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A Comparative Evaluation of Ecosystem Services Provided by Street Trees in Seoul for the Suggestion of Social Equity

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Abstract: Cities must overcome their limitations on quantitative growth by pursuing sustainable development. Road-centered development leads to social problems, including inequality, during urban expansion. This study focuses on quantifying the ecosystem services provided by street trees in the Gangnam and Gangbuk Districts of Seoul, South Korea. This research utilized public data and field surveys conducted between April and August 2023, which is the best time to grow coniferous and deciduous trees. The results helped quantify the improvement in the air quality and ecological economic value from the perspective of plant species structure and carbon storage. The street trees in Gangnam stored 3691.61 t (metric tons) and sequestered 359.45 t of carbon; removed 2.28 t of air pollutants; and reduced 3977.46 m^3 of rainwater runoff annually. In contrast, the street trees in Gangbuk stored 831.61 t and sequestered 74.97 t of carbon; removed 0.4 t of air pollutants; and annually reduced rainwater runoff by 1491.74 m^3. By quantifying the ecosystem services of street trees, this study showed a gap in the supply of ecosystem services, which are relatively poor in economically poor areas, thus contributing to a more holistic understanding of urban growth and advocating for inclusive and socially equitable development strategies and management policies in Seoul.

Keywords: social equity; qualitative growth; street tree; ecosystem service; i-Tree Eco

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1. Introduction

Recently, a new urban environmental theory based on the concept of sustainable development has been proposed, and in the field of urban planning and design, concepts such as green city planning, eco-friendly architecture, and sustainable transportation planning are being utilized [1,2]. The concept of sustainable development is particularly influential in South Korea's policy reflection and research, and is associated with its dramatic quantitative growth. The "Miracle of the Han River", which refers to the rapid economic growth over half a century from the Korean War (1950–1953) to the Asian financial crisis, is representative of this. Compared to 50 years ago, the Korean economy has increased 85.2 times, from USD 19.54 billion (1974) to USD 1664.33 billion (2022), in terms of its gross domestic product (GDP), and the GDP per capita has also increased 57.2 times, from USD 563.3 (1974) to USD 32,236.8 (2022). Korea's global GDP ranking rose significantly from 30th to 10th as a result of the combination of export-led industrialization, high education levels, and technological innovation [3]. However, this growth has led to social structural problems such as polarization, a low birth rate, and an aging population. The slowdown in the GDP growth rate in recent years and the decline in global rankings demonstrate the limitations of this quantitative growth. In line with this trend, Korea is seeking to transition toward qualitative growth. Therefore, sustainable development capable of addressing social equity, the climate crisis, environmental concerns, and the challenges posed by the fourth industrial revolution is essential for transforming the nation into one that prioritizes innovation and inclusivity [4]. Among the various elements of sustainable development, researchers have considered the role of "green infrastructure for the climate crisis".

According to the World Inequality Report 2022 [5], South Korea's income has grown to a level comparable to that of Western Europe. However, when examined in terms of income, wealth, and carbon emissions, the level of inequality and the wealth gap are more severe than in Western Europe. When comparing the economic levels of the top 10% and bottom 50%, the top 10% have 14 times the income and 52 times the wealth of the bottom 50%. This is a critical gap that has been widening for more than 25 years. Moreover, the report identifies South Korea as a high-carbon-emitting country. The top 10% in Korea emit about 8.26 times more carbon per capita (54.5 tCO_2e/capita) than the bottom 50% (6.6 tCO_2e/capita; the per capita emission of the entire population of South Korea is 14.7 tCO_2e/capita). The average level of emissions has increased by 66% compared to the level in 1990, with the level of emissions of the bottom 50% increasing by 43%, whereas those of the top 10% increased by almost 200%, indicating a wealth gap in carbon emissions [5–7].

The association between economic inequality and carbon emissions can be observed in the statistics for not only South Korea as a whole, but also individual districts within Seoul, which represent South Korea's quantitative growth. According to the Seoul Metropolitan Government's report on the gross regional domestic product (GRDP), which is an indicator representing the total value of goods produced in a specific region or district, as of 2021, the GRDP was highest in Gangnam District (USD 5.50 billion) and lowest in Gangbuk District (USD 0.25 billion) [8]. In addition, the number of imported cars registered by the districts in Seoul showed that Gangnam District had the highest number (88,102 cars) in the entire city, whereas Gangbuk District had the lowest number (7433 cars). When comparing the carbon emissions of Gangnam District and Gangbuk District in August 2023, the carbon emissions from electricity use were 5 times higher in Gangnam District than in Gangbuk District, and the emissions from gas use were 3.7 times higher. This shows not only economic inequality between Gangnam District and Gangbuk District, but also inequality in their carbon emissions.

South Korea has the highest level of fine dust pollution among the Organisation for Economic Co-operation and Development (OECD) member countries, which makes it the country with the most severe air pollution. The use of fossil fuels, such as petroleum, has been identified as the main cause of fine dust in the country. According to the 2019 petroleum consumption trends compiled by the Korea National Oil Corporation, the total consumption of petroleum products in the country has increased by 20% compared with 10 years ago, particularly due to the increase in the number of vehicle registrations [9,10]. This is because Korea built cities and roads from the perspective of vehicles moving in the city, rather than of people living in the city, for rapid economic growth [11]. Roads within the city, which are a form of major urban infrastructure responsible for people's movement and logistics, occupy approximately 20–30% of the total area. They are essential for people to live in cities, yet they also cause various problems, such as the destruction of residential areas, traffic accidents, noise, and air pollution. The importance of green infrastructure as an effective solution to these problems has been increasingly highlighted.

Green infrastructure creates a network of physical green spaces, continuously utilizes urban recreational functions, provides natural ecosystem services to humans, and offers solutions to urban social problems [11–13]. The concept of ecosystem services was defined and popularized by the Millennium Ecosystem Assessment (MA) [14]. Ecosystem services refer to the various benefits that people obtain from ecosystems, categorized into provisioning services (such as food and water), regulating services (including climate control and disease regulation), supporting services (essential for ecosystem functioning), and cultural services (such as recreational and aesthetic values). Thus, green infrastructure is an important means of creating a more sustainable urban environment with an improved quality of life [15,16]. Numerous studies have focused on implementing innovative green infrastructure, including three-dimensional road parks, smart parks, and low-impact development, to reshape urban landscapes and uncover synergies within urban nature domains for sustainable growth [13,17]. Despite these efforts, there remains a notable research gap in the examination of street trees, traditional contributors to road-based green infrastructure. Few studies have directly examined how ecosystem services and economic disparities are interrelated [6,7]. However, there is a scarcity of comprehensive studies explicitly quantifying and comparing ecosystem service provision by street trees with regional economic gaps. This gap underscores the need to quantify ecosystem services from street trees and understand how economic disparities shape their availability and distribution, which is essential for fostering social equity and informing urban planning efforts. There is a pressing need to channel endeavors into establishing an evidence base that highlights the economic, social, and environmental benefits associated with nature-based solutions [18–20].

Exploring the benefits of street trees in this study is relevant, as it sheds light on the interplay between economic dynamics, carbon emissions, and the potential role of green infrastructure in fostering sustainable and equitable urban growth. The findings have implications for policymaking, urban planning, and environmental management, emphasizing the need to prioritize nature-based solutions for a more sustainable and socially inclusive future.

Therefore, this study aimed to quantify the ecosystem services provided by street trees in Gangnam District and Gangbuk District in Seoul, South Korea, where it has been confirmed that the economic wealth gap in Seoul is associated with the gap in carbon emissions. By demonstrating the existence of a gap in ecosystem services, this study aimed to promote the qualitative growth of cities based on social equity by utilizing objective evaluation data of ecological value when reflecting plans or policies related to tree planting and street-tree management. We aimed to answer the following four questions: (1) How do street trees in Gangnam and Gangbuk quantifiably contribute to the provision of ecosystem services? (2) Is there a correlation between economic wealth gaps, represented by carbon emissions, and variations in the ecosystem services provided by street trees? (3) How can objective ecological value data from the street tree analysis inform policies and foster qualitative urban growth and social equity?

2. Materials and Methods

2.1. Study Area

Seoul lies within a humid continental climate zone, marked by distinct seasons, with hot and humid summers and cold winters with the occasional snowfall. The city experiences a monsoon-influenced climate, with the majority of its annual 1300 mm of rainfall occurring during the summer monsoon season [21]. The soils in Seoul vary, but generally consist of a mix of loam and clay, with the specific types differing across districts, and the potential natural vegetation includes a blend of deciduous and coniferous forests [22]. The diverse landscape of Seoul encompasses urban areas, parks, mountains, and riverbanks, and is characterized by a juxtaposition of modern skyscrapers and historical landmarks. The Han River divides the city, providing recreational spaces along its riverbanks, and Seoul boasts several parks, such as Namsan Seoul Tower, Olympic Park, and Seoul Forest, contributing to its blue and green infrastructure.

The monitoring areas for this study were roads in Gangnam District and Gangbuk District, Seoul. The urban development in Gangnam began in the 1970s, and the district went through a significant transformation from a primarily agricultural area to a modern, affluent district with commercial and residential development. On the other hand, Gangbuk District, which refers to the northern part of Seoul, has a more historical and traditional character. Regarding land use, Gangbuk District predominantly comprises forest areas, which account for 54.17%, with building sites making up 28%. In contrast, Gangnam District is primarily characterized by building sites, which constitute 40.61%, followed by forest areas at 14.99% (Figure 1). The spatial data were acquired from the databases provided by the Seoul Metropolitan Government (https://space.seoul.go.kr/ and https://data.go.kr/ accessed on 19 December 2023), and the coordinate system used for the maps was the universal transverse mercator (UTM) coordinate system. The street tree routes that were analyzed as target areas are highlighted in Figure 2, and on-site photos for contextualization can be seen in Appendix A.

