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# UNIT 12 GREENHOUSE GAS EMISSION AND CARBON SEQUESTRATION

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## 12.1 INTRODUCTION

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The atmosphere of our planet earth acts as an insulating blanket, which could trap the solar radiation to keep the earth warm enough to support the living things. The concentration of greenhouse gases (GHGs) such as carbon dioxide ( $\text{CO}_2$ ), methane ( $\text{CH}_4$ ), nitrous oxide ( $\text{N}_2\text{O}$ ), water vapour, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ( $\text{SF}_6$ ) in the atmosphere are increasing alarmingly by anthropogenic activities (IPCC, 2001). The greenhouse gases (GHGs) in the atmosphere are responsible for trapping the heat radiated from the Earth Surface. Thus, our planet earth requires the natural greenhouse effect to maintain the global temperature to support life. In this unit, you will be learning about the various emission sources of greenhouse gases, and carbon sequestration.

## 12.2 OBJECTIVES

After studying this unit, you should be able to:

- explain greenhouse gas emission inventories and estimation methods;
- describe the global carbon reservoirs;
- explain carbon sequestration strategies;
- explain carbon sequestration potential of biomes; and
- describe the estimation of soil carbon.

## 12.3 GREENHOUSE GASES

The greenhouse gases like carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), water vapour, chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF<sub>6</sub>) are responsible for trapping terrestrial radiation and making the Earth liveable. The global surface temperature may go down up to -18°C, if our planet's atmosphere is devoid of GHGs (Casper, 2010). Thus, if any changes in the concentrations of the above GHGs would ultimately affect the global surface temperature. Besides, the GHGs in the atmosphere have a specific lifetime and also differed in properties to trapping the heat from the terrestrial radiations (Casper, 2010). Thus, the global warming potential of the GHGs differed according to their residence time in the atmosphere. The global warming potential of the major GHGs is presented in Table 12.1. According to the United States Environmental Protection Agency (EPA), the Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and sulphur hexafluoride (SF<sub>6</sub>) gases are more potent to trap heat and also have a longer lifetime.

**Table 12.1: Global warming potential of the most important greenhouse gases in the atmosphere**

S.No	Greenhouse gas	Lifetime in the atmosphere (Years)	Warming potential over 100 years (compared to CO <sub>2</sub> )
1.	Carbon dioxide (CO <sub>2</sub> )	50 - 200	1
2.	Methane (CH <sub>4</sub> )	12	23
3.	Nitrous oxide (N <sub>2</sub> O)	120	296
4.	Chlorofluorocarbons (CFCs)	550	7000
5.	Hydrofluorocarbons (HFCs)	3.7 – 264	140- 11700
6.	Perfluorocarbons (PFCs)	3200-50000	6500-9200
7.	Sulphur hexafluoride (SF <sub>6</sub> )	3200	23900

*Source:* Adapted from UNFCCC and Casper, 2010.

### 12.3.1 Sources of GHGs

Most of the GHGs (for example CO<sub>2</sub>) are present in nature and they are cycled via global biogeochemical system processes. The industrial revolution and intensive agricultural practices have changed the global biogeochemical system processes at regional to global scale level (Lal, 2004a). The CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O are most important GHGs in the atmosphere and their concentrations have increased many fold in the atmosphere by human activities (IPCC, 2001).

#### Carbon dioxide (CO<sub>2</sub>)

Most of the scientists in the 19<sup>th</sup> century believed that CO<sub>2</sub> in the atmosphere causes the greenhouse effect and regulates and /or maintain the global surface temperature (IPCC, 2001; Casper, 2010). The CO<sub>2</sub>, which normally enters into the atmosphere on account of burning of fossil fuels, coal industries, forest fires, land use and land cover change, soil organic matter decomposition, and plant respiration, (Lal, 2008). The concentration of CO<sub>2</sub> in the atmosphere has increased from ~280 ppm (preindustrial level) to 410 ppm due to anthropogenic activities (NOAA, 2019) (Fig. 1). The fossil fuel combustion and land use change have emitted about 11.3±0.9 Gt C yr<sup>-1</sup> into the atmosphere (Le Quere et al., 2018). The CO<sub>2</sub> concentration is increasing at an alarming rate of 1.5 ppm in the atmosphere (Lal, 2004b).

