VEGETATION ECOLOGY

AND

BIOMASS CARBON SEQUESTRATION POTENTIAL

OF S. P. PUNE UNIVERSITY CAMPUS,

GANESHKHIND,

PUNE - 411007

PREPARED BY

DEPARTMENT OF ENVIRONMENTAL SCIENCES

CONTENT

1.0 VEGETATION ECOLOGY OF SAVITRIBAI PHULE PUNE UNIVERSITY CAMPUS

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1.1 INTRODUCTION

Human intervention in our natural ecosystems is now recognized as one of the most serious threats to global biodiversity and sustainability. Habitat destruction and ecosystem fragmentation is a result of human interference in all of the world's ecosystems including forests, grasslands, wetlands, and even marine environments. The human intervention is in the form of development, overpopulation, overconsumption, exotic species introduction, and human induced environmental change. Pune city is not exception for this. Pune is well known as city of hills because of many hill ranges within and around the city.

Savitribai Phule Pune University (SPPU) campus is located at Ganeshkhind road in Pune city. It is spread over 415 acres (166 hectares) area. During pre-independence days this campus was monsoon residence of the Governor of Bombay. In 1949 this was re-established as the University of Poona campus. The university campus is having unique vegetation pattern. It is occupied largely by *Dalbergia melanoxylon* Guill. (Patangi) – an introduced species from Africa; now it is almost completely naturalized here, and has stretched its habitat on nearby hill ranges like Chatushrungi hills, Vetal hills, etc. It completely dominates the other plant species of the campus. Recently, a massive plantation drive was taken up. During this plantation drive an exotic species – *Gliricidia sepium* (Undirmari) and *Leucaena latisiliqua* (Subabhul) has been given preference, as a result of which, it has become second abundant species of the campus. There are a few evergreen patches, and gardens as well. All these together form a diverse and interesting association of ecosystems that supports a wide variety of fauna.

The campus is lush green during the rains, but it turns to brown soon after the rains recedes. The area receives about 1000 mm of rain every year, most of it between June and September. The University campus contains many fragmented patches of open dry deciduous forest. Apart from *Dalbergia melanoxylon,* other common large trees include Khair (*Acacia catechu*), Banyan (*Ficus bengalensis*), Kanchan (*Bauhinia variegata*), Kate-sawar *(Bombax ceiba*), the Rain Tree *(Pithecellobium saman*), Salai (*Boswellia serrata*), Gulmohar (*Delonix regia*), Neem (*Azadarichta indica*), Buch *(Millingtonia hortensis*), Pachunda (*Capparis grandis*), Mango (*Mangifera indica*), Peepal (*Ficus religiosa*), Shisam (*Dalbergia latifolia*), Palas *(Butea monosperma*), and Son-mohar *(Peltophorum roxburghii*). There are several open areas which support grasses and herbs during the rains. However, most of the grasses disappear during the dry season.

1.2 BIOGEOGRAPHIC SETTING:

According to revised forest types (Champion and Seth, 1968) the study area has been classified as 'Tropical dry deciduous forests' (Group 5, subgroup 5A-C3) – Southern dry mixed deciduous forest. The campus includes Range hills at south-east corner that creates habitat for its fauna. The topography and relief of the area is northeastwards. Soil formation is comparatively poor; however at some places it is fairly good. A small seasonal stream passes through the university campus. The area characterizes more or less sparse to thick vegetation of average height of 4-12 m high. It is further reduced by biotic agencies. The overall vegetation is dry deciduous type mixed with some planted evergreen species. The soil type is lateritic formed from Deccan Trap.

1.3 FLORISTIC ANALYSIS:

Prof. Varadpande (1974) has worked for ten years on the flora of university campus. He documented 780 species belonging to 540 genera and 118 families. Dicotyledons form the major part of vegetation being represented by 620 species spread over 415 genera and 96 families. The largest numbers of species were from Leguminosae, Asteraceae, Euphorbiaceae and Poaceae. However, over the period of 40 years there is fairly large change in the species composition of the campus. Out of the total species reported by Varadpande (1974), 33 species are disappeared, whereas, many new has been introduced.

The vegetation except on the range hill and in the little valley to the north is low shrub more or less xerophytic in characters (Varadpande, 1974). *Acacia chundra* Willd., *Acacia nilotica* Willd., *Acacia leucophloea* Willd., *Dalbergia melanoxylon* Guill., *Dolichandrone falcata* Seem., *Dichrostachys cinerea* Wt. & Arn., *Capparis grandis* Linn., *Zizyphus mauritiana* Lamk. are common and contribute the deciduous forest belt. Coverage species are ephemeral herbs, grasses and thorny bushes of *Securinega leucopyrus* muell.-Arg., *Maytenus senegalensis* Exell. *Zizyphus nummularia* Wt. & Arm., *Ehretia aspera* Willd., *Mimosa hamata* Willd. etc.

Further Prof. Varadpande (1974) observed that in the central area barren rocks are exposed and several monsoon ephemerals occupy areas surrounding the rocks where there is accumulation of soil; the most common ephemerals that grow here are *Mollugo pentaphylla* Linn., *Heliotropium ovalifolium* Forsk., *Cyanotis fasciculata* Schult., *Oldenlandia corymbosa* Linn., *Glossocardia bolvallea* DC., etc. A marked change is induced with few local showers in early May and many monsoon ephemerals sprout, and as a token of their early existence produce first the flower clusters,

the leaves appearing little later. In them *Drimia indica* Kunth tops the list and is followed by many tuberous Liliaceae and Commelinaceae like *Scilla indica* Backer, *Chlorophytum tuberosum* Baker, *Chlorophytum laxum* R. Br., *Iphigenia indica* A. Grey., *Cyanotis tuberosa* Schult., *Cyperus triceps* Endl., and *Melanocenchris jacquemontii* Jaub. The species of *Ophioglossum* are no more observed in the campus.

The ephemeral plants arise after about an inch of rainfall and are characteristic plant of stony or poor rocky ground. Its number and composition vary with weather conditions. Many a times they become indicators of soil depth and moisture. As the soil moisture goes on increasing with the onset of rain *Iphigenia indica* A. Grey., *Chlorophytum tuberosum* Baker, *Chlorophytum orchidastum* Lindl, *Chlorophytum laxum* R.Br. sprout in succession. The order of appearance of these plants seems to have a close relation with the onset and progress of monsoon.

1.4 NATURAL VEGETATION/FOREST TYPE:

The university campus (Ganeshkhind) flora is typically dry mixed deciduous type due to large diurnal range of temperature. The tree species are deciduous and the coverage species are either ephemeral herbs or thorny deciduous shrubs; some of the species growing in more rocky regions are herbaceous ephemerals with perennial sub-surface rootstocks. The few evergreen plants to be found are confined to the central gardens. The flora is so to say an artificial complex, the original vegetation being partly replaced (Varadpande, 1974). Formerly the whole area was under the complete control of Bombay Government and the Governor's residence in the pre-independence days in the central buildings has been responsible for this large scale introduction of exotic trees. On this account herbaceous vegetation has also been affected considerably.

Many herbaceous species have entered the area as mere weeds, along with the garden plants probably in the form of seed mixtures and some through manures and soil. One particular place at least is now a complete mixture of wild and cultivated plants and species introduced as weed viz., the area beyond the canal on the North-East side, the Dhobi Ghat. Formerly this place was a well-kept garden (Varadpande, 1974), but has been neglected in the past few years and the competition between cultivated, introduced and indigenous species is still going on. The place has recently been taken over for the newly started government nurseries.

