

Ecosystem Services Provided By Urban Forests In The Southern Caucasus Region: A Modeling Study In Tbilisi, Georgia

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Research

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Abstract

All cities globally are growing considerably as they are experiencing an intensive urbanization process resulting in significant economic, social, and environmental challenges. One of the major risks is the deterioration of living environment in urban areas due to the high soil consumption and pollution of environmental components. For this reason, cities are required to adopt measures to reduce air pollution concentration and CO₂ emissions, preserve biodiversity and mitigate the urban heat island effect. In this context, tree planting has been suggested as a cost-effective strategy because green infrastructures can provide important environmental and social functions which contribute to the quality of life and health of city dwellers.

Tbilisi is the largest city in Georgia, with a population of over 1,100,000 inhabitants (about 30% of total population of Georgia). The green space availability in Tbilisi (5-6 m² per inhabitant) is low compared to other European cities, and in recent years the need to increase the amount of urban vegetation has been underlined at planning level.

In our study, we implemented for the first time in a Southern Caucasus city the *i-Tree Eco* model to quantify the main ecosystem services provided by urban forests. Trees in two parks in Tbilisi, Expo Park (694 trees) and Red Park (1027 trees), have been measured and a model simulation was performed for the year 2018. These green infrastructures store large amounts of carbon in their woody tissues (198.4 t for Expo Park and 126.5 t for Red Park) and each year they remove 4.6 and 4.7 t of CO₂ for Expo Park and Red Park. They also positively contribute to the air quality by removing 119.6 and 90.3 kg of pollutants (CO, NO₂, O₃, PM_{2.5}, SO₂), and reducing water runoff of 269.5 and 200.5 m³, respectively.

This analysis highlights the key role of urban forests in improving the environmental sustainability of the city of Tbilisi and provides important decision support for tree species selection in this geographic area with the aim of maximizing the benefits trees can supply to cities.

Introduction

The fast urbanization process occurring globally emphasized the importance of interactions between people and nature. Urbanization enhanced human detachment from nature and drastically reduced natural areas in cities. Green spaces as parks, gardens, and tree-lined streets are typically the only chance for citizens to enjoy and connect with nature (Beatley 2009) and supply essential services for people and the environment (Unterweger et al. 2017).

Currently, urbanized areas cover only a small fraction of the global surface area, ranging from approximately 1 to 3% (Liu et al. 2014), although they account for a large share of anthropogenic impacts on the biosphere (Gómez-Baggethun E. et al. 2013). Urban sprawl causes large negative effects on the environment in terms of increased energy consumption, greenhouse emissions and degradation of the natural environment (World Cities Report, 2020). Cities produce only a small fraction of total goods and ecosystem services compared to the ever-increasing demand from urbanized areas (Kampelmann 2014), where half the global population currently lives and about 60% of humanity in 2030 (World Cities Report, 2020).

The major threat to urbanized areas is posed by climate change, and cities are expected to be among the most affected ecosystems (Breuste et al. 2013). Urban areas are characterized by high-level of air pollution caused by anthropogenic sources such as from the stationary (manufacturing, home heating, energy generation, other industrial sources) and mobile sources (automobiles and transport) (Shaddick et al. 2020). In addition to polluted air, the Urban Heat Island Effect (UHI) contributes to increased temperatures in cities, further deteriorating the negative results of global climate change (McCarthy et al. 2010).

Urban forests and green spaces contribute to the uptake of carbon dioxide, remove gaseous pollutants and fine particulate matter from the air (Nowak and Crane 2002), mitigate extreme temperatures (Santamouris and Osmond 2020) by shading and evapotranspiration (Rahman et al. 2020), and slow down soil erosion processes reducing water run-off and facilitating the filtration process in the soil (Grey et al. 2018). They also preserve the animal and plant biodiversity, promoting the pollination process and the biological control of populations (Dwyer et al. 2003). In addition to environmental services, urban green spaces have an important social function as they are essential recreational and cultural spaces for the city (Andersson et al. 2015), providing positive impacts on human health and wellbeing (Higgins et al. 2019).

Most of studies on ecosystem services and urban greenery came from the USA, UK, Australia, Germany, and China (Wang et al. 2021) and are focused on North American, Western/Central European, East Asian, and Australian countries/territories. At the same time, the research about these topics is very rare in the former Soviet states, especially in the South Caucasus region.

During the last two centuries, Tbilisi has experienced several phases of urban development and expansion, transforming from a strategically located trading town into a city with over a million inhabitants, with its own distinctive culture and an important socio-economic role in the Caucasus. Along with the processes of economic downfall, nationalism, and dramatic changes of the social fabric, which are characteristic of the post-Soviet transition process (in the states of former USSR), Tbilisi today is a modern globalized metropolis. The expansion of Tbilisi's territory started during the Soviet Era (1921-1991), when an intensive urbanization occurred and the municipal area increased tenfold, and the population sixfold (Salukvadze and Golubchikov 2016).

The urban green spaces of Tbilisi are mainly represented by man-made and natural green zones, such as parks, public gardens, and tree-lined streets. Green areas include about 145 km², which is 28.9% of the total area of Tbilisi Municipality (502 km²), and are lower than the impervious (i.e., urbanized) areas (158 km², or 31.47% of the total) (Tbilisi in figures 2018). Moreover, the major parks (Mtatsminda Park, Lisi Lake Park and Tbilisi Dendrological Park) in Tbilisi are mainly located in suburbs and places with complex topography, and therefore are difficult for the population to access on a daily basis.

The impact of climate change in Georgia and Tbilisi was recently discussed by the United Nations Framework Convention on Climate Change (Georgia's Second Biennial Update Report 2019), reporting a 1.3 °C increase in average temperature and 60 mm in annual precipitation over the past 25 years (1990-2015). The highest greenhouse gas emitting categories in Georgia are transport (38%), oil and natural gas (17%), energy industries (15%), manufacturing industries and construction (10%) and other sectors (18%) (Georgia's Second Biennial Update Report 2019).

