Article details

Parsa V.A., Salehi E., Yavari A.R. & Bodegom P.M. van (2019), Analyzing temporal changes in urban forest structure and the effect on air quality improvement, Sustainable Cities and Society 48: 101548.
DOI: 10.1016/j.scs.2019.101548

Sustainable Cities and Society 48 (2019) 101548

Contents lists available at ScienceDirect

Sustainable Cities and Society

journal homepage: www.elsevier.com/locate/scs

Analyzing temporal changes in urban forest structure and the effect on air quality improvement

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ARTICLE INFO

Keywords:
Air purification
i-Tree Eco
Green infrastructure
Urban ecosystem services
Quantification
Iran

ABSTRACT

Tree planting practices are being increasingly advocated as measures to improve the air and living quality in urban landscapes around the world. Nevertheless, there is still a lack of quantitative understanding of the effects of the increases in tree cover on the future potential of urban forests when it comes to air quality improvement. Therefore, this research aims to assess and quantify the current and future biophysical and monetary value of the regulating ecosystem service provided by urban forest in Tabriz, Iran (as a case study). Both the current conditions and future prospect are assessed through tree planting scenarios based on the i-tree Eco model. The results indicate that the trees and shrubs removed 238.4 t of pollutants during a year (in 2015), which suggests only a modest potential in air purification when compared with other cities around the world. However, through appropriate – though feasible – urban forest management and development practices, they may improve up to 814.46 t cumulatively over the next 20 years. Tree planting schemes have different efficacies in terms of providing air purification services. Our data-rich temporal approach allowed identifying the optimum tree planting strategy, taking into account the growth and mortality dynamics. Thus, the paper illustrates a methodology to assess the current and future potentials of urban forests to reduce air pollution at the city-scale, which helps the development of future urban tree planting strategies in cities to improve air quality as well as the management of the green infrastructure. Our approach paves the way for the quantitative assessment and optimization of the future condition of (urban) ecosystem services.

1. Introduction

The high population density in cities fostered the idea of an urban society which is independent of the natural ecosystems thanks to high technologies and the built infrastructure (Ausubel, 1996). However, humans still depend on nature as ever (Bolund & Hunhammar, 1999) and while urban dweller demands natural resources and ecosystem services (ES), there is no way to leave the urban lifestyle. In fact, urbanization is one of the main drivers of global environmental change and this increases the necessity of ES (Ayres & Van Den Bergh, 2005; Gómez-Baggethun & Barton, 2013; Guo, Zhang, & Li, 2010; Lourival et al., 2011). Without ES, human life in the cities would not be possible (Grunewald & Bastian, 2015; Guo et al., 2010) as the sustainability of cities depends on the benefits derived from the ecosystems within the urban landscapes, which are known as urban ecosystem services (UES) (Bolund & Hunhammar, 1999; Wang, Bakker, de Groot, & Wörtche, 2014).

Urban ecosystem services are manifold (changing the structures, processes and functions of urban ecosystems (Chen, Chen, & Fath, 2014)). One of the most significant urban ecosystem services is the capturing of air pollution. Air pollution is a major environmental problem in most cities, especially in developing countries, and causes adverse effects on human health and well-being (Escobedo & Nowak, 2009a; Nowak, Crane, & Stevens, 2006; Vos, Maiheu, Vankerkom, & Janssen, 2013; Yang, Mcbride, Zhou, & Sun, 2005). The World Health Organization (WHO) estimated that 92% of the world's population lives in air-polluted areas, and 11.6% of all global deaths (90% occurring in low- and middle-income countries) are associated with air pollution (WHO, 2017). The main air pollutants in cities include NO_x, SO_2, O_3, CO, organic carbon, black carbon and $PM_{10\ \mathrm{and}\ 2.5}$ (particulate matter less than 10 and 2.5 μm) (Carreiro, Song, & Wu, 2008; Sharma, Agarwal, Eastwood, Gupta, & Singh, 2018).

The rapid air quality deterioration shows an urgent need to mitigate and reduce urban air pollution (Jayasooriya, Ng, Muthukumaran, & Perera, 2017; Saunders, Dade, & Niel, 2011). Planting and maintenance of urban green infrastructure (UGI) is one of the most promising

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https://doi.org/10.1016/j.scs.2019.101548
Received 10 July 2018; Received in revised form 10 April 2019; Accepted 10 April 2019
Available online 15 April 2019
2210-6707/

strategies developed to mitigate and overcome urban air pollution problems (Elmqvist et al., 2015; Garcia, 2017; Grimm et al., 2008; Kim, 2018; Kiss, Takács, Pogácsás, & Gulyás, 2015; Tzoulas et al., 2007; Vos et al., 2013) as it has been shown to be effective in mitigating harmful urban air pollutants (Baró et al., 2014; Baró, Haase, Gómez-Baggethun, & Frantzeskaki, 2015; Jayasooriya et al., 2017; Kiss et al., 2015; Nowak et al., 2006). An UGI encompasses diverse vegetation types with different structures. However, in this paper, we have focused on urban trees and shrubs within the city, which, together, comprise "the urban forest (UF)" (Baró et al., 2014; Finlayson-Schuele, 2015; Pearlmutter et al., 2017; Tzoulas et al., 2007).

Atmospheric deposition is an influential process that regulates the transportation of the air pollutants from air to foliar surface and controls their fate (Lovett, 1994; Wu et al., 2018; Zannetti, 1990). Plants are the first feasible receptors and dominant terrestrial sinks for most of the deposited pollutants in the boundary layer (Air Quality Expert Group, 2018; Dochinger, 1980; Hosker & Lindberg, 1982; Manisha & Pal, 2014). Gaseous and particulate pollutants are transferred through three mechanisms: wet, occult and dry deposition (Bytnerowicz, 1996; Lovett, 1994; Nowak, 1994; Powe & Willis, 2004). Wet deposition occurs by the incorporation of pollutants into precipitation and is divided into two main processes regarding aerosol scavenging mechanisms: rainout (in-cloud scavenging, which transfers the pollutants to rain or cloud droplets before falling) and washout (below-cloud scavenging, which transfers the pollutants to the falling raindrops or snowflakes) (Greenwood & Shroder, 2016; Kajino & Aikawa, 2015; Lovett, 1994; Unsworth & Wilshaw, 1989; Wu et al., 2018). Deposition of soluble and insoluble pollutants through the non-precipitating drops of clouds and mist to the receptors is called occult deposition (Greenwood & Shroder, 2016; Lovett, 1994; Underwood, 1991; Unsworth & Wilshaw, 1989). Dry deposition is a phenomenon through which atmospheric gases and particles are directly transferred or fall down, the process of which occurs through the delivery of mass (due to gravity) to surfaces (e.g. urban trees) by non-precipitation (Greenwood & Shroder, 2016; Lovett, 1994; Panas et al., 2014; Unsworth & Wilshaw, 1989). It provides the imperative transferring pathway and also the sink for pollutants (e.g. O_3, SO_2 and PM) (Unsworth & Wilshaw, 1989; Zannetti, 1990). Dry deposition follows three steps: 1) aerodynamic transfer; transporting pollutants from the lowest layer of the air into the very thin quasi-laminar sub-layer; 2) transporting through the boundary layer, and 3) chemical or physical interactions with the surface of the receptor (Mariraj Mohan, 2016; Wu, Davidson, Dolske, & Sherwood, 1992).