A remnant of natural vegetation of the Ganeshkhind area is seen on the range hills. The vegetation is composed of the species like *Morinda pubescens*, *Acacia leucophloea*, *Tectona grandis*, *Heterophragma quadriloculare*, *Rhus mysurensis*, *Dolichandrone falcata*, *Maytenus senegalenisis*, *Flacourtia latifolia*, *Ehretia laevis*, *Grewia flavascens*, *Ziziphus mauritiana*, *Polygala chinensis*, *Polygala erioptera*, *Caralluma fimbriata*, *Sarcostemma brevistigma*, *Wattakaka volubilis*, *Cocculus hirsutus*, *Leptadenia reticulata*, *Cardiospermum halicacabum*, *Chlorophytum orchidastrum*, *Woodfordia fruticosa*, and *Pupalia lappacea*. Several members of family Fabaceae, Poaceae, and Asteraceae shows dominance and makes overs the major portion of hill vegetation. During the wide plantation drives, some exotics have been introduced on this hill *viz*. *Pongamia pinnata*, *Gliricidia sepium*, *Anogeissus pendula*, *Garuga pinnata*, *Boswellia serrata*, *Cochlospermum religiosum*, *Eucalyptus citriodora* and they are doing quite well (Varadpande, 1974). It is obvious that the original vegetation of Ganeshkhind was quite rich but has been greatly altered through human interference a biotic effect which was more on account of its important in the earlier days and in the modern times.

1.5 GRASSES:

The grasses occupy important status in the herbaceous flora; and are conspicuous till it is grazed down or dried at the end of monsoon. Grass plays an important ecological role. In fact, the denser and healthier the grass, the better it can protect the environment. Grass minimizes erosion, absorbs rainwater, cleans the air and neutralizes pollutants and chemicals. The grasses are usually found to grow on the fringes of dense vegetation, open places, in degraded forests, and wastelands. The grasses are useful as fodder and subsequent grazing and to check the exposure of soil. The most common grass species in the campus are *Heteropogon contortus*, *Iseilema laxum*, *Melanocenchris jacquemontii*, *Paspalidium flavidum*, *Aristida*, *Setaria glauca*, *Chloris barbata*, *Cynadon dactylon*, *Digitaria adscendens*, *Dinebra retroflexa*, *Dactyloctenium aegyptiacum*, *Setaria glauca*, *Themeda quadrivalvis*, *Chrysopogon fulvus*, *Eragrostis*, *Bothriochloa pertusa*, *Hackelochloa granularis*, and *Cyperus sp.* There are few locally rare species of grasses *viz*. *Alloteropsis cimicina*, *Nazia racemosa*, *Tetrapogon tenellus* and *Phragmites maxima*.

1.6 THREATENED SPECIES:

The university campus represents open or dense mixed forest, predominated by Patangi (*Dalbergia melanoxylon*), Khair (*Acacia catechu*), Banyan (*Ficus bengalensis*), Kanchan (*Bauhinia variegata*), Kate-sawar *(Bombax ceiba*), the Rain Tree *(Pithecellobium saman*), Salai (*Boswellia serrata*), Gulmohar (*Delonix regia*), Neem (*Azadarichta indica*), Buch *(Millingtonia hortensis*), Pachunda (*Capparis grandis*), Mango (*Mangifera indica*), Peepal (*Ficus religiosa*), Shisam (*Dalbergia latifolia*), Palas *(Butea monosperma*), and Son-mohar *(Peltophorum roxburghii*). The area shows good diversity of flora, and there were few species (Table-1) falling in threatened category as per the Flora of Maharashtra State (2001), and IUCN (2014) record. However, these species are also present elsewhere in Maharashtra or Western Ghats.

Table-1: Threatened plant species of the proposed area.

Botanical Name	Local Name	Habit	Family	Status
Iphigenia indica	Bhuichakra	Herb	Liliaceae	LR
Iphigenia pallida	Bhuichakra	Herb	Liliaceae	VU
Centaurium pulchellum	Lantak	Herb	Gentiaceaeae	LC
Commelina hasskarlii	Kamalini	Herb	Commelinaceae	LC
Crotalaria filipes	Phatphati	Herb	Fabaceae	EN
Santalum album	Chandan	Tree	Santalaceae	VU
Cyanotis fasciculata	Kenpat	Herb	Commelinaceae	LC
Cyathocline purpurea	Gangotra	Herb	Asteraceae	LC

EN- Endangered (BSI); LC- Least Concerned (IUCN); LR- Lower Risk (BSI);
VU- Vulnerable (BSI & IUCN)

1.7 ENDEMIC SPECIES:

The endemic species are those, which have restricted distribution to particular geographical area. This area was rich floristically and represents few endemic species (Table-2), however there was no locally endemic species. In all there were 81 species endemic to India and 07 species (*Achyranthes coynei,Argyreia boseana, Cyathocline lutea, Cyathocline purpurea var. bicolor, Hitchenia caulina, Iphiginia stellata,* and *Pimpinella tomentosa*) endemic to Maharashtra.

Table-2: Plant species endemic to India and Maharashtra.

Plant Species	**Local Name**	**Habit**	**Family**	**Endemic Status**
Boswellia serrata	Salai	Tree	Burseraceae	EI
Clematis heynei	Ran-jai	Climber	Ranunculaceae	EI
Clitoria biflora	Gokarn	Climber	Fabaceae	EI
Crotalaria filipes	Phatphati	Herb	Fabaceae	EI
Cyathocline purpurea	Gangotra	Herb	Asteraceae	EM
Flacourtia latifolia	Tambat	Shrub	Flacoutiaceae	EI
Garcinia indica	Kokam	Tree	Clusiaceae	EI
Haplanthodes verticillatus	Jakara	Herb	Acanthaceae	EI
Iphigenia pallida	Bhui-chakra	Herb	Liliaceae	EI
Iphigenia stellata		Herb	Liliaceae	EM
Vernonia indica	Sahdevi	Herb	Asteraceae	EI

1.8 MEDICINAL PLANTS:

This campus represents good amount of medicinal and herbal plants. Few representative of the medicinal and herbal plants reported are listed in table-3.

Table-3: Medicinal and economically important plants of the area.

Botanical Name	**Habit**	**Local Name**	**Family**
Asparagus racemosus	Climber	Shatavari	Liliaceae
Chlorophytum tuberosum	Herb	Musali/Kuli	Liliaceae
Aegle marmelos	Tree	Bel	Rutaceae
Plumbago zeylanica	Shrub	Chitrak	Plumbaginaceae
Ficus racemosa	Tree	Umbar	Moraceae
Helicteris isora	Shrub	Murudsheng	Sterculiaceae
Tribulus terrestris	Herb	Gakharu	Zygophyllaceae
Cassia fistula	Tree	Bahawa	Caesalpiniaceae
Woodfordia fruticosa	Shrub	Dhayati	Lythraceae
Gardenia resinifera	Shrub	Dikemali	Rubiaceae
Semecarpus anacardium	Tree	Bibba	Anacardiaceae
Psoralea corylifolia	Herb	Bavachi	Fabaceae
Caesalpinia bonduc	Shrub	Sagargota	Caesalpiniaceae

Botanical Name	Habit	Local Name	Family
Ruta graveolens	Herb	Satap	Rutaceae
Boerhaavia diffusa	Herb	Punarnawa	Nyctaginaceae
Hemidesmus indicus	Climber	Anantmul	Asclepiadaceae
Evolvulus alsinoides	Herb	Vishnukranta	Convolvulaceae
Rivea hypocrateriformis	Climber	Phang	Convolvulaceae
Santalum album	Tree	Chandan	Santalaceae
Abrus precatorius	Climber	Gunj	Fabaceae
Terminalia cuneata	Tree	Arjun	Combretaceae
Terminalia bellirica	Tree	Beheda	Combretaceae
Cyperus rotundus	Herb	Nagarmotha	Cyperaceae
Withania somnifera	Herb	Ashwagandha	Solanaceae
Tinospora cordifolia	Climber	Gulvel	Menispermaceae

1.9 LOWER FLORA:

The lower plants need very specific habitats and environmental conditions. They are very much sensitive to their habitats. This area provides moderate habitat for lower flora. Hence, few bryophyte and pteridophyte species were reported. In all six species of Bryophytes (Table-4) and fifteen species of Pteridophytes (Table-5) were reported from this area.

