Assessing environmental services and economic values of urban tree species in open public green spaces at Ecopark, Hung Yen province, Vietnam: An application of i-Tree Eco model

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Đánh giá dịch vụ môi trường và giá trị kinh tế các loài cây đô thị tại Ecopark, Hưng Yên, Việt Nam: Ứng dụng mô hình i-Tree Eco

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ABSTRACT

Urban trees have been widely acknowledged providing a wide range of environmental services. They help to improve air quality by absorbing pollutants, crucial roles in magaging stormwater runoff etc., in urban environments. This study applied i-Tree Eco model to assess the structure of community trees and quantifies the environmental services and economic values in open public green spaces in Eco Park, Hung Yen province, Vietnam. To run the model, we collected profiles of 942 trees in the study area, including: location; species name; diameter at beast height (DBH, 1.3 m above ground); tree height values (crown tree height, canopy length, etc.); height under canopy (canopy width of East-West, South-North directions); canopy missing percentage; and crown light exposure. The result showed that all the tree species contributed to 990kg $PM_{2.5}$ reduction (equal to 231,702 \$/year); 1,338.4 (ton/year) carbon sequestration (equal to 13,384 \$/year) and 26,772.1 (ton) carbon storage (equal to 267721 \$/year); and 37,600.2 (m^3) avoided runoff (equal to 79,712 \$/year). Overall, Khaya senegalensis (Desr.) A. Juss. *species was providing the most environmental services; Ficus subpisocarpa* Gagnep. *species was the most economically valuable with nearly 75 \$/tree. Urban landscape design should consider these superior tree species into green infrustructure projects to maximize the environmental services and economic values.*

Từ khóa:
Cây xanh đô thị, dịch vụ môi trường, Ecopark, giá trị kinh tế, i-Tree Eco.

TÓM TẮT

Cây xanh đô thị đã được ghi nhận là mang lại nhiều giá trị dịch vụ môi trường. Chúng giúp giảm ô nhiễm không khí nhờ khả năng hấp thụ khí ô nhiễm, đóng vai trò quan trọng trong giảm thiểu dòng chảy bề mặt… Để chạy mô hình, nhóm tác giả thu thập dữ liệu của 942 cây xanh tại khu vực nghiên cứu, cụ thể như vị trí, tên loài, đường kính ngang ngực (DBH 1,3 m), chiều cao tán cây, chiều cao dưới tán (chiều rộng tán theo hướng Đông - Tây, Nam - Bắc), tỷ lệ tán khuyết, tỷ lệ tiếp xúc ánh sáng. Nghiên cứu này áp dụng mô hình i-Tree Eco để đánh giá cấu trúc và lượng hoá dịch vụ môi trường và giá trị kinh tế của cây xanh trong các khu công cộng tại khu đô thị Ecopark, tỉnh Hưng Yên. Kết quả cho thấy cây xanh các khu này góp phần giảm 990kg $PM_{2,5}$ (tương đương 231.702 \$/năm); hấp thụ 1.338,4 tấn carbon/năm (tương đương 13.384 \$/năm) và tích luỹ được 26.772,1 tấn carbon (tương đương 267721\$/năm); và giảm dòng chảy mặt 37.600,2 m^3 (tương đương 79,712

$/năm). Khaya senegalensis (Desr.) A. Juss. là loài cung cấp nhiều dịch vụ môi trường nhất, Ficus subpisocarpa Gagnep. là loài cho giá trị kinh tế cao nhất với 75 $/cây. Nghiên cứu này khuyến nghị việc thiết kế cảnh quan đô thị cần cân nhắc trồng các loài cây ưu việt về cung cấp dịch vụ môi trường và giá trị kinh tế cho các dự án xanh hoá đô thị để tối đa hoá lợi ích.

1. INTRODUCTION

The i-Tree Eco model has been widely used to assess ecosystem services for urban areas in many case studies across the world [1-4], and in Vietnam [5-7]. These studies quantified multiple environmental services and some of them estimated these services in monerary value. As a result of high intensity of population, regulation services are even more important in urban areas, where air pollution, flooding and greenhouse gas emissions are more prevalent [8].

