CARBON SEQUESTRATION POTENTIAL OF TREES IN AND AROUND PUNE CITY

By

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SCOPE OF THE STUDY

Global warming is amongst the most dreaded problems of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol.

Trees are amongst the most significant elements of any landscape, both due to biomass and diversity. Their key role in ecosystem dynamics is well known. However, it is paradoxical that the vegetation has undergone destruction and degradation in the modern times due to industrial and technological advancement achieved by human society. This advancement has resulted in emission of carbon in the ecosystem. Therefore, there is need to address environmental issues related to them. Trees are important sinks for atmospheric carbon i.e. carbon dioxide, since 50% of their standing biomass is carbon itself (Ravindranath *et al*. 1997). Importance of forested areas in carbon sequestration is already accepted, and well documented (FSI, 1988, and Tiwari and Singh, 1987). But hardly any attempts have been made to study the potential of trees in carbon sequestration from urban area. Non-forested but tree dominated area in cities include 'green pockets' such as institutions, avenues and public gardens. In this study we make an attempt to explore ecological conservation values of such areas in urban ecosystem. The study constitutes an assessment of standing biomass, carbon sequestration potential of tree flora in and around Pune City, with inventories on indigenous and exotic tree species. Such green areas or pockets act as Hot Spot in urban biodiversity (Kulkarni *et al.,* 2001). The role of such areas in urban ecosystem needs to be addressed. Therefore, to evaluate the status of such green pockets, the present study was undertaken on vegetation in fringe forest pockets and green areas in and around Pune city.

Development of sustainable green cities is the need of today's fast urbanizing world. Nearly half the Indian population will soon be living in urban areas. And urbanization is vigourously promoted both politically and socially as a means to enhance average living standards. However, the ever-growing urbanization threatens escalating of carbon emission due to higher consumption of goods and services compared to the rural sector. Hence it is crucial that the balance be maintained between the carbon emission and carbon sequestration to achieve sustainability. Unfortunately, little is known at the policy or scientific level about the carbon budget of urban areas, despite earlier attempts to estimate carbon emissions. (Parikh *et.al.,* 1994). During the

present investigations, an attempt is also made to assess the current trend of carbon balance in Pune City as a case study from India with possible implications and remedial measures.

For convenience, the topic was divided under following sub heads;

INTRODUCTION :

- What are Carbon Sinks
- Important clauses of Kyoto Protocol related to carbon sequestration
- The Indian scenario

MATERIALS AND METHODS :

- Physical Settings and Climate of Pune City
- Description of Sampling Sites
- Sampling Technique
- Biomass Estimation
- Tree Density Estimation of Pune City
- Carbon emission estimation

RESULTS :

- Carbon emissions of Pune City
- Carbon sequestration of Pune City
- Importance of Forest Patches in Pune- A case study of Vetal Hill (Bhamburda Van Vihar)

DISCUSSION AND CONCLUSION :

INTRODUCTION

Global Carbon Sinks (Some Basic Concepts) : Global carbon is held in a variety of different stocks. Natural stocks include oceans, fossil fuel deposits, the terrestrial system and the atmosphere. In the terrestrial system carbon is sequestered in rocks and sediments, in swamps, wetlands and forests, and in the soils of forests, grasslands and agriculture. About two-thirds of the globe's terrestrial carbon, exclusive of that sequestered in rocks and sediments, is sequestered in the standing forests, forest under-storey plants, leaf and forest debris, and in forest soils. In addition, there are some non-natural stocks. For example, long-lived wood products and waste dumps constitute a separate human-created carbon stock. Given increased global timber harvests and manufactured wood products over the past several decades, these carbon stocks are likely increasing as the carbon sequestered in long-lived wood products and waste dumps is probably expanding.

A stock that is taking-up carbon is called a "sink" and one that is releasing carbon is call a "source." Shifts or flows of carbon over time from one stock to another, for example, from the atmosphere to the forest, are viewed as carbon "fluxes." Over time, carbon may be transferred from one stock to another. Fossil fuel burning, for example, shifts carbon from fossil fuel deposits to the atmospheric stock. Physical processes also gradually convert some atmospheric carbon into the ocean stock. Biological growth involves the shifting of carbon from one stock to another. Plants fix atmospheric carbon in cell tissues as they grow, thereby transforming carbon from the atmosphere to the biotic system.

The amount of carbon stored in any stock may be large, even as the changes in that stock, fluxes, are small or zero. An old-growth forest, which is experiencing little net growth, would have this property. Also, the stock may be small while the fluxes may be significant. Young fast-growing forests tend to be of this type. The potential for agricultural crops and grasses to act as a sink and sequester carbon appears to be limited, due to their short life and limited biomass accumulations. Their role for human management of carbon could increase as we learn more about their potential.

How Forest Ecosystems Act as Sinks : A sink is defined as a process or an activity that removes greenhouse gases from the atmosphere. Carbon sequestration is the extraction of the atmospheric carbon dioxide and its storage in terrestrial ecosystems for a very long period of time - many thousands of years. Forests offer some potential to be managed as a sink, that is, to promote net carbon sequestration.

