Evaluating the Value of Vegetation Ecosystem Services in District 16 of Tehran Municipality using the i-Tree Model

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Abstract

Awareness of the structure, function, and value of vegetation and green space in cities can improve management decisions related to human health and the condition of the environment. In 2015, an assessment of the vegetation in the Tehran urban vegetation was done. The i-Tree Eco model was used to evaluate data from 36 field plots situated throughout District 16 of Tehran Municipality. This study assimilates the i-Tree Eco model to assess the value of vegetation ecosystem services in D16, one of the greenest areas. Based on public trees managed by the district municipality, eliminated about 67 tons of pollutants in one year. This pollution reduction includes about 5 tons of CO, 13 tons of NO_2, 8 tons of O_3, 35 tons of PM_{10}, and 15 tons of SO_2. Two factors, including tree cover and concentrations of air pollutions, significantly affect air pollution removal. Urban trees have a critical role in mitigating air pollution. However, the limitations and increasing sources of production of pollutants, especially air pollutants, are not the only key to this trouble. Therefore, it is advised to increase the per capita and principled maintenance of public urban green space, along with indicators such as environmental characteristics, adjacent urban structures, street design, climate, and the most important plant species compatible with the region.

1. Introduction

Many problems associated with rapid urban development can affect human health. Most human activities release various environmental pollutants, each having a detrimental effect on human health, including cardiovascular-respiratory diseases and mortality (Parsa, Salehi, Yavari, & van Bodegom, 2019).

According to the European Environment Agency, concentrations above the permissible PM (50 g/m3) levels have exposed the population to between 21 and 30% of urban citizens in the EU to environmental and health problems. This percentage of the population reveals about 64 to 83 percent of the population if more stringent standards are considered, such as the World Health Organization (WHO) reference (20 g/m3) (Chaparro & Terradas, 2009; Nowak, Maco, & Binkley, 2018). Meanwhile, in the same period, Tehran's average annual air quality for PM_{10}, SO_2, NO_2, and O_3 pollutants was about 90.58, 89.16, and 85 68.82 μg/m3, respectively (Baró et al., 2014; Rogers, Jarratt, & Hansford, 2011). According to the results of qualitative research on air pollution in Tehran, PM_{10} had the most short-term impact on the health of about 8.5 million residents of Tehran, which in the period 2010 to 2012 caused 2194 deaths per year, which is about 5% of total deaths. However, given the similar rate of unhealthy days and the average concentration of pollutants, we cannot expect significant reductions in these values (Baró et al., 2014; Rogers et al., 2011). Also, during the same period, other contaminants such as sulfur dioxide, nitrogen dioxide, and ozone caused about 1458, 1050, and 819 additional deaths, which is about 7% in total and considering the effects of PM more than 12% of the total mortality in Tehran (Riondato, Pilla, Basu, & Basu, 2020).

So far, various methods and proposals for reducing air pollution in cities have been studied. For example, recently, the use of new technologies for attractive building materials, air pollutants have been able to achieve significant results (Nowak & Crane, 2000; Song, Kim, Mayer, He, & Tian, 2020), and some studies show that increasing the vegetation in public and private spaces has a significant effect on air pollution (Nowak, Crane, & Stevens, 2006; Nowak, Hirabayashi, Bodine, & Greenfield, 2014). Planting trees in the city reduces air pollution and meets other social needs such as recreational, cultural, aesthetic, without incurring extra costs. While urban trees are critical in lowering air pollution and increasing the urban environment's quality, their potential is sometimes neglected in urban policies and strategies.

Various studies of ecosystem services in urban areas, such as ecosystem valuation, have studied the performance of dry deposition function temperature regulation based on shading and evapotranspiration that effectively reduce air pollution (Bhandari & Bijlwan, 2019; Nowak, Hirabayashi, Bodine, & Hoehn, 2013). These strategies reduce the urban heat island (Cavanagh, 2006) and carbon sequestered for climate change mitigation. Nonetheless, some drawbacks have been identified in select instances, including tree emissions of volatile organic compounds (VOC) and increased local air pollution in dense tree plantations (Pey Betrán et al., 2020).

Despite recognizing these services and disservices, there is still a dearth of information about trees' potential in alleviating urban environmental problems and the underlying tree-atmosphere interactions. This information gap is caused by various environmental and computational factors, including the sophistication of the physical and chemical progressions involved in tree-atmosphere interactions in city regions and the absence of mathematical models with sufficient precision and dependability (Parsa et al., 2019). Therefore, models such as Citygreen, UFORE (Urban Forest Effects Model: i-Tree), and STRATUM (i-Tree streets) have been established and used to evaluate tree-atmosphere exchanges, measure ecosystem usefulness, provide accurate information, and provide a comprehensive analysis of urban vegetation status.

Ecosystem services provided by vegetation can be examined from an economic perspective, and various economic evaluation models can be analyzed better to understand the value of these services (Muvuna et al., 2020). This study aims to estimate the first time an ecosystem service eliminates air pollution by vegetation in one of the key urban areas in Tehran. The results of the environmental evaluation show the possibility of pursuing novel approaches to urban design and management. Additionally, the primary objective of this study is to examine the potential for a minor reduction in air pollution by urban trees in Tehran's 16th district through the use of the i-Tree model.

Amini Parsa et al. in 2019 used the i-Tree Eco model to evaluate the structure of urban trees in Tabriz, Iran (AMINI PARSA, SALEHI, & YAVRI, 2019). They estimated that urban trees with a 9.4% tree cover emitted 18428.6 and 49757.5 monoterpenes and isoprene, respectively, in 2015. Moreover, open spaces caused 63.3% of the total emission, which is less than the 92.2% participation of the available local species. The local species are 21% of the entire species.

The U.S. Department of Agriculture, Forest Service, and some partner organizations have worked together to design and develop the i-Tree Eco model to examine urban forests' structure and evaluate green space and vegetation ecosystem services (Nowak et al., 2018). The i-Tree Eco was initially used internationally in study projects in several major cities in different countries, for example, in Barcelona, Spain (Baró et al., 2014; Chaparro & Terradas, 2009); Torbay, United Kingdom (Rogers et al., 2011), Dublin, Ireland (Riondato et al., 2020), and Luohe, China (Song et al., 2020), to evaluate the urban trees' potential of improving environmental quality at the city scale.

Tehran Municipality has paid considerable attention to projects that increase the green space in different urban areas in recent years, which became a controversial issue, causing various concerns and benefits for this policy. Therefore, the evaluation of ecosystem services in Tehran's urban areas can provide helpful information to clarify the accuracy of this approach in Tehran, according to the current state and distribution of green space, climatic conditions, the type and number of trees, and other local conditions. This paper presents the i-Tree Eco model in District 16 (D16) of Tehran and estimates the removal rates of local emissions. It also contains crucial data for developing integrated green space management and sustainable urban policies to reduce pollution.

