Green Cover Analysis using Tree Census Data to Optimize the Biodiversity in Pune Municipal Development Area

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Abstract. In this work, we study the scope and opportunities available in Pune to understand the temporal and spatial status of the green cover across the municipal limits that help improve the scenario in view of maintaining and optimizing the biodiversity. We do review the conversion of land usage due to urbanization over last three decades as well as evaluate the collected census data to provide deeper insights into how the data can be used to create a decision support system by Pune Municipal Corporation to address the expectation of improvements of green cover across the city. A set of metrics is introduced to evaluate the green cover across the city divisions/zones/wards and propose a model to bring in colorful aesthetics as well as maintain balanced floral biodiversity in the ecosystem going forward into the future. It is proposed to plant about 200,000 to 500,000 saplings over next couple of years across the city by bringing in sponsors for saplings to maintain the green stretches in the city.

Keywords: smart city·open data·tree census·bio-diversity.

1 Introduction

The motivation of people to concentrate and build larger cities has generated both positive and negative effects at global level [1]. This has enabled shift in cultural trends with more livelihood opportunities to work together with improved economic conditions. At the same time, it has put challenges to energy and infrastructure development, waste collection, disposal and treatment, use of natural resources such as water and land, etc., as well as management of vehicular traffic, and carbon dioxide emissions.

Pune, once known as Poona, situated 160 km south-east of the most economically important city of Mumbai used to offer few decades back higher quality of life and was less connected to global growth and development. Pune is the eighth largest urban agglomeration (ninth largest municipality) with 5 million inhabitants in 2011 [2]. The economic liberalization before and around 2000s resulted in emergence of numerous Information Technology and Bio-tech Parks and brining in good amount of immigrants into the city. The Special Economic Zone (SEZ) policy introduced by the State Govt. of Maharashtra and the Jawaharlal Nehru Urban Renewal Mission (JNURM) of the Government of India, did provide the necessary impetus and the Pune is more now seen with more of cosmopolitan population.

Pune was once known for dense tree cover with good ambience for greenery but the urbanization has taken toll on many parameters. From 1973 till early 1990s, an increase in built-up area of 38.5 sq km was witnessed with an expansion rate of 2 sq km per year. Subsequently, further after till 2013, the city had expanded by about 82.5 sq km at an expansion rate of 3.9 sq km [3]. The areas in the city green cover can be classified under four categories viz., agricultural land (43 sq km), grassland (33 sq km), woodland (18.2 sq km) and shrub land (7.5 sq km). Pune witnessed a loss of 18 sq km of green cover due to urbanization (residential and traffic flows in the decade ending 2001. The city lost about 52 sq km of land between 2001 and 2013. The population increase and growth of multi-national companies has placed larger demands on commercial infrastructure and residential accommodation which has counterintuitive implications [4].

Air quality (PM 10 levels) is Pune is around 91 as against the expected value of 60. Biochemical oxygen demand (BOD) levels is between 50 and 80 in Mula-Mutha River due to discharge of untreated sewage. Sound pollution due to traffic and congestion is quite high and has open spaces at 7% levels compared to the benchmark values of 15%. Recent citizen survey with Punekars mentioned that clean rivers and water bodies were ranked among the high priority items. A short term goal to develop 3.5 km of riverfront has been taken up under the Smart City Mission as a pilot project and is expected to be replicated based on further inputs [5]. Pune Municipal Corporation (PMC) has garnered support from the National River Conservation Fund to the tune of 900 Cr for river cleaning [6]. This will fund the development of sewage and sanitation related infrastructure along Mula-Mutha river.

2 Review of Literature

Urban forest effects on carbon sequestration and carbon capture have been widely studied across the world, despite the heavy focus on North America [7,8,9]. Several of these studies have proven that trees in urban environments remove carbon dioxide from the atmosphere by storing carbon in roots, stems and branches through growth and photosynthesis. Beyond directly reducing carbon, trees also indirectly reduce carbon emissions by decreasing energy production [10]. They do so by reducing the energy consumed by buildings for cooling internal temperatures since they provide added shade and bring down the overall temperature at a certain level of tree cover. Despite its stated benefits, in order to create a successful model for urban tree cover, there are a series of contingencies that need to be accounted for. Namely, carbon release from tree mortality, biomass and biodiversity [11, 12].