What is Sequestration : Terrestrially, carbon is stored in vegetation and in the soil. Plants store carbon for as long as they live, in terms of live biomass. Once they die, the biomass becomes a part of the food chain and eventually enters the soil as soil carbon. If the biomass is incinerated, the carbon is re-emitted into the atmosphere and is free to move in the carbon cycle.

The role of forests in carbon sequestration is probably best understood and appears to offer the greatest near-term potential for human management as a sink. Unlike many plants and most crops, which have short lives or release much of their carbon at the end of each season, forest biomass accumulates carbon over decades and centuries. Furthermore, carbon accumulation potential in forests is large enough that forests offer the possibility of sequestering significant amounts of additional carbon in relatively short periods – decades.

Fortuitously, forests managed for timber, wildlife or recreation sequester carbon as a by-product. Forests may also be managed strictly to sequester carbon. Such a focus on biomass accumulation could provide a somewhat reduced amount of other forest ecosystem services such as biodiversity. However, if forests managed for carbon sequestration are allowed to mature and remain unharvested, one of the long-term effects may be enhanced biodiversity.

There are four components of carbon storage in a forest ecosystem. These are trees, plants growing on the forest floor (under-storey material), detritus such as leaf litter and other decaying matter on the forest floor, and forest soils. Carbon is sequestered in the process of plant growth as carbon is captured in plant cell formation and oxygen is released. As the forest biomass experiences growth, the carbon held captive in the forest stock increases. Simultaneously, plants grow on the forest floor and add to this carbon store. Over time, branches, leaves and other materials fall to the forest floor and may store carbon until they decompose. Additionally, forest soils may sequester some of the decomposing plant litter through root/soil interactions.

Forest transitions from one ecological condition to another will produce substantial carbon flows – forests can be a carbon source or a sink. It is important to carefully assess exactly what is happening to the carbon as the forest changes to determine the forest's sink/source contribution. Net forest carbon may be released, thereby making the forest a source, due to biomass reductions from fire, tree decomposition, or logging, any of which will reduce the forest biomass. In the case of decomposition or fire, forest carbon is released into the atmosphere. However, the forest may again become a carbon sink as it is restored through forest re growth.

Important clauses of Kyoto Protocol related to carbon sequestration:

The Kyoto Protocol to the UN Framework Convention on Climate Change (UNFCCC, 1997) has provided a vehicle for considering the effects of carbon sinks and sources, as well as addressing issues related to fossil fuels emissions.

There are at least four important points to recognize:

a) Forests are definitely included in the Protocol.

b) The Protocol provides for credit for some human induced forest based emission reduction activities begun in 1990 or later. However,

c) Credits accrue only for carbon sequestered during the 2008-2012 commitment period.

d) Forest management, conservation, and agricultural soil sinks are not specifically mentioned and hence their role in obtaining credits is currently subject to varying interpretations.

The approach of the Kyoto Protocol clearly is not comprehensive in its treatment of sinks, being inherently restrictive in its focus. The Protocol deals only with a small subset of the total carbon fluxes that are generated by selected sinks and sources, limiting its attention to human-induced carbon fluxes dealing with afforestation, reforestation and deforestation undertaken after 1990. Additionally, the approach is further limited by its focus on changes in carbon stocks only in the commitment period of 2008-2012. Thus, the Protocol ignores carbon changes during some periods and from some sources, many human-induced. For example, management and many human-induced actions will generate far more carbon sequestration than credit received. However, the Protocol does have provisions, for making desired changes through time.

The Protocol specifically mentions emissions from sources and removals by sinks resulting from direct human-induced land-use change and forest related activities – deforestation, reforestation and afforestation – undertaken since 1990. However, the Protocol is silent on the role of other sinks in meeting national emission inventories. Agricultural land, for example, is mentioned as a possible carbon source, which must be included in a country's emission inventory, but there are no provisions for national credits for the buildup of the agricultural soil carbon sink. However, Article 3.4 of the Protocol appears to allow for expansion of recognized human-induced sink activities. Finally, the Protocol is largely silent on how such credits would be calculated or verified.

Carbon Reduction Credits:

The cost aspect of forest based carbon sequestration, as an offset mechanism is particularly important. It determines how carbon sequestration compares with other potential carbon offset mechanisms in the broader scheme of greenhouse gas reduction policies. According to the protocol, each country will be given carbon credits based on the carbon emission and sequestration scenario. If developing countries like India, has to improve on the issue of carbon credits, then role of vegetation patches in carbon sequestered should be considered.

A related issue is the "unintended consequences" associated with the development of a carbon sequestration system. Simply focusing on forests for carbon sequestration would probably lead to the almost exclusive establishment of single species tree plantations. As was noted earlier, old growth forest has limited potential for absorbing additional atmospheric carbon. When ecosystem climax levels are reached, old growth forests in effect become neutral, acting primarily as a fixed carbon sink rather than a net sequester. Without proper incentives, there exists the possibility that monoculture crops, which are known to sequester carbon rapidly, and thus offer greater short-term carbon storage gains than the previously existing ecosystem, will replace biodiversed heterogeneous forest ecosystems. Here while formulating a strategy for plantation, care should be taken that diversified plants should be chosen for afforestation programme.