2. Methods

2.1. Study area

This study was conducted in D16 of Tehran, with a total area of 1651 hectares, which includes about 2.5% of the total area of Tehran. This area is one of the small areas of Tehran and is located in the south of the city (Fig. 1). The population of Tehran reached about 8.694 million in 2016. The annual average temperature is 13–22 °C, and the mean annual precipitation is 301–450 mm. The area of parks and public green space in D16 until the end of 2011 was 306 hectares. While all trees in this area contribute to air quality, this study concentrated on urban trees found in public green areas and street tree resources. The municipality is responsible for managing the urban forest resource.

2.2. Air pollution removal: use of the i-Tree Eco model

The i-Tree Eco model was used to determine the state of air pollution reduction by trees and urban green space in D16 of the Tehran Municipality. Numerous variables were combined in the model, including data on the total of trees, species, tree height, crown height, diameter at breast height (DBH), and tree cover, mainly obtained during scheduled field visits. Additionally, utilizing local databases, local environmental data, such as hourly meteorological data, air pollution concentration data, and so on, were collected and used to evaluate the hourly pollution reduction by trees and shrubs (D. Baldocchi, 1988; Ross et al., 2020). The i-Tree Eco dry deposition module has been used to quantify air pollution reduction by trees in urban forests in the required area. The following describes how to collect field and statistical information and the processes of calculating air pollution.

2.2.1. Data collection

The i-Tree model requires a variety of different forms of data in order to quantify air pollution reduction. Local information about the climate and the level of air pollution and the collected information from the structure of the trees such as tree cover, Leaf Area Index (LAI), and percentage of evergreen were used. Additionally, boundary layer height measurements were utilized to evaluate the approximate percentage of air quality improvement associated with the area's potential for pollutant reduction by trees.

2.2.1.1. Sampling strategy and tree cover records

The i-Tree Eco model has comprehensive guidelines for examining the structure of trees that have been used to assess this indicator (Nowak et al., 2018). Sampling and data collection stages were designed and performed in four stages: (i) Demarcation of urban forest under municipal services management D16, (ii) Classification of urban forests based on land use type, (iii) Evaluate tree cover in urban forests, and finally (iv) Generate a field sample and collect field data.

Figure 2 shows the random distribution of 81 proposed plots for visiting and collecting field information on vegetation, especially urban forests in D16, which ultimately 36 points were visited. This map is based on geographic database information (1:10000) and land use information obtained from the D16.

Maps with a scale of 1: 2000 were prepared and used to investigate the 36 final plots. In these maps, circular spatial coordinates with an area of 0.04 hectares were considered for each plot using ArcGIS software. After visiting the team in the predicted coordinates range, information about the circle's center (using GPS), aerial orthophotography, ground cover, tree cover, shrubs, land use, and plantable space are collected based on plant species classification. A separate checklist was prepared and used to record DBH information, total tree height, canopy width, height to living canopy base, canopy light exposure, canopy root percentage, and crown percentage lost. It is noteworthy that the period of the mentioned visits was from April to July 2018.

2.2.1.2. Hourly weather data and pollution records

The hourly meteorological data (wind speed, sky cover, temperature, liquid precipitation, etc.) of Mehrabad Synoptic Station (Tehran) is used. Also, Boundary layer data were gathered from the adjacent monitoring station of the Tehran Meteorological Organization. Information from several online air pollution monitoring centers in Tehran Municipality adjacent to District 16 was used to collect data on hourly concentrations of nitrogen dioxide (NO_2), carbon monoxide (CO), ozone (O_3), sulfur dioxide (SO_2), and particulate matter with a diameter of 2.5–10 µm (large PM_{10}) and < 2.5 µm ($PM_{2.5}$). Finally, the data set was collected for use in the i-Tree dry deposition model to estimate the hourly rate of pollution reduction and the percentage of enhancement in air quality by vegetation and urban forest (Nowak & Crane, 2000; Nowak et al., 2006; Nowak et al., 2014; Nowak et al., 2013).

2.2.2. Calculation of the amount of pollution removed from the air by trees

2.2.2.1. Dry deposition

Removal of air pollutants from the troposphere in a non-precipitation period is the main mechanism in the i-Tree Eco dry deposition calculation module (Bhandari & Bijlwan, 2019; Cavanagh, 2006). This mechanism relies on the character and properties of the pollutant, including gas/particle characteristics, diameter, density, shape/form. Also, the character and properties of surfaces such as size, chemical character, weather variables, wind speed and direction, roughness, temperature, air turbulence, solar radiation, and much more information affect the mechanism (Pey Betrán et al., 2020).

Tree leaves eliminate toxins collected on their surface in two ways: through gaseous pollutant uptake by the leaf stomata and particle matter interception by the leaf (Ross et al., 2020). When leaf stomata uptake the gaseous pollutants, it results in the diffusion of contaminants into the leaf's interior. Additionally, gases may be absorbed or reacted by the plant's surface. The wind action can affect the removal via the second process and decrease intercepted particles' resuspension from leaf surfaces in the region.

As mentioned in the previous section, the i-Tree Eco dry deposition calculation module can be used to estimate the extent of annual pollution removal by urban vegetation during non-rainy periods (Muvuna et al., 2020; Nowak et al., 2018; Parsa et al., 2019). The pollutant flux (F; in g m2 s1) was determined by multiplying the deposition velocity (Vd; in m s1) by the pollutant concentration (C; in g m3):

$$F = V_d C \qquad (1)$$

During the rainy phase, deposition velocities were set to zero (Ross et al., 2020). The inverse of the sum of canopy resistance (Rc), quasi-laminar boundary layer resistance (Rb), and aerodynamic resistance (Ra) was used to compute the deposition velocities of NO2, CO, SO2, and O3:

$$V_d = (R_a + R_b + R_c)^{-1} \qquad (2)$$

Meteorological data are used to calculate aerodynamic resistance. Of course, it should be noted that the type of air pollutants do not affect these calculations, and only quasi-laminar resistance and canopy resistance for each air pollutant are calculated separately (Hirabayashi, Kroll, & Nowak, 2012). The following equation was used to compute the hourly canopy resistance:

$$1/R_c = 1/(r_s + r_m) + 1/r_{soil} + 1/r_t \qquad (3)$$

where the stomatal resistance is r_s, the mesophyll resistance is r_m, the soil resistance is r_{soil}, and the cuticular resistance is r_t. Soil resistance was set to 2941s m^{-1} in the growing season and 2000 s m^{-1} otherwise (Hirabayashi et al., 2012). Stomatal resistance and cuticular resistance values were determined using the literature: for NO_2, r_m = 100 $s*m^{-1}$ (Hosker Jr & Lindberg, 1982) and r_t = 20,000 $s*m^{-1}$ (Wesely, 2007); for O_3, r_m = 10 $s*m^{-1}$ (Hosker Jr & Lindberg, 1982) and r_t = 10,000 $s*m^{-1}$ (Lovett, 1994; Taylor, Hanson, & Baldocchi, 1988); for SO_2, r_m = 0 (Wesely, 2007) and r_t= 8000 $s*m^{-1}$. The CO canopy resistance value was set to 50,000 $s*m^{-1}$ in the in-leaf season and 1,000,000 $s*m^{-1}$ in the out-leaf season (Wright, Zhang, Cheng, Aherne, & Wentworth, 2018).

