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Evaluation of Role of Trees in Atmospheric Carbon Storage, Case of planned city of Bhilai, India

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Abstract: *The study aimed to assess the total amount of carbon that trees hold in the Urban Vacant Lands of Bhilai, (India). Initially, urban vacant lands (UVL) were recognized and categorized before calculating the total biomass and stored carbon of urban trees. Carbon stored values were obtained by the formulas used in allometric modeling and compared against other sectors in the planned city. Complete area and each tree were measured to obtain data of each UVL. Typologies identified for UVL were Planned Vacant Land (4.935 km2) including residual planning space and transport buffers and Geographical Vacant Land (1.297 km2) as natural surroundings. Maximum carbon was seen in Cassia renegeria (20221.85 Tonnes), Pongammia pinnata (5539.64 Tonnes), Tectona grandis (4577.95 Tonnes), Acacia indica (1843.60 T) and Terminalia arjuna (1803.76 T). The average carbon stored per tree was highest in Ficus religiosa at 4.21 Tc/tree, Cassia renegeria at 3.72 Tc/ tree and Syzgium cumini 2.82Tc/tree. The information gained from the investigation will guide understanding of urban trees' effect on CO2 in the air and on carbon storage. The study will be useful in planning of open areas in regions affected by air pollution.*

Keywords: *Allometric model, carbon sequestration, carbon storage, tree biomass, urban vacant lands, volume equations.*

I. INTRODUCTION

A. Urbanization and Its Impacts

Typically, urbanization means making rural land into urban locations that are crowded and have a different use for the land. With more growth, there is more activity in the city, especially with transportation, energy and waste, all of which negatively affect natural resources. It has been shown by [1] that urban areas bring major changes to the environment, affecting both biodiversity and access to natural resources. India is an excellent example of what urbanization entails. Reports by the UN reveal that with 814 million people living in cities as per estimates, the country will see big challenges when it comes to resource use. Air pollution in India's cities is on the rise because of increased exhaust from vehicles and factories [2], Urbanization has brought more vehicles and transport infrastructure, raising the emission of greenhouse gases [3]. People are worried about the rising level of carbon emission; it was discussed in the Kyoto protocol and UNFCCC. Most outgoing terrestrial radiation is absorbed by CO2 which provides about half of the greenhouse effect. Photosynthesis in trees and plants allows them to produce sugar, cellulose and carbon-containing carbohydrates from the carbon dioxide they inhale. Putting carbon from CO2 into long-term storage in parts of plants, like trees, is what's known as carbon sequestration [4].

B. Concept of Biomass and Carbon Storage

Absorbing atmospheric CO2 is a job mainly handled by tree, shrub, soil and seawater. Trees store a large amount of carbon by pulling it from the air and building it into their tissues as they grow. When trees grow, they use carbon from the air to help them grow and develop different parts [5]. Photosynthesis, through which CO_2 is absorbed and then the carbon is saved in tree or plant biomass, is the method of carbon storage [6]. By storing carbon and lowering urban CO_2 emissions, trees in cities help steady the environment and its climate. A range of methods are used to estimate the biomass of trees. The main methods for estimating tree biomass are destructive and non-destructive [7, 8,], Tree biomass estimation almost always relies on non-destructive methods, carbon is often estimated using the same approaches as biomass. In this approach, different species are identified by mathematical formulas to measure tree volume. These equations are called volume equations or allometric equations [10]. The amount of tree biomass is obtained by multiplying the tree density by the estimated total volume. Certain allometric equations are used to measure tree biomass and are called mass equations. Science researchers have built up several equations that relate animal size and lungs. Complementing our previous statement, Navar [11] pointed out that knowing the dimensions of a plant such as its size, height, and diameter is essential for estimating its above ground biomass.

