ISSN No:-2456-2165

Carbon Sequestration An Effective Measure to Combat Climate Change

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Abstract:- Anthropogenic activities like deforestation, industrialization has led to serious deterioration in environmental quality resulting in global climate change. Delhi being the National Capital Territory of India, contributes a lot in terms of atmospheric pollution emitted from various sources. Climate change is an issue of global concern. IPCC have predicted the increase in Earth's temperature by 1.5˚C in coming 5 years. Carbon being the main reason behind all the climatic issues, that can be naturally sequestrated by plants. Many studies have revealed that many tree species are capable of storing large amount of atmospheric carbon through photosynthesis, and the amount of carbon stored is majorly depends on the biomass of the plant. With an increase in natural disasters and problems associated with climate change, it is very important to find a solution to combat climate change. Trees and shrubs being the largest terrestrial carbon sink can help in mitigating global climate change. This paper compared the total carbon stored by 3242 trees belonging to 25 different species taken from three different regions of Delhi - NCR and 1510 shrubs belonging to 8 different species taken from an urban setup of Sarguja, Chhattisgarh, and providing an alternative and feasible prospective to effectively increase carbon sequestration in urban areas by adopting vertical gardening method.

Keywords:- *Carbon Storage, Climate Change, Sequestration, Trees, Biomass, Shrubs, Vertical Garden.*

I. INTRODUCTION

Due to increase in industrialization, urbanization and trade, India is facing serious deterioration in environmental quality which has resulted in disturbances in Earth's natural mechanism which had led to climate change, global warming, erratic precipitation, biodiversity loss, rise in sea level and what not. It has not only affected environment but also affected the whole socio-economic aspect of our country.

Delhi, the National Capital Territory of India being one of the main hubs for education, industries, jobs and offices is contributing a lot in terms of pollution and other environmental issues. Besides Delhi, other metropolitans like Mumbai, Kolkata etc. are considered as quite developed cities but while judging the developed and developing cities we only consider social and economic aspects and often forget about environmental aspects. Now-a-days, Climate change is an issue of global concern.

According to the latest IPCC 2021 report, following predictions has been being made which states : (IPCC, 2021)

- Annual mean global (land and sea) mean near-surface temperature is likely to be at least 1°C warmer than preindustrial levels in each of the coming 5 years and is very likely to be within the range 0.9 – 1.8°C
- 40% chance is there that one of the next 5 years will be at least 1.5°C warmer than preindustrial levels and the chance is increasing with time
- The chance of at least one year exceeding the current warmest year, 2016, in the next five years is 90%
- Over 2021-2025, almost all regions, except parts of the southern oceans and the North Atlantic are likely to be warmer than the recent past.

It has been observed that the mean annual surface air temperature has increased by 0.4-0.6°C in the last 100 years. Warming may increase in the northern parts of India. It is expected that on an average there will be a 20 percent rise in all India summer monsoon rainfall over all states except Punjab and Rajasthan in the North West and Tamil Nadu in the South, which show a slight decrease. As regards the extreme rainfall events, an overall increase in the rainy-day intensity by 1-4 mm/day may occur in most areas in India, except for small areas in northwest India where the rainfall might decrease by 1 mm/day. Using the climate model, it is projected that there will be an overall decrease in the number of rainy days over major parts of India. (Khurana, 2012)

II. CARBON – THE CULPRIT

Carbon dioxide being the main culprit of this issue which is essential for all plant and animal life on earth. The total amount of carbon on the planet is constant, but it moves around and changes form with relative ease. Burning of fossil fuels, which have stored huge amounts of carbon below the earth's surface for many centuries, converts the carbon to carbon dioxide (CO_2). CO_2 is a potent Green House Gas and present in the atmosphere, absorbs infrared radiation which then traps the heat and results in warming of the Earth. It also contributes to various health issues like respiratory problems, skin issues etc. Terrestrial environment and the oceans serve as natural carbon sinks or sponges. (Kumaraguru et al., 2021) The forest ecosystem is considered as the most effective carbon sink in a terrestrial ecosystem, as it lowers atmospheric CO_2 levels during photosynthesis. Tree growth is a significant source of atmospheric carbon capture and storage in vegetation, soil, and biomass materials. It is estimated that forests store approximately 86% of the above-ground carbon and 73% of soil carbon of earth. (Kumaraguru et al., 2021)