The Indian Scene

According to Ravindranath *et al.* (1997) the standing biomass (as above and below ground biomass) in India is estimated to be 8,375 million tons for the year 1986, of which the carbon storage would be 4,178 million tones. The total carbon stored in forests, including soil is estimated to be 9578 m t. On the other hand, carbon emissions from fossil based energy production and consumption activities in India have been estimated at 152-205 m t per year. Clearly, there are wide differences in the estimates made by different scientists and ecologists. The corresponding estimate from agriculture activities including fuel burning ranges from 43 m t to as high as 115 m t. The current rate of carbon emission from agricultural and forestry sectors is just about being balanced by the current rate of reforestation. This still leaves the entire fossil-based emissions unabated. So, does India have any additional potential to sequester more carbon through forestry? If it does, what wold it cost? India has nearly 53 million of degraded lands. According to a study by the Delhi based Institute of Economic Growth, at least 39 m ha of the degraded lands mentioned above are clearly feasible for carbon sequestration. These estimates are based on their land capabilities, feasible forestry options, and demand patterns for different types of forest products. Of these, about 6 m ha of pastureland can be brought under community forestry and about 9 m ha of cultivable wasteland under short timber plantations. 6 m ha of miscellaneous tree crop and other than current fallow lands can be for long timber plantations, 12 m ha of partially degraded areas for natural regeneration and 6 m ha of fully degraded forests for enhanced regeneration.

Such a mix of forestry options with land capability can enhance the sequestration potential by 78 million tones of additional carbon per year by the year 2020.

TABLE 1.1. **LANDUSE IN INDIA**

LANDUSE	AREA (10^6 ha)	% OF TOTAL AREA
Agriculture/area cropped	157.70	47
Forests (area officially recorded as forests)	75.18	22.8
Permanent pastures and other grasslands	1.15	3.7
Land under cultivable tree crop and groves	3.91	1.3
Cultivable wasteland	16.64	5.1
Land under non-agricultural uses (water bodies, settlements etc.)	17.53	5.3
Barren and wasteland	24.6	7.5
Area for which no records exist	24.09	7.3
TOTAL	328.8	100.0

Source: FSI (1988)

Due the additional supply of woody biomass, the current rate of deforestation would also come down, thereby conserving another 69 million tones per year. In this process, 78 to 147 m t of carbon would be sequestered additionally as against 150-200mt of carbon emission from the fossil energy sectors.

Carbon Emissions:

Carbon dioxide and other greenhouse gases are emitted by various anthropogenic activities. Figure 1.1 indicates corbon dioxide estimates for India during 1970 to 1995.

MATERIALS AND METHODS

The following section describes the study areas, the sampling technique, the procedures followed for the estimation of biomass and carbon sequestration.

Study Area:

Physical Settings and Climate: Pune, earlier famous as Poona is one of the most important cities of Western India aptly called the `Queen of Deccan' after it's elevated position atop the Deccan Plateau. The city is nicknamed variously such as `Pensioner's Paradise', the `Oxford of East', `Detroit of India', the cultural capital of Maharashtra', once the `Cycle city ' and now the `Scooter city ' of India and upcoming `IT-BT' capital of India.

It is situated on the Deccan plateau and lies on leeward side of the Western Ghats (Sawant, 1972) and is hardly 50 km from the crest of the Western Ghats. It is about 160 kms south-east of Mumbai, by road. It is situated between, (18°31' N, 73°51' E) at a height of 560m above the mean sea level, near the confluence of Mula and Mutha rivers. The city is surrounded by hills on the east and the south. The Sinhagad-Katraj-Dive ghat range is the southern boundary of the urban area.

The climate is typical monsoonal, with three distinct seasons- summer, rains and winter, as elsewhere in India. The height above sea level and the leeward location with reference to the Western ghats have made the city climate moderate and salubrious. The mean daily maximum and the mean minimum for the hottest month - May is 37°C and 23°C respectively. The mean daily maximum and the mean minimum for the coldest month of December are 30°C and 12°C respectively. The relative humidity ranges from 36% in March to 81% in August. Three fourths of the annual rainfall of 70 cm occurs in just four months from June to September.

The population-increase in Pune City during the last two decades has been particularly rapid with a consequent effect on various environmental factors. The data available from the Pune Municipal Corporation is given below clearly substantiates the above view (Table 2.1).

Table 2.1 **Population Of Pune City**

Year	Mid-year population
1980	1,097,000
1985	1,353,000
1990	1,527,000
1994	1,700,000
2000	2,540,069

Tree Cover of Pune City: Pune is the fourth greenest city in India. Currently it has more than two lakh trees. The major-forested areas of the city include Katraj and Sinhagad valley. The other areas under tree cover include institutions like Pune University, National Defence Academy, Pune Cantonment and gardens like the Empress Garden. Some of the hills in the city, such as the Vetal hill range and the Parvati-Pachgaon hill have undergone extensive afforestation by the Forest Department. According to the Environmental Status Report of the Pune Municipal Corporation, the city has more trees today than a few years ago. The number seems to be increasing by about 1 lakh each year. The total forest area of Pune is 338.64 ha. Of this, 47.06 Ha is encroached upon. The PMC is carrying out plantations on empty plots and along roadsides, besides the plantations by the Forest Department.