Photosynthesis and the transpiration of trees do not affect CO removal. The deposition velocity of PM_{10} particles was assumed to be 0.0064 based on the Lovett study of 1994, according to a 50% resuspension rate for the particles (Lovett, 1994). Wind speed and leaf area based on Nowak et al. (2013) research used to estimate the PM2.5, resuspension rates, and hourly deposition(Nowak et al., 2013).

The base deposition velocity (V_d) was changed to account for local LAI and seasonal variations such as leaf-on and leaf-off dates. The in-leaf time was considered while calculating pollutant deposition for deciduous trees. The LAI is calculated by dividing the total leaf area (m^2) by the total canopy cover in a city (m^2).

We used fifteen days surrounding leaf-on and leaf-off dates to estimate seasonal leaf area variation when deciduous trees transition from no leaves to full leaves and conversely. The i-Tree model is a multi-layered hybrid model that uses different information to achieve its goals. (D. Baldocchi, 1988; D. D. Baldocchi, Hicks, & Camara, 1987). This model considers the effects between species with each other and considers it as a whole canopy. As a result, the overall effect of shading in the study area is investigated. Also, the LAI is considered the same for all canopies and is not considered in any distinction for the rates of deposition velocities of contaminants and particles. However, different effects will be obtained for each plant species depending on the area's amount of leaf area.

2.2.2.2. Air quality enhancement

The boundary layer is a region of the atmosphere directly affected by the earth's surface. Its thickness varies between 1 and 3 kilometers during the day. The amount of pollution contained inside this boundary layer across the entire city (g) is computed as the product of the measured concentration ($g*m^3$), the height of the boundary layer (m), and the area of the city (m^2). This extrapolation from ground-layer concentrations to total pollution within the boundary layer is based on the assumption of a well-mixed boundary layer, which often occurs during the day (dangerous circumstances) (Carruthers et al., 1994). The hourly percent increase in air quality is calculated as the amount of pollution removed divided by the amount of pollution removed and the amount of pollution within the boundary layer (Ross et al., 2020).

3. Results & Discussion

3.1. Structure of public trees

D16's urban forest is estimated to include 185275 trees and has a tree cover of 20.8 percent (Fig. 3). According to the estimates, 71,308 trees are used in green space use (35.5%), 49,219 trees in residential use (26.6%), and 64,748 trees other land uses (34.9%). The overall tree density in D16 is 112 trees/hectare. The highest tree densities in D16 occur in Green Space for stratified projects, followed by other and Residential. Trees with diameters < 6 inches (15.2 cm) constitute 61.1% of the population. The most common species (dominant species) include European ash (18.5%), elm (16.6%), and Arizona cypress (13.4%). Tree density in all 16 districts of Tehran is 112 trees per hectare.

Figure 3- *Number of trees/ha in D16 by land use*

Urban forests are composed of a combination of native and non-native tree species. Therefore, urban forests often have more tree diversity and mixing than entire areas outside the city or suburbs. In recent years, plans to beautify urban landscapes and expand green space in Tehran have added to this trend. Increasing the diversity of trees in the urban area may reduce the destructive effects of pests, insects, and diseases and increase the area's ecological potential. Some non-native and exotic species can act as invasive plants and potentially compete and shift the pattern of native species expansion and create many hazards to the region's environment. About 18% of the trees identified in D16 are native to Asia, and 25% of the total species are exotic and non-native are estimated to be North American.

The main benefit of trees is directly related to the plant's amount of healthy leaf surface. In other words, the higher the healthy leaf surface of the plant, the greater the benefits of the plant for the urban area. As can be seen from Table 1, the predominant plant species in Region 16 are European ash, smooth leaf elm, and white mulberry. Also, other dominant species in this region are presented in Table 1. It is noteworthy that the index of Importance values (IV) is degraded by the relative surface area of the leaf and its relative composition (Ross et al., 2020).

Table 1
D16's most significant species

Species	Percent Population	Percent Leaf Area	Importance Value
European ash	18.5	17.8	36.2
Smooth leaf elm	16.6	15.0	31.5
White mulberry	8.6	12.6	21.2
Afghan pine	6.0	12.2	18.2
Arizona cypress	13.4	2.7	16.1
Black locust	9.6	5.2	14.8
Oriental plane tree	2.1	8.9	10.9
Common fig	4.3	5.1	9.4
Italian cypress	5.4	4.0	9.4
Eastern cottonwood	2.0	5.1	7.0
Chinaberry	3.2	2.4	5.6
Oriental spruce	0.8	4.1	4.9
Rockspray cotoneaster	1.5	2.1	3.5
Wine grape	2.5	0.6	3.1
White mulberry	1.6	0.2	1.7
Russian olive	1.1	0.4	1.5
Japanese persimmon	0.8	0.6	1.4
Quince	0.8	0.6	1.4
English walnut	0.8	0.4	1.2
Atlas cedar	0.2	0.3	0.5
Laurel bay	0.2	0.1	0.3

Tar (33.4%) and Buildings are the most prevalent ground cover categories (30.2%). The region's tree cover is 20.8%, and the shrub cover is 1.6% (Table 2).

Table 2
*The p*ercentage of ground cover in D16

Ground Cover	Plant Space		Cement		Tar		Bare Soil		Rock		Duff/Mulch		Herbs		Grass	
Land Use	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE	%	SE
Green Space	9.4	4.55	10	4.12	12.1	6.51	1.3	1.2	11.3	3.77	10.8	6.6	52.9	8.8		
Other	3.4	2.65	2.1	0.92	43.8	11.05	29.2	10.11	0.4	0.4						
Residential	6.8	4.69	30.4	3.51	0.8	0.54	16	1.81								
CITY TOTAL	2.7	1.27	3.9	2.12	33.4	4.98	14.3	4.39	0.2	0.16	8.6	0.94	1.6	0.88	6.9	1.15

3.2. Assessment of trees' impact

3.2.1. Air Pollution Reduction by Urban Trees

D16 field data include environmental pollution and weather data, has been used in the i-tree model to estimate the amount of air pollutants reduced by trees and shrubs. According to Table 3, 79 tons of air pollution, including carbon monoxide (CO), sulfur dioxide (SO2), ozone (O_3), nitrogen dioxide (NO_2), and particulate matter (PM_{10}), are removed by the activity of trees and shrubs.

Table 3
Average annual tonnage of degraded base pollutants in D16

Pollutant	Annual mean removal (Metric Ton)
CO	5.758
NO_2	13.019
O_3	8.385
PM10	35.901
SO_2	15.846
Total	78.909

Figure 4 depicts the trend chart of the monthly amount of pollution-based pollutants. As expected, the number of suspended particles and their removal was higher in warmer months. Other base pollutants were given more attention in cold months due to temperature inversion. However, in all months, the amount of particulate matter removal was at the forefront of decontaminated pollutants.

