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Research Article

Capitalizing Trees for Carbon Sequestration as a Co-Benefit of Biophilic Urbanism

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Abstract: Biophilic urbanism as an emerging paradigm in the design field has initiated various patterns of nature-based mutation. One of the most associated environmental benefits of this amalgamation of nature in urban design is carbon sequestration [CS]. The main focus of this research was to quantify the potential of trees to act as carbon reservoirs. It was investigated by assessing the roles of several tree parameters, such as diameter at breast height [DBH], height, biomass, and age in CS. A comparison of native and exotic trees was also done for this. In a field survey at Jilani Park, Lahore, 16 different families of trees (N = 115) were measured through a non-destructive method and CS was calculated. The results revealed that sample trees sequestered 588452.9 kg of carbon with an annual rate of 19998.92 kg and Combretaceae (M = 11813.65, SD = 6492.38) and Moraceae (M = 9909.93, SD = 12695.26) were the dominant families in doing so. The Pearson's correlation and linear regression analyses indicated that biomass and DBH have a significant positive relationship with *CS*, r = 0.100, R^2 = 0.99, and r = 0.943, R^2 = 0.89, respectively. The independent-sample t-test revealed a significant difference in CS capacity between native and exotic trees, with t (67.626) = 3.016, p =.004, and the greater biomass and DBH of native trees were the distinguishable factors. To conclude, trees are the most efficient source of carbon attenuation in the urban environment, and native species have an advantage in this process. This study will inspire new endeavours in research related to the benefits of biophilic cities.

Keywords: Carbon dioxide, Carbon sequestration, Biophilic, Urbanism, Biomass.

1. INTRODUCTION

Urban design in the twenty-first century necessitates a cautious approach that not only conserves nature but also finds new ways to incorporate it [1]. A new perspective on biophilic urbanism can aid in designing with nature for a healthier, more climate-friendly, and sustainable urban environment [2]. Biophilic elements, as a natural resource, can act as carbon reservoirs, which can therefore increase adaptability to climate change in cities [3]. Africa *et al*. [4] suggested the incorporation of a biophilic design to combat climate change because sequestration of carbon is reported as a common benefit of biophilic urbanism [5, 6].

Trees act as natural purifiers by captivating carbon in their biomass [7]. The active accumulation of carbon dioxide by trees, both in the form of biomass and in the soil, can act as potential carbon sinks [8]. Urban greenery utilizes atmospheric carbon dioxide in the process of photosynthesis and stores an excess of it in the form of a reservoir [9], thus playing an active role in the natural carbon cycle [10].

Unfortunately, anthropogenic activities like deforestation disturb the natural phenomena of the carbon cycle on a global scale [11]. The aftereffects of this can be seen in the rising temperature of urban areas, which is associated with a high accumulation of carbon dioxide in the atmosphere

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[12]. Consequently, devastating destruction in the environment is observed at an alarming level with an even worse future trajectory [13].

This problem has brought the whole world on the same page by passing climate treaties, including the Kyoto protocol (2005) that was superseded by the Paris agreement (2015), highlighting the need for a reduction in carbon dioxide [CO_2] emissions [14, 15]. The analysis of the reduction in CO_2 emissions in different countries showed a positive result of the Kyoto protocol [16, 17]. However, more effort is required to achieve desirable results [14, 18]. Recent flooding, wildfires, hurricanes, and dense smog in different parts of the world have opened the eyes of all stakeholders to the urgent need to work on eliminating CO_2 emissions throughout the world.

Although there has been debate about the rate of carbon dioxide off-set by urban trees in comparison to the high anthropogenic CO_2 release in cities [19], the high potential of trees in carbon uptake and assisting in the achievement of carbon neutrality cannot be overlooked [20, 21]. Urban tree cover acts as a carbon sink, bending the rising carbon curve at a point where carbon emissions can be controlled below 2 °C [21] and helping to mitigate climate change at the local level [22, 23].

