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Role of Urban Parks in Carbon Sequestration– A Case Study of Safari Park, Karachi, Pakistan

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Cover Page Footnote

Authors are grateful to the management of Safari Park, Karachi for providing access and required information for this study

ROLE OF URBAN PARKS IN CARBON SEQUESTRATION– A CASE STUDY OF SAFARI PARK, KARACHI, PAKISTAN

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ABSTRACT

Urban parks besides their recreational use can be the potential source of climate mitigation through carbon sequestration. Present study aims to identify the carbon sequestration potential of Safari Park which is by far the largest public park of Karachi established in 1970 covering an area of 0.72 km^2. A total of 153 individual trees belonging to 25 species and 14 families were included in the study. Five dominant species with highest Important Value Index (IVI) were *Cocos nucifera* (14.62 %), *Azadirachta indica* (14.21 %), *Guaiacum officinale* (9.93 %), *Washington robusta* (9.31 %) and *Delonix regia* (7.11 %). The highest carbon content was sequestered by *C. nucifera* (9472 kg) followed by *D. regia* (7599 kg), *W. robusta* (3576 kg), *A. indica* (1861.5 kg) while, *C. erectus* sequestered the lowest carbon content (765.6 kg). Pearson coefficient of all 5 dominant species showed a significantly positive correlation ($p < 0.05$) between volume and diameter at breast height (DBH) at 0.80 - 0.93 cm, providing an assumption that trees with high DBH have a greater role in carbon sequestration. With a ratio of 17 native and 8 non-native species, the park can serve as an example of well-balanced and diverse ecosystem (Shanon and Simpson Indices of 2.8 and 0.92) focused on yielding maximum carbon content. Because of its large area with high DBH, *Cocos nucifera* accumulated the most carbon. The tree composition can be taken as a foundation for urban planners who are focused to integrate species diversity, richness and carbon offsetting requirements while setting up a public park in similar arid and semi-arid conditions.

Keywords: Carbon sequestration, climate change, important value index, urban parks, safari park.

INTRODUCTION

Climate change is considered as a modern era challenge resulted from increased human activities and industrialization (Oelkers and Cole, 2008). The rampant rise in fossil fuel usage for transportation and electricity generation has deteriorated the air quality of urban cities (Erickson and Brase, 2020), consequently causing a social damage of > 3$ trillion and approximately 3 million premature mortalities each year (Lelieveld et al., 2015). Emerging evidence demonstrated direct risk to vulnerable populations from environmental carbon dioxide (< 5000 ppm), especially infants, elderly and patients with pulmonary and neurovascular diseases (Jacobson et al., 2019). Evidence also indicated a risk of cognitive impairment in populations with elevated blood CO_2 level (> 600 ppm) living in close quarters. Continuous rise in CO_2 has also amplified the urban heat island (UHI) effect resulting in heat entrapment in concrete structures (Singh et al., 2020).

From the perspectives of pollution tolerance and environmental sustainability, urban vegetation is significantly higher than vegetation in non or less polluted biomes (Rantzoudi and Georgi, 2017).

Trees have a great ability to remove pollutants from the air and improve air quality. Urban tree planting has enhanced the ambiance of residential areas and enhanced human health, making living more comfortable for all (Chen et al., 2015). They also think that urban and street trees can do additional beneficial duties like lowering noise pollution and protecting biodiversity in populated areas, both of which would improve human health (Seiferling et al., 2017).

The green pigments in plants take up atmospheric CO_2, water and sunlight and convert it into energy required for plant growth with the release of oxygen. Relationship between plant characteristics and the rate of carbon sequestration has been studied extensively. Wang et al., (2021) established that carbon sequestration is proved to be more sustainable by integrating medium sized evergreen plants and tall trees (> 12 m) with greater basal area (> 10 cm^2 $year^{-1}$) in a partly open biotope structure. Lahoti et al., (2020) also concluded that dominant trees with bigger girth size are often more adaptable, pollution resistant and tend to sequester more carbon. Tree bole of > 77 cm in diameter remove 70 times more air pollution (1.4 kg/yr) than small healthy trees of < 8 cm diameter (0.02 kg/yr) (Killicoat et al., 2002). A study of *Cedrus Deodara* trees in Gilgit-Baltistan region suggests that diameter at breast height (DBH) and total height of a tree is directly dependent on the volume or growing stock of a tree (Ali et al., 2014). While, net monetary ecological benefits from a tree can be assessed through acquiring data on prices, number of tree species and sizes, proper simulations, accounted with benefits of energy conserved. These studies establish some criteria that can be used to assess the carbon sequestration potential of individual tree species adapted to their local climate and ecological setting.

