HARNESSING URBAN TREES FOR CLIMATE ACTION: LESSONS FROM CARBON SEQUESTRATION AT THE UNIVERSITY OF KARACHI

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ABSTRACT

This study indicates significant species diversity with variability in growth parameters and showed carbon stock potential of dominant trees species across the University of Karachi campus. The mean diameter at breast height (DBH) (93.48 ± 13.53 cm) of *Tamarindus indica* L. is over twice as *Eucalyptus camaldulensis* Dehnh and the mean BA (Basal Area) (6996.80 ± 2138.66 cm^2) incredibly larger than all others, suggesting trees with much greater DBHs and total volume of wood. The mean DBH of *E. camaldulensis* (35.92 ± 17.10 cm) and *Ficus religiosa* L. (36.795 ± 8.83 cm) have the next higher DBH, thus having relatively high mean BAs (1241.71 and 1118.97 cm^2 correspondingly). *E. camaldulensis, Melia azedarach* L., *Guaiacum officinale* L. and *T. indica* consistently register relatively larger Total Biomass (TB), carbon stock and CO_2 equivalent values. While *Conocarpus erectus* L., *F. religiosa* and *Mangifera indica* L. have much lower values for these measures reflecting their less contribution to the overall biomass and carbon stock. It was observed the total amount of 1657.355 tons of CO_2 is heavily dominated by sampled species. Species diversity analysis revealed low species richness and evenness, with a Shannon index of 1.602, Shannon equitability of 0.72 and a Simpson index of 0.7692, suggesting dominance by a few species.

Keywords: Biomass, Carbon Stock, Climate Change, Diversity, Karachi

1.0 INTRODUCTION

According to Filho *et al*. (2024), forests are becoming more and more important natural carbon sink, so that the emerging international climate problem requires a rapid and effective approach for carbon sequestration. Because of their volume, size and large long-term storage potential in their roots, trunks, leaves and the soils around them, trees have a major impact on carbon storage from the atmosphere (Ali *et al*., 2023). Urban green spaces such as in university campuses can be a large opportunity to reduce greenhouse gas emissions by facilitating carbon storage and sequestration (Rasoolzadeh *et al*., 2024; Sharma *et al*., 2020). However, a significant knowledge gap has been noted about the regional specific information on the role of native tree species for urban park carbon sequestration which is obstructing advancement towards an effective green space designing (Rehman *et al*., 2025).

Pakistan has shown a groundbreaking determination in adopting sustainable development Agenda 2030 by setting an ambitious target to decarbonize and preserve its environment (Khan *et al*., 2023). This identifies a prerequisite to assess local carbon storage, particularly at the different levels of trees and soil in urban green spaces, roadside, gated communities, institutions (Khan *et al*., 2023). Operative management of the urban tree cover and its ecological features could be a substantial avenue for extensive environmental benefits and aims to follow sustainable developments (Mohan *et al*. 2022). As academic institutions, universities have a significant role to play in this respect by indulging green infrastructure and providing space for studies into low carbon technologies that will meaningfully improve environmental performance (Ahmad *et al*., 2023). Moreover, overpopulated cities are expanding in housing leads to depletion of green spaces and forest cover results in increased carbon emission (Khan *et al*., 2022). This entails a comprehensive assessment of the sequestration potential of carbon in the urban ecosystem including how native tree species are contributing to CO_2 sequestration in atmosphere (Ajani and Shams, 2016; Ajayi, 2021).