C. Concept of Urban Vacant Land

Urbanization and growth of Urban Centers exerts pressure on natural resources. Urban Centers functions as living organisms that consume natural resources as inputs for its various processes or activities, while generating outputs in the form of pollution. Urban vacant lands are the leftovers or the waste products of economic and industrial processes for the development of urban areas [12]. Development cycle of the city starts with housing expansion due to demographic shift, and urban sprawl and subsequently leads to structural deterioration due to de-industrialization or decline in population, resulting in unused areas in the form of vacant land [13] , [14]. These underutilized areas are mostly left unattended and occasionally becomes area for illicit activities creating negative areas in the urban fabric is termed as "*Urban Voids*". These Urban Voids are indicators of neighborhood deterioration reduced safety, poor quality of life, and decreased property value [15]. The book 'Finding Lost Space [16] discussed these areas as undesirable with no positive contribution to urban environment. Urban voids continued to be treated as negative spaces till Barcelonan urbanist, Ignasi de sola-morales in 1995, reinterpreted the concept of Terrain Vagues, suggesting that these abandoned spaces hold historical significance and reflects previous uses. In English, "*Vague*" means blurred, undetermined, or uncertain. In French etymological root, "vague" implies oscillations, instability, or fluctuations, suggesting a sense of change and potential reuse of the space. Time functions within urban wastelands and vacant lands in diverse and fascinating ways [17] , influencing the cycle of development and nature. This allows the planners & designers to reconsider the concept of urban voids or urban vacant lands as "Drosscapes" suitable for redevelopment through adaptive reuse [18].

Our goal in this study is to measure the tree biomass and carbon accumulated in urban vacant lands of the Bhilai planned city (an industrial city in Chhattisgarh, India), by employing a non-destructive approach to biomass estimation. Improving the air quality in the region by using strong plant species for carbon storage will be made easier by this research. This information supports the right planning for new forest areas in urban areas.

II. MATERIALS AND METHODS

A. Study Area

Bhilai, Chhattisgarh, a major industrial town in the ore-rich state of central India, was selected as the study site. Located at approximately 21°N and 81° E, Bhilai experiences a hot & humid climate. The planned city of Bhilai, established in 1957, following the establishment of the Bhilai Steel Plant. Covering an area of 18.9 km², the city was planned following a gridiron pattern and situated on relatively flat terrain characterized by lateritic soil. The initial city plan compromised 11-sectors, with four additional sectors integrated during subsequent expansion. The town's primary industry is a profitable public sector steel plant, with its industrial infrastructure remaining operational and maintained through present day. The entire planned city is under the ownership of the steel plant administration. The single ownership and range of land typologies present within the planned city, offers a unique opportunity to identify and study urban vacant land.

B. Methods

A systematic methodology was developed for creating urban vacant land typology-1) A detailed review of existing definitions and typologies of urban vacant land was conducted to establish theoretical and classification frameworks. 2) Identification and delineation of urban vacant land using Google Earth and open source GIS platforms, based on predefined criteria derived from the literature review.3)Green coverage within delineated vacant land parcel was demarcated in the open source GIS platforms to assess the spatial distribution patterns.4) A field survey of the vacant land parcels was conducted to validate GIS findings and classify vacant land parcels based on physical attributes, ecological characteristics and potential land use.5)Physical measurements of vacant land parcels dimensions and conditions were conducted to assess the features of different vacant land types.6) Demarcated Green coverage on GIS were analyze for vegetative coverage at detail, providing data on vegetation density and spatial characteristics.7) On-ground surveys for identification of tree species within vegetative covers, for an ecological assessment of biodiversity and estimation of carbon storage through allometric equations.