In year 2020, due to global pandemic Covid 19, Govt. imposed complete lockdown in India which resulted in decrease in industrial activities, vehicular emission and other such activities which emit CO_2 or other such greenhouse pollutants. The findings show that due to Covid 19 lockdown, the total CO emissions in Delhi showed an 86.39% drop compared to normal days.

CO emissions from vehicular movement fell from 31.01 gigagram/month (Gg/month) on regular days to just 3.1Gg/month during the lockdown. The use of unclean household fuel was the second biggest CO contributor in Delhi, adding 1.35 Gg/month when no curbs were in place. (Soumya Pillai, 2021) Notably, however, this number showed no deviation even during the lockdown.

Surprisingly, for the first time in last many years the annual CO_2 emission was recorded in negative in year 2020. (Ian Tiseo, 2020) The fact was clear that the anthropogenic activities like vehicular movement, industrial operations etc led to release of carbon and related pollutants in the atmosphere which further results in Climate Change.

III. SCENARIO OF THE NATIONAL CAPITAL TERRITORY - DELHI

The importance of forests in mitigating climate change has led several countries to analyse their forest carbon budgets and evolve various mechanism for the assessment of enhancing and maintaining carbon sequestration of their forests resource. India, being the 7th largest country area wise in the world has total geographical area of 3.28 million sq. km, out of which 7,12,249 sq. km is total forest cover area accounting for approx. 21.67%. From year 2017 – 2019, India has added 3,976 sq. km of forest. (Geography Host, 2021)

According to the data, it was estimated that in year 2015, Delhi's Total Forest Cover was 299.99 sq. km which accounted for approximately 20.22% of the total land area of National Capital Territory. In year 2021, Delhi's Total Forest Cover was reduced to 195.44 sq. km covering total land area of approximately 13.18% of NCT. With an alarming increase in emission of CO_2 from different indoor and outdoor sources, and decreasing green belt had led to increase in Green House effect in Delhi and adjoining region, resulting in irregular but intense rainfall, very hot and humid summers with maximum temperature 43.73 degrees Celsius recorded on June 30, 2021 and very cold winters.

The National Capital Territory, Delhi has recorded the highest annual carbon footprint in the whole country with annual CO_2 emission of 69.4 million tonnes which is approximately equal to the sum total of the CO_2 emission of Bengaluru, Hyderabad and Chennai. (Lalit Maurya, n.d.) This is mainly due to the exhaust from various industrial setups, vehicular emission, burning of fossil fuels, burning of Municipal Solid Waste, stubble burning in the adjoining states like U.P., Punjab etc, and also some indoor sources like fumes from cooking gas and many more. Many industrial setups in NCR also adds up the carbon and related pollutants emission in Delhi. This not only worsens the environment condition but also deteriorate human health. Hence, it is quite important to capture and store released CO_2 so as to combat Climate Change.

IV. WHAT IS CARBON SEQUESTRATION?

Carbon sequestration can be defined as the removal of carbon dioxide from the atmosphere and storage in a natural system or a human induced system. This aims in the prevention of discharge of large quantities of CO_2 into the atmosphere by capturing, storing and sometimes transporting the CO_2. After Kyoto Protocol it is gaining its importance in carbon credit and trading. Identification of many CDM (Clean Development Mechanism) projects has helped in the carbon reduction and improving the national economy. These projects have estimated the quantity of carbon in various systems and their dynamics associated with it. With these estimations, several strategies and formulations have evolved quantifying and reducing the carbon foot print.