This research aims to fill this vacuum and offers an estimation of the carbon sequestration potential of tree species at University of Karachi, toward sustainable urban planning in Pakistan or corresponding ecological domain (Ali *et al*., 2023; Khan *et al*., 2023). Since, this university is one of the oldest habitat catering species diversity of old trees that have been taking up CO_2 over many years throughout their long lifetime, so they are particularly important in terms of storing carbon for decades within cities (Du *et al*., 2024). The objective of the present study is to evaluate the carbon sequestration potential and to compare the carbon sequestration capacity of various tree species within the campus environment with the ultimate goal of identifying and recommending the most suitable species for plantation at University of Karachi, Karachi. This study is in support of the broader goal regarding the potential role of urban forestry to carbon neutrality target and fulfils national commitments to environmental protection as well as UNSDGs (Khan *et al*., 2023). In particular, Pakistan has actively worked towards the 2030 Agenda and shown the dedication toward environmental conservation and carbon neutrality via various strategies (Khan *et al*., 2023). Nevertheless, global attempts at mitigating climate change through carbon sequestration are under threat in many developing countries like Pakistan due to insufficient research and institutional capacity leading to poor inventory of these resources (Siddiq *et al*., 2021). This study also quantifies the carbon sequestration potential of various tree species within the University of Karachi campus to inform sustainable urban planning and contribute to carbon neutrality goals in Pakistan.

2.0- METHODOLOGY

2.1- Study Area

This research was performed in the University of Karachi, Pakistan's largest university with an area of 1,267 acres at a latitude of 24.94º N and longitude of 67.12º E (Figure 1). Study site biotype is of the fragmented shrub land types. The campus has a high biodiversity in terms of life forms, most likely because of its isolation from the city, which provides a quaint and coherent environment. This context includes a wide diversity of flora including native wild trees and plants, exotic species, medicinal and economically important plants, and ornamental taxa. The dynamics between this diversity of plants and the ever-increasing built up area provide a special case of composing urban green, mixed grasslands that contains several wild shrubs, lianas and herbaceous plants. However, this ecosystem is currently facing significant disturbances from anthropogenic activities such as construction, cattle grazing, and firewood collection. These disturbances profoundly impact the campus ecosystem, threatening numerous floral and faunal species, pushing some towards endangerment, and others near extinction.