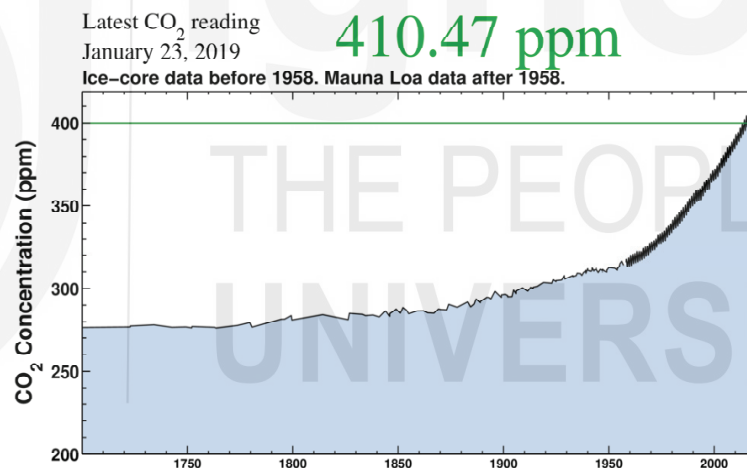


Fig 12.1: The concentration of atmospheric CO<sub>2</sub> (ppm) from 1700 to 2019

(Source: <https://www.co2.earth/daily-co2>)

#### Methane (CH<sub>4</sub>)

The methane is formed when the plant detritus decomposes in the absence of oxygen (anaerobic) during the decomposition process. The global warming potential of methane is 23 times more than CO<sub>2</sub> (Casper, 2010). Livestock, such as sheep, goat, cow, buffalo, camels, and bison, is also contributing a significant amount of methane emission into the atmosphere. The global methane emissions are estimated at 558 Tg CH<sub>4</sub> yr<sup>-1</sup> during the study period between 2003 and 2012 (Saunio et al., 2016). Among, 60% of global methane emissions are anthropogenic in origin. Globally, the livestock and agricultural activities contribute 70-90% of methane emission into the atmosphere (Gerber et al., 2013). The natural emission of methane from permafrost, wetlands, freshwater bodies, oceans, soils, flooded rice fields, and wildfires represent a small portion

(<10%) of the total methane emission (Kirschke et al., 2013). In India, the livestock alone contributes 15.3 Tg yr<sup>-1</sup> which is about 2.74% of the global methane emission into the atmosphere (Kumari et al., 2018). More importantly, the methane emission is increasing annually at the rate of 0.90 × 10<sup>9</sup> kg and 1.10 × 10<sup>9</sup> kg in the world and India respectively (Patra, 2014). Hence an earlier study (Patra, 2014) estimated the projected methane emission rate at 105 × 10<sup>9</sup> kg and 120 × 10<sup>9</sup> kg in the year 2025 and 2050 respectively. Obviously, the nations/regions with more cattle population contribute more methane emission into the atmosphere (Knapp et al., 2014). Tian et al. (2015) found the rapid increase of CH<sub>4</sub> emission from natural wetlands and rice fields due to climate warming.

### **Nitrous oxide (N<sub>2</sub>O)**

The N<sub>2</sub>O has increased from 288 ppbv to 322.5 ppbv (parts per billion volume) in the atmosphere (Lal, 2004b; Butterbach-Bahl, 2013). It is increasing at the rate of 0.77 ppbv yr<sup>-1</sup> in the atmosphere due to anthropogenic activities (Butterbach-Bahl, 2013). Tian et al. (2014) estimated the N<sub>2</sub>O emission as 12.52±0.74 Tg yr<sup>-1</sup> with an increasing rate of 0.14±0.02 Tg yr<sup>-1</sup> from the global land ecosystems during the 1981-2010 period. The N<sub>2</sub>O warming potential is 296 times more than that of CO<sub>2</sub> (Casper, 2010). The main source of N<sub>2</sub>O is from the microbial processes in soils, sediments, water bodies, animal manures and use of nitrogen-based synthetic fertilizers (Tian et al., 2014). Agricultural activities such as the use of nitrogen fertilizers and animal manure management contribute about 4.3 – 5.8 Tg N<sub>2</sub>O N yr<sup>-1</sup> emission into the atmosphere (Syakila and Kroeze, 2011). The natural soils contribute 6-7 Tg N<sub>2</sub>O N yr<sup>-1</sup> emission into the atmosphere (Syakila and Kroeze, 2011). Besides, the livestock and agricultural activities contribute almost two-thirds of all anthropogenic N<sub>2</sub>O emissions into the atmosphere (Steinfeld et al., 2006).