Karachi is the largest metropolitan city of Pakistan and second largest in terms of population in the world. The city is spread over an area of 3,530 km^2 with a density of 4,543 persons per square kilometre. As per 2017 census, total population of the metropolitan has increased by 16.05 % compared to which the green area constitutes of only 11.28 % of the total land cover (Zia et al., 2022). The Karachi has been a victim of unplanned urbanization for past two decades which has severely disrupted balance between the concrete and nature-based infrastructure (Arshad et al., 2020). Pollution load has also increased by manifolds due to uncontrolled vehicular emissions and industrial expansion.

Research has proven the effectiveness of urban parks to fix atmospheric carbon that can easily be integrated into the complex urban structures (Park et al., 2021). Urban parks can be classified as man-made open areas incorporated with vegetation and nature. The green structures provide a forum for social interaction and numerous recreational and ecological benefits including toxins accumulation, nutrients regulation and alleviating the heat stress (Shuib et al., 2015). Pakistan is under the same pressure as other nations, where pollution and a growing population are causing the environment to deteriorate. As the largest and busiest city in Pakistan, Karachi serves as a great case study for similar issues.

Karachi city has a variety of native plant species mainly because of its diverse landscapes including urban settings, coastal areas and adjoining arid regions. Studies report that *Acacia nilotica* (Babul), *Euphorbia caducifolia* (Sabzak), *Tamarix aphylla* (Athel Pine), *Calotropis procera* (Madar), *Ficus benghalensis* (Banyan tree), *Azadirachta indica* (Neem), *Ziziphus mauritiana* (Ber), *Prosopis cineraria* (Kandi) and *Cyperus rotundus* (Nutgrass) are some widely present native plant species in Karachi (Lateef et al., 2020; Iqbal et al., 2021; Kazmi et al., 2022) whereas, the *Conocarpus erectus* and

Guaiacum officinale are among the dominant non-native plants in the Karachi *(*Bhatti et al., 2022).

The purpose of this study is to estimate the current performance of trees growing on either side of streets and traffic islands in an environment that is highly polluted and to assess their capacity to sequester carbon. The decision of selecting the right tree species in urban landscaping holds great significance enhancing the potential of carbon sequestration in urban forest. An attempt has been made to estimate the carbon biomass of the largest public park of Karachi. The model can be applied to other parks within the same region to assess the carbon stock in the urban green areas.

MATERIALS AND METHODS

Safari Park is by far the largest public park of Karachi established in 1970. It covers an area of approximately 150 acres or 0.72 km^2. The study area is located in the Gulshan-e-Iqbal district East of Karachi which is one of the most ecologically diversified towns situated at latitude and longitude of 24.9222° N, 67.1082° E. (Figure 1).