Figure 4- *The trend of changes in the amount of monthly removal of base pollutants in D16 (January as the first month)*

3.2.2. Carbon Storage and Sequestration

In tree growth, a certain amount of carbon is absorbed into the atmosphere every year, which helps grow trees and improve ambient air quality. As expected, the size and health of trees are directly related to the annual carbon sequestration. According to the results, the gross carbon sequestration of trees in the study area is estimated at 511 metric tons per year. Due to Fig. 5, the net carbon sequestration in the D16 urban forest was about 390 metric tons.

Figure 5- *Carbon sequestration and value for species with most significant overall carbon sequestration in D16*

As long as the trees grow, they consume and store significant amounts of carbon. With the death and decay of the tree, some of this carbon returns to the atmosphere. As a result, estimating the amount of carbon stored in the atmosphere by plants can show a relatively good estimate of the amount of carbon released into the atmosphere if the trees in the area dry out and die. As shown in Figs. 6 and 7, the carbon ash storage of the European ash tree species is higher than the other species, with an approximate share of 21.1% of the total stored carbon and 17.4% of all the sequestered carbon.

Figure 6- *Gross sequestration by tree cover by land uses in D16 (tons/year)*

Figure 7- *Carbon sequestration by tree cover by land use in D16 (kg/year/ha)*

3.2.3. Oxygen production

Annual oxygen production by trees in D16 was estimated to be 1,040 metric tons. The advantage of trees is negligible due to the large and relatively consistent amount of oxygen in the atmosphere and massive production by aquatic systems. The atmosphere contains a vast supply of oxygen.

The highest amount of oxygen production in the D16 belonged to European ash, white mulberry, smooth leaf elm, common fig, and oriental planetree (Table 4 and Figs. 8 and 9). Note that these trees in the region usually had the highest carbon sequestration, the highest number of trees, and the highest leaf area.

Table 4
The top 20 oxygen-producing species in D16

Species	Oxygen (metric tons)	Net carbon sequestration (metric tons/yr)	Number of trees	Leaf area (square kilometers)
European ash	180.83	67.81	34,207	1.61
White mulberry	162.93	61.10	16,017	1.14
Smooth leaf elm	152.53	57.20	30,666	1.36
Common fig	125.89	47.21	8,009	0.46
Oriental plane tree	72.53	27.20	3,795	0.80
Black locust	65.31	24.49	17,820	0.47
Afghan pine	53.31	19.99	11,184	1.11
Arizona cypress	42.67	16.00	24,822	0.24
Chinaberry	29.92	11.22	5,886	0.22
Italian cypress	26.27	9.85	9,948	0.36
Eastern cottonwood	24.19	9.07	3,611	0.46
Japanese persimmon	22.93	8.60	1,538	0.05
Oriental spruce	21.97	8.24	1,538	0.37
Wine grape	14.72	5.52	4,614	0.06
Russia olive	13.71	5.14	1,989	0.04
Quince	11.33	4.25	1,538	0.05
White mulberry	5.68	2.13	2,943	0.01
English walnut	5.55	2.08	1,538	0.04
Rockspray cotoneaster	5.47	2.05	2,708	0.19
Laurel bay	0.67	0.25	451	0.01

3.2.4. Emission of volatile organic compounds

In D16, the highest emission of organic compounds from tree cover in terms of kilograms per year belonged to green space use, followed by residential use and other uses. The total amounts of organic emissions, including VOC, isoprenes, and monoterpenes, were estimated to be > 23,995 kg per year. The seven species with the highest emission of organic compounds in kilograms per year included Eastern cottonwood, oriental spruce, oriental planetree, Afghan pine, common fig, black locust, and Italian cypress (Tables 5 and 6).

Table 5
Bio-emissions for Trees and Shrub in D16 by Land Use

Land Use	Monoterpene (kg/yr)	Isoprene (kg/yr)	VOCs (kg/yr)
Green Space	2,005.6	5,127.5	7,133.1
Other	673.5	101.3	774.9
Residential	1,147.8	2,922.0	4,069.8
Total	3,826.9	8,150.9	11,977.8

Table 6
– Bio-emissions for Trees in D16 by Species

Species' Name	Monoterpene (kg/yr)	Isoprene (kg/yr)	VOCs (kg/yr)
Afghan pine	1,670.4	15.0	1,685.4
Arizona cypress	158.6	0.0	158.6
Atlas cedar	29.6	0.5	30.1
Black locust	26.5	501.0	527.5
Chinaberry	8.6	2.3	11.0
Common fig	36.0	1,114.6	1,150.6
Eastern cottonwood	17.3	3,270.9	3,288.2
English walnut	23.6	0.2	23.8
European ash	89.4	24.2	113.6
Italian cypress	237.0	0.0	237.0
Japanese persimmon	2.1	0.6	2.7
Laurel bay	0.3	0.1	0.4
Oriental planetree	19.2	1,818.4	1,837.6
Oriental spruce	980.1	1,234.7	2,214.8
Quince	0.6	0.3	0.9
Rockspray cotoneaster	0.0	0.0	0.0
Russian olive	2.8	0.4	3.2
Smoothleaf elm	48.2	13.0	61.2
White mulberry	87.1	11.8	98.8
White mullberry	1.2	0.2	1.4
Wine grape	0.0	0.0	0.0
Total	3,438.6	8,008.1	11,446.7

In general, the characteristics of urban tree cover in terms of tree cover structure (the number of trees and the number of trees by conventional uses in sampling instructions), species' composition, tree cover density, tree cover diameter at the height of 1.37 m, tree origin, index leaf area, land cover, and the amount of stored carbon (biomass) were studied and estimated.

The highest density belonged to the green space (67%), and the lowest residential use (14%). The percentage of trees with a diameter of < 6 inches (15.2 cm) in plant chest height-DBH (1.37 m) was 61.1%. The tree population of the area is primarily young. Therefore, in the future, along with the growth of trees, the amount of pollution removal and the value of ecosystem services will increase the region's tree cover.

The benefits of many trees directly equal the amount of healthy leaf area of the plant. Leaf area density in the whole area was 5460.1 m^2 per hectare. Furthermore, the leaf area of the whole area was 9.07 km^2. The highest leaf area density was related to green space use and then residential use. The predominant land cover was asphalt (33.4%) and then building (30.2%). Moreover, the region's tree cover was 20.8%, and the shrub cover was 1.6%.

Stored carbon indicates the amount of carbon integral to the wood above and below ground. As trees grow, they store more carbon in the form of wood. Consequently, when trees die and rot, they release large amounts of carbon back into the atmosphere. Therefore, carbon storage indicates the amount of carbon that the death and decay of trees can lose. In D16, the stored carbon was estimated at 10400 tons. Among the tree species sampled in D16, European ash had the highest stored carbon (about 21.1% of the total stored carbon in the area). Most of the carbon storage in the tree cover of Tehran D16 belonged to the green space and then residential use. Carbon storage density in kilograms per hectare had the highest amount and percentage in green space use, followed by residential and other uses.

