Carbon sequestration strategies in the changing global environment

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Abstract: *The human induced activities have shown an adverse impact on biological and physical components of the ecological system altering the global environment. The urbanization and industrialization have caused a heavy loss of primary and natural forest; and the slow growth rate of secondary forest will take much enough time to cover these losses. The mitigation of increasing GHG emissions and its impact on global environment change have emerged as a great challenge in front of environmentalists and forest policy makers. Afforestation and soil carbon sequestration, approaching to intensive agriculture for minimizing surface temperature, increasing aquatic primary productivity are some issues needed to be addressed for minimizing the impact of environmental challenges like global warming and climate changes. Special focus should be on CO_2 capture and sequestration technique that can play a significant role in reducing GHG emissions from new and existing industrial operations and fossil fuel power plants and their geological storage. The technique has potentiality to be adopted by all mega power plants and to meet their carbon pollution standards. The technology is viable in developed countries, and in future all the power plants and projects in developing and under-developing countries have to approach to it for reducing CO_2 emission and assuring a safer and pollution free global environment. This comprehensive review highlights the causes of global forest depletion, carbon degradation and its consequences. The remediation through natural and human induced carbon sequestration technology and their significances are also explored.*

Key Words: *Forest depletion, secondary forests, green house gases reduction, carbon sequestration*

1. INTRODUCTION:

The increasing human populations have resulted in growing demands of food and land with net global forest loss of nearly 50% in the last twenty five years. The global forestry which was 4.1 billion ha in 1990 declined to less than 4 billion ha i.e. a decrease of 3.1 percent during these quarters. In the last twenty five years, the natural forest area have declined to 129 million ha with an annual net loss rate of 0.13 percent, primary forest gets modified up to 31 million ha into naturally regenerated forest, and more interestingly the planted forest area increased to 105 million ha at the same period (FAO, 2016). The tropical forests that once covers half of the world's forestry, even present more deteriorated picture and out of these almost a third are loosed, 46% gets fragmented, 30% degraded, and only 24% or 600 million hectares is either in a mature or relatively undisturbed state showing a significant impact on absorption, storage and thus the whole carbon cycle (TFAR, 2015).

During 2015 most of the world's forests are natural forest, accounting to 3.7 billion ha or 93 % of global forest area, 74% are "other naturally regenerated forest" and 26 % are primary forest (FAO, 2016). The increasing human requirements has exploited the wilderness mainly the wood, fibers and other forest produces thus requiring the understanding of the ecosystem functioning and comparing it with the old natural forest (Noormets *et al.*, 2015). The 96 percent of the world's forests follows both policies and legislation and supports sustainable forest management (SFM), however these forest also shows decline of almost 11 gigatonnes of global carbon stocks in forest biomass, thus a matter of great concern according to the report (FAO, 2016).

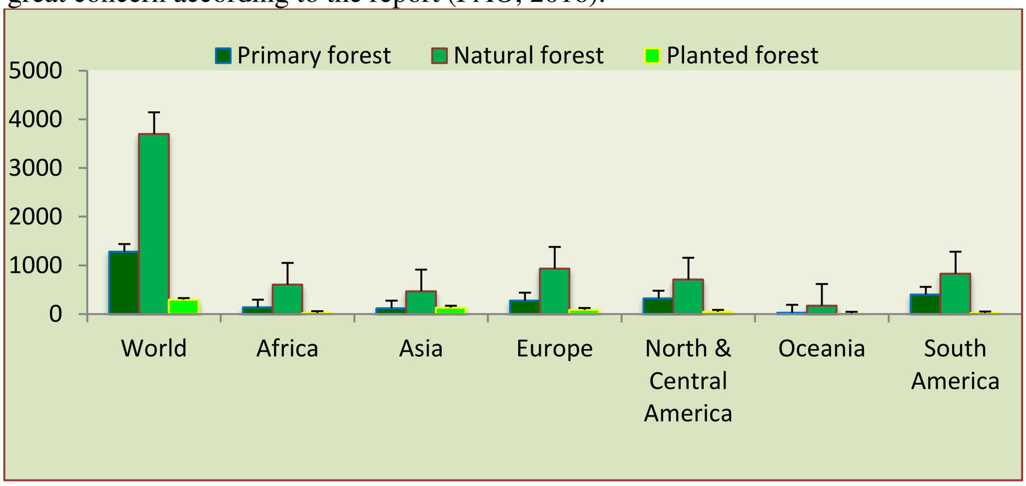

Fig. 1: Global Forest status of primary, natural and planted forest

As of 2015 the natural forest accounts for 93 percent with largest in Europe (925 million ha) followed by Russian Federation. The continents like South America and Africa have shown largest loss of natural forests, followed by Asia and North and Central America whereas Europe and Oceania have depicted a stable trend. During 2015 primary forests accounted for 33 percent of the world's forests, or about 1.3 billion ha, and its area have declined in the tropical region, whereas the boreal and temperate region have shown a slight increase in the area (Fig. 1). In the last twenty five years the Planted forest area has increased accounting for 7 percent of the world's forest area with largest in temperate domain (150 million ha), followed by the tropical and boreal forests with almost 60 million ha each (FAO, 2016).