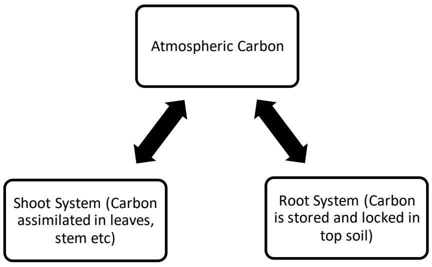

Figure 1. Movement of atmospheric carbon into Plant parts

Trees being the largest terrestrial sink of carbon dioxide, the plantation is granted as the most efficient and biggest terrestrial carbon sequestration method. Out of the five most important terrestrial carbon sequestration system (above ground biomass, below ground biomass, litter, wood debris, and soil organic carbon), the above and below ground biomass are the top two in the pool. Biomass of trees develops when plants take in carbon dioxide from the atmosphere in the presence of sunlight and convert them into starch in their tissues. Several studies have revealed that the carbon content in these tissues is half their biomass. So, with their growth and development, trees go on sequestering CO_2 from the atmosphere and store in their tissues as carbohydrates. This continues until the death of the tree. (Chandan Sahu, Hemendra Nath Nayak, 2020) The rate of carbon sequestration is however maximum during the early stages of growth in trees when trees try to produce more and more amount of food to grow, meet the energy required by them and to stabilize in their respective environmental conditions. After the death and decay of the trees, the carbon is again returned back to the atmosphere so as to complete the carbon cycle as shown in figure 3. (Kaul et al., 2010)

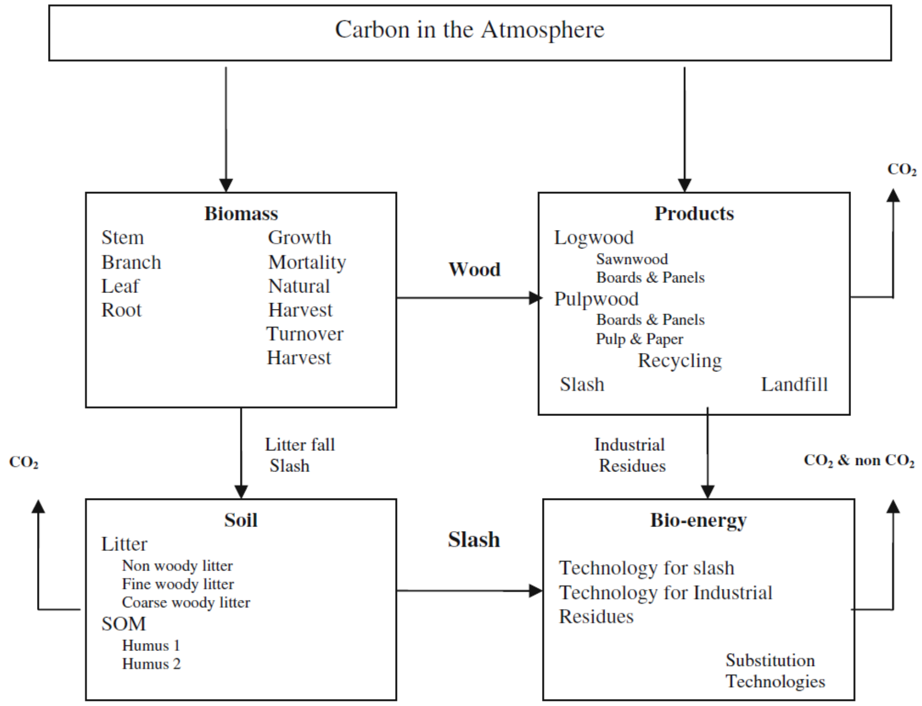

Figure 2. Movement of atmospheric Carbon into various modules (Kaul et al., 2010)

V. ASSESSMENT OF CARBON SEQUESTRATION

Trees capture and store atmospheric CO_2 through photosynthesis and plant growth mechanisms. Carbon in the form CO_2 is absorbed and assimilated by tree foliage and stored as various carbon rich organic compounds like cellulose, hemicellulose, lignin, pectin, lipid, starch etc. Tree biomass plays a crucial role in the process of carbon sequestration.