In general, the performance of tree cover for ecosystem services in the region was studied and estimated in the following cases:- The amount of pollution removed (removal of air-based pollutants) by tree cover

- The amount of carbon deposited by the tree cover

- Calculation of the emission of VOC by tree cover

- Calculation of the amount of oxygen produced by tree cover

- Calculation of the effect of tree cover on reducing energy consumption

According to the information obtained, the trees and shrubs in the D16 removed 79 tons of air pollution per year, equivalent to $567305. The highest percentage of the average annual decontamination by tree cover for suspended particles was < 10 microns and > 2.5 microns. Although the amount of depleted SO_2 was higher than the amount of depleted NO_2, the functional value of depleted NO_2 was much higher than that of SO_2.

As expected, the amount of suspended particles and their removal were higher in warmer months. Due to the temperature inversion phenomenon in cold months, other base pollutants were given more attention. However, in all months of the year, the amount of particulate matter removal was at the forefront of decontaminated pollutants.

The amount of impure carbon deposition occurring in trees in D16 was about 511 tons per year. The net sediment was 390 tons per year. Among the tree species sampled in D16, European ash had the highest deposited carbon (about 17.4% of the total deposited carbon). After European ash, Morus alba and elm had the highest deposited carbon.

Interestingly, the highest amount of carbon deposited per year did not belong to green space use but residential and other uses. This could be attributed to moving and fixed sources leading to carbon dioxide emission in the air of residential areas and other uses. Therefore, tree cover in these areas emits higher carbon dioxide. The amount of carbon deposited per year for green space was about 129 tons per year, while for residential areas, it was about 215 tons per year and, for other uses, about 166 tons per year. However, the amount of deposited carbon density in kilograms per hectare per year was higher for green space use, mainly caused by higher tree cover density in green space use. The density of deposited carbon in the D16 was about 307 kg per hectare per year, whereas, for green space, this density for green space was about 595 kg per hectare per year.

In D16, the highest amount of organic compounds emissions from tree cover in kilograms per year belonged to the green space, followed by residential and then other uses. The total organic emissions of all three types (VOC, aeroprenes, and monoterpenes) were estimated at > 23995 kg per year. In D16, seven species with the highest amount of organic compounds in kilograms per year were cottonwood, spruce, Platanus, ordinary pine, common fig, Mediterranean cypress, and Arizona cypress.

According to calculations, the tree cover in the D16 produces 1040 tons of oxygen annually. Of course, this amount of oxygen production is not significant compared to the large and stable amount of atmospheric oxygen. Also, the fossil fuel reserves and the benefits of all trees and soil organic matter in the region at the provincial level are not significant. It is noteworthy that some related studies on a global scale have shown that if all fossil fuel reserves, all trees, and all soil organic matter in the world are burned, atmospheric oxygen will be reduced by a small percentage (Davankov, 2020). The highest amount of oxygen production in Tehran D16 was related to European ash, Morus alba, elm, common fig, and Platanus. Note that these trees in the region usually had the highest carbon sequestration, the highest number of trees, and the highest amount of leaf area.

Moreover, the most considerable amount of oxygen produced per year did not belong to green space but residential use and other uses. This could be due to moving and fixed sources that lead to carbon dioxide emission in the air of residential areas and other uses. Therefore, tree cover in these areas precipitates higher carbon dioxide and thus produces higher oxygen. The amount of oxygen produced per year for green space was > 282 tons per year, while for residential areas, it was > 453 tons per year, and for other uses, > 303 tons per year. Nevertheless, the amount of oxygen density produced in kilograms per hectare per year was higher for green space use, mainly caused by tree cover density, which was higher in green space use. The density of oxygen produced in the D16 was > 625 kg per hectare per year, while for green space, this density was about 1303 kg per hectare per year.

The effects of tree cover using the i-Tree environment model for D16 were estimated as follows:

- Number of trees: 185000
- Stored carbon: 10400 tons
- Sequestered carbon: 511 tons per year
- Removed pollution: 79 tons per year (equivalent to $567000 per year)

Since the total area of D16 is equal to 1651 hectares, the effects of tree cover for each hectare of Tehran D16 were estimated as follows (density of tree cover effects):

- Number of trees per hectare: 112.05 trees per hectare
- Stored carbon density: 6.3 tons per hectare
- Accumulated carbon density: 0.31 tons per year per hectare
- Decontaminated pollution density: 0.048 tons per year per hectare

Conclusion

Using a mix of air quality monitoring data and the i-Tree Eco (UFORE) model, this study analyses the potential effect of urban trees eliminating air pollutants and examining their ecosystem services. One of the methods of observing and estimating the trend of air quality in urban areas is to study and model the removal of air pollutants by vegetation, mainly native and non-native trees, and plants. The effects of public trees in District 16 of Tehran Municipality are relatively low and have improved the area's air quality by about one percent. The current condition of the D16 public trees annually removes about 79 tons of various air pollutants, so their influential role cannot be ignored. However, this low percentage has significant effects on residents' health, quality of life, and comfort.

Variety, dispersion, density and type of green space design, and street design affect the air quality of urban areas. Hence, in an urban area, the uniform distribution of plant and tree ecosystem services cannot be observed. Of course, it can be said that in places where the variety, dispersion, density, and type of design of green spaces are in favor of vegetation, air quality is certainly more desirable. Various studies confirm this result (Vos, Maiheu, Vankerkom, & Janssen, 2013; Wania, Bruse, Blond, & Weber, 2012). Therefore, planners and city managers should make the most benefit from trees, plants, and green vegetation and their ecosystem services in favor of local air quality. Sustainable planning, choosing the proper location, use of plant diversity appropriate to local conditions can achieve goals such as increasing human health and improving the quality of life for the city.

Declarations

- **Funding:** This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors
- **Availability of data and material:** Confirmatory data from the findings of this study are available upon request from the corresponding author.
- **Code availability:** i-Tree Eco model is the main software used in this article which is open acess and can be download from https://www.itreetools.org/i-tree-tools-download.
- **Authors' contributions:** All the authors contributed to the design and implementation of the research, Data gathering, to the analysis of the results and to the writing of the manuscript.
- **Ethical Approval:** Not applicable
- **Informed Consent:** All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.
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Figures

