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Ecosystem services and economic values provided by urban park trees in the air polluted city of Mashhad

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ABSTRACT

Estimates of air pollutant removal by urban park trees in heavily polluted city of Mashhad, Iran, the associated economic value and the impact on air quality improvement are the main contributors of this study. The economic value of Mellat Park is substantial with a benefit-cost ratio at 0.6; however, the design of Mellat Park has not been adopted in accordance with air quality condition. While carbon emissions is not substantial, a significant part of Mellat Park's value (53.5 %) arises from carbon sequestration. Regarding $PM_{2.5}$, the most harmful air pollutant, there was a decline in air quality. The economic analysis of the park's three most frequent and three most valuable species highlights the inconsistency between the tree species and the environmental demands. If *Acer rubrum* (the most valuable species) or *Paulownia* (the second most valuable species) had been planted rather than *Platanus orientalis* (the most common species), the park's tree value would have seen 2.7 times increase and a 41.8 % boost. Local scale design considering the link between air pollution and vegetation configuration -including landscape for vegetation and superior plant species - can maximize value of the park's trees on removal rates and air quality improvement.

1. Introduction

Urban trees make a significant contribution to Goal 3 of sustainable development related to promoting good health and well-being, Goal 11 focused on creating sustainable cities and communities, and Goal 13 centered on taking action to combat climate change (United ations, 2015). This contribution stems from their ability to generate a multitude of ecosystem services, including the detoxification of air pollutants resulting from human activities, mitigation of noise pollution, safeguarding local water resources, assisting in storm water management, and enhancing aesthetic qualities (Abd Kadir & Othman, 2012; Giedych & Maksymiuk, 2017; Nowak et al., 2006).

Among many ecosystem services provided by urban trees, regulating ecosystem function – that is the process through that the quality of air and climate are maintained –is the least understood, but the most valuable (Cortinovis & Geneletti, 2019). According to Wei et al. (2021), 70 % of GHG emissions are produced in cities worldwide. According to the survey conducted by World Health Organization (WHO, 2022), ambient (outdoor) air pollution has caused 4.2 million premature deaths worldwide in 2019, with 89 % occurring in low- and middle-income countries. The highest number of these deaths was recorded in south-east Asia and western pacific regions. Hence, many municipalities are committed to develop strategies to reduce CO_2 emission and plan to purify air from pollutants (Wei et al., 2021). Interesting findings have emerged from recent studies on the ecological benefits of urban trees on air pollution.

Ottosen and Kumar (2020) found that planting hedges alongside roads significantly reduced pollutant concentrations, with a 44 % decrease in PM2.5 during the maturity phase. Isaifan and Baldauf (2020) estimated the annual benefits of tree-related CO_2 emission removal in Ghatar, Doha, to be up to $14 billion. Suchocka et al. (2023) used i-Tree software to valuate urban trees in Warsaw, revealing values of $25, $15, and $10 USD per tree in parks, residential areas, and streets, respectively. These values can increase by up to 62 % under the best vitality

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conditions. Zhao et al. (2023) found that the economic value of urban trees for pollution removal is 4.5 RMB (Chine's currency) per tree, with 0.66 % for C, 2.44 % for SO_2, 3.99 % for NO_2, 4.21 % for O_3 and 88.69 % for $PM_{2.5}$ removals. With a value of $110 per urban tree in California, McPherson et al. (2016) illustrated that for every dollar invested, urban trees would yield a benefit of $5.82. Overall, these studies emphasize the long-term benefits of urban trees, especially as they mature, making them a strategic choice for microclimate regulation.

While ecosystem services significantly enhance urban quality and social health, their valuation is constrained, particularly in developing and underdeveloped countries due to financial limitations and insufficient data. More specifically, studies assessing air pollution abatement policies are crucial for the highly air polluted cities in Asia where the health impacts of air pollution are severe and well-documented (Kumari et al., 2020). However, most of the research has focused on developed cities in regions such as Europe (Baró et al., 2014; Bottalico et al., 2016; Kiss et al., 2015; Selmi et al., 2016), the United Stated (Nowak et al., 2013, 2014) and Canada (Nowak et al., 2018) where Air Quality Index (AQI) levels comply with the WHO's standards for greenhouse gas emissions. This challenge was mentioned by Sicard et al. (2018) and Roy et al.(2012) and Lin et al. (2019) in a systematic review of 115 studies on urban trees. By economic analysis of urban trees in the highly polluted city of Mashhad, Iran, our study makes a contribution to the case-study literature in developing countries.

In response to the heavy air pollution, Iranian municipalities, like those in many countries, often consider urban park construction as a potential solution. Their argument is based on global and national standards for green space, which dedicate that there should be at least 20 m^2 per capita (based on global standard) (UN-Habitat, 2018) and 25–50 m^2 per capita (based on national standard) (Hami & Maruthaveeran, 2018; Haq, 2011; Pourmohammadi et al., 2011). However, in many large cities, the actual amount of green space is less than 15 m^2 per capita (Hami & Maruthaveeran, 2018; Khalilnezhad et al., 2021; Kolahi, 2005). Conversely, water supply organizations resist urban park development, citing water deficits. They advocate for waterless alternatives like artificial grass, emphasizing that directing water to sectors such as industry yields higher economic returns than allocating it to green spaces during water deficits. Although both arguments have merit, a decision on urban park development requires a comprehensive understanding of benefits and costs associated with urban parks. The interconnected services of urban park ecosystems, including pollutant filtration, carbon dioxide absorption, oxygen release, and temperature regulation, highlight the need for a comprehensive investigation into their important ecosystem benefits. Therefore, the first step in deciding whether to develop urban parks is to evaluate the benefits they provide. Of those benefit, air pollution removal is the most important for the heavily polluted cities of Iran such as Mashhad.

The objective of this study is to estimate the value of ecosystem services provided by trees in Mellat Park, located in Mashhad, a heavily polluted city in Iran with increasing pollution rate (Miri et al., 2016). The city's AQI based on $PM_{2.5}$ is more than 30.3 at the red level (Environmental Pollutants Monitoring Center, 2022; World Air Quality Index, 2022). The valuation focuses on ecosystem services provided by trees in Mellat Park, which include air pollution removal, air quality improvement, CO_2 storage and sequestration, and runoff prevention. Another achievement of this study is analysis of environmental benefits associated with air quality improvement caused by commonly planted species including *Platanus orientalis, Acer rubrum, Morus nigra, Paulownia, Acer negundo* and *Cupressus*. It addresses a notable gap in urban tree research, specifically the limited economic analysis of *Platanus orientalis*. Despite its widespread distribution in cities worldwide (Hasmik et al., 2021; Sabr, 2021), there has been a lack of economic studies conducted on this species (Roy et al., 2012). The outcome of this study is to stimulate local municipalities, as a part of government involved in urban planning, to get inspired by economic analysis in order to maximize air quality improvement and the associated benefits.

2. Methods

2.1. Study area

Mellat Park is our study area, located in Mashhad, the second largest city in northeastern Iran with an area of 351 square kilometers (Fig. 1). The maximum and minimum height of Mashhad is 1150 and 950 meters above the sea level. The latitude and longitude coordinates are 36° 31′ N and 59° 59′ E. The city has a variable climate, but it is prone to dryness with hot summers and cold winters. The maximum temperature in summer is 43 ℃ and minimum in winter is −15 ℃. The average annual temperature of the city is 15.7 ℃ and the average annual rainfall is 230 mm. According to the latest census (Statistical Centre of Iran, 2022) the population of the city is 3,001,184 people. Hosting annually about 30 million pilgrims, the city has a high potential for air pollution. According to the report published in 2021(Shahbazi et al., 2021), bus stations, railway stations, and airports due to their high demand in the city, operate at levels higher than normal, leading to a significant contribution to poor air quality. For instance, in 2017 on-road transportation was responsible for 45 % of PM_{10}, 45 % of $PM_{2.5}$, 24 % of NO_x and 96 % of CO emissions in the city. From air pollutants released from the three terminals of bus, railway, and airport, bus stations contribute 91 % to PM_{10}, 92 % to $PM_{2.5}$, 25.4 % to CO, and 20 % to CO_2, playing a significant role in air pollution.

Mellat Park with the area of 72 hectares, which is about 0.2 % of the city, is the largest park in Mashhad. Recreational and regulatory functions are the most important ecosystem services of Mellat Park (Organization of Park & Green Landscape, 2022).