Generally, there are two methods which are used to estimate the carbon sequestration in plant biomass which includes

- Direct method
- Indirect method

In direct method, it is estimated by cutting of tree which is why it is considered as Destructive method whereas in Indirect method, carbon sequestration is calculated by the above ground biomass and below ground biomass method without harming the tree. Indirect method is preferred for the estimation of carbon sequestration in the plant biomass as it is more ecologically accepted.

It is usually done by measuring the girth at breast height (GBH) by using a measuring tape at a height of approx. 1.96 m from the ground level. Trees with a GBH of 30 cm as usually considered for this study. The height of trees is measured by fixing a reference point to the height of a nearby building or tower. The above ground biomass (AGB) and below ground biomass (BGB) is calculated by using following formula: (Chandan Sahu, Hemendra Nath Nayak, 2020)

Basal area (m^2) = $(GBH)^2/4\pi$
Bio-volume (m^3) = Basal area x Height of the tree
AGB (kg) = Bio-volume x Wood density (kg/m^3)
BGB (kg) = AGB x 0.26
Where 0.26 is taken as Root to Shoot ratio

Total Biomass (TB) in kg/tree = AGB + BGB
Total Carbon Sequestered (TC) in kg/tree = TB/2

The amount of carbon present in the trees is considered to be around 50% of the total biomass. The CO_2 equivalent can be calculated by using formula:
$CO_{2equ.} = (TC \times 44)/12$
Where, 44 and 12 are the molecular and atomic weight of CO_2 and C, respectively.

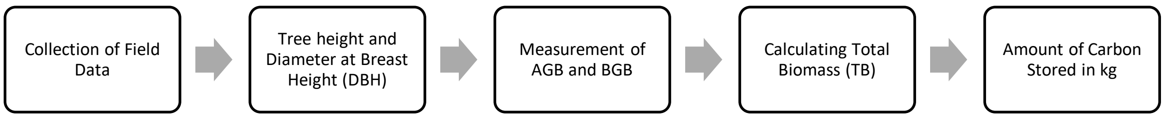

Figure 3. Methodology flowchart

ISSN No:-2456-2165

Now a days, with an advancement in the technology, tree biomass can be roughly estimated by using aerial surveys of forest cover through remote sensing and GIS technology. But by using remote sensing, complete and accurate biomass data cannot be measured because it can only estimate only few of the forest characteristics like crown density, reactivity or brightness. Therefore, ground methods are more acceptable and widely used. (Anjali et al., 2020)

VI. CALCULATING BIOMASS, CAPTURING CARBON – A COMPARATIVE STUDY

Trees and shrubs being capable of effectively capturing and storing atmospheric CO_2 through photosynthesis and plant growth mechanisms. Carbon in the form CO_2 is absorbed and assimilated by tree foliage and stored as various carbon rich organic compounds like cellulose, hemicellulose, lignin, pectin, lipid, starch etc. Biomass plays a crucial role in the process of carbon sequestration.

By using the existing data and literature, a study was conducted in which total 3242 trees of 25 different species were taken into consideration from 3 different locations of Delhi NCR namely, University Campus of GGS Indraprastha University - Dwarka (Anand M., Gunjan Som, 2021), University Campus of Amity University - Noida (Sharma et al., 2020), Mayur Vihar Phase 1 (Mayank Tripathi and Hema Joshi, 2015). With the same objective of calculating the total carbon stored, another study was done on 8 different shrub species in an urban setup of Sarguja, Chhattisgarh (Khan et al., 2020)

Field data was collected and estimated AGB, BGB and amount of carbon stored by different tree and shrub species which was calculated using Indirect method. According to the findings, it was observed that the amount of the carbon captured is directly proportional to

- Biomass of the plant
- Number of trees present in a location

which means more the number of trees, more carbon is captured and stored.