Table-4: Lower plant species from the area - Bryophytes

Botanical Name	Family	Habitat and Distribution
Riccia sorocarpa	Ricciaceae	Moist soils, shady and exposed places
Riccia huebeneriana	Ricciaceae	Moist soils and stream banks
Plagiochasma sp.	Aytoniaceae	On wet rocky or soil surface
Targionia sp.	Targionaceae	Damp soils
Antheceros punctatus	Anthocerotaceae	Damp soils
Notothylas sp.	Notothyladaceae	Damp Plaines

Table-5: Lower plant species from the area - Pteridophytes

Botanical Name	Habit	Family	Status
Adiantum caudatum	Herbs	Adiantaceae	Cultivated
Adiantum incisum	Herbs	Adiantaceae	Cultivated
Adiantum lunulatum	Herbs	Adiantaceae	Cultivated
Athyrium sp.	Herbs	Athyriaceae	Cultivated
Azolla pinnata	Aquatic herbs	Salviniaceae	Wild
Cheilanthes farinosa	Herbs	Cheilanthaceae	Cultivated
Lycopodium sp.	Climber	Lycopodiaceae	Cultivated
Marsilea minuta	Aquatic herbs	Marsiliaceae	Wild
Marsilea quadrifolia	Marshy herbs	Marsiliaceae	Wild
Nephrolepis sp.	Herbs	Thelypterideae	Cultivated
Pteris biaurita	Large herbs	Pteridoideae	Cultivated
Pteris longifolia	Large herbs	Pteridoideae	Wild/Cultivated
Selaginella ciliaris	Small Herb	Selaginellaceae	Wild
Selaginella delicatula	Suberect herb	Selaginellaceae	Cultivated
Tectaria cicutaria	Herbs	Tectariaceae	Cultivated

1.10 WATER BODIES AND WETLANDS:

Water body is any significant accumulation of water covering the land surface, either natural or artificial. It most often includes smaller pools of water such as ponds, puddles, rivers, streams, or wetlands; or other geographical feature where water moves from one place to another are also considered bodies of water. Wetlands are transitional zones between terrestrial and aquatic systems where the water table usually at or near

the surface or the land is covered by shallow water.

The university campus site represents few water bodies in the form of lakes, streams and temporary wetlands. These wetlands are playing an integral role in the ecology of this area. Many species of birds and mammals rely on wetlands for food, water and shelter, especially during migration and breeding. Aquatic macrophytes were studied from different aquatic sites/water bodies. During the field work emphasis was given to document the macrophyte status of these wetlands. In all 20 species belonging to 16 families of macrophytes (Table-6 and Photo-1) representing Dicots, Monocots, Algae, and Pteridophytes were documented; however, no one was under threatened category.

Table-6: Macrophytes documented during field work.

Species Name	Type	Family
Asclepias curassavica	Shrub	Asclepiadaceae
Azolla pinnata	Free floating	Azollaceae
Bacopa monnieri	Marshy	Scrophulariaceae
Centella asiatica	Marshy	Apiaceae
Ceratophyllum demersum	Submerged	Ceratophyllaceae
Cyperus iria	Marshy	Cyperaceae
Eclipta prostrata	Marshy	Asteraceae
Fimbristylis dichotoma	Marshy	Cyperaceae
Fimbristylis miliacea	Marshy	Cyperaceae
Hydrilla verticillata	Submerged	Hydrocharitaceae
Hygrophila schulli	Marshy	Acanthaceae
Ipomoea aquatica	Marshy	Convolvulaceae
Ipomoea carnea	Marshy	Convolvulaceae
Lemna gibba	Emergent	Lemnaceae
Ludwigia octavalvis	Emergent/Marshy	Onagraceae
Marsilea quadrifolia	Marshy	Marsileaceae
Nymphaea pubescens	Rooted & leaved floating	Nymphaeaceae
Persicaria glabra	Marshy/Emergent	Polygonaceae
Phyla nodiflora	Marshy	Verbenaceae
Spirodela polyrrhiza	Free floating	Lemnaceae
Typha angustata	Emergent	Typhaceae

1.11 HERBACEOUS FLORA:

During monsoon, the open places are covered with abundance of herbaceous species. The whole ground becomes carpeted with a variety of herbs and grasses which cover the surface with green color. The most conspicuous and the flourishing seasonal belong to the families Fabaceae, Asteraceae, Rubiaceae, Amaranthaceae, Tiliaceae, Lamiaceae, Convolvuaceae, Acanthaceae, Commelinaceae, Cyperaceae, and Poaceae. The most common herbs are: *Cassia uniflora*, *Hyptis suaveolens*, *Logasca mollis*, and species of genus Indigofera, Alysicarpus, Desmodium, Cassia, and Commelina. The other associated species are *Triumfetta rhombodea*, *Blainvillea acmella*, *Corchorous olitorius*, *Tribulus terrestris*, *Cleome simplicifolia*, *Cleome viscosa*, *Trianthema portulacastrum*, *Bidens biternata*, *Euphorbia geniculata*, *Trichodesma amplexicaulis*, *Digera alternifolia*, *Euphorbia hirta*, *Heteropogon contortus*, *Iseilama laxum*, *Microchloa indica*, *Zornia gibbosa*, *Polygala chinensis*, *Polygala erioptera*, *Tripogon jacquemontii*, and *Tripogen lisboe*,. Besides these herbs, numbers of annual and perennial twiners and climbers add to the rainy season aspect of the flora.

Among them the most common are: *Cocculus hirsusus*, *Ipomoea obscura*, *Merremia emarginata*, *Ipomoea quamoclit*, *Rhynchosia minima*, *Phaseolous trilobus*, *Timospora cordifolia*, *Passifora foetid*a, *Cardiospermum halicacabum*, *Pergularia daemia*, *Cryptolepis buchmani*, etc. In the months of August-September most of these are studded with flowers but with the onset of winter the herbaceous vegetation begins to slow down and by November most of them dry up & entire area bears a parched appearance in the months of February-March. Prof. Varadpande (1974) further observed that *Dalbergia melanoxylon* shows winter yellowing of its leaves in January and sheds them completely in about three weeks. The vegetation of the area presents therefore two distinct seasonal aspects; the summer and the winter aspect, when most of the tree and shrubs flower, and the soil is devoid of any ground cover; and the rainy season aspect when the vegetation is at its best and the soil which is otherwise barren between trees and shrubs is covered by a green carpet of seasonal vegetation (Varadpande, 1974).

1.12 EXOTIC FLORA:

Previously, there was a botanical garden from which several exotic garden species like *Torenia asiatica*, *Tithonia diversifolia*, *Impetiens balsamina*, *Ipomoea quamoclit*, *Saponaria vaccaria*, *Barleria cristata*, *Clitoria ternatea*, *Antigonon leptopus*, *Cosmos bipinnatus*, and *Zephyranthes rosea* have escaped and naturalized; some of them became invasive species. The other highly invasive species are *Hyptis suaveolens*, *Parthenium hysterophorus*, *Cassia uniflora*, *Broussonetia papyrifera*,

Leucaena latisiliqua, *etc*. One of the oldest banyan trees has about 80 to 90 prop roots. The twigs' forming an avenue of 100 meters long is a prominent landmark. Some conspicuous exotic plants have been introduced in the area e.g. *Adansonia digitata*, with a trunk 4m in diameter, *Colvillea racenosa*, *Delonix regia*, *Gliricidia sepium*, *Cassia grandis*, *Bauhinia galpini*, *Tabebuia pentaphylla*, *Chrysophyllum cainito*, *Cordia sebestena*, *Millingtonia hortensis*, *Spathodea campanulata*, *Parmentiera cereifera*, *Jacaranda mimosifolia*, *Persea gratissima*, *Grevillea robusta*, *Pterospermum acerofolium*, *Guazuma ulmifolia*, *Kleinhovia hospita*, *Garcinia indica*, and *Callistemon lanceolatus*. Various palms, gymnosperms and ornamental climbers belonging to Bignoaceae, Apocynaceae, Oleaceae and Convolvulaceae have been introduced (Varadpande, 1974). The most notable of these last mentioned being: *Aganosma caryophyllata*, *Pryostegia venusta*, *Bignonia unguiscati*, *Bignonia magnifica*, *Roupellia grata*, *Allamanda cathartica*, *Beaumontia grandiflora*, *Aristolochia ringens*, *Porana panuculata*, *Bougainvillea spectabilis*, *Ipomoea horsfalliae*, *Passiflora quadrangularis*, *Passiflora racemosa*, and *Lonicera japonica*, *etc*.