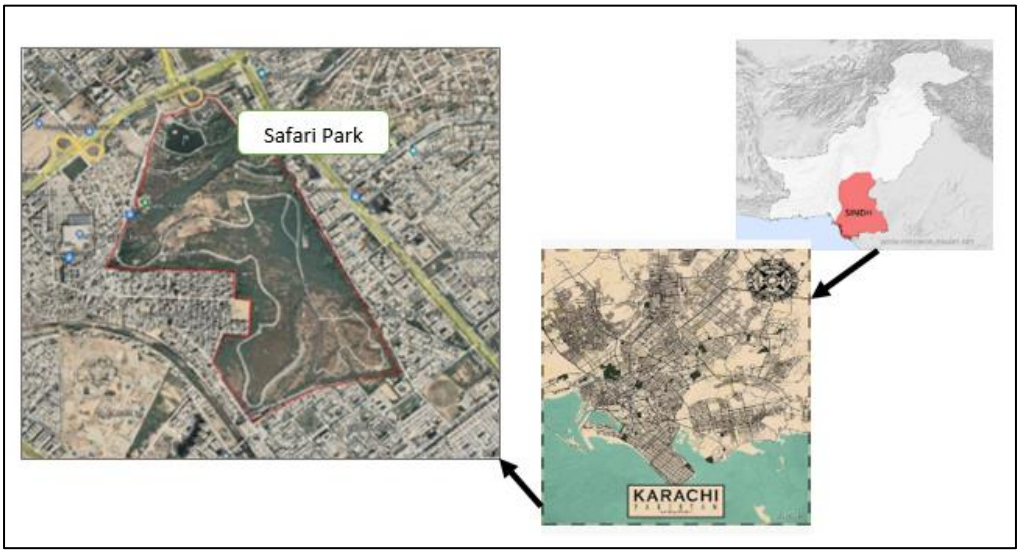

Figure 1: Location Map of the Safari, Park, Karachi, Sindh, Pakistan

The climate of Karachi is governed by the influence of land and sea breeze. The coastal belt categorizes as arid zone which is highly vulnerable and sensitive to drought (Adnan et al., 2017). In summers, the temperature rises to average 78°F (26 °C) and 95 °F (35 °C) with events of heat waves causing a rise of 40 + °C, while winters are mild with temperature variation between 52 °F (11 °C) and 81 °F (27 °C). The average temperature in both seasons has been predicted to increase due to air pollution and carbon emissions (Amjad et al., 2023).

The study was conducted on a limited vegetation area of Safari Park available for public activities. The area excluded from study was animal safari which can only be accessible through bus rides. The total vegetation cover selected for study includes open gardens, playgrounds and lakes spread over 0.26 km^2 lands within park boundary, constituting about 36.11 % of total park area. A total of 153 individual trees belonging to 25 species and 14 families were sampled. All the species were identified, classified and counted with their botanical names, families and number of individual trees to establish a tree inventory for biomass estimation and assess structural diversity of the park. Tree identification and classification was made with the help of Flora of Pakistan @ Efloras.Org; Search — The Plant List.

The sampling approach and parameters measurement and computation were based on Intergovernmental Panel on Climate Change (IPCC) 2006 and Reducing Emissions form Deforestation and Forest Degradation Pakistan 2018 (REDD + Pakistan, 2018). Random sample technique was applied in which 3rd tree along the perimeter and within the covered area was taken for measurement to draw a sample size at 95 % confidence interval and 5 % margin of error, and for even representation of every species present in the area. Tree measurements included were diameter at breast height (DBH), tree height and crown cover. DBH (stem diameter at 1.37 m) was measured by measuring tape (Bettinger et al., 2018). Total tree height and crown cover were measured by clinometer and measuring tape respectively. The crown cover of a tree was measured in a cross intersectional manner to numerate the widest and narrowest points. The average of both points was considered as the canopy spread (Powell and Avenue, 2005). For trees smaller than 1.37 m height at base, top and middle was measured and averaged.

To determine the dominant tree species in a given community, Important Value Index (IVI) was calculated (Ismail et al., 2017) by summation of relative density, relative dominance and relative frequency using below equations:

$$Relative\ Density = \frac{Density\ of\ individual\ species}{Sum\ of\ densities\ of\ all\ species} * 100$$

$\boldsymbol{Where}$!

$$Density\ of\ individual\ species = Total\ number\ of\ individuals\ of\ a\ species$$

$$Relative\ Dominance = \frac{Dominance\ of\ species}{sum\ of\ dominance\ of\ all\ species} * 100$$

$\boldsymbol{Where}$!

$$Dominance\ of\ species = Total\ basal\ area\ of\ species$$

$$Relative\ frequency = \frac{frequency\ of\ species}{sum\ frequency\ of\ all\ speices} * 100$$

$\boldsymbol{While}$!

