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PERFORMANCE OF DIFFERENT SIZED URBAN TREES FOR ABOVEGROUND CARBON SEQUESTRATION IN SEMI ARID ENVIRONMENT

AFSHEEN KHAN[1*], S. SHAHID SHAUKAT[2], TOQEER AHMED RAO[3] AND BUSHREEN JAHAN[3]

[1]*Moinuddin Ahmed Research Laboratory of Dendrochronology and Plant Ecology, Department of Botany, Federal Urdu University of Arts, Science and Technology Karachi, Pakistan*
[2]*Institute of Environmental Studies, University of Karachi, Karachi-75270, Pakistan*
[3]*Department of Botany, Federal Urdu University of Arts, Science and Technology Karachi, Pakistan*
[*]*Corresponding author: khanafsheen913@ymail.com*

Abstract

The study primarily focuses on the evaluation of carbon sequestration capability of seven tree species (*Conocarpus erectus*, *Azadirachta indica*, *Vachellia nilotica*, *Delonix regia*, *Parkinsonia aculeate*, *Cassia fistula* and *Guaiacum officinale*) commonly growing on roadsides and off-roadsides in Karachi city. The DBH (diameter at breast height) and height of trees of each species were recorded from two habitats (off-roads i.e., inner streets, including Karachi University Campus) and main roadsides in Gulshan-e-Iqbal area. The former habitat is only slightly polluted while the later is amply polluted. Soil samples were collected (from 0-30 cm depth) and analysed physically and chemically. The DBH distribution was examined using histograms. Using tree DBH and height data simple but authentic equations put forward by earlier workers were applied to estimate total biomass and carbon stocks accumulated by the tree species. The highest carbon stock was accumulated by *Azadirachta indica* because of its greater size and mostly older trees with high DBH.

Key words: ____

Introduction

During the process of photosynthesis, plants and cyanobacteria utilize light energy from the sun transforming it to chemical energy (stored as carbohydrates) taking up atmospheric carbon dioxide at a rate of 123 PgC/ yr. (1 PgC=10^{15} g of carbon) (Beer *et al*., 2010). It is estimated that 1950-3050 Pg of organic carbon is stored in the terrestrial ecosystems of the world that includes plant, animals other organisms whether living or dead both above-ground and underground (Prentice *et al*., 2001). Nonetheless, since the commencement of industrial revolution, global concentration of CO_2 has increased by 40 percent (Dlugokencky & Tans, 2015). Global increase in carbon emissions, temperature and pollution with a significant damage in ozone layer are chiefly the resultants of urbanization (Rantzoudi & Georgi, 2017). Green areas in the cities are remarkably facing increased pollution in which CO_2 behaves as a dominant greenhouse gas (Nowak *et al.,* 2002). Presence of trees is essential for urban areas as well as other regions in the biosphere (Zhao *et al*., 2018) so as to fix rising levels of carbon in the form of emissions, pollution from atmosphere through photosynthesis (Nowak *et al*., 2002). With regard to pollution tolerance and environmental sustainability perspectives, urban vegetation takes much importance rather than vegetation in non or less polluted biomes, claimed by Coutts *et al*., (2016) and Rantzoudi & Georgi, (2017). Physiology of trees governs a tremendous capability to purify the pollutants from air and can improve air quality (Jim, 1999; Alonzo *et al*., 2014; Seiferling *et al*., 2017). Plantation of urban trees have come up with human health gain, improvement in atmosphere of residential areas hence provides comfort to human life (Chen *et al*., 2015). Besides these, they consider some other instrumental functions can be performed by urban and street trees like mitigation in noise pollution, biodiversity conservation in populated areas that eventually leads to improvement of human health (Seiferling *et al*., 2017; Tallis *et al*., 2011).

Presence of street trees i.e. maintaining urban forests hold a great significance for provision of ecosystem services in busy cities by functioning as urban ecosystem. With the rising global population and technological advancements, climatologists, naturalists and ecologists are being focused on urban forestry development. Many studies have been undertaken to integrate the function and performance of urban forests, roadside vegetation, street trees etc including those of Zhao *et al*., (2018); Dobbs *et al*., (2011), Chen *et al*., (2015) and Nowak *et al*., (2013).

For mitigation of atmospheric characteristics and to put forward the improvement strategy, biomass measurement is regarded as a necessary tool that estimates carbon stocks (Bouvet *et al.,* 2018). With this in view, Nowak *et al.,* (2013) sampled different trees from urban sites and estimated carbon stock from their biomass. Singh *et al.,* (2015) claim biomass to be strongly correlated with features of tree structure and in particular, diameter at breast height (DBH) as a basic attribute. Zhang *et al.,* (2016) described equations for biomass evaluation from DBH as a critical value that is responsible for defining an ecosystem performance in both urban and natural forests. Logically the relation of biomass with carbon sequestration justifies as it conserve total organic matter as the main reserve of a plant body. According to Gazioglu *et al.,* (2015) and Gazioglu & Okutan, (2016), carbon sequestration refers to the storage of CO_2 that indirectly mitigates global warming. The CO_2 storage from atmosphere is reserved by the trees in the form of their biomass that is non-hazardous to living beings. Arya *et al.,* (2017) emphasized on tree biomass that the trees efficiently perform carbon sequestration which reduces pollution to a great extent. Subedi *et al.,* (2010) focused on tree canopies that are important to produce cooling effect on micro-climatic conditions by providing shade.