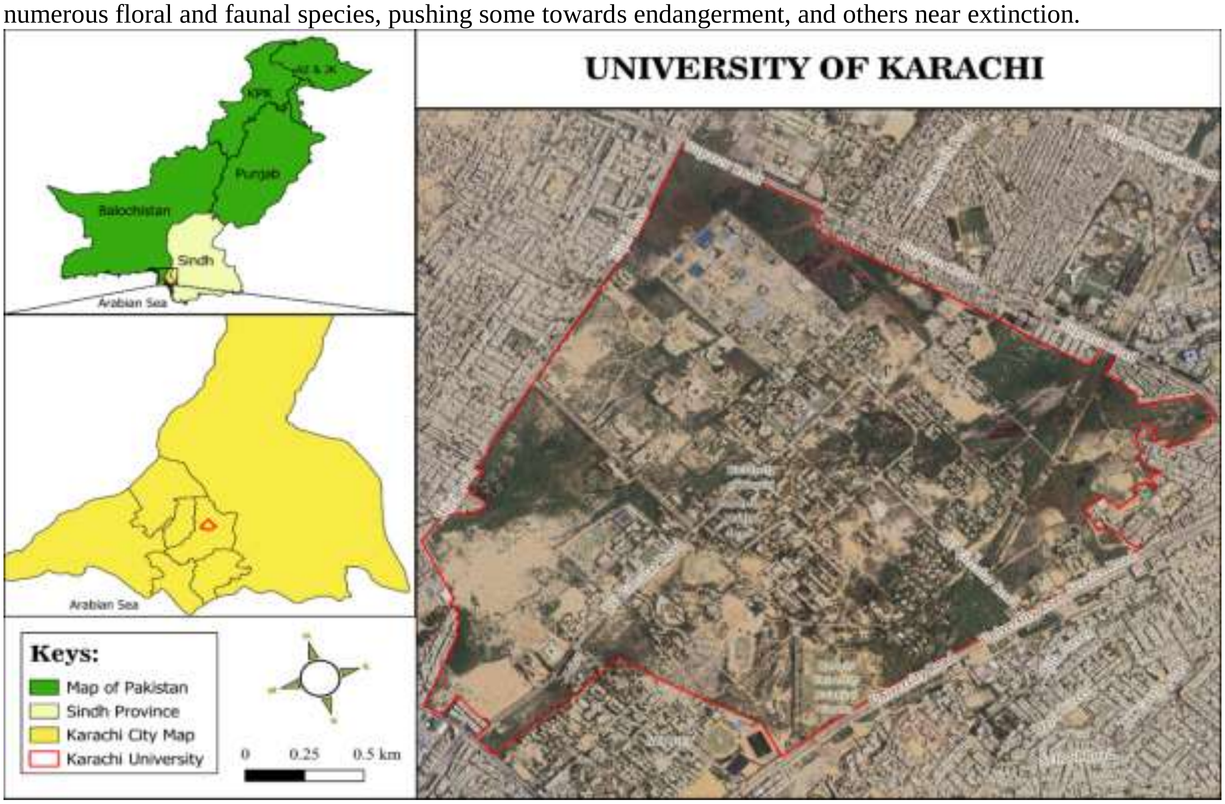

Fig. 1. Study Area Map.

2.2 Sampling

A total of 1,515 trees were sampled during September to December 2024 in University of Karachi as shown in Table 1. DBH of each tree were taken with a measuring tape at about 1.3 meters from the ground and height was determined using the Arboreal mobile application (which though, had been calibrated with Haga altimeter).

2.3 Carbon Stock Estimation

2.3.1 Allometric Equations using Dendrometric Variables:

For each tree species, Above Ground Biomass (AGB) and Below Ground Biomass (BGB) has been derived using dendrometric variables, i.e., tree height and tree (DBH) methodology of (Chavan and Rasal, 2012) and (Daba and Soromessa, 2019).

2.3.2 Above Ground Biomass (AGB):

Firstly, AGB is Calculated (Hangarge *et al*., 2012) using Eq.1 for which the global wood density Database (Zanne *et al*., 2009) is employed to acquire the varying wood density for each species, volume of the trees will be calculated as Eq. 2.

AGB = Volume of tree (V) × Wood Density (Wd) Eq. 1.

$V = \pi r^2 H$ Eq. 2.

Where V is the tree Volume (m^3); r is tree trunk' radius at breast height which is the half of the diameter at breast height (DBH) (m) and H is height of tree (m)

2.3.3 Below Ground Biomass (BGB):

BGB is considered for the living roots of the trees having diameter of more than 2mm with fine roots. BGB is calculated as Eq. 3.

$$BGB = AGB \times 0.26 \quad \text{Eq.3.}$$

Thus, the total biomass of the tree can be calculated as Eq. 4.

$$TB = AGB + BGB \quad \text{Eq.4}$$

2.3.4 Total Carbon Stock (CS_T): Finally, the total carbon stock CS_T will be calculated by taking half of the TB as Eq. 5.

$$CS_T = \frac{TB}{2} \quad \text{Eq. 5}$$

2.4 Biodiversity Indices

2.4.1 Simpson's Diversity Index

Simpson's diversity index is used to calculate a measure of diversity, considering the number of something as well as its abundance. The index is most often used for ecological studies that measure species diversity. Denoted as D, this index is calculated as:

$$D = 1 - \frac{\sum n(n-1)}{N(N-1)} \quad \text{Eq.6}$$

2.4.2 Shannon Diversity Index

The Shannon diversity index (Shannon- Wiener Index) is a way to measure the diversity of species in a community. Denoted as H, this index is calculated as.

$$H, = -\sum pi \times \ln(pi) \quad \text{Eq.7}$$

2.4.3 Shannon Equitability Index

The Shannon equitability index (EH) is a direct extension of the Shannon diversity index used to measure the evenness of species in a community (Pielou,1966) and it is calculated as equation 15:

$$EH = \frac{H}{\ln(S)} \quad \text{Eq. 8}$$

Where, H represents Shannon Diversity Index and ln (S) represents the natural logarithm of the number of species

3.0 RESULTS AND DISCUSSION

3.1 Growth Parameters:

The outcomes of growth parameters such as DBH, tree height, and basal area of 9 different species identified at the campus are presented in a (Table 1).