The city has 21 air monitoring stations positioned throughout various areas of the city, with some areas are more polluted than others. The data released by North Khayyam station -the closest station to the Mellat Park- showed that this region with AQIs higher than 100 in about half of a year is the third most polluted area of the city (Environmental Pollutants Monitoring Center, 2022). Due to the park's proximity to a central bus station (Fig. 3), the area around Mellat Park is one of the most heavily polluted regions in Mashhad.

2.1.1. Air Quality Index: level of air pollution

Air quality index (AQI), which is measured based on concentrations of five critical air pollutants, $PM_{2.5}$, nitrogen dioxides (NO_2), carbon monoxide (CO), ozone (O_3) and sulfur dioxide (SO_2), is used to represent daily air quality condition to the public. The equation (1) is used to calculate AQI for each pollutant. The highest level of the calculated AQIs is used to report air quality of the region.

$$I_p = \left(\frac{I_{hi} - I_{lo}}{B_{phi} - B_{plo}} \times \left(C_p - B_{plo}\right)\right) + I_{lo} \tag{1}$$

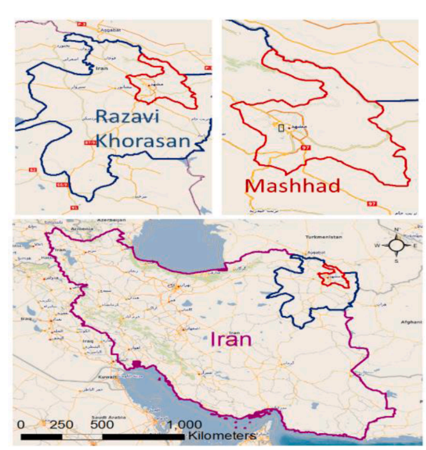

Fig. 1. Location of Razavi Khorasan province and Mashhad.

Where I_p: air quality index for pollutant "p"

B_{phi}: the upper end breakpoint concentration

B_{plo}: the lower end breakpoint concentration

I_{lo}: the AQI value corresponding to B_{plo}

I_{hi} the AQI value corresponding to B_{phi}

C_p: the pollutant concentration measured at the air monitoring station

While Tehran (the capital of Iran) was amongst the most polluted city in the world (Heger & Sarraf, 2018), air pollution of Mashhad has been sometimes more than that of the capital city. For instance, the concentrations of CO, NO_2 and $PM_{2.5}$ in 2017 were respectively three times, two times and one and half times greater than those concentrations of the capital city. The amount of SO_2 emitted in 2018 in Tehran was about half of the emission of this pollutant in Mashhad (Environmental Pollutants Monitoring Center, 2018). Based on the studies (Bonyadi et al., 2016; Hadei et al., 2017; Miri et al., 2016; Sarkhosh et al., 2022), $PM_{2.5}$ is the most important pollutant used to present the country's air quality and causing poor condition of Mashhad air. It was reported that on-road transportation makes a significant contribution to the air pollution in Mashhad, including 96 % of CO emissions, 45 % of $PM_{2.5}$ emissions, and 24 % of NO_x emissions. Power plants and refineries account for 35 % of $PM_{2.5}$ emissions (Shahbazi et al., 2021).

Over the years between 2014 and 2020, $PM_{2.5}$ concentration has been always at least three times higher than the standard of air quality guidelines of 12μg m^{-3} (EOHC, 2018). Due to the atmospheric inversion phenomenon, the $PM_{2.5}$ concentrations over a year were not constant and reached at its highest (44 μg m^{-3}) during November. The atmospheric inversion phenomenon refers to the situation in which the temperature of the atmospheric layer above the ground is higher than that of on the ground, which causes to prevent air pollutants from diffusing vertically (Feng et al., 2020).

2.2. i-Tree Eco model description

Using the i-Tree Eco software, we assessed the ecosystem services provided by urban trees in Mellat Park. i-Tree Eco assesses the structure of community trees and quantifies the environmental services they provide by integrating datasets including tree data (number of trees, species, tree height, diameter at breast height (DBH), height to crown, tree cover, etc.), local environmental data (hourly meteorological data, air pollution concentration data, etc.), and location information (latitude and longitude) of the study area. Fig. 2 illustrates the i-Tree Eco framework for assessing ecosystem services.

Since the main purpose of this paper is to evaluate emissions' removal, runoff mitigation, and their economic assessment the following paragraphs will focus on the calculations for these services.

2.2.1. Dry deposition: the emissions removal

Dry deposition is the mechanism through which vegetation removes air pollutants from the troposphere over non-precipitation periods (Selmi et al., 2016). i-Tree Eco model uses the following formular to calculate dry deposition:

$$f = V_d \times C \quad (2)$$

Where F is pollution removal or flux (g m^{-2} s^{-1}) V_d is deposition velocity (m s−^{1}), and C is pollutant concentration (g m^{-3}). V_d is calculated using the following formula (Baldocchi et al., 1987), except during the precipitation period when it is zero (Nowak et al., 2006).

$$V_d = (R_a + R_b + R_c)^{-1} \quad (3)$$

Where R_a is the aerodynamic resistance, R_b is the quasi-laminar boundary layer resistance, and R_c is the canopy resistance. Hourly estimates of R_a and R_b are calculated using standard resistance formulas (Killus et al., 1984; Nowak et al., 1998; Pederson et al., 1995) and hourly weather data. R_a and R_b effects are relatively small compared to R_c effects.

Hourly values of R_c for O_3, SO_2, and NO_2 are calculated based on a modified hybrid of big-leaf and multilayer canopy deposition models (Baldocchi, 1988; Baldocchi et al., 1987). R_c has three components: stomatal resistance (r_s), mesophyll resistance (r_m), and cuticular resistance (r_t) as below:

$$1/R_c = 1/(r_s + r_m) + 1/r_t \quad (4)$$

r_m is set to 0 (s m^{-1}) for SO_2 and 10 (s m^{-1}) for O_3 (Hosker Jr & Lindberg, 1982). r_m is set to 100 (s m^{-1}) for NO_2 to account for the difference between transport of water and NO_2 in the leaf interior and to bring the computed deposition velocities in the range typically exhibited for NO_2. Depending on the type of pollutant, r_t is set at 8,000 (s m^{-1}) for SO_2, 10, 000 (s m^{-1}) for O_3, and 20,000 (s m^{-1}) for NO_2 (Lovett, 1994).

As removal of CO and particulate matter by vegetation is not directly related to transpiration, R_c for CO is set to be constant at 50,000 (s m^{-1}) for leaf-on season and at 1,000,000 (s m^{-1}) for leaf-off season based on data from Bidwell and Fraser(1972). For $PM_{2.5}$, hourly deposition velocities and re-suspension rates vary with wind speed as detailed in (Nowak et al., 2013b).

Carbon storage is estimated by multiplying tree biomass by 0.5 (Chow & Rolfe, 1989). To estimate annual gross carbon sequestration, the tree DBH (Diameter at Breast Hight) is incrementally increased in the computer model based on an estimated annual growth rate. The carbon

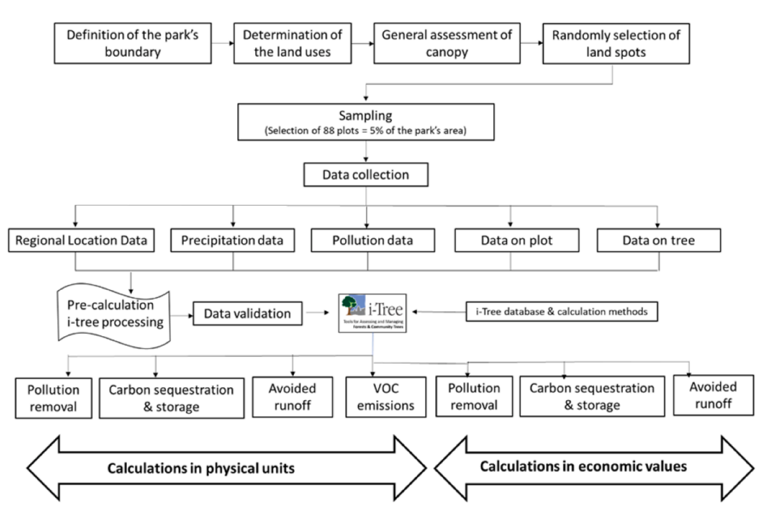

Fig. 2. Conceptual framework of i-Tree Eco model to assess ecosystem services.

storage in the current year (year 0) is then contrasted with carbon storage in the next year (year 1) to estimate the annual sequestration (Nowak, 2020). i-Tree Eco estimates hourly rain interception, evaporation from leaf surfaces, potential evapotranspiration, transpiration, and avoided runoff values based on leaf area data and local hourly weather data. Estimates are generated based on the current tree conditions and then without trees in order to estimate the impact of trees on surface runoff (Nowak, 2020). Numerous calculations were made to estimate hourly interception, evaporation, transpiration, potential evapotranspiration, and avoided runoff values (Hirabayashi & Nowak, 2016).

