressus sempervirens	0.67	502.14	101	0.20
Platanus orientalis	0.67	500.91	10	0.40
Juglans region	0.51	381.85	11	0.68
Abies nordmanniana	0.44	329.45	20	0.04
Prunus cerasifera	0.32	239.97	10	0.01
Picea pungens	0.26	193.44	10	0.01
Prunus dulcis	0.08	61.04	15	0.09
Elaeagnus angustifolia	0.01	9.35	5	0.05
Morus alba	0.01	7.94	5	0.32
Morus nigra	0.01	7.83	4	0.26

The calculation indicates that the trees within Akyol Cemetery generate approximately 34.79 tons of oxygen annually (Table 9). According to the data presented in the table, despite the small number of *Morus alba* trees, their oxygen production exceeds that of the coniferous *Cupressus sempervirens*. Similarly, the limited number of broad-leaf species, *Ficus carica*, has been observed to generate more oxygen compared to the more abundant coniferous species, including *Cupressus sempervirens, Cupressus macrocarpa* and *Thuja occidentalis* (Table 8).

Table 8. The first 13 species in Akyol Cemetery that produce the most oxygen

Çizelge 8. *Akyol Mezarlığı'nda yer alan, en çok oksijen üreten ilk 13 tür*

Type name	Oxygen (tons)	Gross carbon sequestration (tons/year)	Number of trees	Leaf area (decar)
Pinus nigra	9.59	7,195.60	241	18.19
Cupressus arizonica	8.46	6,344.74	276	5.69
Pinus pinea	6.35	4,765.28	71	1.82
Eriobotria	3.45	2,584.00	51	0.02
Tilia tomentosa	2.50	1,876.73	50	0.58
The ficus carica	1.00	752.92	16	0.15
Cupressus macrocarpa	0.93	698.85	21	0.03
Prunus cerasifera	0.92	688.82	21	0.05
Thuja occidentalis	0.68	510.91	21	0.02
Prunus dulcis	0.42	311.59	51	0.25
Morus nigra	0.34	253.98	50	1.36
Morus alba	0.08	58.86	10	0.23
Cupressus sempervirens	0.07	52.03	21	0.23

The trees within Gülcü, Isparta Garrison Martyrdom-Karaağaç and Akyol cemeteries collectively produce a noteworthy quantity of oxygen on an annual basis. Upon evaluating all three cemeteries collectively, they are found to produce a total of 125.89 tons of oxygen. The cemetery estimated to produce the highest amount of oxygen, totaling 49.24 tons, is the Isparta Garrison Martyrdom-Karaağaç Cemetery. Following closely, Gülcü Cemetery is estimated to produce 41.86 tons of oxygen, while Akyol Cemetery is estimated to produce 34.79 tons. Across all three cemeteries, *Pinus nigra* emerges as the most prolific oxygen-producing tree, primarily attributable to its abundant presence, as indicated in Table 9.

Table 9. Comparison of the cemeteries in terms of oxygen production

Çizelge 9. *Mezarlıkların oksijen üretimi bakımından karşılaştırılması*

Cemetery	Total oxygen production (tons/year)	Most oxygen-producing species and percentage (%)
Gülcü Cemetery	41.86	*Pinus nigra* (64.7%)
Isparta Garrison – Karaağaç Cemetery	49.24	*Pinus nigra* (34.9%)
Akyol Cemetery	34.79	*Pinus nigra* (27.6%)

Avoided Runoff

Another ecosystem service provided by trees is to reduce runoff. Using local weather data obtained from the meteorological station, the runoff prevented was estimated. Gülcü Cemetery contributes to the prevention of water erosion by preventing 144.8 cubic meters of runoff per year. As the most successful species, *Pinus nigra* stands out for its effect on reducing water erosion. Isparta Garrison Martyrdom-Karaağaç Cemetery reduces water erosion by helping to prevent 102 cubic meters of runoff per year. As the most successful species, *Cupressus arizonica* is noted for its effectiveness in preventing surface runoff. Akyol Cemetery contributes to preventing water erosion by reducing 126.8 cubic meters of runoff per year. As in Gülcü cemetery, *Pinus nigra* stands out as the most successful species with its effectiveness in preventing runoff (Table 10).