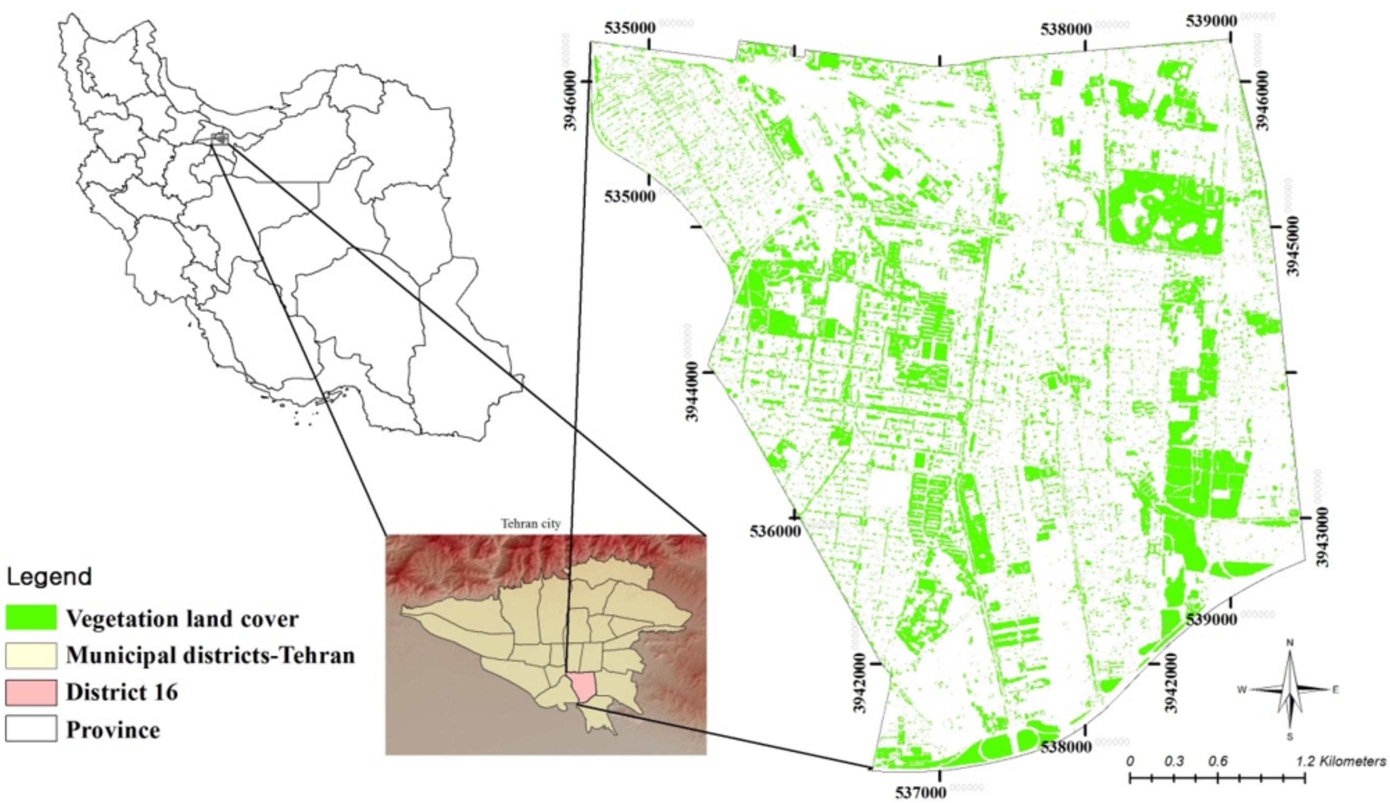

Figure 1

Tehran D16

Figure 2

Random sample plot

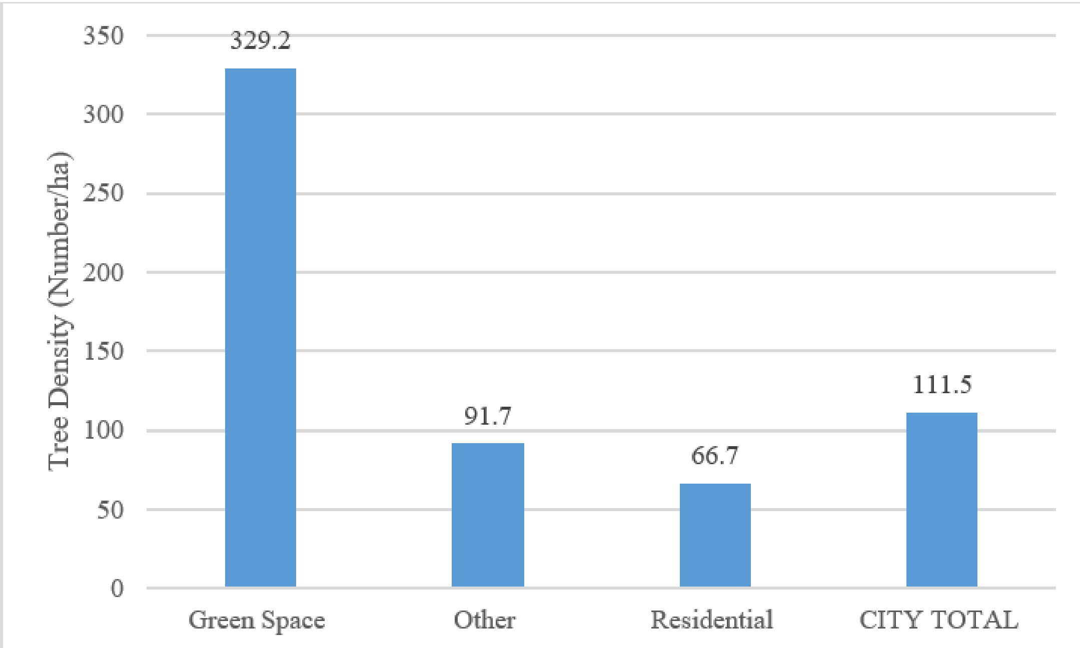

Figure 3

Number of trees/ha in D16 by land use

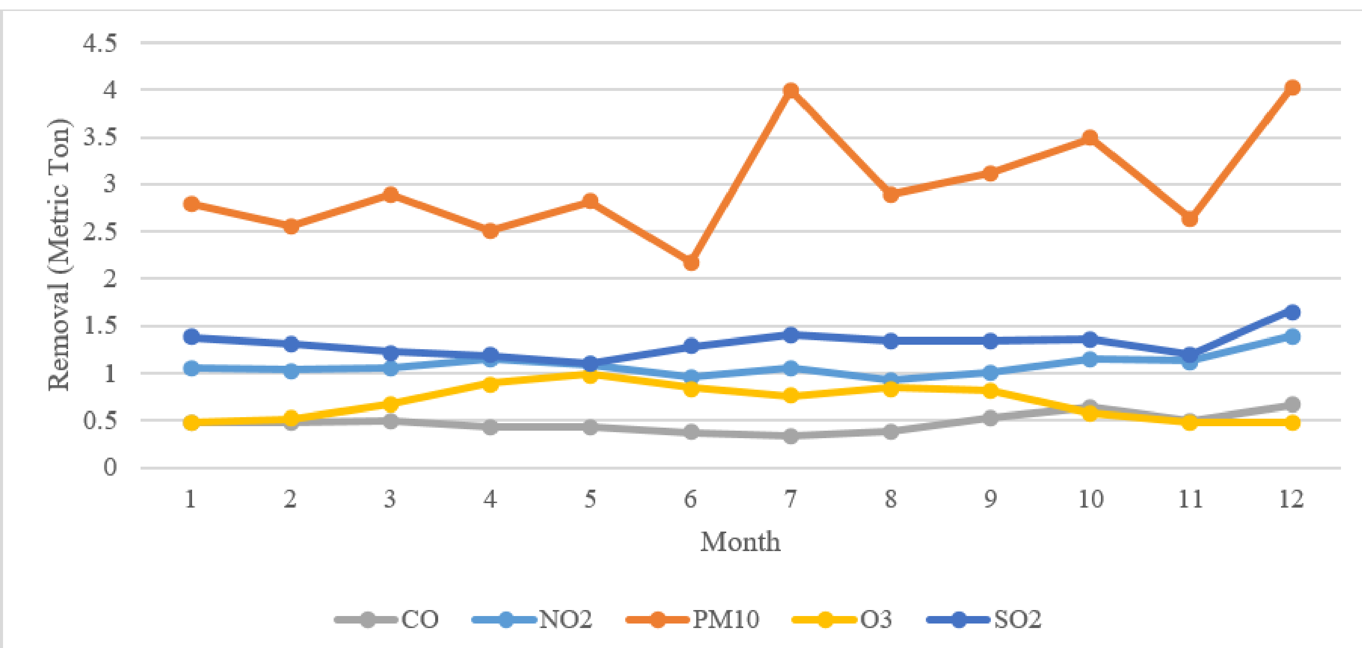

Figure 4

The trend of changes in the amount of monthly removal of base pollutants in D16 (January as the first month)