Different mitigation and adaptation strategies have been suggested as a solution and for adding resilience to live with this situation better [24]. One of the most economical solutions is to increase green spaces in cities, which would have the potential to cut down on the rising level of CO_2. The biophilic design focuses on incorporating natural elements and features, including green plantations in cities, for an enhanced environment. There is much research that has addressed different benefits of biophilic urbanism, but a gap has been identified in assessing the direct role of biophilic cities in reference to the tree's capacity for CS. This research is designed to assess the urban tree capacity for carbon pooling and compare the roles of native and exotic trees in sequestering carbon dioxide. The objectives of this study are:

- To assess the role of trees in carbon sequestration, which can be a potential benefit of biophilic urbanism.
- To evaluate the relationship between carbon sequestration and DBH, height, total biomass, and age of a tree.
- To compare native and exotic trees for carbon sequestration.

2. MATERIAL AND METHODS

2.1 Site Characteristics

This study was conducted in Jilani Park, covering an area of 88 acres on Jail Road, Lahore shown in Fig 1. This city has a composite climatic condition with marked seasons of harsh summers, cold winters, and a heavy monsoon period. The Jilani Park is renowned for its beautiful flora on fertile soil and has many other recreational facilities. One of the more dominant characteristics of this park is the presence of more than 100 types of native and exotic species of trees that made it suitable for data collection in this study.

2.2 Measurement Protocol and Data Collection

This study was developed to assess the capacity of trees for CS. The field survey was conducted from January to March 2020 to collect data in the old and densely planted areas with native and exotic tree species in Jillani Park. The two detailed lists of trees having information about local names, girth measurement (DBH), and age of the trees were provided by the Pakistan Horticulture Authority [PHA] as this park is directly under their supervision. The non-destructive method of biomass estimation was used [22, 23, 25, 26]. The DBH (1.3 m above ground) and height were measured using tape and a clinometer, respectively [22, 27]. The estimated height of the trees was computed with the help of a given formula [28, 29]:

$$h = (\tan A \times d) + \text{eye height}$$

The pilot study was carried out on ten trees at the campus of Lahore College for Women University, Jail Road, Lahore, which ensured the accuracy of the measurement technique, and after that, the actual field survey was conducted in Jilani Park. The record of girth measurement (DBH) was already done by PHA staff for the selected trees, and the height was measured by using the formula. The data was recorded in spreadsheets for further

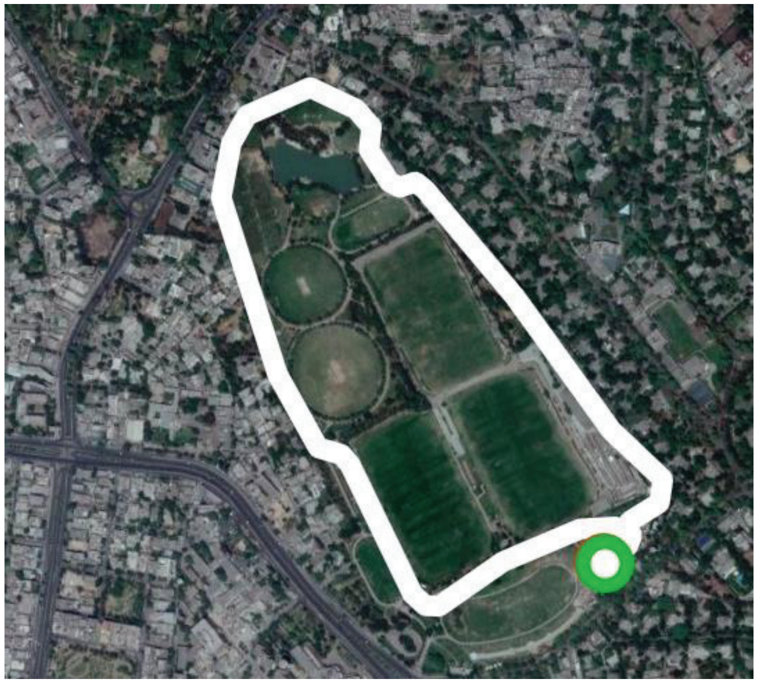

Fig.1. Google Map of Jilani Park at Jail Road, Lahore

calculation.

2.3 Data Analysis

The collected data was utilized to measure the amount of CS in a tree through a formula developed by the University of Nebraska [29 - 33].