The transport sector is a major air polluter in Tbilisi, the main hub of social and economic activities in Georgia (51.2 % of Gross Domestic Product of Georgia) (National accounts of Georgia, 2019). The increasing number of second-hand passenger vehicles, manufactured before year 2000 (48% of approximately 1.4 million vehicles, registered in the country) is further exacerbating air quality. According to air pollution data of 2017, the average annual concentration of particulate matter in some locations of Tbilisi exceeded, in given periods, the EU standard norm for PM_{2.5} and PM₁₀ in ambient air (0.025 mg/m³ and 0.04 mg/m³, respectively). High concentrations of particulates have been detected near construction sites (1.5 of the standard norm) and busy urban road intersections (Air Quality in Tbilisi, Thematic Inquiry, 2019).

This study aims to evaluate the air quality and climate-related ecosystem services of two Tbilisi's public parks and the role of this green infrastructure in improving the environmental quality of the city. The analysis has been carried out using i-Tree Eco model, which for the first time has been applied in a scientific study of urban ecosystem services in the South Caucasus. Based on this thorough assessment of the multiple environmental benefits of urban trees, most of common of species were evaluated and compared, for a detailed selection for future afforestation programs.

Methods

Study area

The city of Tbilisi presents a stretched geographical layout (from North to South-East), with most of the built-up area squeezed between the mountains. In 2019, Tbilisi Municipality had a population of 1.171 million inhabitants, which is about 31.45% of the total population of Georgia (3.723 million in 21019) (National statistics Office of Georgia, 2019).

Tbilisi is situated in the valley terraces of the Mtkvari (Kura) river at altitudes of 410-370 m above sea level (a.s.l.). The Mtkvari river divides the city into two distinct parts, the left and right banks, surrounded by the mountain gorges. On the right bank, the Trialeti Range (770 m, part of the Lesser Caucasus Mountains) sharply descends to the river valley shaping the highest part of the city, while the left bank is limited by the Makhata mountain (630 m) forming the widest part of the river valley.

Tbilisi has a humid subtropical climate (Köppen climate classification: Cfa) with considerable continental and semi-arid influences. The average annual temperature is 12,7 °C, with average temperature of 0,9 °C in January, and 24,4 °C in July. The

absolute minimum and maximum temperatures, historically recorded, were -23 °C, and + 40 °C. The annual precipitation varies from 400 to 560 mm. The rainiest month is May (90 mm), and the driest month - January (about 20 mm). The snowfalls may happen for 15-25 days per year, without forming a stable snow cover. Northwesterly winds dominate in most parts of Tbilisi throughout the year, but southeasterly winds are common as well. Generally, given the proximity of The Greater Caucasus Mountains Range (further to the north), which prevents the intrusion of cold air masses from Russian planes, Tbilisi experiences a mild and pleasant climate.

The study area includes two urban forests, Vaso Godziashvili Park (also known as a 'RED Park') with a total area of around 3.3 ha (on the right bank of the river Kura, 455 m a.s.l.), and Expo Georgia Park with an area of around 3.2 ha (on the left bank of the river Kura, 418 m a.s.l.). They are located within the urban area of Tbilisi and are 2.7 km apart from each other (Fig. 1).

These two parks were designed in the 1950s-60s. RED Park is a typical urban public park, developed in the densely populated district of Saburtalo and mainly used for recreational and sports activities. EXPO Park is located in the Didube district and is a part of Georgia EXPO, an exhibition space owned by a private company with free access for the public. The area of EXPO Georgia consists of buildings, exposition pavilions and the park, created for the exhibition space in 1958.

Tree inventory

Field work was conducted during the 2019 growing season (July-September) and was designed according to the i-Tree Eco v6 guidelines (i-Tree Eco, field guide v6.0, 2020). A complete tree inventory was sampled in both parks RED Park (Vaso Godziashvili Park) and EXPO Park (EXPO Georgia Park). Tree parameters collected from field data included species identification (scientific names), diameter at breast height (DBH), tree height, height to live top of crown, crown base height, crown width, percentage of canopy missing (relative to crown volume), percentage canopy dieback, and crown light exposure (Nowak et al, 2008).

Model settings

Model simulation was performed for 2018, the latest year available in i-Tree Eco, using hourly meteorological data (air temperature, radiation, wind speed) registered at the Tbilisi Airport weather station (Tbilisi/Lochini Airport) and hourly precipitation data, provided by the National Environmental Agency (NEA) of Georgia.

Hourly air pollution concentration data (2018) were provided by NEA, from the operational monitoring station at Kazbegi Avenue in Tbilisi. The station is located at the entrance of Red Park, ensuring accurate data for air pollution concentration of O₃, NO₂, SO₂, PM₁₀ and PM_{2.5} (fine particulate matter that is 10 microns and with a diameter equal or less than 2.5 microns). Tree inventory information, air pollution concentrations, and meteorological data were processed using i-Tree Eco software (i-Tree Eco v6).

These two datasets were used to analyze ecosystem services provided by urban forests in sequestering and storing the carbon, improving the air quality (pollution removal), and avoiding rainwater runoff.

Results

Weather and pollution data

In 2018, the average daily temperature in Tbilisi was 15.3 °C, with a minimum at the end of December (-0.6 °C) and a maximum in July (31.2 °C). The mean Photosynthetically Active Radiation (PAR) was 330.1 W m⁻², with a lowest value in December (77.5 W m⁻²) and highest - in June (572.5 W m⁻²). Precipitation was distributed relatively evenly (a monthly average of 33 mm) though having seasonal features, with maximums in June, August, and November (73.2, 64.4, 63 mm, respectively), and the lowest value in February (6.2 mm) (Fig. S1).

The average CO concentration in 2018 was 388 µg m⁻³ with higher values in winter months (max value = 1712.5 µg m⁻³). SO₂ showed average values of 7 µg m⁻³ with frequent peaks during the year up to 30.4 µg m⁻³. The concentration of PM_{2.5} and PM₁₀ was relatively constant throughout the year (15.8 and 40.3 µg m⁻³ on average, respectively) with highest values in December (70.8 and 196.9 µg m⁻³, respectively). Also, another peak (177.9 µg m⁻³) was registered for PM₁₀ on July 27th due to the spread of the

dusty air masses from the South in all Eastern Georgia including Tbilisi (NEA, Georgia). O₃ annual mean was 33.8 µg m⁻³ with higher values in spring and summer (max value = 78.8 µg m⁻³). On the other hand, NO₂ showed an opposite trend with higher values in winter months (75.7 µg m⁻³) and an annual average of 34.5 µg m⁻³. A peak concentration of NO₂ (108.8 µg m⁻³), as with PM₁₀, was recorded on July 27th (Fig. S2).