Firstly, tree mortality. Compared to natural forests, urban forests typically store less carbon per hectare in trees due to the relatively low tree cover – 25.1 tons of carbon per hectare (tC/ha) for urban forests to 53.5 tC/ha for natural forests. However, if we are to disaggregate carbon capture at the per unit tree cover level, urban forest trees are more effective [13]. This is primarily due to the carbon release from a larger number of decomposing trees in forests. In urban areas, it is thus imperative to account for extended mortality when selecting tree saplings for increased coverage.

Secondly, the model must account for biomass. In urban areas, especially Pune, one of the largest concerns is physical space limitations to plant trees. With ever expanding residential areas and commercial buildings, it is difficult to find areas to create enough tree cover for carbon sequestration to be effective – this problem has persisted in multiple cities in the United States as well [14]. In order to circumvent the issue of space, it might be useful to refer to tree species which have a higher root-to-shoot ratio. On average, the root-to-shoot ratio is 0.26 [15]. In Pune, the newer tree saplings planted should aim to have a higher root-to-shoot ratio in order to isolate the majority of the biomass underground.

Thirdly, and most importantly, the group of species of trees selected for planting must include native species and account for biodiversity. Blindly planting trees in a homogenous pattern has shown to potentially slow the sequestration of the accumulation of atmospheric carbon [16]. Pune, being a part of Western Ghats (an identified biodiversity rich area), contribution in increasing the diversity of tree species becomes an essential effort for effective capturing of carbon. Operationalizing the measurement of biodiversity in an urban environment though is not standardized. There is limited scientific consensus on biodiversity indices standardizing measurement in general [17]. The difficulty in establishing an index, primarily originates from the complex nature of biodiversity – biodiversity can be defined in terms of composition, structure and/or function at multiple levels [18]. Despite that, there are organizations around the world which deal with biodiversity targets who have commissioned the creation of multiple biodiversity indices for measurement.

The most prominent is perhaps the Convention on Biological Diversity (CBD) which adopted a target of reducing the rate of biodiversity loss by 2010 [19]. There has been a plethora of biodiversity indices which have popped up to attempt to meet the requirements to operationalize the targets of the CBD, although none had adequately done so [20, 21].

3 Improving Green Cover

Trees contribute to their environment by various ways *viz.* providing oxygen, improving an air quality, climate amelioration, conserving water, preserving soil, and supporting wildlife. During the process of photosynthesis, plants absorb carbon dioxide and produce the oxygen we breathe. Some tree species are providing food for particular birds and vice versa birds are spreading seeds throughout the area with their behaviors. The tree cover/flowering & fruiting is of interest to ornithologists. The Pune Municipal

Corporation (PMC) has recently completed a GIS enabled tree census of about 4 Million trees. The Pune Municipal Development Area has 14 administrative wards and the total of 40,09,623 trees as recorded in the census data. The ward-wise tree count is depicted in the chart in figure 1.