(When D < 11inches)

$$W = \frac{0.25 \times D^2 \times H \times 120\,\% \times 72.5\,\% \times 50\,\% \times 3.6663}{\text{Tree age}}$$

(When D $\geq$ 11inches)

$$W = \frac{0.15 \times D^2 \times H \times 120\,\% \times 72.5\,\% \times 50\,\% \times 3.6663}{\text{Tree age}}$$

Here, W stands for the weight (lb., later converted into kg) of CS in a year, D denotes the diameter (inches), and H shows the height (ft.) of a tree. The tree capacity of CS was estimated in the following step.

- To calculate total green weight, the above-ground weight [AGW] was estimated by taking the product of diameter (squared) and height with 0.25 and 0.15 for trees with a diameter of more than 11 and less than or equal to 11 respectively. The below-ground weight of the root system is composed of 20 % as much as the above-ground weight that was multiplied with it to get the total green weight.
- The total dry weight of a tree was calculated by taking the product of total green weight and 72.5 % (on average, a tree has 72.5 % dry matter and 27.5 % moisture).
- The total carbon content in a tree was computed by multiplying the total dry weight by 50 % (on average, 50 % of a tree's volume is composed of carbon compounds).
- The CS by a tree was estimated by taking the product of total carbon weight and 3.67 (this value is based on the carbon ratio in CO_2 which has one molecule of carbon along with two molecules of oxygen as well).
- The final step was to calculate the annual CS of a tree that was determined by dividing the attained carbon sequestration weight by the age of the tree.

After computing the required values on Microsoft Excel, a detailed analysis of carbon sequestration by trees was done through SPSS (23.0). The descriptive statistics were used to calculate the frequencies and mean scores of the variables under study. The relationship among the variables was explored with the Pearson correlation coefficient and linear regression analysis. The independent sample t-test was applied to estimate differences between native and exotic trees in sequestrating carbon.

3. RESULTS AND DISCUSSION

3.1 Carbon Sequestration by Trees

The assessment of CS in the different families of trees in the sample was done through descriptive statistics. The results showed that a total of N=115 trees from 16 families were enumerated to acquire data, in which the distribution of native 56 (48.7 %) and exotic 59 (51.3 %) trees was almost the same. The division of trees into evergreen and deciduous domains was 57 (58.3 %) and 48 (41.7 %) respectively. The dominant families of trees in this sample were Moraceae 23 (20 %), Bignoniaceae 16 (13.9 %), Fabaceae 15 (13 %), Apocynaceae 14 (12.2 %), and Sapotaceae (Table 1).

The efficacy of trees in CS was assessed among 16 families and a total of 588452.9 kg and 19998.92 kg annually was computed for these 115 trees. Among the families of trees, the three main types, including Combretaceae *(M=11813.65, SD=6492.38),* Moraceae *(M=9909.93, SD=12695.26),* and Bombacaceae *(M=8350.60, SD=4720.94)* had a higher ability to do so (Figure 2).

Furthermore, it was found that Combretaceae (N=4) was composed of native trees, *Terminalia arjuna*, for this sample showed the highest average capacity for carbon pooling among all families. The Moraceae (N=23), with 19 native and 4 exotic trees, had the second-highest average value of CS for its native trees, including *Morus alba, Ficus religiosa, and Ficus benjamina.*

The third family, Bombacaceae (N=2), showed a prominently significant mean value for sequestrating carbon and had exotic trees like *Chorisia insignis* in it. The compatibility of these findings was found to be consistent with the results of previous research on *Terminalia arjuna* [34] (Combretaceae), *Morus alba* [35], *Ficus benjamina* [22], and *Ficus religiosa* [36] (Moraceae), in which these trees proved to be a good source of carbon