2.2.2. Air quality improvement

A further outcome of i-Tree software is improvements in air quality for each air pollutant. The estimate is based on the mass of air pollutants and boundary-layer height (Nowak, 2020). Changes in air pollution concentrations (ΔC) are calculated as:

$$\Delta C = \Delta Pt / (BL \times CA) \quad (5)$$

Where:

ΔPt = change in pollutant mass (μg) due to the net of effect of removal (flux)

BL = boundary layer height (m)

CA = study area (m^2)

Percentage in air quality improvement is calculated as:

$$\%\Delta = \Delta Pt / (\Delta Pt + Pa) \quad (6)$$

where:

P_a = pollutant mass (μg) in the atmosphere (=c × BL × CA)

2.2.3. Avoided runoff

i-Tree Eco estimates hourly rain interception, evaporation from leaf surfaces, potential evapotranspiration, transpiration, and avoided runoff values based on leaf area data and local hourly weather data. Estimates are generated based on the current tree conditions and then without trees in order to estimate the impact of trees on surface runoff (Nowak, 2020). Numerous calculations were made to estimate hourly interception, evaporation, transpiration, potential evapotranspiration, and avoided runoff values (Hirabayashi, 2013).

2.2.4. Volatile Organic Compounds (VOCs) emissions from

Using data collected during field surveys, i-Tree Eco estimates the hourly emissions of isoprene and monoterpenes. These estimates are then aggregated for the entire year, on a monthly basis, during daytime in each month, and over the leaf-on period. The outcomes are further summarized for individual trees, species within the analysis domain, and species in different land use types. Numerous calculations were established to quantify the effects of vegetation genus, leaf dry weight biomass, also environmental factors such as air temperature, and leaf temperature on VOC emissions (Hirabayashi, 2012).

2.2.5. Economic value

i-Tree Eco was used to estimate the economic value of health effects arising from removing air pollutants. For CO, 1598.86 USD (in 2011) per one ton of removal was adjusted based on producer price index (PPI) ratio between 2011 and 2018, resulted in $1520 per ton of removal. Health-related problems - that are avoided by removing air pollutants - including increased number of deaths, health treatment expenses and productivity losses are the basis for estimates of the economic values for NO_2, O_3, $PM_{2.5}$ and SO_2. These economic values (USD per one ton of removal) were determined based on Mashhad's human population density in regression (Eqs. 7-10) constructed from US Country's population and level of air pollution removal (Nowak et al., 2014; US EPA, 2012).

$$NO_2 \; : y = 0.7298 + 0.6264\,x \; (r^2 = 0.91) \quad (7)$$

$$O_3 \; : y = 9.4667 + 3.5089\,x \; (r^2 = 0.86) \quad (8)$$

$$PM_{2.5} \; : y = 428.0011 + 121.7864x \; (r^2 = 0.83) \quad (9)$$

$$SO_2 \; : y = 0.1442 + 0.1493\,x \; (r^2 = 0.86) \quad (10)$$

For future studies, it is recommended that regressions be determined for heavily polluted cities in specific, and if it is not feasible, at least at the country -wide level. According to Miri et al. (2016) that indicates 2, 059 (equal to 15.70 %) of the premature deaths in 2015 in Mashhad city attributable to the air pollution and the yearly value of an adult's life (between $5,373 using value of life method and $26,309 using value of statistical life method) (Bayat et al., 2019), it is most probably that values of one tone reduction in air pollutants are higher than i-Tree default values. Hence, the valuation of the air pollution removal using those values is recommended for Mashhad and the other highly polluted cities in Iran.

2.3. Data collection

Mellat Park contains various land use including playground, walking and jogging paths, sports fields and courts, stake parks, water features and botanic gardens. The sampling design and data collection were conducted in four steps: 1) Defining the boundary of Mellat Park 2) Classifying the park based on land uses 3) Conducting a general assessment of tree cover across various land uses 4) Randomly selecting land spots with trees from among various land uses (land uses without trees were excluded).

Using simple random sampling on a printed map of the park, 88 plots (Fig. 3) were selected, each with a radius of 11.3 meters and the area of 0.0405 hectares (i-Tree Eco User's manual, 2020).

The total number of trees (15,000) in Mellat Park was included in the sample selection process. The sample plots constitute 5 % of the Mellat Park and were randomly distributed around the park. For each plot of the study, we collected five groups of data (Table 1).

The data collection was conducted in the summer 2018. To ensure a consistent evaluation of economic costs, all values were adjusted to the international dollar value in 2018, as the emission prices were based on this year. Table 1 summarizes the data required for the i-Tree Eco model to assess the ecosystem services provided by the park's trees.

All the collected data was submitted to US Forest Service through i-Tree database software to review, approve and analysis.

We obtained the cost data for park maintenance from municipal records. Two interviews with different managers were then conducted for validation.

3. Results and discussions

3.1. Pollutant emissions in Mellat Park

The average concentrations of air pollutants collected by air quality monitoring stations adjacent to the Mellat Park during the years between 2016 and 2021 shows that concentration of $PM_{2.5}$ has increased by 28 % since 2016 (Fig. 4) (Environmental Pollutants Monitoring Center, 2018).

Among the air pollutants, $PM_{2.5}$ has been the most hazardous in most cities of Iran including Mashhad (Esfahanian et al., 2014).The yearly average of $PM_{2.5}$ concentrations between 2016 and 2021 were between 28 μg m^{-3} and 36 μg m^{-3}- more than two times the standard level of 12 μg m^{-3} addressed by the Air Quality Guidelines (EOHC, 2018). High concentration of $PM_{2.5}$ is considerably hazardous for human health since it has a strong relationship with lung diseases and mortality (Feng et al., 2019). Average concentrations of NO_2, CO, O_3 and SO_2 during

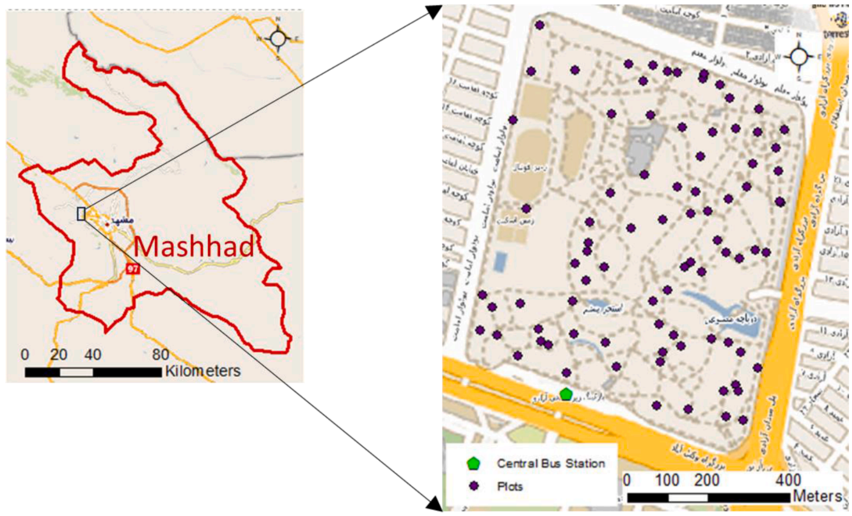

Fig. 3. Location of Mellat Park and the plots studied.

Table 1
i-Tree data requirements.

Data item	Data details
Regional Location Data	Continent, country, latitude and longitude, altitude, climate zone and vegetation
Precipitation data[1]	Hourly records
Pollution data[2]	Hourly records of the concentration of pollutants in the air
Plot	
Access area	Part of the plot in percent that is accessible for measurements
Tree cover	Part of the plot in percent that is covered by tree canopy
Land use	Types of land uses applied in the plot
Ground cover	Measurement of the percentage of different ground cover type(s) in the plot
Shrub cover	Part of the plot in percent that is covered by shrubs
Geographical location of the plot	This includes Longitude and latitude of plot center
Tree	
Species	Species and genus of tree.
Diameter at Breast Height (DBH)	Tree stem diameter at 1.37 meters above the ground
Planted/self-seeded tree	Specifying if the tree was planted or self-seeded
Distance and direction	Specifying distance and direction of the tree from the center of each plot
Street tree	Specifying if each tree in the plot is a street tree or not
Public/private tree	Specifying if the tree is managed and treated by public services or private
Tree height	Measurement of the tree height from the ground to the top of the tree (alive or dead)
Live tree height	Height from the ground to the live top of the tree
Height to crown base	Height from the ground to the base of the live crown
Crown width	The width of the crown in two directions: north-south and east-west
Percent crown missing	Percent of the crown volume that is not occupied by branches and leaves
Crown health	A visual assessment of the amount of dead branches (i.e., dieback) in a tree's crown
Crown light exposure	Number of sides of the tree's crown receiving light from above or the side (maximum of five)

[1] (Khorasan Razavi Meteorological Organization, 2018).
[2] (Environmental Pollutants Monitoring Center, 2018).