2. CARBON DEGRADATION-CAUSES AND CONSEQUENCES:

Use of wood-based biofuels and less energy-intensive construction materials, has potentiality in reducing greenhouse gas emissions and the harvested wood products plays a significant role in carbon accumulation, along with providing GHG sequestration benefits (FAO, 2016). The carbon sequestration under Clean Development Mechanism, a prominent agenda of Kyoto Protocol, using afforestation and reforestation activities influences global climate change and global warming (Sohel *et al*., 2009), helps in increasing carbon sinks and also generate revenue to low-income class in developing countries along with social and ecological services (Paquette et al., 2009). Biomass and carbon stocks in forests are indicators of productivity, energy potential and carbon sequester capacity and according to global forest resource assessment report, 2015 the world forest stores nearly 296 Gt of carbon in above- and below-ground biomass (FAO, 2016). Although the global carbon stocks likely to decrease continue however it can be level out by applying REDD+ and other initiatives that helps in exploring the role of the forests as a terrestrial sinks and an important sources of CO_2.

Anthropogenic activities, together with the natural calamities have deteriorated the environment causing decline in tree species and affecting carbon stocks globally and requires a relevant strategies for their preservation up to species or even to ecological grade for the proper functioning of the ecosystem (Pandey *et al*., 2016). The forest as a principal carbon sink need a detailed study of natural and regenerated forests, more specific a managed and unmanaged forest, specially for notifying observed and expected changes (Noormets *et al*., 2015). Various agricultural practices like shifting cultivation have shown major impact on forest degradation. The old forest have higher carbon in the aboveground and living woody biomass followed by old to new fallow sites of secondary forest, mainly due to the patch size. However there is a need of detail analysis to understand the sources of aboveground biomass (Mukul *et al*., 2016). Carbon sequestration mainly depends on wood density, carbon content and annual increment of stems and standard deviation value of carbon stock is double in tropical secondary forest (Nabuurs *et al*., 2008). There are various obstacles in enhancing the plantation activities especially in old fallow forests, thus before implementation these projects the advantages, economic risks, and adjustment with existing models of the real market should be considered (Paquette et al., 2009).

3. CARBON STOCKS AND FOREST PRODUCTIVITY:

The carbon stocks and biomass in forests represents its productive capacities, energy potentiality and carbon sequester capacity. According to an estimate the global forestry store nearly 296 Gt of carbon in both above- and below-ground biomass, which accounts for half of the total carbon accumulated in the forests. The global average of carbon is 74 tonnes per hectare and in the last 25 years the carbon stocks in forest biomass have declined by almost 11.1 Gt due to degradation of forest land or their conversion to agriculture and settlements. Recently the Global Forest Resources Assessment report 2015 reveals that the countries in South America, Africa and Oceania shows highest densities of carbon in above and below ground forests biomass(ABGFB) thus accounting for most of the losses whereas Europe, North and Central America and Asia have significantly minimized the rate of forest losses (Fig 2) during these period. The awareness about forests as terrestrial sinks and sources of co_2 is mainly due to implementation of REDD+ and other initiatives like use of wood-based biofuels as a substitute for fossil fuels, wood and bamboo as construction materials and harvested wood products thus contributing to reductions in greenhouse gas emissions and providing GHG sequestration benefits (FAO, 2016).

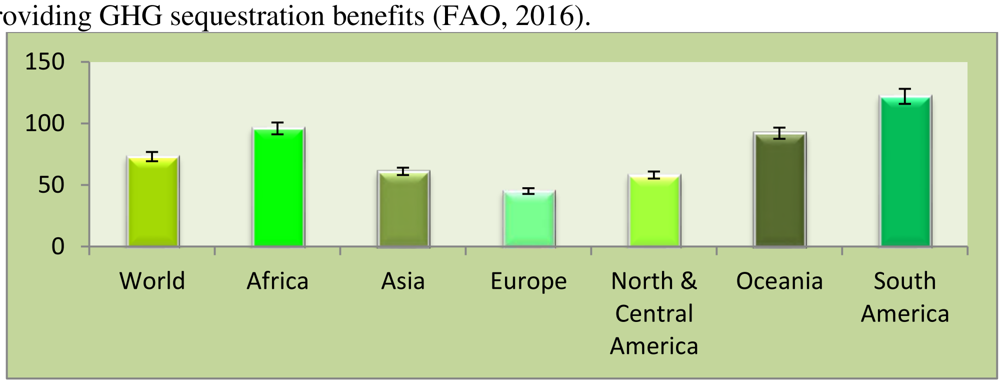

Fig. 2: Global carbon stock above and below ground biomass (tonnes per hectare) in 2015