Urban forests

For the evaluation of ecosystem services provided by urban forests, we analyzed their structural characteristics. A total of 1,030 trees (tree cover: 1.5 ha) for Red Park (Tab. 1) and 694 trees (tree cover: 1.8 ha) for EXPO Park (Tab. 2) were measured.

In RED Park there are 52 different tree species. The most common tree species are *Cupressus sempervirens* (12.1% of total tree population), *Punica granatum* (7.9%), *Cupressus arizonica* (7.7%) and *Platycladus orientalis* (7.7%). The overall tree density in RED Park is 312 trees/ha with a tree cover of 44.3%. Dominant species in terms of canopy cover, leaf area, and basal area are Deodar cedar (*Cedrus deodara*), Italian cypress (*Cupressus sempervirens*), White poplar (*Populus alba*), and Oriental plane tree (*Platanus orientalis*) (Tab. 1).

Expo Park's tree population includes 62 different species. The most abundant species are *Cupressus sempervirens* (16.7% of total), *Cedrus deodara* (8.4%), and *Aesculus hippocastanum* (7.8%). The overall tree density in Expo Park is about 217 trees/ha with a tree cover of 55.8%. Dominant species in terms of canopy cover, leaf area, and basal area are the Deodar cedar (*Cedrus deodara*), Italian cypress (*Cupressus sempervirens*), Oriental plane tree (*Platanus orientalis*), and Horse chestnut (*Aesculus hippocastanum*) (Tab. 2).

Carbon storage and sequestration

Trees are estimated to store 126.5 and 198.4 t of carbon in Red and Expo Parks, respectively. *Cedrus deodara* (27%), *Cupressus sempervirens* (24.6%), and *Populus alba* (15.8%) are the species that accumulated the most carbon in Red Park. In Expo Park, *Cedrus deodara* (33.8%) and *Cupressus sempervirens* (20%) store more than half of the total carbon (Fig. 2).

The gross sequestration is about 4.7 and 4.6 t of carbon per year for Red and Expo Parks, respectively. Similar to carbon storage, *Cedrus deodara* (23.4%), *Cupressus sempervirens* (19.1%), and *Populus alba* (11.3%) in Red Park; and *Cupressus sempervirens* (29%) and *Cedrus deodara* (25.6%) in Expo Park, are the species that sequester more than half of the total carbon per year (Fig. 2).

Pollution removal

In 2018, trees in Red Park and Expo Park, remove 90.3 and 119.6 kg of pollutants, respectively. Ozone (O₃) is the most removed pollutant from trees (48.9 kg in Red Park and 63.8 kg in Expo Park), particularly in summer, with a maximum in June (7.7 kg in Red Park and about 10 kg in Expo Park). Nitrogen dioxide (NO₂) removal is nearly constant during the year with an average of 2.1±0.4 kg (in total 24.6 kg) for the Red Park and 2.8±0.5 kg (in total 33.1 kg) for the Expo Park. The annual amount of total fine particulate matter (PM_{2.5}) removed, is 6.6 kg for Red Park and 9.5 kg for Expo Park, with highest values in June, March, and December (1, 0.8, 0.7 kg for Red Park and 1.5, 1.1, 1.2 kg for Expo Park). Also, trees remove 8.2 and 10.8 kg of sulfur dioxide (SO₂) in Red Park and Expo Park, respectively, with highest values in February, March, April, and October. Finally, carbon monoxide (CO) is mostly removed during the growing season of trees (in total 2 kg in Red Park and 2.4 kg Expo Park) with a peak in October (Fig. 3).

In 2018, trees emitted an estimated 69.9 (45.9 kg of isoprene and 24 kg of monoterpenes) and 55.7 kg (20 kg of isoprene and 35.7 kg of monoterpenes) of volatile organic compounds (VOCs) in Red and Expo Parks, respectively. About the half of the VOC emissions from urban forests were from *Populus alba*, *Cedrus deodara* in Red Park, and *Cupressus sempervirens* and *Cedrus deodara* in Expo Park (Fig. 4).

Hydrology effects

Trees in Red and Expo Parks, in 2018, transpired 3039.6 and 3334.2 m³ of water, respectively, with highest values in July (651.8 m³ for Red Park and 715.6 m³ for Expo Park). The annual avoided runoff was 200.5 m³ in Red Park and 269.5 m³ in Expo Park, with highest values in Summer, particularly in June (28.6 and 37.5 m³ for Red and Expo Parks, respectively) (Fig. 5).

Discussion

Urban forest structure and ecosystem services provision

Our modeling analysis shows that Red and Expo Parks supply important environmental services to the city of Tbilisi. These urban forests are located in the urban fabric and have a similar size (3.3 ha for Red Park vs 3.2 ha for Expo Park) but have a different number of trees (1030 for Red Park vs 694 for Expo Park). There are more species in the Expo Park (62) than the Red Park (52), although with only a few trees each, and about half ($\approx 47\%$) are evergreen in both urban forests, with some conifers dominating such as *Cupressus sempervirens* and *Cedrus deodara*.

Despite the different tree density (312 trees/ha for Red Park vs 217 trees/ha for Expo park), tree cover in Expo Park (1.8 ha) is greater than Red Park (1.5 ha) because there are larger trees as shown by basal area (32.7 m² for Red Park vs 53.6 m² for Expo Park) and this clearly affects the amount of carbon stored by the forests (126.5 t for Red Park and 198.4 t for Expo Park) (Nowak and Crane, 2002). However, Red park's annual carbon sequestration (4.7 t) is slightly higher than Expo Park (4.6 t). This result is mainly due to a higher number of trees in open light conditions (Crown light exposure (CLE) 4-5) which have a larger growth base (Nowak et al. 2008) (Red Park – CLE 0-1: 125, CLE 2-3: 535, CLE 4-5: 370 vs Expo Park – CLE 0-1: 98, CLE 2-3: 338, CLE 4-5: 258). Despite the higher tree density, the smaller size of the trees reduces the competition for light, which promotes growth in diameter and thus, carbon sequestration.