C. Mapping and Field Assessment of Vacant Land

A set of observational variables, derived from systematic review of literature was developed to evaluate characteristics, functions and classify urban vacant land typologies. The observational variables based on their characteristics, were systematically characterized into physical and biological parameters. Urban vacant land parcels were demarcated using publicly available data, satellite imagery (Google Earth), and open-source GIS software, supplemented by field survey and verification [19] conducted across all study area sectors. Field surveys were conducted to assess all the vacant land parcels and enumerate all trees within these vacant land parcels [20], [21] across each sector. These data were then aggregated to generate metrics for the entire planned city. Field surveys were conducted during winters and summers of 2022-2023. Details of each vacant land parcel's physical and biological characteristics were documented, compared and grouped based on their similarities and differences to develop a vacant land typology for both the sector and the entire planned city. Because Bhilai planned city is managed by the Bhilai Steel Plant Authority, homogeneity in land ownership, administration and property valuation within the study area was ensured. Vacant lands in Bhilai were categorized into two types: planned vacant land and geographical vacant land. Planned vacant land consisted of residual planning spaces and buffers for road network, while geographical vacant land comprised of natural sites with water channels and sloping terrains.

D. Mapping and Field Assessment of Biomass & Carbon Stored in Trees of Urban Vacant Lands

To estimate the biomass of different trees, Non-Destructive method that do not damage the trees were used to understand regional biomass changes and the various aspects of forest management and ecology [22] [23]. The estimated biomass of trees is determined using both their diameter at breast height (DBH) and height (height of tree). From March to May, the study was conducted in the summer season. Ecologists have invented many methods to estimate the biomass of forests. Such methods are divided into destructive and non-destructive alternatives. Trees are cut up completely and separated into biomass by wells and have their canopies removed. For this reason, clearcutting should not be used in older forests. With the Non-destructive method, allometric equations are used to estimate the amount of tree biomass measured by DBH, tree height and canopy diameter.

E. Measurement of Girth Size at Breast Height (GBH)

All the trees in our study area were measured for GBH or circumference at breast height, approximately 1.3 meters above the ground. For trees with a diameter above ten centimeters, we measured GBH by using a measuring tape. GBH was then adjusted to DBH values by dividing it by π (3.14) according to (1).

$$DBH = (GBH/\pi), \text{ where } \pi = 3.14 \quad (1)$$

F. Measurement of Tree Height

Researcher measured tree height using a Suunto Clinometer. Measurements of the treetop and base were made by observing the tree from 20/30m away, so that both the top and the bottom were in view. The measurement taken at the top was added to the measurement from the base if the top was lower and the top and base readings were taken away from each other if they were both the same height. Only tree species over 3 meters high were included in the study.

G. Determining AGB

It consists of trees with living parts above the soil. The annex group biomass (AGB) was measured by looking at both bole and non-bole parts of the plants. Bole biomass is found by taking the bole volume (m3) and multiplying by the density (kg/m3) of wood. Bole volume is estimated with allometric models that depend on a tree's DBH and height [24] [25] [26]. Should species-specific allometric be missing, the general equations are the practical choice [27] [28]. The density (kg/m3) of each tree comes from USDA general technical report [29] and from world agro-forestry database [30]. For those species without a given wood density, a standard value of 610 kg/m3 was chosen. To obtain non-bole biomass, we multiplied the bole biomass by the biomass expansion factor (BEF). The present investigation uses BEF equal to 1.6 [31].

AGB (kg) = Bole Biomass (kg) + Non-Bole Biomass (kg) (2)

Bole Biomass (kg) = Bole Volume of Biomass (m3) x Wood Density (kg/m^3) (3)

Non-Bole Biomass (kg) = Bole Biomass (kg) x BEF (4)

H. Biomass (Determining Below Ground BGB)

All aboveground and subsurface roots are included except for the smaller roots under 2 mm. The BGB is calculated by multiplying the AGB by a root ratio of 0.26 [32].

BGB (kg) = 0.26 x Above Ground Biomass (kg) (5)

I. Computing Total Biomass (TB)

TB is the sum of the AGB and BGB.

TB (kg) = AGB (kg) + BGB (kg) (6)

J. Carbon Storage and CO_2 Removed

Generally, for any Plant Species 50% of its Biomass is Considered as Carbon [33] .

Carbon Storage = Total Biomass /2 (7)

CO^2 Removed (kg) = Carbon Storage (kg) × (44.12) (8)

III. RESULT AND DISCUSSION

Table 1: Distinguishing Variables in Vacant Lands Found in Bhilai Planned City.