1.13 REFERENCES:

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2.0 BIOMASS CARBON SEQUESTRATION POTENTIAL OF THE SAVITRIBAI PHULE PUNE UNIVERSITY CAMPUS

D.M. MAHAJAN, HAMED HAGHPARAST, AND DR. VENKAT GUNALE

2.1 INTRODUCTRION:

Increasing levels of carbon dioxide in the atmosphere are of growing concern globally and locally, and urban forests have a role to mitigate to certain level against climate change. Vegetation helps to reduce atmospheric carbon through photosynthesis and this process known as carbon sequestration, transforming CO_2 into carbon and making use of it to build living matter - leaves, stems, trunk, roots, etc. The university campus is spread over 166 hectares, out of that about 50% is covered by deciduous plants dominated by *Dalbergia melanoxylon*, *Gliricidia sepium*, *Acacia sp.*, *Samania saman*, *Ficus benghalensis*, *etc cpvering large part of the university campus.* A comprehenvie analysis was carried out to understand the present total carbon pool.

2.2 SITE SELECTION FOR ASSESSMENT OF CARBON POOLS:

For the assessment of Above Ground Biomass (AGB) and Below Ground Biomass (BGB), the university campus was divided into ten major sites (Table-1; Fig.1) namely, Range hills (11.63 ha), Shivaji Garden (4.5 ha), Opposite of Botany Department (6.6 ha), Botanical Garden (5.25 ha), Elese Garden (5.35 ha), Q-Building (Teachers Quarters) (8.7 ha), Gen. Joshi gate No. 1 (7.14 ha), Gen. Joshi gate No. 2 (5.42 ha), Agricultural Center 9.6 ha), and IUCCA (Inter-University Centre for Astronomy and Astrophysics) gate (0.4 ha). Total seventy six plots of 25×25 meters ($625m^2$) were laid in 64.59 hectares vegetated area of the university campus.

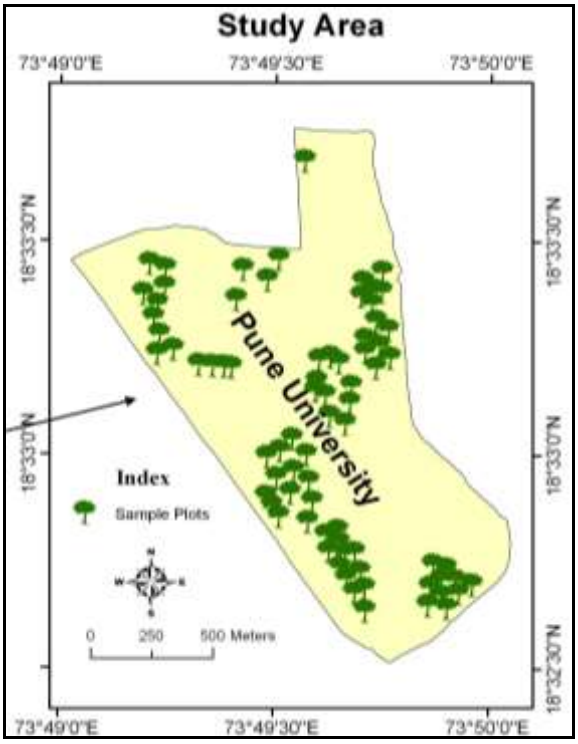
Table 1: Sampling sites.

Sr. No.	Sites	Number of Sampling plots	Total Area of site (In Hectare)
1	Range Hills	10	11.63
2	Shivaji Garden	12	04.50
3	Opposite of Botany Department	10	06.60
4	Botanical Garden	03	05.25
5	Elease Garden	10	05.35

6	Q Building (Teachers Quarters)	13	08.70
7	Gen. Joshi Gate No. 1	07	07.14
8	Gen. Joshi Gate No. 2	06	05.42
9	Agriculture Centre	04	09.60
10	IUCAA	01	00.40
	TOTAL	**76**	**64.59**

These ten major areas varied from highly hetrogenous forested cover such as Botanical garden, Elise garden and Gen. Joshi gate sites, to homogenoues planted areas such as Range hills, Shivaji garden, Opposite of Botany Department, *etc*, which are planted with *Dalbergia melanoxylon* and *Gliricidia sepium*. Plots were laid in all study sites as per standard methods. 47,500 m^2 area was undertaken in terms of biomass evaluation in above and belowground biomass. Q-building (teachers quadrat), Shivaji garden, Range hills, Elease garden and Gen. Joshi gate sites were the biggest area in terms of plot numbers, whearas IUCAA and agricultural center were lowest (Table 1).

Fig.1: Sampling plot location map.



2.3 ABOVE GROUND *VERSES* BELOWGROUND BIOMASS ASSESSMENT:

The assessment of above ground and belowground biomass of university campus was carried out using known methods of Ravindranath and Ostwald (2008). In all 76 sampling plots were laid.

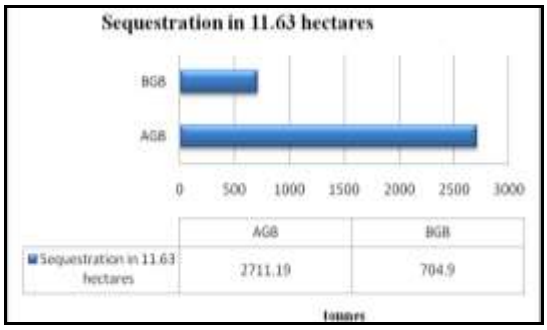
2.3.1: RANGE HILLS SITE:

Total ten plots covering 6250 m^2 were laid in Range hills. This forested part of the study area was dominated by *Gliricidia sepium* and *Dalbergia melanoxylon* species. Meanwhile harvesting of timber by the nearby labour people can be assumed as a potential risk to this site. Dumping of left constructional stuff was the second threat. Besides being a major carbon pool, Range hills play an important role as habitat for birds. Fig.-2 shows plot-wise and total AGB and BGB carbon sequestration in Range hills.

According to the Fig.-1, the highest biomass was recorded in plot no. 2 *i.e.* 31.98 tonnes. Accordingly plots number one, five, and nine show relatively high volume of biomass. The lowest recorded volume of biomass was 6.76 tonnes (Plot no.10). The average biomass per plot was 14.57 tonnes. The above and below ground assemssment proved this site as one of the high sequestrated carbon pools. In addition it was catagorized as one of the homogeneous planted sites covered mostly by *Gliricidia sepium* and *Dalbergia melanoxylon* which were highly adopted exotic species to the climate of Pune city. Fig.-3, illustrates the sequestration in the entire area of Range hills after extrapolation to 11.63 hectares. Among the selected areas, Range hills were categorized as a high potential carbon sequestrated area.

Fig.2: AGB *Vs* BGB in Range hills.

Fig.3: After extrapolation.



