CIVIL AND ENVIRONMENTAL ENGINEERING REPORTS

E-ISSN 2450-8594

CEER 2024; 34 (2): 0224-0241
DOI: 10.59440/ceer/189915
Original Research Article

RELATIVE ANALYSIS FOR CARBON SEQUESTRATION POTENTIAL OF PROMINENT PRIVATE AND PUBLIC GREEN SPACES IN BENGALURU, INDIA

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Abstract

With the advent of Climate Change and Global Warming, highly populated urban spaces are becoming more prone to various Environmental disasters. While forest are good sinks of CO_2, it is highly impossible to introduce them into urban-level planning. In this context, nurturing Urban Green Spaces within cities, can serve well to perform the regulatory functions just like forests do. However, it is also imperative that their inception, must also ensure effective carbon sequestration. The objective of current research includes determination of carbon sequestration value for various 'tree' species, which eventually would serve to identify species with potential to serve better in Strategic Climate Sustainable Township Guidelines. To accomplish this objective, firstly three observatories (Richard's Park, BMSIT&M Green Campus, and Lalbagh Botanical Garden) having distinct floral diversity were selected. Further, physical data collection was undertaken at these observatories and employed for biomass computation viz. 'Biostatistics-based Allometric' equation. Statistical Validation of data was accomplished viz. Multiple Linear Regression Modelling and One-way ANOVA. The average value of carbon sequestered (in tonnes per species) was found to be 20.13, 0.727 and 0.292, at Lalbagh Botanical Garden, Richard's Park, and BMSIT&M, respectively. Upon comprehensive evaluation, it was found that best three species offering high carbon sequestration potential are *Eucalyptus grandis*, *Eucalyptus globus* and *Samanea saman*. These species would hence be keystone species that could play a potential role in naturally lowering CO_2 levels in intra-urban spaces. These species would serve well in empowering Green Spaces to behave as Urban Cool Islands, to combat Urban/Global Warming.

Keywords: allometric, global, warming, urban, sequestration, distometer, carbon

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1. INTRODUCTION

The Anthropocene era is fast witnessing several environmental disasters, with most of them having cities as the epicentre [1]. These profound undesired events are presently being attributed to human-induced Climate Change, owing to accelerated global warming and urban warming [2]. Consequently, worldwide the ambient air temperature, near-surface air temperature and surface temperature of urban spaces has borne trends of constant increase [3].

This has begun to have irreversible impact on the urban ecology as well [4], [5]. Herein, there has been a consensus that under the guise of urbanisation; the loss of natural surfaces, increasing built-up spaces and rising levels of various greenhouse gases is further triggering severe climatic modifications across urban spaces [6], [7], [8]. Furthermore, there is an agreement that this in turn have worsened the pollution levels, which has further compounded significantly to increase the ambient temperature levels and atmospheric Carbon-di-oxide CO_2 [9], [10].

'Carbon footprint' as an environmental indicator has been instrumental in decoding the contribution of CO_2 equivalents emitted directly or inadvertently at an Individual or Societal, or Industrial levels. Consequently, the solutions to reduce carbon footprint are also worked upon in terms of individual carbon footprint, product footprint and corporate footprint [11]. However, the remedial solutions are more on the lines of corrective measures, rather than preventive measures [12]. These includes indulgence on renewable energy resources, green techniques, policies/subsidiaries etc. [13], [14]. However, these solutions though sincerely attempting to aid in mitigating global warming effect, are still far-fetched on account of lack of technical know-hows, political interventions, disruptive technologies etc. [15]. Hence, if large-scale carbon capture projects were to be implemented, it would take several decades to witness a defence. Also, a minute error in the transportation of captured carbon would invariably lead to catastrophic environmental consequences, beyond imagination.

To overcome the lacunae of afore-mentioned solutions, the present study addresses the potential role played by trees in naturally combatting the rising levels of CO_2. This is because CO_2 is naturally removed into the standing forests, forest under-storey plants and leaf and forest debris; by the process of Terrestrial Carbon Sequestration [16].

India as a nation alone generates 8.2% of world's CO_2, wherein its annual quantum of generation is around 4 billion metric tons of CO_2 per year. Consequently, India would require more than 20000 crores per year to treat this quantum [17]. In this context, a well drafted policy in-place with earnest implementation and governance could be benevolent in the mitigation of about at least 25% of the desired global CO_2 levels. This can be achieved via reduced deforestation (42%), adequate forest management (31%) and afforestation (27%). Even without any direct carbon sequestration policy in action, forests are naturally trapping about 4 billion tonnes of CO_2/year [18].

Consequently, when forest-fires or deforestation occurs, most of these stored carbon gets vented back each year into the atmosphere in the form of CO_2, further strengthening global warming and climate change. Therefore, the most obvious solution across the globe to counter the rising CO_2 levels would be to conserve the natural inherent forests as they behave as excellent CO_2 sinks [19]. However, it is also most improbable that forests can ever be embedded into urban-level planning [20]. Hence, the best solution in this context would be to imbibe the functions of forests into town planning aspects would be by increasing the number of green spaces and their expanse, strategically within urban environ [21].

However, sadly today most of the lung-spaces have shrunk to the rising glass and concrete facades across the globe [22], [23]. Bengaluru is no exception and is presently facing the brunt of rampant deforestation and urbanisation [24]. Hence, this study is an attempt to enlighten the society, by highlighting the role played by urban green spaces of Bengaluru in carbon sequestration [25].

Henceforth, strategically conserving numerous ‘urban’ private and public green spaces within cities, can serve well to perform the ‘climate’ regulatory functions just like forests do. However, in this context, it is also imperative that their inclusion, must also ensure effective carbon sequestration. During the literature review it was observed that the studies on estimating carbon sequestration potential have been conducted focusing on individual sub-plots of smaller sample size and not the entire area [26], [27], [28], [29]. Thereby, none of the existing research have oriented the outcome towards designing its effective potential and need for similar spaces [30]. As part of novelty, the current research attempts to overcome these challenges, by ascertaining both the quantitative and qualitative facets. To plug the gaps in research, the present study attempts to achieve the following objectives.