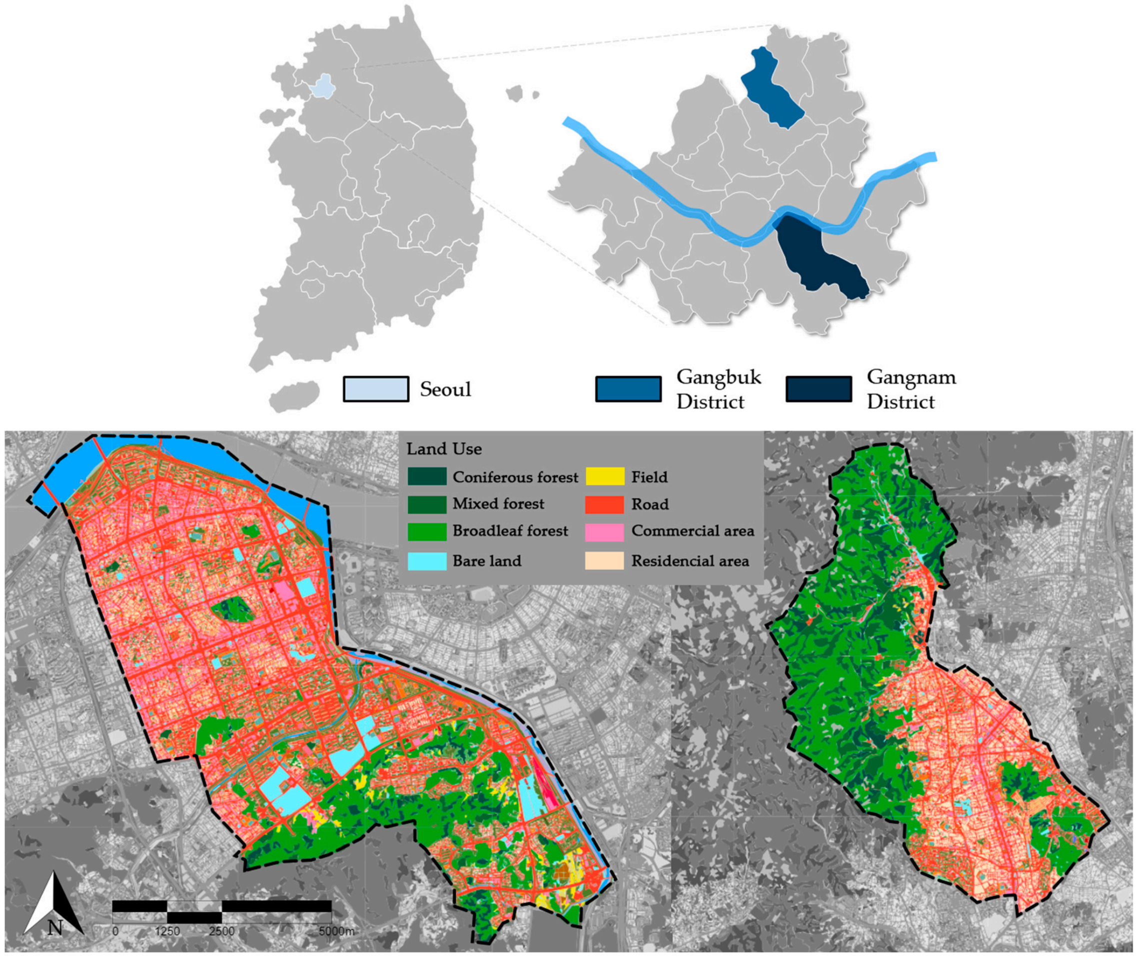


Figure 1. Road route of Gangnam District (**left**) and Gangbuk District (**right**).

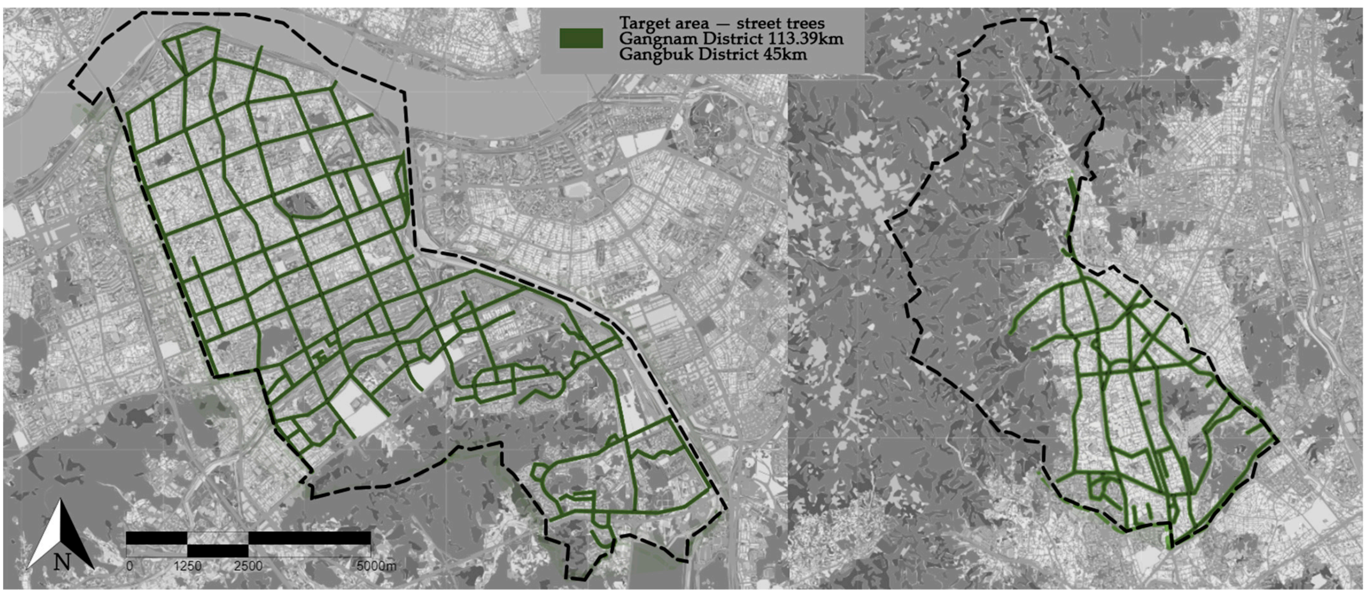


Figure 2. Street tree route of Gangnam District (**left**) and Gangbuk District (**right**).

These districts were selected because they represent the most significant economic disparity within Seoul, a city that epitomizes South Korea's quantitative growth. Before comparing these two target areas, it was necessary to examine each area's GRDP, total road length, jurisdictional area, and population (Table 1).

Table 1. Status of road length, area, population, and GRDP in Gangnam District and Gangbuk District.

Category	GRDP (USD)	Length of Road (km)			Population	Area (km^2)	Population/Area
		District Road	City Road	Total			
Gangnam District	54.49 billion	41.61	71.78	113.39	541,565	39.5	13,710.5
Gangbuk District	2.49 billion	17.2	27.8	45	289,372	23.6	12,261.5

To understand the economic wealth gap among the districts in Seoul, we compared their GRDP, a figure that evaluates the value of goods and services produced in a specific area over a certain period at market prices. There is a stark economic wealth gap between the two districts, with the wealth of Gangnam District being 22 times the level of Gangbuk District. Moreover, although the two differ in population and area, the population per unit area is similar, making these two target areas suitable for a comparative analysis to elucidate the association between economic and ecological wealth gaps.

2.2. i-Tree Eco V6 Modeling and Analysis

In this study, i-Tree Eco (www.itreetools.org) was used to compare and evaluate the ecosystem services and values provided by the street trees in Gangnam District and Gangbuk District.

i-Tree Eco is an open-access software tool developed by the United States Forest Service. It uses sample or inventory data collected on-site, along with local hourly air pollution and weather data, to evaluate ecosystem services, such as tree species' structural characteristics, air pollution removal, carbon sequestration and storage, and stormwater runoff reduction [23].

i-Tree Eco presents distinctive advantages in urban forest assessments. Its approach considers diverse factors, including the tree species, size, and health, offering a comprehensive view of the urban environment. The incorporation of robust scientific models ensures accuracy in quantifying essential ecosystem services such as carbon sequestration and stormwater management [24]. With a user-friendly interface and accessible data input, i-Tree Eco accommodates a broad range of users, from researchers to community members, while its customizable report generation facilitates the effective communication of its findings. However, it is important to note some limitations, such as its dependence on accurate data input and its potential sensitivity to regional variations [25,26].

Currently, an international version of i-Tree Eco can directly reflect the atmospheric conditions of South Korea, which makes it suitable for research targeting South Korea.

The results of the i-Tree Eco model can be used to understand urban green structure, ecosystem services, and value and can help improve the policies, plans, and management related to street trees [23].

2.3. Data Collection and Analysis

This model was used to evaluate ecosystem services and environmental value, including air pollution reduction due to trees and urban greenery, for street-tree planting areas of 113.39 km in Gangnam District and 45 km in Gangbuk District, Seoul.

The operation of i-Tree Eco is divided into two methods: complete inventory and plot sample [23]. In this study, we devised a method that applied both the complete inventory method, which inputs accurate data values for each tree into an Excel file to derive results, and the sample method, which sets multiple points randomly in a specific area for reasonable value inference for a large research target area and applies probabilistic values through the data of those points. When planting street trees on one road, it was assumed that trees of a specific species with a similar shape and characteristics (e.g., height and age of the tree and width of the crown) were planted in bulk, and that the planted street trees were exposed to similar growing environments on one road; thus, their growth speed and shape were assumed to be similar.

The growth status and shape of the street trees on each of the 103 roads were analyzed, and in similar cases, representative street trees for each species were selected and the data values were applied in bulk. In exceptional cases where the shape, growth status, and growth environment were different, a method was devised and applied to classify and input the data separately. Considering the characteristics of trees that grow daily and the fact that the state of the leaves changes every season, field surveys were conducted from April to August 2023, during the time when growth is the most vigorous. Information on 12 tree categories, such as the species, total height, diameter at breast height (DBH), and stem size, was collected directly as field data using a clinometer and a laser rangefinder (Table 2). All the data were entered into an Excel file to further analyze and evaluate the vegetation structure of street trees and related ecosystem services, and this was converted into an access file of the i-Tree Eco model and entered.