Among various environmental issues, global warming is undoubtedly the leading one. Global warming is drastically increasing due to anthropogenic activities and urbanization. For the upgradation of life standards, it can be a valuable approach to improve environmental standards for healthy living, hence for this purpose trees are the primary source. Many studies are now focusing towards the evaluation of role and magnitude of urban trees in a busy and unnatural environment like Nowak *et al.,* (2013), Arya *et al.,* (2017) , Tang *et al.,* (2016); Raciti *et al.,* (2014). Tang *et al*., (2016) examined street trees and their magnitude to offset anthropogenic carbon emissions. Therefore, for the study of urban environments and to help improve the environment, it is necessary to study the performance of planted trees in populated and polluted areas of the cities.

Like other countries, Pakistan is also experiencing the pressure of pollution and increased population leading to environmental degradation. Karachi being Pakistan's biggest and busiest city can be chosen as an excellent example facing such problems. Therefore, the aim of this study is to develop an estimation of current performance trees growing along on either side of streets and traffic islands in a highly polluted environment and evaluate their capability of carbon sequestration.

Materials and Methods

Karachi city that lies in the southwest of Pakistan, climatically belongs to semi arid region. It receives 174.6mm average annual rainfall while mean maximum and mean minimum temperatures are 35°C and 24°C respectively.

Karachi was selected for being the most industrial and populated urban city in Pakistan (Fig. 1). As the urbanization expanded, it was at the cost of elimination of suburban green areas in the city. As shown in the map (Fig. 1), few green patches remained in the city. Sampling was conducted in three busy streets of Karachi and in three off road sites. The sites selected for sampling were: 1) inside and outside areas of Karachi University, inside areas were farther from roads while outside areas comprised of main roads that experience traffic and construction work frequently; 2) Main Rashid Minhas road for roadside samples while for off-road samples, residential areas were preferred; 3) Residential and road facing areas in Gulistan e Johar and areas near Safari Park. Seven tree species were frequently found namely *Conocarpus erectus* L., *Azadirachta indica* A. Juss, *Vachellia nilotica* (L.) P. Hurter & Mabb., *Delonix regia* (Bojer) Rafin, *Parkinsonia aculeata* L., *Cassia fistula* L. and *Guaiacum officinale* L. Trees were measured by their diameter and height using by measuring tape and a hypsometer respectively. Tree age was estimated by aid of Department of Parks, District East Karachi, Sindh, from the records of tree plantation year. All sampled species are fast growing, can tolerate arid environment in common, the specific features are briefly mentioned in Table 1.

Using tree DBH and height data simple but authentic equations put forward by earlier workers (He *et al*., 2007; Vieilledent *et al*., 2012; (Nowak & Crane, 2002; Tang *et al.,* 2016) were applied to estimate total biomass and carbon and CO_2 stocks accumulated by the tree species.

The formulae applied for calculation of biomass and carbon stock in trees are as follows:

D = diameter measured in cm, D= D × 0.3937 in
H = Height in meters (m) or H = H × 3.28084 ft
Wa = above ground green weight of tree (in lbs or Kg)
For D<11 in (=27.94 cm)
$Wa = 0.25\, D^2\, H$ *lbs (or Wa × 0.453592 Kg)*
For D ≥ 11 in (=27.94 cm)
$Wa = 0.15\, D^2\, H$ *lbs or Wa × 0.453592 Kg*
W_{TG} *= Total green weight =Wa × 1.2 Kg*
W_{TD} *= Total dry weight =* $W_{TG} \times 0.725$ *Kg*
W_{carb} *= Carbon sequestered =* W_{TD} *x 0.5 Kg*
W_{CO2} *= Carbon dioxide sequestered per tree =* W_{carb} *x 3.663 Kg*

The estimated carbon and tree attributes were correlated, subjected to ANOVA and regression models were applied using Past3 (Hammer, 2018).