- ✓ To undertake reconnaissance survey, for the identification of the prominent Public and Private Green Spaces in the city of Bengaluru.
- ✓ To shortlist three urban green spaces as potential observatories for detailed study.
- ✓ To compute the overall carbon sequestration potential across each observatory.
- ✓ To delineate the species based on their individual carbon sequestration potential.
- ✓ To validate the data (parameters) statistically viz. Multiple Linear Regression Modelling and one-way ANOVA.

2. METHODOLOGY

The first objective was accomplished viz. visits to various prominent green spaces which included Cariappa Park, Jubilee Park IISc, Coles Park, Hebbal Lake Park, JP Park, Bannerghatta National Park, Jayamahal Park, MN Krishna Rao Park, Bugle Rock Park, Madhuvana Park, General Aiyappa Park and Cubbon Park etc. Figure 1 highlights the Google image presenting the various urban green spaces explored as part of the Reconnaissance survey. The second objective was accomplished by shortlisting three major (2 public and 1 private) urban green spaces across Bengaluru. The selection criteria encompassed high-species diversity and variable physical Area. The shortlisted observatories were namely BMS Institute of Technology and Management (13.1342°N, 77.5694°E), Lalbagh Botanical Garden (12.9494°N, 77.5847°E) and Richard’s Park (13°0'20.9088"N, 77°36'58.59"E). The physical location of these observatories within the city of Bengaluru has been depicted in Figure 2 to demarcate the distribution and essentially the proximity of the green spaces from each other.

The 1st observatory, BMS Institute of Technology and Management (herein after referred to as BMSIT&M) is a private engineering college in Bengaluru and is located on SH-9. Figure 3 depicts the birds-view of BMSIT&M and its surrounding landscape viz. Google Imagery. It is a 21-acre campus with green space of around 3.27 acres with a large diversity of species. Figure 4 displays a photographic close-up view of the species seen in the green campus of BMSIT&M. The 2nd observatory, Lalbagh Botanical Garden (created in 1760) is a lush green paradise with an area of 240 acres in the heart of the city with trees that are over 100 years old. Figure 5 depicts the birds-view of Lalbagh Botanical Garden and its surrounding urbanised landscape viz. Google Imagery. It has a net area of 131.55 acres with an adjoining large waterbody. Figure 6 showcases a photographic close-up view of the species in the Lalbagh Botanical Garden.

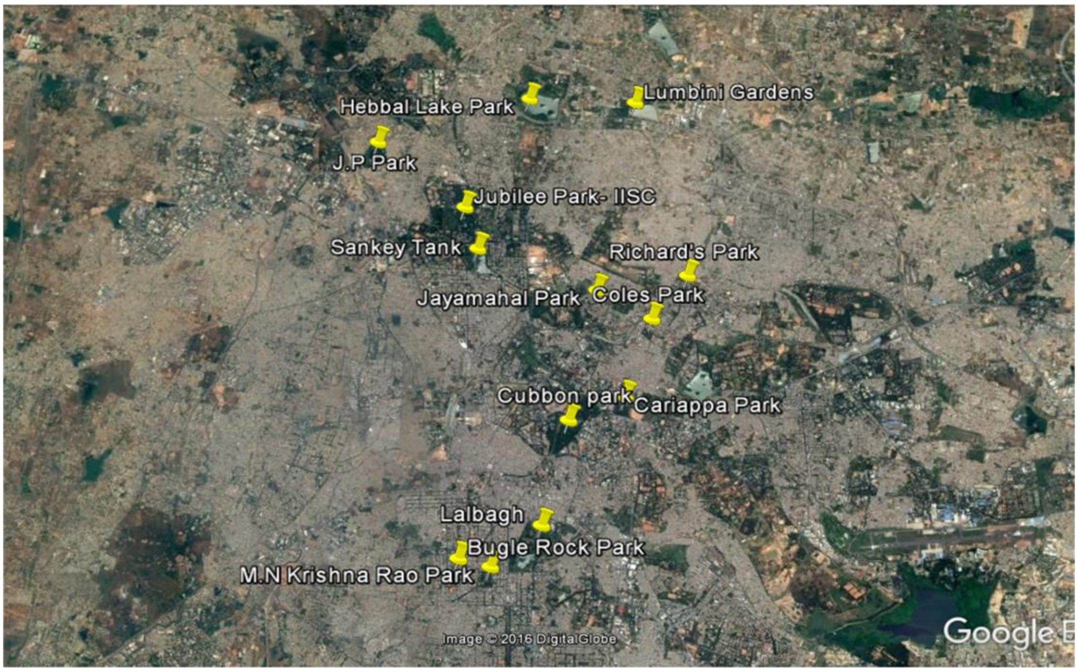

Fig. 1. Google Earth Image showcasing location of major public green spaces of Bengaluru