Tables given below summarizes the Above Ground biomass (AGB), Below Ground Biomass (BGB), Total Biomass (TB), Total stored carbon (CS) in different species found in three different locations.

Table 01. Total biomass (kg) in different tree species

S. No.	Scientific Name	Common Name	No. of trees	AGB (kg)	BGB (kg)	TB (kg)	Location
1	*Ficus bengalensis*	Bargad	15	8672.03	1300.8	9972.84	1
2	*Ficus religiosa*	Sacred Fig	75	26149.19	3922.38	30071.57	3
3	*Bombax ceiba*	Semal	139	37549.75	5632.46	43182.21	3
4	*Acacia nilotica*	Babool	137	30192.92	4528.94	34721.86	3
5	*Senna siamea*	Cassia	28	5562.26	834.34	6396.6	1
6	*Tamarindus indica*	Imli	176	34757.38	5213.61	39970.99	3
7	*Terminalia bellerica*	Baheda	185	34908.32	5236.25	40144.57	3
8	*Cassia fistula*	Amaltash	174	29524.96	4428.74	33953.7	3
9	*Ficus virens*	White Fig	569	76385.89	11457.88	87843.78	1
10	*Morus alba*	Sehtoot	51	6304.87	945.73	7250.6	1
11	*Azadirachta indica*	Neem	82	8326.51	1248.98	9575.49	1
12	*Putranjiva roxburghii*	Putijia	134	13149.76	1972.46	15122.22	1
13	*Syzygium cumini*	Jamun	117	11301.05	1695.16	12996.21	3
14	*Dalbergia sisso*	Shisham	235	18975.94	2846.39	21822.33	3
15	*Musa sp.*	Banana	25	835.56	125.33	960.9	2
16	*Ficus benjamina*	Weeping Fig	436	14,481.29	2172.19	16,653.5	2
17	*Ficus microcarpa*	Curtain fig	82	2716.93	407.54	3124.47	2
18	*Mimusops elengi*	Medlar	24	791.78	118.77	910.55	2
19	*Neolamarckia cadamba*	Kadam	100	3274.72	491.21	3765.92	2
20	*Moringa oleifera*	Drumstick	10	326.28	48.94	375.22	2
21	*Phyllanthus emblica*	Amla	19	615.51	92.33	707.84	2
22	*Eucalyptus sp.*	Eucalyptus	36	1155.93	173.39	1329.32	2
23	*Polyalthia longifolia*	Ashok	48	1349.57	202.44	1552.01	1
24	*Terminalia arjuna*	Arjuna	37	1004.19	150.63	1154.82	1
25	*Alstonia scholaris*	Devil's tree	308	7769.11	1165.37	8934.48	2
		Total	**3242**	**376081.7**	**56412.26**	**432494**	

Tree species taken from Dwarka (L.1) = 08
Tree species taken from Noida (L.2) = 09
Tree species taken from Mayur Vihar Phase 1 (L.3) = 08