Through ecosystem services significantly enhance urban quality and social health, their evaluation are less visible, particularly in developing countries. Against to the background, Our study's aim to estimate environmental services and economic values provided by tree species in open public green spaces, in Eco Park, Hung Yen province, a rare area with high green coverage in Hanoi, Vietnam. We focused on $PM_{2.5}$ removal, carbon sequestration and storage, and avoided runoff of fifty observed tree species in the study area. The economic contribution of these urban tree species are also highlighted. Altogether, our study contribute to the case-study literature in the field and motivate the local government to design urban plantings in a manner that maximizes the benefits.

2. RESEARCH METHODS

2.1. Study area

The study conducted in Ecopark, Hung Yen province. The total area is 500 ha. We investigate benefit of tree species in two type of open green spaces which are parks and utilities (Figure 1).

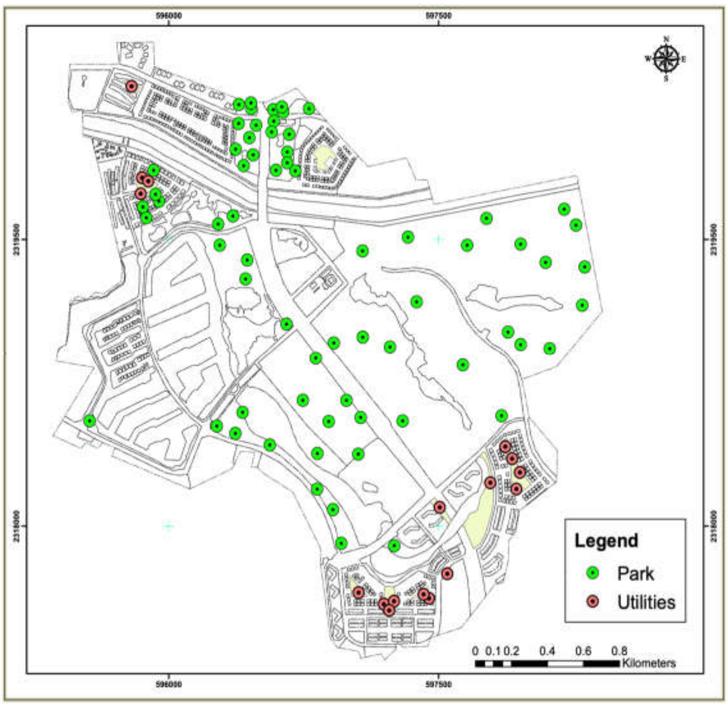

Figure 1. Distribution of sample plots of open public green spaces (Parks and Utilities) at Ecopark, Van Giang district, Hung Yen province

2.2. Sample plots and field data collection

Field date was conducted in 2 months (August and September in 2023). We carried out a complete inventory with a total of 84 random circular plots, each plot area was 405m^2 (R~ 11.34 m). Of which 17 plots of utility areas and 67 plots of public parks were investigated. Following the i-Tree Eco field manual, trees' profile were collected: location; species name; diameter at beast height (DBH, 1.3m above ground); tree height values (crown tree height, canopy length, etc.); height under canopy (canopy width of East-West, South-North directions); canopy missing percentage; and crown light exposure. All the field data were imported from Excel files to Access files in the i-Tree Eco model to further analyze such as assess vegetation structures of urban green spaces and associated environmental services.

In total, 942 trees were measured in the field, of which 178 trees within17 utility area plots and 764 trees within 67 public park plots. Using ArcGIS 10.8, boundaries and areas of the two green spaces were determined. The average tree density in each area is defined by the following formula:

$$N_{trees} = \frac{n}{(\text{Plot size} \times \text{Number of plots})} \times (\text{Area of each green space})$$

where,

N: average of tree density for each green space;

n: the total numbers of measured trees in each green space;

Plot size: Approximately 0.0405 hectares (R~11.34 m);

Number of plots: the total number of plots established for each green space;

Area of each green space: the total area for each green space, calculated by using ArcGIS 10.8.