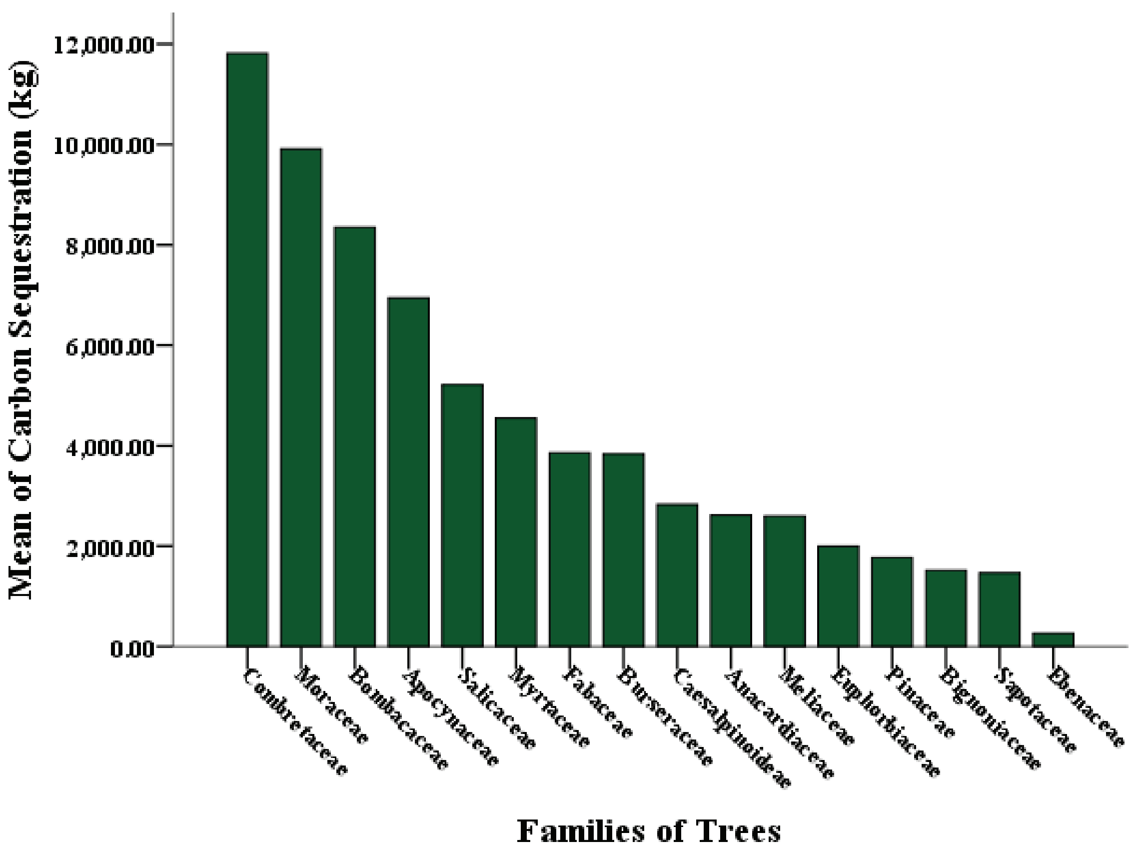

Fig. 2. Bar chart showing Carbon Sequestration by different families of trees

storage in the particular study areas.

Figure 3 indicated that families with native trees had the highest mean values for CS, and at the same time, families with exotic trees also showed a good capacity for carbon storage, as demonstrated by *Chorisia insignis* of Bombacaceae in this case. Several studies have found that combining different families of native and exotic trees improves carbon sequestration performance [22, 37, 38]. Mixing different species of trees had more profound results in carbon storage [39, 40].

The findings tended to suggest that even with less frequency, a few families had shown better results for CS, and a difference was also found between native and exotic types. Therefore, there would be some major components of trees that play a vital role in absorbing and storing carbon that was further explored in detail in the next section.

3.2 Carbon Sequestration and Characteristics of Trees

It was anticipated in the previous section that the phenomenon of CS in trees would be based on certain characteristics, including DBH, average height, total biomass, and age of a tree. Therefore, to explore associations among these variables, correlation and linear regression analyses were applied. The analysis of the relationship between DBH, height, biomass, age of a tree, and CS has shown a good positive and statistically significant correlation among variables. The biomass (r = 1.000, p < .01) and DBH (r = .943, p < .01) of the trees showed a strong positive correlation with CS. Tree age and height both had a moderately strong positive correlation with CS, with r = .711, p < .01 and r =.505, p < .01, respectively (Table 2).