Table 2. Field investigation method by item.

Category	Measurement Method
Tree species	It was visually confirmed; when writing in the inventory, the eco specifications list provided by i-Tree Eco V6 was referenced for scientific and general names.
Height	When the distance between [researcher-lowest point] and [researcher-highest point] was measured, the principle of the trigonometric ratios (Pythagoras' principle) was used to measure labor.
DBH	Measurements were made using a caliper.
Width of crown	The height of the starting point of the crown was subtracted from the height of the tree.
Exposure to sunlight	The crown was divided into four parts (east, west, south, and north), and the area where exposure to sunlight was blocked due to the relationship with surrounding buildings and facilities was input.

Public data were collected through the National Statistics Portal for the GRDP, the Seoul Data Plaza for the road status and species status by route, and i-Tree Eco for weather data. These were used for evaluation using the local database.

Air pollution data, including the hourly concentrations of nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), PM10, and PM2.5, were compiled from the National Fine Dust Information Center, provided by the Ministry of Environment [27]. The regional weather information was obtained from the Meteorological Administration Open Data Portal [21].

3. Results

3.1. Tree Species' Structural Characteristics

Among the 233,469 trees (15 species) in Gangnam District, the 5 species with the most individuals are *Ginkgo class* (31.3%), *American sycamore* (27.7%), *Japanese zelkova* (13.8%), *Japanese mountain cherry* (10.0%), and *Fringetree* spp. (4.6%) (Figure 3). Among the 6496 trees (20 species) in Gangbuk District, the 5 species with the most individuals are *Ginkgo class* (44.2%), *Pine* spp. (13.5%), *American sycamore* (11.1%), *Fringetree* spp. (7.8%), and *Japanese mountain cherry* (7.0%) (Figure 3).

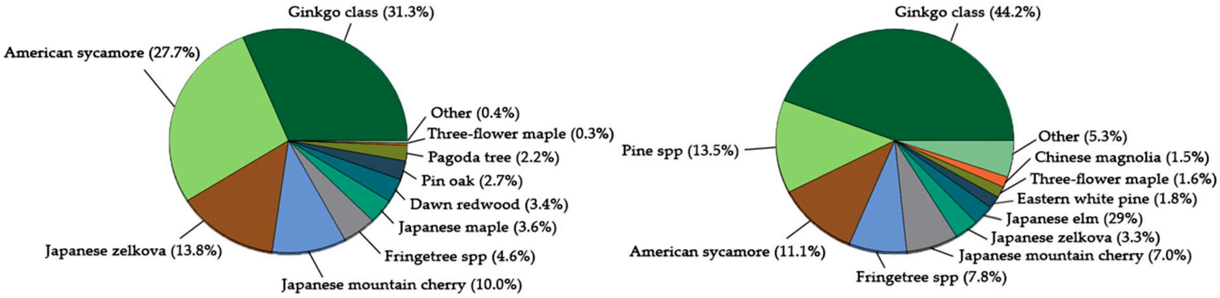


Figure 3. Tree population summary by species of Gangnam District (**left**) and Gangbuk District (**right**).

Both Gangnam District and Gangbuk District include a variety of species recommended by the Korea Forest Service, such as timber, ornamental, and specialized species, but the diversity of species is greater in Gangbuk District.

The degree of air purification by trees is directly proportional to the plant's healthy leaf area. The street trees in Gangnam District are planted at a density of 2059 trees per km of road, and the leaf area is 115.26 hectares. The street trees in Gangbuk District are planted at a density of 191 trees per km of road, and the leaf area is 18.9 hectares. This showed a large enough gap to predict the results, namely, that the street trees in Gangnam District will provide more ecosystem services than those in Gangbuk District (Table 3).

Table 3. Structure summary by species and importance values by species.

Region	Species	Tree Quantity	Percent of Population	Leaf Area (ha)	Percent Leaf Area	Leaf Biomass (ton)	Importance Value
Gangnam District	*Ginkgo class*	7300	27.7	35.204	30.5	33.821	61.8
	American sycamore	6466	31.3	61.13	53.0	29.616	80.7
	Japanese zelkova	3231	13.8	7.699	6.7	4.986	20.5
	Japanese mountain cherry	2339	10.0	1.134	1.0	0.878	11.0
	Fringetree spp.	1070	4.6	0.756	0.7	0.586	5.2
	Japanese maple	830	3.6	0.56	0.5	0.315	4.0
	Dawn redwood	797	3.4	4.964	4.3	2.804	7.7
	Pin oak	633	2.7	2.318	2.0	2.098	4.7
	Pagoda tree	523	2.2	1.395	1.2	1.585	3.5
	Tree-flower maple	72	0.3	0.059	0.1	0.033	0.4
	Japanese rowan	34	0.1	0.017	0.0	0.013	0.2
	Japanese cornelian dogwood	20	0.1	0.009	0.0	0.005	0.1
	Chinese quince	17	0.1	0.009	0.0	0.006	0.1
	Japanese apricot	8	0.0	0.004	0.0	0.003	0.0
	Japanese persimmon	6	0.0	0.003	0.0	0.002	0.0
Total		23,346	100	115.261	100	76.753	
Gangbuk District	*Ginkgo class*	2868	44.2	10.811	57.2	10.386	101.4
	Pine spp.	876	11.1	0.728	28.4	0.701	39.5
	American sycamore	724	13.5	5.367	3.9	2.6	17.3
	Fringetree spp.	507	7.8	0.307	1.6	0.238	9.4
	Japanese mountain cherry	457	7.0	0.258	1.4	0.199	8.4
	Japanese zelkova	213	3.3	0.601	3.2	0.389	6.5
	Japanese elm	188	2.9	0.178	0.9	0.122	3.8
	Eastern white pine	115	1.8	0.23	1.2	0.148	3.0
	Three-flower maple	104	1.3	0.058	1.0	0.033	2.3
	Chinese magnolia	100	1.6	0.052	0.3	0.035	1.9
	Pagoda tree	85	1.5	0.182	0.3	0.207	1.8
	Japanese maple	63	1.0	0.038	0.2	0.021	1.2
	Silver maple	57	0.9	0.032	0.2	0.017	1.0
	Common crapemyrtle	40	0.6	0.018	0.1	0.024	0.7
	Giant dogwood	30	0.5	0.012	0.1	0.007	0.5
	Flowering dogwood	30	0.5	0.012	0.1	0.009	0.5
	Chinese hawthorn	30	0.5	0.013	0.1	0.01	0.5
	Lace-leaf maple	4	0.1	0.002	0.0	0.001	0.1
	Japanese apricot	4	0.1	0.002	0.0	0.001	0.1
Total		6495	100	18.901	100	15.149	

The top five species in terms of leaf area in Gangnam District are the *American sycamore* (61.13 ha), *Ginkgo class* (35.204 ha), *Japanese zelkova* (7.699 ha), *dawn redwood* (4.964 ha), and *pin oak* (2.318 ha); in Gangbuk District, they are the *Ginkgo class* (10.811 ha), *American sycamore* (5.367 ha), *Pine* spp. (0.728 ha), *Japanese zelkova* (0.601 ha), and *Fringetree* spp. (0.307 ha). In terms of leaf area provision, the *American sycamore*, a species with wide leaves, plays an important role in Gangnam District, and the *Ginkgo class*, which has the most trees, covers the largest area in Gangbuk District (Table 3).

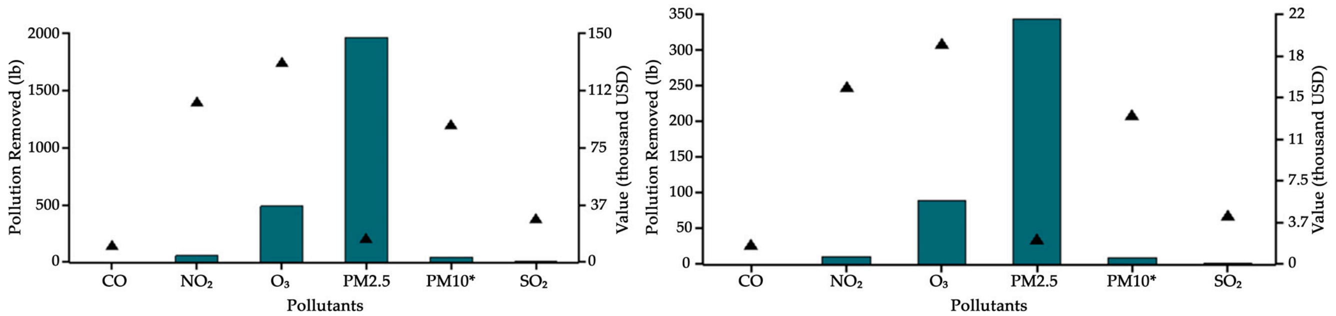
The importance value (IV) was calculated based on the proportion of individual trees and the leaf area; the higher the value, the more species dominate the tree structure in the city. In Gangnam District, the top five species in terms of the IV are the *American sycamore* (80.7), *Ginkgo class* (61.8), *Japanese zelkova* (20.5), *Japanese mountain cherry* (11.0), and *dawn redwood* (7.0); in Gangbuk District, they are the *Ginkgo class* (101.4), *American sycamore* (39.5), *Pine* spp. (17.3), *Fringetree* spp. (9.4), and *Japanese mountain cherry* (8.4) (Table 3). Gangnam District, like Gangbuk District, has the greatest number of *Ginkgo class*, but the importance of the *American sycamore*, which has a wide leaf area, is emphasized.

3.2. Analysis of Removal of Atmospheric Pollution Substances

Trees in cities affect the air quality by altering the deposition and dispersion of pollutants. Dispersion occurs when pollutants in the atmosphere are transported by airflow, and the presence of buildings and trees can obstruct airflow and change local dispersion patterns [24].