2.3. Assessing environmental and economic benefits of trees

2.3.1. Air pollution removal

Due to unavailable hourly concentration of ozone (O_3), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) for at least 1 year, this study used the only available hourly pollution data of $PM_{2.5}$ of Hanoi in 2017 for running i-Tree Eco model. The hourly $PM_{2.5}$ removal based on equation of Nowak [9]. The values of wind speed and precipitation were taken from the data of Ha Dong Weather Station in Hanoi.

2.3.2. Carbon storage and sequestration

Based on forest-derived biomass equations and field measurements, tree carbon storage was calculated for each tree. Using allometric equations, biomass was calculated for each tree. Root-to-shoot ratios of 0.26 were used to convert aboveground biomass to whole tree biomass. Dry weight biomass was calculated by multiplying fresh weight biomass by species conversion factors (0.48 for conifers and 0.56 for hardwoods). In order to account for the difference between trees in natural stands (e.g., forests) and urban trees, biomass results were multiplied by 0.8 [10].

2.3.3. Avoided runoff

i-Tree Eco estimates avoided runoff values based on leaf area data and local hourly weather data. With trees and without trees method is used to calculate the impact of trees on surface runoff [11].

2.3.4. Economic benefits

We applied default prices from previous studies to calculated economic benefits of pollutant removal, carbon storage and sequestration, and avoided runoff. Specifically, $PM_{2.5}$ removal was 234$/ton based on the reference of [12]; carbon storage and sequestration was 10 $/metric ton based on the one carbon credit price of running LEAF/Emergent project in Vietnam; runoff prevention was 2.12$ per m^3 [13]

2.4. i-Tree Eco running and output

After importing the field collected data into i-Tree Eco model, analysis was took place and inital results gennereated for the year of the study. Depending on focusing discussion the output format can be selected to meet the wish.

3. RESULTS AND DISCUSSION

3.1. Characteristics of urban trees in open green spaces at Ecopark

Two highest tree densitites of open green space are in parks and utility areas that accounts for 46% of leaf coverage in Ecopark. 42% of the trees have DBH ranges from 35.5 cm to 45.7 cm, next are mature trees and large trees (DBH: 15.2 - 30.5 cm and 45.7 – 61 cm) accounts equally to 18.71%, while young trees (DBH: 0 - 7.6 cm) only account for 4.12%.

Most of the trees originally from Asia (40%) and native to Africa (29%). In total, there are 50 tree species in the open green spaces, of which nine dominant trees species to leaf areas, an important factor influencing to $PM_{2.5}$ removal and avoided runoff. The three most common species are *Cocos nucifera* (17.1%), *Elaeis guineensis* (16.1%), and *Khaya senegalensis* (11.6%). However, *Khaya senegalensis* has the highest important value (30.9) since this species has the highest leaf area (19.3%) while *Elaeis guineensis* and *Cocos nucifera* contributed only 8.8% and 6.3% leaf area in the study site, respectively (Figure 2).

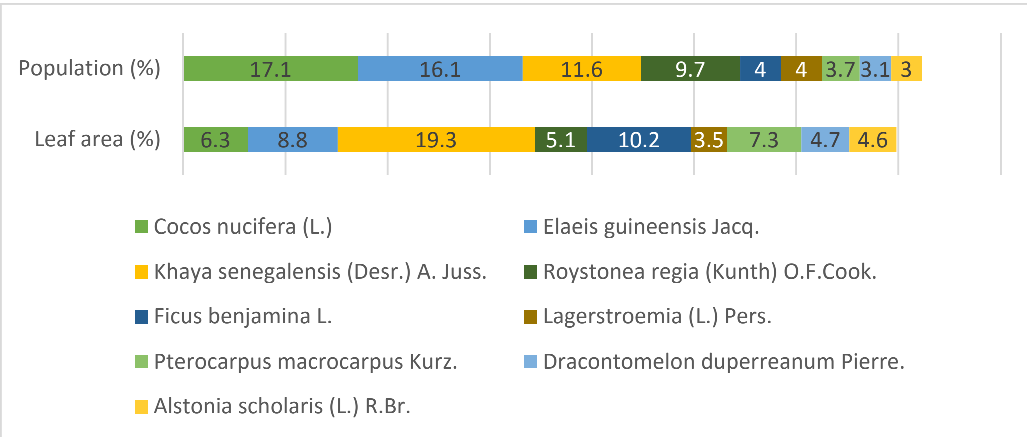

Figure 2. Nine most dominate tree species and their leaf area in the open green spaces at Ecopark

3.2. Environmental services

Species' profile and their provided environmental services in the study area are presented in (Table 1).