T. indica stands out as the structurally dominant species. Its mean DBH (93.48±13.53 cm) is more than double that of the next largest species, and its mean Basal Area (6996.80±2138.66 cm^2) is exponentially higher than all others, indicating trees with significantly larger DBH and overall wood volume. The mean DBH of *E. camaldulensis* (35.92±17.10 cm) and *F. religiosa* (36.795±8.83 cm) exhibit the next highest DBH, resulting in relatively large mean Basal Areas (1241.71 and 1118.97 cm^2 respectively). *G. Officinale* is also a close second in size. Differences in structure of species indicate difference biomass accumulation and carbon sequestration potential (Ajani and Shams, 2016).

Species such as *A. indica, C. erectus and M. azedarach* present lower Basal Areas (which range from 12.67 cm to 26.96 cm) and also very low mean DBH values considering their overall figure, which would make them apparently the structurally thinner and least voluminous per tree specimens, all of them except *C. erectus* -one of the tallest taxa- attending to average height. Such structural diversity between species reveals the differential share of various species in overall biomass and carbon pool of site, while some like *E. camaldulensis* performs better for carbon storage (Yasin *et al*. 2024). These growth rates are important for calculating the AGB of each tree and thus the carbon stored by individual trees on campus site-area (Mohan *et al*. 2022). These estimates will also help to quantify the total carbon stock so that a solid quantitative base could be developed for evaluation of future sequestration efforts and study land management practices for sustainable development (Yasin *et al*. 2024).

Table 1. Growth Parameter: Tree Height (cm), Diameter at breast height (cm) and Tree basal area (cm^2) at the University of Karachi.

Specie name (Number of Trees sampled)	**Growth Parameters**			
	Common Name	**Height (cm)**	**DBH (cm)**	**Basal Area (cm^2)**
		Min - Max Mean ± SD	**Min - Max Mean ± SD**	**Min - Max Mean ± SD**
Azadiracta indica A. Juss (475)	Neem	226.02-2004.63 1071.77 ± 509.30	6.718-34.304 15.031 ± 5.27	35.424-923.778 199.154 ± 140.21
Conocarpus erectus L. (348)	*Conocarpus*	461.41-2064.264 1368.53 ± 406.97	6.99-18.36 12.67 ± 3.21	38.39-264.67 134.064 ± 63.99
Eucalyptus camaldulensis Dehnh. (264)	Sufaida	483.35-1600.72 1078.21 ± 325.77	8.29-65.58 35.92 ± 17.10	54.01-3376.04 1241.71 ± 1018.29
Ficus religiosa L. (12)	Peepal	258.16-398.15 338.47 ± 47.53	27.609-57.273 36.795 ± 8.83	598.406-2575.042 1118.974 ± 569.43
Guaiacum Officinale L. (336)	Lignum Vitae	405.33-1821.54 1086.93 ± 422.25	7.15-51.72 29.10 ± 12.63	40.15-2099.78 789.73 ± 586.65
Mangifera indica L. (21)	Mango	344.02-444.84 391.45 ± 38.59	20.65-44.61 31.35 ± 7.35	334.63-1561.90 811.76 ± 377.62
Melia azedarach L. (15)	Bakain	312.69-447.54 373.95 ± 36.08	20.71-32.44 26.96 ± 3.86	336.70-826.02 581.48 ± 158.49
Syzygium cuminii (L.) (23)	Jamun	337.05-457.01 391.70 ± 36.10	20.52-44.54 32.92 ± 7.73	330.63-1557.45 895.59 ± 407.49
Tamarindus indica L. (21)	Imli	706-1176 995.23 ± 123.97	75.66-131.56 93.48 ± 13.530	4493.68-13586.80 6996.801 ± 2138.66

3.2 Tree Biomass and Carbon Stock:

The biomass and carbon stock parameters measure the ecological services of tree. High biomass leads to more carbon stock, which is important for the mitigation of climate change (Telila *et al*., 2024). Different tree species exhibit different growth habits, produce wood with varying Physical properties, and have a distinct tree form which in return influence their total biomass and carbon sequestration potential (Majid *et al*., 2023).