Description of Sampling Sites:

Ghera Sinhgad: - It is situated 25 km south west of Pune and covers an area about 2273 ha. Valley situated in the eastern offshoot of the Western Ghats was chosen for the study. In the past it hosted a good patch of closed forest with predominantly moist deciduous tree species. Now it has turned into a degraded secondary deciduous forest with open canopy, average height of the trees is 15-20 m. Planted teak is abundant here and the mouth of the valley is under paddy cultivation. Predominant tree species are *Lagerstroemia microcarpa, L. papviflora, Elaeodendron glaucum.* Lopping and moderate cattle grazing are the current problems.

Katraj: It is situated along the southwest flank of the city, approximately 10 km away. Katraj hills harbour a mosaic of dry deciduous forests with 5-10m tall trees, and grasslands. The type of forest is dry deciduous open type. Average height of the trees is 10-15 m. thickets comprising of *Zizyphus-Acacia-Flacourtia-Lantana* are important features of the locality. Lot of anthropogenic activities like stone quarrying, cattle grazing are the main causes of disturbance. Trees considered for afforestation programme are *Gliricidia sepium* and *Acacia auriculiformis.* The area occupied by afforestation measures is 102 ha. The predominant tree species are *Boswellia serrata, Odina odier, Cochlospermum religiosum.*

The scrub at Parvati-Pachgaon (P) and forest at Vetal Hills (V) have dwarf (3-6m), scattered wild trees as well as exotic ones planted.

Parvati-Pachgaon: A scrubby hill situated 4 km to the south west of Pune and prone to fire and cattle grazing. The dominant tree species are *Acacia chundra, Acacia leucophloea, Flacourtia, Boswellia serrata.* The average height of the trees is 6m. Local civic authorities and forest department conducted several afforestation measures. The species that are considered for afforeststion are *Gliricidia sepium, Dalbergia melanoxylon, Leucaena leucocephala* etc.

Vetal Hill (Bhamurda Van Vihar) : Forests at Vetal hill are comprised of dwarf, scattered natural trees (3-6m tall) amidst planted exotic ones. The vegetation here predominantly comprises of *Anogeissus latifolia, Acacia catechu, A. leucophloea* etc.

The Table 2.2 gives comparative account of the above localities on the basis human impact gradient.

Table 2.2 Comparative Account of Various Localities

LOCALITY	I : E	IMPACT LEVEL	TREES
Ghera Sinhgad,	35:1	Low Impact	Predominantly wild, Indigenous species
Katraj	13:1		
Vetal Hill	3:1	High Impact	Cultivated and Exotic species
Parvati-Pachgaon	2.5:1		
Pune University	1.4:1		
Sambhaji Garden	1.35:1		

Pune University: The total area of the Pune University campus is 166 ha. (0.23% of city) which constitutes 51% of vegetation cover. This is categorized in to four vegetation types.

1. Scrub savanna (29%) – Barren land, with dry deciduous trees frequently distributed.
2. Monoculture (32% of vegetation area) – Plantation of dry deciduous species like *Dalbergia melanoxylon* & *Gliricidia* .
3. Mixed vegetation (32% of vegetation area) – Quite dense with more % of evergreen species .
4. Garden (6%) – Highly diverse species with a high percentage of evergreen trees. It is the densest vegetation type.

Sambhaji Udyan: Pune city has forty gardens covering a total area of 2.2 sq.km. Sambhaji Ubyan was taken as a representative garden. These gardens have a high percentage of exotic trees.

Methodology (Sampling Technique) : Trees and lianas were sampled either by quadrat method or by strip transect. Both these are area-limited surveys. A line transect of 500m × 20m was laid in each vegetation type. The adjoining figure (fig. 2.1) gives diagrammatic representation of the sampling units.

Biomass Estimation: The biomass of a tree is the sum of the biomass of its roots, trunk, branches, leaves and reproductive organs- flowers and fruits. For an accurate measure of biomass the tree would have to be felled. To avoid this, the standing woody biomass has been estimated in this study in the following manner:

The height of the tree is measured. Height can be measured by ocular, non-instrumental and instrumental methods. For the present project, the ocular method was chosen, since it is the fastest, easiest and least expensive method. First the investigator (in this case the author) marked the tree at her height (154 cm, assumed to be 1.5 m or 5 ft). Then, from a distance of about 3 meters from the tree base, the number of 1.5 m sections from tree base to tree top were counted and multiplied by 1.5 to get the height of the tree in meters. Since this method can lead to errors, the following precautions were taken: -

- Height estimation was practiced with trees growing next to multi-storey buildings (to get a scale and for easy verification –1 storey = 10 ft =3m approx.)
- Height classes were created for ease in calculations

TABLE 2.3 **Height Classes**

Height class	Height (ft)	Average height (ft)	Average height (m)*
A	5-10	7.5	2
B	10-20	15	4.5
C	20-30	25	7.5
D	30-40	35	10.6
E	40-50	45	13.5

*Approximate height in meters was used for calculations.