The effect of CLE on ecosystem services has been already shown in a previous modeling study in Germany with i-Tree Eco (Pace et al. 2018) and from the sensitivity analysis of model inputs (Lin et al. 2020). Tree species with greater basal area accumulate and sequester more carbon in both urban forests, in particular *Cedrus deodara*, *Cupressus sempervirens* and *Populus alba* for the Red Park, and *Cedrus deodara* and *Cupressus sempervirens* for the Expo Park. Some species (e.g., *Cupressus arizonica*, *Fraxinus americana* for the Red Park and *Aesculus hippocastanum* for the Expo Park), while relatively smaller in diameter, remove a greater amount of carbon because there are enough trees in better light and health condition (Nowak et al. 2008; Lin et al. 2020).

The total pollution removal rate was 6.1 and 6.7 g m⁻² for Red and Expo Park, respectively. The highest removal rate was for O₃ (3.3 g m⁻² for Red Park and 3.6 g m⁻² for Expo Park), then NO₂ (1.7 g m⁻² for Red Park and 1.9 g m⁻² for Expo Park), SO₂ (0.6 g m⁻²), PM_{2.5} (0.5 g m⁻²), and CO (0.1 g m⁻²). Comparing these values with other modeling studies, the total removal rate per unit tree cover is higher than in other European cities, such as Munich (5.3 g m⁻²) (Pace et al. 2018) or Strasbourg (5.1 g m⁻²) (Selmi et al. 2016), but lower than in London (8.7 g m⁻²) (Rogers et al. 2015) or the calculated average for the US cities (7.5 g m⁻²) (Nowak et al. 2006) considering PM_{2.5} removal rate instead of PM₁₀ (Nowak et al. 2013). Regarding the VOC emissions from trees, it is interesting to note that the two parks, which have similar composition, differ greatly in isoprene emissions (20 vs 45.9 kg) due to the presence of *Populus alba* in Red Park as dominant species, which is a high emitter (Fitzky et al. 2019).

Trees in Red and Expo Park also provide a beneficial cooling effect by transpiring in the warmer months up to 1.7 l m⁻² day⁻¹ in July. Similar results have been modeled (Rötzer et al. 2019) and measured in Germany on broadleaves, showing an energy reduction through cooling and shading of 75 kW m⁻² and an air temperature reduction up to 3°, within the canopies (Rahman et al. 2017). Furthermore, the presence of these green infrastructures within the city, allows to promote the infiltration in the soil and reduction of water runoff (Berland et al. 2017) (35.9 and 33.7 m³ ha⁻¹ yr⁻¹ per unit of leaf area in Red and Expo Park, respectively). These values are high in terms of efficiency, considering the total precipitation of 397.6 mm in 2018, and are in the same range of London (32.6 m³ ha⁻¹ yr⁻¹) (Rogers et al. 2015), but lower than Kyoto (130.3 m³ ha⁻¹ yr⁻¹) (Tan et al. 2021), where the amount of precipitation is higher (1,770 mm per annum).

Urban green planning in Tbilisi and future perspectives

In Georgia's context, until recent years, green infrastructure as an essential part of the complex and diverse fabric of the city, was not considered as part of the agenda for urban spatial planning, design and/or as a necessary tool for city resilience. However, in 2018, the Tbilisi Land Use Plan was approved, including priorities for urban green infrastructure development. This document envisages the protection of natural and man-made landscapes, supporting their protective and restorative functions, enhancing biodiversity protection measures, and minimizing natural and industrial hazards. Furthermore, the increase and development of new green recreational areas along the Kura River and in densely populated residential zones is also planned.

In this regard, Tbilisi City Hall adopted a list of recommended tree species, best suited to the Tbilisi municipal landscape and climate, as a guidance for urban green infrastructure planning and development. The list comprises tree species marked as "priority" species, and others, marked as "recommended". Some of the suggested species are also among the dominant species in the Red and Expo parks (Tab. 3). Considering carbon sequestration, *Cedrus deodara*, *Cupressus sempervirens*, and *Fraxinus americana* are the species that accumulate more carbon per unit of canopy cover. *Fraxinus americana*, *Picea pungens* and *Platanus orientalis*, allow for a greater reduction in stormwater runoff; *Fraxinus americana*, *Picea pungens* and *Tilia cordata* contribute to the removal of higher amounts of air pollutants; *Fraxinus americana*, *Fraxinus excelsior*, *Tilia cordata*, and *Tilia platyphyllos* are non-emitting species of VOCs, thus contributing to lower levels of ozone concentration.

In general, evergreen species in Tbilisi, despite an extended leaf-on season and thus the possibility of longer interaction with pollutants and precipitation, are not able to provide more ecosystem services than deciduous species. For example, rainfall is abundant in spring-summer season, which allows for greater fine particulate matter removal (Nowak et al 2013; Pace and Grote, 2020; Pace et al. 2021a), as well as greater rain interception and thus reduced runoff (Fig. 3-5). Furthermore, rainfall allows to increase the soil water content and ensures a higher stomatal conductance and therefore, a cooling effect and uptake of gaseous pollutants (Pace et al. 2021b). Another important selection criterion is the choice of non-VOC emitting species (Churkina et al. 2015), such as the species within the genus *Acer*, *Fraxinus* and *Tilia*, to ensure high ozone removal (Sicard et al. 2018) by preventing its formation (Calfapietra et al. 2013).

The value and role of urban forests

The concepts of green infrastructure, urban forests, and ecosystem services, defined as the multiple benefits flowing from nature to society, are relatively new topics in scientific research. Despite their inclusiveness and participation, these approaches often find difficulty in implementation and applicability, especially in urban planning and management stages (Turkelboom et al. 2018).