2016–2020 were most of the time less than the level of 0.053, 4.4, 0.059 and 0.034 in ppm suggested by the Air Quality Guidelines, and thus it is less hazardous than $PM_{2.5}$ in Mellat Park and the surrounding area.

3.2. Structure of Mellat Park

58.7 % of Mellat Park is covered by grass, 12.5 % by rock, 10.1 % by bare soil, 6.6 % by herbs, 4.2 % by cement, 3.2 % by duff, 2.4 % by buildings, 2 % by turf and 0.3 % by water body.

The 72-hectare Mellat Park includes 15,790 trees, with 125.3 hectares of leaf area occupying 47.0 % of the park. In total, there are 30 tree species in the park. Fig. 5 illustrates the population frequencies and contributions of the four dominant tree species to leaf area, an important factor influencing the removal of air pollutants in the park (McDonald et al., 2007; Rogers et al., 2018; Sæbø et al., 2012). i-Tree reports ecological condition in a seven-scale levels including excellent, good, fair, poor, critical, dying and dead. Fig. 6 presents ecological condition of the four superior tree species in Mellat Park. No percentage of the tree species in Mellat Park was in excellent condition. More than half of the park trees (69 %) were in good condition and 25 % in fair condition. A considerable percentage of *Platanus orientalis* (6.4 %) and *Cupressus* (6.7 %) were in either poor or critical condition.

3.3. Assessment of trees ecosystem services

3.3.1. Air quality improvement

Tree impacts on improving each pollutant are presented in (Table 2). The greatest air quality improvement is observed for O_3 at 0.27 % and for SO_2 at 0.26 %. This is important to note that air quality improvement is negative for $PM_{2.5}$ – the most hazardous air pollutant – indicating that re-suspension of previously deposited $PM_{2.5}$ by trees in Mellat Park is greater than the removal rate. Thus, urban trees in Mellat Park would increase local concentration of $PM_{2.5}$ due to re-emitting $PM_{2.5}$ in the atmosphere. Depending on amount of tree cover, pollution concentration, length of growing season and area of evergreen leaf, urban trees removal rate differ (Nowak et al., 2013). Therefore, urban trees with larger area and longer life of leaf (Karimian et al., 2019; Nejatian et al., 2022) and higher leaf-level capacity for capturing particulate matters such as *Quercus ilex* (Blanusa et al., 2015), black walnut (*Juglansnigra*) (Nowak, 2000; Selmi et al., 2016) would greatly reduce $PM_{2.5}$ concentration and minimize human exposure to it. Further research is required to evaluate the climate adaptability and stress tolerance of these species.

3.3.2. Air pollution removal

Total pollution removal was 2,539 kg $yr^{-1,}$ with contributions to the removal of O_3, SO_2, NO_2, CO and $PM_{2.5}$ at 32.4 %, 31.5 %, 24.3 %, 10.5 %, and 1.4 %, respectively. Among the tree species, *Platanus orientalis* with 50 % and *Acer negundo* with 16 % were the most contributors to

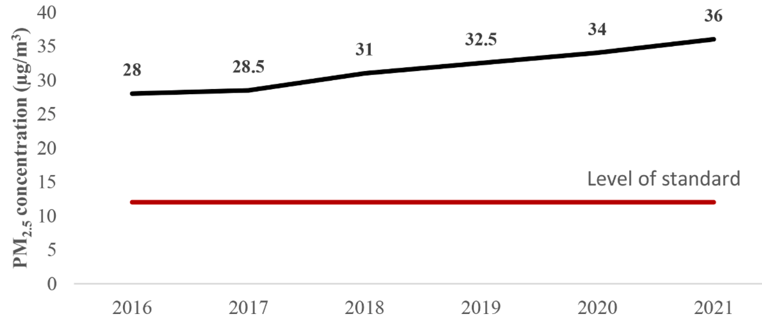

Fig. 4. The $PM_{2.5}$ concentration at the North Khayyam station, the closest station to Mellat Park, during 2016–2021.

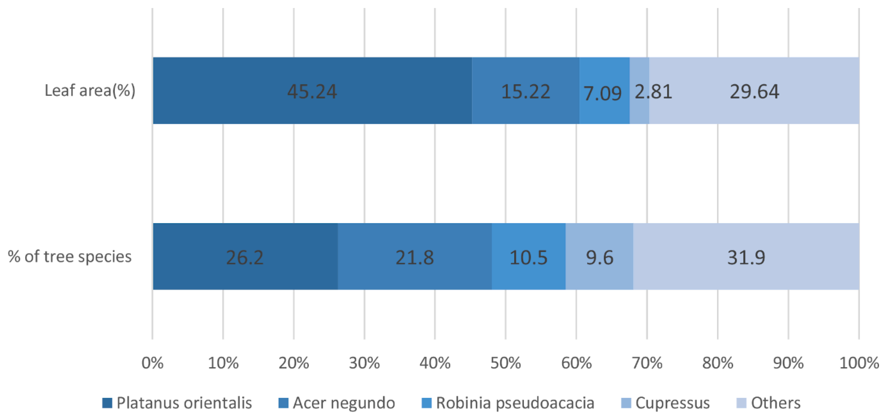

Fig. 5. Dominate tree species in Mellat Park.

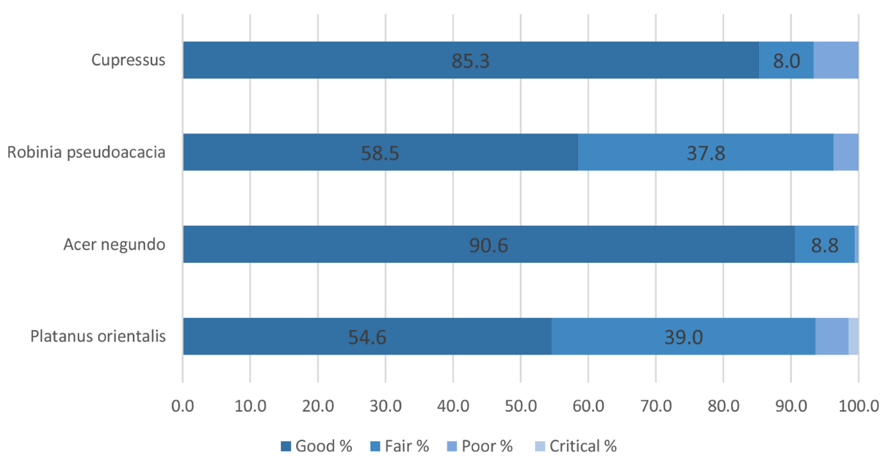

Fig. 6. Ecological condition of the four superior tree species in Mellat Park.

Table 2
Air pollutant removal and air quality improvement for each pollutant.

Air Pollutant	Removal (kg yr^{-1})	Removal Rate (g $m^{-2}yr^{-1}$)	Air Quality Improvement (% yr^{-1})
CO	266	0.79	0.002
NO_2	617 (341–931)	1.82 (1.01–2.75)	0.186 (0.103–0.268)
O_3	822 (277–1334)	2.43 (0.82–3.94)	0.272 (0.121–0.413)
$PM_{2.5}$	35 (4.3–75)	0.10 (0.01–0.22)	−0.034 (−0.007 to −0.166)
SO_2	799 (458–1601)	2.36 (1.36–4.73)	0.267 (0.163–0.491)
Total	2,539 (1347–4206)	7.51 (3.98–12.44)	

remove air pollutants.