True trees are defined by girths at breast height (GBH) of more than 30 cm. The corresponding GBH (Girth at Breast Height) and height for each individual tree were noted. Biomass and stored carbon for each vegetation type was calculated as per the standard procedure

The girth of the tree was measured at breast height (1.3m). The trees with girth above 30 cm were considered. Besides, saplings with a girth of over 20cm were also taken into consideration, as young saplings sequester carbon at a faster rate and their chance of survival is high.

The following precautions were taken while measuring the girth: -

- If the tree is branched below breast height, the girth must be taken for individual branches, and must be noted separately.
- All branches with a girth above 10 cm were taken into account.
- If the tree is at an incline, stand in the upper slope while taking the girth.
- If the tree branches at GBH, then measure the girth slightly below the swell.

Biomass was estimated by multiplying the biovolume by the green wood density of tree species.

Bio-volume = b = $0.4 \times (GBH/\pi)^{2} \times H$

Biomass = Specific gravity of wood $\times$ b

Where,

D = (GBH/π), diameter calculated from GBH, assuming the trunk to be cylindrical.

H = Height

Wood densities were taken from the Poona district gazetteer of the Bombay State (revised), Vol. 20,1954. Wherever the wood density of the tree species was unavailable, the standard average of O.6 gm/ cm^3 was taken.

The carbon sequestration rate was calculated as 1% of the standing biomass each year.

Besides vegetation, fertile soil and wetlands are good sinks of carbon. Pune has many wetlands including The Mula-Mutha-Pavana River system, Pashan Lake, Lakaki Lake, Katraj lake- upper and lower and the CME Lake.

Carbon storage in forest soils of India is considered based on the soil organic carbon content in the top 30 cm soil in different forest types from published studies. The soil carbon content of tropical dry deciduous forests have been calculated by Sachan *et. al.* (1980), Singhal *et al*. (1983), Kumar *et. al.* in 1987, and R. Singh *et. al.* in 1990 . On the basis of their studies, it is estimated that 57.99 tons of carbon is present per hectare in tropical dry deciduous forests.

The estimation of carbon sequestration capacity of water bodies and soil were not undertaken in the present study.

Tree Density Estimation of Pune City: The city under PMC is divided into 48 wards. (Map1). A grid of 1 x 1 km^2 was superimposed on the map of Pune City and the tree density was estimated by ranking on a scale of 1 to 5. At least one transect was taken in representative areas of each vegetation scale, and the tree biomass was estimated for Pune city. (Map3)

Carbon emission estimation: The estimation of carbon dioxide emission of the city was calculated on the basis of a case study of India, done by Parekh *et al.* (1994). This study dealt with the environmental implications of consumption patterns across income classes in India. The analysis was based on the input-output model using consumption, expenditure distribution data from various sources. The rich have a more carbon intensive lifestyle than the middle class and the poor communities. In fact, the per capita direct and indirect emission level of the urban rich was calculated to be about 15 times that of the rural poor. According to this study, the carbon emission for urban India according to the expenditure classes were given as follows: -

TABLE 2.4 **Per capita carbon emissions by income classes (kg C/year)**

Urban	**1989-90**	**Doubling of PCE 2010**
Bottom class	103.4	122.5
Middle class	245.7	279.4
Top class	873.6	914.7
Total	237.4	476.4

Of this consumption, 62% are due to private consumption, while 38 % is due to public or Govt. Sector consumption.

The direct or indirect consumption of each resource including food items, manufactured goods, energy, transport, durable goods , fuel etc. was converted to the carbon emitted during the production and consumption of that resource. Assuming a linear rise in the per capita expenditure values, we can calculate it for the intermediate years. Table 2.5 depicts per capita emission values by various income classes.

TABLE 2.5 **Per capita carbon emission, by income classes (kg C/year)**

	1990	2000	2002	2010	2020	2030
Top class	873.6	894.15	898.26	914.7	935.25	955.8
Middle class	245.7	262.55	265.92	279.4	296.25	313.1
Bottom class	103.4	112.95	114.86	122.5	132.05	141.6
All India	127.9	200.5	215.08	273.2	345.85	418.5

(Increase per capita per year: Top =2.055 kg C /year, Middle = 1.685 kg C /year, Bottom = 0.955 kg C /year , All India = 7 .265 kg C /year.)

For the present study, the 1 x 1 km^2 grid map of Pune City was used. Each cell was categorized according to the socio-economic status of majority of the people in that area. Carbon emission was calculated assuming average population density in Pune City.

Two such maps were created. Refer appendix for Maps 2 and 3. The first map zoned the city into low class, middle class and high class regions, on the basis of the socio-economic status of the majority of the people living in each 1x1 km^2 cell.

The classification was done on the basis of the income generated per family (i.e. the sum of the incomes of all earning members in a family). Each family member was expected to emit carbon according to the income class.

Assuming income:

Less than Rs. 50,000 p.a. = Low class

Rs. 50,000 to Rs. 5,00,000 p.a. = Middle class

More than Rs. 5,00,000 p.a. = High class

According to the rates of carbon emission per capita per year of each class (Parekh et.al.,1994) , the total carbon emission was estimated.