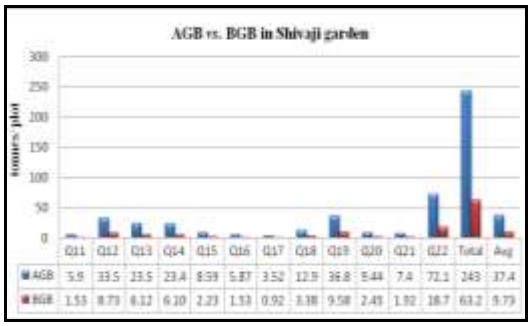
2.3.2: SHIVAJI GARDEN:

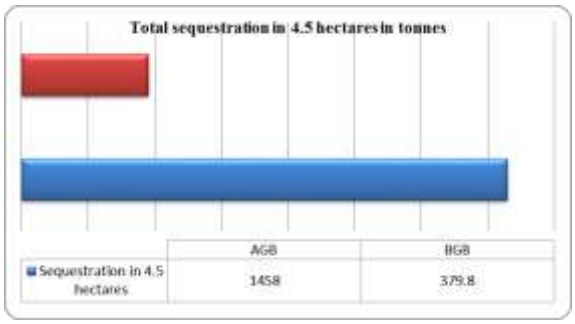
Shivaji gardens' site covers 4.5 hectares area, dominated by *Dalbergia melanoxylon* and *Gliricidia sepium*. It starts from the main gate of Pune University and ends to the back side of the Department of Environmental Sciences. The biomass density in Shivaji garden was more as compared with Range hills and total twelve plots were laid in all over site for biomass estimation.

Contrary to the Range hill which was dominated by *Gliricidia sepium,* GBH measurement of this site had some difficulties due to multi-trunk *Dalbergia melanoxylon* trees. The sequestration showed variation between 5.9 tonnes and 72.2 tonnes/ plot in 7500 m^2. According to the Fig.4 total 243 tonnes of biomass was estimated in 7500 m^2, whereas 37.4 tonnes/ plot recorded as the average sequestration of biomass in sampled area. The density of biomass shifted to higher concentration towards Environmental Sciences Department. Fig.5 illustrates the AGB and BGB sequestration.

Beside above-ground sequestration 63.3 and 9.73 tonnes/ plot, was recorded as total and average below-ground biomass (BGB) values, respectively. After extrapolation, 1458 tonnes as above-ground and 379.8 tonnes as below-ground biomass were calculated.

Fig.4: AGB vs. BGB for Shivaji Garden. **Fig.5: After extrapolation.**



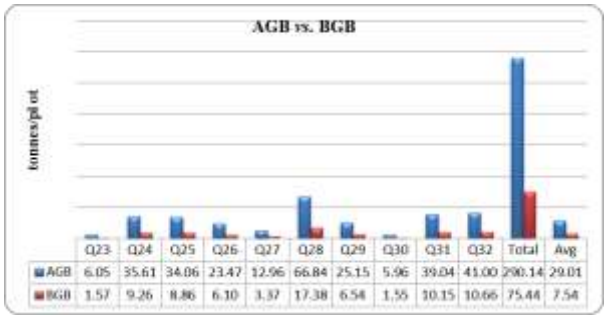


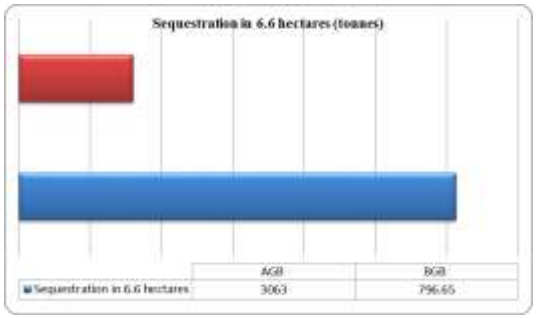
2.3.3: OPPOSITE TO BOTANY DEPARTMENT:

This site includes 6.6 hectares of the forested area that was covered with *Dalbergia melanoxylon* and *Gliricidia sepim* as two dominant species. *Dalbergia melanoxylon* individuals mostly cover those parts that are along the eastern road toward Geography and Geology Departments whereas *Gliricidia sepium* was mostly recorded at the center and western margin of this site which borders with Botany and Physics Departments.

Calculation of above-ground biomass indicated 66.84 tonnes/ plot as the highest and 5.96 tonnes/ plot as the lowest volume of biomass (Fig.6). It is safe to say that this part of the campus plantation has remained as one of the pristine planted areas in the entire campus. After extrapolation, 3063 tonnes and 796.65 tonnes were the AGB and BGB respectively, for 66000 m^2 area (Fig.7).

Fig.6: AGB vs. BGB at Opp. Botany. **Fig.7: After extrapolation.**

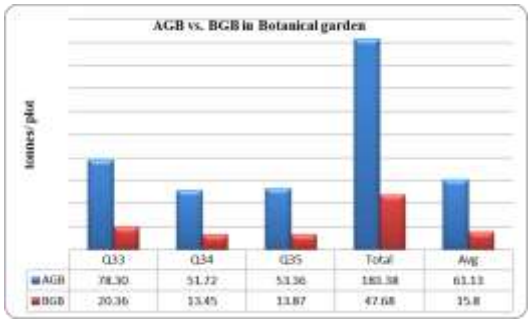


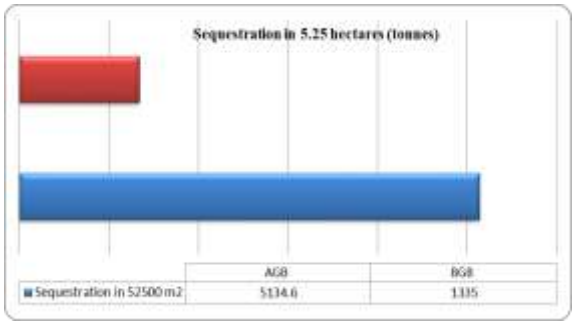


2.3.4: BOTANICAL GARDEN:

Botanical garden is considered as conservation site and in the other word a genetic bank for many plant species. It was assessed in terms of terrestrial carbon sequestration site in the university campus. This heterogeneous garden covers 5.25 hectares (52,500 m^2) area. Botanical garden along with Elease garden and Gen. Joshi gate were categorized as the most heterogeneous carbon pools of campus. The species like *Leucaena leucocephala*, *Mangifera indica*, *Roystonia regia*, *Cocos nuciferia*, *Gliricidia sepium*, *Filicium decipiens*, *Dalbergia melanoxylon*, *Santalum album*, *Eucalyptus globules*, *Ceiba pentandra*, *etc*. were documented here. Among all mentioned species *Roystonia regia* was recorded as the most abundant species available in the garden. According to the shape of the area, accuracy and precision, three plots were laid over the site to assess the biomass carbon sequestration. Fig.8 shows the amount of biomass carbon sequestration in Botanical garden.

Fig.8: AGB *vs*. BGB Botanical Garden. **Fig.9: After extrapolation.**





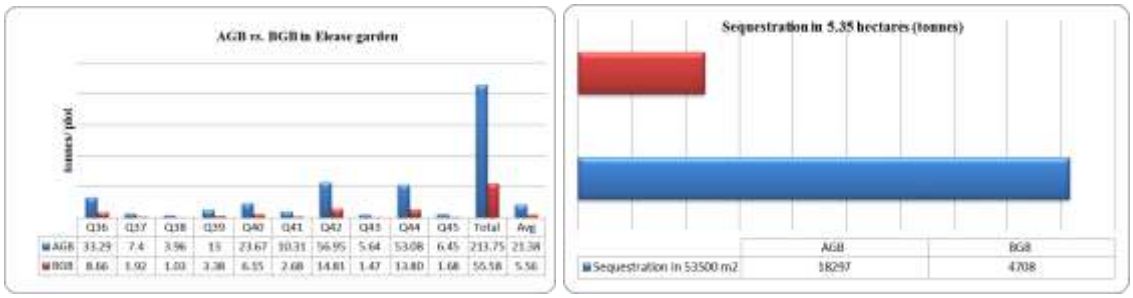
The maximum of 78.3 tonnes/ plot and minimum of 51.72 tonnes/ plot of biomass was recorded. The major species with high density and biomass was *Roystonia regia*. Fig. 9 shows above and below-ground biomass carbon over the entire site after extrapolation.