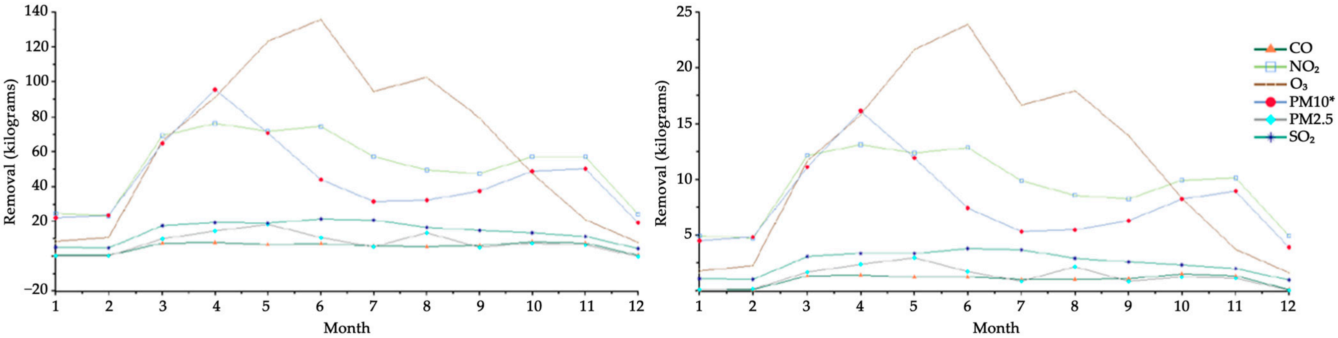
According to the i-Tree Eco analysis, the street trees in Gangnam District can remove an average of 2284.571 kg of air pollutants annually. These include 63.741 kg of CO, 632.578 kg of NO2, 788.296 kg of O3, 540.216 kg of PM10, 91.272 kg of PM2.5, and 168.468 kg of SO2. The simulation results show that the removal represents an annual economic value of USD 196019.11 (Table A1).

The street trees in Gangbuk District can remove an average of 743.925 kg of air pollutants annually, including 11.589 kg of CO, 112.059 kg of NO2, 139.357 kg of O3, 94.178 kg of PM10, 15.335 kg of PM2.5, and 371.407 kg of SO2. The simulation results show that the removal represents an annual average economic value of USD 29,806.49, and both Gangnam District and Gangbuk District showed the greatest benefits from the removal of fine dust and ozone. In terms of the amount of air pollutant removal, Gangnam District recorded 5.67 times that of Gangbuk District, and the annual economic value obtained was 6.57 times higher (Table A1). The removal value of pollutants per month and the type of pollutant are shown in Figures 4 and 5.



Obs.: PM10* — Particule matter less than 10 microns and greather than 2.5 microns.

Figure 4. Annual pollution removal and value by tree in Gangnam District (**left**) and Gangbuk District (**right**).



Obs.: PM10* — Particule matter less than 10 microns and greather than 2.5 microns.

Figure 5. Monthly pollution removal by trees and shrubs in Gangnam District (**left**) and Gangbuk District (**right**).

When comparing the annual and monthly air pollutant removal in Gangnam District and Gangbuk District, the shape of the graphs was very similar (Figures 6 and 7). This is presumably because the proportion of *Ginkgo* trees is high on the roads of both Gangnam District and Gangbuk District. In addition, it was assumed that the analysis target was street trees in Seoul, a common point; the provided air environment data value was similar; and various factors, such as the distance between buildings and street trees when planting, were similar.

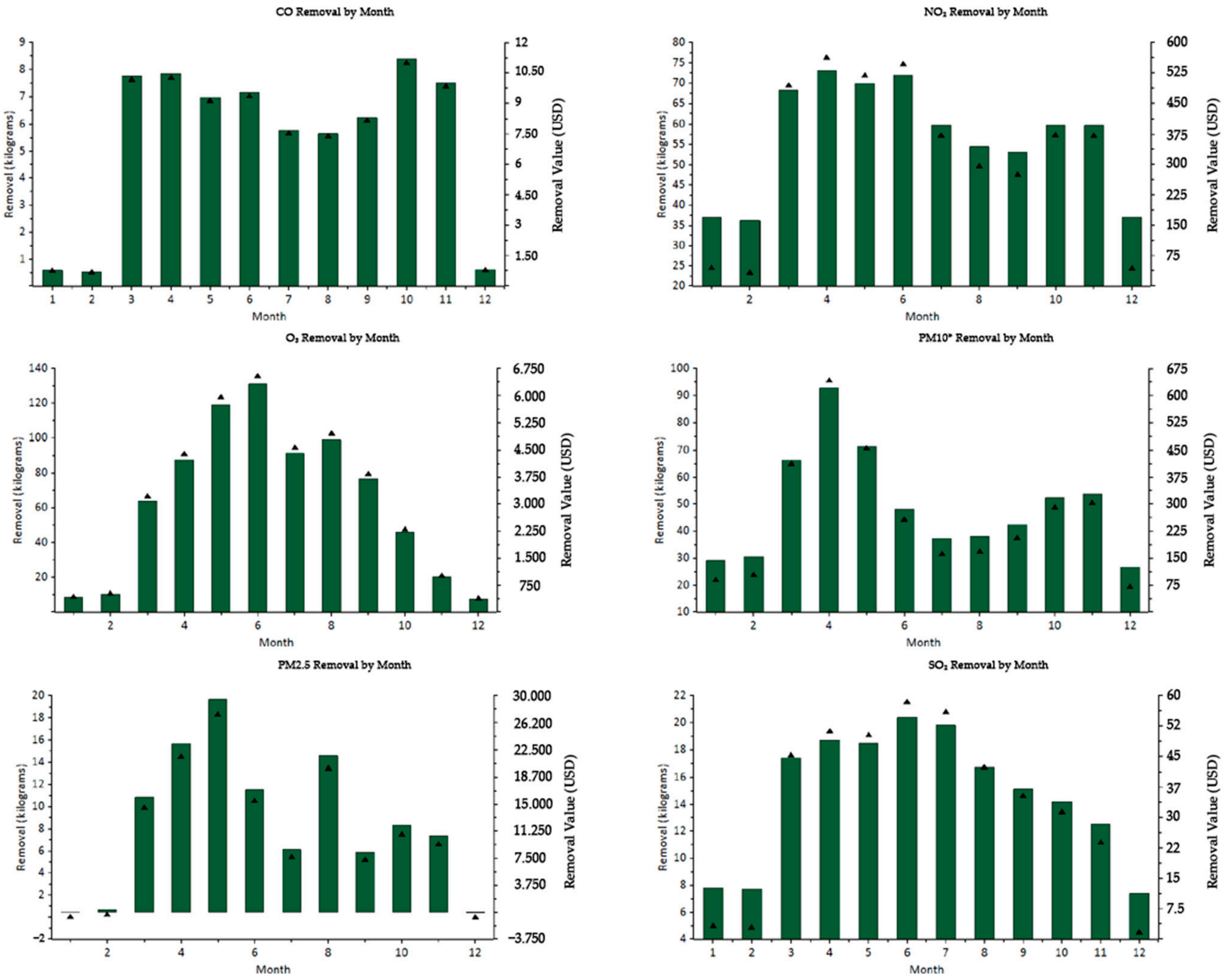


Figure 6. Monthly pollution removal by trees and shrubs in Gangnam District.

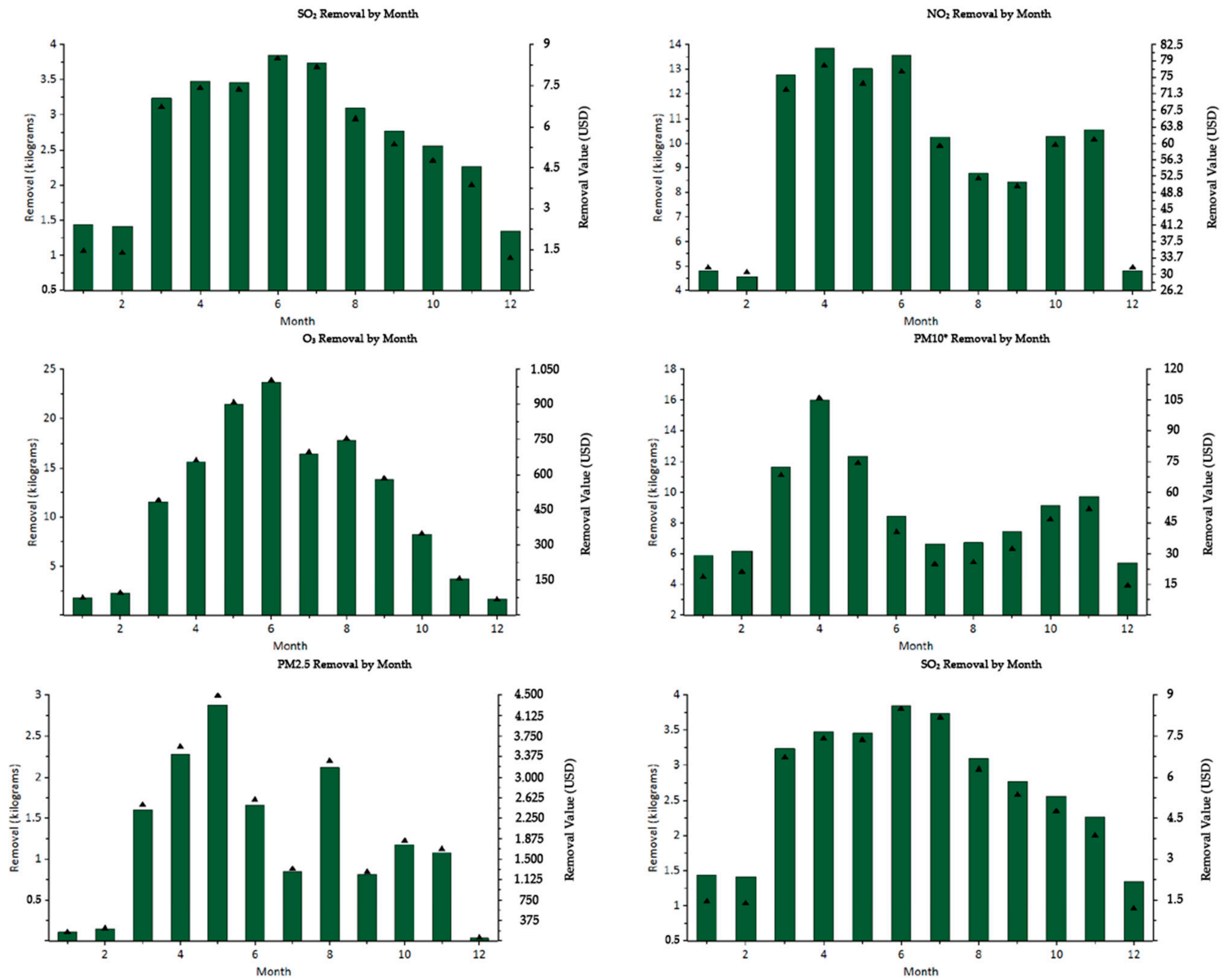


Figure 7. Monthly pollution removal by trees and shrubs in Gangbuk District.