Pollution removal is different in various months of the year (Fig. 7). Since the greatest leaf area and the highest concentrations of pollutants are in June, the maximum pollution removal (12.5 % of yearly estimated air pollution removal) was during June with the maximum of 116.2 kg per month for O_3 and SO_2.The minimum pollution removal for most pollutants occurred during February with the minimum of 1.21 kg for CO. The negative value of $PM_{2.5}$ removal in June and July indicates that the Mellat Park trees increased concentration of $PM_{2.5}$ in the atmosphere because local winds re-suspended $PM_{2.5}$ accumulated on leaves back to the atmosphere. Therefore, during the non-precipitation month of June and July, the Mellat Park trees had not only contributed to the removal of $PM_{2.5}$, but even increased its concentration in the atmosphere. Similar result was reported in the study of Nowak et al.

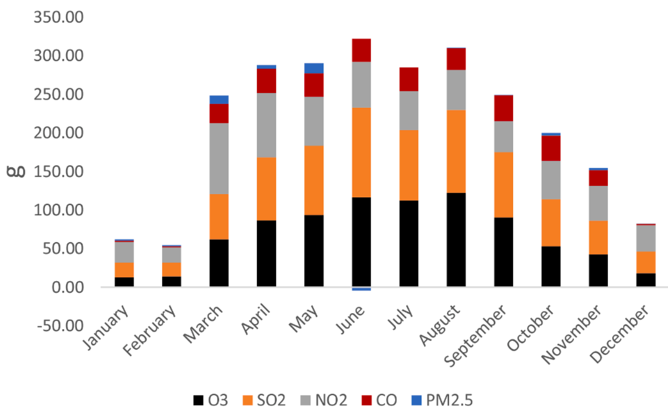

Fig. 7. Air pollution removal (g per month) by trees in Mellat Park

(2013b) in US cities with $PM_{2.5}$ re-suspension rate varying from 26.7 % in Syracuse and 42.6 % in San Francisco. The amount of $PM_{2.5}$ re-suspension and removal by the park's trees can be increased or decreased by changes in the park's landscape pattern, in particular vegetation and tree species (Wu et al., 2015). For example, urban trees in Strasbourg, comprising the three most common species of European beech (*Fagus sylvatica*), European filbert (*Corylus avellana*), and European ash (*Fraxinus excelsior*) as found in Selmi et al. (2016) contribute approximately 7 % to the reduction of PM_{10}, while their impact on other air pollutants is comparatively insignificant. The structure of leaf surfaces has been found to be a significant factor in capturing $PM_{2.5}$ (Chen et al., 2017).

Annual pollution removal per square meter of tree cover was 7.51 g m^{-2} yr^{-1} (Table 3). We compare our measures with those of other studies to better address Mellat Park trees contribution to pollution removal (Tables 3–5). The difference, however, cannot be attributable solely to the park's trees. Pollution removal rates (kg m^{-2} yr^{-1}) depends on several factors including pollution concentrations (high level of pollution concentration increases removal rate), weather conditions (intensive precipitation reduces removal rate), tree cover (a higher proportion of tree cover leads to greater removal rate), leaf area index (larger leaf area increases pollutant deposition and the associated removal rate), and length of growing season (increased length of growing season causes larger removal rate) (Nowak et al., 2006; Sicard et al., 2018). Pollution removal by Mellat Park is 17.5 % higher than the minimum measure reported in the previous studies (e.g.in Strasbourg in 2016), while it is 80 % lower than the maximum - reported measure (e.g. in Los Angeles in 2006). As Mellat Park is a highly-polluted area, removal rates are not high enough. More specifically, Eq. 2 suggests that increasing deposition velocity can enhance removal rates. External leaf wetness, surface wetness chemistry, stomatal opening and the roughness length that are determined by the canopy height, canopy closure, leaf area index and longer growing season can increase V_d and improve removal rates by at least 69 %, as per the literature (Sicard et al., 2018; Yang et al., 2005). Species with high deposition velocities per unit leaf area such as *Pinus nigra* can further augment the park's pollution removal capacity (Vigevani et al., 2022). Forest management activities such as maintaining trees at the minimum height necessary, promoting homogenous stands, establishing deciduous mono-culture and managing the under-storey can contribute to reduction in deposition (Erisman & Draaijers, 2003). However, the question arises if these activities have unintended impacts on other ecosystem services such as biodiversity and recreational use?

Table 3
Air pollution removal rates in different areas.

Author	Year	Region	Pollution removal rate (g m^{-2} yr^{-1})
This study	2021	Mashhad (Mellat Park)	7.51
Nowak, et al	2006	Minneapolis	6.2
Nowak, et al	2006	Washington	11.3
Nowak, et al	2006	New York	13.5
Selmi, et al	2016	Strasbourg	5.89

3.3.3. *Carbon storage and sequestration*

Overall carbon storage by Mellat Park trees was 2464.6 ton yr^{-1}. The gross and net carbon sequestrations were 162.1 ton yr^{-1} and 149.9 ton yr^{-1}, respectively. The net carbon sequestration makes 92.4 % of the gross carbon sequestration.

The two main species contributors to stored carbon are *Platanus orientalis* with 794.2 ton (32.2 %) and *Acer negundo* with 359.2 ton (14.6 %) of the total carbon stored; also of the overall carbon sequestrated 57.8 ton yr^{-1} (39.2 %) related to *Platanus orientalis* and 25.66 ton yr^{-1} (17.4 %) to *Acer negundo*.

Carbon storage per hectare of the study area was 34.23 ton ha^{-1}. The gross carbon sequestration per hectare of the total park's area was 2.2 ton ha^{-1} yr^{-1} and the net carbon sequestration was 2.08 ton ha^{-1} yr^{-1}, making up 94 % of the gross carbon sequestration. Carbon storage per square meter of tree cover was 7.29 kg m^{-2}, and the gross and net carbon sequestration rates at 0.48 kg m^{-2} yr^{-1} and 0.44 kg m^{-2} yr^{-1}, respectively. Comparing our study results to studies conducted in other regions (Table 4) indicates that amounts of carbon storage and sequestration by Mellat Park are relatively high.

3.3.4. *Avoided runoff*

i-Tree reports that the park trees decreased 1,333.13 m^3 yr^{-1} in runoff with the total precipitation of 237 mm over the study year. With the average yearly runoff volume of 4332.5 m^3 (Zebardast & Roshani, 2019), the trees in park can absorb 30.7 % of the total runoff over the study area. The *Platanus orientalis* with absorption of 603.09 m^3 yr^{-1} (45.2 %) and *Acer negundo* with 202.9 m^3 yr^{-1} (15.2 %) absorbed the most yearly runoff by the park trees.

3.4. *Comparison between Mellat Park and other parks*

Table 5 interprets our study results in comparison with findings from other studies conducted in Hyde Park (Rogers et al., 2018), Balboa Park (Castanon, 2018) and Ridge Park (Seed Consulting Services, 2016). The three studies employed approaches and techniques similar to those used in our study. Although the common DBH class (i.e., the class with the greatest frequency of tree count) varied across the parks, carbon storage efficiency was similar, in a range of 7 to 9 kg m^{-2}, across the parks. Since tree sizes for each park were broadly distributed, they may be similar on average.

The carbon sequestration rate was greatest for Mellat Park (0.48 kg m^{-2} yr^{-1}). This may be due to smaller (and younger) trees as evidenced in the common DBH class. These younger trees tend to grow faster than mature trees.

In Mellat Park, the annual pollution removal rate of 7.51 g m^{-2} was well within the common range (Table 3). The estimate of air pollutant removal is greatly dependent upon the air quality of a study area. Also, LAI, and weather conditions are key factors (Hirabayashi et al., 2011). In terms of the weather conditions, Mellat Park is very similar to Balboa Park. The difference in the pollution removal rate (7.5 vs. 10.15 g m^{-2}) may be attributed to variations in air quality or other factors such as ecological condition of the trees.

Avoided runoff rate was smallest in Mellat Park, given the smallest amount of annual precipitation. Runoff can be avoided mainly due to rainfall intercepted and evaporated by leaves. With the smallest and intermittent precipitation in Mashhad, the park trees may have not performed their maximum capacity of rainfall interception, which

Table 4
Carbon storage/sequestration in different areas.

Author	Year	Region	Carbon storage		Carbon sequestration		Net carbon sequestration		Net carbon sequestration rate (% of gross carbon sequestration rate)
			Total (ton)	Rate (kg m^2)	Total (ton yr^{-1})	Rate (kg $m^{-2}yr^{-1}$)	Total (ton yr^{-1})	Rate (kg m^{-2} yr^{-1})	
This study	2021	Iran Mashhad, Mellat Park	2,464 ± 167	7.29	162 ± 8	0.48	150 ± 8	0.44	92.4
Nowak, et al	2013a	US Los Angeles		4.59		0.17		0.10	58.8
Nowak, et al	2013a	US Minneapolis		4.41		0.15		0.08	53.3
Nowak, et al	2013a	US Washington		8.52		0.26		0.20	76.9
Nowak, et al	2013a	US New York		7.33		0.23		0.12	52.1
Strohbach and Haase.	2012	Germany Leipzig		6.82		-		-	-
Chaparro and Terradas	2009	Spain (Barcelona)		4.45		-		-	-

Table 5
Comparison of our study with other studies in foreign countries.