$$Frequency\ of\ species = \frac{Number\ of\ plots\ where\ a\ species\ is\ observed}{Total\ number\ of\ survey\ plots}$$

Shannon Wiener Index was calculated as:

$$H' = \sum_{i=1}^{s} Pi\ \ln(Pi)$$

It is the diversity index where S = total number of species in a community, Pi is the proportion of S made of the ith species and *ln* is the natural logarithm. Simpson Diversity Index was calculated as a measure of diversity which takes into account total number of Individual as (N) and total number of an individual species as (n) in an area as:

$$D = 1 - \frac{\sum n\ (n-1)}{\mathrm{N}\ (\mathrm{N}-1)}$$

Volume of a tree species is assessed as:

$$V = \pi r^2 . \mathrm{H}$$

Where H = Total height of a tree, r = radius of the trunk diameter calculated from diameter at breast height and π =

constant (3.142). Above ground biomass assessment was calculated by multiplying volume of a tree by average wood density (kg/m^3) while below ground biomass was calculated by multiplying above ground biomass with root to shoot factor of 0.26 (Ajani & Shams, 2016). Total biomass was computed by adding above ground biomass and below ground biomass. To convert the calculated green biomass into dry weight carbon stock (CS) a conversion factor of 0.475 was used (Jha, 2018).

Carbon Stock (kg) = (above ground biomass + below ground biomass)

RESULTS

Physiognomy

The Table 1 provides the inventory of important tree species sampled from the safari park, Karachi.

Family Name	Species Name	No of Sampled Trees
Anacardiaceae	*Searsia lancea*	2
Annonaceae	*polyalthia longifolia*	4
	Quercus phellos	1
Araucariaceae	*Araucaria cunninghamii*	4
Arecaceae	*Washington robusta*	13
Caesalpiniaceae	*Delonix regia*	10
	Parkinsonia aculeata	2
	Peltophorum pterocarpum	2
	Pithocelobium dulce	2
	Saraca asoca	9
	Tamarindus indica	2
Casuarinacea	*Casuarina equisetifolia L.*	8
Combretaceae	*Conocarpus erectus*	10
	Phoenix sylvestris (Linn.)	6
Fabaceae	*Butea monosperma*	2
Meliaceae	*Azadirachta indica*	24
Mimosaceae	*Acacia nilotica*	2
	Albizia julibrissin	2
	Albizia lebbeck	3
	Guaiacum officinale	16
	Leucaena leucocephala	1
Moraceae	*Ficus religiosa*	1
Myrtaceae	*Syzygium cumini*	6
Palmae	*Cocos nucifera L.*	19
Rhamnaceae	*Ziziphus jujuba*	2

The park structure with respect to tree diameters is found to be unevenly distributed with 9.2 % of 7-12 cm, 68 % of 13-36 cm, and 23 % of remaining > 36 cm Diameter trees, respectively (Figure 2). The average DBH ranged between 12.73 cm to 261.40 cm of *Araucaria cunninghamii* and *Quercus phellos*. The other two species recorded with > 50 cm DBH are *Acacia nilotica* and *Phoenix sylvestris* (Table 3). Most of the trees are falling in the middle range of 13-36 cm as there are several small gardens within park which are dominated by fewer or individual tree species (such as *Cocos nucifera*, *Delonix regia*, *Azadirachta indica* and *Phoenix sylvestris* trees). There is a dedicated *C. nucifera* park having a mix of adult and juvenile trees. Similarly, the trees planted along the sidewalk or perimeters were also in growing stage with slender branches and pointed tops.

Height distribution demonstrates 56.8 % of 2-2.9 m, 38.5 % of 3-3.9 m trees while remaining 4.5 % consists of tallest trees recorded between 4-8 m (Figure 3). The tallest tree species were recorded to be *Casuarina equisetifolia L.* with average height of 2.91m followed by *Washington robusta* and *Quercus phellos* (> 2.5m). The smallest specie was *Searsia lancea with mean* 0.55m height (Table 3). Similar to trunk diameter, most of the standing tree height is between 2 to 3 m which shows that they are still growing. Some of them which are planted along the pedestrians also undergo pollarding to maintain their height to a certain level.