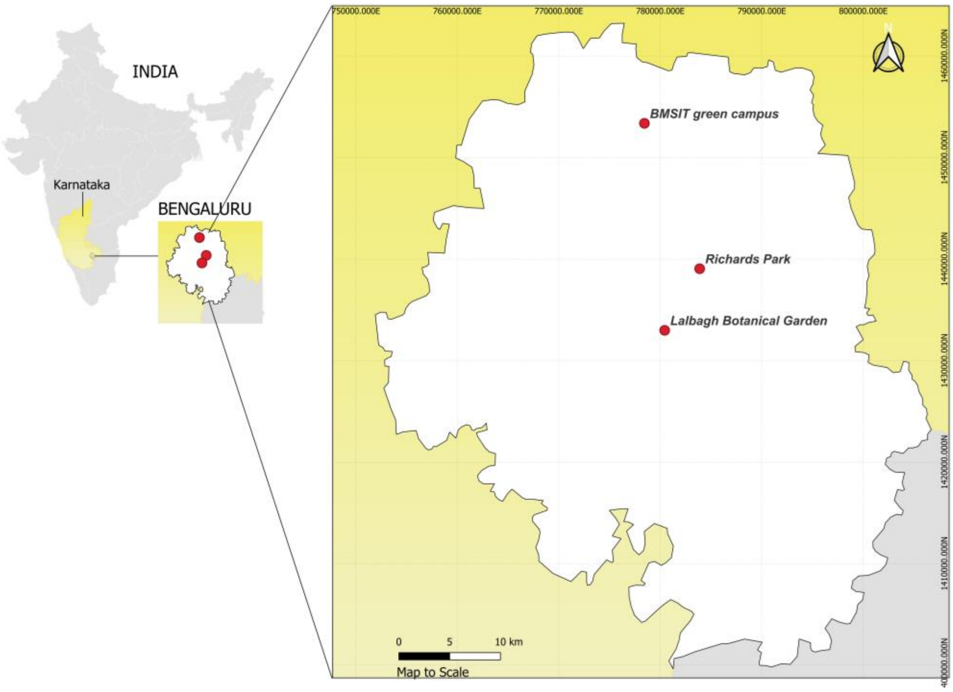

Fig. 2. Location of shortlisted observatories

Fig. 3. Google Imagery of BMSIT&M

Fig. 4. Photographic close-up view of BMSIT&M Green Campus

Fig. 5. Google Imagery of Lalbagh Botanical Garden

Fig. 6. Photographic close-up view of Lalbagh Botanical Garden

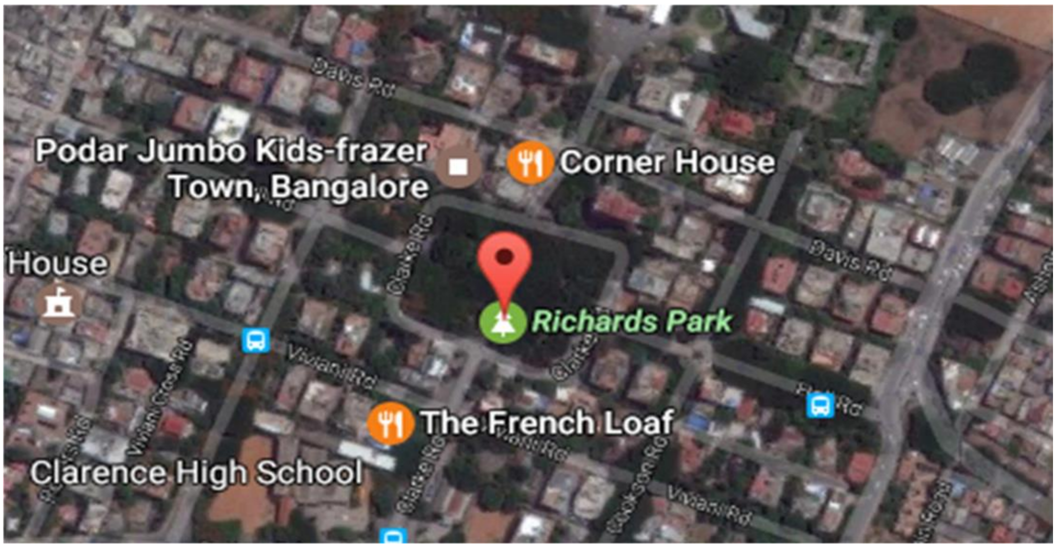

Fig. 7. Google Imagery of Richard's Park

Fig. 8. Photographic close-up view of Richard's Park

The 3rd observatory, Richard's Park is relatively a smaller urban green space located in the ward of Frazer Town. It is the only green space located in this cramped residential area, with old trees grown massively to a great height and thereby providing good shade within the park [31]. Figure 7 depicts the birds-view of Richard's Park, and its surrounding congested urban landscape viz. Google Imagery. It has a physical/geographical area of 2.35 acres and is confined to a lesser number of species. Figure 8 displays a photographic close-up view of the species in the Richard's Park.

The 3rd objective was accomplished by computing the biomass for all the existing individuals of all tree-species within each observatory by using the 'Biostatistics-based Allometric' equation [32]. Biomass, in this context, refers to the sum of all organic material that constitutes a tree's physical structure, i.e. Above-Ground Biomass (AGB) and Below-Ground Biomass (BGM).

While AGB encompasses the parts of the tree that are visible above the soil-line; BGM consists of the roots, which, though are less visible, is equally crucial for the tree's stability and nutrient uptake. The role of CO_2 uptake within all types of trees is intimately connected to their developmental-growth dynamics, primarily through biomass accumulation [33]. Hence, the most precision-based methodology to estimate stored terrestrial-carbon and subsequently derive CO_2 equivalents is by fetching input variables by directly quantifying the select-features of all the trees at the study-based locations [34]. This results in the creation of a large database i.e. sampling inventory. To accomplish this humongous task, vigorous physical data collection was undertaken by the authors, which would eventually serve as inputs to compute carbon sequestration potential of every individual of each tree species. All details were recorded in a worksheet, species-wise, for each observatory.

The taxonomic information (i.e. identification of species) of commonly known species was accomplished viz. general observation. For those relatively unknown species, the taxonomic information was collected on-site from the labelled name plate affixed to the tree. In the case of trees whose identification could not be confirmed by direct observation or due to absence of name plate; therein photographic images for parts of concerned individual tree was collected. This served towards confirming the binomial nomenclature, with help of naturalists/botanists/experts from GKVK (Agricultural University) and the Horticulture Department.

The physical data that ought to be collected for providing as input in the 'Biostatistics-based Allometric' equation includes 'height' of the tree, 'girth at breast-height', and Wood-Density [35], [36]. 'Laser-beam Distometer' was used to measure the 'height' of the tree. The accuracy of the Distometer was 0.01 cm and encompasses accurate sub-nano second timing circuitry. The 'girth at breast-height' (GBH) was measured 4.5 feet above ground surface, directly by using a standard measuring tape. Tree Bio-Volume value established by multiplying of diameter and height of tree species (Equation 2.1). Tree diameter (d) was measured to the actual marked girth of species (Equation 2.2). The data collection involved physical measurement of each individual tree for all tree species in each of the 3 green spaces, during bright sunny weekdays.

Fig. 9. Physical determination of Height and Girth of Trees

The height was derived with the application of Pythagoras Theorem and Vertical Alignment Method. As highlighted in Figure 9; the on-site application of Pythagoras method was benevolent in determination of tree height, wherein neither tree is straight, nor the top foliage is visible. Conditions wherein, the tree is nearly straight, the top foliage is visible, and the ground is nearly levelled; the Vertical Alignment Method was deployed. Herein the laser beam from Distometer is directed at about 90° to the crest of tree, thereby directly providing height.