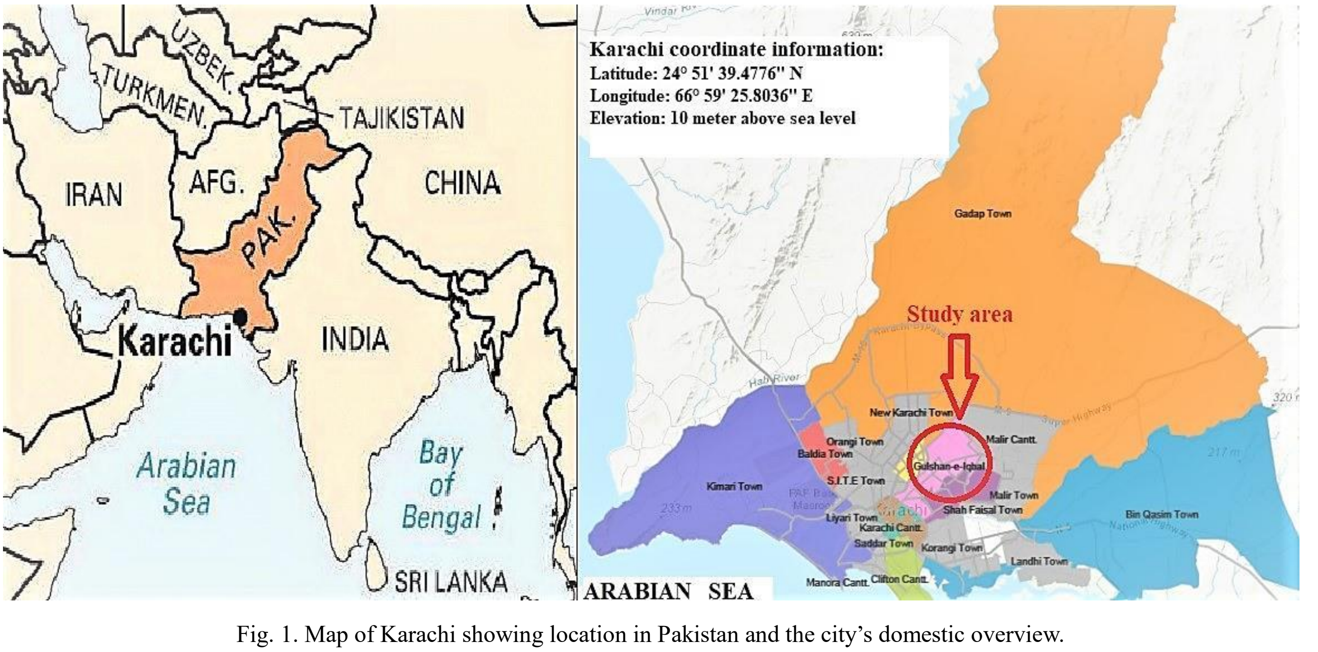

Fig. 1. Map of Karachi showing location in Pakistan and the city's domestic overview.

Table 1. Details of selected tree species frequently found growing along main busy roadsides and off-road streets in the residential areas.

Species	Sampled areas		Importance
	Off-road	Roadside	
Conocarpus erectus	UoK Green pockets among departments inside campus	Trees along the roads outside campus	Tropical and sub-tropical species frequently used for landscaping. Also used for phytoremediation, allopathic, homeopathic and other traditional medicines. Planted in a wide range of soil types (Rehman *et al*., 2019).
Azadirachta indica	UoK Green pockets among departments inside campus	Trees along the roads outside campus	Widely used in herbal medicines, used as herbicide, fungicide. Combat against deforestation, desertification, soil degradation Ogbuewu *et al*., 2011).
Vachillea nilotica	MRR Trees present in the residential areas in the locality	Main road facing trees	Well known urban tree species for providing shade, improvement of soil, climate mitigation. Provides fruits, fodder, gums etc. A beautiful for plantation in parks (Amadou *et al*., 2020).
Delonix regia	GeJ Trees present in the residential areas in the locality	Main road facing trees	Tropical with wide ecological amplitude. Ornamental. Tolerate wide range of pH, soil types (PIER, 2009).
Parkinsonia aculeata	MRR Trees present in the residential areas in the locality	Main road facing trees	Spread of species from grasslands to semi arid lands. Used for weed and pest management, as herbicide in many countries (Katende *et al*., 1995).
Cassia fistula	SfP Trees present inside the park	Trees present outside the park facing main road	Deciduous tree species, efficient in growing drought and temperature extremes. Widely distributed in African, South Asian and South American regions. Well known for its wood quality, phytochemicals used in various medicines to treat stomach and skin problems (Verma, 2016).
Guaiacum officinale	UoK Green pockets among departments inside campus	Trees along the roads outside campus	Tropical species used for edible and medicinal purposes. In addition a good choice for landscaping plantation Well known as street tree. Resins produced by the species are used for various economical purpose (Howard, 1988).

Where, UoK = University of Karachi, MRR = Main Rashid Minhas Road, GeJ = Gulistan-e-Johar, SfP = Safari Park

Results

Study area consisted of three sites having a comparison of busy roads and off roads (Fig. 1) from where at least 30 trees of frequently grown species were selected for diameter size measurement (DBH) and height. Histograms were constructed to differentiate size classes occupied by sampled trees from both sites (Fig. 2). The average lowest size was recorded from *Parkinsonia aculeata* (13.85±0.2 cm and 12.8±0.3 cm from off-road and roadsides respectively), distribution was normal as the middle sizes were at their highest peak. Maximum sizes were observed in *Azadirachta indica* trees obtaining average diameter sizes 45±10 cm and 35.73±7.2 cm from off-road and roadsides respectively, the distribution fit was inclined towards younger sizes from both the sites. The other species also followed normal distribution fits following a regular growth pattern in Dbh sizes. The average sizes with respect to the species were illustrated in Table 1 while frequency in size distribution is demonstrated in Fig. 2.

