

# An Assessment of Urban Forest Landscape Services for Green Space Management Improvement in Bandung City, West Java, Indonesia

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**Abstract.** In the Bandung metropolitan area, urban forests (UFs) play a crucial role in providing landscape services, especially within the Babakan Siliwangi Urban Forest (BSUF). The BSUF is currently facing multiple development challenges, necessitating scientific evidence to elucidate its role in Bandung's urban landscape. This research analyzes the BSUF's function in carbon storage, carbon sequestration, and oxygen production and to formulate management recommendations to provide optimal future benefits. Data collection was carried out in 14 sample plots and i-Tree Eco was used to analyze landscape services and predict future vegetation structure based on planned plantings. The findings reveal that (1) BSUF has a high tree diversity, with a 3.3 Shannon index and 41 tree species identified; (2) it stores 381 tons of carbon, sequesters 25.17 tons of carbon annually, and produces 65.07 tons of oxygen per year; (3) to enhance landscape services value for the next 30 years, a minimum 300 trees must be planted per year. These results demonstrate the BSUF's significance and the importance of tree diversity in sustaining landscape services provided by UF. Additionally, this research introduces i-Tree Eco as a valuable tool for conducting vegetation analysis, aiding stakeholders in monitoring and formulating improved landscape management strategies.

## 1 Introduction

Bandung is the capital city of West Java Province which has evolved into one of Indonesia's metropolitan cities. This rapid growth of population also has an impact on Bandung's

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environmental quality. According to BPS data in 2021, the population of Bandung City is 2,527,854 people. This is directly proportional to the number of vehicle ownership which reached 1,571,795 motor vehicles [1]. The increment of vehicle intensity affects pollution levels and decreases air quality. Furthermore, the high population can also cause other problems, such as land conversion, land subsidence, to air and water pollution.

Green open spaces are an integrated part of green areas in urban areas which provides benefits to cities and their residents in various forms, including physical, emotional and health aspects [2]. Green open spaces provide oxygen supply for living creatures, absorb carbon and other sources of pollutants [3]. Referring to Bandung City Regional Regulation Number 5 of 2022 concerning the city's spatial plan, it is stated that the Babakan Siliwangi Urban Forest (BSUF) is an urban forest (RTH-1) and one of the city's strategic areas (KSK) from the perspective of environmental carrying capacity, aimed at realizing its function as the lungs of the city. The existence of the BSUF is an important component of maintaining comfort for city residents through the function of forming the city's microclimate and landscape services, and is also used as a public space based on environmental conservation [4]. The BSUF was awarded as the best urban forest in Indonesia through the 2023 Adipura Plaque Award given by the Ministry of Forestry and Environment. However, the BSUF is currently facing various development challenges. BSUF has the lack of vegetation monitoring and landscape services evaluation. It requires scientific evidence to explain its role, as well as develop management recommendations so that it can continue to provide benefits to the Bandung urban landscape and raises public awareness on the importance of urban forest.

In order to tackle this problem, a collaborative effort was made by different parties such as academics and experts to conduct a comprehensive research on vegetation assessment to offer data-driven insights on the structure, composition, and landscape services provided by the BSUF using i-Tree Eco. i-Tree Eco, a software program, has been developed by the United States Forest Service (USFS), specifically designed to assist in measuring and evaluating the ecological and economic benefits provided by urban forests. In the context of future green space management, i-Tree Eco can answer the requirements to analyze and understand the landscape services or environmental benefits provided by trees and urban forests, including oxygen production, carbon storage and absorption, avoided runoff and water quality improvement. The analysis results from i-TreeEco can assist in sustainable management planning, environmental health monitoring, and enable efficient management of urban forests in the future [5].

## 2 Materials and Methods

### 2.1 Study area



**Fig. 1.** Babakan Siliwangi Urban Forest as the site location for this study.

This research was conducted in the Babakan Siliwangi Urban Forest, Bandung City, West Java. The total area of BSUF is 5 hectares, with the total area of the plot samples used is 10% from the urban forest area. The field study was held from February to March 2023.