3.3. Carbon and Oxygen Change Analysis

Carbon storage and sequestration are the two major ways in which trees contribute to the carbon cycle. Carbon storage refers to the process by which trees absorb CO_2 from the atmosphere during growth and convert it into the body of the tree [28]. This process continues as the tree grows; thus, carbon is a continuously accumulating value as long as the tree is alive. Conversely, carbon sequestration represents the ability of a tree to absorb and isolate carbon over a certain period. This value can be surveyed annually and can vary depending on the tree's growth rate, its health status, and the environmental conditions [29].

According to the i-Tree Eco analysis, the street trees in Gangnam District can store 13,540.8 metric tons of carbon. The species with the highest carbon storage are, in order, the *Ginkgo class* (6784.90 t), *American sycamore* (4129.20 t), *Japanese zelkova* (539.9 t), *pagoda tree* (488 t), and *Japanese mountain cherry* (468.2 t). Carbon sequestration was recorded at 1318.11 metric tons per year, and the top five species in terms of carbon sequestration are the *Ginkgo class* (525.09 t/yr), *American sycamore* (448.02 t/yr), *Japanese mountain cherry* (101.61 t/yr), *Japanese zelkova* (63.34 t/yr), and *Fringetree* spp. (48.77 t/yr), with some differences in species and order (Table A2).

The street trees in Gangbuk District can store a total of 3049.6 metric tons of carbon. The species with the highest carbon storage are, in order, the *Ginkgo class* (2082.8 t), *American sycamore* (390.9 t), *Pine* spp. (172.5 t), *Fringetree* spp. (125 t), and *Japanese mountain cherry* (102.4 t). Carbon sequestration was recorded at 82.63 metric tons per year, and the top five species in terms of carbon sequestration are the *Ginkgo class* (161.3 t/year), *American sycamore* (35.34 t/year), *Fringetree* spp. (18.98 t/year), *Japanese mountain cherry* (18.93 t/year), and *Pine* spp. (15.08 t/year), with some differences in species and order (Table A2).

When considering the top five species of street trees in Gangnam District and Gangbuk District based on carbon storage and sequestration, it was found that the *Ginkgo class* and *American sycamore* ranked first and second, respectively, but with a substantial difference in the absolute quantity (Figures 8 and 9). Moreover, while Gangnam District heavily relies on the *American sycamore* in all aspects of carbon storage and sequestration, Gangbuk District is at a level of dependence on it.

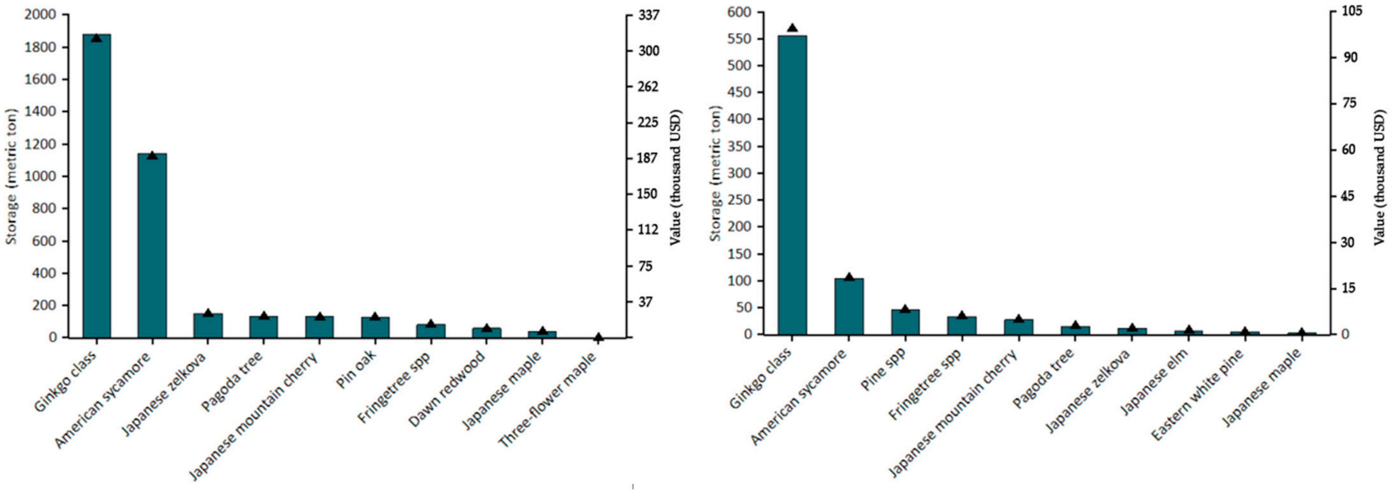


Figure 8. Estimated carbon storage and values for tree species with the greatest storage in Gangnam District (**left**) and Gangbuk District (**right**).

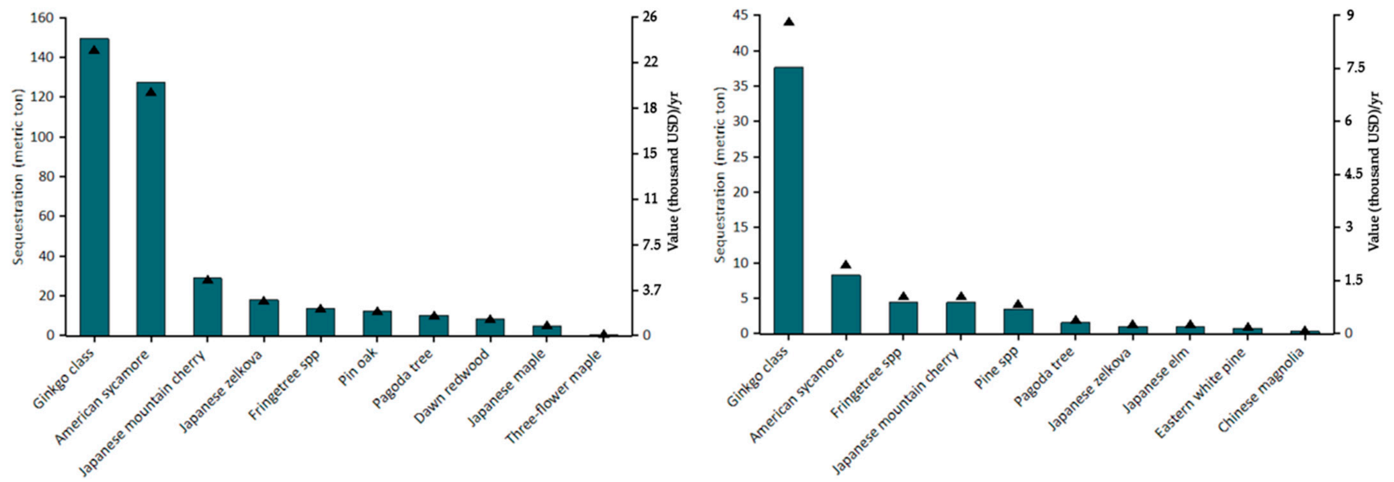


Figure 9. Estimated annual gross carbon sequestration and values for tree species with the greatest sequestration in Gangnam District (**left**) and Gangbuk District (**right**).

To compare the effects of different greenhouse gases, the United Nation's Intergovernmental Panel on Climate Change (IPCC) has defined the "global warming potential", and the CO_2 equivalent (CO_2e) index shows the warming effect compared to CO_2 for a certain amount of greenhouse gas over a certain period (usually 100 years) [30]. The CO_2e due to carbon storage is 13,540.8 metric tons in Gangnam District and 3049.6 metric tons in Gangbuk District, and the CO_2e due to carbon sequestration is 1318.1 metric tons/year in Gangnam District and 274.9 metric tons/year in Gangbuk District (Table A2).

The amount of carbon absorption and the total carbon sequestration in i-Tree Eco was calculated based on a price of USD 174.00 per metric ton. In this evaluation, the total carbon storage value of the street trees in Gangnam District was estimated to be USD 642,481.47, and the total carbon sequestration value was estimated to be USD 62,541.52. The total carbon storage value of the street trees in Gangbuk District was estimated to be USD 144,693.20, and the total carbon sequestration value was estimated to be USD 13,043.29 (Table 4). Oxygen, a gaseous substance, accounts for 21% of the atmosphere by volume, and according to Professor Yoshiya of Doshisha University in Japan, the amount of oxygen in the atmosphere decreases by one millionth every year through the circulation survey process of trace elements using isotopes. This has been attributed to an increase in CO_2 [31]. It is estimated that the street trees in Gangnam District (1056.61 t) will produce approximately 4.8 times the oxygen of the street trees in Gangbuk District (220.37 t), and this is expected to contribute to reducing not only the carbon in the region, but also global warming (Table A3).

3.4. Hydrological Influence Analysis

The hydrological analysis included water-related analyses on aspects such as evaporation, transpiration, water interception, and avoided runoff.