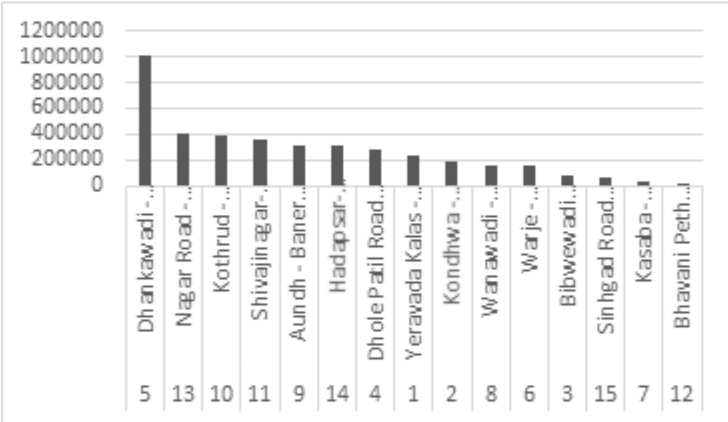

Fig. 1. Ward-wise tree count data in Pune City

This data would be extremely useful to the Government authorities including PMC Department staff, Ecologists/Ornithologists/Botanists as well as citizens. This project focuses on statistical as well as geo-spatial analysis of this BIG dataset.

4 Scope of the Study

We attempt as a first step using the census data to analyze and visualize the geo-spatial spread of the trees across Pune estimating the following factors: trees per sq km, bio-diversity of the wards, percentage of native species and tree cover area per ward. The flowering calendar of the trees using bio-diversity analysis can be generated to improve the aesthetics and colorful beauty of the across the city.

The model depicting the “fall” from trees, on the basis the tree species and its current canopy can be used for ward/prabhag wise “Fall” calendar. This input to be used by Solid waste Management / Health Department for planning their “garden waste clearance” activity. Palm type trees are a special case as the tree fall is non-compostable and shredding capacity is required

It is intended to define and present a Model for CO_2 absorption capacity for various administrative wards. Using the ward-wise population figures, we can determine the “gap” in “required trees” taking into account the saplings planted in 2017-19 as well as the growth in tree foliage, shrubs, etc. The heat-map of the green cover is expected to be used identify and prioritize where new tree plantation is required and come up with suggested locations for new saplings. In the Pune Municipal Corporation’s proposed development plan, certain areas have been identified as “Bio-Diversity Parks”. For ex. certain birds are attracted to certain types of trees. The specifications to be articulated by ecologists/ornithologists/botanists for the areas earmarked as bio-diversity parks abating the issue of deceased tree propagation. The work focuses on following aspects:

1. Improving the green cover of the city by analyzing the existing data sets to figure out the gaps in coverage as well as open spaces.
2. Identifying sponsors to care for saplings of required types to simultaneously improve the green cover as well as the aesthetics and colorful beauty of the across the city.

The study uses evidence-based analytical methods for selecting sapling varieties and greenery improvement opportunities. The insights and perspectives from the analytical study produced are validated against the data observed from field visits, detailed government-stakeholder consultation and a collective approach on greenery analysis of zone/ward-wise interventions in various Municipal divisions of Pune City. The interesting part of the study is that all the collected data on tree census is made available on open data portal of the PMC.

5 Biodiversity of Trees in the Pune Municipal Corporation

There are three indices which fit the requirements stated above. They are the simple biodiversity index, the Biodiversity Intactness Index (BII) and the original Natural Capital Index (NCI) implemented in the Netherlands [22, 23]. The NCI accounts for ecosystem quantity and ecosystem quality, requires a baseline and time-series data [23]. Applications of NCI in Hungary and Mexico, however reveal shortcomings in its applicability to urban areas like Pune [24,25]. NCI as an indicator is not optimized for urban use since it is primarily aimed at conservation of rare species. That is not usually a priority issue in urban areas for municipal corporations. Further NCI's requirement of time-series data constricts us since the PMC's tree census does not have time-series data. The BII, on the other hand seems more appropriate.

$$\mathrm{BII} = (\Sigma_i \Sigma_j \Sigma_k R_{ij} A_{jk} I_{ijk}) / (\Sigma_i \Sigma_j \Sigma_k R_{ij} A_{jk})$$

where the population impact(I_{ijk})is defined as the population of species group i under land use activity k in ecosystem j relative to a reference population in the same ecosystem type. And, whereR_{ij} = richness (number of species) of taxon i in ecosystem j, andA_{jk} = area of land use k in ecosystem j [22].