## **2.2 Data inventory**

Field inventory and data collection were carried out according to the i-Tree Eco field manual which emphasized the use of sample plots as a key reference point for subsequent research [5, 6]. 14 plot samples with a 22.1 m diameter [7] and an area of 400 m<sup>2</sup> each were used based on a 10% sampling intensity. Plot locations were determined using the stratified-random sampling method with ArcMap software.

In each plot samples, the examined data collection was divided into plot data and tree data. Plot data includes plot geolocation, cover and ground cover percentage, shrub data (species, height), and photo documentations. Meanwhile, tree measurements were carried out only from trees inside the plots with DBH (the diameter of a tree at breast height or typically at 1.3 m above groundlevel) greater than 10 cm, based on the criteria which stated that trees can be divided into 2 based on vegetation structure, namely saplings with a diameter of 10 – 20 cm and tree level with a diameter > 20 cm [8]. The tree data inventoried includes tree species, DBH, tree height (measured on total height, top height, and base height), crown width and health, percentage of impervious/shrub under the tree and light exposure estimated by one person by visual examination. Furthermore, data from the field were analyzed to determine the structure, composition and landscape services provided by the urban forest.

## **2.3 Data analysis**

Data and information collected during field survey and measurements were inputted and analyzed using the i-Tree Eco programme. The model used in assessing urban forest structure, functions, and values is called the Urban Forest Effects (UFORE) model [6]. The given data and the accessible templates of i-Tree Eco made it possible for the model to calculate structural and functional information such as biomass, leaf area, and landscape services provided by the urban forest utilizing a set of scientific formulas or algorithms that have been specified in the programme [5, 9, 10]. The report based on the computations will be sent to the users email address that were supplied on the input stage after the competition that took close to an hour [5]. The i-Tree Eco modelling and landscape services analysis used in this research consist of vegetation structure and diversity, oxygen production, carbon storage and sequestration, and avoided runoff in the BSUF.

The present vegetation structure and the value of landscape services in urban forests can be used to make future predictions of the created scenario model. Predictive analysis is produced after the tree inventory data and plot characteristics have been processed by i-Tree Eco. The results of this predictive analysis are influenced by several things that affect trees and their annual mortality rate, namely the influence of pests and other natural events. If these two pieces of information have been obtained, then a scenario model can be created by including a plan for the number of trees to be planted each year. This scenario model can help managers and stakeholders determine urban forest management policies.

# **3 Results and Discussion**

## **3.1 Vegetation composition and structure**

The BSUF was sampled and estimated to have 1,607 individual trees with an average density of 321 trees/Ha and a percentage of tree cover around 40,9%. The species with the highest

number of individuals that dominate in BSUF are *Gmelina arborea* (11%), *Khaya anthotheca* (11%), and *Spathodea campanulata* (7.7%). Meanwhile, the most dominant ground cover types are bare soil (28.0%) and duff/mulch (27.8%).

The amount of tree cover and tree health in urban forests is closely related to the benefits that the urban forest can provide. From the total area of 5 hectares, 2.05 hectares is shaded by trees. The species of trees with the highest percentage of leaf area that contribute to providing the highest importance values in BSUF are *Filicium decipiens* (22.8%), *Gmelina arborea* (12.7%), and *Terminalia catappa* (10.2%). Further examinations shows that there are 11 tree species that contribute to providing importance values higher than 5 in BSUF, which comprise a range of native and exotic tree species as seen in Table 1.