The majority of the urban air pollutant removal by urban trees and shrubs occurs through dry deposition (Cabaraban, Kroll, Hirabayashi, & Nowak, 2013; Carreiro et al., 2008; Mcpherson, 1998). The UF takes up the gaseous air pollutants via its leaf stomata and also intercepts (captures or traps) the airborne particles through sedimentation or impaction (Dochinger, 1980; Gómez-Baggethun et al., 2013; Konijnendijk, Nilsson, Randrup, & Schipperijn, 2005; Nowak, 1994; Nowak et al., 2006). A small portion of intercepted particles (only fine and superfine particles) may be absorbed into the leaves, but the remnants are kept on or adhered to the tree surfaces, which is often re-suspended, washed off or dropped through leaf fall (Grunewald et al., 2018; Manisha & Pal, 2014; Nowak et al., 2006; Peper, McPherson, Simpson, Vargas, & Xiao, 2009). Though rough, bark, hairy, moist and sticky surfaces help retain particles, foliar surface is a temporary resting site (Grote et al., 2016; Powe & Willis, 2004). Like the gases necessary for the functioning of the tree (e.g. CO_2), the air pollutants, which can be effectively metabolized inside the leaf tissues (e.g. SO_2, NO_2 and O_3), are absorbed through the stomata. Also some of the pollutants (e.g. NO and NO_2) can enter into the inner space of the tree through the cuticle (Bytnerowicz, 1996). The gaseous pollutants diffused into the intercellular spaces are absorbed by water films or chemically modified by the tree tissues (Nowak et al., 2006; Omasa et al., 2002). Once the pollutants go inside the cells, they face defense as well as primary and secondary metabolic reactions (Bytnerowicz, 1996). Each pollutant is biochemically transformed through different metabolic processes in tree leaves (Omasa et al., 2002). It is assumed that the absorbed SO_2, uptaken predominantly through leaf stoma, dissolves in the aqueous phase of inner-leaf cell walls (apoplast) or in the cytoplasm, producing bisulfite and sulfite ions and eventually forming sulfurous or sulfuric acid (Nowak, 1994; Omasa et al., 2002). NO_2 may be assimilated into amino acids or accumulated in vacuoles once absorbed through stomata (Chaparro-suarez, Meixner, & Kesselmeier, 2011; Gasche et al., 2002; Hu, 2011; Nowak, 1994). Once O_3 is uptaken through stomata, it may be ozonolyzed in the sub-stomatal cavity and apoplast (Temmerman et al., 2002). The CO absorbed by trees is mainly fixed into serine and subsequently goes through the serine pathway to sucrose. Some portion of CO may also be fixed as $C0_2$ through photosynthesis (Bidwell & Fraser, 1972; Nowak, 1994). It is important to note that the atmospheric gaseous pollutants are removed when they react with urban trees and are uptaken (Nowak, 1994).

Hence, it seems that the efficacy of urban forests for air purification varies according to the structural characteristics of trees and shrubs (e.g. species, canopy size, leaf area, DBH), the local climate, the concentration of the air pollutants (Carreiro et al., 2008; Mcpherson, 1998) as well as the green patch configuration at the scale of urban landscape throughout the year (Nowak & Dwyer, 2007). The accurate quantification of these ES is not usually easy (Costanza et al., 1997; Findlay, 2013); meanwhile, appropriate practices for urban tree management need quantitative evidence (Findlay, 2013). Hence, i-Tree Eco was developed to assess the UF structure and to quantify the ES generated by the UF as well as to evaluate the monetary values of these regulatory services provided by the UF (Hirabayashi, 2016; i-Tree Eco User's Manual, 2016); it is widely acknowledged for its capabilities in estimating air quality improvement by UF (eg., Baró et al., 2014; Escobedo, Varela, Zhao, Wagner, & Zipperer, 2010). However, the number of applications like i-Tree Eco, through which the future conditions of (urban) ecosystem services are assessed and optimized based on quantitative modeling approaches, is still very limited; see (Steenberg, Millward, Nowak, Robinson, & Ellis, 2017) as examples of modeling temporal changes in UF structure. They did not consider the future potential of the UF regarding air pollution removal. Instead, they mainly focused on the variability in the spatial and temporal nature of the UF vulnerability.

Despite the quantification of the current air pollution removal by the UF, the information about the possible UF changes over time is also important, as the future pollution removal (and the monetary valuation thereof) varies according to these changes. This is despite the fact that it is vital for urban planners and policymakers to quantitatively understand the current and particularly the future conditions of the UF in providing essential urban ES. Moreover, such a quantitative analysis aids developing an optimal sustainable green infrastructure for an optimal provision of urban air pollution removal, e.g. through comparing the efficacy of various UF planting and management scenarios. As a result, the awareness of the role of urban trees with regard to ecosystem services (particularly air quality improvement) is raised. Urban policy tends to focus mainly on technical planning measures. Therefore, the potential of the UF in providing services, and hence supporting urban policies with the associated policy targets and environmental air quality standards, is mostly neglected.

While urban forests are known to substantially help alleviate the urban environmental problems (and especially urban air pollution), researchers and urban managers face the challenge of finding out how to quantify the consequences of, and to optimize, the urban forest management (e.g. by maintenance and future tree planting). It is not common to assess and to optimize the future conditions of (urban) ecosystem services, and there is virtually an absence of quantitative understanding of the future contribution of urban forest strategies to air pollution mitigation. This knowledge gap can be bridged by evaluating the potential future structures of the UF through elaborating different tree planting scenarios and estimating the resulting potential of the future urban trees in improving the air quality at the city-scale. The potential of the UF to remove air pollutants may in fact be high due to the high levels of air pollutant emissions, and cities could be an optimal place for tree planting and air quality improvement (Bodnaruk et al., 2017). These claims also need quantitative substantiation. Therefore, using Tabriz, Iran as a case study, we aimed to 1) quantify the biophysical and economical value of the air purification UES provided by the current UF, 2) elaborate scenarios on alternative tree planting schemes in order to predict the potential changes in the UF structure and composition as well as their effects on the air pollution removal potentials (the scenarios attempt to address the impact of the different levels of human manipulation of the UF structure from the potential lowest level to the highest level as well as the effects of tree planting methods on the future structure and the regulatory ES provided), and 3) assess the scenarios using different measurements to select a suitable tree planting method and the associated green infrastructure. The i-Tree Eco model was used to model the temporal dynamics of tree growth and mortality and then the impacts on air purification. By considering the number of trees planted as well as the methods of tree planting, the results may help understand the impacts of the possible structural changes on the ability of the UF to mitigate the urban air pollution problems at the urban landscape, which will in turn help develop urban policies that include appropriate UF strategies. This analysis can provide important information for such policies so that they can provide optimized future air purification ES delivered by the UF.

2. Materials and method

2.1. The study area

Iran is no exception to the air pollution problem, and some of the Iranian cities are actually among the most polluted cities in the world. In 2015, the Iranian cities experienced average air pollution with moderate to severe health effects for more than 300 days a year, and the air pollution was responsible for 19,644 deaths in 2013 (World Bank Group, 2016).

This study was conducted within the municipal administrative borders of Tabriz, the capital of the Eastern Azerbaijan province, northwestern Iran (Fig. 1), which had a population of 1,558,693 people in 2016 (Statistical Center of Iran, 2016) in an area of 24,479.40 ha.

This mountainous city has a semiarid climate with 4 distinct seasons (spring, mild; summer, dry; autumn, rainy; and winter, snowy and very cold) (Azarafza & Ghazifard, 2016). The hot, cold, welt, and dry periods and the growing season in Tabriz last, respectively, for 3.4 (June 6 to September 19), 3.5 (November 25 to March 8), 7.3 (October 21 to May 30), 4.7 (May 30 to October 21) and 7.6 months (July 1 until June 30), respectively (IMO, 2017). The annual wind speed is about 3.2 knot. The annual mean precipitation is about 311.1 mm, which is mostly during autumn and winter (from October 16 to June 1). A total accumulation of 24 mm of precipitation falls during the middle of the spring. Temperature typically varies from -12.5 °C–38 °C and the annual mean is 12 °C (IMO, 2017).

Like other urban regions in Iran, Tabriz encounters diverse environmental issues, indicated by poor environmental health indicators (Ghozikali, Mosaferi, & Naddafi, 2013). The most important environmental problems in the city are air pollution and water scarcity. Tabriz is one of the most polluted Iranian cities; statistics indicate that only 19% of the year had seen clean air in 2014 (World Bank Group, 2016). NO_x, SO_2, CO and PM are among the main air pollutants in Tabriz (Azarafza & Ghazifard, 2016). There is a relatively high anthropogenic pollutant emission, as it is considered the “commercial and industrial heart” of NW Iran, and its unique topography, shaped as a huge bowl located in a plain surrounded by mountains, acts as a trap for heavily polluted air (Esmailnejad, Sani, & Barzaman, 2015; Gorbani, Delir, & Firoozjah, 2012) with occasional aggravation of air pollution by thermal inversions as well as the meteorological conditions, which places Tabriz among the cities with the worst urban air quality.