The crown cover is majorly distributed between > 230-345 cm, > 115-230 cm and > 345-460 cm constituting 27.45 %, 20.9 %, 20.2 % respectively, while 31 % falls between > 460 to 960 cm indicated in Figure 3. The attribute is associated to tall trees (> 1.37m) which majorly consists of average heightened trees with the crown also in growing phase, therefore falling in the range of 1.15-3.45 m.

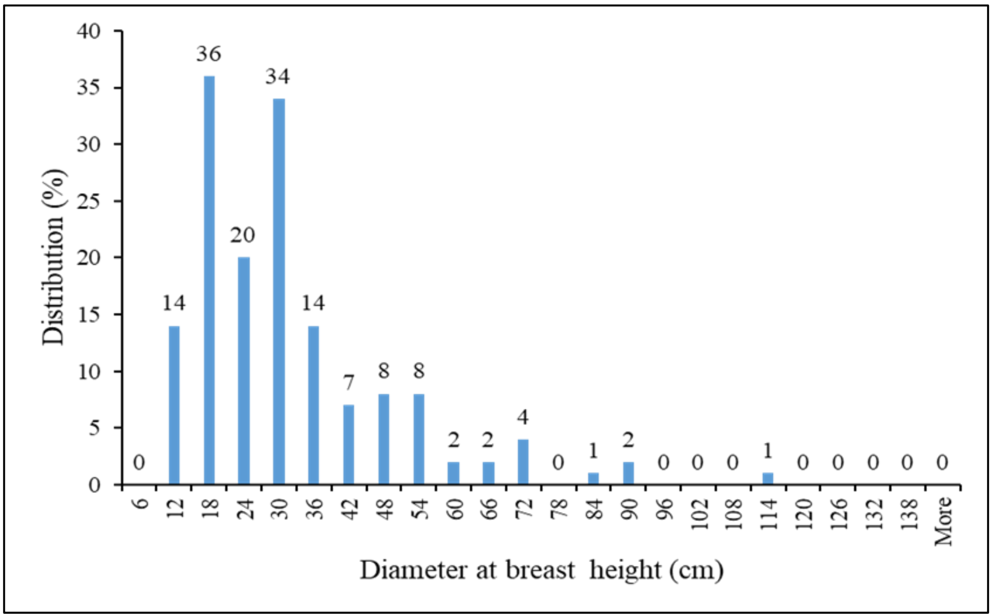

Figure 2: Distribution of tree species with respect to their diameter at breast height.

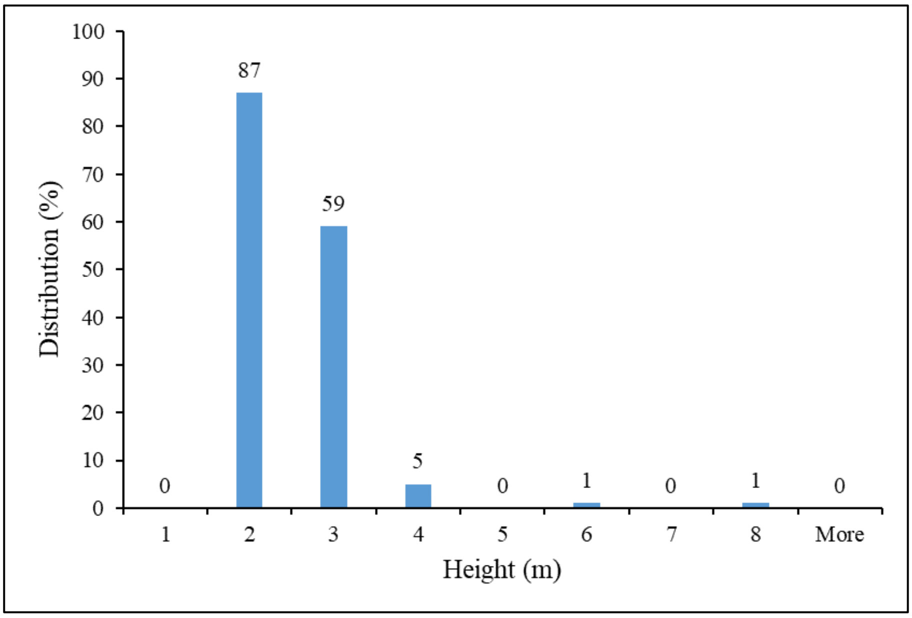

Figure 3: Distribution of tree species with respect to their height.