**Table 1.** The highest importance value of species greater than 5 in Babakan Siliwangi Urban Forest

Species	Status[10]	Percent Population	Percent Leaf Area	Importance Value
<i>Filicium decipiens</i>	Exotic	6	22.8	28.9
<i>Gmelina arborea</i>	Exotic	11	12.7	23.7
<i>Terminalia catappa</i>	Exotic	7.1	10.2	17.4
<i>Khaya anthotheca</i>	Exotic	11	3.5	14.5
<i>Spathodea campanulata</i>	Exotic	7.7	4	11.7
<i>Ficus benjamina</i>	Native	1.6	7.2	8.9
<i>Pinus merkusii</i>	Native	4.4	3.9	8.3
<i>Swietenia mahagoni</i>	Exotic	3.8	4.1	8
<i>Theobroma cacao</i>	Exotic	3.3	4.7	8
<i>Diospyros sp.</i>	Native	4.9	2.9	7.9
<i>Parkia speciosa</i>	Native	2.2	3.1	5.3

These high importance values show the species that currently dominate the urban forest structure, and it does not always imply that these trees must be promoted in the future. The diversity of vegetation composition in BSUF, which consists of native and exotic trees, with a dominance of species originating from Asia (32%) and Africa (25%). This condition occurs due to the state that in general, urban forest is deliberately planted with a variety of species, and often has a higher diversity value compared to the surrounding natural landscape. The diversity indices of BSUF assessed using 3 criterias is depicted in Table 2.

**Table 2.** Diversity indices of Babakan Siliwangi Urban Forest

Urban Forest	Area (Ha)	Shannon-Wiener	Menhinick	Simpson
Babakan Siliwangi	5	3.3	2.2	21.4

Results of the Shannon-Wiener diversity indices above shows that BSUF has high diversity with a high number of tree individuals. The Menhinick and Simpson diversity indices are dependable measures for assessing urban vegetation diversity due to their minimal susceptibility to sample size variations [12]. The high level of diversity can minimizedamage potentials from natural pests or diseases, but can also be a threat to the existence of native species if it is dominated by exotic species that grows invasively to replace the nativespecies.

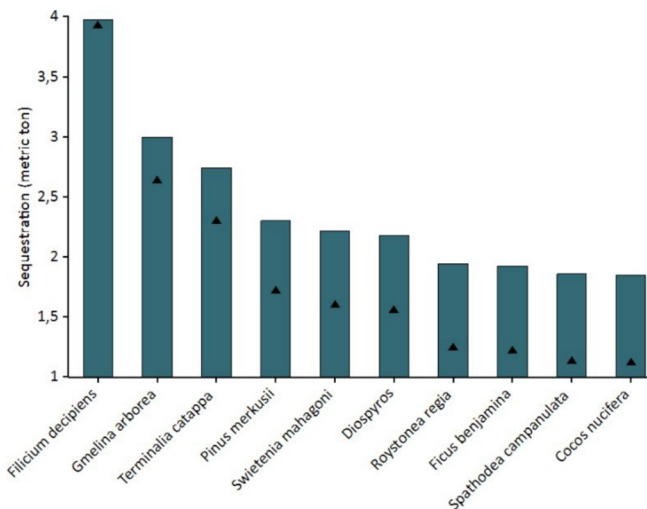
### 3.2 Landscape services

#### 3.2.1 Carbon storage and sequestration

Forests naturally function as carbon sinks by absorbing carbon during the process of photosynthesis, trees store carbon as above-and below ground biomass and produce oxygen

as a product of photosynthesis [13]. Urban trees play a crucial role in mitigating climate change as they actively absorb atmospheric carbon (from carbon dioxide) into their tissues. This becomes essential considering urban areas in particular contribute to atmospheric pollution from mobile and immobile sources and sustainable development [13].