The centeralized economic growth has caused an influx of industries and people into the metropolitan area of Tabriz, extending the city size by about 35 times over since a century ago. This has led to the formation of slums in the urban fringe (Ahari & Sattarzadeh, 2018; Rahimi, 2014; 2016) and land use changes, with 4715 ha of green spaces converted into urban land uses during the last three decades (Rahimi, 2014), all taken together resulting in accelarated environmental quality deterioration (Esmailnejad et al., 2015; Gorbani et al., 2012). The city is surrounded by semi-arid areas and is characterized by a poor level of UGI (both artificial and natural green spaces) and different categories of urban parks, which limits the accessibility of the UGI ecosystem services to the dwellers (Breuste & Rahimi, 2015; Teimouri & Yigitcanlar, 2018). The green spaces in Tabriz have become increasingly isolated and fragmented and the green patches are increasingly disconnected (Ghorbani & Teymouri, 2017; Mikaeeili & Sadeghe, 2011; Teimouri & Yigitcanlar, 2018), which results in the impairment and dysfunction of the remaining UF (Akbarzadeh, Shahrokhi, Kouhgardi, & Farboodi, 2011). The city has about 874 parks within the 10 municipal districts. The per capita green space in the city (14.8 m2) remains fair compared with the national average but much lower than the international standards; moreover, the distribution of the UGI does not balance the public access to the UGI on foot (Breuste & Rahimi, 2015; Ghorbani & Teymouri, 2017; Toutakhane & Mofareh, 2016).

2.2. The i-Tree Eco model

The i-Tree suite is a peer-reviewed software toolkit developed by the USDA Forest Service to quantify UF structure and ecosystem services and disservices. It includes several analysis tools (e.g. i-Tree Eco) and utility programs (e.g. i-Tree Pest Detection Module) (i-Tree, 2018; i-Tree Eco User’s Manual, 2016). Among these, Eco is the most suitable tool for international projects (Kiss et al., 2015). The basic i-Tree process is Structure-Services-Value, which contains four main steps to quantify the ES and values (Nowak, 2019) (Fig. 2). It means that there is a dependency between the assessment of urban forest structure and ES and values. The application of the correct urban forest data along with accurate methodology to quantify ES leads to valid estimations of the ES provided by the UF (Nowak, 2019). The i-Tree Eco model has been designed based on field-based assessments and provides detailed data required by urban managers in order to make sustainable decisions on UF (D. Nowak, 2013). The model estimates the amount of pollution removed by UF within a year through dry deposition modeling for O_3, SO_2, NO_2, CO and $PM_{2.5}$ and also estimates the associated economic values (i-Tree Eco User’s Manual, 2016). It combines the characteristics of tree and shrub species with information on location, environment and the abundance of trees and shrubs based on the collected field data so as to estimate air pollution removal by UF (Fig. 3) (i-Tree Eco User’s Manual, 2016; Nowak et al., 2006; Nowak, Hirabayashi, Bodine, & Greenfield, 2014).

As this model was specifically developed for the US, the steps for conducting and completing projects outside the US need more work and require additional data collection (Fig. 3). In order to develop i-Tree Eco for our case study, additional data was collected on location, hourly precipitation as well as on air pollution concentrations. Hourly precipitation data (meters per hour) for a complete calendar year (2015) of the synoptic station of Tabriz (located in 38.13 °N and 46.23 °E) obtained from Iran Meteorological organization (IMO, 2017) and submitted to i-Tree Database. Pollution data for O_3, SO_2, NO_2, CO and $PM_{2.5}$ in the hourly format for the same year obtained from Department of Environment, Iran (DOI, 2016) for an atmospheric monitoring station (located in 38.07 °N and 46.29 °E) and submitted to i-Tree Database. Also, other required weather data obtained automatically by i-Tree Eco form selected station (synoptic station of Tabriz).

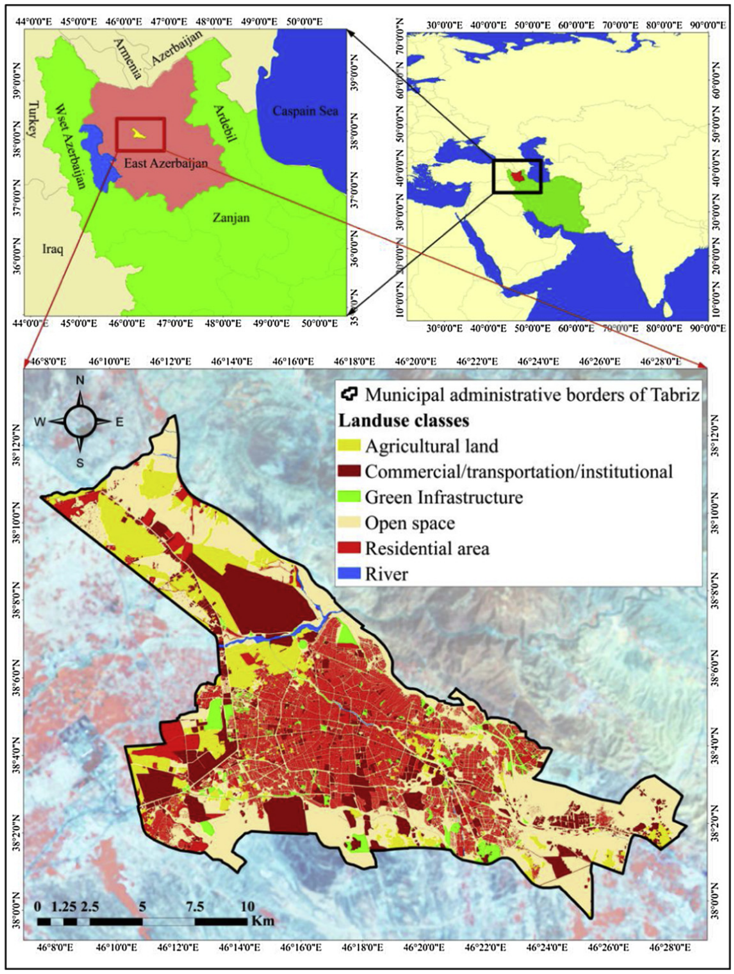

Fig. 1. Location of the study area and land use classes (Source: Land use map of Tabriz (scale; 1:25,000) obtained from municipality of Tabriz).

2.2.1. Field data collection

The i-Tree Eco protocols (i-Tree Eco International Projects, 2016; i-Tree Eco User's Manual, 2016; i-Tree Field Guide, 2016) were followed to collect the required field data in 2015 (thus the results of the model will correspond to the year 2015). A pre-stratification method was applied in order to divide Tabriz into smaller units based on land use classes. The original land use map was obtained from the municipality of Tabriz (with 1:25,000 scale, for the year 2017) and was reclassified into 7 classes (see Fig. 1 and Table 1). In order to balance data uncertainty, time, resource limitation and costs for the field survey, a total of 330 plots with a radius of 11.34 m were sampled. This would allow achieving a standard error of about 10% for the entire city (Nowak, Walton, Stevens, Crane, & Hoehn, 2008). A total of 300 plots would be sufficient for this purpose, and an additional 5–10% were added to replace inaccessible plots if needed (i-Tree Eco User's Manual, 2016).

The plots were pre-stratified such that more plots were achieved in those land use classes of the interest with the highest number of trees. The level of interest was assessed by distributing a questionnaire to 15 experts (academic staff of the University of Tabriz, Iran) to score each land use based on interest, possibility and potential for the existence of

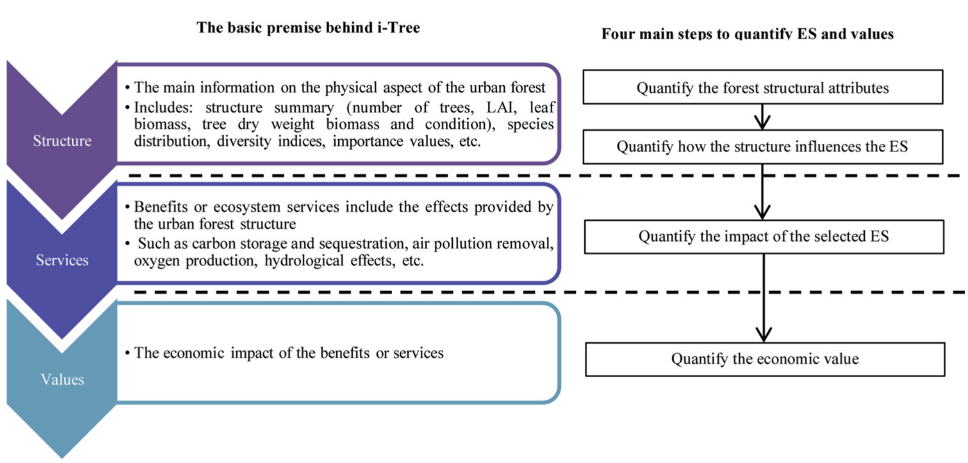

Fig. 2. The relation between the critical elements behind the i-Tree process and the four main steps to quantify the ES and values (adapted from (Nowak, 2019)).

