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Investigation of the effect of green areas on urban air quality in a park in Erzurum with I-Tree Canopy

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ABSTRACT

Introduction: Urbanization, accelerated by the Industrial Revolution, has led to dense construction and a reduction in green areas. It is well-established that diminishing green spaces in cities contribute to declining air quality levels. Poor air quality poses one of the most significant direct threats to human health in urban environments. Increasing the presence of trees key components of ecosystems known for their role in mitigating air pollution can address this issue by reducing air pollution through particulate matter absorption and filtration, mitigating the urban heat island effect, regulating ozone levels, storing carbon, and improving airflow and distribution

Materials and methods: This study calculated the economic benefits of green spaces by assessing the land cover distribution and carbon sequestration capacity of tree canopy cover in the 100^{th}-Year National Garden, located in Erzurum, Turkey, using the I-Tree Canopy application. The v7.1 version of the i-Tree Canopy software was employed for this purpose.

Results: Results revealed that 0.13 ha of the area consisted of soil or bare ground, while 1.11 ha were covered by trees and shrubs. The study estimated that 398.23 kg of particulate matter were removed from the area, with a crown cover of 34.57%. The economic benefit derived from the trees' contributions was valued at 185 U.S dollars.

Conclusion: Consequently, the i-Tree Canopy application, a freely available tool, is considered a valuable resource for broader applications, offering benefits for air quality improvement strategies in urban areas.

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Introduction

Green spaces play a critical role in enhancing air quality in urban settings. Rapid urbanization, population growth, and industrial activities, coupled with fossil fuel consumption, significantly degrade air quality. Dense urban development adversely affects atmospheric and climatic conditions [1]. Urban air pollution represents a major environmental challenge, with profound negative impacts on human health. Air pollution arises from the accumulation of harmful gases and Particulate Matter (PM) in the atmosphere, resulting from both direct emissions and secondary chemical reactions. Key pollutants include Sulfur dioxide (SO_2), Nitrogen Oxides (NO_x), Ozone (O_3), Carbon monoxide (CO), Volatile Organic Compounds (VOCs), and various toxic air pollutants. Anthropogenic sources, such as industrial emissions, motor vehicle exhaust, energy production, and fuel combustion for heating, are primary contributors to these pollutants.

Particulate Matter (PM), consisting of tiny solid particles suspended in the air, is a major pollutant. It is primarily generated from the combustion of solid and liquid fuels, diesel and leaded gasoline vehicles, thermal power plants, certain industrial processes, and atmospheric gas transformations [2]. The Air Quality Index (AQI) is determined by measuring levels of five primary pollutants: Particulate matter (PM_{10}), Carbon monoxide (CO), Sulfur dioxide (SO_2), Nitrogen dioxide (NO_2), and Ozone (O_3) [3].

Air pollution monitoring in Turkey began in the 1960s [4]. According to the Clean Air Right Platform (THHP), air pollution was the seventh leading risk factor for diseases and mortality in 2007, rising to sixth by 2017 [5]. Given that over 70% of the global health burden from air pollution stems from anthropogenic emissions, most policies aimed at improving air quality focus on emission reductions. Examples include cleaner energy production, efficient industrial chimneys, reduced reliance on diesel vehicles, and sustainable agricultural practices. For outdoor air pollution, urban vegetation, green areas, and green infrastructure are widely recognized as effective nature-based solutions in the literature [6]. Trees, as fundamental ecosystem components, provide numerous benefits for improving urban air, water, and soil quality [7]. Vegetation significantly enhances the comfort, well-being, and health of urban residents. Urban trees and green infrastructure are also known to reduce CO_2 emissions and sequester carbon [8]. Trees absorb gaseous pollutants, such as O_3, SO_2 and NO_2 through leaf stomata. A study has shown that trees reduce air pollutants by capturing particulate matter, with effectiveness depending on leaf surface area, canopy structure, pollutant concentration and weather conditions [2]. High stomatal density and leaf thickness further enhance the removal of gaseous pollutants [9]. Globally, urban trees cover approximately 26.5% of urban landscapes and are considered the most vital vegetative component in cities. Measurements of tree and shrub cover, such as size and height, provide essential indicators of potential ecosystem services. These benefits include mitigating urban heat islands, reducing flooding, decreasing air pollution, attenuating noise, enhancing aesthetic value, increasing biodiversity, and improving human well-being [10, 11]. Among these, air pollution reduction stands out as a critical ecosystem service [12]. This process involves pollutant gases diffusing into leaf stomata's intercellular spaces, reacting with water films for absorption, and trapping particulate matter on plant surfaces, which is later removed by rain or leaf shedding [13]. Various methods assess the effectiveness of urban trees in reducing air pollutants. Field studies involving tree data collection are often time-consuming and costly, and accessing every tree in an urban area may be impractical or restricted. Consequently, Remote Sensing (RS) and Geographic Information Systems (GIS) based technologies have become widely adopted for gathering spatial and numerical tree data [14-17]. To evaluate the impact of tree canopy cover on ecosystem services and air quality, the USDA developed the i-Tree software suite in 2006 [18]. The i-Tree Canopy module, in particular, is widely used to quantify particulate matter removal by urban vegetation [2]. This tool supports assessments of local ecosystem services, land cover classification, air pollution reduction trends, land use changes, and the monetary valuation of ecological benefits provided by vegetation [19].