AGB was estimated by multiplying the bio-volume to the green wood density of tree species (Equation 2.3). The Wood-Density was obtained from Global wood density database [37]. Usually, the standard average density of 0.6 gm/cm was applied whenever the density value is unavailable for certain species. Equations that predict above-ground biomass were converted to whole tree biomass based on root-to-shoot ratio of 0.26 [32]. These computations paved way for the data analysis of 'net' carbon sequestration potential of each green space. The equations used in the current study has been divulged further on.

Bio-volume (T_{bv}) = $= \frac{\pi d^2}{4} \times h$ (2.1)

Where, 'd' is diameter (meter) calculated from GBH, assuming the trunk to be cylindrical,

$d = \frac{\text{Girth}}{2\pi}$ (2.2)

and, 'h' is Height (meter).

AGB=Wood density × T_{bv} (2.3)

BGB=AGB × 0.26 (2.4)

Total Biomass (TB) = AGB + BGB (2.5)

Carbon Storage = TB / 2
(2.6)

The 4th objective was accomplished viz. statistical validation of the extensive data, by using the Multiple Linear Regression Analysis and One-Way ANOVA. The statistical tool of Multiple Linear Regression Analysis is an extension of Simple Linear Regression Analysis. It is used to examine the relationship and relevance for two or more independent variables, with a single continuous dependent variable. The generic multiple linear regression equation is indicated in Equation 2.7 [38].

$$\hat{Y} = b_0 + b_1 X_1 + b_2 X_2 + \ldots + b_p X_p \quad (2.7)$$

One-way ANOVA (Analysis of Variance) is a statistical method which compares the means of two or more independent groups, so as to determine if the associated population means are significantly different [39]. Though all tree species have a specific potential in terms of carbon sequestration; yet, only a select few have been studied for and the true potential of remaining many are yet to be probed. In the present research, intensive documentation is undertaken for the amount of carbon sequestered by each of the individual tree species located for all the 3 study areas. The detailed results and inferential discussion is presented in the next section.

3. RESULTS AND DISCUSSION

A total of 3786.441 tonnes of carbon was found to be sequestrated from the three observatories, wherein most of it is attributed to Lalbagh Botanical Garden (3643.578 tonnes). In the case of BMSIT&M Green Campus and Richard's Park, it was 118.143 and 24.732 tonnes respectively. As can be observed from Table 1, there hence exists a directly proportional relationship between physical area of green space and net Carbon Sequestered. Among the 3 observatories, Lalbagh Botanical Garden has the greatest area. It is at least 35-40 times greater than that of BMSIT&M Green Campus and Richard's Park. The largest quantum of biomass sequestered at Lalbagh Botanical Garden, is hence owing to its larger physical expanse, which supports greater number of trees (2533 individuals) and species (181). Richard's Park on the other hand, had the least physical area (2.35 acres) among all three observatories and could suffice only about 24.732 tonnes, owing to presence of only 4 species and 34 trees. It may hence be concluded from the initial observation that physical area should be an integral component while planning for urban green spaces. Greater the area, more the number of species and trees would thrive to sequester carbon. The highest value of carbon sequestered per species upon computation was also observed at Lalbagh Botanical Garden, with 20.13 tonnes per species. Also the highest value of carbon sequestered per species upon computations was found to be at Lalbagh Botanical Garden with 1.43 tonnes per tree. The species having the highest sequestration potential was *Eucalyptus grandis* (15%) and Magnifera Indica (14%), followed by *Albizia Saman*, *Pterocarpus indicus*, *Swietenia macrophylla*, *Albizia lebbeck* and *Ficus*. Owing to its greater area and larger number of trees; over the 264 years it has sequestered more carbon than the other 2 observatories. The total amount of average carbon sequestered by each tree was further determined by dividing the total amount of carbon sequestred at an observatory with its total number of trees. This has revealed that the 'carbon sequestered per tree' is 1.438, 0.292 and 0.727 tonnes at Lalbagh Botanical Garden, BMSIT&M Green Campus and Richard's Park respectively. Surprisingly, herein it is imperative to note that despite the lesser number of trees, Richard's Park presented better storage potential than BMSIT&M Green Campus. Also, the potential of Lalbagh Botanical Garden is merely twice that of Richard's Park and not multi-fold which should have been the norms considering the huge area difference. This is owing to the age-factor of trees. Most of the trees in Richard's Park are in the age range of 50 to 100+ years. At this age, the trees play a dominant role in absorbing the atmospheric carbon-di-oxide, and strongly accumulate biomass. Within Lalbagh Botanical Garden, most of its inherent trees are matured, ageing above 200 years. Herein, the sequestration rate will invariably retard, as most of the energy is used by these trees to repair the damages sustained. Subsequently, the energy produced by these matures trees naturally does not contribute towards producing new wood or capturing carbon in it. Nevertheless, owing to its long age, a mature tree will continue to store more carbon than a young tree. Though unable to capture newer carbon, trees of unable to capture newer carbon will continue to retain great volumes of carbon as biomass over time. In the case of BMSIT&M Green Space, the trees are still younger and hence most energy is diverted towards resource-based inter-completion and intra-competition for light, resources, and growing space. In these cases, the trees that survive all odds and continue to grow, shall sequester more carbon as they mature. This inferential outcome has been discussed further.

As can be observed from Table 1, the highest value of carbon sequestered/acre upon computation was found at BMSIT&M, with about 54.44 tonnes of carbon sequestered per acre. This is about twice of that of Lalbagh Botanical Garden and five-times to that of Richard's Park. The major reason for this

is the presence of its several young trees aged 10-15 years. Any forest in its youth or growing stages, grows rapidly and subsequently sequesters comparatively greater quantity of surplus carbon.
Thus, a young green space such as BMSIT&M though may presently hold lesser carbon yet will eventually sequester additional carbon over time.