Surface runoff occurs when a significant amount of rainfall is not absorbed by the tree's crown or soil. Trees and shrubs in cities primarily capture rainwater through the leaves of the crown, and the root system filters and stores water in the soil to reduce runoff [32]. All the physical components of the tree structure, such as the leaves, branches, and bark, are essential for capturing rainfall; however, in the i-Tree Eco analysis, only the amount held by the leaves was considered. In this analysis, the avoided runoff value was calculated at USD 2.28 per cubic meter, and it was estimated using an annual rainfall of 1.29 m. The street trees in Gangnam District were estimated to reduce rainwater runoff by 3977.45 m^3 per year, and those in Gangbuk District were estimated to reduce rainwater runoff by 695.37 m^3 per year annually (Tables A4 and A5).

When comparing the avoided runoff values (Figure 10), a difference was observed between Gangnam District and Gangbuk District, albeit not a significant one; this is because of geographical features. Gangbuk District has highlands in the north and lowlands in the south; therefore, when it rains, rain flows from north to south, and when it flows down to lower areas, the terminus is the Han River. However, Gangnam is an area in Seoul that suffers from flood damage during rainfall events because it has a very high coverage rate and a topography such that rainwater gathers toward the center of the district. Therefore, the large difference between the two regions found in the hydrological influence analysis is rather reasonable, considering the regional characteristics.

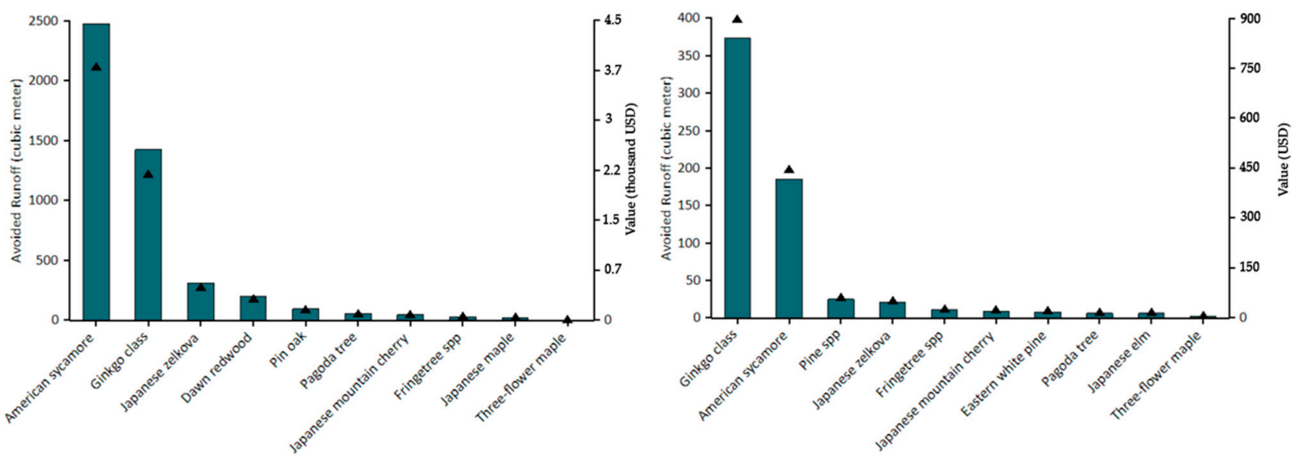


Figure 10. Avoided runoff and value for species with greatest overall impact on runoff in Gangnam District (**left**) and Gangbuk District (**right**).

3.5. Total Benefits and Economic Values of Trees

The street trees in Gangnam District and Gangbuk District provide benefits and economic value in terms of carbon storage, carbon sequestration, rainwater runoff prevention, and air pollution removal. When converted into economic value, the street trees in Gangnam District have 4.4 times the value of those in Gangbuk District in terms of carbon storage, 4.8 times for carbon sequestration, 5.7 times for avoided runoff, and 6.5 times for pollution removal (Tables 4 and 5).

The replacement value refers to the expected cost when a tree needs to be replaced with a similar one, and it comprehensively reflects various values analyzed before the cost estimation. The street trees in Gangnam District can be converted into an economic value of a total of USD 20,657,535, and those in Gangbuk District can be converted into an economic value of a total of USD 4,362,512.

Table 4. Benefits summary of trees by species in Gangnam District.

Species	Tree Number	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
		(Ton)	(USD)	(ton/year)	(USD/year)	(m^3/year)	(USD/year)	(ton/year)	(USD/year)	(USD)
Ginkgo class	7300	1850.26	321,927.98	143.19	24,914.51	1214.85	2606.15	0.70	59,870.92	7,943,977.84
American sycamore	6466	1126.03	195,919.35	122.18	21,257.41	2109.49	4525.37	1.21	103,960.95	7,887,344.33
Japanese zelkova	3231	147.23	25,616.59	17.27	3005.53	265.70	569.98	0.15	13,094.20	1,496,170.52
Japanese mountain cherry	2339	127.69	22,216.34	27.71	4821.08	39.14	83.97	0.02	1928.93	832,296.36
Fringetree spp.	1070	80.74	14,047.48	13.30	2314.03	26.07	55.93	0.01	1284.95	489,701.69
Japanese maple	830	37.60	6542.89	4.76	827.41	19.33	41.47	0.01	952.63	356,613.29
Dawn redwood	797	57.52	10,008.09	7.95	1382.61	171.28	367.45	0.10	8441.30	794,808.64
Pin oak	633	126.23	21,962.81	12.04	2094.68	79.99	171.60	0.05	3942.26	427,795.86
Pagoda tree	523	133.08	23,154.21	9.85	1713.37	48.13	103.25	0.03	2371.88	374,816.38
Three-flower maple	72	2.25	390.88	0.37	63.84	2.03	4.36	0.00	100.13	22,318.34
Japanese rowan	34	1.45	252.55	0.34	59.58	0.59	1.26	0.00	28.92	12,719.43
Japanese cornelian dogwood	20	0.81	140.35	0.18	30.87	0.31	0.65	0.00	15.05	7482.02
Chinese quince	17	1.16	201.50	0.19	32.50	0.29	0.63	0.00	14.46	6359.72
Japanese apricot	8	0.44	75.72	0.10	17.75	0.14	0.30	0.00	6.87	2886.00
Japanese persimmon	6	0.14	24.73	0.04	6.35	0.11	0.25	0.00	5.65	2244.61
Total	23,346.00	3692.61	642,481.47	359.45	62,541.52	3977.46	8532.62	2.28	196,019.10	20,657,535.03

Table 5. Benefits summary of trees by species in Gangbuk District.

Species	Tree Number	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
		(Ton)	(USD)	(ton/year)	(USD/year)	(m^3/year)	(USD/year)	(Ton/year)	(USD/year)	(USD)
Ginkgo class	2868	567.98	98,823.32	43.99	7653.28	397.75	853.27	0.23	17,049.26	2,531,942.57
Pine spp.	876	47.03	8182.92	4.11	715.37	26.77	57.44	0.02	1147.65	432,718.87
American sycamore	724	106.59	18,546.13	9.64	1676.59	197.45	423.58	0.11	8463.63	715,784.06
Fringetree spp	507	34.08	5929.94	5.18	900.69	11.30	24.25	0.00	484.58	195,352.63
Japanese mountain cherry	457	27.92	4858.09	5.16	898.03	9.48	20.34	0.01	406.47	151,404.74
Japanese zelkova	213	11.88	2066.34	1.23	213.29	22.13	47.47	0.01	948.49	111,606.20
Japanese elm	188	7.48	1301.13	1.	206.53	6.56	14.08	0.00	281.33	48,143.32
Eastern white pine	115	5.28	918.71	0.91	157.80	8.45	18.13	0.00	362.34	65,581.95
Three-flower maple	104	1.31	227.97	0.29	51.18	2.13	4.57	0.00	91.25	10,160.28
Chinese magnolia	100	1.06	184.67	0.38	65.33	1.91	4.09	0.00	81.75	10,908.96
Pagoda tree	85	16.00	2783.15	1.82	316.85	6.69	14.35	0.00	286.71	48,978.39
Japanese maple	63	2.89	502.13	0.30	51.61	1.38	2.97	0.00	59.36	23,897.77
Silver maple	57	0.48	84.18	0.18	30.85	1.16	2.49	0.00	49.68	3407.18
Common crapemyrtle	40	0.50	86.29	0.18	30.57	0.68	1.45	0.00	29.06	3676.17

Table 5. *Cont.*

Species	Tree Number	Carbon Storage		Gross Carbon Sequestration		Avoided Runoff		Pollution Removal		Replacement Value
		(Ton)	(USD)	(ton/year)	(USD/year)	(m^3/year)	(USD/year)	(Ton/year)	(USD/year)	(USD)
Giant dogwood	30	0.33	57.48	0.15	26.08	0.44	0.94	0.00	18.71	2757.13
Flowering dogwood	30	0.39	68.12	0.13	23.15	0.44	0.94	0.00	18.71	2757.13
Chinese hawthorn	30	0.30	52.96	0.11	19.24	0.49	1.06	0.00	21.15	2757.13
Lace-leaf maple	4	0.05	8.77	0.02	2.89	0.08	0.18	0.00	3.51	390.78
Japanese apricot	4	0.06	10.91	0.02	3.94	0.07	0.14	0.00	2.85	286.76
Total	6495	831.61	144,693.20	74.97	13,043.29	695.37	1491.74	0.40	29,806.49	4,362,512.01

3.6. Comparative Evaluation of Street Trees' Replacement Value

It is possible to compare the ecosystem services provided by street trees in Gangnam District and Gangbuk District through an alternative method that comprehensively reflects their value.

In this study, we did not compare the replacement value of the street trees in Gangnam District (approximately USD 20,657,535) and Gangbuk District (approximately USD 4,362,512) in absolute numbers, but we converted the two districts' replacement value per unit population, unit area, and unit road length for comparison (Table 6). Both the population and the conversion value per total length of the area of street trees were determined to have a higher replacement value in Gangnam District than in Gangbuk District.