Among the examined species, *Azadirachta indica, Vachellia nilotica, Delonix regia, Cassia fistula and Guaiacum officinale* trees attained greater biomass and consequently stored higher amount of carbon from both sites (Fig. 3). Off-road areas were seen complimentary for the growth of *Azadirachta indica* trees by attaining greater biomass (1952.66±744.8 kg) and stored carbon (3583±1366 kg) while 987.3±372.4 kg and 1811±770 kg of biomass and carbon sequestered from roadsides respectively (Table 2, Fig. 3). *Azadirachta indica* trees were mostly older and perhaps showed greater efficiency in carbon storage mechanism as their average age was approximated in the range of 20-40 years from both sites bearing an average growth rate *i.e.*,1.5±0.67 cm/year and 2.38±0.5 cm/year from off-raod and raodsides respectively. Highest growth rate achieved by *Guaiacum officinale* (0.74±0.03 cm/year) from off-roads while *Parkinsonia aculeata* responded well on the roadsides by attaining growth at the rate of 0.6±0.01 cm/year (Table 2).

Relationship between carbon sequestered (kg) corresponding to their DBH sizes is presented in Fig. 4. *Delonix regia* and *Parkinsonia aculeata* produced non-significant relationship while *Conocarpus erectus, Vachellia nilotica, Cassia fistula* and *Guaiacum officinale* attained highly significant relationship between diameter size and CO_2 sequestered ($p<0.001$) from off-raod sites (Table 3). A similar pattern observed from roadside as all the species produced significant relationships except that of *Parkinsonia aculeate* (Table 3).

ANOVA has resulted into a significant ($p<0.05$) relationship in the attainment of biomass of trees from both the sites i.e., off-road and roadsides. While highly significant difference ($p<0.001$) appeared in the carbon sequestration amount by the trees from both sites (Fig. 5). The average biomass of all sampled trees cumulatively possessed significant relationship with the average carbon sequestered in both sites. Thus it is clear from the findings by averaging overall biomass gain and carbon sequestered from the trees of both sites regardless of species that off-road trees attained a remarkable carbon consumption rather than that of road facing trees.