3.2.1. Air pollutants removal

Tree plays a crucial role in $PM_{2.5}$ removal in crowded urban areas by absorbing fine dust in leaves making the air cleaner. The green public areas in Ecopark could remove about 1 ton of $PM_{2.5}$ annually. Among the tree species, *Khaya senegalensis* (Desr.) A. Juss was the most contributor to remove $PM_{2.5}$ with 0.19 ton/year due to its leaf area cover was the largest (19.3%). The species with leaf area were less than or equal to 0.1% did not contribute to the dust reduction (Table 1).

The amount of $PM_{2.5}$ removed varies by month of the year (Figure 3). The minimum $PM_{2.5}$ removal was 38.7kg. It occurred in February, the dry season the year in Hanoi. Very much in line with other studies, $PM_{2.5}$ dramatically decreased removal capacity, even re-suspension during dry time of the year [14].

Table 1. Benefit of tree species in the open public green spaces in Ecopark

No.	Species	Number of tree	Population (%)	Leaf area (%)	Imprortance value (IV)	Pollution removal (ton/year)	Carbon storage (ton)	Gross carbon sequestration (ton/year)	Avoided runoff (m^3/year)	Economic value per tree ($)
1	*Alstonia scholaris* (L.) R.Br.	1931	3.00	4.60	7.60	0.05	803.2	46.4	1724.1	6.3
2	*Areca catechu* L.	325	0.50	0.10	0.60	0.00	6.7	0.6	36.9	0.5
3	*Artocarpus heterophyllus* Lam.	838	1.30	0.90	2.20	0.01	186.0	12.1	355.3	3.3
4	*Averrhoa carambola* L., 1753	338	0.50	0.30	0.90	0.00	103.3	1.9	129.1	3.9
5	*Barringtonia acutangula* (L.) Gaertn.	25	0.00	0.00	0.10	0.00	3.5	0.4	15.9	2.9
6	*Bauhinia variegata* L.	187	0.30	0.10	0.40	0.00	125.7	2.0	27.5	7.1
7	*Bischofia javanica* Blume, 1827.	875	1.40	2.00	3.40	0.02	1145.7	30.5	757.2	15.3
8	*Broussonetia papyrifera* (L.) L'Hér. ex Vent.	244	0.40	0.10	0.50	0.00	9.1	3.3	30.1	0.8
9	*Cassia fistula* L.	443	0.70	1.50	2.20	0.02	692.6	13.4	575.5	18.7
10	*Ceiba pentandra* (L.) Gaertn.	12	0.00	0.10	0.10	0.00	13.1	1.4	19.5	15.6
11	*Chrysophyllum cainito* L.	244	0.40	0.20	0.60	0.00	18.5	1.5	79.5	1.5
12	*Chukrasia tabularis* A.Juss.	1882	2.90	2.90	5.80	0.03	460.9	71.9	1097.6	4.1
13	*Cinnamomum iners* Rein.	488	0.80	0.10	0.80	0.00	7.0	3.2	29.4	0.3
14	*Cocos nucifera* (L.)	10994	**<u>17.10</u>**	<u>6.30</u>	23.40	0.06	745.9	62.9	2365.9	1.2
15	*Dalbergia tonkinensis* Prain	163	0.30	0.10	0.30	0.00	5.0	1.2	26.0	0.7
16	*Delonix regia* Hook.	968	1.50	1.60	3.10	0.02	276.1	32.5	607.0	4.5
17	*Dimocarpus longan* Lour.	12	0.00	0.10	0.10	0.00	10.5	0.3	25.0	13.4
18	*Diospyros decandra* Lour.	94	0.10	0.10	0.20	0.00	12.8	1.9	35.8	2.4
19	*Diospyros kaki* Thunb.	244	0.40	0.20	0.60	0.00	10.8	1.6	75.2	1.2