The GFRA report somehow gives relief that the area of planted forest have increased during past twenty five years though the last five year data's of North America, Europe, East and South Asia and Southeast Asia have shown a slight decrease. Thus the forest managers have to think of designing new policies to maintain carbon balance in nature.

Forest restoration is a challenging task, requiring negotiation and similar multidimensional ecological and social compatibility and governance maneuver for implementing and managing it (Guariguata and Brancalion, 2014). Natural regrowth of secondary forests provides a low-cost mechanism yielding a high carbon sequestration which is highly beneficial to biodiversity and ecology (Chazdon *et al*., 2016). Forest modeling, mapping, forest certification, species domestication, remote sensing and computer databases are some of the important tools used in conservation and forest regeneration activities (Pandey *et al*., 2016). The operations research models and planning along with tactical, strategic, forest management and conservation has potentiality in addressing environmental issue (Rönnqvist *et al*., 2015). The assessment of rate of success of forest regeneration programs can be measured by estimating carbon accumulation in forest restoration areas varying with plant age and life form over time (Shimamoto *et al*., 2014).

Understanding dynamics of soil chemistry and structure becomes significant for land conversion in tropics as it helps in comparing and establishing baseline data for determining the impact of land conversion on soil properties which can act either as source or a sink for atmospheric Co_2 and nitrogen. There is strong evidence of faster litter decomposition with depth in some entity eg. pine forest showing regaining in soil structure, chemical variables and fertility similar to that of natural forest (Sohng *et al*., 2017). The equilibrium dynamics of secondary forests needs evaluation of community reassembly and species composition, depending on successful invasion of seeds, saplings and young trees of forest community and achieved through abundance of general species in regional flora, high intensity of seed dispersal, and presence of old-growth forest remnants (Norden *et al*., 2009). For optimal ecosystem management there is a need of understanding the belowground sharing, availability of carbohydrate, heterotrophic respiration, and stabilization of carbon in the soil (Noormets *et al*., 2015).

4. CARBON SEQUESTRATION- TECHNIQUES AND APPROACHES:

Among various techniques the carbon sequestration also referred as carbon pools, has emerged as a viable technique which involves removing of carbon from the atmosphere and accumulating it in form of forest biomass (a complex mixture of live and dead organic matter and minerals), soils, wood products and the atmosphere and thus has a potentiality to mitigate environmental problems like global warming and climate change (Dhanwantri *et al*., 2014).
Carbon sequestration mainly involves two approaches- biological and mechanical or human induced. The biological approach refers to increase soil carbon or carbon storage in biomass through afforestation and reforestation whereas mechanical approach is based on capturing carbon either through direct air capture (DAC) or from the exhaust stacks like oil refineries or large fossil fuel power plants, and their storage (Moriarty and Honnery, 2016). Human induced Carbon pools involve carbon capture and storage (CCS) technology through industrial processes or fuel combustion, transferring through pipelines, and finally underground storage in deep saline forms and depleted oil and gas fields (Dhanwantri *et al*., 2014).This technology can play an important role in reducing GHG emissions, along with low-carbon electricity generation from power plants (nearly 80-90%), cement production, ethanol and natural gas processing. The captured co_2 is used for a wide range of end uses including food and beverage manufacturing, metal fabrication, pulp and paper manufacturing, and enhanced oil recovery (EOR). Geologic formations suitable for sequestration include deep coal seams, depleted oil and gas fields and saline formations (www.epa.gov)

5. ESTIMATING NATURAL CARBON STORAGE THROUGH SECONDARY FOREST:

Removal of forest vegetation either completely or nearly followed by regeneration of secondary forests has potentiality in storing carbon in aboveground biomass, thus helping in partial balancing of carbon emissions caused due to forest degradation and other anthropogenic activities. Ten countries led by Brazil, Colombia, Mexico, and Venezuela account for 95% of carbon storage potential after second-growth forests (Chazdon *et al*., 2016). In various forest like Atlantics the slow growing trees shows more amount of total biomass compared to fast-growing species and the former contribute more to the carbon stock during the later stages of succession and the later shares more amount of carbon stock during the early years but slows down with time (Shimamoto *et al*., 2014). The forest gap model like FAREAST were effective in Russian forest to estimate biological growth parameters of several forest along with their economic perspectives as a timber and carbon sequestration with the remark that forest stands with higher species diversity were less sensitive to extreme temperatures and species like *Pinus sylvestris* was found a heat-tolerant species, showing an continuous enhancement in timber harvesting and carbon sequestration (Lutz *et al*., 2013).