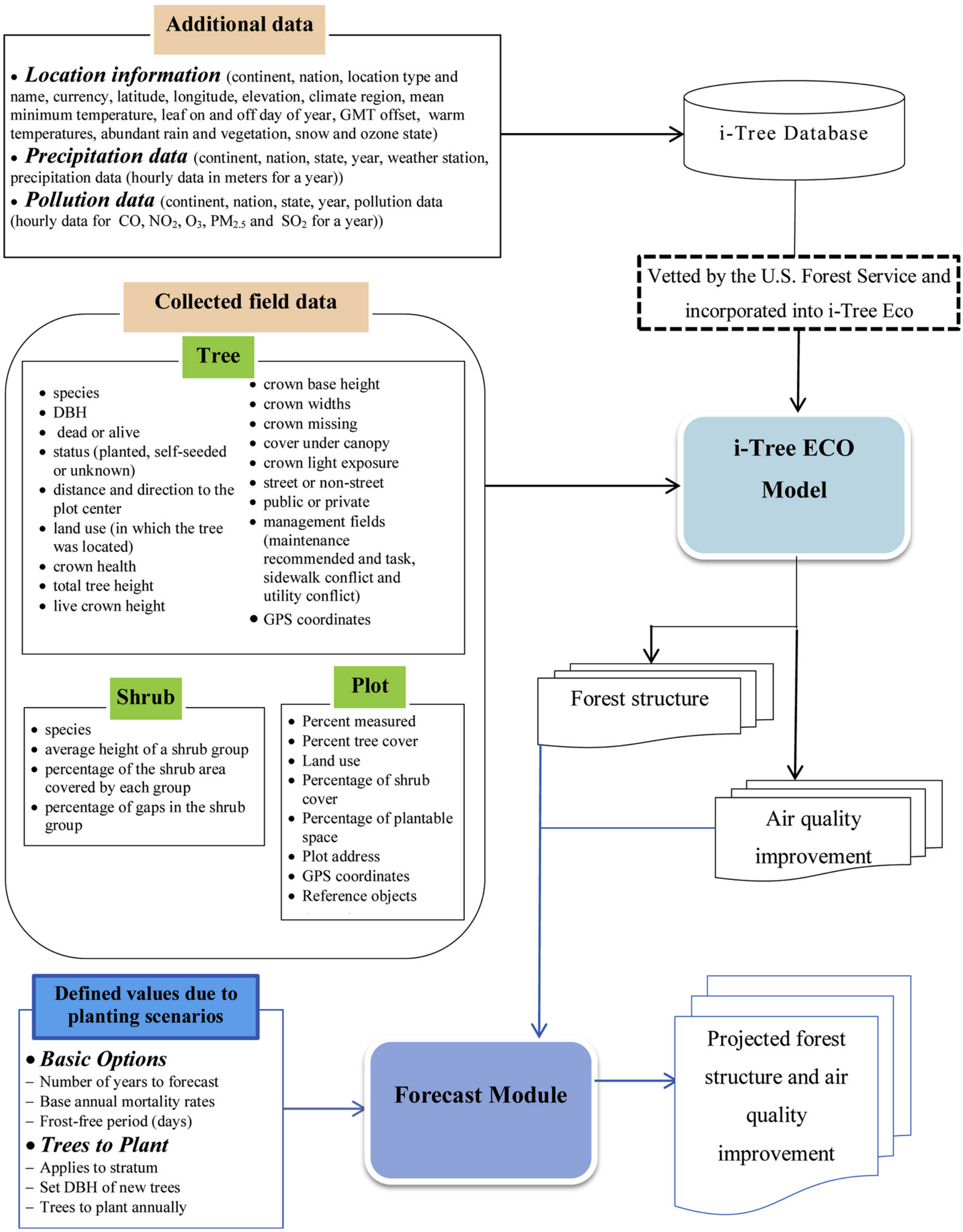

Fig. 3. Summary of the methodological process and the data used.

Table 1
Land use classes of Tabriz and the number of plots.

Land uses classes	Area (ha)	Area (%)	WOI	RWOI	Final number of plots
Commercial/transportation/institutional (CTI)	4325.55	17.67	0.46	0.15	51
Agricultural	3026.90	12.37	0.53	0.17	57
Green Infrastructure	760.71	3.11	0.92	0.30	100
Residential	5080.01	20.75	0.54	0.18	59
Open space	11119.00	45.42	0.57	0.19	63
River	167.24	0.68	0.00	0.00	0
Total	24479.40	100	–	1	330

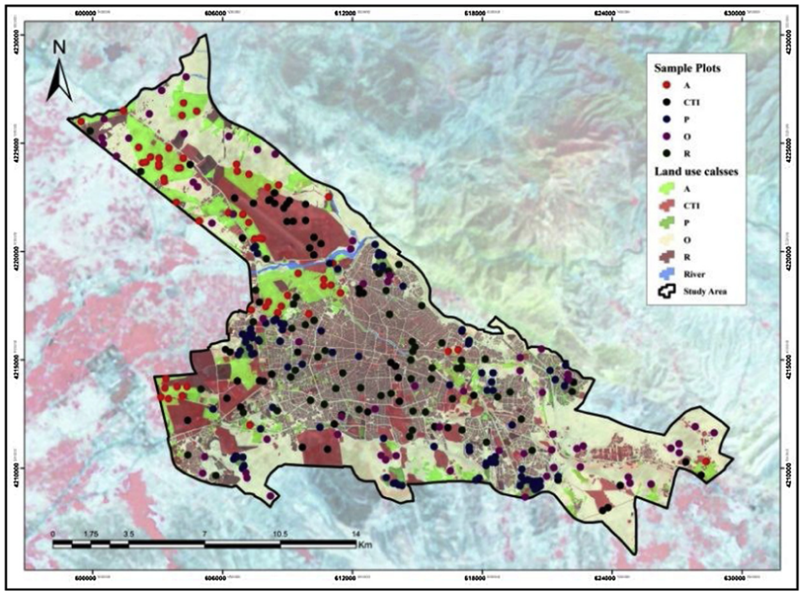

Fig. 4. Spatial distribution of sample plots within the municipality of Tabriz.

trees within each land use class from 0 to 1 (1 being more interested). The Weight of Interest (WOI) for each land use class shows the average level of interest provided by the experts and calculated as:

$$WOI = \frac{\sum_{i=1}^{n} a_i}{n} \tag{1}$$

Where WOI is the mean value of interest for each land use class; a_i is the level of interest of expert (i) for each land use class; and n is the total number of experts (n= 15).

The RWOI (Relative Weight of interesting) was calculated by multiplying WOI by the area percentage of each class. Finally, RWOI was multiplied by the final number of plots (330) to obtain the number of plots for the each land use class (Table 1). Water bodies (rivers) were omitted from the analyses because only terrestrial ecosystems (UF) were taken into account. Moreover, the i-Tree Eco model is not able to assess the ES of water bodies. The sample plots were randomly placed within the boundaries of each land use class using the Random Points Generator of ArcGIS 10.4.1 (Fig. 4).

The field survey was carried out from June 5 to October 2, 2017. The plot center was located using a GPS device, 1:5000 digital aerial photos (obtained from municipality of Tabriz), and Google Earth, and outlined to 11.34 m utilizing reference flags. Only 5 plots turned out to be inaccessible (e.g. due to a lack of permission to enter) and were omitted from further analyses.

All the data on the plot, trees and shrubs was collected for each plot (Fig. 3). This adds to the cost of the project but substantially improves the accuracy of the Eco estimates. This huge collected dataset can be subsequently used for proper UGI management.

The i-Tree Eco model uses the field data to assess the urban forest structure through the composition and structure module. This module provides information on the summary of structure by species and strata (e.g. the number of trees, LA, leaf biomass, tree dry weight biomass), summary of population (e.g. the percentage of population), distribution of species by DBH classes, diversity indices, ranges of species (native range) and importance values by species (i-Tree Eco User's Manual, 2016; Nowak, 2019). Importance values (IV), which show the species currently dominating the urban forest structure, was calculated as follows:

$$IV_i = P_i + LA_i \tag{2}$$

Where P_i is the percentage of population and LA_i is the percentage of leaf area of species (i). It should also be noted that high importance values do not mean that these trees should necessarily be encouraged in the future (i-Tree Eco User's Manual, 2016; Nowak, 2019).