Parameter	Unit	Mellat Park (Mashhad/Iran) 2021	Hyde Park (London/UK) 2017	Balboa Park (San Diego/USA) 2018	Ridge Park (Unley/Australia) 2016
Common DBH class	(cm)	7.6–15.2	23.0–30.5	22.9–30.5	3.0–10.0
Dominant species		Platanus orientalis	Platanus acerifolia	Eucalyptus cladocalyx	Eucalyptus camaldulensis
Tree cover	(ha)	33.84	48.99	78.36	3.85
Leaf area index		4.32	5.26	4.54	3.80
Average temperature[1] (day-night)	(°C)	15.2 (21.2–9.7)	11.2 (14.7–7.7)	17.9 (21.3–14.4)	16.5 (20.2–12.7)
Average precipitation[1]	(mm)	237	695.2	334	494.7
Average wind speed[2]	(kmph)	14.8	25.4	14	24.49
Carbon storage	(ton)	2,464	3,872	5,794	342
	(kg m^{-2})	7.28	7.90	7.39	8.88
Carbon Sequestration	(ton yr^{-1})	162.0	88.0	218.5	10.08
	(kg m^{-2} yr^{-1})	0.48	0.18	0.28	0.26
Pollution removal	(kg yr^{-1})	2,537	2,710	7,949	204
	(g m^{-2} yr^{-1})	7.51	5.53	10.14	5.29
Avoided runoff	(m^3 yr^{-1})	1,333.1	3,584.0	4,267.0	262.1
	(m^3 m^{-2} yr^{-1})	0.0039	0.0073	0.0054	0.0068

[1] Average are based on historical data (2010–2022) at https://www.worldweatheronline.com.
[2] Average are based on the year 2020 at https://www.worldweatheronline.com.

resulted in the least efficient runoff reduction.

3.5. Assessment of trees ecosystem disservices

In addition to common ecosystem services, trees provide other less-studied disservices on health effects due to creating a site for breeding harmful insects and pests, damages to infrastructure, vegetation emissions affecting air quality, unexpected economic costs and social challenges such as a potential for vandalism and theft (Dunn, 2010; Shackleton et al., 2016; Yeshitela, 2020).

In i-Tree Eco, Biogenic Volatile Organic Compounds (BVOCs), including isoprene and monoterpene, emitted by trees are quantified as ecosystem disservices. BVOCs are carbon-based, highly reactive chemicals produced in plant leaves and released into the atmosphere. In the presence of sunlight, and particularly when nitrogen oxides are abundant, BVOCs emitted by plants undergo oxidation. This process leads to the formation of tropospheric ozone, a significant air pollutant in the troposphere with well-documented human health effects (Soni et al., 2018). Furthermore, the photooxidation of BVOCs contributes to the generation of secondary organic aerosols, including atmospheric particulate matter such as PM_{10} and $PM_{2.5}$ (Limbeck et al., 2003). The two famous VOCs of isoprene and monoterpene, have different potentials for forming ozone. For instance, one gram molecule of isoprene generates about three times more ozone than one gram molecule of monoterpenes (Carter, 1994).

The total amount of organic emissions, including isoprene and monoterpene, was estimated to be 2,209 kg yr^{-1}, with 24 % attributed to monoterpene and 76 % to isoprene, respectively. Calculating organic emissions per tree reveals that the *Populus alba* species emit the highest level of isoprene (961.27 g yr^{-1}), and the highest VOC emissions (966.20 g yr^{-1}). *Pinus eldarica*, with emissions of 244.4 g yr^{-1}, has the highest monoterpenes emissions. Notably, among the three most frequently occurring species (including *Platanus orientalis, Acer negundo* and *Cupressus*) and the most valuable species (including *Morus nigra, Paulownia* and *Acer rubrum*) in Mellat park (Fig. 8), *Platanus orientalis*

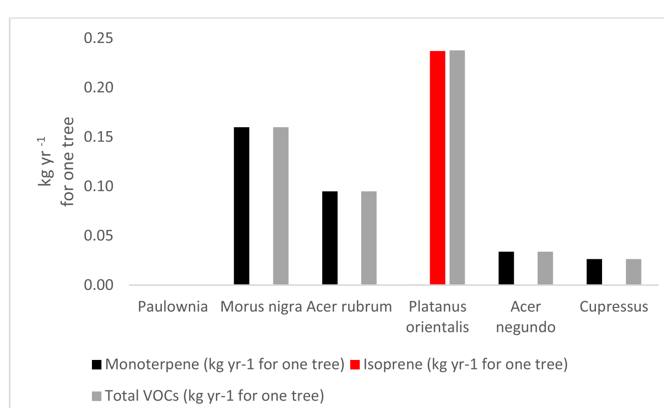

Fig. 8. VOC emissions (kg yr^{-1} per one tree) from 6 species in Mellat Park.

exhibits the highest level of VOC emissions.

3.6. Benefit-cost analysis

3.6.1. Economic values [1]: ecosystem benefits

3.6.1.1. Pollution removal value. Total air pollution removal value by trees in Mellat Park was estimated at $18,162 per year including O_3 (48.5 %), NO_2 (36.4 %), SO_2 (11.5 %), CO (2.2 %) and $PM_{2.5}$ (1.4 %).

The superior species in the removal value of pollutants are *Platanus orientalis* with $8,216.2 per year and *Acer negundo* with $2,765 per year. This is due to their abundant population – e.g. *Platanus orientalis* with 26.2 % and *Acer negundo* with 21.8 % of the total tree population in the park.

Pollution removal values were different in various months of the year. The value of pollution removal was the highest in June with 12.10 % of the yearly estimated value. The greatest value regarding pollutants was $1,309 for O_3 removal during August, while $PM_{2.5}$ removal during June with -$31.67 was the smallest.

3.6.1.2. Carbon storage and sequestration value. Total carbon storage value of trees in Mellat Park is $462,944.5. The gross carbon sequestration value is $30,463.97 year. *Platanus orientalis* with 32.2 % and *Acer negundo* with 14.5 % of the total carbon stored value; and 29.6 % and 18.7 % of the gross carbon sequestrated value is the most contributor to the carbon removal values.

3.6.1.3. Avoided runoff value. The benefit from reducing runoff volume was estimated at $6,286.3 per year. Similar to the total avoided runoff, *Platanus orientalis* and *Acer negundo* have the most contributions to absorb runoff.

In total, the value of the park trees associated with regulating function including pollution removal, carbon sequestration and avoided runoff is $52,596.2. Except for the carbon storage due to its nature that is the carbon accumulated over the years of lives, the total value includes carbon sequestration with 53.50 %, pollution removal with 34.5 % and avoided runoff with 12 %.

3.6.1.4. Species- specific pollutant removal capacity. Table 6 presents descriptive statistics of ecosystem values by trees in Mellat Park. The high coefficient variations show significant differences among tree species in the ecosystem values. Table 1 in the supplementary material details the economic value of the 30 tree species found in Mellat Park.

The following outcomes concerning the estimates of the benefits resulting from air pollution removal, carbon sequestration and avoided runoff associated with developing both the three most frequently occurring species (including *Platanus orientalis, Acer negundo and Cupressus*) and the most valuable species for air pollution removal (including *Morus nigra, Paulownia and Acer rubrum*) among the 30 species in Mellat Park. The findings contribute to the challenge of selecting appropriate tree species for planting in heavily polluted urban areas. This particularly helps address one important limitation of studies on urban trees that *Platanus orientalis* with a widespread distribution in cities around the world (Hasmik et al., 2021; Li et al., 2022; Sabr, 2021) has not been well studied (Roy et al., 2012).

Fig. 9 presents the total values per tree for the six tree species. The most valuable tree species (*Acer rubrum* with $11.99 per tree) is 9 times more worth than the least valuable tree species (*Cupressus* with $1.24 per tree). Averagely, the value of the three most valuable species is 2.5 times higher than the value of the least valuable species.