Physical Characteristics	Biological Characteristics
Shape-Rectangular or Irregular	Green Coverage Area: < 50% or > = 50%
Slope: Gentle 5% or more	Tree Species
Proximity of Natural Feature: Yes or No	No of Trees

The Study area characterized as a planned city, exhibited regular shape plots and uniform soil conditions. Identification and classification of urban vacant land, based on parameters outlined in Table-I, facilitated the development of distinct typologies. The methodology employed to categorize vacant land resulted in two distinct typologies: Planned vacant land and Geographical vacant land and green coverage of these plots was measured through Google Map and GIS and tabulated in Table-II.

A total of 24894 trees from 21 important species could be found on Urban Vacant Lands in Bhilai Planned City. The field investigation of these species was carried out and their results were reviewed. As seen in Fig.1, the frequency of trees and total carbon stored in it in different areas of Bhilai Planned city. Fig. 2 demonstrates that the most common species were *Tectona grandis* (6346), followed by *Cassia renegeria* (5430), *Pongamia pinnata* (3470), *Acacia indica* (2596) and then *Dalbergia sissoo* (1432).

Table II: Comparison of Percent Green Cover of Each Sector of Bhilai Planned City Vis A Vis Each Type of Urban Vacant Land & Total Trees Present

Sector Names	Vacant Land Green Coverage Area in m^2	Green Coverage in Planned Vacant Land m^2	Green Coverage in Geo-graphical Vacant Land In m^2	Average % of Green Area in Total Vacant Land	Average % of Green Area in Sector	Total No of Trees
Sec-1	71733	71733	0	39.81	9.60	306
Sec-2	196480	143084	53396	54.50	15.14	1771
Sec-3	383991	383991	0	89.58	27.32	3698
Sec-4	120267	87007	33260	41.14	8.84	1141
Sec-5	217186	92292	124894	55.16	17.38	1232
Sec-6	410005	214485	195520	56.86	18.85	1772
Sec-7	326377	289156	37221	63.98	18.50	1583
Sec-8	179360	128358	51002	49.69	18.56	1577
Sec-9	219977	182649	37328	50.44	22.65	846
Sec-10	210955	158693	52262	45.56	13.42	2455
Sector-11	26244	26244	0	45.74	6.75	462
Civic Center	823756	823756	0	71.64	50.69	3189
Sec-9 Hospital & 32 Bungalow	237914	225041	12873	61.38	16.61	2714
Ruabandha	32007	4377	27630	30.93	10.26	856
Risali	113426	65716	47710	52.12	11.76	927
Maroda	67416	43140	24276	39.96	10.17	402

The amount of carbon per tree in Bhilai planned city was highest for Ficus religiosa at 4.21 tones C/tree and lowest for Terminalia cuttappa at 0.28 tones C/tree (Fig.3).

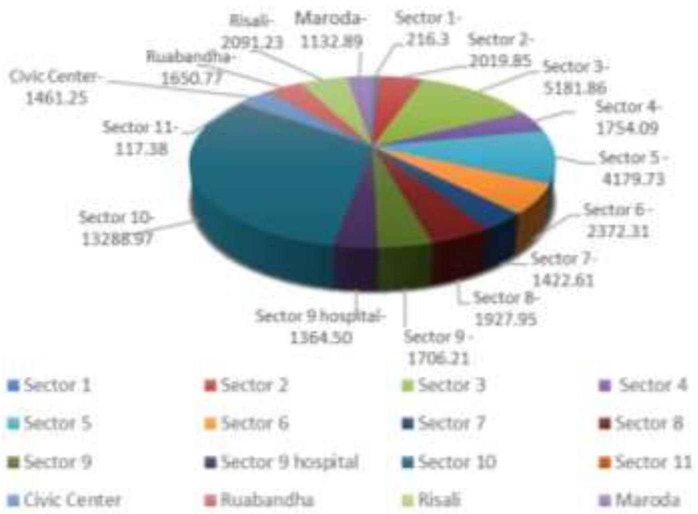

Fig. 1. Carbon Stored in Each Sector of Bhilai Planned City.