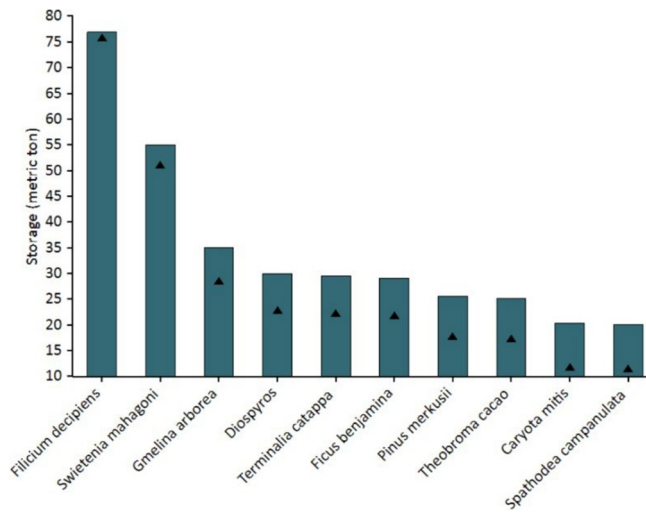
Annual carbon storage and carbon sequestration efficiency which represent the capacity for annual carbon sequestration, can be determined using i-Tree Eco. This software takes into account factors such as tree size, tree's health, coverage of the canopy, and spatial distribution. Trees reduce the amount of carbon in the atmosphere by sequestering carbon in new growth every year. The amount of carbon annually sequestered is increased with the size and health of the trees. The gross sequestration of Babakan Siliwangi Urban Forest trees is about 25.17 metric tons of carbon per year, while the net carbon sequestration in the urban forest is about 24.4 metric tons. The tree species that sequester the most carbon is *Filicium decipiens* (3.79 ton/yr) followed by *Gmelina arborea* (2.57 ton/yr) and *Terminalia catappa* (2.24 ton/yr). The ranking of trees with the highest carbon sequestration is depicted in Fig. 2.



**Fig. 2.** Tree species with the highest carbon sequestration in Babakan Siliwangi Urban Forest.

Correlating the function of trees to one of the biggest air pollution problem today, which is emissions of greenhouse gasses, trees can influence climate change which becomes an issue of global concern. Through the process of its growing, a tree accumulates carbon by storing it within its growing tissue. In line with this, as a tree dies and decays, it releases much of the stored carbon back into the atmosphere. Trees in BSUF are estimated to store 381 metric tons of carbon. From the sampled species, it is known that the tree species that store the most carbon is *Filicium decipiens* (75.64 ton) followed by *Swietenia mahagoni* (50.86 ton) and *Gmelina arborea* (28.32 ton). Tree species with the highest capability in storing carbon in BSUF is depicted in Fig. 3.

Based on the Table above, it is known that *Filicium decipiens* both stores and sequesters the most carbon (approximately 19,9% of the total carbon stored and 15,6% of all sequestered carbon). This is related to the number of leaf area and importance value, in which *Filicium decipiens* has the largest percent leaf area (22,8%) and importance value (28,9). Maintaining healthy trees will keep the carbon stored in trees, but tree maintenance may also contribute to carbon emissions [15].



**Fig. 3.** Tree species with the highest carbon storage in Babakan Siliwangi Urban Forest.

### 3.2.2 Oxygen Production

Trees in urban forest are frequently recognized for their ability to produce oxygen, which is commonly mentioned as one of their major advantages. Nevertheless, the advantage provided by this tree is rather insignificant due to the substantial and relatively constant quantity of oxygen in the atmosphere as well as the extensive oxygen production from aquatic ecosystem. The atmosphere contains a significant amount of oxygen. Even if all fossil fuel reserves, all trees, and all organic matter in soils were burned, the atmospheric oxygen levels would only decrease slightly. [16]. Trees in Babakan Siliwangi Urban Forest are estimated to produce 65.07 metric tons of oxygen per year. The largest oxygen producing tree species at this site is *Filicium decipiens* with oxygen production of 10.11 metric tons, followed by *Gmelina arborea* (6.86 ton/yr) and *Terminalia catappa* (5.98 ton/year) (Table 3).