T. indica tops the AGB record of 8.537±3.37 tons by tree, this may go in line with the highest DBH and Basal Area ever observed for such species. Mean BGB is 2.219±0.87 tons, suggesting a huge structure underground to obtain such a large value of above-ground mass. *E. camaldulensis* has the second largest AGB (0.94±0.86tons) and BGB (0.245 ± 0..22 tons). The AGB to BGB is of fundamental importance for the stability and resources requirements of the tree. In most species, BGB constitutes roughly 20-30% of the AGB, as would be expected from an allometric relationship (Paul *et al*., 2018). *M. azedarach* and *C. erectus* have the least mean AGB (0.082±0.02 tons and 0.126±0.07 tons) which is followed by BGB (0.021±0.005tons, 0.0329± 0192tons) respectively. This reinforces their classification in the slender structural group with limited biomass accumulation and high buckling risk (Karlinasari *et al*., 2023).

E. camaldulensis, *G. officinale, M. azedarach and T. indica* consistently show larger AGB, TB, TC, and CO_2 equivalent values, representing their greater growth rates and carbon sequestration potential within university environment (Figure.2) Comparatively, other groups of species such as *C. erectus*, *M. indica* and *F. religiosa*, showed lower values in these parameters, indicative of less contribution to TB and associated TC. The findings of this study are in great agreement with facts and figures of recent research studies in Pakistan, including Islamabad (Ali *et al*., 2024) and Multan (Yasin *et al*., 2024), where *E. camaldulensis* and *M. azedarach* were also identified as the highest-performing species for carbon sequestration, while native species showed less effectiveness in urban plantation owing slower growth. The species having high potential for carbon stock and high growth rate with dense wood such as *E. camaldulensis* not only has physiological ability for high primary productivity but also showed high tolerance to different altered urban environmental settings, such as reduction in soil volume or a high pollutants level (Ali *et al*., 2024). The above results were the same as those for Karachi data except that this species had the highest average AGB, ACD and BCD. The positive relationship between DBH, tree height and AGB in all sites also strengthens the argument that urban plantation success is a function of adequate growth environment and popular species selection based on high wood density, faster growth rate (Ali *et al*., 2024). However, where expected AGB and carbon densities in some of the Karachi species were not met this is an indication about limitations urban trees could face such as air pollution soil compaction and drought which may limit their potential to uptake more carbon compared with more pristine or rural forest sites.

On the contrary, Table 1 shows that the mean TB values across the species varied remarkably ranging from a minimum of 0.104 tons for *M. azedarach* to a maximum value of 10.757 tons (*T. indica*). Three species only had a mean TB of more than 0.5 tons: *T. indica, E. camaldulensis and G. Officinale*. This means that these three taxa account for the majority of the biomass stored in the study area. The average carbon absorbed per *T. indica* is 5.378±2.12 tones and it becomes the most efficient species of carbon sink among the selected sample trees. Secondary sources of carbon sink are *E. camaldulensis* (0.594±0.54 tons) and G. officinale (0.355±0.32 tons). The rest of the species *M. indica*, *F. religiosa* and *Syzygium cuminii (L.)* sequesters in mean <0.2 ton C per tree considering an average carbon sequestration by *M. azedarach* is minimum (CS = 0.052±0.01 ton) forest stand level.