Fig. 10 presents the values of the most valuable and the most frequent species with regard to the three ecosystem functions of carbon sequestration, pollution removal and avoided runoff. For the carbon sequestration, the most valuable species (*Acer rubrum* with $8.45 per tree) is more than 10 times worth than the third most frequent species (*Cupressus* with $0.84 per tree). For avoided runoff, the value difference between the most valuable species (*Paulownia* with $0.61 per tree) and the third most frequent species (*Cupressus* with $0.06 per tree) is more than 10 times. For pollution removal, the most valuable species (*Paulownia* with $3.55 per tree) is more than 10 times worth than the third most frequent species (*Cupressus* with $0.34 per tree). On average, the three most valuable species are 2.5, 3.2 and 3.2 times worth than the third most frequent species in regard to carbon sequestration, avoided runoff and pollution removal, respectively. It's worth noting that the variations in values among the three most valuable species stem mainly from differences in carbon sequestration.

If *Acer rubrum* (the most valuable species with 70.4 % and 31.9 % arising from CO_2 and air pollutant removals) had been planted instead of the *Platanus orientalis* (the most common species), the value of the park's trees would have increased by 2.7 times. Opting for *Paulownia* over *Platanus orientalis* (the second most valuable tree with 58 % and 31.9 % of its value attributed to air pollution and CO_2 removals), leads to a 41.8 % increase in the park's overall tree value.

To have a more comprehensive analysis of the planted tree species suitable to Mellat Park, plant's ability to tolerate urban environmental stresses, particularly water deficit and climate change for Mashhad city, should be considered. In the supplementary section, botanical characteristics of the four most valuable species including *Morus nigra, Paulownia* and *Acer rubrum* (as the most valuable species) and *Platanous orinentalis* (as the most common species) are described.

3.6.2. Maintenance costs of Mellat Park

The costs of urban parks can be summarized into maintenance, acquisition and development (Fig. 11). The maintenance cost is generally the highest ranging between 85 % and 95 % of the total cost (McPherson et al., 2005).

The most commonly reported cost of Mellat Park is the maintenance cost comprising more than 95 % of the total cost. The annual cost to maintain the park is 123,164,431 Rials per hectare – equal to 80, 616.7 in US dollars in 2018 –including manually and mechanically weeding, clean-up, water supply and irrigation, modifying basin of trees, pruning, removing sucker and offshoot and foliar spraying and pest control. Most of the maintenance activities are performed by workforce, and thus most of the cost (70–80 %) is spent on labor. All costs were calculated on a 10-year average and adjusted for inflation indicator to study year.

The results showed that the most expensive item is pruning with 74 % of the total cost, followed by the costs of foliar spraying and pest control for 13 % of the total cost. Clean-up contributes to the least portion of the total costs at 0.05 %. The maintenance costs for urban green landscapes can be effectively reduced through the strategy of public involvement. Many countries, especially those experiencing reductions in municipal budgets for urban green space management, have found this approach to be advantageous (Coffey et al., 2020; Molin & van den Bosch, 2014). To ensure the success of this strategy, research and studies should be initially conducted to assess the public's level of knowledge about green landscapes, their sense of ownership, and their social interactions and sense of community (Molin & van den Bosch, 2014; Ohmer et al., 2009).

3.6.3. Benefit- cost evaluation

Table 7 shows that the benefit-cost ratio associated with the first-order effects of a typical Mellat Park's tree on the removal of air pollutants is 0.6 indicating that the benefits from the pollution removals are more than half of the maintenance costs. Using Mitchell' s rule (Lennon, 2009) and DBH measurement of 7.6–15 for Mellat Park's trees indicate that the trees are young (less than 10 years). For trees at the early years of growth (less than 20–30 years), the costs of tree planting and maintenance are higher than the benefits provided by their services.

[1] All values are calculated based on US international dollars in 2018.

Table 6
Descriptive statistics of ecosystem values from tree species in Mellat.

Functions	Maximum (US$ per tree)	Minimum (US$ per tree)	Average (US$ per tree)	Standard division (US$ per tree)	Coefficient variation (%)
Net carbon sequestration	*Acer rubrum* (8.45)	*Cercis canadensis* (0.28)	1.97	1.9	98.4
Carbon storage	*Morus nigra* (272.9)	*Prunus armeniaca* (0.44)	42.2	56.1	133.6
Pollution removal	*Paulownia* (3.6)	*Prunus armeniaca* (0.04)	1.23	1.09	89.2
Avoided runoff	*Ailanthus altissima* (4.18)	*Prunus armeniaca* 0.007	0.73	2.6	34.5

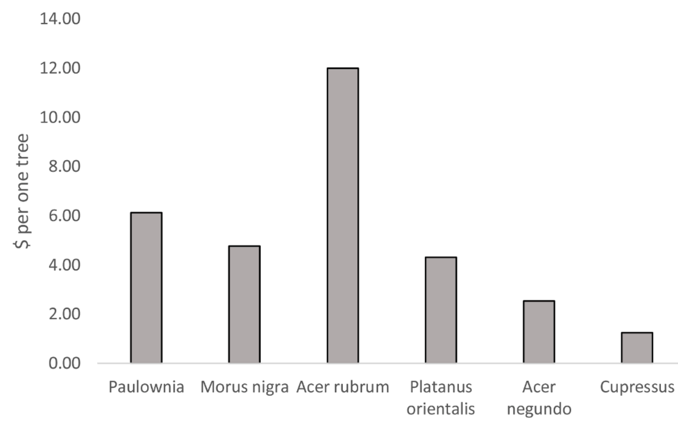

Fig. 9. The three most valuable and frequent species in Mellat Park.

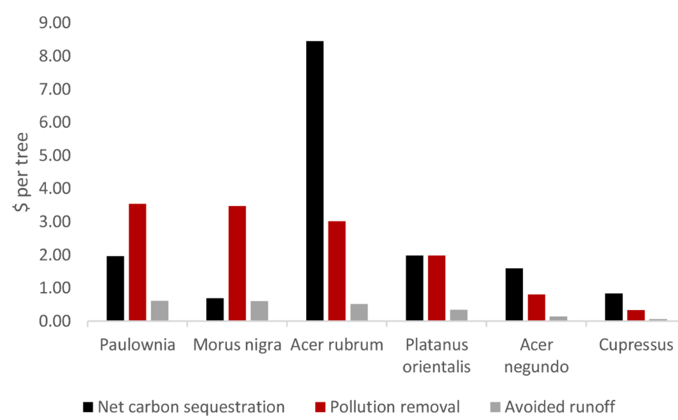

Fig. 10. The economic values of the six tree species in ecosystem functions.

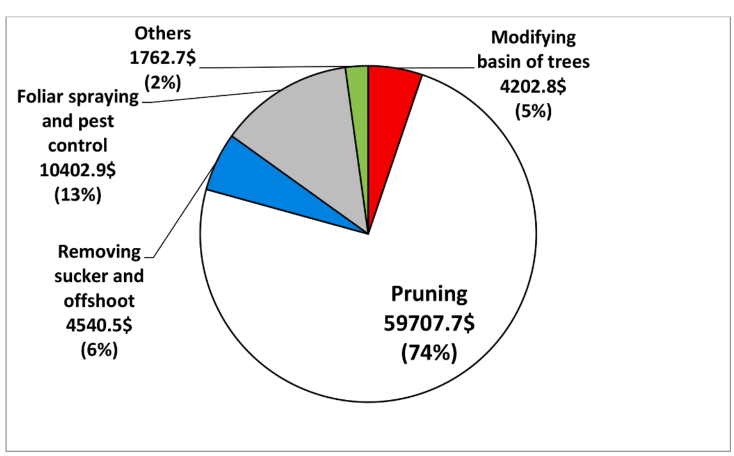

Fig. 11. Maintenance costs of Mellat Park ($per ha).

However, the situation reverses as the tree's life expectancy extends beyond 40 years (Horváthová et al., 2021; McPherson et al., 2016; Suchocka et al., 2023). Furthermore, improving the health of the park's mature trees, none of which are in excellent condition, can enhance air pollutant removal benefits by up to 62 % (Suchocka et al., 2023).