Table 10. Comparison of the cemeteries in terms of the amount of runoff prevented

Çizelge 10. *Mezarlıkların önlenen yüzey akış miktarı bakımından karşılaştırılması*

Cemetery	Prevented surface runoff (cubic meters/year)	The most successful species
Gülcü Cemetery	144.8	*Pinus nigra*
Isparta Garrison Martyrdom – Karaağaç Cemetery	102	*Cupressus arizonica*
Akyol Cemetery	126.8	*Pinus nigra*

DISCUSSION

The analysis conducted within the study delineates that the trees and shrubbery within the cemeteries offer significant ecosystem services to the environment. This study evaluated the contributions of Gülcü Cemetery, Isparta Garrison Martyrdom-Karaağaç Cemetery and Akyol Cemetery to various ecosystem services. Gülcü Cemetery emerges as the most effective in air pollution removal and surface runoff reduction, while the Isparta Garrison Martyrdom-Karaağaç Cemetery exhibits a distinct advantage over other cemeteries in carbon storage and oxygen production. Akyol Cemetery performs at a moderate level in air pollution removal and carbon storage (Table 11).

The findings compared with the results of research conducted in many different regions of the world (Table 12).

According to the research conducted in the cemeteries examined in Isparta, the collective urban forest cover rate of the cemeteries amounts to 21.1%. This figure underscores the substantial contribution of cemeteries to the green spaces within the city center of Isparta. However, it is noted that the percentage of urban forest cover observed in the studied cemeteries is relatively low compared to other areas examined. The study conducted in Hyde Park revealed the highest urban forest cover (Rogers et al., 2018) with 345%. 2. Kyoto (Kang et al., 2022) holds the second place with 104.3%. In the Luohe study (Song et al., 2020), which boasts the highest tree count, the urban forest cover is reported to be 54%. The presence of a large number of trees in a particular area with low urban forest cover suggests an unequal distribution of trees, with concentrations in certain regions while being sparse or absent in others.

Table 11. Ecosystem services provided by the 3 surveyed cemeteries

***Çizelge 11.** İncelen 3 mezarlığın sağladığı ekosistem servisleri*

Cemetery	Number of trees	Urban forest cover (%)	Air pollution removal (kg)	Carbon storage (tons)	Carbon sequestration (tons/year)	Production of oxygen (tons/year)	Surface runoff Prevention (m^3/year)	The most common types of trees
Gülcü Cemetery	1000	20.3	136.35	1.980	15.7	41.86	144.8	*-Pinus nigra* *-Cupressus sempervirens*
Isparta Garrison Martyrdom-Karaağaç Cemetery	1166	24	96.21	2.430	18.47	49.24	102	*-Pinus nigra* *-Cupressus arizonica* *- Citrus × aurantiifolia*
Akyol Cemetery	900	21.3	121.99	2.360	13.05	34.79	126.8	*-Acer platanoides* *-Acer pseudoplatanus*
Total	3066	21.1	354.55	6.770	47.22	125.89	373.6	*-Pinus nigra* *-Cupressus arizonica*

Table 12. Comparison of ecosystem service parameters with research data in similar studies

***Çizelge 12.** Benzer çalışmalardaki ekosistem hizmet parametrelerinin araştırma verileri ile karşılaştırılması*

Research	Number of trees	Urban forest cover (%)	Air pollution Removal (tons)	Carbon storage (tons)	Carbon sequestration (tons/year)	Oxygen production (tons/year)	Surface runoff prevention (m^3/year)	The most common types of trees
Texcoco (Mexico, Texcoco)	391	-	6	64,14	7,82	-	201,17	*-Ficus benjamina* *-Schinus molle*
Hyde Park (London, UK)	3174	345	2,71	3,872	88	-	358	*- Platanus × acerifolia* *- Castanea sativa* *- Citrus × aurantiifolia*
Drumcondra Road (Dublin, Ireland)	36	4.6	0,3	7	0,5	10	100	*-Acer platanoides* *-Acer pseudoplatanus*
University of Auburn (Alabama, USA)	7345	16	2,970	10000	291	8000	10000	*- Quercus lyrata* *- Quercus nuttallii*
Kyoto (Kyoto, Japan)	2000+	104.337	3	71,13	7,63	-	218,88	*-Quercus serrata* *-Prunus serrulata*
Luohe (Luohe, China)	1.006.251	54	92	54329	4973	-	122636	-
The Eugene Pioneer Cemetery (Oregon, USA)	356	40.9	0,143	1,610	7,136	19,03	452	*-Pseudotduga* *-Thuja chicicata*
SDU Boulevard (Isparta, Türkiye)	1498	7,11	-	21,83	197,56	-	-	*-Cedrus libani* *-Pinus nigra Arnold. subsp.*
Burdur (Burdur, Türkiye)	588	11,2	0,066	1,220	12,92	34,44	52	*-Fraxinus angustifolia* *-Tilia tomentosa*
Isparta-Cemeteries (Isparta, Türkiye)	3066	21,1	0,35	6,770	47,22	125,89	373,6	*-Pinus nigra* *-Cupressus arizonica*