Following that, to determine the magnitude of the relationship between the independent variables,

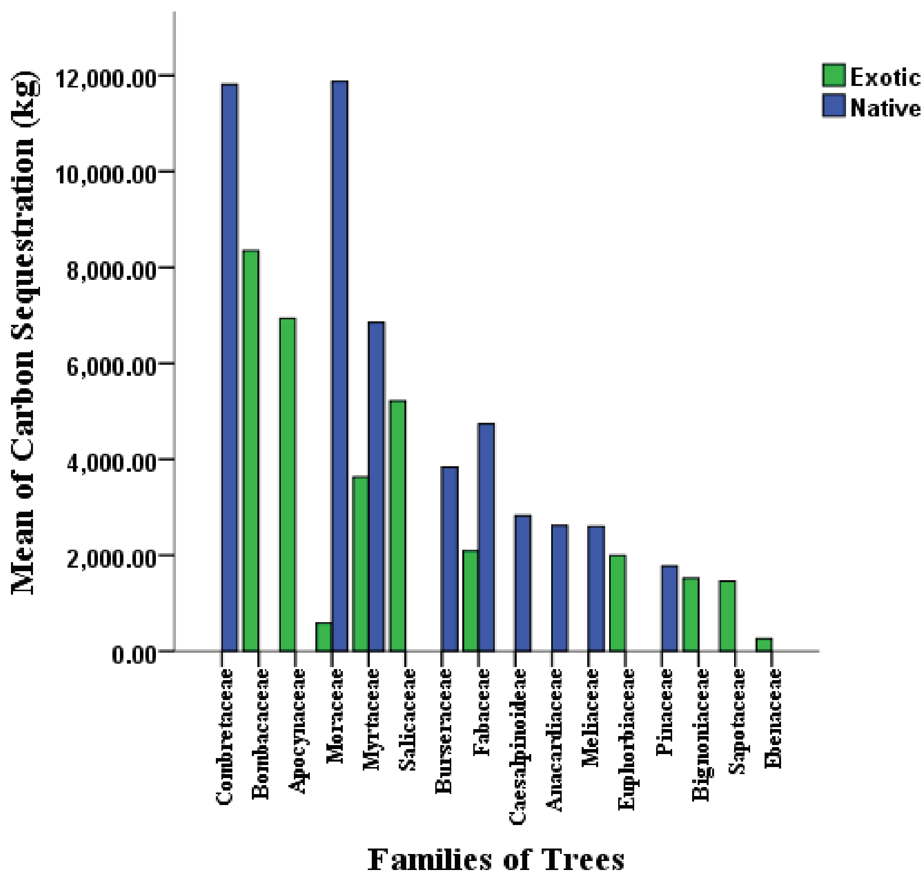

Fig. 3. Bar chart showing Carbon Sequestration by the native and exotic trees in different families of trees

DBH, height, biomass, and age were regressed against CS. The regression model suggested that the biomass had shown a significantly high relationship with CS as the model explained 99 % of the variance with F (1,113) = 165441.13, p <.001(b=.520, p < .001). The DBH also had a significant impact on CS with 89 % of variance and F (1,113) = 902.67, p < .001 (b = 621.68, p < .001). The age of the trees explained 51 % of the variance with F (1,113) = 115.705, p <.001 (b = 607.41, p <.001). The height explained 26 % of the variance, with F (1,113) = 38.58, p <.001 (b =337.84, p <.001), (Table3).

The biomass had a strong and significant positive linear relationship, which had the most notable influence on CS in this study. The findings of previous research verified that biomass was a major contributor to the carbon stock in trees [41, 42]. Wellbrock *et al*. [43] found 46 % of carbon storage in above and below biomass.

The link between DBH and CS was found to be significantly good, which confirmed its major role in developing carbon storage in trees. In a study by Mildrexler *et al*. [44], trees with a diameter of more than 21 inches accounted for only 3% of the total sample but had a carbon content of 42%. In another study, 93 % of carbon was stocked in stems [45]. Maren & Sharma [46] found that pine trees of large size with variation in stem size sequestered more carbon.