No.	Species	Number of tree	Population (%)	Leaf area (%)	Imprortance value (IV)	Pollution removal (ton/year)	Carbon storage (ton)	Gross carbon sequestration (ton/year)	Avoided runoff (m^3/year)	Economic value per tree ($)
20	*Dipterocarpus alatus* Roxb. ex G.Don	325	0.50	0.10	0.60	0.00	9.7	3.5	38.0	0.7
21	*Dracontomelon dao* (Blanco) Merr. & Rolfe	2013	3.10	4.70	7.80	0.05	1561.3	49.3	1752.5	9.9
22	*Elaeis guineensis* Jacq.	10341	**16.10**	**8.80**	24.90	0.09	1193.8	127.5	**3319.0**	2.0
23	*Erythrina fusca* Lour.	12	0.00	0.00	0.00	0.00	2.6	0.2	5.8	3.3
24	*Erythrophleum fordii* Oliver.	975	1.50	0.70	2.20	0.01	83.6	16.2	267.2	1.6
25	*Ficus benjamina* L.	2569	4.00	**10.20**	14.20	0.10	**6721.2**	83.7	**3835.7**	29.7
26	*Ficus elastica* Roxb.	399	0.60	3.60	4.20	0.04	**2449.8**	2.8	1356.2	**68.7**
27	*Ficus microcarpa* L.f.	94	0.10	0.20	0.40	0.00	47.8	1.0	78.9	7.0
28	*Ficus racemosa* L.	1488	2.30	3.30	5.60	0.03	138.7	23.4	1248.4	2.9
29	*Ficus religiosa L.*	931	1.50	2.60	4.00	0.03	1044.0	54.0	967.4	14.0
30	*Ficus subpisocarpa* Gagnep.	175	0.30	1.90	2.20	0.02	1156.5	0.2	725.0	**74.9**
31	*Khaya senegalensis* (Desr.) A. Juss.	7471	**11.60**	**19.30**	**30.90**	**0.19**	**3810.4**	**352.9**	**7260.6**	7.6
32	*Lagerstroemia speciosa* L.	2578	4.00	3.50	7.50	0.04	399.9	43.0	1315.1	2.8
33	*Leucaena leucocephala* (Lam.) de Wit.	325	0.50	0.10	0.60	0.00	3.2	2.4	23.8	0.3
34	*Livistona chinensis* (Jacq.) R.Br. ex Mart.	1894	2.90	1.10	4.10	0.01	277.7	25.9	416.1	2.1
35	*Magnolia alba* DC.	163	0.30	0.10	0.40	0.00	3.1	0.7	44.9	0.8
36	*Mangifera indica* L.	806	1.30	1.70	3.00	0.02	339.7	27.5	640.5	6.2
37	*Manilkara zapota* (L.) P.Royen.	163	0.30	0.10	0.30	0.00	0.3	0.1	27.5	0.4
38	*Mimusops elengi* L.	163	0.30	1.30	1.60	0.01	580.5	9.0	507.3	42.8