### **Chlorofluorocarbons (CFCs), Hydrofluorocarbons (HFCs) and Perfluorocarbons (PFCs)**

The CFC is an organic compound comprises of carbon, chlorine and fluorine atoms. If the compound contains hydrogen, then it called as HFCs. They are commonly used as the refrigerants, cooling agents, the propellant in medicinal aerosols, blowing agents for foams, cleaning agents, solvents and degreasing agents. The CFCs have a serious deteriorating effect on ozone layers in the stratosphere. As we know that, ozone layer in the stratosphere shields living organisms from the harmful ultraviolet (UV) radiation from the sun. The solar radiation breaks down the CFCs molecules and releases the chlorine atoms into the atmosphere. Thus the chlorine atoms react with ozone molecules and deplete the ozone layer in the stratosphere. The CFCs have a long lifetime in the atmosphere (Table 12.1). The Montreal protocol was adopted in 1988 to control the CFCs usage by industries for the protection of the ozone layer. To replace the CFCs, the refrigerant industries started to use the HFCs. The HFCs contain fluorine instead of chlorine and they do not damage the ozone layer. However, they do trap the heat in the atmosphere (Casper, 2010). The fluorocarbons (PFCs) have recently been used as coolants in refrigerators, solvents, anesthetics in surgery, water repellents and chemical reagents (Casper, 2010).

### Sulphur hexafluoride (SF<sub>6</sub>)

The SF<sub>6</sub> is one of the most important GHGs with a global warming potential of 23900 times more than that of CO<sub>2</sub>. The electrical equipment's and magnesium smelting sectors are the main sources of SF<sub>6</sub> emissions (Zhou et al., 2018). The natural source of SF<sub>6</sub> is almost negligible as compared to anthropogenic sources (Vollmer and Weiss, 2002). The SF<sub>6</sub> contributes about 0.1% of the total anthropogenic radioactive forcing and its concentration continuously increasing in the atmosphere (Levin et al., 2010; Rigby et al., 2010). The total emission of SF<sub>6</sub> globally in the year 2010 was estimated about 1.25 Gt of CO<sub>2</sub> (equivalent to CO<sub>2e</sub>) (UNFCCC). Most of the SF<sub>6</sub> emission is coming from the electrical sectors of the developing countries and it's expected to increase in coming years (Fang et al., 2013). Thus, understanding the SF<sub>6</sub> emission of developing countries is more crucial in order to develop a mitigation strategy.

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## 12.4 GREENHOUSE GAS EMISSION INVENTORIES

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Under the United Nations Framework Convention on Climate Change (UNFCCC), the Annex I (developed countries) and Annex II (developing countries) parties in climate accord have been publishing, since 1996, the periodic national inventories of GHGs emissions and removals (Jonas et al., 2010). Besides, the GHGs emission inventories are essential for a nation to identify and quantify the sources and sinks of GHGs to combat climate change (IPCC, 2006). Scientists use this inventory to make the reliable atmospheric models, whereas the policy makers used to develop strategies to reduce the GHGs emissions. The following GHGs are included in the revised version (IPCC, 2006) of guidelines for greenhouse gas inventories. They are CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs, SF<sub>6</sub>, nitrogen trifluoride (NF<sub>3</sub>), trifluoromethyl sulphur pentafluoride (SF<sub>5</sub>CF<sub>3</sub>), halogenated ethers and halogenated carbons (IPCC, 2006). The emission information from the ratified countries helps to discover their GHGs emission contribution to the total GHGs emission (Sharma et al., 2001) and also to develop strategies and policies for GHGs emissions reductions.

### 12.4.1 Sectors and Categories

The GHGs emission inventories are estimated from five different sectors with several categories. They are 1) Energy, 2) Industrial process and product use (IPPU), 3) Agriculture, Forestry and Other Land Use (AFOLU), 4) Waste and 5) Others (IPCC, 2006). Thus, a nation would construct an emission inventory from lower level (categories) to a higher level (sector) using the IPCC guidelines (IPCC, 2006). The first comprehensive IPCC greenhouse gas emission inventory guidelines were first published in the year 1996 and subsequently they were revised with good practice guidelines (GPG) in 2000 by including energy, agriculture and waste sectors with subcategories (Sharma et al., 2011). The upgraded version of IPCC guidelines for a greenhouse gas inventory was published in the year 2006. Each sector has different subcategories. For example, in the energy sector, transport is the category and cars, two-wheelers are subcategories. Thus a nation can remove the uncertainty of the data from each sector.



### 12.4.2 Estimation Methods

The IPCC has developed three different methodological approaches (tier 1, tier 2 and tier 3) based on the quantity of data requirement and analytical complexity (Houghton et al., 1996; IPCC, 2006). The tier 1 approach employs the coarse data obtained from the global land use and land cover maps, deforestation rates, agricultural production data from statistics and other parameters provided by the IPCC. Whereas the tier 2 approach employs the emission factors and other parameters more specific to the country. For example, emission data from deforestation and land use and land cover change in different climatic regions of the particular country. The tier 3 approach uses higher-order methods which include models and data from the national forest inventory measurement systems tailored to address national circumstances (Sharma et al., 2011). The above-mentioned tier approaches are generally used to reduce the uncertainty of GHGs estimates from different sectors of a nation. Sharma et al. (2011) reported the GHGs emissions from different anthropogenic sources and removals by sinks in India. Table 12.2 shows the GHGs emission and sink from different sectors of India.