Urban parks, gardens and other green areas give cities a greater identity and uniqueness by contrasting with the surrounding urban fabric. Notable examples are the *Englischer Garten* in Munich, Germany, or *Central Park* in New York City, USA. Nevertheless, they are very often not considered as drivers or determinants in the city's land use policies, city development, or sustainable urban practices.

The ecological value and capacity of urban parks to provide ecosystem services, based on the type or quality of vegetation, is often neglected, and the presence of green spaces in cities is generally described only as a per capita share (Badiu et al. 2016). However, relatively small urban forests, such as Expo Park, can offset CO₂ emitted by more than 80 Georgian citizens (2.14 t per capita, www.worldometers.info) and fine particles of more than 200 diesel cars EURO VI (PM limits of 4.5 mg/km according to Commission Regulation (EU) No 459/2012 of 29 May 2012) with an annual mileage of 20000 km (assuming the concentration of PM_{2.5} is half of the total mass of particles).

The Sustainable Development Goals (SDGs) focus much attention on reducing the impact of cities on the environment and mitigating the effects of climate change. In this regard, the study of the biotic component of urban forests and their ecosystem services will be of great support for de-carbonization and minimization of pollution in urban areas.

Moreover, it is also very important to consider the contribution of urban parks to the human health and well-being, producing multiple benefits such as increasing physical activity, increasing life expectancy, reducing health problems, and promoting psychological wellness (Lafortezza et al. 2013). These essential social and psychological services contribute directly and indirectly to the livability, comfort, positive image, and attractiveness of the city (Yessoufou et al. 2020). Therefore, the provision and availability of urban green spaces, as a common and shared natural good for all city residents, raises the questions of ethics

and environmental justice, equitable distribution of urban green infrastructure, and its accessibility to various urban population groups (Selmi et al. 2020).

The assessment of socio-environmental services provided by urban green spaces in Tbilisi, Georgia, deserves further investigation in future studies, considering the aspects of equality, equity, and equitable distribution of urban green infrastructure, as approach for sustainable development of Tbilisi.

Conclusion

Urban green infrastructure and park trees contribute to improving air quality and mitigating climate change and its effects in cities. These services of urban vegetation are well recognized though less implemented in urban planning decisions from local administrations. In this study, we showed the impact and the environmental importance of two parks in Tbilisi by implementing the i-Tree Eco model for the first time in a Southern Caucasus city. The assessment of ecosystem services provided by urban forests and the selection of suitable and effective tree species for future reforestation and afforestation programs are essential for proper urban green planning and management and sustainable development of rapidly expanding and growing cities such as Tbilisi.

Declarations

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LA designed the research, carried out the field measurements, and wrote the main text. RP contributed significantly to the design, analysis, discussion of results, and writing of the text.

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Tables

Table 1. Dominant species in Red Park with a relative number, canopy cover, leaf area, and basal area greater or equal to 1%, 300 m², 1000 m², and 0.3 m².

Species	Number trees (N°)	Canopy Cover (m ²)	Leaf area (m ²)	Basal area (m ²)
Italian cypress (<i>Cupressus sempervirens</i> L.)	125	2265.5	9496.2	6.3
Oriental arborvitae (<i>Platycladus orientalis</i> (L.) Franco)	79	406.5	1105.1	0.4
Deodar cedar (<i>Cedrus deodara</i> (Roxb.) G. Don)	61	2327.2	10895.5	10.7
European ash (<i>Fraxinus excelsior</i> L.)	60	595.1	1749.2	1.1
White ash (<i>Fraxinus americana</i> L.)	41	475.4	1631.4	0.3
Bigleaf linden (<i>Tilia platyphyllos</i> Scop.)	32	306.5	1028.3	0.4
Japanese pagoda tree (<i>Styphnolobium japonicum</i> (L.) Schott)	30	844.5	2679.2	2.2
Oriental planetree (<i>Platanus orientalis</i> L.)	23	1462.4	8757.8	3.3
White mulberry (<i>Morus alba</i> L.)	17	612.4	2768.4	1.2
White poplar (<i>Populus alba</i> L.)	15	1478.1	6942.2	5.6
TOT urban forest	1030	14625	55917.6	32.7
TOT dominant species	483	10773.6	47053.3	31.5
Relative number of dominant species (%)	46.9	73.7	84.1	96.3

Table 2. Dominant species in Expo Georgia park with a relative number, canopy cover, leaf area, and basal area at least 1%, 300 m², 1000 m², and 0.3 m², respectively.

Species	Number trees (N°)	Canopy cover (m ²)	Leaf area (m ²)	Basal area (m ²)
Italian cypress (<i>Cupressus sempervirens</i> L.)	116	3311.3	17373.0	10.3
Deodar cedar (<i>Cedrus deodara</i> (Roxb.) G. Don)	58	3726.7	14477.1	20.9
Horse chestnut (<i>Aesculus hippocastanum</i> L.)	54	1090.5	5883.6	1.3
Japanese privet (<i>Ligustrum japonicum</i> Thunb.)	47	909.3	3307.8	0.6
Oriental planetree (<i>Platanus orientalis</i> L.)	23	1142.3	6913.0	2.9
Blue spruce (<i>Picea pungens</i> Engelm.)	13	297.0	1930.8	0.9
White ash (<i>Fraxinus americana</i> L.)	12	616.5	4454.9	1.3
White mulberry (<i>Morus alba</i> L.)	11	399.9	1629.4	0.9
Little leaf linden (<i>Tilia cordata</i> Mill.)	11	621.4	3401.2	1.6
European ash (<i>Fraxinus excelsior</i> L.)	7	713.9	2983.2	3
TOT urban forest	694	17866.4	79992.2	53.6
TOT dominant species	352	12828.8	62354	43.7
TOT (%)	50.7	71.8	78.0	81.5

Table 3. Results per unit of canopy cover of dominant species in Red and Expo parks. [**Expo Park, *Red Park - R=Recommended, P=Priority]