2.2.2. Air quality modeling

The i-Tree Eco model uses input data on air pollution, meteorology and the collected field data on trees and shrubs to quantify the air purification (during non-precipitation periods) throughout the year (Hirabayashi, Kroll, & Nowak, 2015; Nowak et al., 2006). The model estimates pollutant fluxes for CO, NO_2, SO_2, O_3 and $PM_{2.5}$ as a product of the input air pollutant concentration and the deposition velocity (Hirabayashi et al., 2015):

$$F = V_d \times C \times 3600 \tag{3}$$

Where F is the pollutant flux ($gm^{-2}h^{-1}$), V_d the deposition velocity (ms^{-1}), and C is the air pollutant concentration (gm^{-3}).

V_d for CO, NO_2, SO_2, and O_3 is calculated as the inverse of the sum of the canopy resistance (R_c (sm^{-1})), quasi laminar boundary layer resistance for a type of air pollution (R_b (sm^{-1})) and aerodynamic resistance (R_a (sm^{-1})) (Baldocchi, Hicks, & Camara, 1987) :

$$V_d = \frac{1}{R_{a+R_b+R_c}} \tag{4}$$

The V_d estimation for $PM_{2.5}$ was based on literature and assumed to vary according to the wind speed (Beckett, Freer-Smith, & Taylor, 2000; Freer-Smith, El-Khatib, & Taylor, 2004; Pullman, 2009).

The hourly air quality improvement per unit of tree cover due to the dry deposition of the pollutants I_{unit} (%) was calculated as follows:

$$I_{unit} = \frac{F}{F + M_{total}} \times 100 \tag{5}$$

Where F is the pollutant flux ($gm^{-2}h^{-1}$) and M_{total} is the total air pollutant mass per unit of tree cover ($gm^{-2}h^{-1}$). The hourly air quality improvement for total tree cover (I_{total}) is as follows:

$$I_{total} = \frac{F \times \frac{T_c}{100}}{F \times \frac{T_c}{100} + M_{total}} \times 100 \tag{6}$$

Where T_c is the urban total tree cover (%). (For a more detailed description, see Hirabayashi et al., 2015).

2.2.3. Economic value

To estimate the economic value associated with air pollution removal by the UF, i-Tree Eco uses median externality values established for the U.S for pollutants from the scientific literature (Murray, Marsh, & Bradfor, 1994) which are based on the value of dollars in 2007 (Hirabayashi et al., 2015). Consequently, the pollution removal value is based on 1517.07 $ per tonne of CO_2, 10,681.240 $ per tonne of O_3, NO_2, 2614.94 $ per tonne of SO_2, and 7131.37 $ per tonne of $PM_{2.5}$.

2.3. Scenarios

Enhancing the quantity and quality of regulatory ES received from the UF is a valuable measurement in terms of the air quality improvement and hence the sustainability of urban development (Finlayson-Schuele, 2015; Pearlmutter et al., 2017). The UF may change over time not only by management (e.g. tree planting and logging), but also by natural factors (e.g. succession, natural regeneration and pests) (Nowak, 1993; Nowak, Kuroda, & Crane, 2004). Projecting future trends of the UF based on different scenarios can help urban planners to optimize the UF structure and its UES by understanding the changes in the UES (Nowak, Hoehn, Bodine, Greenfield, & O'Neil-Dunne, 2016). The Forecast module of the i-Tree Eco model provides the tool for simulating the future projects with various tree covers, compositions, and structures (tree population density, canopy cover, age, LAI, DBH and biomass distribution as well as patch configuration) and benefits (carbon storage and sequestration and pollutant removal) based on the current urban forest structure as well as the user-defined basic options demonstrated in Fig. 3 (i-Tree Forecast Model, 2016; Nowak, 2019). The main elements of this module are: 1) *tree growth;* annual DBH growth for the study area estimated as a function of tree competition and condition, the length of the growing season, mean growth rates and existing tree height referred to the maximum value, 2) *tree mortality*; annual mortality rates based on canopy dieback and user-defined rates based on tree size classes and DBH, and 3) *tree establishment;* based on the user-defined number of trees planted annually. Forecast projects urban forest population (classified as species and DBH cohorts) according to the user-defined mortality rates, the estimated growth rates, the annual rate of planting and the air pollution removal as well as variable removal rates in regards to tree LAI) (i-Tree Forecast Model, 2016; Nowak, 2019).

UF managers may alter the UF structure through several management practices (e.g. tree planting programmes) so as to improve the ES provided by the UF. In other words, the UF structure are managed so as to indirectly influence the UF functions in order to obtain the desired condition. Besides these man-made changes in the UF structures, the current UF and the state of environment (e.g. tree growth and mortality) has important impacts on the UF structure. The scenarios attempt to cover the impact of the potential levels of human manipulation of the UF structure from the zero level (no man-made changes, which reflects the effects on the current UF and environment such as tree growth and mortality), through the low manipulation or the pessimistic option (to sustain the current condition), and the probable and real goal (following the municipal planting programme), to the most optimistic option (to achieve the 40 Percent Urban Tree Canopy Goal) on the future structure and the regulatory ES provided. In order to present alternative potential futures of the UES in general and the air pollution removal capacity in particular and in order to optimize the planting practices, the pessimistic, optimistic and probable options were considered in four scenarios that were run for 20 years within the Forecast module of the i-Tree Eco model (i-Tree Forecast Model, 2016). In order to assess the effects of the tree planting methods on the UF structure and the air pollution removal potentials, each scenario may be divided into two sub-scenarios based on the differences in the planting regime; sub-scenario "a") *proportional planting:* trees are planted in all land use classes randomly; new trees are added proportionally to each class based on the number of trees already in that stratum and sub-scenario "b") *assigned planting:* planted trees are distributed among various classes based on what an optimal class may be for trees to improve the air quality, e.g. more trees are planted in land use classes with more polluting activities and lower tree cover. The four main scenarios are:

A ***Continuing the current UF situation without planting any trees***

The most pessimistic scenario is based on the hypothesis that no tree is planted for the next 20 years. This scenario aims to outline the consequence of when there is no human influence on the UF structure and to understand what happens to tree society if the planting programs paused (which means that the number of trees is not altered by managers). In other words, this scenario attempts to simulate the impacts of the existing UF and environment, especially tree growth and mortality, on the future forest structural elements (e.g. tree cover and number) as well as the effects of the changes on the resulting air quality improvement ES.

- ***Avoid reducing the number of existing urban trees***

This scenario aims to estimate what the UF will look like if the current number of trees is maintained. This scenario is considered as the low level of human manipulation of the UF, or the pessimistic option. Based on the planting method and location, this scenario is divided into two sub-scenarios: $\mathbf{B_a}$) *proportional planting* and $\mathbf{B_b}$) *assigned planting.*

- ***Tabriz Municipal Tree Planting Programs***

The municipality of Tabriz aims to plant 100,000 trees per year. In this realistic and probable scenario (the mid-level of human manipulation of the UF structure), two sub-scenarios were developed to assess the future condition; $\mathbf{C_a}$) proportional planting, $\mathbf{C_b}$) assigned planting.

- ***Achieving a 40 Percent Urban Tree Canopy Goal***

A benchmark to achieve a 40% tree canopy cover was adopted from (Ian Leahy, 2017), and served as the optimistic scenario (high level of human manipulation of the UF structure). This scenario is also divided into two sub-scenarios; $\mathbf{D_a}$) proportional planting and $\mathbf{D_b}$) assigned planting.

Finally, the efficacy of each sub-scenario in mitigating urban air pollution problems was compared through four measures (Table 1). These measures are proxies for the economic costs of tree planting, tree maintenance and the environmental benefits (air purification ecosystem service) (Table 2).

3. Results

3.1. UF structure in Tabriz

The UF in Tabriz contain an estimated number of 1,928,000 (± 237,045, the standard error of about 12.3%) trees covering of 9.4 percent of the urban area, and provide 83.73 km^2 of leaf area (Table 3). The dominant tree species include *Robinia pseudoacacia* (12.5%), *Fraxinus excelsior* (9.8%), and *Elaeagnus angustifolia* (8%). Trees with DBH of less than 15.2 cm constitute 77.9% of the tree population. Fig. 5 shows the 10 species with the greatest importance values (*IV*).