The BII is an aggregate index meant for overviews from public policy makers. It can be disaggregated based on the specifics of the user of the mode: by ecosystem or regions, land use activity, specie groups or functional types. It provides an average richness and an area-weighted impact of the biodiversity. However, the PMC Tree Census data lacks certain attributes for the BII and does not need the same level of detail. The final index, the simple biodiversity index, on the other hand, accounts for the number of species living in an area, divided by the total number of individuals [26]. We need to further assess our carbon sequestration model to decide which biodiversity index is most applicable.

Accounting for the three contingencies stated above, there have been a series of models which measure carbon sequestration. We need to create an adapted model which can be extracted from geospatial data. To that end, there are three prominent models we seek to evaluate for adaptation for the PMC: UFORE (Urban Forest Effects model), CTCC (The Centre for Urban Forest Research's Tree Carbon Calculator) and Russo et al.'s adapted allometric model [27,28]. All three account for specific mortality and biomass concern.

The tree data from Pune had 484 tree species with about 201 species being directly identified to native category (either from India or Indian sub-continent) and rest belonging to non-native category. Ecologically, the native species are those that naturally occur in a given geographical area and are expected to be stable in their habitat. While non-native species, also known as introduced, some of which can become invasive in the local area. A total of 32,16,823 trees captured in the census records 25% of the trees are native ones and 73% are non-native species. We could not find classifications for about 2% of the population. We did find 342 nativity classification across 484 species of which 124 classification were representing India Geography with 201 species.

The diversity of the trees when analyzed from economic and social utility perspective can be classified into following categories: Edible oils, Essential oils, Firewood, Fodders, Fruits, Medicinal, Ornamental, Paper industry, Rubber source, Spice, Timber wood, and Vegetable types. The frequency distribution of classification of trees is presented below figure 2.

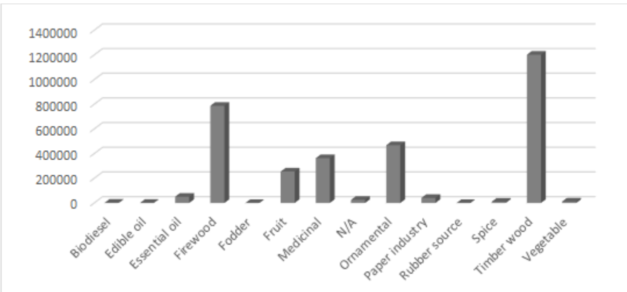

Fig. 2. Spread of tree species based on socio economic categories

We do observe that 7% of the trees are evergreen and 93% of them are deciduous. Deciduous in reference to trees and shrubs refer to seasonally shedding leaves after flowering. The flowering seasonal definitions have been looked into across the year various tree species and below chart in figure 3 gives the distribution of trees that have flowering periods across the year. The theoretical maximal biodiversity value for all the wards in Pune could maximally be defined between 1 and 0.00076 with the assumption that each one of the wards does have all possible tree species variety when the count of the trees are more than the number of individual trees or all trees are unique of its kind when the count of the individual trees are less the number of species available in Pune.