Table 1. Carbon Sequestration computations across all three observatories

Name of Observatory (Age in Years)	Total carbon sequestered (tonnes)	Total Count of Trees	Carbon Sequestered / Tree (tonnes)	Total Count of species	Carbon Sequestered / Species (tonnes)	Net Area (acres)	Carbon Sequestered / Unit Area (tonnes/acre)
Lalbagh (264)	3643.578	2533	1.438	181	20.130	131.55	27.697
BMSIT&M (15)	118.143	610	0.292	29	6.139	3.27	54.443
Richard's Park (119)	24.732	34	0.727	4	6.183	2.35	10.524

Table 2. Species-wise computation at Richard's Park

Species	Count of Trees	Avg. Girth at Breast Height (m)	Avg. Radius (m)	Avg. Height (m)	Wood Density (kg/m^3)	Average Organic Carbon (t/tree)			Organic Carbon (tonnes /species)
						AGB	BHB	TB	
Araucaria columnaris	2	0.5	0.08	9.3	530	0.098	0.025	0.124	0.124
Delonix regia	4	1.52	0.24	9.8	600	1.081	0.281	1.362	2.724
Samanea saman	15	2.01	0.32	13.05	523	2.194	0.571	2.765	20.737
Sarala Asoka	13	0.62	0.10	7.51	610	0.140	0.036	0.177	1.148

While physical area of the green space and age of its inhabiting trees play an important role in overall carbon sequestration, the type of species and its count also tends to be a deciding factor. Therefore the presence of right kind of species in great numbers can support even a smaller sized green space to uptake more atmospheric carbon. This logic was observed in both Richard's Park and BMSIT&M green campus. About 84% of the net carbon sequestration potential of the 119-year-old Richard's Park was contributed by *Samanea saman*, followed by *Delonix regia* (11%), *Saraca asoca* (4.5%) *and Araucaria columnaris* (0.5%). The carbon sequestering potential from *Samanea saman* was around 20.737 tonnes. In the case of BMSIT&M green campus, *Samanea saman* exhibited the maximum carbon sequestration potential of about 26% of the total. Species such as *Eucalyptus globulus* and *Neolamarckia cadamba* contributed 14% and 12%, respectively. The same can be observed in Figure 10.