Dominant species parks	Suggestion Hall	Tbilisi City	Carbon sequestration (g m ⁻² yr ⁻¹)	Avoided Runoff (l m ⁻² yr ⁻¹)	Pollution removal (g m ⁻² yr ⁻¹)	Total VOCs (g m ⁻² yr ⁻¹)
<i>Aesculus hippocastanum</i> **	R		259.1	18.2	8.1	0.3
<i>Cedrus deodara</i> *	P		473.4	16.8	7.6	4
<i>Cupressus sempervirens</i> **	R		403.1	17.7	7.8	4.1
<i>Fraxinus americana</i> **			397.9	24.3	10.8	0
<i>Fraxinus excelsior</i> **	P		242.8	10.5	4.7	0
<i>Ligustrum japonicum</i> **	P		10	12.3	5.4	12.9
<i>Morus alba</i> *			212.1	16.2	7.3	1.8
<i>Picea pungens</i> **	R		314.8	21.9	9.7	14.5
<i>Platanus orientalis</i> **	P		219.4	20.4	7.6	4.5
<i>Platycladus orientalis</i> *			352.8	9.7	4.4	1.7
<i>Styphnolobium japonicum</i> *	P		181.9	11.4	5.1	5.9
<i>Tilia cordata</i> **			349.4	18.4	8.2	0
<i>Tilia platyphyllos</i> *	P		248	12	5.4	0

Figures

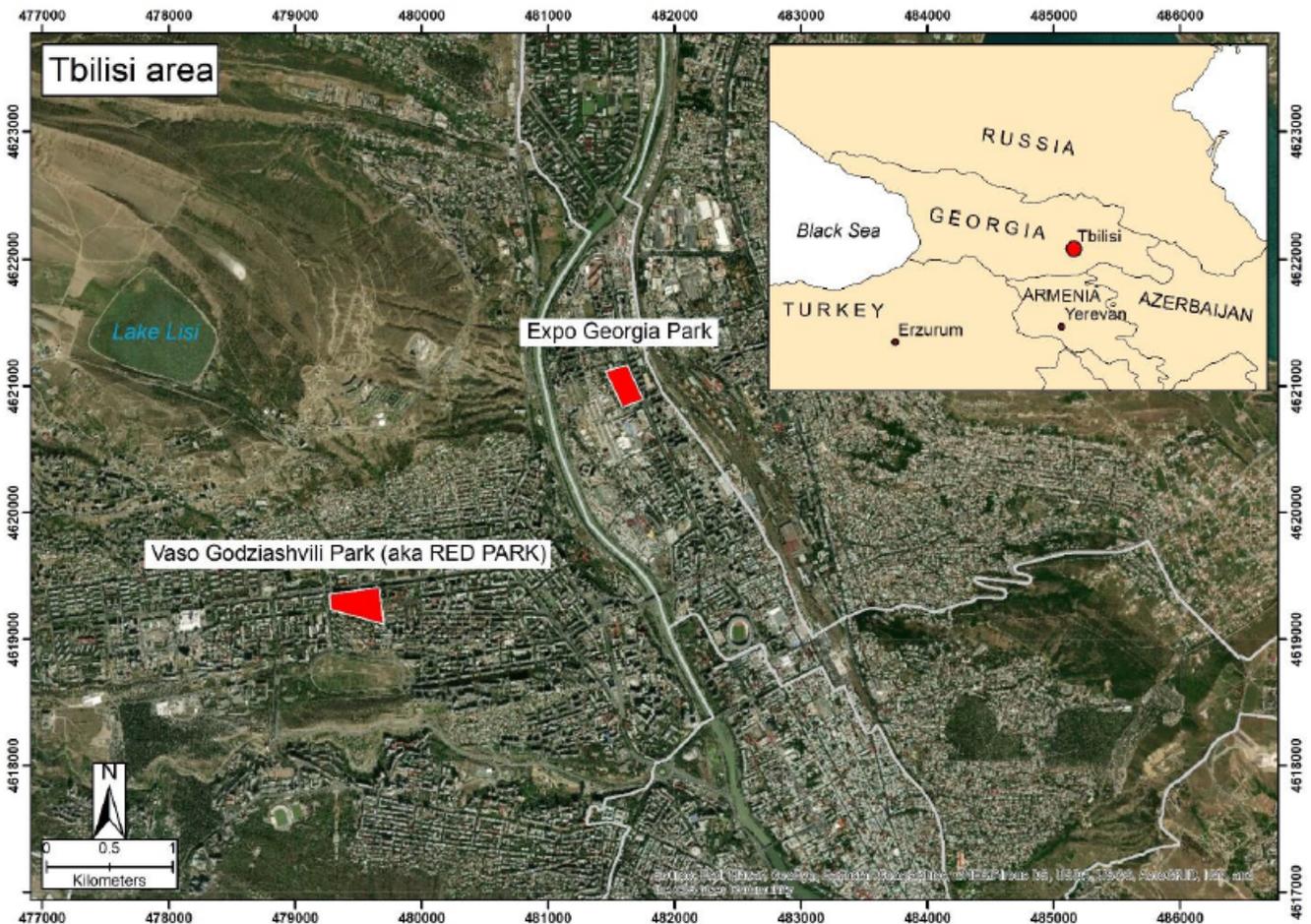


Figure 1

Vaso Godziashvili and Expo Georgia parks, Tbilisi aerial photograph (designed by Giorgi Kirkitadze and Levan Alpaidze, 2020)
 Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