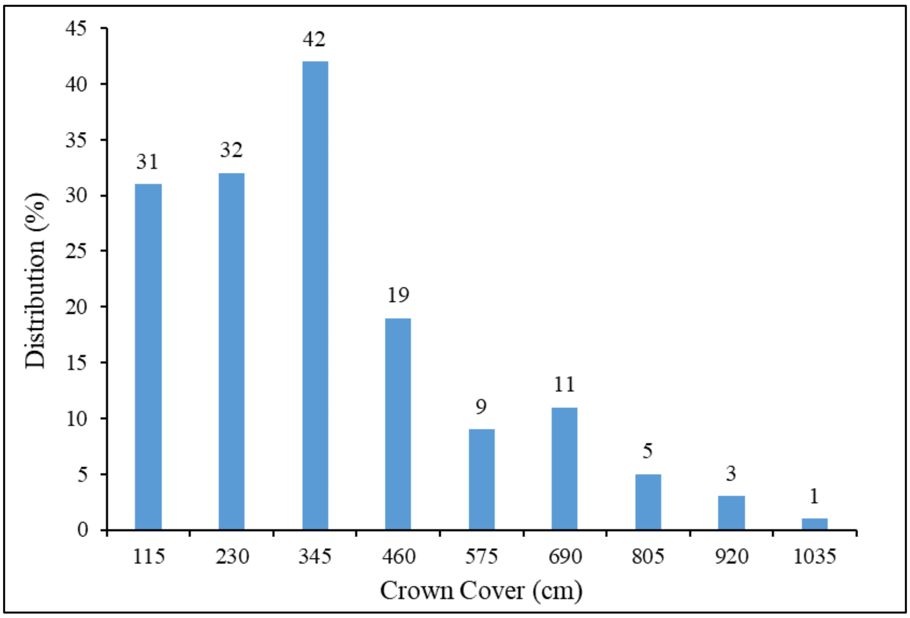

Figure 4: Distribution of tree species with respect to their crown cover.

Species Diversity and Distribution

The park exhibits substantial diversity and evenness with a mixture of 17 native and 8 non-native species. The diversity calculated by Shanon-Wiener Index reported at 2.80 which is > 1. This index indicates a higher biodiversity of species in park. Park has shown greater diversity and variation in composition of trees. The value of Simpson Index of diversity was found to be higher (0.92) indicating higher diversity. The vegetation evenness was also found near 1 at 0.86, exhibiting equal distribution across the park (Table 2).

The top five most abundant species with highest Important Value Index (IVI) included *Cocos nucifera (14.62 %), Azadirachta indica (14.21 %), Guaiacum officinale (9.93 %), Washington robusta (9.31 %)* and *Delonix regia (7.11 %)*, While the least dominant were found to be *L. leucocepahala*, *Q. phellos* and *F.*

religiosa with lowest abundance. It also represents the dominancy of native tree species over non-native with a ratio of 3:2.