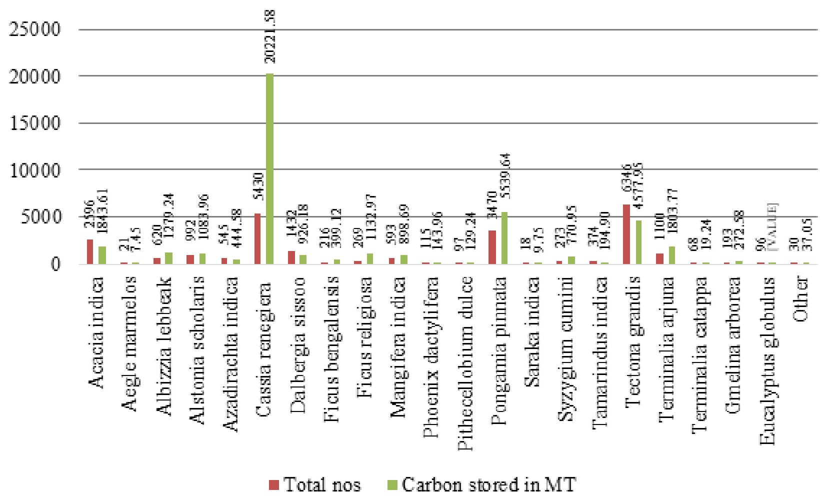

Figure 2. Frequency and Carbon Stored as per Species in Bhilai Planned City.

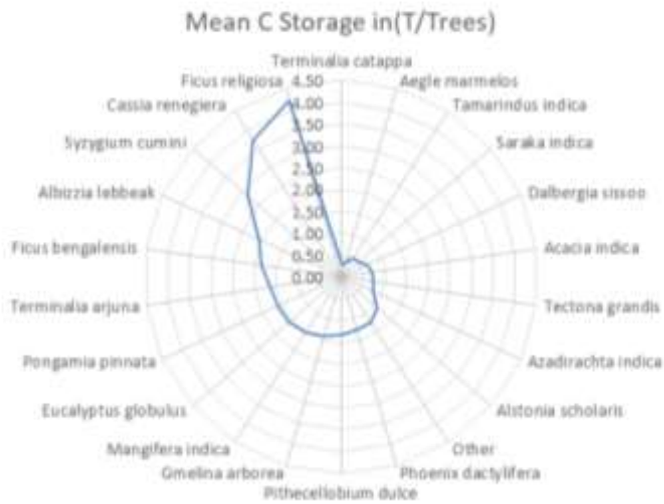

Fig. 3. Mean Carbon Stored in Each Tree Type in Bhilai Planned City.

It was found that tropical urban forests store around 55% of the land-based carbon found in above ground biomass [34].The present investigation revealed that trees with greater DBH (diameter at breast height) contained more carbon in their Above Ground Biomass resulting in more Total Biomass.

IV. CONCLUSIONS

Carbon sequestration can make a significant role in decreasing greenhouse gases from atmosphere. Carbon storage and sequestration can be greatly enhanced by forest and plantations in urban areas. The impact of climate change can be addressed by storage of carbon in terrestrial sinks such as plants, plant products and soils, for longer duration. This study estimated the total amount of carbon stored in urban vacant lands in the Planned city of Bhilai and observed species which demonstrated better mean carbon stored per tree in the city. These inferences can help in planning the vacant lands with species with higher mean carbon stored per tree for better ecological benefits, pollution reduction and in reducing climate change effects.

The UVL Typology framework created in this study serves as a decision support tool for the planning and design of these vacant land parcels for increased environmental benefits. Sites with less than 50% green coverage provides a potential for ecological enhancements and optimization of ecological benefits.

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