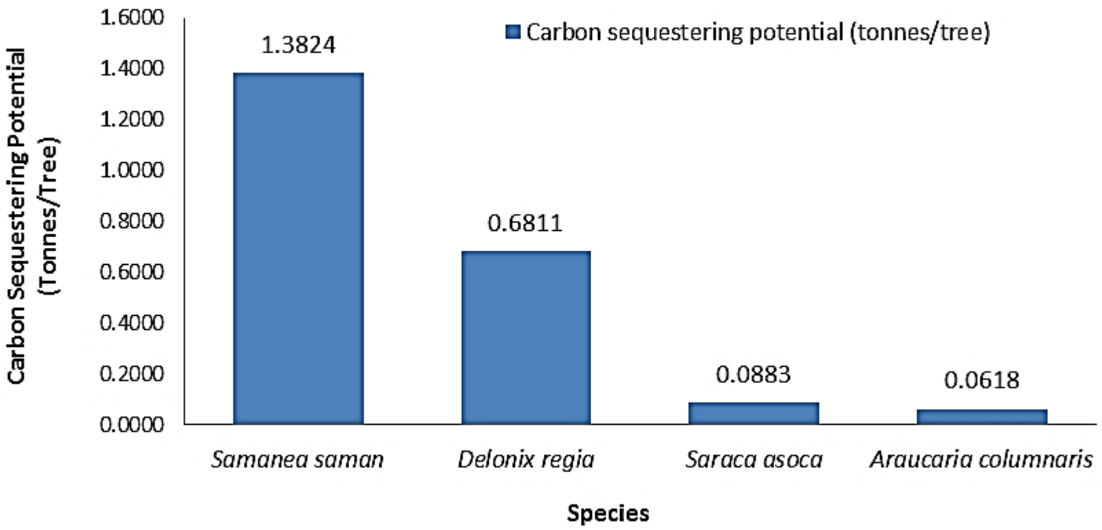

Fig. 10. Carbon sequestering potential (in tonnes per trees) at Richard's Park

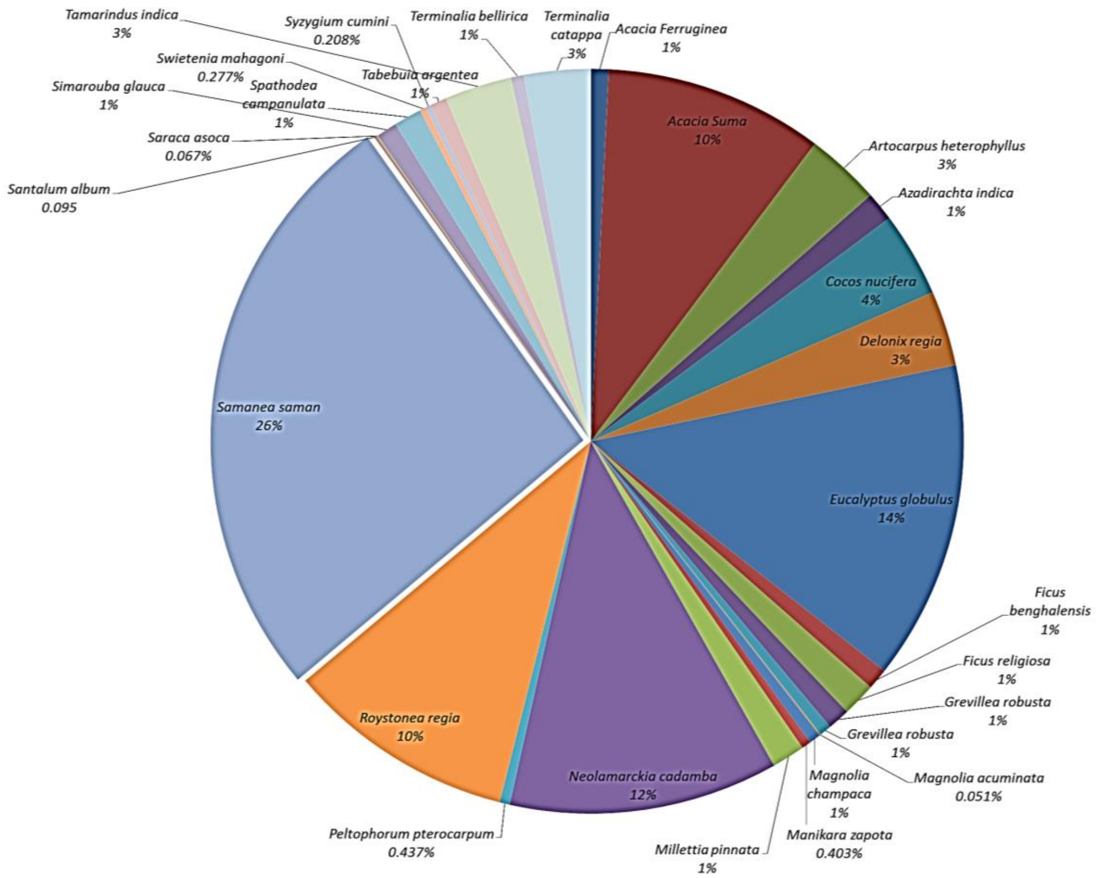

Fig. 11. Carbon Sequestration Potential by each species at BMSIT&M

Incidentally from the study it was decoded that *Samanea saman* satisfied this criterion, wherein lesser number of individuals of this species was able to sequester more carbon than other species that possessed more individuals. The advantage this situation offers is that in smaller urban green spaces, the prospect of inducing higher rate of growth for maximum stocking could automatically facilitate optimum carbon sequestration. This rationale is also supported by species-wise inventory computation for Richard's Park as showcased in Figure 11 and Table 2. The tabulation for other two observatories has not been included in the current manuscript, as they are too voluminous and would encompass several pages of the manuscript, on account of their vast species count. Further on, statistical validation was engaged.

Firstly to verify if both 'girth' and 'height' of trees were significantly contributing to the carbon uptake. This was accomplished using Multiple Linear Regression Analysis. The results are presented in Table 3.

Table 3. Output of Multiple Linear Regression Analysis

Variable	Estimated Value	Standard Error	't' value	'p' value
AGB [β_0]	-5.777	0.5109s	-10.918	2×10^{-16}
Girth [β_1]	2.7179	0.1751	15.524	2×10^{-16}
Height [β_2]	0.3238	0.0505	6.412	1.24×10^{-9}

Interpretation:

(i) H_0: $\beta_0 = 0$, $\beta_0 \neq 0$
$t = \beta_0/se(\beta_0) = -5.5777/0.5109 = -10.918$
p-value = $2x10^{-16} < 0.05$
Reject H_0: $\beta_0 = 0$ at 5% level of significance
$\Rightarrow$ Intercept term β_0 is important.

(ii) H_0: $\beta_1 = 0$, $\beta_1 \neq 0$
$t = \beta_1/se(\beta_1) = 2.2179/0.1751 = 6.412$
p-value = $2x10^{-16} < 0.05$
Reject H_0: $\beta_1 = 0$ at 5% level of significance
$\Rightarrow$ Intercept term β_1 is important.

(iii) H_0: $\beta_2 = 0$, $\beta_2 \neq 0$
$t = \beta_2/se(\beta_2) = 0.3238/0.0505 = 15.524$
p-value = $2.2x10^{-16} < 0.05$
Reject H_0: $\beta_2 = 0$ at 5% level of significance
$\Rightarrow$ Intercept term β_2 is important.

Interpretation:

(i) The 95% confidence interval for β_0 is (-6.589001, -4.5695953).
(ii) The 95% confidence interval for β_1 is (2.3724055, 3.0633395).
(iii) The 95% confidence interval for β_2 is (0.2241779, 0.4234972).

The analysis reveals that for all the 3 coefficients (β_0, β_1 and β_2), the p values are less than 0.05 (level of significance), and hence they are significant. Herewith the Null Hypothesis (h_0) is rejected. It can hence be confirmed that the Model is effective and both 'girth' and 'height' are relevant to the computation of carbon sequestration. Further on, as the difference between Adjusted R^2 (0.7214) is less than R^2 (0.7245), and their difference is small. It can hence be concluded that the fitting regression model is good.

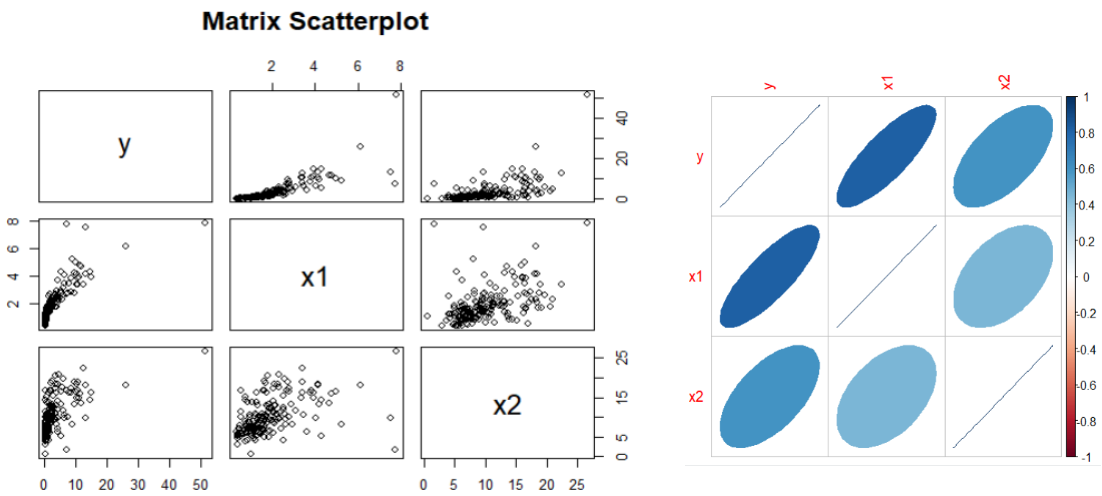

Fig. 12. Degree of correlation existing between dependent and independent variables in the linear regression model

Figure 12 represents the Matrix Scatterplot and Correlation Plot, highlight the degree of correlation existing between the dependent and independent variables. As can be observed, there exists no linear relationship between x1 (girth) and x2 (height). This hence resolves the problem of Multi-collinearity. Also, it is much obvious that x1 (girth) contributes more significantly to y (AGB) than x2 (height). This was clarified upon cross checking computations. It was found that *Ficus benjamina* and *Albizia richardiana*, 2 distinct different species, had similar girths and also similar sequestration potential. But comparatively, the same cannot be confirmed for height. For instance, even though the average height of *Grevillea robusta* was larger than the height of *Ceiba pentandra*, the carbon sequestration potential of the latter was still larger. This helps in relatively concluding that the height of a tree cannot be directly translated to its carbon sequestration potential.