The age and height of a tree have shown a moderately good relationship and a considerable impact on CS. Leverett *et al*. [47] reported that large trees had dominance in accumulating carbon and aged trees had a high accumulation rate of carbon. Matured and aged trees showed high values for CS along with the R^2 0 .99 for basal area and 0.60 for height [48].

Zribi *et al*. [49] found that aged trees have the largest biomass and thus the highest capacity of CS but less potential for future CS in comparison to young trees, which have not only rapid growth but also more CS capability. The consensus found that as a tree grows older due to an increase in DBH and height, a constant increase in biomass is attained and the tree thus becomes a good carbon reservoir [50].

3.3 Carbon Sequestration in Native and Exotic Trees

In the final stage, the CS of native (n=56) and exotic trees (n=59) was assessed through descriptive analysis. The results revealed that the DBH for native trees with a mean of 24.83 (*SD*=12.34) is greater than exotic trees (*M*=17.56, *SD*=76.92). The average heights of 46.45 (*SD*=9.81) and 44.82 (*SD*=10.92) and age at 26.13 (*SD*=9.580) and 24.29 (*SD*=6.04) haven't shown much difference for both species.

The native trees have significantly higher biomass (*M*=13574.98, *SD*=17411.83), *CS* (*M*=7093.76, *SD*=9049.06) and annual carbon sequestration (*M*=231.57, *SD*= 212.81) values than exotic trees (*M*=6231.95, *SD*=6080.80; *M*=3240.72, *SD*=3162.12; *M*=119.17, *SD*=91.79) (Table 4).

Then, to compare the carbon sequestration between native and exotic trees, an independent sample t-test was conducted. A significant difference was found (t (67.626) =3.016, p=.004) in the scores of variables. The mean of native trees (*M*=7093.7610, *SD*=9049.06255) was higher than that of exotic trees (*M*=3240.72161, *SD*=3162.11839). The magnitude of the difference in the mean values (mean difference=3853.04491, 95 % CI: 1303.80497 to 6402.28485) was significant (Table 5).

It can be extracted from the results that the total amount of biomass is one of the key characteristics that have a vital role in the carbon sequestration of trees, along with DBH. As previously discussed, native trees with higher biomass and DBH demonstrate a greater capacity to capture and store carbon dioxide from their surroundings. So, it can be inferred from the findings that native trees are more capable of sequestering carbon.

These findings were supported by other studies as Rodríguez-Loinaz *et al*. [51] suggested plantation of native trees for better CS in the long term. Ajani and Shams [52] compared the carbon sequestration between native trees like *Azadirachta indica* and exotic trees like *Conocarpus erectus* in Karachi and reported that native species showed a significantly higher value for carbon sequestration. Omoro *et al*. [53] found that native forests sequestered more

Table 1. Descriptive analysis of types of family

S. No.	Family	*f*	%	Mean					
				DBH (inches)	Height (ft.)	Age	Biomass (kg)	Carbon Sequestration (kg)	Annual Carbon Sequestration (kg)
1	Anacardiaceae	4	3.5	17.55	46.50	20.50	5034.35	2617.94	128.47
2	Apocynaceae	14	12.2	25.03	56.36	33.71	13342.84	6938.50	206.05
3	Bignoniaceae	16	13.9	15.71	32.74	20.88	2923.79	1520.42	72.78
4	Bombacaceae	2	1.7	30.65	46.65	35.00	16058.34	8350.60	238.59
5	Burseraceae	6	5.2	19.68	45.50	25.00	6753.93	3835.25	135.36
6	Caesalpinoideae	9	7.8	20.43	32.99	20.00	5436.91	2827.28	140.00
7	Combretaceae	4	3.5	31.53	61.50	35.00	22638.48	11813.65	341.51
8	Ebenaceae	1	0.9	8.40	34.00	20.00	501.11	260.59	13.03
9	Euphorbiaceae	1	0.9	15.00	49.00	20.00	3838.16	1995.91	99.79
10	Fabaceae	15	13.0	17.61	48.72	21.13	7418.41	3857.69	170.72
11	Meliaceae	1	0.9	19.00	39.40	22.00	5003.88	2602.10	118.28
12	Moraceae	23	20.0	28.20	45.05	30.00	19070.81	9909.93	270.05
13	Myrtaceae	7	6.1	20.43	53.49	21.00	8750.60	4550.46	217.90
14	Pinaceae	1	0.9	14.00	50.00	22.00	3411.70	1774.14	80.64
15	Salicaceae	1	0.9	24.00	50.00	25.00	10026.21	5213.79	208.55
16	Sapotaceae	10	8.7	12.89	47.40	20.50	2809.37	1460.92	70.30
	Total	115	100	21.10	45.62	25.18	9807.69	5116.98	173.90