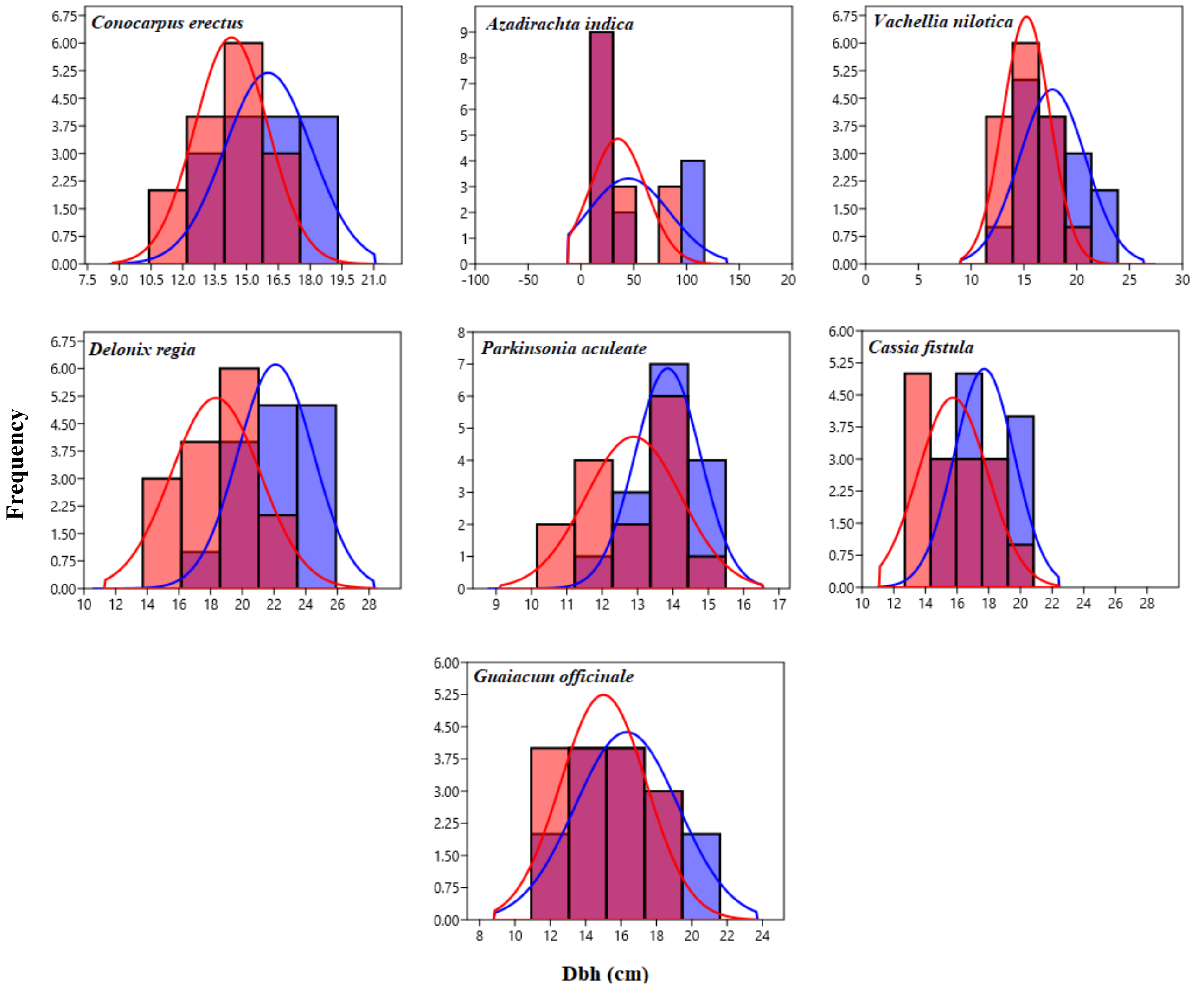

Fig. 2. Histograms showing distribution of diameter size classes occupied by off-road trees (indicated in blue color), road-side trees (indicated in orange color), overlapped size classes (overlapping indicated in maroon colored bars) diameter size classes.

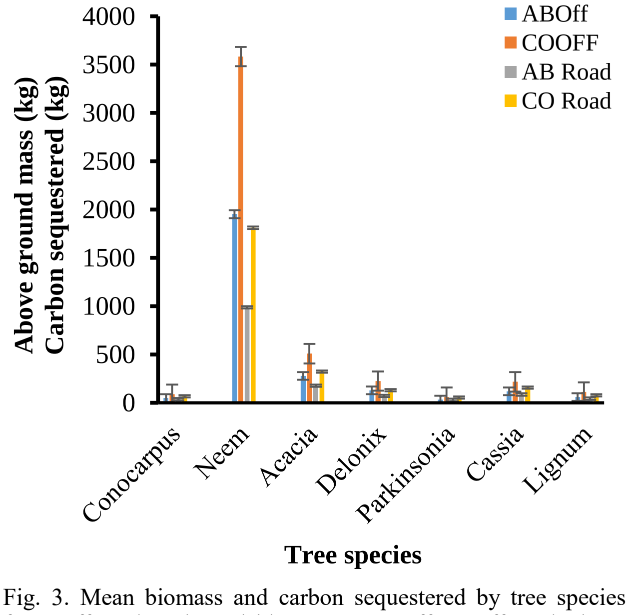

Fig. 3. Mean biomass and carbon sequestered by tree species from off-road and roadside areas. ABOff = Off-road above ground biomass, COOff = Off-road Carbon sequestered, AB Road = Roadside above ground biomass, CO Road = Roadside Carbon sequestered.

Soil variables from the sample sites showed approximately similar values in their chemical and edaphic nature as presented in Table 4. Soil conditions are an obligatory factor for consideration of tree response in the concerned environmental conditions. Being in an arid environment, the soil characteristics were in a promising state to promote vegetation.

Discussion

World is in the process of conversion of habitat i.e., from natural to unnatural as a consequence of expansion in urbanized areas by destructing forests and clearing of natural vegetation. These urban areas are unintentionally being served as a source of carbon hence particularly vegetation of these areas is usually ignored for carbon cycle determination (Churkina, 2008; 2016). However, the ecologists are now focusing on this global issue as urban trees have now recognized as carbon sinks (Tang *et al.*, 2016). Thus, it is a better approach to collect carbon inside trees in the form of tree biomass rather than human body by compromising with health. According to Idso *et al.*, (2002) and Lovett *et al.*, (2002), urban trees bear higher concentration of carbon and nitrogen as well as high temperature exposure than rural trees. Carriero & Tripler (2005) identified nitrogen and carbon based by-products effectively utilized by urban trees while Gregg *et al*., (2003) and Tang *et al*., (2016) claimed urban trees more efficient to utilize atmospheric by-products than rural trees. Our study configured the efficiency of urban trees by making a comparison between much exposed trees (roadside) to pollution with relatively less exposed trees (off-road).