Table 02. Amount of Carbon stored per year in different tree species

S. No.	Scientific Name	CS (kg/year)	CS (Ton/Year)	CS (kg/tree/year)	CS (tons/tree/year)
1	*Ficus bengalensis*	4986.42	5.497706725	332.428	0.366513782
2	*Ficus religiosa*	15035.79	16.57749724	200.4772	0.221033297
3	*Bombax ceiba*	21591.11	23.80497244	155.3317266	0.171258795
4	*Acacia nilotica*	17360.93	19.14104741	126.7221168	0.139715675
5	*Senna siamea*	3198.3	3.526240353	114.225	0.125937155
6	*Tamarindus indica*	19985.5	22.03472988	113.5539773	0.125197329
7	*Terminalia bellerica*	20072.29	22.13041896	108.4988649	0.119623886
8	*Cassia fistula*	16976.85	18.71758545	97.56810345	0.10757233
9	*Ficus virens*	43921.89	48.42545755	77.19137083	0.085106252
10	*Morus alba*	3625.3	3.997023153	71.08431373	0.078373003
11	*Azadirachta indica*	4787.74	5.278654906	58.38707317	0.06437384
12	*Putranjiva roxburghii*	7561.11	8.336394708	56.42619403	0.062211901
13	*Syzygium cumini*	6498.11	7.164399118	55.53940171	0.06123418
14	*Dalbergia sisso*	10911.17	12.0299559	46.43051064	0.051191302
15	*Musa sp.*	480.45	0.529713341	19.218	0.021188534
16	*Ficus benjamina*	8326.74	9.180529217	19.09802752	0.02105626
17	*Ficus microcarpa*	1562.24	1.722425579	19.05170732	0.02100519
18	*Mimusops elengi*	455.27	0.501951488	18.96958333	0.020914645
19	*Neolamarckia cadamba*	1882.96	2.076030871	18.8296	0.020760309
20	*Moringa oleifera*	187.61	0.206846748	18.761	0.020684675
21	*Phyllanthus emblica*	353.92	0.390209482	18.62736842	0.020537341
22	*Eucalyptus sp.*	664.66	0.732811466	18.46277778	0.020355874
23	*Polyalthia longifolia*	776	0.855567806	16.16666667	0.017824329
24	*Terminalia arjuna*	577.41	0.636615215	15.60567568	0.017205817
25	*Alstonia scholaris*	4467.24	4.925292172	14.50402597	0.015991208
	Total	**216247**	**238.4200662**	**66.70172733**	**0.073541044**

Table 03. Amount of Carbon stored in shrubs (tons/hectare/shrub)

S. No.	Shrub Species	Total Count	Basal Area (m^2/ha)	Biomass (t/ha)	Vol. of Shrub (m^3/ha)	CS (t/ha)	CS (t/ha/shrub)
1	*Calotropis gigantea*	330	0.019	0.718	0.06	0.278	0.000842424
2	*Cestrum nocturnum*	90	0.06	1.533	0.168	0.66	0.007333333
3	*Ipomoea carnea*	90	0.008	0.196	0.08	0.084	0.000933333
4	*Lantana camara*	520	0.03	1.066	0.071	0.459	0.000882692
5	*Nerium indicum*	190	0.08	1.751	0.255	0.753	0.003963158
6	*Ocimum tenuiflorum*	80	0.004	0.174	0.023	0.075	0.0009375
7	*Ricinus communis*	60	0.004	0.13	0.027	0.056	0.000933333
8	*Ziziphus xylopyrus*	150	0.007	0.044	0.03	0.076	0.000506667
	Total	**1510**	**0.212**	**5.612**	**0.714**	**2.441**	**0.001616556**

The total carbon stored by 25 different species of trees came out to be 0.073541044 tons/year/tree whereas the total carbon stored by 8 different species of Shrubs, calculated as 0.002 t/ha/shrub. Among tree species, *Ficus bengalensis* stored maximum amount of carbon ie. 0.366513782 tons/year/tree, and in shrubs *Cestrum nocturnum* stored maximum amount of Carbon 0.007333333 t/ha/shrub.