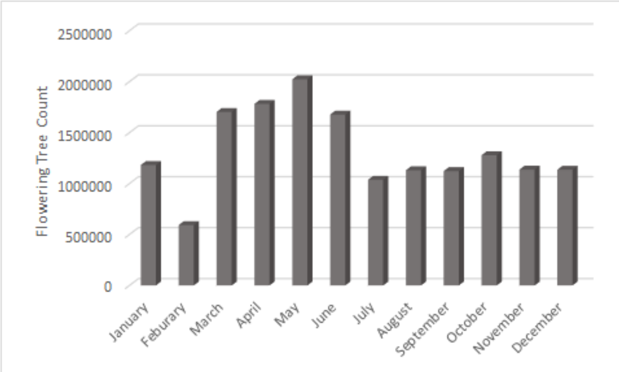

Fig. 3. Spread of count of trees across flowering seasons

It is essential that measure of biodiversity essentially considers not only count of individual trees and number of species of trees but various other factors such as area of shade provided, conditions of health of the trees as well as growth parameters such as girth, height and canopy dimensions, socio-economic value provided and also maintaining all-year-round nutrition. Trees provide soil and water conservation, facilitate carbon sequestration, improve biodiversity and increase the number of pollinators and natural pest predators, like birds. The genetic diversity is important for landscape restoration efforts. The loss of genetic diversity of the main tree species results in elimination of other species, like insects and fungi, that are specifically associated with certain trees leaving the whole forest ecosystem biologically impoverished. Many people in urban and rural localities depend on trees for fuel, medicine, food, tools and containers, fodder for livestock, shade, and watershed maintenance. In our work, we do propose to achieve an improvement of about 5% to 10% increase in the biodiversity of trees across various wards in Pune. Hence, the diversity of the tree species need to be maintained across various localities of the city considering the factors that are relevant each locality rather than considering all the factors in one go.

6 Fall Calendar

The trees shed their petals typically after flowering season and the fall is the right time to prepare the trees and shrubs for winter. Pruning of the branches of the trees in fall periods of the year can help protect trees from subsequent cold winter season so they bloom as vibrant as possible in the spring. The fall period provides us an opportunity to see the tree’s branch structure visibility to evaluate and prevent the spread of certain disease pathogens or insect infestations in the trees. The other interesting part is the use of the fallen leaves for recycling to create rich farm manure. We attempted to depict the fall calendar for the trees covered in the collected census data and the figure 4 presents the count of the trees that could enter into fall periods during the various months of the year. Nearly about 35% of the trees have the fall period beginning in the month of July/August every year.

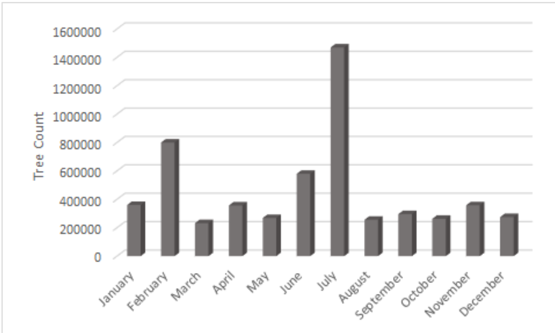

Fig. 4. Depiction of count of trees for fall calendar

7 CO_2 Absorption Model

Trees absorb CO_2 from the atmosphere and then transforms this greenhouse gas into oxygen and biomass. It is estimated that a well grown tree can absorb about 22 kg of Carbon di-oxide (CO_2) per year and sequester around 1 ton of CO_2 by the time it turns 40 years [29]. The absorption of CO2 gases by the trees is directly dependent on the amount of phosphorous content in the soil. If the availability of phosphorous content in the soil is scare, the absorption rate may be expected to come down by 50% to even sometimes 100%

In this work, we attempt to bring in the various factors that can act as a motivator for evolving a model for CO_2 absorption for Pune city. The following data have been made available

1. Geo-coordinates of the tree locations
2. Species names along with their seasonality cycle definitions (flowering season & fall calendar)
3. Conditions of the health of the tree (healthy, good, average and poor)
4. Girth, length and canopy dimensions of the trees.

The geo-coordinates data will enable us to identify the greenery gaps across various wards which in turn can be used for identifying open spaces for potential locations for planting of new trees. Planting of new trees in open spaces require investments in terms of participation of many stake holders as well as bringing in right set of tree samplings to ensure that the diversity of trees in each one of the localities in maintained in a balanced manner. The figure 5 presents the scope of the proposed model that intends to maximize CO_2 absorption as well as maximizing the diversity of tree cover in each locality.