The second map depicts the vegetation cover pattern over the city. Five vegetation classes were assigned. Depending on the biomass density of each category, the total carbon sequestration was calculated.

RESULTS

There is an increasing tendency among the environmentalists to view holistically the ever-decreasing forest cover and subsequent fall in carbon sinks. This decline in carbon sinks has resulted in concomitant increase in carbon emission and a subsequent rise in global temperatures. Thus global warming is amongst the most dreaded problems of the new millenium, and carbon emission is supposedly the strongest causal factors of global warming.

The role of forested areas, afforested patches, soil in carbon sequestration and their relation with carbon flows in the ecosystem is very well discussed by Ravindranath *et al.* (1997). In this context, standing biomass and carbon sequestration potential of the 'green areas' in and around Pune City was calculated. Table 3.1 depicts locality wise standing biomass and carbon sequestration potential across various vegetation types studied.

TABLE 3.1 **Estimated Values of Standing Biomass and Carbon Sequestration at Different Localities *.**

Locality	Area (sq. km)	Unit Biomass (t/ha)	Total Standing Biomass (tons)	Stored Carbon (tons)	C. seq. T/yr.
Vetal Hill	0.97	45.00	43.65	21.82	0.43
Parvati-Pachgaon	2.1	13.36	28.05	14.02	0.28
Katraj	10.5	38.44	403.62	201.81	4.03
Sinhgad	22.73	56.88	1292.8	646.4	12.92
Sambhaji Garden	0.12	110.9	13.30	6.65	0.13

* Biomass & stored carbon in each vegetation type for each of the localities mentioned were calculated according to Gadgil *et al.* and Ravindranath *et al.* 1997.

Urbanization is rapidly increasing worldwide, and the scenario of developing countries like India is not different. With constant immigration from rural areas to urban areas, nearly half the population would soon be living in urban areas.

Parikh *et al.* (1994) reported that carbon emissions are much higher in urban, consumerist societies than rural, and biomass dependent landscapes. The direct or indirect consumption of each resource including food items, manufactured goods, energy, transport, durable goods, fuel etc. was converted to the carbon emitted during the production and consumption of that resource. Assuming a linear rise in the per capita expenditure values, we can calculate it for the intermediate years.

ESTIMATION OF CARBON EMITTED BY PUNE CITY

A grid map of Pune city was used. (Map 1)

1 cell =1.0 square kilometer.

Total number of cells covering PMC area = 250 cells

Cells covering cantonments, forest areas = 27 cells

Hence, total area under PMC = 223 cells

The total population of Pune city (PMC) according to the census2001 = 25,40,069

Total area under PMC 233.1 sq. km.

Therefore, the population density = 2540069/233.1

= 10897 persons per sq. km.

Total cells covering residential area under PMC=223

Therefore,

Population density=2540069/223= 11390. This population density was taken into consideration for further calculations.

The Pune City grid map was zoned according to various economic classes. (Map2)

Assuming equal population density all over Pune city, the following table was generated: -

TABLE 3.2.

CLASS	No. of CELLS	AREA sq. km. (A= cells x 1.0)	POPULATION (B= A x11390)	C- EMISSION Kg C/capita/yr (C)	TOTAL C-EMISSION kgC/yr (D=B xC)
Top Class	26	26.0	296140	898.26	266010716.4
Middle Class	148	148.0	1685720	265.92	448266662.4
Low Class	49	49.0	558110	114.86	64104514.6
Total			**2539970**		**778381893.4**

- At the present rate, Pune emits 7.8 lakh tons each year.
- The C – emission rates were taken from "consumption pattern differences and environmental implications"- a case study of India done by Jyoti Parekh *et. al.* in 1994.

ESTIMATION OF CARBON ABSORBED BY THE TREES IN PUNE CITY

The Pune City grid map was was zoned according to four vegetation classes 1-4. (Map3)

Class 4 was considered to have vegetation cover like that over Prabhat Road and Model Colony For this class, the biomass was assumed to be similar to that of Sambhaji Udyan and the gardens of Pune University , i.e. 110 tons/year.

Class 3 included areas like Aundh

Biomass for class 3 = ¾ x 110tons/yr = 82.5 tons/years

Class 2 included areas like Warje

Biomass for class 2 = 1/2 x 110tons/yr = 55 tons/years

Class 1 included areas like Laxmi Road, Vishrant Wadi

Biomass for class 1 = 1/4 x 110tons/yr = 27.5 tons/years

A special class, Class 5 was assigned to the most wooded regions. And their biomass was estimated on the basis of sampling results. Table 3.3 shows biomass estimation of various localities under study.