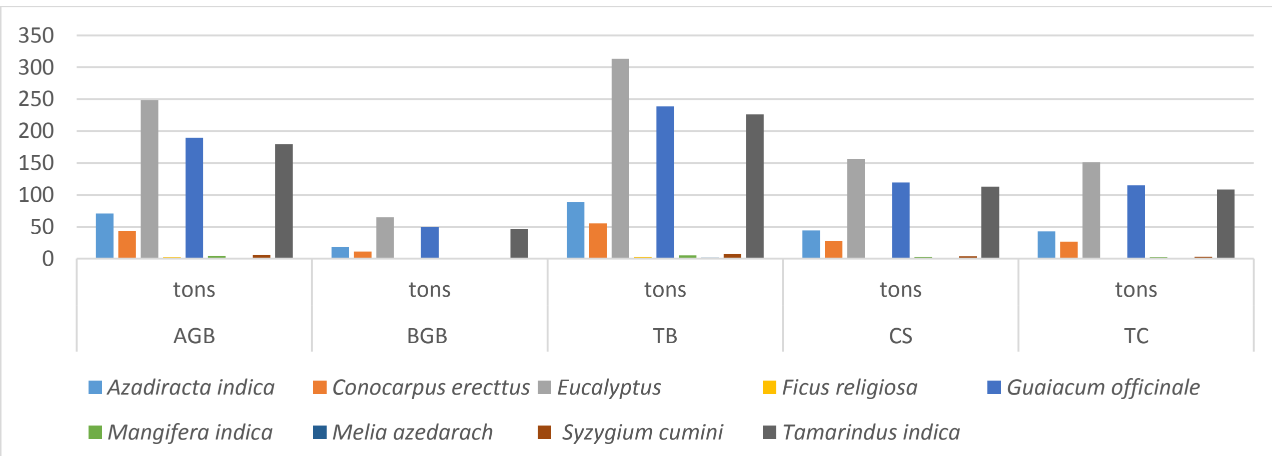

Fig 2. Total AGB, BGB, TB, CS and TC of various Tree species at University of Karachi.

The full categorization also confirmed that the selection of optimal species for tree management or planting to sequester maximum carbon will prioritise higher, denser species such as *T. indica, E. camaldulensis and G. officinale*. It was also shown that the very high coefficient of variation in SD among these top species for TB and CS metrics implies conservation effort should be directed to the largest, oldest individuals in these populations as they may represent much of the carbon stock (Tesfaye *et al*., 2020). On the other hand, the contribution of such species as *E. camaldulensis* that have a fast growth rate and high wood density is essential in maximizing carbon sequestration in replantation programs and agroforestry (Telila *et al*., 24). This also brings out the need to incorporate tree feature-specific attributes and growth traits for species when calculating carbon stock (Tesfaye *et al*., 2020). In addition, sequestration potential of *A. indica* and some other species in university campus was found to contribute greatly to the carbon pool (Ajani and Shams, 2016; Yasin *et al*.,2024), although findings have been observed varying among studies. This confirms the tree traits, ecological system, growth habit in carbon sequestration (Ajayi, 2021) and leads to variations among climate zones and species. The performance of studies of urban forestry in the context of climate change mitigation should be evaluated taking into account both species selection and site conditions (Parsa *et al*., 2019). Further research on growth rates and biomass distribution of urban trees under different environmental conditions would provide improved estimates of carbon sequestration by urban tree species, and hence more sustainable paths to green towns (Steenberg *et al*., 2023).

We observed high SD of *T. indica, E. camaldulensis and G. officinale* in BA, TB and CS that showed maximum variation in size among trees. In contrast, in species with the lowest SDs (*M. azedarach, S. cumini*) may form young or even managed populations. That heterogeneity brings out the need to account for tree structure and species identity in carbon stock estimations. Each individual-tree characteristic plays a critical role on overall carbon content (Mansingh *et al*., 2025). Moreover, the substantial overall carbon stock leading by few dominant species regardless of potential immaturity in individuals indicates that the selection of its populations would be crucial for preferring the best strategy for optimizing carbon sequestration (Choudhury *et al*., 2020).

Evaluation of CO_2 equivalent sequestration (Fig 3) showed that the total amount of 1657.355 tons is quite dominated by a small number of species. Among these species, the most effective is *E. camaldulensis* with 33.38%. When combined with *G. Officinale* (25.44%) and *T. indica* (24.06%), these three species are responsible for approximately 82.88% of the collective CO_2equivalent sequestered. The remaining six species contribute less than 18%, with *A. indica* (9.48%) and *C. erectus* (5.91%) making up most of that remainder. The four least effective species *S. cumini, M. indica, F. religiosa, and M. azedarach* are all marginal, collectively contributing less than 2% of the total, underscoring the critical need to focus carbon mitigation efforts on the highly dominant species.