Table 2: Tree species diversity and richness in Safari Park

Scientific Name	No. of Trees	Relative Frequency	Relative Dominance	Relative Density	Important Value Index	Shannon Wiener Index (H')
Acacia nilotica	2	1.31	7.52	1.31	3.38	0.06
Albizia julibrissin	2	1.31	3.09	1.31	1.90	0.06
Albizia lebbeck	3	1.96	7.92	1.96	3.95	0.08
Araucaria cunninghamii	4	2.61	0.43	2.61	1.89	0.10
Azadirachta indica	24	15.69	11.26	15.69	14.21	0.29
Casuarina equisetifolia	8	5.23	2.15	5.23	4.20	0.15
Cocos nucifera	18	11.76	20.32	11.76	14.62	0.25
Conocarpus erectus	10	6.54	2.58	6.54	5.22	0.18
Phoenix sylvestris	6	3.92	6.50	3.92	4.78	0.13
Delonix regia	11	7.19	6.94	7.19	7.11	0.19
Ficus religiosa	1	0.65	0.17	0.65	0.49	0.03
Guaiacum officinale	16	10.46	8.88	10.46	9.93	0.24
Leucaena leucocephala	1	0.65	0.12	0.65	0.48	0.03
Parkinsonia aculeata	2	1.31	0.36	1.31	0.99	0.06
Peltophorum pterocarpum	2	1.31	2.35	1.31	1.66	0.06
Pithocelobium Dulce	2	1.31	1.81	1.31	1.47	0.06
polyalthia longifolia	4	2.61	1.10	2.61	2.11	0.10
Quercus phellos	1	0.65	0.15	0.65	0.49	0.03
Saraca asoca (Roxb.)	9	5.88	2.93	5.88	4.90	0.17
Searsia lancea	2	1.31	0.32	1.31	0.98	0.06
Syzygium cumini	6	3.92	0.98	3.92	2.94	0.13
Tamarindus indica Linn.	2	1.31	0.39	1.31	1.00	0.06
Washington Robusta	13	8.50	10.94	8.50	9.31	0.21
Ziziphus jujuba Mill.	2	1.31	0.55	1.31	1.06	0.06
Butea monosperma	2	1.31	0.25	1.31	0.96	0.06
Total		**100**	**100**	**100**	**100**	**2.81**
Shanon Wiener Index (H')						**2.80**
Simpson's Index (1-D) **Evenness**						**0.92** **0.87**

Total Carbon Sequestered

The biomass of most five abundant trees was determined by estimating above ground, below ground and dry carbon in kilograms of each species. *Table 3* shows the highest mean carbon content sequestered by *C. nucifera* (9472 kg) followed by *D. regia* (7599 kg), *W. robusta* (3576 kg), *A. indica* (1861.5 kg). The least carbon storage capacity was found to be in *C. erectus* at 389 kg. Each tree of *A. indica, Cocos nuifera, G. officinale and W. robusta* estimated to have stored 77.56 kg, 498.5 kg, 105.9 kg and 275 kg of Carbon. 22.30kg. This also indicates that the trees either are in growing phase as compared to other areas or experiencing stunted growth.

Table 3: Carbon sequestered by dominant tree species in Safari Park

Tree species	Height (m)	Diameter at breast height (cm)	Above ground biomass (kg)	Below ground biomass (kg)	Total Biomass (kg)	Carbon sequestered (kg)
Azadirachta indica	1.92	24.63	77.1	20.1	3751.7	1861.5
Cocos nucifera	1.92	35.31	136.9	33.8	9007	9472
Conocarpus erectus	2.04	26.43	60	15.6	1611.7	389
Guaiacum officinale	1.89	27.68	75.3	19.6	2609	1695
Washington Robusta	2.63	36.06	106	27	4083	3576
Delonix regia	1.83	29.91	74.6	19.4	4802.3	7599

Table 4 shows the Pearson correlation between growth attributes of a species. The coefficient between carbon volume and DBH (cm) for all five species was found to be significantly correlated between 0.80 and 0.93 and vice versa, representing that higher DBH would possess greater trunk volume, hence a greater carbon content. However, the height attribute exhibited an insignificant and even a negative correlation with respect to tree volume at ($p < 0.005$) which reflects that tree heights could not be taken exclusively as to assess carbon ratio in a tree.