Table 6. Replacement value compared to population, area, and length of road in Gangnam District and Gangbuk District.

Category	Area	Formula	Replacement Value
Replacement value to population	Gangnam District	USD 20,657,535 ÷ 541,130 people	USD 38.17/capita
	Gangbuk District	USD 4,362,512 ÷ 288,735 people	USD 15.11/capita
Replacement value to area	Gangnam District	USD 20,657,535 ÷ 39.5 km^2	USD 522,975.56/km^2
	Gangbuk District	USD 4,362,512 ÷ 23.6 km^2	USD 184,852.20/km^2
Replacement value to the length of roads	Gangnam District	USD 20,657,535 ÷ 114 km	USD 181,206.44/km
	Gangbuk District	USD 4,362,512 ÷ 45 km	USD 96,944.71/km

The ecosystem service data of the street trees between the two districts investigated and organized in this study showed a large difference when quantitatively compared, and we were also able to see the difference when conducting field surveys. In addition to the total number of street trees provided through public data, the field survey also revealed large differences in the overall height of the street trees, their width and the width of their crowns, their DBH, and the planting type (e.g., one row or two rows) and planting density of the street trees, which could be clearly observed with the naked eye. It was predicted that the ecosystem services of the street trees in Gangnam District would be far superior to those in Gangbuk District.

4. Discussion

4.1. Overall Analysis of Results

The outcomes obtained through the application of the i-Tree Eco model were systematically examined for 29,451 trees (comprising 26 species) situated in Gangnam District and Gangbuk District in Seoul, South Korea. Our analysis encompassed the tree species' structural characteristics, air pollution removal, alterations in carbon and oxygen levels, and hydrological impact and quantified the benefits and ecological economic value associated with these trees.

The evaluation of the tree species' structural characteristics revealed a dominance of the *Ginkgo class* in both Gangnam District and Gangbuk District (Figure 3). However, the *American sycamore* emerged as the most important species in Gangnam District, whereas the *Ginkgo class* assumed a greater importance in Gangbuk District (Table 3). Importance was determined by employing the importance value (IV), and factors such as the species, diameter at breast height (DBH), leaf area, and biomass were considered pivotal in the computation of the IV values.

In the context of air pollution removal, where the analysis covered CO, NO2, O3, PM10, PM2.5, and SO2, the monthly and annual patterns demonstrated remarkable similarities between Gangnam District and Gangbuk District (Table A1, Figures 4 and 5). The *Ginkgo class* and *American sycamore*, which were consistently prominent in both districts, contributed substantially to this uniformity. Notably, coniferous trees, such as the *Pine* spp. in Gangbuk District, exhibited a lower removal capacity due to their reduced leaf area. This observation aligns with the study conducted by Jo (2020) [16], which highlighted the significance of the tree species, density, and design guidelines in maximizing carbon and PM2.5 reduction. The density and cover of street trees were identified as crucial factors influencing their efficacy in offsetting carbon emissions and PM2.5 deposition.

In the analysis of changes in carbon and oxygen, the degree to which each species contributed to mitigating global warming through the storage and sequestration of carbon (Table A2, Figures 8 and 9) and oxygen production was identified (Table A3). Carbon storage represents the cumulative value accrued during a tree's lifespan, whereas carbon sequestration is an annual measurable value. In the comparison between Gangnam and Gangbuk, the carbon storage value was 4.5 times greater in Gangnam, and the carbon sequestration value was 4.8 times higher. The diverse contributions of each species emphasize the importance of species characteristics, such as the canopy size and the net photosynthetic rate, in influencing CO2 assimilation. Therefore, a mix of species can help maximize CO2 uptake and maintain biodiversity [28].

The hydrological impact analysis, encompassing evapotranspiration, pre-rainfall interception, and runoff prevention, demonstrated that Gangnam surpassed Gangbuk in rainwater reduction, achieving a 5.7-fold reduction annually (Tables A4 and A5).

In the analysis of the benefits and economic value of trees, the benefits and value of carbon storage and sequestration, rainwater runoff prevention, and air pollution removal can be quantitatively compared through the "replacement value", which is the estimated monetary cost to replace a tree with a similar tree (Table 5).

Therefore, in this study, when comparing the replacement value of the street trees in Gangnam District and Gangbuk District by classifying the replacement value per total population, total area of the district, and total length of the road, it was confirmed that Gangnam District received overwhelmingly more ecosystem services in all the result values than Gangbuk District (Table 6). This suggests that the economic gap between regions can affect the gap in the ecosystem services received from street trees.

4.2. Reliability and Validity

Following substantial quantitative expansion, Korean cities, having pushed against their limits, must transcend these boundaries through sustainable planning and enhancements, fostering qualitative advancement. The foundation for a city's quantitative growth lies in urban development, and is often skewed towards road-centric progress instead of prioritizing people. Street trees, constituting 20–30% of urban areas, stand as a public resource accessible to everyone, promoting equitable usage [32].

In road construction projects in South Korea, the estimated benefits of non-market goods, such as street trees, are limited to the contingent valuation method (a method that ensures objective reliability for external effects by investigating and analyzing the relationship between awareness, satisfaction, usage behavior, social capital, personal characteristics, and willingness to pay). However, this method has limitations in quantifying the benefits of parks and ecosystem services. The main advantage of using the i-Tree Eco model is that it estimates trees' functions based on locally measured site data and reviewed studies [33].

However, this research, conducted using the i-Tree Eco model, has several limitations. First, the ecosystem services provided by street trees are not the only quantitative elements; others include regulatory services. During the field survey, a gap was also observed in qualitative elements, such as cultural services, between the two districts; however, a quantitative evaluation of this gap had limitations.

Second, trees continue to grow and are at risk of pests; therefore, the data value can always change and incur various errors. However, the results of this study showed a significant difference, even when considering various error ranges and variables; thus, it is a value that can be applied to suggest social equity.

Finally, prior studies have delved into social equity, a crucial component for qualitative urban development, with investigations affirming the presence of disparities extending beyond economic dimensions, encompassing cultural and ecological realms [34–37]. However, because only Gangnam District and Gangbuk District were compared, it is not possible to generalize the correlation between the economic and ecological wealth gaps. Furthermore, to prove the correlation between the economic wealth gap in Seoul and the difference in the ecosystem services provided by street trees, and to suggest that social equity contributes to Seoul's qualitative growth, an additional value comparison analysis targeting Gangnam District, Gangbuk District, and other districts and additional research on qualitative elements such as cultural services need to be conducted.

4.3. Implications and Suggestions

The substantial divergence observed in the comparative evaluation of street trees between Gangnam District and Gangbuk District primarily stems from the discrepancy in tree quantity. Even though Gangbuk District features fewer roads than Gangnam District, a noteworthy difference persists in the value per unit length of roads. This distinction holds true, notwithstanding the growth rate of street trees in Gangnam District being lower (85% good) than that observed in Gangbuk District (99% good). This underscores the urgency of increasing the number of street trees in Gangbuk District to bridge the existing gap in ecosystem services between the two districts.

The analysis of the structural characteristics of Gangnam District and Gangbuk District shows that, unlike Gangnam District, where *Ginkgo* spp. and *American sycamore* are the main species, the street trees in Gangbuk District are quantitatively biased toward *Ginkgo* spp.

Therefore, even if the number of street trees in the two districts was assumed to be the same, the value of the ecosystem services provided by Gangbuk District would have been lower than that of Gangnam District. This is because the *American sycamore* has a wide leaf area and a high importance. Therefore, it is necessary to work toward a situation where the value of ecosystem services provided to the citizens of Gangbuk District increases when the quantity of street trees in Gangbuk District increases.

To address these disparities, strategic interventions are proposed that place emphasis on the importance of tree selection and planting practices for maximizing the carbon reduction capacity [29].

First, areas such as Gangnam District, which has enough street trees, but lacks in terms of growth rate, should seek measures to balance the ecosystem services in large cities such as Seoul, considering the tree management aspect. Areas such as Gangbuk District, which has a shortage of street trees, should consider the quantitative aspect. Second, by densely planting species with wide and rough leaves around the road to form a multi-layered vegetation structure, air pollution can be reduced. Third, it is important to implement carbon neutrality in response to climate change by prioritizing species with a high economic value and carbon storage capacity based on the functional value of the tree structure.

Conducting additional economic value comparison analyses of the ecosystem services provided by street trees in districts beyond Gangnam District and Gangbuk District, coupled with research on qualitative elements such as cultural services, holds promise.

These endeavors are anticipated to serve as crucial data for evidence-based urban forest planning. This comprehensive approach not only enriches the understanding of urban ecology, but also lays the groundwork for fostering social equity in Seoul city, advancing urban development sustainably and inclusively.

Furthermore, the findings of this study underscore the critical role of urban green spaces, particularly street trees, in enhancing environmental sustainability and fostering more inclusive and resilient cities. By systematically comparing the ecosystem services between Gangnam District and Gangbuk District, our research provides valuable insights into the disparities in access to these vital resources, aligning with SDG 11 (sustainable cities and communities) and SDG 10 (reduced inequalities). Furthermore, our analysis demonstrates how street trees contribute to climate change mitigation (SDG 13: climate action) and biodiversity conservation (SDG 15: life on land) through carbon storage, air pollution removal, and habitat provision. The observed economic and ecosystem service wealth gaps highlight the need for targeted interventions to address disparities and promote social equity in urban development, aligning with SDG 3 (good health and well-being) and SDG 12 (responsible consumption and production) [38]. By integrating these findings with the SDGs, our study provides a robust foundation for evidence-based urban planning policies aimed at creating more sustainable, inclusive, and resilient cities on a global scale.