Current study utilized density, basal area and height of frequently found tree species in the most busy areas in Karachi city. Among the investigated trees, *Conocarpus erectus* showed stable growth in both the sites. *Azadirachta indica* collected highest amount of carbon from off-road sites with higher diameter of trees. *Azadirachta indica* is a well known species of arid environment but has been discovered for its adaptive pattern against pollution under the light of current findings. *Vachellia nilotica* has produced greater growth in Off-road sites while roadside sites possessed lower growth and carbon stock by the species. However, the difference in growth is well expected being not too far lowered showing acceptance of urban environment by *Vachellia nilotica*. Peng *et al*., (2001) and Mc Hale *et al*., (2009) sampled urban trees and compared their DBH-Height and carbon sequestered equation with rural trees. They discovered greatest DBH gain in urban trees as a consequence of which greater carbon storage is achieved.Nativity of the species has been reported in saline habitats, moreover, the species also considered for plantation in degraded soil (Bargali & Bargali, 2009). Pandey *et al.,* (2000); Nair (1993); Palm (1995) suggested *Vachellia nilotica* being efficient in nutrient cycling by their leaf litter even in harsh climatic conditions and good for protection of land from soil erosion. Arid and saline soils are higher contributors of Ca, Mg, K (David *et al.,* 1982) hence the species has greater capability to tolerate pH fluctuations and ionic gradients. *Vachellia nilotica* is a greater contributor of ammonia in the form of NH_4-N for being a leguminous species (Hussain *et al*., 1990). In our findings, soil has higher degrees of Mg, Ca, K and Na from roadsides which can be adaptable by some tree species, hence in addition to *Vachellia nilotica, Parkinsonia aculeata* has also reported by some workers for its greater efficiency against pollutants rich soils like Partsons & Cuthbertson, (1992); Webb *et al*., (1984); Singh (1989); Luna (1996). *Parkinsonia aculeata* thrived within a wide range of pH and salinity as our findings stated by thriving under arid conditions with lowest carbon sequestered amount in both sites. *Cassia fistula* and *Guaiacum officinale* is reported as a slow growing coastal species native to South America (Howard, 1988; Record & Hess, 1943) and has a strong tolerance mechanism to survive in poor soil (Schubert, 1979).

In the light of current findings, *Conocarpus erectus* being a fast growing species with an adequate DBH size, sequestered considerable amount of carbon. Although, *Vachellia* trees associated with roadsides were younger than other trees but their response against urbanization was positive may be due to more adaptive capability of the trees at this stage. *Azadirachta indica* performed relatively slower at highly polluted areas whereas in the less exposed areas, the species could be the much suitable for plantation. *Delonix regia, Cassia fistula* and *Guaiacum officinale* rather competed well in urban sites while *Parkinsonia aculeata* survived at a lowest rate which is quiet unexpected from the species as it was reported to be a good soil binding resource and can tolerate sandy soils (Abohassan *et al.,* 1978; Mahmoud & El-Sheikh, 1981; Hocking, 1993).

Azadirachta indica being older among other examined trees, possessed greater suitability to the environment with regard to carbon sequestration compared to other species studied. Nevertheless, relatively few studies have been conducted on urban tree growth and carbon storage efficiency, climatic studies have now pointed about the seriousness of this issue. Thus still there is urgent need to explore activity, urban plantations of prespecies are not only useful for carbon sequestration but absorb a number of pollutants from both atmosphere and contaiminated soils, have cooling effect on urban dwellings and structures and also provide much needed suitable habitats and microhabitats for increasing the biodiversity (McPherson *et al*., 2005; Nowak *et al*., 2006; Oberndorfer *et al*., 2007).

Table 2. Mean DBH (cm) and carbon sequestered by seven frequently found species from off roads and roadsides in urban areas.

Species	Mean DBH (cm)	Mean age (years)	Mean growth rate (cm/year)	Carbon sequestered (kg)
			Off-road	
Conocarpus erectus	16.02 ± 0.5	15 ± 2	1.07 ± 0.03	87.4 ± 9.4
Azadirachta indica	45 ± 10	30 ± 2	1.5 ± 0.67	3583 ± 1366
Vachellia nilotica	17.69 ± 0.8	16 ± 2	1.1 ± 0.05	508 ± 65
Delonix regia	22.1 ± 0.6	22 ± 3	1 ± 0.03	224.9 ± 19
Parkinsonia aculata	13.85 ± 0.2	21 ± 2	0.65 ± 0.01	58.4 ± 2.5
Cassia fistula	17.71 ± 0.5	20 ± 2	0.9 ± 0.02	216.7 ± 19
Guaiacum officinale	16.32 ± 0.8	22 ± 2	0.74 ± 0.03	110.8 ± 12
			Roadside	
Conocarpus erectus	14.29 ± 0.4	15 ± 2	0.95 ± 0.02	67.8 ± 4.8
Azadirachta indica	35.73 ± 7.2	20 ± 2	2.38 ± 0.5	1811 ± 770
Vachellia nilotica	15.24 ± 0.6	16 ± 2	0.95 ± 0.04	323 ± 40.5
Delonix regia	18.32 ± 0.7	22 ± 3	0.83 ± 0.03	130.5 ± 12
Parkinsonia aculeata	12.8 ± 0.3	21 ± 2	0.6 ± 0.01	54.5 ± 2.3
Cassia fistula	15.7 ± 0.6	20 ± 2	0.78 ± 0.03	157.3 ± 15
Guaiacum officinale	15 ± 0.6	22 ± 2	0.7 ± 0.03	78 ± 7