Table 4: Correlation Coefficient of tree diameter at breast height and tree height of five most important tree species

	Diameter at breast height (cm)	Tree height (m)
Azadirachta indica	0.80	0.002
Cocos nucifera L.	0.82	0.10
Conocarpus erectus	0.92	0.01
Guaiacum officinale	0.93	0.16
Washington Robusta	0.93	0.11

DISCUSSIONS

Results indicated that despite belonging to the same plant group, different tree species contribute to varying amounts of carbon sequestration rates. The effect of carbon sequestration varies depending on the type of plant species, according to Mandal et al. (2016). For example, parks with trees and shrubs have the best carbon sequestration effect. Therefore, it was established by the results that higher plant specifications result in higher carbon sequestration value. For instance, the greater amounts of carbon are absorbed by the plants when the plants are maintained and cared for with the right landscape maintenance practises used as the trees age, grow taller, and their trunk diameter increases. In addition, the total rate of carbon sequestration is influenced by the quantity of plants planted. The results showed that planting with more of it and to higher standards has a greater capacity to store more carbon dioxide. With reference to Table 2, there are significant differences in each plant category's capacity to store carbon.

Urban trees can help mitigate climate change and achieve the goals of the climate action plan by sequestering atmospheric carbon (from carbon dioxide) in tissue and by modifying energy use in buildings (Abdollahi et al., 2000). These actions will also change carbon dioxide emissions from fossil fuel-based power facilities.

During their growth, trees accumulate and sequester carbon dioxide in their tissue. The most populated parts of Karachi city were used for the current study, which considered tree species' density, basal area, and height. *C. nucifera*, which had the largest diameter of all the trees under investigation, had consistent growth and collected the most carbon. Despite being a well-known species in arid environment, *C. nucifera* adaptive strategy against pollution has only just been revealed in light of recent studies. The species' reduced growth and carbon stock was produced by *C. erectus*. Although the difference in growth was not as great as anticipated, it does indicate that *C. erectus* has adapted to living in cities. Urban trees were studied, and their DBH-Height and carbon sequestered equation compared to rural trees by McHale et al. (2009). Greater carbon storage is attained as a result of their discovery of the highest DBH gain in urban trees.

In terms of carbon sequestration, *C. nucifera* was more compatible with the environment than other species under study. Other studies that examined the carbon content sequestered by *C. nucifera* found that it ranged from 9140 to 9472 kg (Selvaraj et al., 2016). Despite the paucity of studies on urban tree growth and carbon storage effectiveness, climate studies have lately highlighted the severity of this issue. So, there is still a pressing need for research. Urban plantations of various species are not only helpful for carbon sequestration but also absorb a number of pollutants from the atmosphere and contaminated soils, have a cooling effect on urban dwellings and structures, and provide much-needed suitable habitats and microhabitats for increasing biodiversity (Nowak et al., 2002).

Some other research studies have also reported the carbon capturing dynamics of the urban parks in Karachi. For example, Ajani and Shams, (2016) reported the carbon sequestration potential of some trees located in the Karachi University. This study found that *Azadirachta indica* and *Conocarpus erectus* can capture about 662.32 Kg and 192.70 Kg of carbon per tree respectively in their biomass (Khan et al., 2023). Another study finds the carbon capturing potential of some trees including, *Azadirachta indica*, *Vachellia nilotica*, *Delonix regia*, *Cassia fistula* and *Guaiacum officinale* located along the road sides and off-roads in Karachi. Among the selected trees the *Azadirachta indica* stored the highest amount of carbon (about 3583±1366 kg per tree) with the tree biomass of about 1952.66 ± 744.8 kg.

CONCLUSION

Karachi parks and gardens have significant potential of carbon sequestration. *Cocos nucifera*, *Delonix regia* and *Azadirachta indica* among the examined tree species have a greater carbon sequestration potential. The results exhibited the study area to be highly diverse and species well distributed across the park. A ratio of 3:2 plantations, native to non-native species in the park showed sheer consideration of planners who focused on planting a mixture, to integrate ecological, aesthetical and ornamental benefits in park's beautification. The vegetation of park green cover can be taken as an example to develop and diversify other parks and while planning carbon offsetting and carbon credits in arid climates to yield maximum sequestration benefits. However, maintenance and nutrients requirements of these trees should be taken into consideration to determine complete carbon and energy balance.

CONFLICT OF INTERESTS

We have no conflicts of interest to disclose among authors.

AUTHOR'S CONTRIBUTION

All authors have equal contribution in designing, conducting the study, data analysis and writing the manuscript.

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