An important revelation from the study is the significant contribution of cemeteries to air pollution removal. The study determined the air pollution within the cemeteries to be 0.35 tons, a notably lower rate compared to other studies reviewed above. The study conducted on Drumcondra Road (Riondato et al., 2020), which encompasses 36 trees, achieved an air pollution reduction of 0.3 tons. Despite the relatively small number of trees, it demonstrated a comparable level of air pollution removal to the cemeteries investigated in this research. Conversely, in Texcoco, Mexico (Martinez-Trinidad et al., 2021), a study involving 391 trees estimated a substantial air pollution removal of 6 tons. Similarly, Hyde Park (Rogers et al., 2018), with a tree count of 3,174, provided 2.71 tons of air pollution removal. The findings indicate that cemeteries exhibit lower performance in air pollution removal despite harboring a large number of trees and maintaining a typical urban forest cover percentage compared to other research sites. This suggests that the preference for coniferous trees in cemeteries may result in less oxygen production and reduced air pollution removal compared to broad-leaf trees.

Conversely, the performance of the cemeteries examined in terms of carbon storage is noteworthy, with a cumulative storage capacity of 6,770 tons. In comparison, Hyde Park (Rogers et al., 2018), with a comparable tree count, stores 3,872 tons of carbon. This indicates that the cemeteries under study excel in carbon storage relative to Hyde Park. This suggests that coniferous trees may excel in carbon storage compared to broad-leaf trees, whereas broad-leaf trees may exhibit superior carbon sequestration capabilities (Abdollahi et al., 2000). In the study conducted at Eugene Pioneer Cemetery involving 356 trees (Hepcan & Coşkun Hepcan, 2021), the substantial carbon storage of 1,610 tons is noteworthy relative to the tree count.

However, the performance of the cemeteries examined in terms of carbon sequestration appears to be comparatively lower. The annual carbon sequestration within the cemeteries amounts to 47.22 tons. Despite exhibiting a lower carbon sequestration capacity compared to other research sites, cemeteries evidently contribute to the carbon cycle. For instance, in Hyde Park (Rogers et al., 2018), where a study with a similar number of trees, predominantly broadleaf species, estimated annual carbon sequestration of 88 tons. This difference points to an ecologically significant scenario.

Concerning oxygen production, the cemeteries produce 125.89 tons annually, a seemingly substantial figure; however, considering the number of trees examined, the performance in oxygen production appears modest. For instance, on Drumcondra Road (Riondato et al., 2020), where only 36 trees are present, an annual production of 10 tons of oxygen is observed, indicating a remarkably high level of oxygen production relative to the tree count. The results of this study, in which a small number of broadleaved trees were evaluated, show that broadleaved trees may be more efficient in oxygen production than coniferous trees. As stated by Değermenci (2023), broad-leaved trees and coniferous trees have different photosynthesis strategies. Broad-leaf trees can achieve more efficient photosynthesis by capturing a greater amount of solar energy, attributed to the expansive surface area of their leaves. Therefore, trees with large leaves can often have higher oxygen production. In the study conducted at Auburn University (Martin, 2013), the production of 8,000 tons of oxygen per year was calculated with the broad-leaf tree species. This substantial amount suggests that the trees in this area are generating significant oxygen compared to other studies. In the research conducted at Eugene Pioneer Cemetery (Hepcan & Coşkun Hepcan, 2021), where coniferous tree species are dominant, 19.03 tons of oxygen production is calculated annually, while in the research conducted in Burdur (Kacmaz Akkurt et al., 2023), 34.44 tons of oxygen production was calculated.

In terms of runoff prevention, the cemeteries examined in the city of Isparta exhibit a relatively low performance, amounting to 373.6 tons, compared to findings from other studies. The amount of runoff prevented in Eugene Pioneer Cemetery (Hepcan & Coşkun Hepcan, 2021), which was built with 356 trees, is 452 tons. Despite the relatively small number of trees, other research sites have achieved significantly higher performance in runoff prevention compared to the cemeteries examined. In the study conducted at Hyde Park (Rogers et al., 2018), which features a comparable number of trees, a total of 358 tons of runoff was prevented. The amount of runoff prevention of the cemeteries studied in Isparta is higher than the study conducted in Hyde Park (Rogers et al., 2018). These rates are thought to vary according to the preferred plant species. It is believed that employing broad-leaf tree species instead of the predominantly coniferous tree species in the cemeteries under study could yield more successful outcomes in terms of runoff prevention. This is because broad-leaf species are considered more effective than coniferous species in preventing water erosion (Zhao et al., 2000).

In terms of tree species, coniferous tree density is higher in all 3 cemeteries examined within the scope of the study. Studies conducted at Eugene Pioneer Cemetery (Hepcan & Coşkun Hepcan, 2021) and SDU Boulevard (Tuğluer & Gül, 2018) also predominate coniferous tree species, and broad-leaf tree species were examined in all other studies. As research findings and literature surveys show, broad-leaf trees sequester good carbon and prevent surface runoff at a higher level, while coniferous trees store better carbon.