TABLE 3.3 **Biomass Estimations of Various Localities under Study**

Locality with Biomass value 5	**Biomass (tons/Ha)**	**Area covered (sq.km.)**	**Total biomass (tons)**
Katraj	38.44	1	3844
Parvati Panchgaon	13.36	3	3446.88
Bhamburda, FC College	45.00	3	116.10
Khandoba	30.00	3	7740
Smriti Van, Nehru Herbarium, Sanctuary	20.00	3	5120
Empress Garden, Forest Nursery	110.00	2	18920
Osho park, Koregaon Park	110.00	1/2	4370
University	107.00	2	18404
Fruit research Institute	110.00	1	9460

Total biomass of class 5 = 70882.82 tons

Map 3 gives grid wise distribution of green areas in Pune City. The zones have been categorized as follows: -

TABLE 3.4 **Zoning of Pune City Based on Tree Cover**

Category	Biomass t/km^2	No. of cells	Area(sq. km.)	Biomass(tons)
5	Variable	17.5	17.5	70882.82
4	11000	38.5	38.5	423500.00
3	8250	52	52	453750.00
2	5500	79	79	434500.00
1	2750	63.0	63.0	171675.00

Total Biomass in tons = 1554307

= 15 lakh tons

Carbon sequestered per year is 1% of the total standing biomass

Therefore, the trees of Pune City are currently sequestering **fifteen thousand tons of carbon each year.**

Importance of Forest Patches in Pune

CASE STUDY – Vetal Hill (Bhamburda Van Vihar)

The forest patches and plantations in class 5 seem to have a very low biomass and carbon sequestration potential, according to TABLE 3.3. But their true importance from a conservation point of view can be seen by the following case study of Bhamburda.

The vegetation of Bhamburda hill constitutes 88 ha. of *Gliricidia* plantation and 9.62 ha. of *Anogeissus latifolia* plantation.At present the *Anogeissus latifolia* trees on the upper slopes have an average volume of 0.054 m^3 At other places the plantation is just 2 – 3 years old.

According to the Age-Girth table given by Maslekar *et. al.* in the 'Forester's Companion' (1981), at the age of 10 years, the *Anogeissus latifolia* tree has a 0.047 cu. m. volume.

An average volume of 0.134 m^3 would be achieved bt the year 2020. The trees on the lower slopes would reach a volume of about 0.08 m^3 would be achieved. These calculations were made on the basis of transects taken during this project.

Bio volume of the *A. latifolia* tree population at Bhamburda :

Particulars of transect		2002			2030		
Transect No	No. of trees	Age	Avg. Vol. m^3	Tot. vol. m^3	Age	Avg. Vol. m^3	Tot. Vol. m^3
1	32	5	0.026	0.832	35	0.134	4.288
2	649	1	0.008	5.192	36	0.134	60.836 *
3	36	12	0.054	0.648	42	0.269	9.684

*The trees in transect 2 are placed very close together. Hence some trees are expected to perish due to over crowding. Hence the total volume for this transect was calculated assuming a survival rate of 70%.

The total area covered under the transects = 1400 m^2

Total area under *Anogeissus latifolia* mixed plantation at Bhamburda=9.14 ha.

Total Biovolume of *Anogeissus latifolia* trees = 6.67cu. m .

Total Biomass of *Anogeissus latifolia* trees = 6.67 m^3 *994.48 kg/ m^3

= 520246.7 kg

= 520.25 tons

Carbon stored in 2002 = 37.2 tons

In the year 2030,

Total Biovolume of *Anogeissus latifolia* trees = 74.808 m^3

Total Biomass of *Anogeissus latifolia* trees = 74.808 m^3 * 994.48 kg/ m^3

= 74.4 tons

Carbon stored in 2030 = 2428.5 tons

This is a 65-fold increase in carbon storage in 30 years.

In this case we have ignored all regeneration and any stray logging incident, since Bhamburda is a protected forestland.

We must remember that *Anogeissus latifolia* is an indegenous tree species with a high wood density, that is suited for the climate of Pune and can regenerate here naturally.

DISCUSSION AND CONCLUSION

The present study has calculated the standing biomass of the above ground wooded parts of the trees in Pune City, within Pune Municipal Corporation limits. The estimations regarding carbon emission and sequestration potential of the Pune city and its various sectors were also made. And the figure that appears for the rate of carbon sequestered is 15,000 tons per year. The present study indicated that Pune city emits 7.8 lakh tons of carbon per year and its trees absorb 2 % of it, causing 98 % atmospheric overload!

The determination of a baseline by which to assess carbon sequestration is critical as it provides the frame of reference for determining how carbon sequestration projects are contributing to the net carbon sink at either the project or national level. Baseline determination is closely tied to the concern that carbon sequestration activities be 'real and additional', meaning that carbon sequestration for which credits are given as a result of some forestry based activity