**Table 3.** Top 8 oxygen production species of Babakan Siliwangi Urban Forest

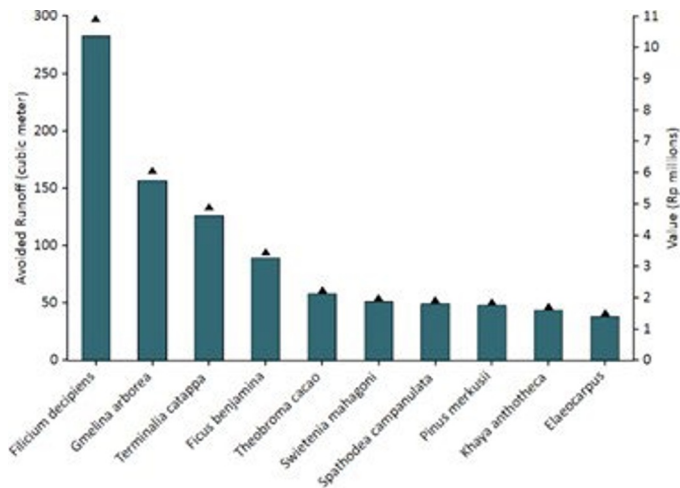
Species	Oxygen (metric tons)	Number of Trees	Leaf Area (hectares)
<i>Filicium decipiens</i>	10.11	97	5.56
<i>Gmelina arborea</i>	6.86	177	3.09
<i>Terminalia catappa</i>	5.98	115	2.49
<i>Pinus merkusii</i>	4.45	71	0.94
<i>Swietenia mahagoni</i>	4.04	62	1.01
<i>Diospyros sp.</i>	4.04	79	0.72
<i>Rovstonea regia</i>	3.27	18	0.07

The Table above shows that the amount of oxygen production is influenced by the number of trees and leaf area. However, the absolute magnitude of oxygen production by urban forests is 2.5 times greater than carbon absorption (Table 2), but the relative impact of carbon absorption is much more significant than oxygen production. This oxygen production benefit is relatively insignificant compared to other benefits such as carbon sequestration and air pollution removal, considering the relatively constant quantity of oxygen in the atmosphere as well as the extensive oxygen production from aquatic ecosystem. The value of oxygen production from urban trees almost has nothing to do with the amount of oxygen in the atmosphere (approximately 21% of the atmosphere's volume is oxygen) year [17].

### 3.2.3 Avoided Runoff

Based on the BPS data in 2020, floods often occur in the city of Bandung, with a number of 38 sub-districts affected. Flooding in urban areas causes an increment in surface runoff contamination which continues to cause a decline in rivers, lakes, and wetlands quality [18]. The surface runoff is increased by the extent of impervious coverage in urban areas. During precipitation, a portion of the rainfall is captured and retained by the tree's canopy, bark, and branches while the remaining water reaches the ground. Water that falls on an impermeable surface cannot seep into the soil to become surface runoff.

Surface runoff is a significant issue in numerous urban areas by potentially contaminating streams, rivers, and even oceans. Urban trees and shrubs, however, are beneficial in reducing surface runoff. Trees and shrubs intercept precipitation, while their root systems promote infiltration and storage in the soil. The trees and shrubs of BSUF help to reduce runoff by an estimated 1.36 thousand cubic meters a year. On average, each tree and shrubs contributed to an intercept of 0.81 m<sup>3</sup> of rainfall annually. *Filicium decipiens* (296.77 m<sup>3</sup>/yr), *Gmelina arborea* (164.76 m<sup>3</sup>/yr), and *Terminalia catappa* (132.69 m<sup>3</sup>/yr) had the greatest effect on stormwater runoff reduction benefits (Fig. 4).



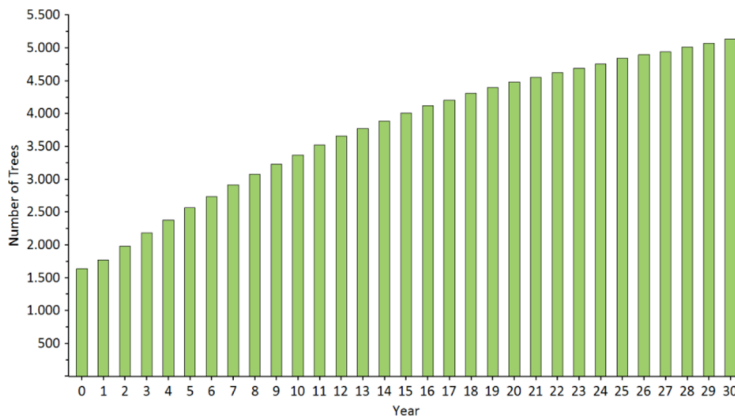
**Fig. 4.** Tree species with the highest avoided runoff in Babakan Siliwangi Urban Forest.