2.3.5: ELEASE GARDEN:

Elise garden can be categorized among the three heterogeneous planted sites. It has covered an area of 5.35 hectares (53500 m^2) and represents a unique plantation cover. *Samania saman, Albizia lebbeck, Alstonia scholaris, Dalbergia lanceolaria, Eucalyptus sp., Gauzuma tomentosa, Putranjiva roxburghi, Gliricidia sepium, Tamarindus indica, Ficus benghalensis, etc.* was listed as the dominant species.

Ten plots were laid for biomass estimation, out of that two were belt transacts. Measurements of some individuals, especially *Samania saman* and *Ficus benghalensis* were undertaken by belt transect, as they were planted in rows. The highest biomass per plot was 56.95 tonnes, whereas the lowest was 5.64 tonnes (Fig.10). Total above and below ground biomass was 213.8 and 55.58 tonnes/ sampled plot respectively. The average above and belowground biomass for the sampled area was 21.38 and 5.56 tonnes, respectively. After extrapolation, the total aboveground biomass was 18,297 tonnes, whereas total belowground biomass was 4708 tonnes, (Fig.11).

Fig.10: AGB vs. BGB at Elease Garden. **Fig.11: After extrapolation.**

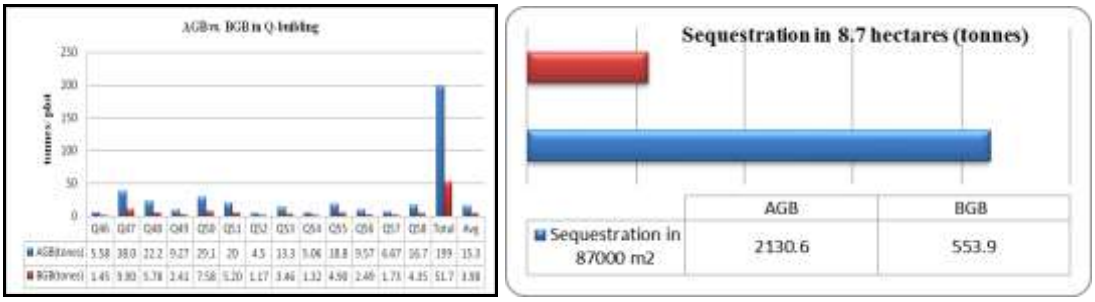


2.3.6: Q-BUILDING SITE:

Teacher quarters or Q-building was categorized as one of the densely vegetated areas. The major vegetation of this part was occupied by *Dalbergia melanoxylon* and to some extent *Gliricidia sepium*. This area covers 8.7 hectares of the entire area of the campus.

In all thirteen sampling plots covering 8,125 m^2 areas were laid over 87,000 m^2 area. Sampling plots covered a vast area from backside of teacher's quarters towards International Boy's hostel and toward the Kothi Gate of university. The highest biomass carbon sequestration was 38.07 tonnes/ plot and the lowest was 4.5 tonnes/ plot (Fig.12).

Fig.12: AGB vs. BGB at Q-building site. **Fig.13: After extrapolation.**



Total 2130.6 tonnes of biomass carbon sequestration was recorded in entire area of Q-building as above-ground biomass whereas 553.9 tonnes was recorded as below-ground biomass, after extrapolation (Fig.13).

2.3.7: GEN. JOSHI GATE SITE NO. 1:

Gen. Joshi gate site includes 12.56 hectares (125600 m^2) of the university campus. The area was divided into two sites namely site 1 and site 2. The site-1 covers 7.14 hectares (71,400 m^2) of old vegetation. Joshi gate flora was the most natural and best vegetated area in the entire campus having huge trees. The vegetation includes species such as, *Pongamia pinnata, Tamarindus indica, Samania saman, Phoenix sylvestris, Dalbergia melanoxylon, Acacia chundra,* and *Ficus benghalensis, etc*.

This site represents a heterogeneous and unequal texture of biomass in terms of GBH, height, and species diversity. The trees at this site have attended good height and girth. The highest aboveground biomass was 72.11 tonnes/ plot and the lowest was 2.89 tonnes/ plot (Fig.14). Huge trees such as *Samania saman* and *Ficus benghalensis* contribute to high volume of biomass as compare to *Pongamia pinnata, Tamarindus indica* and some other species stands for low volume of carbon sequestration.

2.3.8: GEN. JOSHI GATE SITE NO. 2:

This site covers 5.42 hectares (54200 m^2) area and was located at the opposite side of the Gen. Joshi site no.1. Floral composition was highly similar to that of Gen. Joshi Gate site no.1. The most common species were *Samania saman, Ficus bengalensis* and *Phoenix sylvestris, etc.*

The highest and lowest value for above ground biomass carbon sequestration were 47.51 tonnes/ plot and 6.22 tonnes/ plot (Fig.15) respectively, whereas 105.7 and 27.48 tonnes were recorded as the total AGB and BGB, respectively. After extrapolation, the total AGB and BGB carbon sequestration (site no. 1 and 2), was 4272.3 and 1110.7 tonnes, respectively (Fig.16).

Fig.14: AGB vs. BGB at Gen. Jashi gate site no. 1.

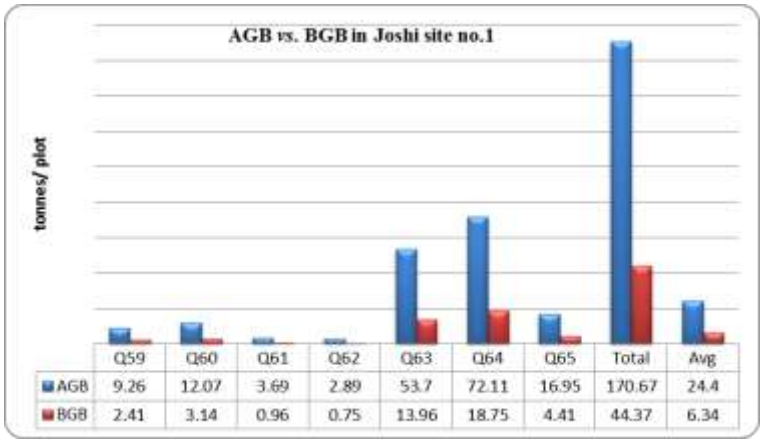


Fig.15: AGB vs. BGB at Gen. Joshi Gate site no. 2.

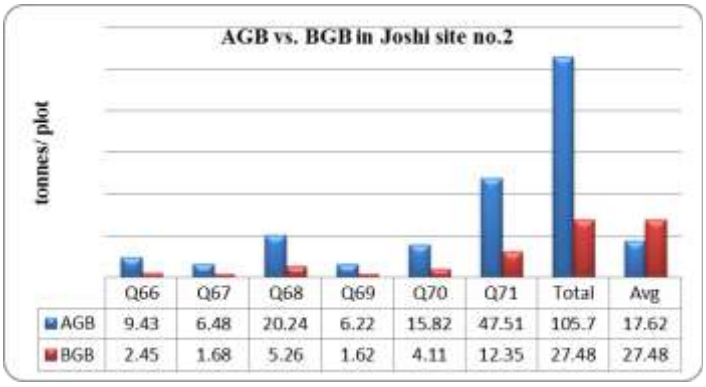
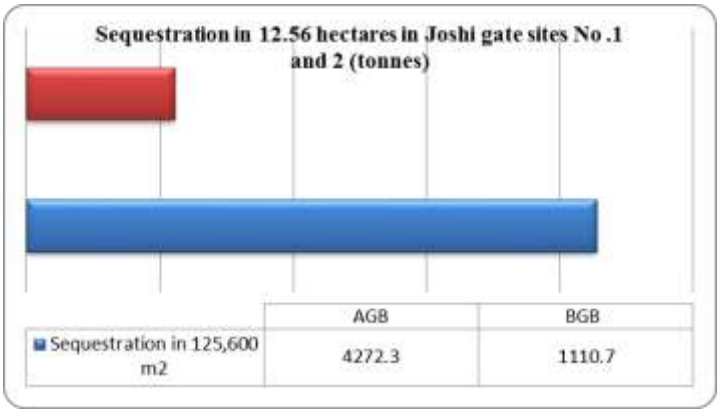


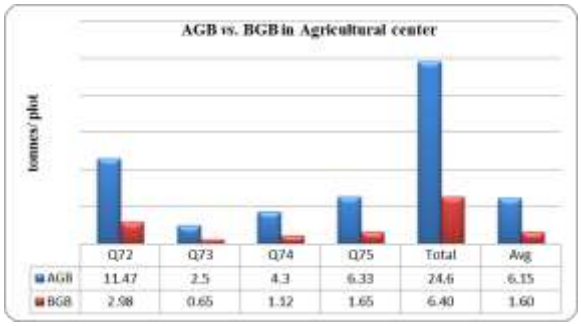
Fig.16: After extrapolation.