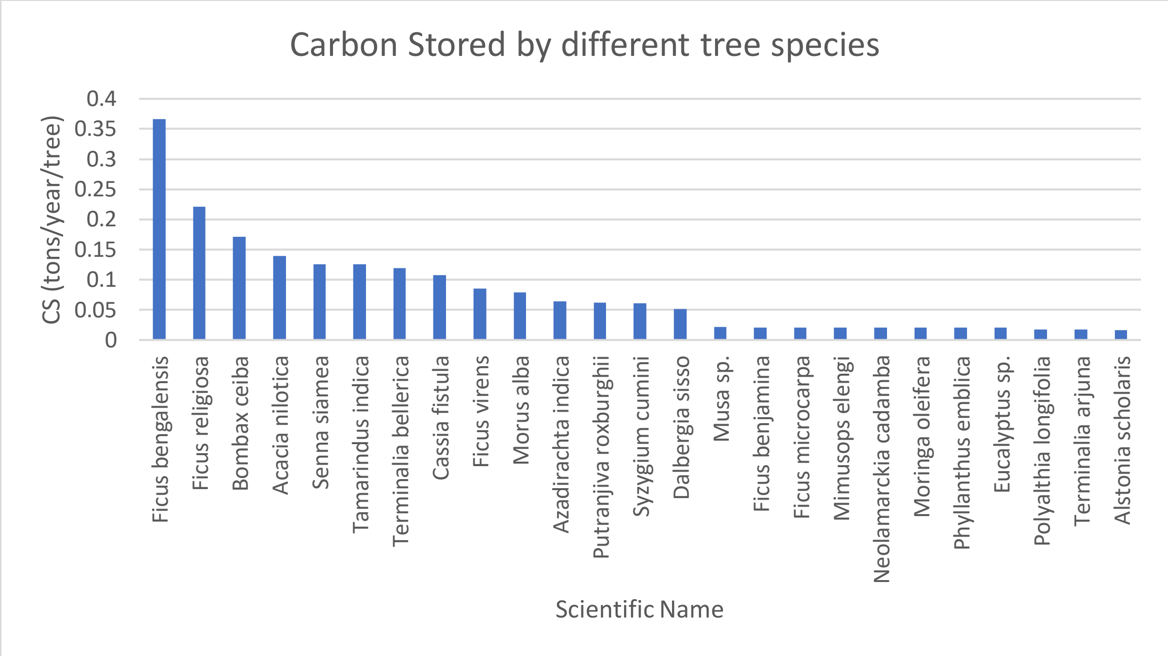

Figure 04. Amount of Carbon stored by different tree species

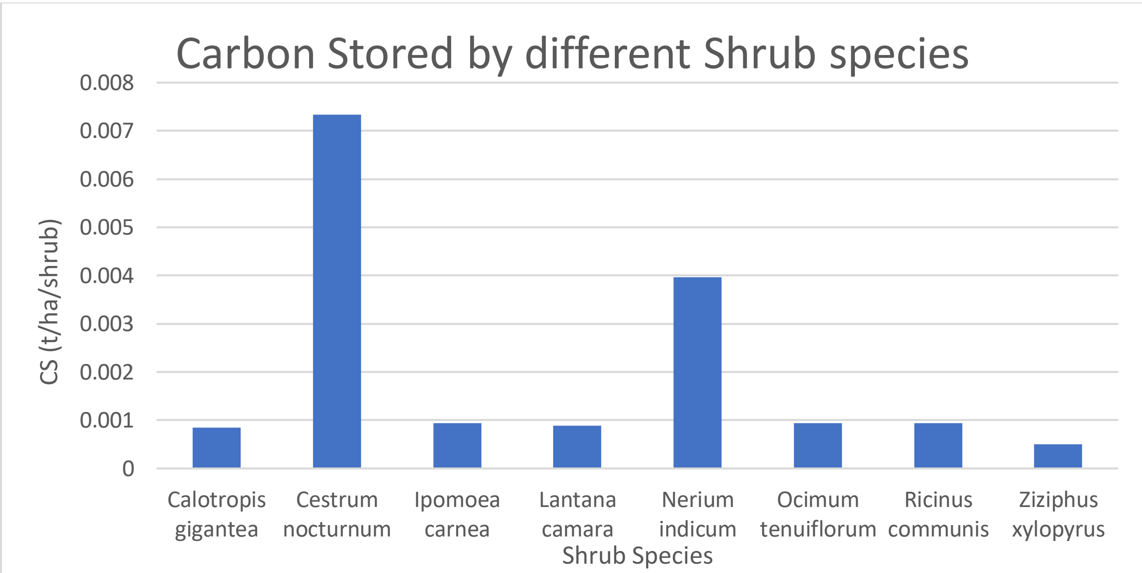

Figure 05. Carbon stored by different Shrub species

Form the above analyses, we can say that trees capture and store more carbon as compared to shrubs. This is due to high biomass of the trees and they cover larger area. Planting trees is not the only task to do to combat climate change but there's a urgent need to consider other factors as well including their survival rate. Despite of having higher biomass in trees as compared to shrubs, trees require more time and space to grow. Shrubs being short multi stemmed woody plant, dominate over trees because of their certain characteristics which make them more suitable to be grown on a larger scale. They require less time to attain full size as compared to trees. They have higher growth rate and survival rate after partial cutting and are more widespread than trees. In addition, shrubs play crucial roles in maintaining ecological balance. Shrubs are important for mitigation of climate change, maintaining water balance and carbon uptake and storage, soil stabilization and production, preventing water and soil erosion. They tend to survive even in dry conditions. (Götmark et al., 2016)

According to (Mills & Cowling, 2014) maximum amount of carbon sequestrated by a CAM C3 shrub, *Portulacaria afra* commonly known as Spekboom, was found to be 15.4 t/ha/year. Spekboom being a drought resistant plant can be easily grown and maintained with less or no care at all. Moreover, Spekboom have many advantages over other shrubs and trees, like it improves air quality by capturing and storing large amount to atmospheric carbon, fights climate change, considered as water wise due to its drought resistant character which can withstand water scarcity and can survive on 250-350 mm of water per year. Furthermore, it can grow in all weather conditions and in all seasons. (Monique Warner, 2018).

VII. VERTICAL GARDENING – A STEP TOWARDS GREENER CITY

In the era of urbanisation and modernisation, buildings and road construction has resulted in inadequacy of space for growing trees. Clearing trees for industrial and residential setups has decreased the green belt area and has eventually led to climate change. Vertical gardening, nowadays is the one of the possible method by which we can again increase greenery around us in a limited space. Vertical Gardening (also referred as, Bio walls, live walls or green walls) is a concept of growing plants like shrubs, creepers on a vertical wall covering it completely or partially. Shrubs can be easily