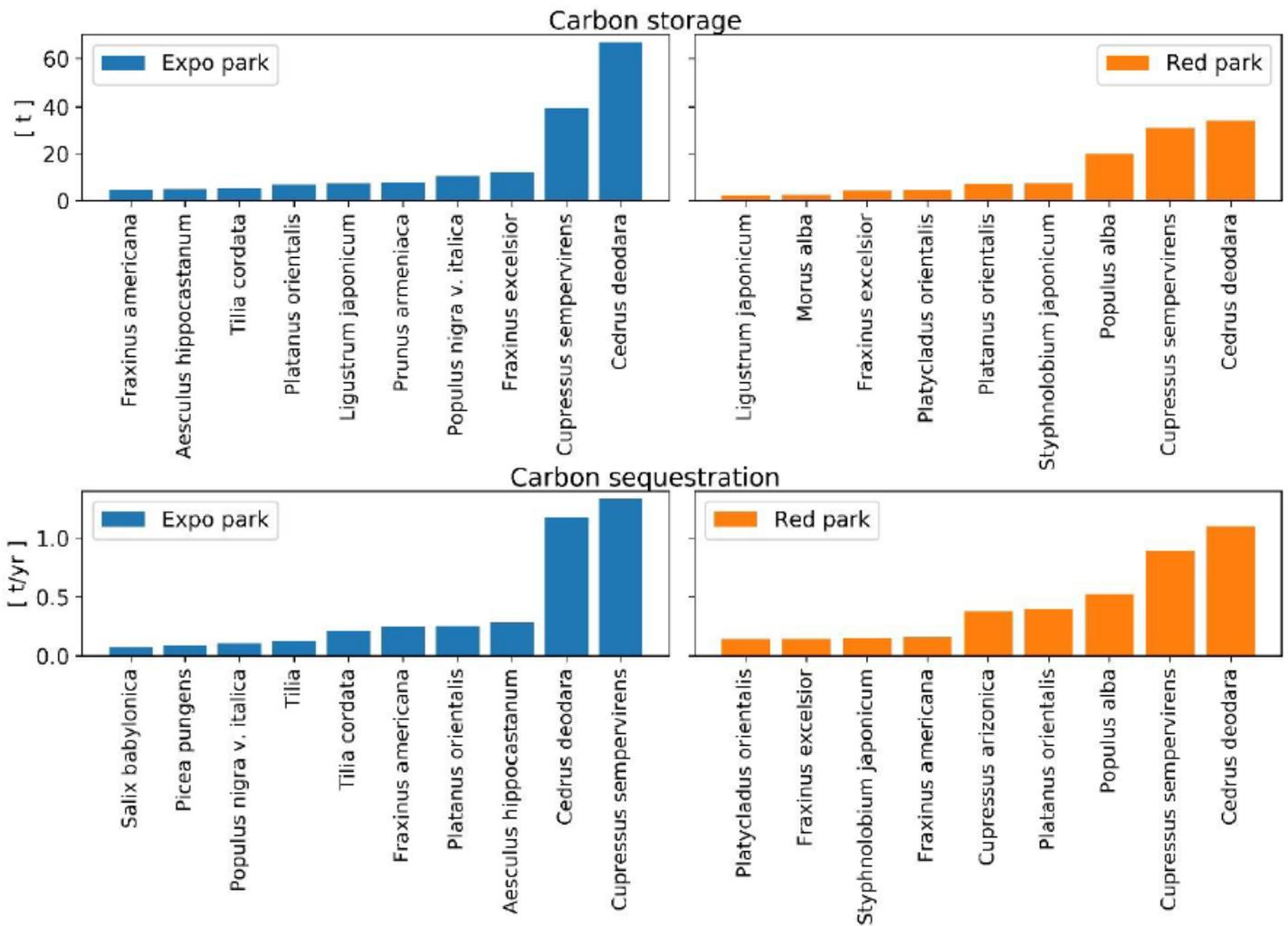


Figure 2

Species that store (carbon storage) and sequester (carbon sequestration) the most carbon in Expo and Red park.

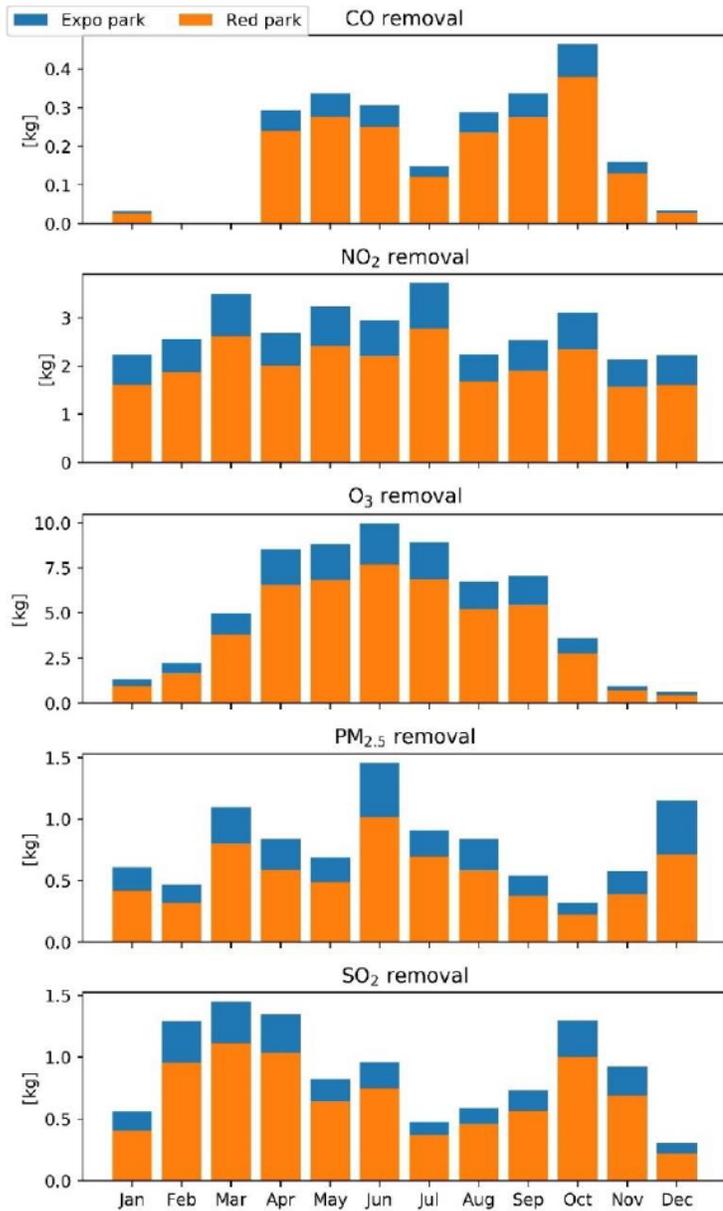


Figure 3

Monthly pollution removal of CO, NO₂, O₃, PM_{2.5}, and SO₂ from Expo and Red Park of Tbilisi in 2018.