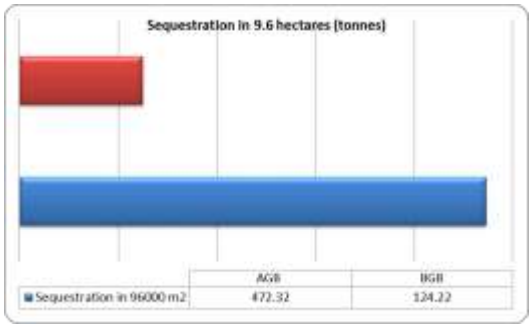


2.3.9: AGRICULTURAL CENTER:

Agricultural center site covers 9.6 hectares (96000 m^2) area. Though this site represents large area, most of it was under cultivation or experimental plots for agriculture center. It was characterized by the species like *Cocos nucifera* and *Mangifera indica*. The maximum and minimum biomass carbon sequestration was 11.47 tonnes/ plot and 2.5 tonnes / plot, respectively (Fig.17), whereas, after extrapolation, the total AGB and BGB was 472.32 and 124.22 tonnes, respectively (Fig.18).

Fig.17: AGB vs. BGB at Agricultural Center. Fig.18: After extrapolation.

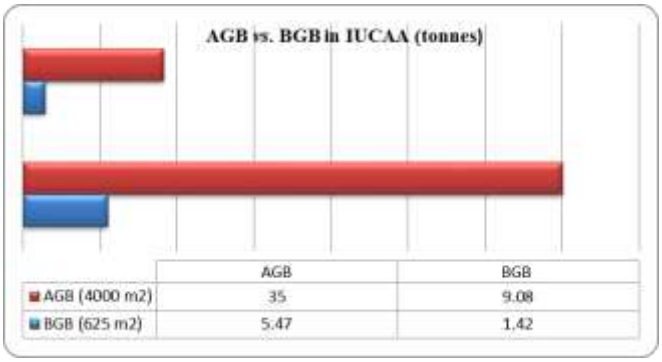




2.3.10: IUCAA SITE:

IUCAA (The Inter-University Centre for Astronomy and Astrophysics) site was analyzed for biomass carbon sequestration; and it covers an area of 4000 m^2. The above and belowground carbon sequestration at this site was 35 and 9.08 tonnes, respectively (Fig.19).

Fig.19: AGB *vs*. BGB carbon sequestration at IUCAA site.



2.4 DISTRIBUTION OF ABOVE AND BELOW-GROUND BIOMASS:

Arc view 9.2, was used for better interpretation, analysis, and eventually conceptualizing of above-ground biomass carbon sequestration in the university campus. All the sampling sites are summarized in table-2. Above and below ground values of all plots located in different pools were entered in the software to show the concentration and distribution of biomass. As it was predicted prior to the study, the Botanical garden, Elease garden, Gen. Joshi gate sites and planted sites in front of the Botany Department and Shivaji garden site, have sequestrated the maximum carbon in its above-ground biomass. 78.3 tonnes/ plot was the highest value, whereas, 2.5 tonnes/ plot was the lowest in above ground biomass in the entire campus.

The highest sequestration in terms of area and number of plots was recorded in the Botanical garden wherein 178.88 tonnes biomass were recorded. Total 1694.54 tonnes of sequestrated carbon were recorded in seventhly six plots covering 47,500 m^2 of the entire study area, whereas 21.73 tonnes / plot is recorded as the average value of biomass carbon for each plot. GIS based map shows the location and value of above-ground carbon sequestration for each plot. Green color shows the high concentration and shifting toward red indicated lower biomass carbon concentration (Fig.20). Similarly, belowground biomass indicated 26.96 tonnes as highest and 0.65 tonnes as lowest biomass carbon sequestration values (Fig.21).

2.5 HEIGHT DISTRIBUTION OF SAMPLED SITES:

Assessment of height apart from being one of the most important parameters for calculation in carbon inventory projects along with DBH was considered as a reliable parameter to find out the maturity of a natural or man-made forest for terrestrial sequestration projects. The tallest tree was 13.94 meters high whereas shortest was 0.77 meters in university campus. Botanical garden, Elise garden and Gen. Joshi site showed the maximum average height. Species such as *Samania saman, Ficus bengalensis, Roystonia regia* and *Cocos nucifera* were categorized as the highest trees recorded in the entire study area Fig.22 illustrates the tree height distribution in the campus.

Fig.20: Distribution of above-ground biomass carbon sequestration.

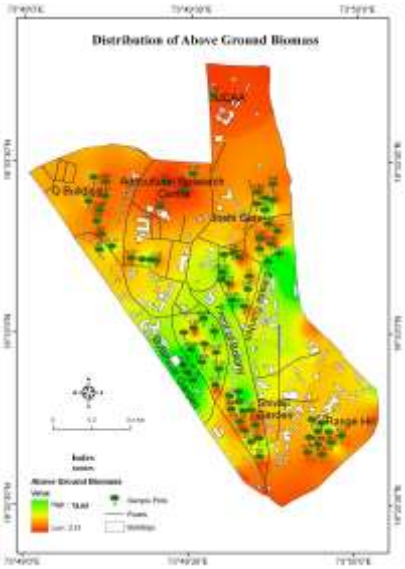
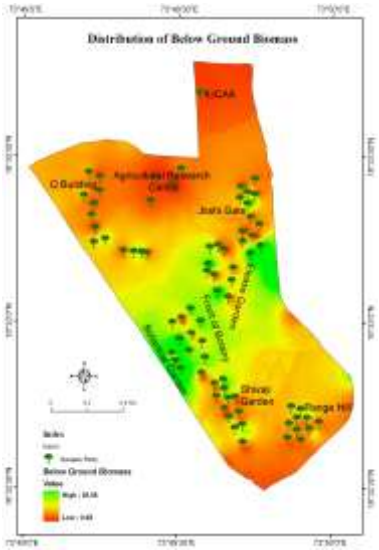


Fig.21: Distribution of below-ground biomass carbon sequestration.



2.6 DISTRIBUTION OF DOMINANT TREE SPECIES AND ITS RELEVANCE TO CARBON SEQUESTRATION:

In any carbon inventory project on above ground biomass, the main focus is paid to the dominant species of living trees in the project areas. Pune University campus was almost a homogeneous forest. The field surveys revealed that the university campus was dominated by *Dalbergia melanoxylon* and *Gliricidia sepium*, covering 77% of the campus. These were followed by *Ficus benghalensis*, *Samania saman*, *Cocos nucifera* and *Delonix regia*. Numerically, *Dalbergia melanoxylon* stands as the most dominant species having 57% of the counted species in the campus (Fig.23). It was followed by *Gliricidia sepium* which covers 20% of the green standing biomass of the study area (Fig.23). In terms of amount of biomass carbon sequestration *Dalbergia melanoxylon* (49%) was recorded as the most dominant species (Fig.24), followed by *Gliricidia sepium* amounting 31% of biomass carbon sequestration. *Samania saman*, *Ficus bengalensis*, *Cocos nucifera*, and some other species follow *Dalbergia* and *Gliricidia*, in terms of amount of biomass carbon sequestration (Fig.24).