The number of avoided runoff were estimated based on local weather from the user-designated weather station. In Bandung area, the total annual precipitation in 2020 was 241,6 centimeters. The results above show that urban green spaces, specifically urban forest, is effective in reducing floods by increasing flood mitigation. Urban forest is considered a component of effective rainwater management infrastructure and an important element of an effective forest water management strategy [19].

### 3.2.4 Tree planting forecast

The forecast feature in i-Tree Eco programme can help visualize the future state for policymakers in determining the optimal quantity of tree plantings within a specified timeframe to enhance the value of landscape services at BSUF. The resulting predictions for plantings are contingent upon the composition and structure of existing trees, as well as disturbances to the UF such as adverse weather conditions that can lead to the death or illness of individual trees. In the case of tropical storms occurring in BSUF, weather disturbances

can result in a yearly mortality rate of 5%, thereby impacting the fluctuations in the number of individual trees within BSUF. According to the forecast results provided by i-Tree, the ideal number of trees that should be planted annually at BSUF is a minimum 300. This figure can be deemed as ideal, considering the projected significant increase in the number of trees to reach 5,135 trees in the 30th year as seen in Fig. 5, compared to the estimated existing tree count of 1,607 trees. Additionally, the value of the landscape services produced also experiences a corresponding increase. The estimated carbon storage in the 30th year is 700.1 tons, while the estimated total carbon sequestration up to the 30th year amounts to 1,123.5 tons, and 50,012.7 m<sup>3</sup> for avoided runoff.



**Fig. 5.** Number of trees forecast in Babakan Siliwangi Urban Forest for the next 30 years.

The recommended species of trees that can be planted are the existing species in BSUF that is classified as native species. Replacing sensitive native species with exotic species will threaten biodiversity in a certain range of time [20]. The adaptive ability possessed by invasive plants, combined with their strength, reproductive capacity, and lack of natural enemies, can replace the presence of native species and threaten the preservation of natural areas. However, large-scale extinctions do not automatically result by the local short-term existence of non-native species, and other environmental factors could affect vegetation composition stronger than biological invasions [21]. Therefore, the ability of tree species to provide landscape services and benefits can also be a consideration in choosing the species to be planted. In BSUF, *Pinus merkusii* is a native tree species that is effective in providing carbon sequestration and oxygen production. In its function to store carbon, *Diospyros sp.* is a native species with a high benefit. Meanwhile, *Ficus benjamina* is another native tree species that is effective in avoiding runoff. Therefore, the vegetation composition of native species needs to be enriched, considering the present condition of BSUF that only has two existing native species that are effective enough in providing landscape services.

## 4 Conclusion

The results presented in this study finds that BSUF has a high tree diversity with a 3.3 Shannon index and 41 tree species identified. The landscape services provided by the trees in BSUF stores 381 tons of carbon, sequesters 25.17 tons of carbon annually, produces 65.07 tons of oxygen per year, and avoids up to 1,360 m<sup>3</sup> water runoff a year. Furthermore, the ideal number of trees that should be planted annually to enhance the landscape services of BSUF is at least 300 trees, with the consideration of the plant's origin and the enrichment of native trees that are valuable and effective in providing landscape services. Extensively, this research describes the first tree inventory sample of urban forest landscape services

assessment in Bandung City, West Java, Indonesia, by using i-Tree Eco. Even though i-Tree has limitations as it is database-driven, but vegetation analyses using i-Tree are still highly valuable to support scientifically-based urban forest management.

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