Within Pune, the most crowded areas like Kasaba Peth, Gurwar Peth, Rasta Peth show excess carbon emissions because of high population density and less tree cover. Since there is lack of space for conducting tree plantations or public garden, in future years, this central part of the city will continue to be the carbon emission source. On the contrary, the south and south western parts of the city such as University Campus, Vetal Hill, Parvati-Pachgaon, Katraj are least carbon loaded areas with better tree cover. The eastern areas (NE and SE) of Pune city, such as Lohagaon, Hadapsar, Kondhve etc. appear to be less tree covered, but also emit medium to low amounts of carbon. Massive tree plantations drives need to be taken up in these areas, along avenues and public places for raising carbon sequestration potential. While considering the massive tree plantations, the indigenous species that support biodiversity should be given preference over exotic tree species like *Eucalyptus, Acacia auriculiformis.* Results obtained by working with *Anogeissus latifolia* indicates its potential and can serve as the promising candidate for future afforestation programmes. It is also fire resistant and can indirectly help in checking and spreading of forest fires and subsequent release of carbon in atmosphere due to trash burning. While undertaking massive tree plantation programmes in naturally tree deficient areas such as grasslands, care should be taken to leave some part of the grassland untouched. This will help conserve their biodiversity (Nalavade *et al.,* 2000-01). The studies on urban biodiversity published by Ecological Society in 2001, reported that the green areas with assemblage of indigenous and exotic tree species such as Parvati-Pachgaon, Vetal Hill continue to be the sources of biodiversity elements seen in the city. Every fifth bird species and sixth butterfly species seen in the city has its source populations situated in such forest pockets. The carbon sequestration potential of such wooded areas will be an added advantage in this regard.

Urbanization & habitat fragmentation seem to be increasing world wide, proved by a case study in Pune City. A study shows 25% decline in vegetation cover within 50 years of time due to encroachment of human habitation (Nalavade *et al.,* 2000-01). But still, institutes in Pune like Pune University campus harbor a good vegetation cover. Such areas are the 'GREEN LUNGS' of the ever-burgeoning cities. Though the area of the University is just 0.23% of the city, it harbors 51% (194) of tree species (Patwardhan and Gandhe, 2000-01) and 40% (40) butterfly species from total recorded species in the city (Kunte, 2000-01). Though gardens occupy just 6% of total area of the campus, they are highly rich in biomass, holding almost 108 ton/ha. This is quite comparable with semi evergreen forest i.e.120-130 ton/ha. (Ravindranath *et. al.*, 1997). The importance of forested areas in carbon sequestration is already accepted. Non-forested but tree dominated area such as University campus, including avenues and public gardens also play some role. This area comes under cities and infrastructure, which accounts for 5.3% of country's total area. This area has not been considered for its carbon sequestration capacity. Since our study area represents this 5.3 %, it holds up to 1846 tons of Carbon. These aspects definitely add to the conservation value of such institutionally safeguarded areas.

The sequestration estimates are based on the standing biomass. Carbon emissions from tree vegetation have been ignored at present, as the litter is removed and disposed off in city outskirts. Though Pune does have other vegetation like herbs, shrubs and grasses, and many agricultural fields, these cannot be considered as carbon sinks, since they have a short life span. Carbon sequestration necessitates the storage of carbon for at least a hundred odd years.

While tree plantations would enhance carbon sequestration, policy makers must also initiate promoting carbon friendly goods and services so as to reduce carbon excess budget. In this regard, encouragement to public transport over private, subsidy to organic farming over synthetic etc. measures should be considered, so that emission levels will also reduce.

This study has relevance if we consider the debate going on all over the world regarding carbon issues. Kyoto protocol has already highlighted that the future world policy will be determined and governed by taking into account carbon budgeting. Generally developing countries like India have a deficit budget than excess budget like developed countries. Unfortunately excess carbon budgets may lead to economic deficiency on one hand and loss of economic compensation possible from developed countries under the Kyoto protocol. Thus developing countries sought to penalize carbon emitting developed countries to pay for Eco-friendly development of developing countries (WRI, 1998). Indian scientists already brought the double standard adopted by developed countries to light. In line with this, the present study revealed that Pune city commits 10-50 times more carbon sin than surrounding villages, while an American or European city commits 50-100 times more carbon crime than Pune.

The costs of carbon sequestration must be clarified. When analyzing carbon sequestration based on the opportunity cost of land, proponents of carbon sequestration note that a great deal of forested land is located in remote regions, often characterized by high timber extraction costs due to rugged terrain and limited access. From a financial cost-benefit perspective, the opportunity cost of these forested lands is very low, implying that if tree cover establishment costs are low, the total cost of afforestation or reforestation to establish permanent tree cover will likely be lower than many other carbon-offset mechanisms. Given that reduction of atmospheric CO_2 is a long run goal, carbon sequestration will likely be best used as one of a broader portfolio of carbon offset mechanisms. This carbon-offset portfolio will differ among nations, with developing countries perhaps relying heavily on carbon sequestration offsets in the short to medium term.

However, carbon sequestration through forest activity has considerable potential to generate low-cost sequestration alternatives, especially in certain developing countries. Nonetheless, care must be taken to recognize the true opportunity costs of alternative land uses and to identify that, in many cases, social values other than carbon sequestration are also involved, and trade-off is necessary.

Nevertheless, overall, the size of the global forest carbon stock appears to be declining, thereby generating a net carbon source. However, while forest decline contributes to the build-up in atmospheric carbon, analysts widely agree that the primary cause of the build-up in atmospheric carbon is not attributable to land use changes, but rather is due largely to fossil fuel burning and its associated emissions. In view of this, the potential of the urban green areas can not be overlooked. This case study of Pune City highlighted the role of urban tree cover in carbon sequestration which is generally ignored while calculating the carbon budget of the country.

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