To conclude, irrespective of the type of species, greater the girth of a tree, larger would be its carbon sequestration value. Finally statistical analysis viz. One-way ANOVA was carried out to identify if there existed any significant difference within same species (in terms of their potential of carbon uptake) for all the 3 observatories. For this the hypothesis has been defined as follows.

Null Hypothesis: h_0: The net Carbon sequestration by the respective species across the observatories (Richards Park, BMSIT&M & Lalbagh Botanical Garden) is not significantly different from one another ($\mu_1 = \mu_2 = \mu_3$)

Alternate Hypothesis: h_a: The net Carbon sequestration by the respective species across the observatories (Richards Park, BMSIT&M & Lalbagh Botanical Garden) is significantly different from one another ($\mu_1 \neq \mu_2 \neq \mu_3$)

From the analysis, the calculated value of f (1.519764) was found to be less than its critical value (4.256495) at 5% level of significance. Also the p-value (0.26991) was found to be greater than 0.05.

Herein, as the p-value reported was found to be greater than 0.05, the outcome is deemed to be statistically significant at 95% confidence level and h_0 is accepted. Therefore, town planners and ecologist should not restrict themselves to the physical presence and expanse of green spaces; but rather must also introspect w.r.t. decision making upon the selection of type of trees, their maintenance aspects (age factor) and population (cumulative benevolence) etc. With proper monitoring and policy in place, an urban green space can serve similar climatic benefits to a society, as a forest would have, in terms of its regulatory functions.

4. CONCLUDING REMARKS

As cities are fast growing, it has become difficult for it to maintain its ambient air temperature. Coupled with the advent of human-caused global warming and rise in industrialisation; there is an urgent need to find a solution w.r.t. depreciating Human Thermal Comfort Factor. In this scenario, the Urban Green Spaces if existing within urban environs, can serve to attain a carbon neutral area. Based on a combination of physical exercise involving data collection, further computations involving empirical relationship, and finally data analysis by statistical evaluation using Multiple Linear Regression Analysis and One-way ANOVA. Multiple linear regression analysis has confirmed that girth played a more important role than height in the process of Carbon Uptake. One-way ANOVA test has also revealed that the carbon sequestration potential of a particular species within one geographical area having same climate profile is not influenced by surrounding landscapes. Hence, strategic decisions should be interlaced with parameters such as placement, type of trees, their age and count etc. The present study proposes to introduce in higher numbers the tree species such as *Eucalyptus grandis*, *Eucalyptus globus* and *Samanea saman*. Also, certain other species that have moderate Carbon sequestration potential (*Ceiba pentandra*, *Mangifera indica*, *Neolamarckia cadamba* and *Roystonea regia*) can as well be introduced. However, low-yielding species such as *Pinus* and *Cycas circinalis*, which have low carbon uptake, may be ignored. Hence, there is an urgent need to increase Public Urban Green Spaces through reforestation and encourage more Private Green Spaces as well. Most importantly, it is also to be realised that the reverse of carbon sequestration must not happen, due to deforestation or tree felling practices for want of development. Thereby, improvement in monitoring and verification protocols for carbon sequestration in Soil-Plant ecosystems is also suggested for policy formulation.

ACKNOWLEDGEMENT

The authors extend their sincere thanks to NERALU, an NGO for assistance during the reconnaissance survey as a part of Bengaluru’s Tree Mapping Festival. The authors also wish to acknowledge the benevolence of Lalbagh Horticultural Department, Richards Park Management officials, Experts at GKVK (Agricultural University) and Mr Praveen Kumar TP (Green Campus i/c BMSIT&M) for their invaluable time and support for conducting research within their managed premises.

REFERENCES

1. Abbass, K, Qasim, MZ, Song, H et al. 2002. A review of the global climate change impacts, adaptation, and sustainable mitigation measures. *Environ Sci Pollut Res* **29**, 42539-42559. https://doi.org/10.1007/s11356-022-19718-6
2. Karl, TR, Trenberth, KE 2003. Modern global climate change. *Science* **302**, 1719-1723. https://doi.org/10.1126/science.1090228