5. Conclusions

This research compared and conducted a quantitative assessment of the disparity in ecosystem services, considering budget and development variations between Gangnam District and Gangbuk District. Gangnam District showed a 6.6 times higher removal of atmospheric pollution, 4.4 times higher carbon storage, 4.8 times higher carbon sequestration, and 5.7 times higher avoidance of runoff (hydrological influence) than Gangbuk District. This result reflects the fact that Gangnam District has a much higher density of street trees than Gangbuk District, especially street trees with wide crowns and high heights. However, the data also show that the growth rate of Gangnam District (85% good) is lower than that of Gangbuk District (99% good). In conclusion, it was confirmed that Gangnam District, despite being in the same city, is more economically affluent, stores more carbon, and provides superior ecosystem services from street trees than Gangbuk District. This shows that the supply of ecosystem services, whose importance is increasing owing to the adverse effects of climate change and air pollution caused by the emission of a large amount of carbon in affluent areas, may be relatively poor in economically poor areas.

These results can be used as objective evaluation data for the ecological value when reflecting street-tree planting and management-related plans or policies, and this preliminary study suggests a new perspective to explore the correlation between the regional economic and ecosystem service wealth gaps. This research is expected to promote qualitative urban growth based on social equity. For future research, implementing a pilot questionnaire with criteria such as the residents' perception, awareness, and usage behavior of street trees, along with assessing the social capital, equity in access, willingness to pay, and cultural services, is crucial for understanding the social dimension of these urban green spaces. These data can provide insights into the role of street trees in community well-being, potential disparities in access, and their cultural significance, aiding in formulating informed urban planning policies for more inclusive and sustainable development.

Author Contributions: Conceptualization, Y.C. and G.K.; methodology, Y.C., J.M. and G.K.; software, Y.C. and G.K.; data curation, Y.C.; writing—original draft preparation, Y.C. and G.K.; writing—review and editing, Y.C., J.M. and G.K.; visualization, Y.C. and J.M.; supervision, G.K.; project administration, G.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The data presented in this study are available upon request.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Figure A1. On-site photos of Gangbuk District and Gangnam District.

Appendix B

Table A1. Annual pollution removal and value by trees and shrubs.

Pollutant	Gangnam District Removal (kg/year)	Gangnam District Value (USD/year)	Gangbuk District Removal (kg/year)	Gangbuk District Value (USD/year)
CO	63.741	88.17	11.589	16.03
NO_2	632.578	4476.90	112.059	707.54
O_3	788.296	37,348.03	139.357	5890.50
PM10*	540.216	3576.09	94.178	623.43
PM2.5	91.272	150,095.52	15.335	22,499.30
SO_2	168.468	434.40	371.407	69.69
SUM	2284.571	196,019.11	743.925	29,806.49

Table A2. CO_2-equivalent carbon storage and carbon sequestration of trees by species.

Gangnam District			Gangbuk District		
Species	Carbon Storage—CO_2 Equivalent (Ton)	Carbon Sequestration—CO_2 Equivalent (Ton/year)	Species	Carbon Storage—CO_2 Equivalent (Ton)	Carbon Sequestration—CO_2 Equivalent (Ton/year)
Ginkgo class	6784.90	525.09	*Ginkgo class*	2082.80	161.3
American sycamore	4129.20	448.02	*American sycamore*	390.9	35.34
Japanese zelkova	539.9	63.34	*Pine* spp.	172.5	15.08
Pagoda tree	488	36.11	*Fringetree* spp.	125	18.98
Japanese mountain cherry	468.2	101.61	*Japanese mountain cherry*	102.4	18.93
Pin oak	462.9	44.15	*Pagoda tree*	58.7	6.68
Fringetree spp.	296.1	48.77	*Japanese zelkova*	43.5	4.5
Dawn redwood	210.9	29.14	*Japanese elm*	27.4	4.35
Japanese maple	137.9	17.44	*Eastern white pine*	19.4	3.33
Three-flower maple	8.2	1.35	*Japanese maple*	10.6	1.09
Japanese rowan	5.3	1.26	*Three-flower maple*	4.8	1.08
Chinese-quince	4.2	0.68	*Chinese magnolia*	3.9	1.38
Japanese cornelian dogwood	3	0.65	*Silver maple*	1.8	0.65
Japanese apricot	1.6	0.37	*Common crapemyrtle*	1.8	0.64
Japanese persimmon	0.5	0.13	*Flowering dogwood*	1.4	0.49
			Chinese hawthorn	1.1	0.41
			Giant dogwood	1.2	0.55
			Japanese apricot	0.2	0.08
			Lace-leaf maple	0.2	0.06
Total	13,540.80	1318.11	Total	3049.60	274.92

Table A3. The top 15 oxygen-producing species of Gangnam District and Gangbuk District.

Gangnam District		Gangbuk District	
Species	Oxygen (Ton)	Species	Oxygen (Ton)
Ginkgo class	420.92	*Ginkgo class*	129.3
American sycamore	359.13	*American sycamore*	28.33
Japanese mountain cherry	81.45	*Fringetree* spp.	15.22
Japanese zelkova	50.78	*Japanese mountain cherry*	15.17
Fringetree spp	39.09	*Pine* spp.	12.09
Pin oak	35.39	*Pagoda tree*	5.35
Pagoda tree	28.95	*Japanese zelkova*	3.6
Dawn redwood	23.36	*Japanese elm*	3.49
Japanese maple	13.98	*Eastern white pine*	2.67
Three-flower maple	1.08	*Chinese magnolia*	1.1
Japanese rowan	1.01	*Japanese maple*	0.87
Chinese quince	0.55	*Three-flower maple*	0.86
Japanese cornelian dogwood	0.52	*Silver maple*	0.52

Table A3. *Cont.*

Gangnam District		Gangbuk District	
Species	**Oxygen (Ton)**	**Species**	**Oxygen (Ton)**
Japanese apricot	0.3	*Common crapemyrtle*	0.52
Japanese persimmon	0.11	*Giant dogwood*	0.44
Total	1056.62	Total	219.53

Table A4. Hydrology effects of trees by species.

Gangnam District					Gangbuk District				
Species	**Evaporation**	**Transpiration**	**Water Intercepted**	**Avoided Runoff**	**Species**	**Evaporation**	**Transpiration**	**Water Intercepted**	**Avoided Runoff**
	m^3/Year	**m^3/Year**	**m^3/Year**	**m^3/Year**		**m^3/Year**	**m^3/Year**	**m^3/Year**	**m^3/Year**
American sycamore	10,294.37	21,262.38	10,294.38	2109.49	*Ginkgo class*	1935.37	4539.49	1935.37	397.75
Ginkgo class	5928.51	12,244.96	5928.52	1214.85	*American sycamore*	960.76	2253.50	960.76	197.45
Japanese zelkova	1296.61	2678.06	1296.61	265.7	*Pine* spp.	130.28	305.57	130.28	26.77
Dawn redwood	835.87	1726.44	835.87	171.28	*Japanese zelkova*	107.67	252.54	107.67	22.13
Pin oak	390.37	806.28	390.37	79.99	*Fringetree* spp.	55.01	129.02	55.01	11.3
Pagoda tree	234.87	485.1	234.87	48.13	*Japanese mountain cherry*	46.14	108.23	46.14	9.48
Japanese mountain cherry	191.01	394.51	191.01	39.14	*Eastern white pine*	41.13	96.48	41.13	8.45
Fringetree spp.	127.24	262.8	127.24	26.07	*Pagoda tree*	32.55	76.34	32.55	6.69
Japanese maple	94.33	194.84	94.33	19.33	*Japanese elm*	31.94	74.91	31.94	6.56
Three-flower maple	9.91	20.48	9.91	2.03	*Three-flower maple*	10.36	24.3	10.36	2.13
Japanese rowan	2.86	5.91	2.86	0.59	*Chinese magnolia*	9.28	21.77	9.28	1.91
Japanese cornelian dogwood	1.49	3.08	1.49	0.31	*Japanese maple*	6.74	15.81	6.74	1.38
Chinese-quince	1.43	2.96	1.43	0.29	*Silver maple*	5.64	13.23	5.64	1.16
Japanese apricot	0.68	1.41	0.68	0.14	*Common crapemyrtle*	3.3	7.74	3.3	0.68
Japanese persimmon	0.56	1.16	0.56	0.11	*Chinese hawthorn*	2.4	5.63	2.4	0.49
					Flowering dogwood	2.12	4.98	2.12	0.44
					Giant dogwood	2.12	4.98	2.12	0.44
					Lace-leaf maple	0.4	0.93	0.4	0.08
					Japanese apricot	0.32	0.76	0.32	0.07
Total	19,410.11	40,090.37	19,410.13	3977.45	Total	3383.52	7936.20	3383.52	695.37

Table A5. Avoided runoff value by species.

Gangnam District		Gangbuk District	
Species	**Avoided Runoff Value (USD/Year)**	**Species**	**Avoided Runoff Value (USD/Year)**
American sycamore	4525.37	*Ginkgo class*	853.27
Ginkgo class	2606.15	*American sycamore*	423.58
Japanese zelkova	569.98	*Pine* spp.	57.44
Dawn redwood	367.45	*Japanese zelkova*	47.47
Pin oak	171.60	*Fringetree* spp.	24.25
Pagoda tree	103.25	*Japanese mountain cherry*	20.34
Japanese mountain cherry	83.97	*Eastern white pine*	18.13
Fringetree spp.	55.93	*Pagoda tree*	14.35
Japanese maple	41.47	*Japanese elm*	14.08
Three-flower maple	4.36	*Three-flower maple*	4.57
Japanese rowan	1.26	*Chinese magnolia*	4.09
Japanese cornelian dogwood	0.65	*Japanese maple*	2.97
Chinese quince	0.63	*Silver maple*	2.49
Japanese apricot	0.30	*Common crapemyrtle*	1.45

Table A5. *Cont.*

Gangnam District		Gangbuk District	
Species	Avoided Runoff Value (USD/Year)	Species	Avoided Runoff Value (USD/Year)
Japanese persimmon	0.25	*Chinese hawthorn*	1.06
		Flowering dogwood	0.94
		Giant dogwood	0.94
		Lace-leaf maple	0.18
		Japanese apricot	0.14
Total	8532.62	Total	1491.74

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