The distribution of *Dalbergia melanoxylon* and *Gliricidia sepium;* and the amount of carbon sequestration by these species are illustrated in Figure 25a and 25b, respectively. *Dalbergia melanoxylon* showed maximum sequestration at Shivaji garden site, opposite of Botany Department, Range hills and to some extent in Q- building, representing its dominance (Fig.25a). Multiple trunk formation and high wood density were the main reasons of high carbon sequestration. The distribution and amount of carbon sequestration by *Gliricidia sepium* has been shown in the figure 25b. Accordingly, *Gliricildia* has dominated Range hills, whereas it showed insignificant presence at Q-building, Shivaji gardedn and Gen. Joshi gate (Fig.25b).

Fig.22: Distribution of average tree height in the entire study area.

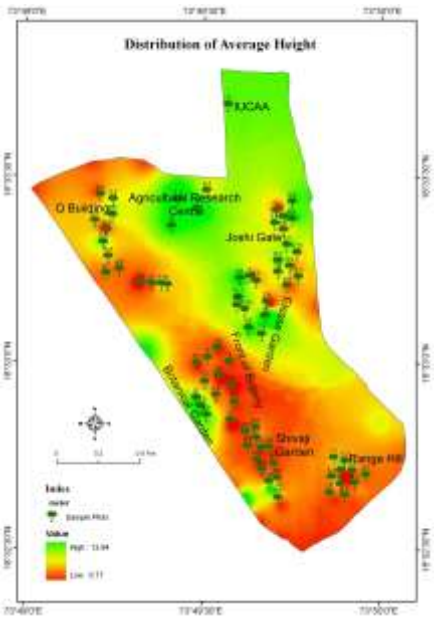
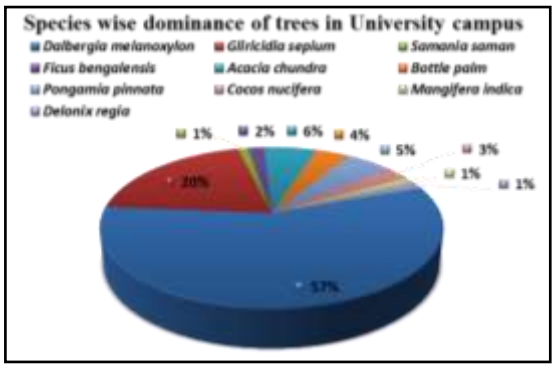
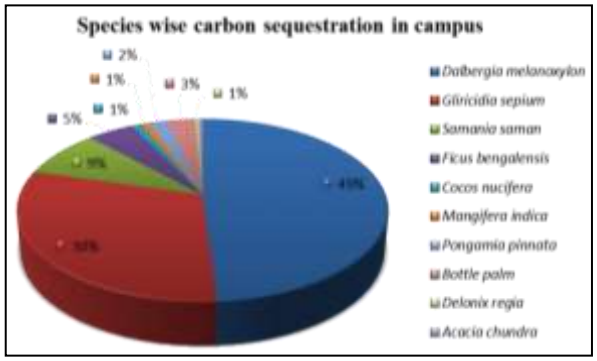


Fig.23: Species dominancy in the Campus. **Fig.24: Carbon in dominant species**





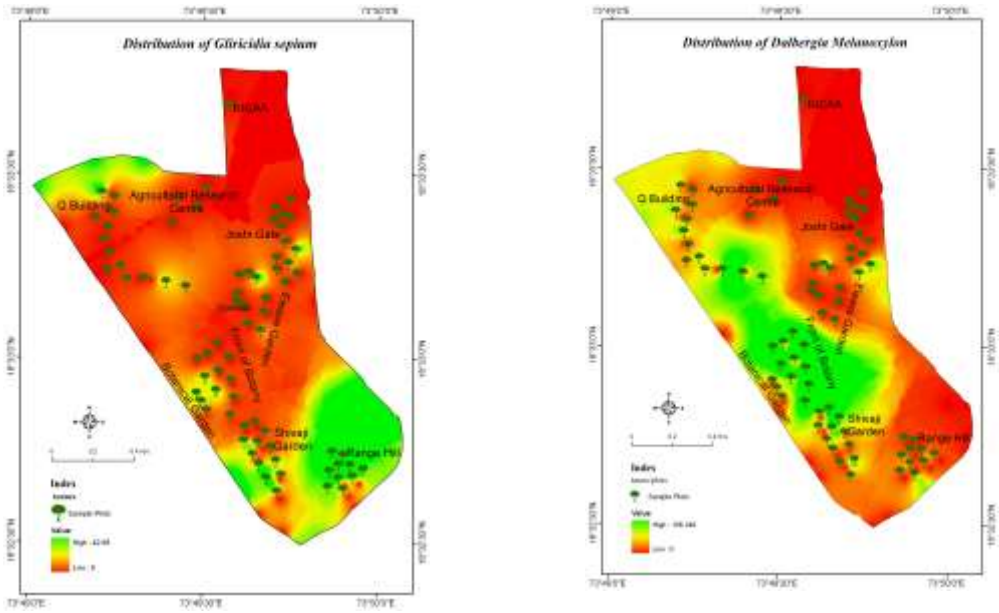
2.7 HERB, LITTER AND DEAD ORGANIC MATTER:

Herbaceous carbon sequestration is excluded in many carbon sequestration projects whereas while assessing the biomass carbon pool of university campus, it was observed and assessed as an important carbon pool. The herbs eventually become a part of soil organic carbon in the due course of time, after decomposition. We have calculated a total of 21.18 tonnes of herbaceous biomass in sampled area and 252.8 tones was obtained after extrapolation to whole campus.

Assessment of litter biomass carbon sequestration proved the importance of this pool as a vast carbon storage in the university campus. As it was predicted, Range hills, Joshi gate sites and Q-building has sequestrated the major volume of litter biomass carbon. In all 366.6 tonnes of litter biomass was obtained from the campus. As compared to litter, deadwood contributed very low volume of biomass sequestration. Only 2.71 tonnes of deadwood biomass carbon sequestration was recorded in the campus.

Fig.25: Distribution of AGB carbon sequestration in

a. Gliricidia sepium ***b. Dalbergia melanoxylon***



2.8 TOTAL BIOMASS CARBON:

The total biomass (living as well as dead) obtained has been summerised below in table 2.

Biomass carbon = (aboveground biomass carbon + belowground biomass carbon + dead organic matter carbon + Herb carbon)

Table 2: Total biomass carbon sequestration in university campus.

Carbon pool	Estimated Quantity (Tonnes)
Aboveground Biomass	37574.01
Belowground Biomass	9722.25
Herb Biomass	252.80
Litter and Dead Wood	369.31
TOTAL	47918.37

Putting a conservative value of US$ 5 per tonne of carbon locked in university campus, this huge sink of about 47918.37 tonnes is worth of US $ 239591.85, or Indian Rs 1,50,94,286.55/-

2.9 CONCLUSION:

This study concluded that selecting well adopted exotic or indigenous species is of great importance especially for further tree plantation as green belts or urban forest which plays an important role not only as ornamentals in gardens but also for biomass carbon sequestration in developing cities. Eco-friendly adaptation of tree species has been hopefully a major concern for the authorities, but beside the aesthetic aspects of such green plantation, its potential for carbon sequestration must be considered at prior stages. Pune city due to sufficient air humidity and regular monsoons has been known as the fourth greenest city of India and green urban forests such as university campus are the valuable pools of biomass carbon for such fast developing cities.

Measuring the urban forest is one of the first steps toward understanding this resource and developing appropriate management plans. The inventory process yields baseline reports that serve as benchmarks on which future changes in carbon pool size would be calculated. Establishing more properly chosen and located urban trees, in addition to maintaining the present structure, can make urban forests a larger sink for atmospheric carbon, along with producing other urban forest benefits.

Future research is needed to analyze the carbon budget of urban trees. More field measurements are needed in urban areas to help improve carbon accounting and other functions of urban forest ecosystems.

2.10 REFERENCES

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