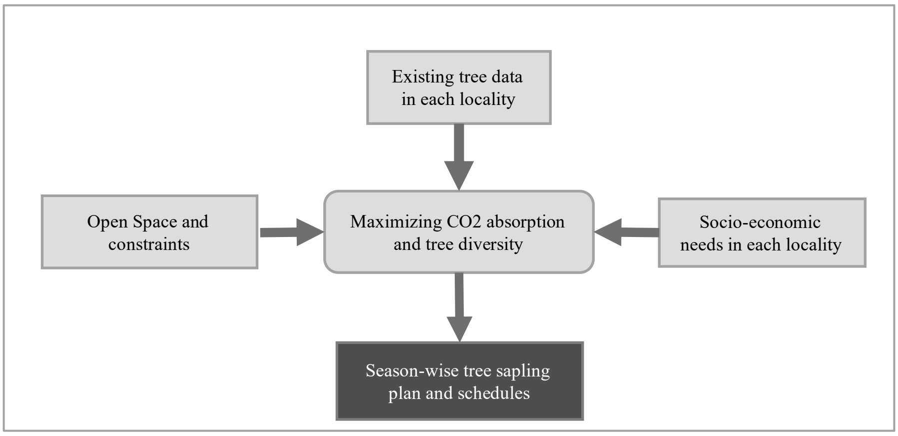

Fig. 5. Creation of plan for planting of saplings using CO_2 absorption needs and other factors

The root to short ratio is an important measure that helps us in assessment of overall health of the plants and trees. Each tree species has a normal root to shoot ratio and any changes in from this normal level (either up or down) would be an indication of a change in the overall health of the trees/plants. Apart from planning the planting of tree saplings, it is also necessary to keep observations on what is happening with the identified plants. The ratio of the amount of plant tissues that have supportive functions to the amount of those that have growth functions is defined using root to shoot ratio. Variations that are quite significant on root to shoot ratio values during a plant's life cycle is part of an intrinsic ontogeny, but growth rates of roots and shoots continually adjust to resource availability with photo-assimilate (hence biomass). In herbaceous plants, root to shoot ratios typically decrease with age (size) due to sustained investment of carbon in above-ground structures. An unexpected shoot response to above-ground conditions results in increase of the root biomass which is influenced by below-ground conditions where low availability of either water or nutrients commonly leads to greater root to shoot ratio.

8 Benefits and Implications to the Stakeholders and Need for Voluntary Contributors

The involvement of various stakeholders and their contribution to improve the green cover needs to be sustained over a period of time as well as going forward in future. This necessitates bringing in motivation by highlighting the contribution of the sponsors, communities and other stakeholders in the system to improvement of various metrics relevant to air quality levels, BOD levels, etc. in the various print forms, broadcasts and other mechanism. Subsequently in near future, the tree census data for over 40 lakh trees and their numerous attributes can be measures and used for improving the bio-diversity and preservation of bird/animal ecology quite effectively.

9 Conclusions

In this paper, we do make an attempt to understand about 26 attributes of the trees collected for the 40 lakh trees that have been capture in the city tree census data. We do analyze to characterize the census data to classify the trees considering ward details, socio-economic needs, flowering season for trees and various other information. We do create a fall calendar for the trees across the Pune Municipal locality to understand the quantum of leave that may fall during various months of the year to plan for recycling and composting process. We propose to conceptualize a model for planting of new samplings going forward in the future using CO_2 absorption needs of various wards/localities in Pune, availability of open spaces and expectations on socio-economic benefits. A systematic treatment to the data obtained through this exercise would be beneficial for understanding the status of tree vegetation across the municipal unit, recognizing the gaps in plantation schemes and projecting plants as a significant resource for the citizens.

Acknowledgements

We acknowledge Yash Chahande, Siddhartha Sengupta and Sanam Panjwani, the graduate students from University of Toronto for working with us in preparation and analysis of data as well providing valuable insights into the different perspectives of problem definitions from academic perspectives. We warmly acknowledge Kishore Padmanabhan, Tata Consultancy Services, Chennai India for providing us with research directions and guidance in defining the scope of this work. We sincerely thank Devdatta Tengshe, a freelance consultant and an open data enthusiast to help us creation of data for our analysis. We would like to acknowledge the encouragements received from the authorities of Savitribai Phule Pune University and College of Engineering Pune.

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