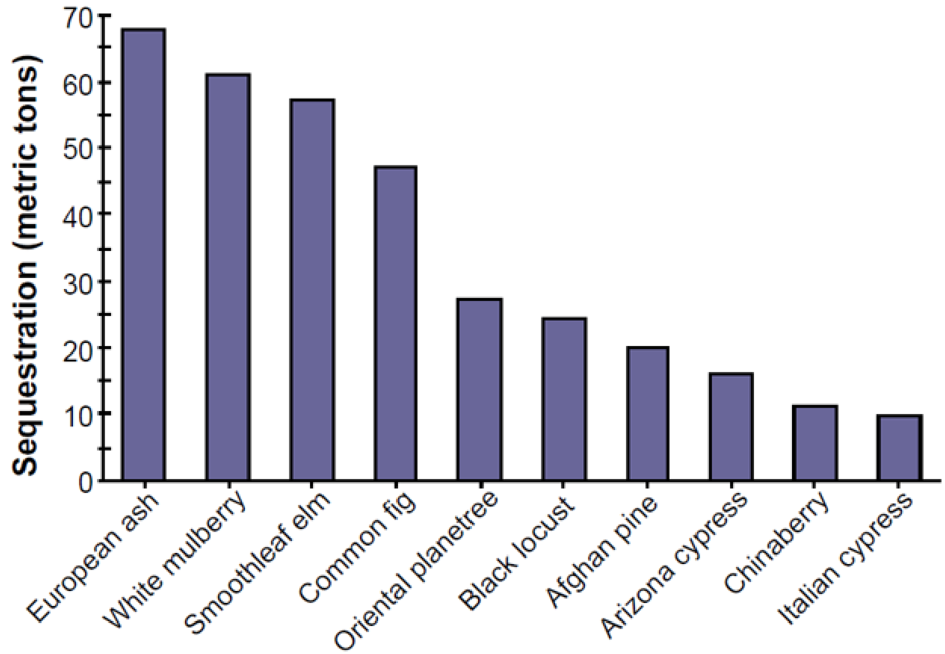

Figure 5

Carbon sequestration and value for species with most significant overall carbon sequestration in D16

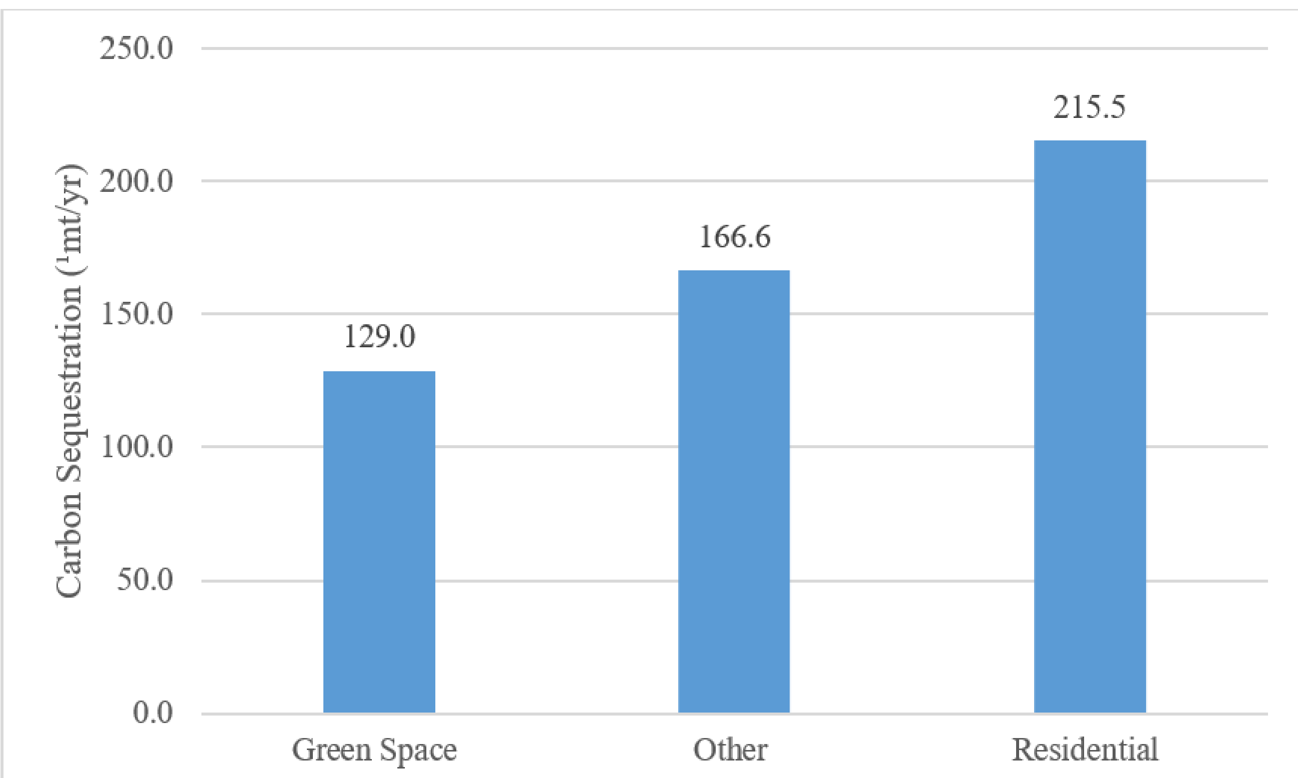

Figure 6

Gross sequestration by tree cover by land uses in D16 (tons/year)