planted and maintained in less space by using vertical method which will not only mitigate the problem of climate change but will also impart ornamental and aesthetic value to the urban landscape. There are numerous benefits of vertical gardening which includes that they reduce thermal efficiency of the building by reducing surface temperature by as much as 15.2˚C. (Jain, 2016) Furthermore, they improve indoor air quality, reduce the energy usage by 28% which would have used for cooling purpose, saves water, provides excellent air circulation for surrounding plants. Economically, they can reduce the cost of painting. (Jain, 2016) Spekboom, being the maximum carbon sequestering shrub, can be easily potted on vertical walls, irrespective of watering and maintenance frequency.

Industries with high carbon emission, buildings near roadside, educational institutions, even in houses, should adopt vertical gardening method to reduce atmospheric Carbon emitted as a result of various indoor and outdoor anthropogenic activities. Hence, more emphasis should be given on creating vertical gardens wherever possible.

VIII. CONCLUSION

Increase in population increases resource demand which further increases the pressure on Earth to satisfy everyone’s need and sometimes greed as well. Rapid establishment of industries and construction of roads and highways on a large scale by clearing out forest and green belt, degrading Earth’s natural flora and fauna has resulted in noticeable changes in temperature and rainfall pattern and lack of green space. Climate change is clearly associated with Green House Gas emission and air pollution, and situation is worsening day by day. Need of the hour is to equally consider environmental issues as an important social issue. Even after knowing several facts and importance of plants, we humans are prioritizing economic development instead of overall sustainable development. In the above case study, we have seen the role of trees in capturing and storing large amount of atmospheric carbon. Trees with higher biomass store more carbon but they require more time and space to grow but planting shrubs in a feasible manner requires less space and time. Maintenance of urban green spaces and green walls using shrubs not only imparts ornamental and aesthetic value but also mitigates the impacts of climate change at local level. It is quite important to increase green belts around us using vertical gardening methods within the limited space using limited resources. Hence, more emphasis should be given on creating vertical gardens wherever possible.

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