Table 2
Measures to assess the efficacy of the scenarios.

Measure	Unit	Target
Total air pollutant removal	Tonnes	Maximize
Trees planted each year	Number per year	Minimize
Tree cover	%	Maximize
Total number of tree	Number	Maximize

Table 3
Tree population summary by Strata.

Strata (Land use classes)	Number of Trees	Percentage of Population	Tree Density (Number/ha)	Leaf Area (%)
Agricultural land	110222	5.7	36.4	711.88
CTI	257913	13.4	59.6	795.06
Open spaces	702131	36.4	63.1	3559.42
Green spaces	346616	18.0	455.6	1310.76
Residential area	510684	26.5	100.5	1995.92
Study Area	1927566	100.0	79.3	8373.04

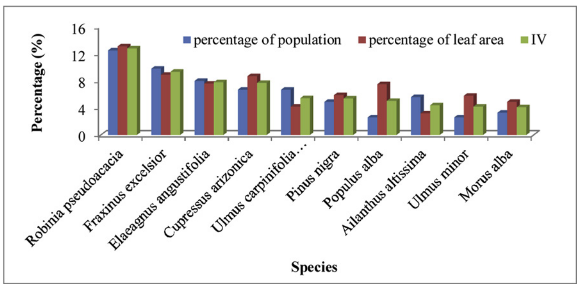

Fig. 5. The most important and dominant species in Tabriz based on Importance Value (*IV*).

The overall tree density was about 79 trees per hectare, with the highest tree densities occurring in green spaces, followed by residential and open spaces (Table 3).

3.2. Quantification and valuation of the air quality improvement

It was estimated that trees and shrubs in Tabriz removed 238.4 t of the air pollutants in 2015 (65.38 t of O_3, 18.04 t of CO, 89.04 t of NO_2, 12.21 t of $PM_{2.5}$ and 53.69 t of SO_2 per year) with an associated economic value of 190,889.873 $. Pollution removal was greatest for NO_2, accounting for 49.92% of the total economic value (953,395.34 $ year^{-1}), followed by the value for O_3 while lowest values occurred for CO and $PM_{2.5}$ (Fig. 6).

The green space areas removed most air pollution (37.34%) followed by residential areas (8.51%), open spaces (6.93%) and agriculture (5.09%), while the CTI had the lowest contribution (3.98%). This air pollution removal pattern was related to the compositional and structural characteristics of the trees in each class and especially to tree cover (see Table 3). These results indicate that tree and shrub cover in the more polluted areas (e.g. in CTI) was not in the proper condition to act as an effective tool to improve the air quality. An increase in the number of trees in CTI may lead to greater air pollution removal, which was investigated through the scenarios.

The air pollutant removal varies throughout the year (Fig. 7), and peaks in May for O_3 and NO_2 and in October for SO_2, similar to studies in the US (Nowak David, 1994). In general, the results showed that

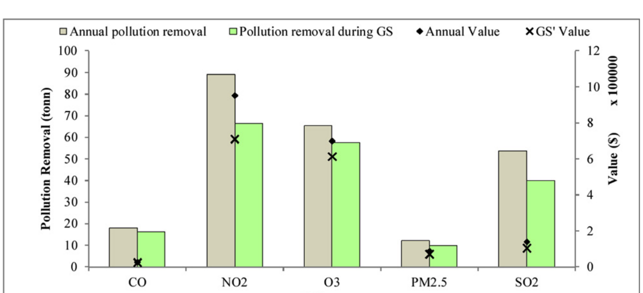

Fig. 6. Annual and growing season' (GS) air pollution removal and economic values.

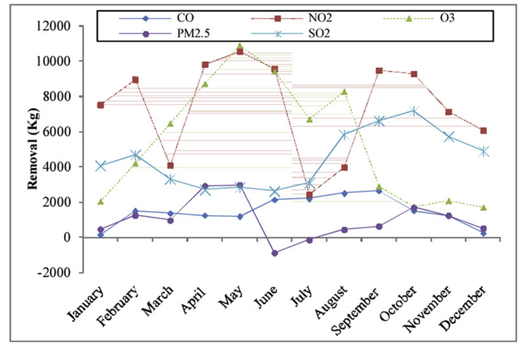

Fig. 7. Monthly and annual air pollution removal by trees and shrubs in Tabriz, 2015.

July, August, and September were the months where the sum of the pollutant uptake values was highest for all pollutants except for $PM_{2.5}$ (40.9, 17.9, 27.4 and 29.0% of the total removal for CO, NO_2, O_3 and SO_2 respectively). For $PM_{2.5}$, about 50% of the total uptake occurred in May and April. This implies that 79.65% of the total annual air pollution removal and 89.23% and 87.75% of the total CO and O_3 removal occur during the growing season in Tabriz (March to November) (see Fig. 6 and Table 4). This is supposedly the result of a combination of more leaf area, higher activities of trees and shrubs and the seasonal variation in air pollutant emissions (Baró et al., 2014; Nowak, 1994).

The results also showed negative values for $PM_{2.5}$ removal in June and July (Fig. 7 and Fig. S 1) which means the trees resuspended more particles than they removed. The $PM_{2.5}$ deposition process is mostly mechanical, involving the particulates being deposited on the leaf surface during times of low wind (such as in June and July) and removed from the system, typically by rainfall and dissolved or transferred to the soil (Nowak, Greenfield, Hoehn, & Lapoint, 2013; Nowak, Hirabayashi, Bodine, & Hoehn, 2013), as happened in the other months. This combination of events can lead to positive or negative pollution removal and value depending on various atmospheric factors. In this case, the annual $PM_{2.5}$ removal was positive (see Table 4). The $PM_{2.5}$ is not "locked-up" by the tree and can be redistributed from leaf surface into the air during high winds. It is in these cases, when the trees are actually facilitating the redistribution of particulates, that the negative impact of trees on $PM_{2.5}$ occurs (for more information see (Hirabayashi et al., 2015)). So, in our study, this may due to the combination of very low precipitation, drought and winds.

3.3. Performance of the scenarios

Fig. 8 summarizes the results for the air pollutant uptake, number of trees and the percentage of tree cover in each of the scenarios. If no tree is planted for the next 20 years (Scenario A), the number of trees decreases by 1,298,650 (which is a decline of 67%), while tree cover increases by 25.1% (0.785% increase per year) and will remove 486.3 tonnes of air pollutants in the 20th year. This latter effect is due to

Table 4
Annual pollution removal by trees and shrubs during the entire year of 2015 and Growing Season (GS; t year^{-1}) and the economic value (thousand $) in Tabriz.

Pollutants	Air pollution removal			Values		
	Annual	GS	GS/Annual (%)	Annual	GS	GS/Annual (%)
CO	18.04	16.10	89.26	27.44	24.43	89.26
NO_2	89.04	66.45	74.64	953.40	709.80	74.64
O_3	65.38	57.37	87.75	700.07	612.75	87.75
$PM_{2.5}$	12.21	9.94	81.46	87.26	70.90	81.46
SO_2	53.69	40.00	74.49	140.76	104.60	74.49

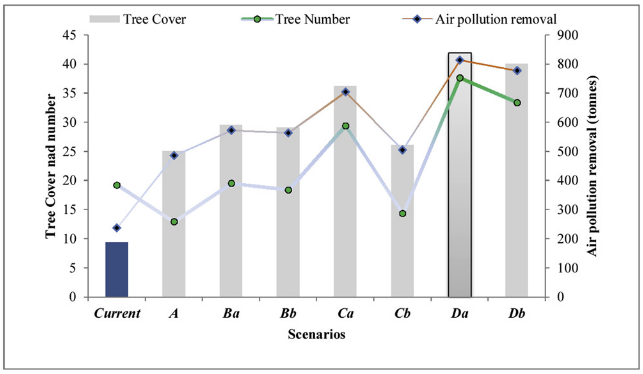

Fig. 8. Comparison of the current values with the final tree cover (%) and number (in 100 thousand) and the combined air pollutant removal in the 20th year throughout the scenarios.

the growth of the surviving trees. About 40,000 trees need to be planted proportionally per year in order to maintain the current number of trees (scenario B_a). This leads to a 20.2% increase in the tree cover and a pollutant removal of 335.4 t by the 20th year. However, through the assigned planting method (Scenario B_b), a total of 400,000 trees needed to be planted annually (e.g. 160,000 and 139,600 trees per year in CTI and R) to maintain the current number of trees. This planting method allows gaining an additional 19.7% tree cover, and removes 564.39 tonnes of the pollutants with an associated value of 3043.6 thousand USD in the next 20 years. The B_a scenario removes 9.4 tonnes of pollutants more than B_b, while it needs 10x fewer trees (this will be discussed in the next section). If the tree planting programme in Tabriz carries out planting 100,000 trees annually proportionally (C_a), the city will reach a tree cover of 36.3% and the number of trees will increase 1.57 times, removing 647.5 t of pollutants by the 20th year. If the planting programme is carried out through the assigned planting method, a tree cover of 26.1% is obtained, with the final number of trees being 1,438,677. Achieving a 40% tree cover in Tabriz requires planting 150,000 and 1,500,000 trees annually for the proportional (D_a) and assigned planting method (D_b), removing 814.46 and 778.48 t pollutant by the 20th year, respectively.