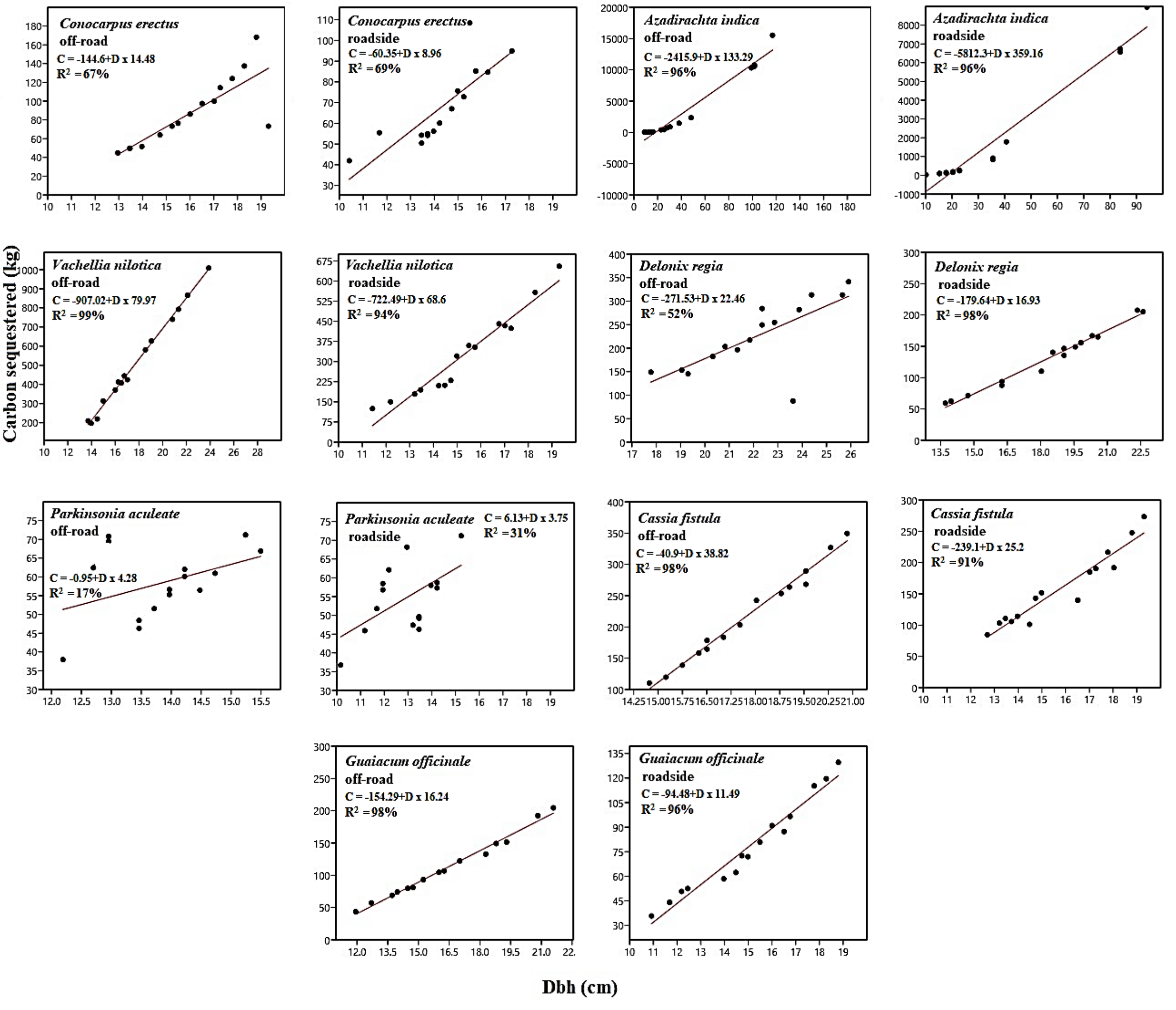

Fig. 4. Linear regressions for off-road and road-side between DBH (cm) and carbon sequestered (kg) by *Conocapus erectus*, *Azadirachta indica, Vachellia nilotica, Delonix regia, Parkinsonia aculeata, Cassia fistula* and *Guaiacum officinale*.
Where Carbon sequestered (C) is taken as y axis mentioned in regression model.

Table 3. Regression correlation between tree diameter and total carbon sequestered by seven frequently found species from off- roads and roadsides in urban area of Gulshan-e-Iqbal area.

Species	R value	Significance level	F value	SE of Regression equation
		Off-Road		
Conocarpus erectus	0.81	p<0.001	26.55	± 1.22
Azadirachta indica	0.98	p<0.001	316.83	± 8.02
Vachillea nilotica	0.99	p<0.001	246.81	± 0.22
Delonix regia	0.72	ns	14.36	± 1.71
Parkinsonia aculeata	0.41	ns	2.11	± 0.88
Cassia fistula	0.99	p<0.001	882.24	± 0.24
Guaiacum officinale	0.99	p<0.001	92.83	± 0.33
		Roadside		
Conocarpus erectus	0.82	p<0.001	28.43	± 1.01
Azadirachta indica	0.98	p<0.001	345.68	± 5.53
Vachillea nilotica	0.97	p<0.001	210.37	± 0.55
Delonix regia	0.99	p<0.001	688.51	± 0.40
Parkinsonia aculeata	0.56	ns	7.97	± 1.16
Cassia fistula	0.95	p<0.001	138.78	± 0.67
Guaiacum officinale	0.98	p<0.001	312.84	± 0.49