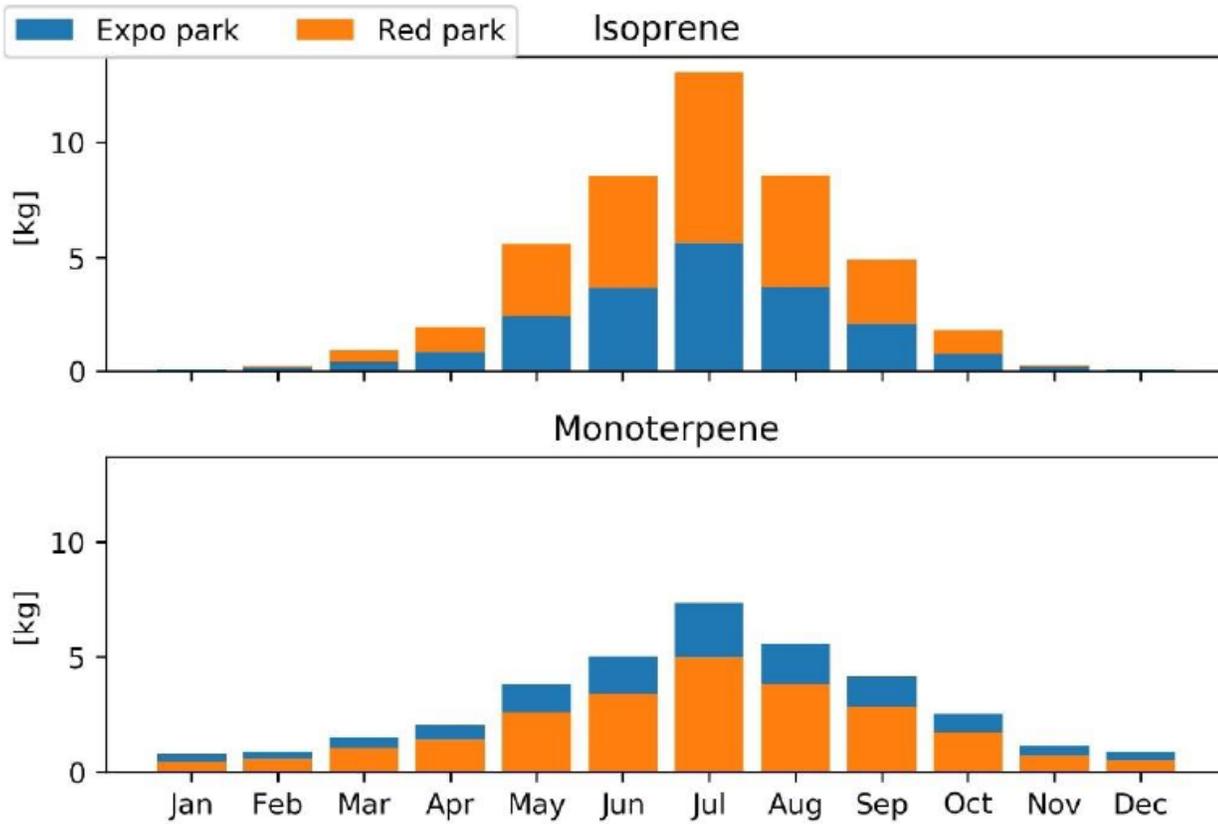


Figure 4

Monthly isoprene and monoterpenes emitted by Expo and Red park of Tbilisi in 2018.

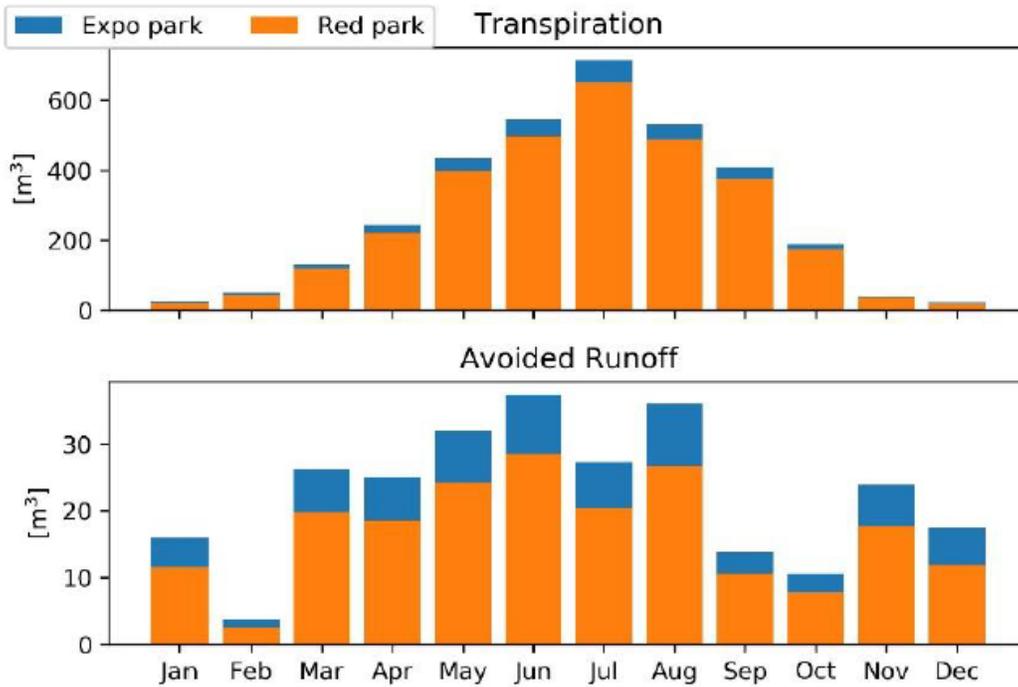


Figure 5

Monthly transpiration and avoided runoff by trees in Expo and Red Park of Tbilisi in 2018.

Supplementary Files

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