The tree species in the park also play an important role in influencing the benefits provided by the park (Zhao et al., 2023). *Platanus orientalis,* as the dominant species in the park, exhibits a low benefit-cost ratio (0.82) compared to the most valuable species*, Acer rubrum,* with a ratio of 2.29. Furthermore, the results from the ecological assessment reported by i-Tree indicate that *Platanus orientalis* trees are in relatively poor condition. While the ecological condition of a typical tree (except for *Platanus orientalis*) in Mellat Park was at 94.5 %, ecological condition of *Platanus orientalis* was 87.42 % indicating the trees were not in good health. Previous studies (Lakzian et al., 2013; Pourkhabbaz et al., 2010; Sabr, 2021) confirm our result that *Platanus orientalis* is not suitable for urban green landscapes in countries with water stress due to the issues of early dieback and yellowing leaves. Water deficiency, drought, low temperature in winter and early spring are mentioned as the climatic causes of the low pollution removal. Furthermore, Platanus orientalis is not suitable for urban settings with high environmental risks due to sensitivity of its physiological and anatomical properties to air pollution (Hasmik et al., 2021; Khosropour et al., 2019). Leaf area of *Platanus orientalis* that is a key factor to remove air pollutants can be predicted before mass plantation using biological models such as non-destructive equation that predicts leaf area based on average sizes of leaf length and leaf width in the study field (Sabr, 2021).

The adaptation of trees to climate and their ecological growth should be considered when selecting trees for urban planting. Acer *rubrum*, recognized as the most valuable species in the park, exhibits a benefit-cost ratio at 2.29. Although *Acer rubrum* has the advantage of fast growth and a beautiful shape, further investigation is required because it prefers moist and acidic soil, which reduces its adaptability to drought or soil water deficit (Li et al., 2015). *Paulownia* and *Morus nigra* as the second and third most valuable tree can be a suitable option to have more investigation on their adaptability. *Paulownia* has an excellent tolerance to water tension, drought and extreme soils (Alagawany et al., 2022; Ayrilmis & Kaymakci, 2013). The tree was found to be suitable for polluted zones in Iran (Abbasi et al., 2020). *Morus nigra* exhibits tolerance to drought stress, air pollution removal with low maintenance requirements and the ability to grow in warm-temperature climates. The notion that *Morus nigra* has its origins in Iran (Ahlawat et al., 2016; Orwa, 2009; Taufik et al., 2016) implies a well-suited adaptation to the Iranian climate.

The benefit-cost ratio is most likely to be more than one if other benefits accruing from the trees were included into the measurement. In the support of this conclusion, the study of Tempesta (2015) showed that the largest benefits generated by urban parks are related to recreational function and hedonic values associated with the society's properties . McPherson et al. (2005) illustrated that benefits generated by urban parks including energy saving, carbon sequestration, flood damage reduction, air quality improvement and hedonic price of properties largely overweigh the costs with the biggest contribution from hedonic value. According to the study conducted by Mostofi and Hosseini (2016), recreational value of Mellat Park estimated by conditional valuation method was 2,430 dollars per hectare in a year. By the inclusion of the recreational benefit in the benefit-cost analysis, the ratio associated with ecosystem functions of Mellat Park increases to 2.8.

In addition to common benefits, urban parks and trees provide other less-studied benefits that can be categorized into improvement in public physical health and psychological well-being. Studies illustrate that urban trees improve public physical health through protection from ultraviolet radiation, heat exposure (Wolf et al., 2020; Yeshitela, 2020), and the facilitation of physical activities (Song et al., 2015). Urban parks contribute to the mitigation of psychological effects of living in urban environments, such as anxiety, depression and psychosis (McKenzie et al., 2013). From a psychological perspective, it is well-documented that urban parks significantly enhance perceived thermal comfort (Klemm et al., 2015), happiness (Kwon et al., 2021), relaxation (Song et al., 2015) and social inclusion (Kweon et al., 1998; Stigsdotter et al., 2010) . While assessing the economic values of these services can be a complex endeavor, it is essential to incorporate them when evaluating the benefit-cost ratio for urban development plans. Similarly, the economic values of disservices, such as VOC emissions generated by trees, should be evaluated and included in the cost-benefit analysis. This inclusion provides a more comprehensive assessment of both the services and disservices of urban trees.

4. Conclusion

Recently, due to substantial contribution of large cities to air pollution and GHG emissions, scholars' attention towards economic value of urban parks to improve air quality has been growing. Although the world's most polluted cities are located in Asia, studies on urban and street trees have been mainly conducted in developed cities that meet WHO recommended safe threshold. Since air polluted cities are developing their economies, such estimating approaches are helpful to adjust market failures in evaluating the competition of allocating urban lands between industrial activities and urban tree landscapes. This study attempted at estimating economic value not only GHG (CO_2) but also pollutions removed by urban trees in Mellat Park located in the most polluted district of Mashhad, a heavily polluted Iranian city. Engineers, urban city planners and those involved in the management of air pollution can use the study findings to better understand factors determining economic value of urban trees in the aspect of improving air quality. The study emphasizes economic evaluations of urban trees – as a key mean of nature-based solution to mitigate air pollutants – before park construction, development and tree plantation.

Among the five air pollutants, $PM_{2.5}$ with averagely three times higher than the WHO standard level is the most hazardous air pollution around Mellat Park, however this is the least removed pollutant by urban trees. The relatively low pollutant removal rate of $PM_{2.5}$ indicates that the park's landscape pattern needs to be restructured to achieve

Table 7
Benefit-cost analysis of the Mellat Park.

Benefits/Costs	Mellat Park per tree (US $)	Mellat Park per hectare (US $)	Mellat Park (US $)	*Platanus orientalis* per tree (US $)	*Acer rubrum* per tree (US $)
Benefits					
Air pollution removal	1.1	252.2	18,162	1.98	3.01
Net carbon sequestration	1.8	390.9	28,148	1.97	8.45
Avoided runoff	0.40	87.3	6,286.2	0.34	0.52
Total	3.3	730.4	52,596.2	4.29	11.98
Costs					
Weeding (manually)	0.08	18.69	1,345.87	0.08	0.08
Weeding (mechanically)	0.009	2.09	150.61	0.009	0.009
Cleaning	0.002	0.52	6,237.51	0.002	0.002
Irrigation	0.01	3.17	228.7	0.01	0.01
Modifying basin of trees	0.27	58.37	4,202.88	0.27	0.27
Pruning	3.89	829.27	59,707.74	3.89	3.89
Removing sucker and offshoot	0.29	63.06	4,540.5	0.29	0.29
Foliar spraying and pest control	0.67	144.48	10,402.89	0.67	0.67
Total	5.22	1119.65	80,616.7	5.22	5.22
B/C	**0.63**	**0.65**	**0.65**	**0.82**	**2.29**

better performance of air pollution removal. Superior tree species in relation to removing $PM_{2.5}$ should be particularly considered in the restructure of landscape and green space development. Among the six species analyzed, *Acer rubrum, Paulownia* and *Morus nigra* emerge as the most economically valuable. If they had been planted instead of the most frequently occurring species *(Platanus orientalis*) in the park, the trees' benefit would have increased, significantly. *Paulownia* and *Morus nigra*, in particular, present exceptional tolerance to water tension and drought stress.

Our study recommends i-Tree and software professions to develop environmental programs by combining ecological models and economic valuation techniques in order to assess different configurations of urban park designs and planning before the construction. A few key recommendations are offered to the city professionals, policy makers and authorities:

- When developing or replacing trees in the park, it is recommended to take into account tree species characteristics, such as tree-leaf surface area, which can have an impact on air quality improvement and particularly the removal of $PM_{2.5}$. For instance, Platanus may not be a suitable choice for this purpose.
- It is recommended to involve public opinion in designing urban park's structure since integration of knowledge from science and community –in terms of maintenance costs- can be achieved. This provides a platform for public participation in maintaining park tree activities, which can significantly reduce overall maintenance costs if the involvement is well-designed.
- It is recommended to conduct similar studies in other urban parks of Mashhad to assess overall economic performance of Mashhad's urban parks and economic performance of other tree species in terms of improving air quality.

The issues mentioned in the introduction in regard to valuing Mellat park are remained poorly understood, and thus further studies are required on the following subjects:

- Economic value of other common and uncommon ecosystem services – such as capacity of air pollutants, tolerance to drought and enhancement of the society's quality of life– provided by Mellat Park's trees.
- Economic value of ecosystem disservices – such as allergic effects, damages to infrastructure, BVOC emissions such as Isoprene and α-Pinene as the most emissions affecting air quality – generated by Mellat Park's trees.
- Regional value of removing one ton of each air pollutant in particular $PM_{2.5}$. This can be calculated by computing social costs and physical damages avoided by removing one ton pollutant.
- Developing an enhanced database of common urban tree species that present the benefits and costs of removing air pollutants.

Declaration of Competing Interest

We confirm that there is no conflict of interest among authors.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.scs.2023.105110.

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