A comparison of the sub-scenarios with respect to the chosen measures is shown in Table 5. Scenario D_a can be considered as the most promising strategy for Tabriz' UF development, as it provides most environmental benefits (most tree cover, the highest number of trees and most pollutant removal) with low costs (cost for tree planting and maintenance). The proportional planting methods reached the goals by planting fewer trees in all scenarios and it can be considered as the most cost-effective method.

4. Discussion

UF is generally recommended as an effective measure for removing the air pollution at the city-scale, which consequently helps improving the human health in cities (Nowak et al., 2006; Nowak, Hirabayashi, Doyle, McGovern, & Pasher, 2018; Vos et al., 2013). Integrating the UF services into the environmental quality strategies can help to identify the UF structure that optimizes the quality of life in the cities (Escobedo, Kroeger, & Wagner, 2011). While a growing number of studies focus on the current air purification provided by UF, there is still a lack of studies that assess the efficacy of the future urban tree planting strategies for local air pollution removal. Insights gained from such studies can provide useful, supplementary information for urban policymakers to make more sustainable decisions. The potential of urban trees in removing air pollution significantly depends on structural and configurational factors of urban forests, which change over time by natural (e.g. growth and mortality) and anthropogenic (e.g. tree management measures) drivers. Therefore, it is essential to understand the impacts of the possible structural changes on the ability of the UF in mitigating the urban air pollution problems at the city-scale. This helps the urban policymakers develop urban policies that include appropriate UF strategies. Such policies should include choices for the number of trees planted, as well as the methods of planting. Scenario analysis can prove important for such policies to provide optimized air purification ES in the future through UF.

Table 5
The efficacy assessment of the scenarios.

Ranked	Scenarios	Combined Air pollution removal (t)	Tree Cover (%)	Number of Trees (per ha)	Tree planted per year
1	$\mathbf{D_a}$	**814.4636**	**42**	**38**	**150000**
2	D_b	778.4835	40	33	1500000
3	C_a	705.0377	36	29	100000
4	B_a	573.7935	30	20	40000
5	B_b	564.3969	29	18	400000
6	C_b	506.2547	26	14	100000
7	A	486.3141	25	13	0

Therefore, in addition to quantifying the current air pollution removal by the UF, this research made an attempt to assess the future UF structures and the consequent air pollution removal potential through determining the impacts of different scenarios (the four main scenarios with seven sub-scenarios regarding planting methods) and to evaluate them using several measures associated with environmental and economic objectives so as to identify the most appropriate UF strategy for the study area. This scenario planning can serve as a tool for urban planners helping them to determine preferable planning approaches, and to understand the trends in the UF structure and ES, including air purification.

Comparing the results to other cities (Table 6) shows that Tabriz has a somewhat below-the-average number of trees, but its tree cover is among the lowest, exceeding only Phoenix, Casper and Bangkok (suggesting that it has relatively small trees). Pollutant removal by the trees in Tabriz is also amongst the lowest (followed only by Jersey City, Bangkok, and Casper when expressed per hectare). While tree cover may be a dominant factor for this low removal, the incongruity of the biological cycle of the tree species with the climate and seasonal variations in air pollutant concentrations may also have contributed to this effect. In addition, factors excluded in the i-Tree model, such as resource limitations for tree growth, pollutants dispersion at different scales and different physiological characteristics among different climatic zones, may affect pollutant removal as well (Jayasooriya et al., 2017; Saunders et al., 2011; Yang et al., 2005). This comparative analysis considered neither the spatial configuration of the tree cover, nor other structural aspects such as core areas for tree cover, or the local patterns of air pollution. The spatial configuration, including for instance the connectedness of the green network, its structure and natural matrix connectivity also affects the provision of other ecosystem services as well as the resilience of the urban landscape/green cover. More research is needed for a better understanding of how these factors affect trade-offs among ecosystem services.

The results showed that the current composition and structure of the UF in the study area is not optimal for air quality improvement (77.9% of the trees have not grown enough to provide substantial air pollution removal (Nowak, 1994)). These predominant young trees can also be considered as a potential for the future. If their growth is properly managed, then they will become healthy large trees and remove more air pollution than they currently do (as shown in scenario A). This means that the current weakness (young trees) can be overcome and changed into an opportunity (healthy large trees) by proper UF maintenance and management (Mini-Maxi Strategies).

Despite the modest air quality improvement by the UF, even such small improvements in air pollution can have significant health benefits (in addition to the economic savings) (Baró et al., 2014; Nowak et al.,

Table 6
Annual air pollution removal and trees for different Cities.

City	Tree			Air pollution removal		References
	Number	Cover (%)	per hectare	Tonnes/yr	Kg/hectare/yr	
Tennessee, U.S	284116000	37.7	450	27100	42	Nowak, Cumming, and Twardus, 2011)
Houston, U.S	33300000	18.4	83	2400	13	Nowak et al. (2017))
Toronto, Canada	10,220,000	26.6	160.4	1,905	29.9	Nowak et al. (2006))
Atlanta, GA	9,415,000	36.7	275.8	1,509	44.2	Nowak et al. (2006))
Los Angeles, CA	5,993,000	11.1	48.4	1,792	14.7	Nowak et al. (2006))
New York, NY	5,212,000	20.9	65.2	1,521	19	Nowak et al. (2006))
London, Eng	4,376,000	24.7	185.5	370	15.7	Nowak et al. (2006))
Chicago, IL	3,585,000	17.2	59.9	806	13.5	Nowak et al. (2006))
Phoenix, Arizona	3166000	9	33	1770	17.5	Mikulanis (2014))
Bangkok, Thailand	2504000	8.6	27	738	8	Intasen, Hauer, Werner, and Larsen, 2017)
Baltimore, MD	2,479,000	21	118.5	390	18.6	Nowak et al. (2006))
Philadelphia, PA	2,113,000	15.7	61.9	522	15.3	Nowak et al. (2006))
Mesquite,U.S	2091000	24.4	174	288	24	Pace and Sales (2012))
Washington, DC	1,928,000	28.6	121.1	379	23.8	Nowak et al. (2006))
Tabriz, Iran	**1,928,000**	**9.4**	**79.3**	**238.4**	**9.8**	**(this study)**
Oakville, Canada	1,908,000	29.1	192.9	172	12.4	Nowak et al. (2006))
Plano, U.S	1690000	16.4	89	337	18	PARD (2014))
Barcelona, Spain	1419823	25.2	140	305.6	30	Chaparro and Terrasdas (2009))
Boston, MA	1,183,000	22.3	82.9	257	18	Nowak et al. (2006))
Syracuse, NY	1,088,000	26.9	167.4	99	15.2	Nowak et al. (2006))
Woodbridge, NJ	986,000	29.5	164.4	191	31.9	Nowak et al. (2006))
Minneapolis, MN	979,000	26.4	64.8	277	18.3	Nowak et al. (2006))
San Francisco, CA	668,000	11.9	55.7	128	10.7	Nowak et al. (2006))
Morgantown, WV	658,000	35.5	294.5	65	29.2	Nowak et al. (2006))
Strasbourg, France	588,000	19.02	75	88.23	11	Selmi et al. (2016))
Moorestown, NJ	583,000	28	153.4	107	28.1	Nowak et al. (2006))
Hartford, CT	568,000	25.9	124.6	52	11.5	Nowak et al. (2006))
Jersey City, NJ	136,000	11.5	35.5	37	9.6	Nowak et al. (2006))
Casper, WY	123,000	8.9	22.5	34	6.2	Nowak et al. (2006))
Freehold, NJ	48,000	34.4	94.6	20	39.6	Nowak et al. (2006))