Note: *f* = Frequency; % = Percentage

Table 2. The correlations coefficients for DBH, height, biomass, age of a tree, and carbon sequestration

Variables	*N*	*M*	*SD*	DBH	Height	Biomass	Age	CS
DBH	115	21.10	10.54	--				
Height	115	45.62	10.38	.489**	--			
Biomass	115	9807.69	13366.70	.943**	.504**	--		
Age	115	25.1826	8.14	.695**	.567**	.711**	--	
CS	115	173.90	171.23	.943**	.505**	1.000**	.711**	--

Note: ***p* < .01

Table 3. Linear regression analysis of carbon sequestration

Variables	R^2	*B*	*p-value*
DBH	.89	621.68	.000
Height	.26	337.84	.000
Biomass	.99	0.520	.000
Age	.51	607.41	.000

Note: ***p* < .01

Table 4. Descriptive analysis of native and exotic trees

	Native			Exotic		
	n	*M*	*SD*	*n*	*M*	*SD*
DBH	56	24.83	12.34	59	17.56	76.92
Height	56	46.45	9.81	59	44.82	10.92
Biomass	56	13574.98	17411.83	59	6231.95	6080.80
Age of a tree	56	26.13	9.85	59	24.29	6.04
Carbon Sequestration	56	7093.76	9049.06	59	3240.72	3162.12
Annual Carbon Sequestration	56	231.57	212.81	59	119.17	91.79

Table 5. Independent sample t-test to compare native and exotic trees for CS

				Levene's Test for Equality of Variances		*t*-test for Equality of Means						
		M	*SD*	*F*	Sig.	*T*	*df*	Sig. (two-tailed)	Mean difference	Std. Error difference	95% Confidence Interval of the difference	
											Lower	Upper
Carbon sequestration	Native	7093.76	9049.06	13.90	.000	3.016	67.626	.004	3853.04	1277.39	1303.80	6402.28
	Exotic	3240.72	3162.12									

Note: ***p* < .01

carbon in their biomass than exotic plantations.

In sum, the trait of carbon captivation and storage among different families and types of trees according to the local scenarios of anthropogenic carbon emission was reported by different researchers with the assessment that trees are one of the major contributors to producing carbon sinks for enhancing the environment [54 - 57]. Although, at the same time, arguments related to trees' ability to extract carbon on a large scale in comparison to other methods that could lower its concentration at a required level are still under discussion [58 - 60]. In general, the importance of trees in the development of carbon footprints cannot be overstated [10]. The most important point that should be highlighted here is the potential of different trees in carbon extraction from the surroundings and their ability to have a significant role in cutting off carbon dioxide rates from the environment is confirmed by the findings [61 - 63].

4. CONCLUSIONS

This study was initiated with the idea that biophilic urbanism can provide an additional benefit of carbon sequestration. Therefore, urban tree potential was assessed in this regard, and synthesis indicated a significantly positive effect. In line with the findings of this study, it can be concluded with statistical evidence that urban trees are the most effective source of carbon elimination from the environment. In addition to this, biomass and DBH are major components in the facilitation of more carbon absorption and storage in trees. For instance, native trees with greater total biomass and DBH are better carbon reservoirs than exotic trees in this study. To conclude, carbon sequestration by trees can be considered as a co-benefit of biophilic cities that tend to show both compatible and complementary trends in the future. Yet, more research is required to explore this in-depth with a large and diversified sample.

5. ACKNOWLEDGEMENTS

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6. CONFLICT OF INTEREST

The authors declared no conflict of interest.

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