Mean square of error (SE)

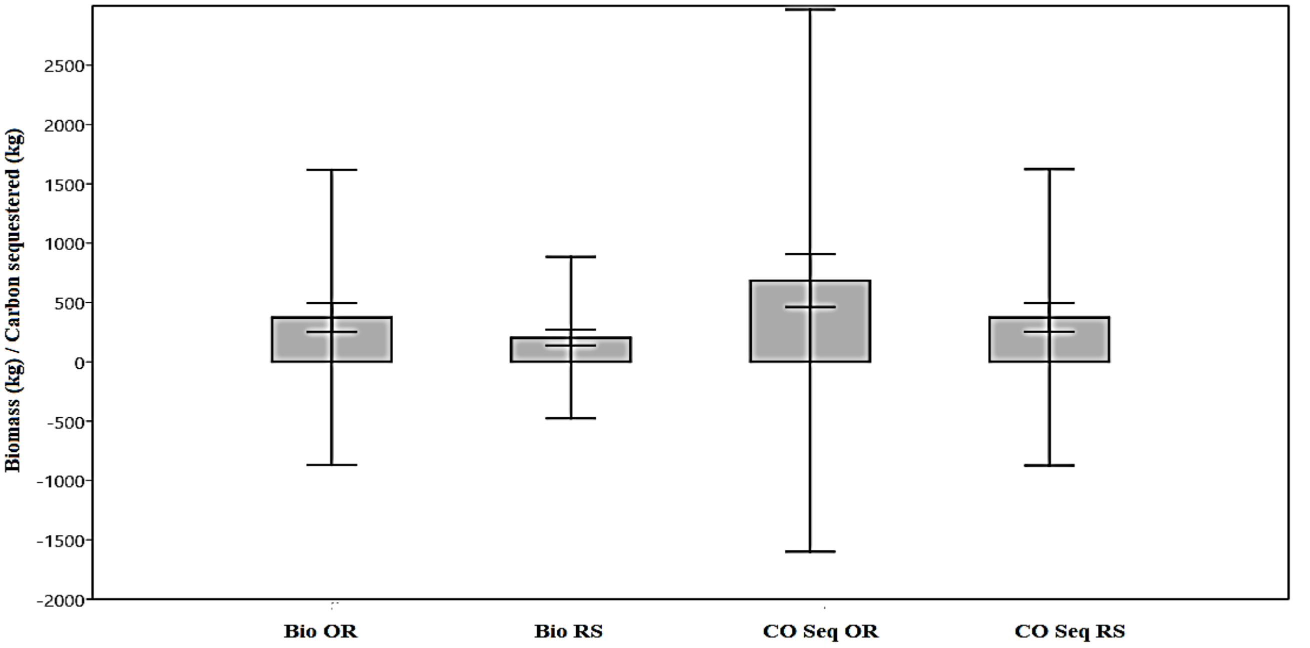

Fig. 5. Presents difference in average gain in biomass (kg) and carbon sequestered (kg) of all sampled tree species combined from off-road (OR) and roadside (RS) respectively. Where, Bio OR and Bio RS represent Biomass of off-road and roadside trees, CO Seq OR an CO Seq RS present Carbon sequestered by roadside trees respectively.

Table 4. Mean values of soil variables recorded from roadside and off-road localities.

Soil variables	Roadside	Off-road
pH	7.63 ± 1.3	7.38 ± 1.1
WHC %	25.5 ± 4	29.31 ± 3
OM %	O.35 ± 0.04	0.42 ± 0.02
Total Kjel N	0.48 ± 0.02	0.50 ± 0.01
Ex Ca^{++}	59.50 ± 7	46.28 ± 5
Ex Mg^{++}	44.17 ± 5	36.10 ± 4.5
Ex K^{+}	26.33 ± 3	22.40 ± 2
Ex Na^{+}	204.36 ± 21	186.50 ± 17
Soil Texture	Sandy loam	Loamy sand

Ex = Exchangeable, Kjel = Kjeldahl, OM = Organic matter, WHC = Water-holding-capacity

Conclusion

From Gulshan-e-Iqbal area seven frequently grown species were evaluated for their carbon storage efficiency and compared with less exposed trees of same species to polluted area (off-road). The magnitude of carbon stock among the species was comparable from both kinds of areas. The trees were of different sizes and ages and their average carbon stock efficiency was recommendable for further plantation of these species in urban areas. Tree plantation is necessary in urban areas but it needs proper management and selection of appropriate species. There is need for further determination of physiological role of trees in urban environment as well as exploration of more tree species that are suitable in the respective climate, soil type and state of pollution. However, there is a significant relationship between size class and carbon except Delonia and Parkinsonia trees.

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