2018; Pérez, Sunyer, & Künzli, 2009). Therefore, even the current air purification service should be taken into account in local policy decisions. Unfortunately, while air quality problems are considered in urban planning process, the ES delivered by UF remain widely overlooked, despite the scientific evidences. This implies that the local planners require more information about, and increased awareness of, the ecosystem services and economic values provided by urban ecosystems. Such awareness will also increase their willingness to consider the ecosystem services that will be delivered in the future and to optimize to concomitant planning of future urban forests

As a first step to consider the spatial configuration, our study estimated the future UF growth and the associated pollutant removal for scenarios differing in spatial planting regime. The i-tree Eco model and the Forecast module therein help to evaluate the future composition and characteristics of the urban trees as well as the results for the air quality improvement. The results showed that adding new trees through the tree planting scenarios will increase the tree density by 155.19, 137.58, 121.25 trees per hectare and provide a total removal of 814.46, 778.48 and 705.03 t through scenarios D_a, D_b, C_a respectively by the final simulated year. Among the seven different tree planting sub-scenarios that were assessed, the D_a was identified as the most beneficial practice for the study area as it led to the highest air pollutant uptake and tree cover with the lowest costs compared to others.

The analyses also indicated that implementing the tree planting programme in Tabriz through the assigned method was less effective than through a random planting scheme, despite the fact that the assigned method aimed to do better by planting in areas with most pollution. The reason for the poorer performance was the increased mortality in the assigned planting scheme. As a consequence, the assigned method was not able to keep the current number of trees (438,928 trees die by the end of the projected period). Therefore, the assigned method led to less tree cover. For instance, a comparison between C_a and C_b shows that while the number of trees per year was the same for both scenarios, C_a reached 1.4 times more tree cover and removed an additional 198.78 t of pollutants by the end of the simulated timespan (see Fig. 8). As a consequence, the assigned methods needed about 10x more trees to achieve the same goals compared with proportional planting. There are several reasons that might have caused the higher mortality. Variables such as tree condition, crown light exposure, etc. will impact how trees from one stratum grow compared to another stratum and how quickly each tree increases its canopy cover. Further analyses are needed to evaluate whether a spatial configuration of UF exists, given the spatial configuration of air pollution and human exposure, that provides a higher future air purification ES than random planting. Such analyses should also account for the economic and technical feasibility of more urban tree cover as well as the maintenance demands and local constraints such as soil conditions, climate and water availability. Appropriate, locally adapted plant species will be cheaper to grow, and will provide more potential ecosystem services such as air purification in cities. Many ambitious urban tree planting programs do not comprehensively consider the species' potential ES in tree selecting process. It is suggested that the strategies for selecting and breeding urban trees should be prioritized which enables the development of new initiatives for more proper plant materials in urban forestry (Sæbø, Benedikz, & Randrup, 2003). This can be a sign of greater attention to selecting and using proper urban tree species with specifically high potential for providing ES (e.g. air quality improvement). Selecting tree species based on their potential environmental benefits, directly effects the amount of urban tree planting and indirectly influences the final tree selection (Behrens, 2011). An environmental beneficially sound urban tree selection process could be added to the list of opportunities for a more sustainable city. More research is needed to identify the most appropriate species to remove the urban air pollution. In this regard, an appropriate list of the potential urban tree species have to be recognized according to the desired ES (air pollution removal) in order to optimize the provision of environmental benefits by the urban trees

(Nowak, 2008). Insights from such studies, ideally run at smaller scales like land use patches, can help improving the sustainability of urban planning.

For such future analyses for Tabriz, it is important to note that the i-Tree Eco results showed that about 34% of the study area (8266.2 ha) could be considered as plantable space, which means that space is available for planting more trees within the study area by urban forest managers (leading to more air pollutant removal). At the same time, though, these same vacant plots (plantable area) are usually considered for future urbanization projects by urban planners. Such conflicts between greenery goals and urbanization is a common problem of urban ecosystem services. This is another argument for the need for scenario analyses – as provided in this study – to examine the future ecosystem services so as to increase the awareness and to persuade urban planners to assign area for urban greenery as well.

While using the i-Tree Eco model to estimate the current and future air pollution removal by trees has clear advantages such as the use of locally collected field data and of standardized peer-reviewed procedures (Nowak, Crane et al., 2008)), it has some limitations too. These limitations include:

- Its original was developed for the USA and there are problems associated with extrapolating the procedures to other countries (i-Tree Eco International Projects, 2016);
- Uncertainty was involved in the pollution removal quantification, as expressed by the dry deposition model for which alternatives exist (e.g. Manning, 2008; Pataki et al., 2011);
- There are complex physical and chemical interactions between trees and atmosphere (e.g. local-scale interactions with wind);
- Climatic and meteorological conditions, distribution of air pollutants and spatial particle re-suspension rates (Baró et al., 2014; Nowak, 2019; Selmi et al., 2016) were not taken into account;
- The damage that a high level of air pollution can do to trees and shrubs and its effect on reducing their pollution removal ability due to stomatal closure (Escobedo & Nowak, 2009b; Robinson, Heath, & Mansfield, 1998) were not considered in the i-Tree Eco (Baró et al., 2014);
- i-Tree Eco doesn't consider the effect of drought on gas exchange (Nowak, 2019);
- The estimation of PM10 was dropped in favor of using PM2.5;
- The model excluded air pollution removal by grass/herbaceous;
- Weather data in the i-Tree database (from the National Climatic Data Center (NCDC)) is only available until 2015 which limits projects supposed to be conducted based on the data from the last few years (2016–2018). As for the projects in which the samplings are done in the years after 2015, the collected field data and the weather and pollution data would not belong to the same year; for example in this study, the field data was for 2017 but the weather and pollution data were limited for 2015. So there is a gap between the weather and pollution data and collected field data for the projects done after 2015;
- The amount of estimation error in calculating leaf area, leaf biomass and tree biomass is unidentified (Nowak, Greenfield et al., 2013; Nowak, Hirabayashi et al., 2013);
- While the model allows for spatial analysis, it does not consider the impacts of spatial network and configurations of trees and the results are not spatial.

Other limitations of this study include, some of the plots (5 plots) were inaccessible; the valuation of air purification was based on the default values of i-Tree Eco, not the local valuation data; the turnaround (vetting the user-submitted additional data to the i-Tree database and then incorporating into the updated i-Tree Eco (i-Tree Eco International Projects, 2016) took time; some of the model components (e.g. air quality health impacts and values) are not available for this project. Estimation variance may decrease by distributing the plots to the areas with the highest variability. However, this is not certain prior to the sampling. So two approaches were adopted: pre-stratify the plots by either a) putting more plots in the areas that are of the highest interest, and b) putting more plots in areas that will have most trees (as trees are the primary interest). Due to the lack of knowledge, information and particularly a map of tree cover prior to this study, we had to distribute the plots based on experts' interests, not on the real tree cover (which can help putting more plots in areas that have most trees). The lack of access to remotely sensed data, which can be used to extract the UF structural traits such as tree canopy, makes us unable to compare the i-Tree results on the UF structure with them. Future research is needed to help overcome these limitations.

5. Conclusions

The effects of the current UF in Tabriz are relatively small (less than 1%), but this can improve through appropriate planting practices. We have seen how the future air quality may improve by air purification through UF. Our research also shows that the efficacy of the urban tree planting strategies in improving the air quality varies according to the number of trees planted and the spatial planting method. Implementing an optimal planting design, along with other technological and non-technological measures, can help to substantially alleviate the air pollution. This study provides hints on the potential contribution of UF to the air pollution removal and in sustaining human health in urban areas. Assessing the current and particularly possible future air quality improvements by UF demonstrates how urban green infrastructure makes cities more sustainable for future generations.

Acknowledgments

We would like to give our warmest regards to Mr. Babak Chalabiani for his invaluable help during the field survey. We thank Dr. David Nowak from USDA Forest Service for his valuable support and advice, the i-Tree tools team, especially Dr. Jason Henning and Erika Teach for their technical assistance. We also thank all scientific colleagues for completing the questionnaire. We also would like to express our deep gratitude to the people of Tabriz for their help and kindness during the field work. This research was partially funded by the Iranian National Science Foundation (No. 96000398).

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