This study investigates the role of tree cover in the 100th-Year National Garden, located in central Erzurum, Turkey, in mitigating air pollution and its economic value as an ecosystem service using the i-Tree Canopy module. It quantifies the annual sequestration and removal of key pollutants Carbon dioxide (CO_2), Carbon monoxide (CO), Nitrogen dioxide (NO_2), ozone (O_3), Sulfur dioxide (SO_2), and fine particulate matter ($PM_{2.5}$ and PM_{10}) and calculates their economic contributions. No prior research has examined the effect of this park's green cover on air pollution.

Materials and methods

This study focuses on the 100th-Year National Garden, situated in the Yakutiye district of Erzurum, Turkey. Located at coordinates 39°54'21"N and 41°15'25"E, the park spans 36,000 square m² (Fig. 1).

Fig. 1. Location of the Study Area (Google Earth, 2024)

It was selected due to its proximity to major roads with heavy vehicle traffic and densely built-up areas, which contribute to elevated levels of pollutants such as Particulate Matter (PM_{10}), Carbon monoxide (CO), Hydrocarbons (HC), Nitrogen oxides (NO_x), lead (Pb), and other particulate matter.

Methods

The i-Tree Canopy v7.1, developed by the USDA Forest Service in 2006, was utilized in this study. This tool estimates tree cover and other land cover classes using Google Earth imagery by assigning random points within defined study boundaries. In this research, 3,000 random points were allocated across the study area, and land cover was evaluated based on these points. The software calculates statistical estimates of cover class percentages and their standard errors, quantifying the benefits of tree cover in both ecological and economic terms [20].

The point sampling method was employed to analyze the study area's impact on air quality [21]. The software also assesses the air quality improvement and economic benefits provided by tree cover, presenting carbon storage capacity and its economic equivalent in U.S. dollars [22]. During the analysis, cover classes were defined by the user while assigning random points. Statistical estimates for each class were calculated as follows:

$$\% = \frac{n}{N} \tag{1}$$

n= Number of points hitting the covering class

N = Total number of points analyzed across all cover classes.

The standard error (SE) of the estimate is calculated as follows:

$$SE = \sqrt{\frac{(p \cdot q)}{N}} \tag{2}$$

$$p = \frac{n}{N} \tag{3}$$

q= 1-p (4) [23]

The percentage of tree cover was multiplied by the total area to determine the tree cover area. Analyses yielded land cover distributions, carbon capture/storage estimates, and air pollutant removal rates. Using aerial imagery and the i-Tree Canopy application, six land cover categories were assessed: trees/shrubs, grass/herbaceous plants, impervious building surfaces, other impervious surfaces, water surfaces, and soil/bare ground (Table 1).

Table 1. Meteorological data measurements at the landfill

Number	Class	Description
1	Impervious buildings	Impervious areas occupied by buildings
2	Grass and/or herbaceous plants	Grass and other herbaceous ground covers
3	Impervious surfaces	Other impervious covers (e.g., sidewalks, roads, concrete surfaces)
4	Soil and/or bare ground	Soil surface and bare areas without vegetation
5	Trees and/or shrubs	Areas covered with tree and tall shrub vegetation
6	Water surface	Artificial and natural water surfaces without vegetation

Results and discussion

Land cover classification and comparative analysis were conducted using random sample points from the i-Tree Canopy application. Although the i-Tree Canopy user guide does not specify a recommended number of sampling points. This study allocated 3,000 random points across the 36,000 m² area (Fig. 2).