CONCLUSION

The concepts of cemetery and grave have been an integral part of human life since the earliest periods of human history. Cemeteries are cultural landscapes that reflect people's beliefs and rituals related to the afterlife. They are places where people show respect for their ancestors and the past, and where commemoration ceremonies are held. Moreover, cemeteries are places where people connect with nature and utilize the symbolic meanings of plants. According to some sources, in the past, especially in cities with a long urban history in our country, cemeteries were sometimes in the form of shrines, integrated with neighborhoods, and located in areas actively used by people. However, today they have been pushed to the outskirts of cities, isolated from society and distanced from everyday life (Özhancı & Aklıbaşında, 2017). Although they are less integrated into urban habitat networks and green infrastructure systems than parks and other green spaces, they have the potential to be hotspots of culture and biodiversity with their multifunctional character. For this reason, they need to be evaluated with a holistic and interdisciplinary approach using multi-stakeholder approaches, redesign and planning.

In this context, the potential of Gülcü Cemetery, Isparta Garrison Martyrdom -Karaağaç Cemetery, and Akyol Cemetery as a sample area within the city of Isparta was investigated. Utilizing the I-Tree Eco model, the study aimed to assess these cemeteries not only for their sacred and memorial roles but also as integral components of the urban green area system.

The research findings confirm that cemeteries provide a diverse array of ecosystem services through their multifunctional structures. These services include conserving urban biodiversity, mitigating the heat island effect, enhancing air quality and preventing surface runoff. As a result of the analysis;

- **Air pollution removal, carbon storage and sequestration:** The study results show that cemeteries are not good enough at air pollution removal and carbon storage. The value of air pollution removal emphasizes the importance of further reforestation in order to provide a more effective response to air pollution problems. Similarly, increasing carbon storage capacity plays a critical role in combating climate change. Increased carbon storage can play a crucial role in balancing carbon dioxide levels in the atmosphere, leading to positive outcomes for the overall health of ecosystems and society. According to the study results, the primary factor contributing to the lower carbon sequestration rates of cemeteries compared to similarly sized urban parks is believed to be dependent on the type of vegetation they contain. Cemeteries frequently feature a denser presence of coniferous tree species, whereas urban parks tend to host a higher proportion of broad-leaf trees. Broad-leaf trees have the capacity to more effectively absorb carbon dioxide through photosynthesis, thereby enhancing their capability to store carbon. This suggests that broad-leaf vegetation has the potential to sequester carbon faster than coniferous vegetation. This result highlights the need for a careful and balanced approach to plant species selection in cemetery plantations.
- **Oxygen production and surface runoff prevention:** In line with the findings of carbon sequestration and storage, it is believed that opting for a greater variety of broad-leaf tree species can yield more positive effects in both oxygen production and surface runoff prevention. Due to their larger leaf area, broad-leaf trees possess the potential to generate more oxygen through photosynthesis. This enhancement would not only ameliorate the air quality in the immediate vicinity of the cemeteries but could also have a positive impact on the overall oxygen balance throughout the city. In addition, the larger leaf area of broad-leaf trees slows down the descent of rainwater to the soil surface, diminishing surface runoff, facilitating better water absorption and mitigating soil erosion.

As mentioned above, correct and effective planning/design with plant species selection plays an important role in increasing the ecosystem services provided by cemeteries. At this point, local authorities should take responsibility for the planting of sub-areas outside the burial plots to prevent the traditional practice of grave owners determining the tree species in cemeteries. Additionally, care should be taken to select broad-leaved tree species for these areas. In addition, to achieve harmony between the urban landscape and cemeteries, it is imperative to integrate and design cemeteries properly within the urban green infrastructure system.

As a result, cemeteries play a pivotal role in enhancing the sustainability and livability of the urban landscape. When they are planted with large trees and green spaces, they can effectively provide regulatory ecosystem services such as carbon storage, air pollution removal, and water runoff prevention. They also play a crucial role in providing natural habitats and promoting urban biodiversity. They improve the quality of urban life with proper planning, design and management approaches. Preserving and nurturing cemeteries, which serve as the green lungs of cities and hold historical memories and cultural heritage, are essential for the well-being of both humanity and nature in the future.

Data Availability

Data will be made available upon reasonable request.

Author Contributions

Conception and design of the study: GKA, HÇ; sample collection: HÇ; analysis and interpretation of data: GKA, HÇ; statistical analysis: GKA, HÇ; visualization: GKA, HÇ; writing manuscript: GKA.

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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