LiDAR data and GIS, with canopy height model, canopy cover model and digital terrain model for more accuracy, can be effectively employed in estimating above ground biomass and carbon stocks of mangrove vegetation (Pillodar *et al*., 2017). The above ground biomass increases due to forest restoration mainly in case of planted stems as the alteration in biodiversity slows down due to low growth rate of the stem, but it is comparatively better than degraded plot with low diversity and above ground biomass (Charlotte *et al*., 2016). The secondary forest stores more carbon compared to immature forest giving indication of success in the direction of forest management, conservation and regeneration (Shimamoto *et al*., 2014). The global carbon stock can be managed by public training, their involvement and strategically implementing green house gas protocol standards and carbon legislation (Vieira *et al*., 2014; Guariguata and Brancalion, 2014; Pandey *et al*., 2016). For effective forest regeneration the implementation of this legislation requires knowledge about local biological and physical factors with special emphasis on the financial aids needed for developing and monitoring the secondary and newly formed forest areas (Vieira *et al*., 2014).

6. IMPROVING GLOBAL CARBON STOCK DEPOSITS:

In order to conserve the biodiversity, the anthropogenic and other developmental activities should be strategically implemented to sustain the wilderness of the region (Singh and Pandey, 2017). Carbon footprint estimation for analyzing carbon dioxide emissions caused due to depletion of natural resources proves an efficient metrics in managing the emission and thus plays a crucial role in carbon balance (Pandey *et al*., 2016). Forest with mixed species stands reports higher carbon stock and proves an effective tool in sustainable forestry policy development (Carnol *et al*., 2014). The changes in forest stand patterns can be explored by enhancing plant size and nutrient availability. The prolonged carbon sequestration potentiality in soils can be better assessed by estimating the ratio of heterotrophic respiration and total detritus yield (Noormets *et al*., 2015). Forest litters are best sources of carbon stock therefore understanding the chemistry becomes significant in forest regeneration and conservation (Pandey *et al*., 2016). In general agroforestry systems especially the cultivated plants has potentiality in managing edaphic phenomena equivalent to natural regeneration (Cezar *et al*., 2015). The success of forest restoration depends on governance issues which can play a significant role in eventually determining multiple scales in regard to renewed perspectives for exploring programs globally (Guariguata and Brancalion, 2014).

The reclamation of former mined area using relevant techniques and management strategies has potentiality in enhancing atmospheric carbon dioxide (Stevens *et al*., 1998; Holloway 2005; Rooyen *et al*., 2013). Coal-bed methane an eco-friendly fuel, accepted globally as a best alternative of conventional fossil fuel (Rao *et al*., 2014; Tripathi and Pandey, 2017) has potentiality in sequestering large amount of carbon dioxide from coal fields (Zuo-tang *et al*., 2009; White *et al*., 2005; Pashin *et al*., 2004). The timber logging in the tropical forests releases a huge amount of carbon dioxide and reduces carbon stocks, thus achieving sustainability in forest-management requires technical ecological standards and reevaluation of UN proposals on climate change like REDD (Zimmerman and Kormos, 2012). Among forest governance policy Polycentric arrangements which helps in analysing international effort to minimize greenhouse gas emissions through degradation and deforestation (REDD) and climate change, provides an effective framework in protecting social-ecological systems and sustainability of diverse forests (Nagendra and Ostrom, 2012).

7. CONCLUSIONS:

Thus afforestation is a significant phenomenon as the forests and agricultural soils enhances the photosynthesis resulting in carbon storage or sequestration and regulate global carbon cycle and plays a vital role in managing global climate change. Natural carbon sequestration helps in conserving existing wilderness and soil carbon, and minimizing emissions of carbon dioxide, methane and nitrous oxide through carbon accumulation in trees and soils. The more emphasis should be on improved anthropogenic activities that can mitigate global warming and limiting CO_2 emissions by taking measures in energy sector, using and modifying land, and forestry activities that can reduce the effects of climate change, either by accelerating the removal of GHG from the atmosphere or by reducing emissions.

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