Previous studies have used different numbers of sampling points. For example, one study used 280 points for vegetation classification [24], another study used 1000 points for land features in Australia [25], and another study used 10,608 points to examine the effects of land use on ecosystem services [26]. Another study suggested an optimum spacing of 760 ± 32 points/ ha [19].

The analysis determined that the study area's land cover comprised 34.57% trees/shrubs, 33.57% grass/herbaceous plants, 1.57% impervious building surfaces, 25.43% other impervious surfaces, 0.67% water surfaces, and 4.2% soil/ bare ground (Fig. 3).

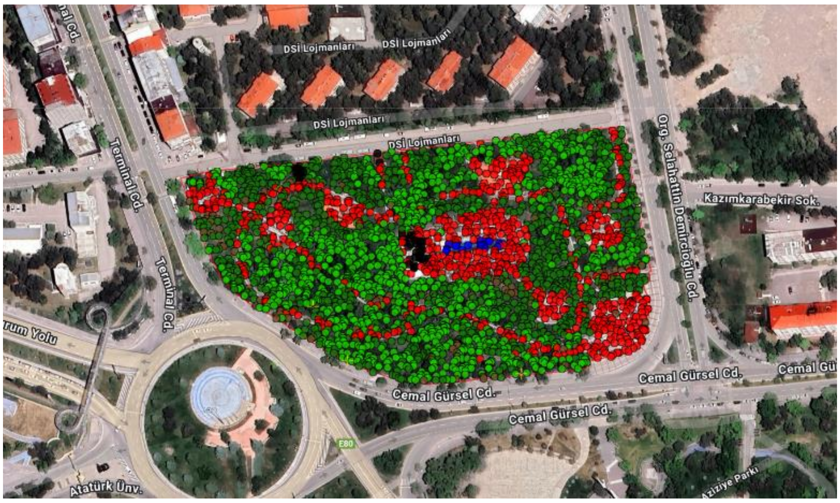

Fig. 2. Distribution of sample points in the study area

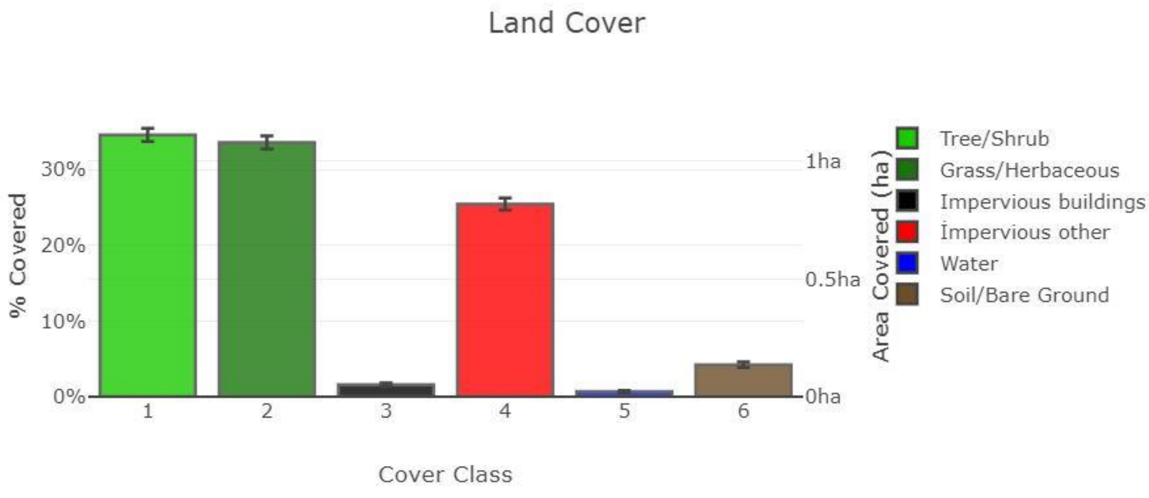

Fig. 3. Proportions of sample points within land cover classes

Of the 3,000 points, 1,037 were classified as trees/shrubs, 1,007 as grass/herbaceous, 47 as impervious building surfaces, 763 as other impervious surfaces, 20 as water surfaces, and 126 as soil/bare ground. Standard deviation values for all land cover classes were below 1%, indicating uniform point distribution across surfaces, consistent with (Table 2) [27].