3. Vrinda, T and Rajesh, G 2018. Artificial Neural Network trained 'Simultaneous Extent Analysis' as a Logical Tool in Computation of Urban Heat Island Intensity. *Science and Technology Asia* **23**, 18-22. https://doi.org/10.14456/scitechasia.2018.28
4. Aadarsa, VRR, Rajesh, G, and Ashok, S 2021. Inadvertent implications of climate change for butterflies. *ACTA Universitatis Sapientiae Agriculture and Environment* **13**, 13-22. https://doi.org/10.2478/ausae-2021-0002
5. Aftab, JB et al. 2021. Impact of Chaotic Urbanisation on Bengaluru's (India) Urban Avian Diversity. *Transylvanian Review of Systematical and Ecological Research-The Wetlands Diversity* **23**, 81-94. https://doi.org/10.2478/trser-2021-000710.2478/trser-2021-0007
6. Muralidhar, Akarsh, CU and Rajesh, G 2022. Time-line based aerial analysis for impact of rampant urbanization on lakes of Bengaluru (India). *Civil and Environmental Engineering Reportst* **32**, 1-18. https://doi.org/10.2478/ceer-2022-0001
7. Sachin, S et al. 2017. Real-Time Thermal Mapping for Heat and Cool Archipelagos of Bengaluru, India. *Civil and Environmental Engineering* **13**, 106-111. https://doi.org/10.1515/cee-2017-0014
8. Sachin, S et al. 2020. Real-Time Isohume Mapping for Cool and Warm Humidity Isles of Bengaluru City. *Present Environment and Sustainable Development* **14**, 266-275. https://doi.org/10.15551/pesd2020141021
9. Rajesh, G, and Balasubramanya, N 2017. Historical trend of ambient air quality indices at key observatories for major cities in Karnataka, India. *Bulletin of Volgograd State University of Architecture and Civil Engineering, Series: Construction and Architecture* **49**, 189-195, Volgograd State University of Architecture & Civil Engineering, Russia.
10. Monica, K et al. 2021. Spatial and Temporal Real-Time Ambient Carbon Monoxide ward-wise Mapping for Bengaluru City. *Present Environment and Sustainable Development* **15**, 23-33. https://doi.org/10.15551/pesd2021151002
11. https://www.repsol.com/en/sustainability/sustainability-pillars/climate-change/reducing-carbon-footprint/index.cshtml
12. Feigin, S et al. 2023. Proposed solutions to anthropogenic climate change: A systematic literature review and a new way forward. *Heliyon* **9**, 1-26. https://doi.org/10.1016/j.heliyon.2023.e20544
13. Yaleeni, KD et al. 2023. Unlocking the potential of microalgae bio-factories for carbon dioxide mitigation: A comprehensive exploration of recent advances, key challenges, and energy-economic insights. *Bioresource Technology* **380**.https://doi.org/10.1016/j.biortech.2023.129094
14. Belcakova, I, Swiader, M, and Bartyna-Zielinska, M 2019. The green infrastructure in cities as a tool for climate change adaptation and mitigation: Slovakian and Polish experiences. *Atmosphere* **10**, 1-23.
15. Gupta, D, and Prakash, A 2023. Barriers and opportunities in achieving climate and sustainable development goals in India: a multilevel analysis. *Journal of Integrative Environmental Sciences* **20**, 1-16. https://doi.org/10.1080/1943815X.2022.2163665
16. Naorem, A 2022. Carbon Sequestration. *Reson* **27**, 1237-1245. https://doi.org/10.1007/s12045-022-1416-0
17. Macauley, M and Sedjo, RA 2011, Forests in Climate Policy: Technical, Institutional and Economic Issues in Measurement and Monitoring. *Mitigation and Adaptation Strategies for Global Change* **16**, 489-513.
18. https://ourworldindata.org/co2/country/india
19. Ross, WG 2009. Carbon Sequestration in Forests. *CRS Report for Congress*, Rl31432. https://www.hsdl.org/?view&did=736925

20. Shubham, B et al. 2021. Development and Parametric Analysis of Human ‘Outdoor’ Thermal Comfort Index for Public Green Spaces in Bengaluru, India. *Modeling in Civil and Environmental Engineering* **16**, 12-25. https://doi.org/10.2478/mcee-2021-0012
21. Faraaz, K et al. 2023. An extensive investigation into the influence of public green spaces for the climate of Bengaluru. *Present Environment and Sustainable Development* **17**, 85-99. https://doi.org/10.47743/pesd2023172007
22. Deepak, DG and Rajesh, G 2017. A Site-based practical Improvisation for the Analytical Determination of Aspect Ratio. *Architecture and Engineering* **2**, 11-20 p. Эл № ФС77-70026. https://doi.org/10.23968/2500-0055-2017-2-3-11-20
23. Bhanumurthy, PR et al. 2014. Influence of Bangalore’s Canyon Geometry on the Intra-Urban Ambient Air Temperature. *Scientific Herald of the Voronezh State University of Architecture and Civil Engineering, Construction and Architecture* **23**, 40-50.
24. Bhanumurthy, PR et al. 2015. Parametric study of heat island effect due to urban sprawl in Bangalore, PhD Thesis, Jawaharlal Nehru Technological University, Anantapuram. http://hdl.handle.net/10603/46778
25. Vijayalakshmi, A et al. 2015. Township Guidelines to Curb Urban Heat Island Effect. *Journal of the Indian Institute of Architects* **80**, 47-49. ISSN 0019-4913, International Press
26. Suryawanshi, MN et al. 2014. Carbon Sequestration Potential of Tree Species in the Environment of North Maharashtra University Campus, Jalgaon, India. *Bioscience Discovery* **5**, 175-179.
27. Gavali, RS and Shaikh, HMY 2016. Estimation of Carbon Storage in the Tree Growth of Solapur University Campus, Maharashtra, India. *International Journal of Science and Research*, **5**, 2364-2367.
28. Chaveet, J 2005. Tree Allometry and Improved Estimation of Carbon Stocks and Balance in Tropical Forests. *Oecologia* **14**, 87-99.
29. Gupta, B and Sharma, S 2014. Estimation of Biomass and Carbon Sequestration of Trees in Informally Protected Areas of Rajouri, J&K, India. *International Research Journal of Environment Sciences* **3**, 56-61.
30. Corona, P et al. 1997. Sustainable Management of Forests for Atmospheric CO_2 Depletion: The Italian Case. *J Sustfor* **3**, 81-91.
31. www.karnatakatourism.org
32. Priya, K et al. 2022. Allometric equations for biomass and carbon stock estimation of small diameter woody species from tropical dry deciduous forests: Support to REDD+, *Trees, Forests and People* **9**, 1-10. https://doi.org/10.1016/j.tfp.2022.100289
33. Pator, S et al. 2021. Modelling the scaling of belowground biomass with aboveground biomass in tropical bamboos, *Trees, Forests and People* **3**, 1-11. https://doi.org/10.1016/j.tfp.2020.100054
34. Mulatu, A et al. 2024. Species-specific allometric models for reducing uncertainty in estimating above ground biomass at Moist Evergreen Afromontane Forest of Ethiopia. *Sci Rep* **14**, 1-11. https://doi.org/10.1038/s41598-023-51002-6
35. Bandana, G and Sanjay, S. 2014. Estimation of Biomass and Carbon Sequestration of Trees in Informally Protected Areas of Rajouri, J&K, India. *International Research Journal of Environment Sciences* **3**, 56-61.
36. Ishan YP et al. 2013. Quantitative Analysis on Carbon Storage of 25 Valuable Tree Species of Gujarat. *Indian J. Sci. Res.*, **4**, 137-141.
37. Nowak, DJ et al. 2001. Brooklyn’s Urban Forest. *USDA Forest Service General Technical Report*, Newtown Square, PA, 1-107.
38. https://apps.worldagroforestry.org/sea/Products/AFDbases/WD/Index.htm
39. https://sphweb.bumc.bu.edu/otlt/mph-modules/bs/bs704_multivariable/bs704_multivariable7.html

40. https://www.itl.nist.gov/div898/handbook/ppc/section2/ppc231.htm