No.	Species	Number of tree	Population (%)	Leaf area (%)	Imprortance value (IV)	Pollution removal (ton/year)	Carbon storage (ton)	Gross carbon sequestration (ton/year)	Avoided runoff (m^3/year)	Economic value per tree ($)
39	*Muntingia calabura* L.	163	0.30	0.10	0.30	0.00	4.7	1.5	28.6	0.7
40	*Parashorea chinensis* H. Wang	12	0.00	0.00	0.00	0.00	0.7	0.2	2.2	1.1
41	*Peltophorum pterocarpum* (DC.) Backer ex K.Heyne	663	1.00	1.20	2.30	0.01	213.4	33.2	458.5	5.2
42	*Pinus kesiya* Royle ex Gordon.	148	0.20	0.20	0.40	0.00	20.8	1.1	68.6	2.5
43	*Podocarpus macrophyllus* (Thunb.) Sweet.	163	0.30	0.40	0.60	0.00	109.9	0.1	134.8	8.5
44	*Psidium guajava* L.	81	0.10	0.10	0.20	0.00	1.1	0.3	26.5	0.9
45	*Pterocarpus macrocarpus* Kurz.	2392	3.70	7.30	11.00	0.07	916.9	94.7	2734.7	6.7
46	*Roystonea regia* (Kunth) O.F.Cook.	6227	9.70	5.10	14.80	0.05	900.5	84.2	1911.9	2.2
47	*Senna siamea* (Lam.) Irwin et Barneby.	12	0.00	0.00	0.00	0.00	11.9	1.1	9.2	12.5
48	*Spathodea campanulata* P.Beauv.	1057	1.60	0.90	2.50	0.01	72.7	7.5	331.1	1.4
49	*Streblus asper* Lour.	12	0.00	0.10	0.10	0.00	52.9	2.1	33.0	51.7
50	*Syzygium jambos* (L.) Alston	12	0.00	0.10	0.10	0.00	6.7	0.4	19.1	9.2
	Total	**64134**				**0.99**	**26772.1**	**1338.4**	**37600.2**	

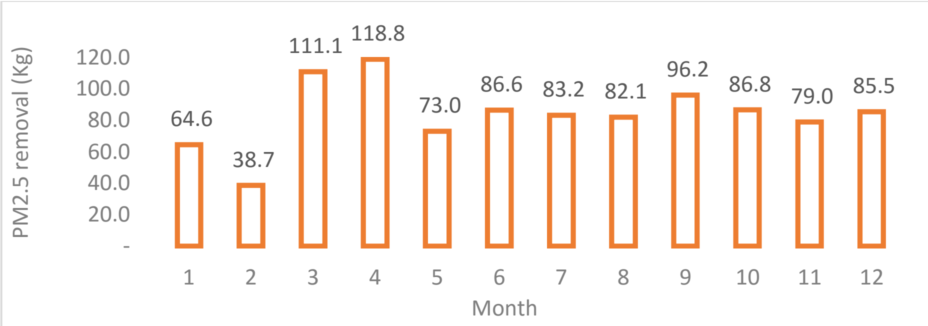

Figure 3. $PM_{2.5}$ removal by month

3.2.2. Carbon storage and sequestration

Overall carbon storage by trees in the study site was 26772.1 ton/year. The net carbon sequestration was 1338.4 ton/year. The three main species contributors to stored carbon are *Ficus benjamina* L. with 6721.2 ton (25%); *Khaya senegalensis* (Desr.) A. Juss. with 3810.4 ton (14%); *and Ficus elastica* Roxb. with 2449.8 ton (9%). Of the overall carbon sequestrated, 352.86 ton (26%) related only *Khaya senegalensis* (Desr.) A. Juss. is the highest sequestrator, among all the tree species.

3.2.3. Avoided runoff

i-Tree estimates that the trees in the open public green spaces in Ecopark decreased 37600.2 m^3/year in runoff. The *Khaya senegalensis* (Desr.) A. Juss. with absorption of 7260.6 m^3/year (19%); *Ficus benjamina* L. with 3835.7 m^3/year (10%); and *Elaeis guineensis* Jacq. with 3319.0 m^3/year (9%) absorbed the most yearly runoff. Due to the fact that runoff reduction is proportional to tree cover, these three species have the highest leaf area (Table 1).

3.3. Economic benefits

Estimated economic values of environmental services of the species in the study sites showed that we could save costs for managing urban environmental systems (Table 2).

Table 2. Eonomic values of environmental services in open public green spaces at Ecopark

Environmental services	Price	Environmental benefits	Economic values ($/year)	References for the price
$PM_{2.5}$ removal	234 ($/ton)	0.99 (ton/year)	231,702	Nowak [12]
Carbon sequestration	10 ($/ton)	1,338.4 (ton/year)	13,384	ERPAs for 11 provinces of central region and Central Highlands of Vietnam with LEAF/emergent
Carbon storage	10 ($/ton)	26,772.1 (ton)	267,721	
Avoided runoff	2.12 ($/$m^3$)	37,600.2 (m^3/year)	79,712	Wang [13]
Total			**592,519**	

In total, economic value of all the tree species in open public green spaces at Ecopark was $592,519. Carbon storage and $PM_{2.5}$ removal services are the most contributors.