The study calculated that trees annually sequestered 3.40 tons of carbon (C), equivalent to 12.46 tons of CO_2, with an economic value of 639 USD. The total carbon stored in the trees (a non-annual value) was 85.35 tons, equivalent to 312.94 tons of CO_2, valued at 16,045 USD (Table 3).

Table 2. I-Tree Canopy Land Cover Distribution (i-Tree Canopy, 2024)

Class	Definition	Number of Points	Area covered (%)	± SS	Area covered (Ha)	± SS
Tree/Shrub	Tree and tall shrub	1037	34.57	0.87	1.11	0.03
Grass/Herbaceous	Grass and herbaceous plants	1007	33.57	0.86	1.08	0.03
Impermeable Building Surfaces	Roof surfaces	47	1.57	0.23	0.05	0.01
Other Impermeable Surfaces	Concrete, stone paving, rubber paving	763	25.43	0.80	0.82	0.03
Water Surfaces	Artificial water surface	20	0.67	0.15	0.02	0.00
Soil/Bare Ground	A surface with no soil or vegetation	126	4.20	0.37	0.13	0.01
Total		3000	100		3.21	
SS- Standard deviation						

Table 3. Tree Benefit Estimates (Carbon and Carbon Dioxide Equivalent) (i-Tree Canopy, 2024)

Definition	Carbon (t)	± SS	CO_2 Equivalent (t)	± SS	Value ($)	± SS
Found on trees every year	3.40	0.09	12.46	0.31	639 $	16
Stored in trees (This benefit is not an annual rate)	85.35	2.14	312.94	7.86	16.045$	403

SS- Standard deviation

In the study area, the tree canopy facilitated the removal of 1.19 kg. of carbon monoxide (CO), 4.69 kg of nitrogen dioxide (NO_2), 56.58 kg of ozone (O_3), and 10.13 kg of sulfur dioxide (SO_2) annually. Additionally, small particulate matter ($PM_{2.5}$) removal was quantified at 2.95 kg, while particulate matter ranging from 2.5 to 10 µm (PM_{10}) amounted to 22.69 kg. Among these pollutants, ozone (O_3) was the most effectively removed, whereas carbon monoxide (CO) was the least. The removal of $PM_{2.5}$ exceeded that of PM_{10} by 7.7%. The total annual removal of pollutants from the atmosphere by the existing vegetation in the area was calculated as 98.23 kg (Table 3). Vegetation, particularly leafy trees, absorbs and mitigates harmful pollutants through their leaf surfaces. The efficiency of pollutant removal by trees depends on factors such as crown structure, leaf surface morphology, particulate matter concentration, and meteorological conditions [2]. Historically, urban afforestation aimed to enhance the aesthetic appeal of streets, alleys, gardens, and squares. However, contemporary objectives extend beyond aesthetics to include biodiversity conservation, climate change mitigation, provision of recreational opportunities, and job creation [28]. Comparable perspectives are evident in related studies. For instance, urban trees in the United States are estimated to remove 711,000 tons of pollutants annually [29]. In the United Kingdom, increasing tree cover in the West Midlands from 3.7% to 16.5% reduced ambient primary PM_{10} concentrations by 10% (equivalent to 110 tons per year), while in Glasgow, an increase from 3.6% to 8% resulted in a 2% reduction (4 tons/year) [30].

A study covering a 10 km² area with 25% tree cover in London estimated that the canopy removed 90.4 tonnes of PM_{10} per year [31]; another study estimated that London's urban tree canopy reduced PM_{10} by 852 to 2,121 tonnes per year [32]. In 2010, ten US cities reported that $PM_{2.5}$ removed by trees ranged from 4.7 tonnes in Syracuse to 64.5 tonnes in Atlanta [33]. Studies in the US suggest that trees and shrubs account for approximately 9% of national nitrogen dioxide removal, compared with approximately 3% in Canadian cities [34].The Dublin City Council (DCC) posits that planting approximately 5,000 trees annually in the city's most congested areas could reduce local pollutant concentrations [9]. One study found that urban forests planting 1,000 new trees each year can sequester 2,625 metric tons of carbon [35]; another study found that Barcelona's urban forests remove 305,000 kg of air pollutants each year [36]. In Strasbourg, urban trees have been shown to be capable of absorbing 7% of PM_{10} pollutants [37]. In Melbourne, urban trees, green roofs, and green walls were studied within green infrastructure systems, concluding that trees demonstrated the highest air pollution removal capacity [38]. Combining trees with green roofs and walls did not significantly enhance overall air quality but offered localized benefits, such as improved building energy efficiency.