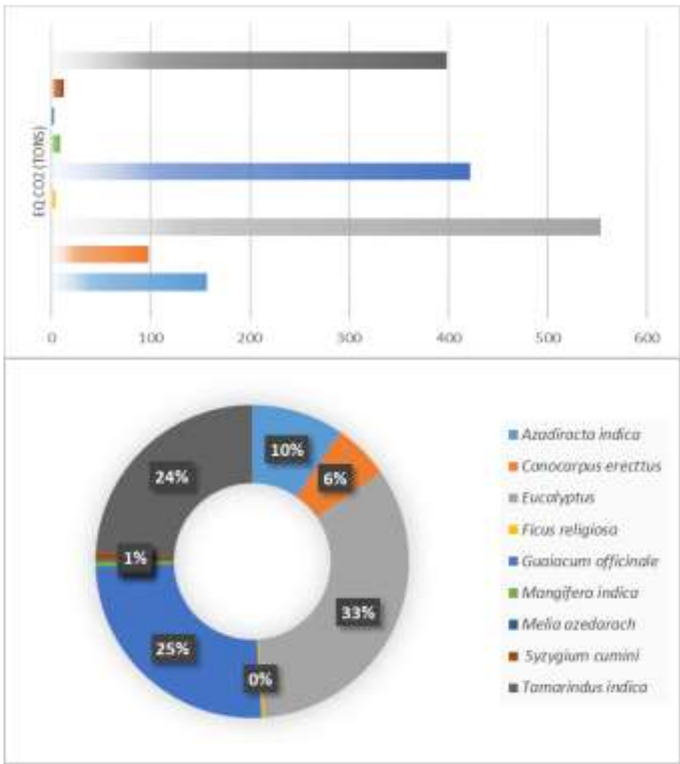

Fig 3. CO_2 equivalent sequestration of each species in this study.

3.3 **Analysis of species diversity**

The study also found the species diversity at the University of Karachi campus. These values collectively indicate that the campus exhibits low species richness and low species evenness among its nine identified tree families.

A lower Shannon Index value generally suggests lower species diversity. The reported value 1.602 in conjunction with the other indices, points to a relatively limited variety of tree species or an uneven distribution of individuals among the species present. Shannon Equitability Index measures how evenly distributed the species are. A value of 0.72, while not extremely low, supports the finding of low species evenness, meaning that some species are much more abundant than others. The Simpson Index (0.769) with probabilities of two random individuals being the same species was showed that there is a moderate to high dominance in tree population. This suggests that a few species, notably *T. indica*, which also exhibited the highest growth parameters, disproportionately contribute to the overall tree population. The diversity indices, together with growth parameters discussed in the results point toward certain ecologic processes and pattern of species distribution in campus. The patterns tend to a dominance by some species rather than representing a highly diverse and well distributed tree community. This is consistent with results from other institutional-owned lands where few dominant species contribute most to the carbon sequestration potential and overall biomass (Yasin *et al*., 2024). This prevalence of few species recorded with *T. indica* does have consequences for both ecosystem stability and the efficiency surrounding carbon sequestration concerns compared to those forests that are diverse (Sahoo *et al*., 2021). As such, species richness and evenness of those plant species promoting referral service (thus developing strategic monitoring strategies) could enhance the overall long-term ecological stability and carbon sequestration potential on the entire university campus (Romoke *et al*., 2018).

Conclusion

The study emphasizes on the considerable contribution of urban trees in carbon sequestration and reveals that different species have distinctive contributions to CO_2 emissions under an institutional setting such as University of Karachi. The findings provide critical empirical values for promoting the optimization of tree planting and campus greening, so as to further enhance the importance of high growth rate tree species with capacity of carbon sequestration. *T. indica, E. camaldulensis* and *G. Officinale* contributing more carbon sequestration and species has low diversity. Moreover, the low species diversity observed implies that sustainable management with the aim of increasing species richness and evenness might also be able to improve long-term ecological stability and carbon sequestration potential at the university campus as a contribution towards national/international environmental conservation objectives.

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