Figure 4 presents the total ecocomic values per tree of ten most contributed tree species. *Ficus subpisocarpa* Gagnep. species is the most valuable species with nearly $75.

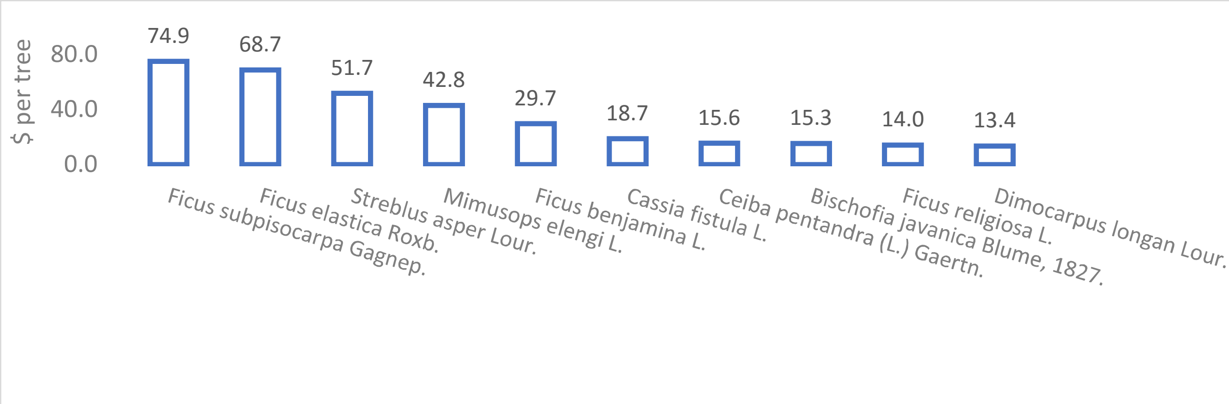

Figure 4. The ten most valuable tree species in the open green spaces at Ecopark

3.4. Considering the link between superior plant species and urban air quality improvement, and in climate change context

The study has been presented initial environmental and economic contributions of the tree species in the study area. Each species shows varied capacity in providing services. For instance, despite being planted most, *Cocos nucifera* (L.) species provides far lower environmental services than *Khaya senegalensis* (Desr.) A. Juss. species does. Thus, the efficiency of atmospheric cleansing highly depends on choosing and appropriate tree species.

Climate change is an issue of global concern. Carbon from CO_2 is fixed and stored in biomass during photosynthesis process, thus urban trees play a critical role in mitigating climate change. In Beijing, China, 2.4 million trees in the central city stored 0.18 million tons of C in their biomass in 2002 [15], and in Shengyang, the C sequestration rate of urban forests is 29,000 ton/year, which can offset 0.26% of the annual C emissions from the city [16]. In New York City's borough Manhattan, USA, 52,000 tons of carbon sequestered in trees [17] and so on. In the context of climate change, this estimation serves the basic for urban trees to be considered as fundamental criteria for designing urban green infrastructure.

4. CONCLUSION

This study supports the notion that urban trees can significantly contribute to polutant removal, climate mititation and reducing runoff. The study also emphasizes economic evaluation of these regulation services for the urban trees. Among the 50 species planted in the open green spaces in Ecopark, *Ficus subpisocarpa* Gagnep. and *Ficus elastica* Roxb. exhibit the most economic value. *Khaya senegalensis* (Desr.) A. Juss. shows exceptional to sequester carbon dioxide and to avoid runoff. If they had been planted instead of the most dominant species (*Cocos nucifera* (L.)) in the study site, the total tree's benefits would be significantly increased. Hence, it is recommended to consider tree species characteristics e.g., leaf area and integration of science knowledge in replacing or developing urban forestry.

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