The total economic value of the tree canopy's contribution to urban air quality in this study was approximately 285 USD. When disaggregated by pollutant, this value was distributed as follows: 2 USD for CO, 1 USD for NO_2, 36 USD for O_3, 77 USD for $PM_{2.5}$, and 169 USD for PM_{10}. Analysis of these data revealed that the green area contributed most significantly to the local economy by removing PM_{10}, followed by $PM_{2.5}$, O_3, NO_2, and CO, in that order (Table 4).

Table 4. Estimated benefits provided by the tree canopy using the i-Tree Canopy application (i-Tree Canopy, 2024)

Abbreviation	Definition	Amount (kg)	± SS	Value ($)	± SS
CO	Carbon monoxide (annual)	1.19	0.03	2 $	0
NO_2	Nitrogen dioxide (annual)	4.69	0.12	1 $	0
O_3	Ozone (annual)	56.58	1.42	36 $	1
SO_2	Sulfur dioxide (annual)	10.13	0.25	-	0
$PM_{2.5}$	Particulate matter smaller than 2.5 microns (annual)	2.95	0.07	77 $	2
PM_{10}	Particulate matter larger than 2.5 microns and smaller than 10 microns (annual)	22.69	0.57	169 $	4
Total		98.23	2.47	285 dolar	7
SS -Standard Deviation					

In corroborating studies, $PM_{2.5}$ removal by urban trees was consistently lower than PM_{10} removal. In urban areas, the cost of $PM_{2.5}$ removal has been estimated to range from 1.1 million USD in Syracuse to 60.1 million USD in New York, with annual per-ton costs varying from 142,000 USD in Atlanta to 1.6 million USD in New York [39]. The effect of urban vegetation on $PM_{2.5}$ removal was investigated in Shenzhen in 2015. This study determined that annual $PM_{2.5}$ emissions from existing vegetation in the city were 1000.1 tons [40].

Conclusion

This study aimed to quantify the impact of vegetation in the 36,000 m^2 100th-Year Park, located in Erzurum's Yakutiye district, on air quality and its economic contributions using the i-Tree Canopy. The analysis estimated that the plant canopy removed 98.23 kg of air pollutants annually, including 1.19 kg of CO, 4.69 kg of NO_2, 56.58 kg of O_3, and 10.13 kg of SO_2, with a tree and shrub cover of 34.57%. The annual carbon (C) sequestration by trees was 3.40 tons, equivalent to 12.46 tons of CO_2, while the total carbon stored (a non-annual value) was 85.35 tons, equivalent to 312.94 tons of CO_2, yielding an economic value of 16,045 USD. Among the pollutants, O_3 was the most removed, and CO the least. The freely available i-Tree Canopy software effectively evaluated tree cover's role in enhancing urban air quality and providing economic benefits, demonstrating its potential as a low-cost, rapid, and repeatable tool for mitigating air pollution exposure. Urban parks, forests, and gardens filter harmful gases, purify the air, produce oxygen through photosynthesis, and regulate temperatures, indirectly reducing energy-related pollution.

Local governments play a pivotal role in planting and protecting trees and preserving accessible lands. In Erzurum, where prolonged winters elevate fuel consumption and air pollution, increasing tree cover is particularly critical. Green spaces, such as the 100th-Year National Garden, significantly reduce carbon emissions, enhance livability and comfort, and bolster ecosystem services. Given these benefits, expanding green areas and integrating the i-Tree Canopy model into cost-benefit analyses for new landscaping projects could prove highly effective. The i-Tree Canopy model offers substantial potential for future research into the ecosystem services of urban green spaces.

The findings of this study can inform urban planners, policymakers, and landscape architects in optimizing ecosystem benefits through targeted urban green space initiatives.

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Competing interests

The authors declare no conflicts of interest.

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Ethical considerations

"Ethical issues (Including plagiarism, Informed Consent, misconduct, data fabrication and/ or falsification, double publication and/ or submission, redundancy) have been completely observed by the authors."

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