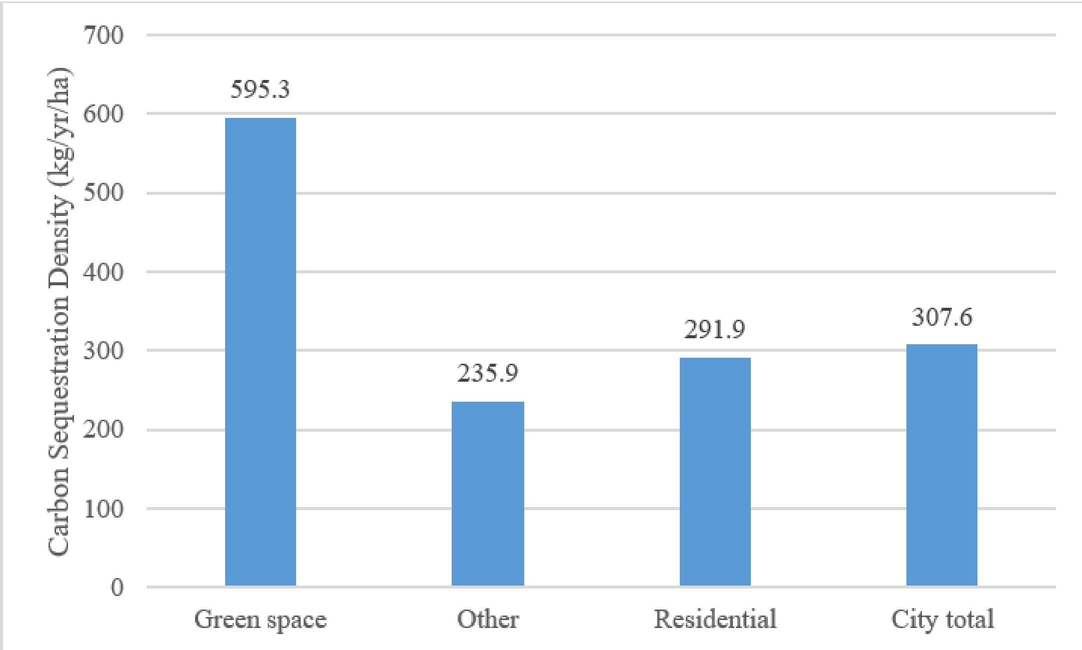

Figure 7

Carbon sequestration by tree cover by land use in D16 (kg/year/ha)

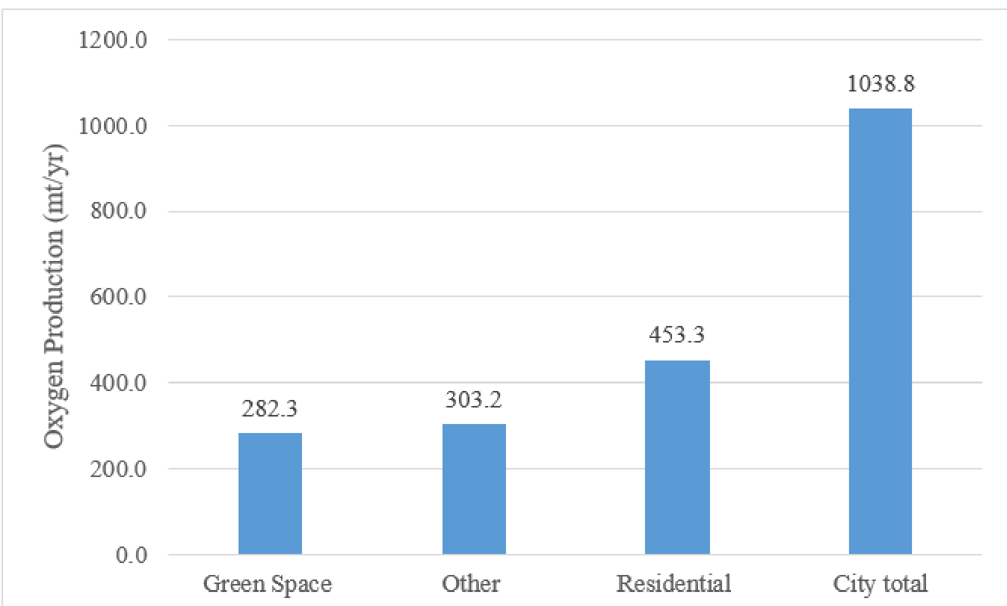

Figure 8

Oxygen production by tree cover by land use in D16 (metric ton/year)

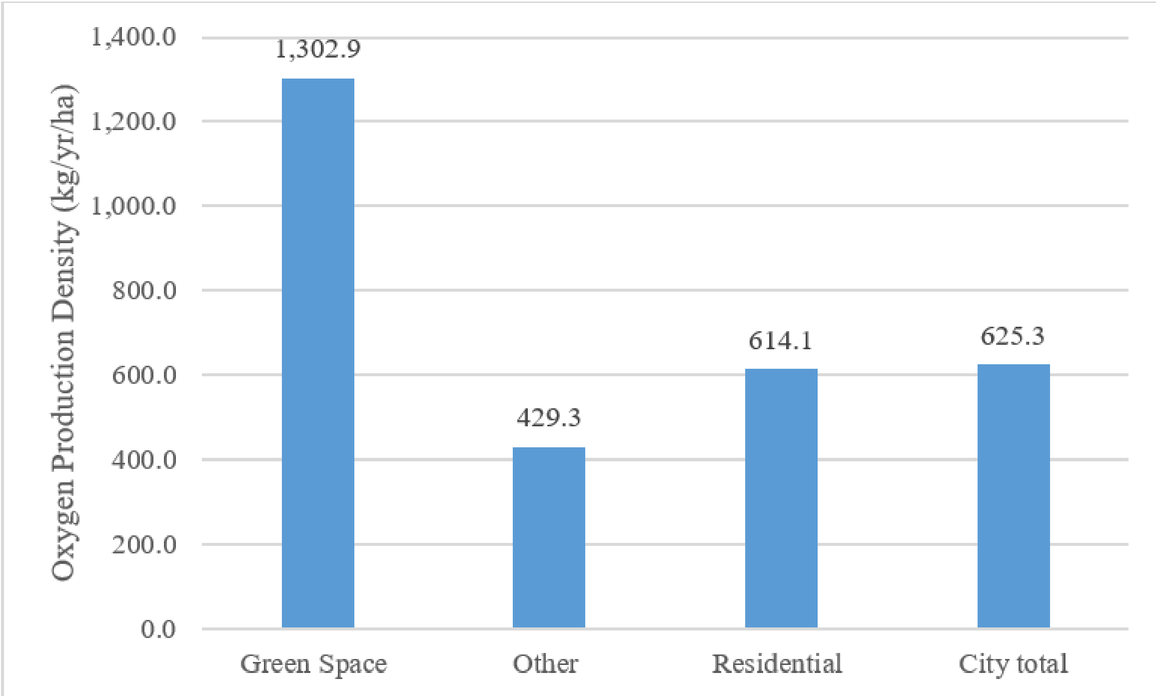

Figure 9

Oxygen production Density by tree cover by land use in D16 (kg/year/ha)