**Table 12.2: GHGs emission and sink from different sectors of India (during 2007). (Values are in Gg, 1 Gg = 1000 tonnes) (Adapted from Sharma et al., 2011).**

Sector	CO <sub>2</sub> emission	CO <sub>2</sub> removal	CH <sub>4</sub>	N <sub>2</sub> O	HFCs	CFCs	SF <sub>6</sub>
Energy (includes energy industries, refinery, transport, construction industries, emission from fossil fuels)	1,285,814.30		4,060.93	55.53			
Industrial process and product use (includes metal production, mineral products, and chemicals)	154,085.03		10.65	17.13	2.91	1.62	0.12
Agriculture (includes manure management, agricultural soils, rice cultivation, burning residues)			14,310.68	232.67			
Forestry and Other Land Use (forest, grassland, wetland, fuelwood burning)	98,330.00	275,358.00					
Waste (includes solid waste disposal, commercial and industrial waste water disposal)			2,515.51	15.81			
Grand total (Gg)	1,538,229.33	275,358.00	20,897.77	321.14	2.91	1.62	0.12

### 12.4.3 Effect of Greenhouse Gases

The earth surface temperature is maintained by the energy balance of the sun rays that strike the planet and heat that is radiated back into space under the normal CO<sub>2</sub> concentrations in the atmosphere (Casper, 2010). But over a century (since the industrial revolution) the proportion of GHGs, especially CO<sub>2</sub> and CH<sub>4</sub>, have increased significantly in the earth's atmosphere (IPCC, 2006). However, when there is an increase in GHGs concentrations in the atmosphere, the thick layer of these gases prevents the heat from being re-radiated out (Houghton et al., 2001). This thick GHGs layer thus acts like the glass panels of a greenhouse, allowing the sunlight

to filter through, but preventing the heat from being re-radiated into outer space. This is called the greenhouse effect (Houghton et al., 2001). Due to re-radiation of the sunlight to the earth's surface increases the surface air temperature of the earth. The increase in global temperature during the 20th century has been estimated at 0.6°C and is projected to be 1.4 to 5.8°C by 2100 relative to the global temperature in 1990 (IPCC, 2001). Scientists believed that CO<sub>2</sub> is one of the major components of greenhouse gases causing the rising of global temperature and melting of Arctic and Antarctic ice sheets (Meehl et al., 2007). According to the IPCC (IPCC, 2018), the global surface temperature would likely to reach 1.5°C between 2030 and 2052 if we continue to emit the rate of GHGs into the atmosphere.

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## **12.5 INTERNATIONAL NEGOTIATIONS ON GREENHOUSE GASES AND CLIMATE CHANGE**

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The UNFCCC is an international organization set out to address climate change problems and to prevent the GHGs emission by anthropogenic activities (Reilly et al., 2002). They have convened a meeting in 1996 with the main aim to stabilize the GHGs in the atmosphere at preindustrial levels (IGBP Terrestrial carbon working group, 1998). The COP3 meeting was held in Kyoto, Japan, where the landmark agreement was made to reduce the GHGs emission by at least 5% from 1990 levels during the period between 2008 and 2012 (IPCC, 2001). According to the Kyoto Protocol (IPCC, 2001), the developing countries can receive investments from developed countries for carbon sequestration projects through the clean development mechanism. The climate accord at Copenhagen held in December 2009, failed to agree on a legally binding treaty to reduce global warming emissions, but they did make important progress in one area: “a set of policies referred to as REDD+” (Hunter, 2010). So, carbon sequestration is the only option that would allow the use of fossil energy without the threat of dangerously altering earth's climate system (Lal, 2008). World's scientists and politicians are agreed that the excess amount of CO<sub>2</sub> in the atmosphere could be sequestered by afforestation and reforestation processes (one of the potential options to remove atmospheric CO<sub>2</sub>) on terrestrial land ecosystems (IPCC, 2014). Carbon sequestration is currently being considered as a way to mitigate the greenhouse effect and, simultaneously, combat land degradation (Lal, 2004a; Olsson and Ardo, 2002). The recent COP21 meeting of the UNFCCC in Paris 2015 developed the Paris climate agreement. It implies the reduction of global warming to less than 2°C compared to pre-industrial levels and thus makes efforts to limit the increase to 1.5°C. In order to limit global warming below 2°C, then all the countries have to limit the GHGs emission into the atmosphere. At COP21, the ambitious program was launched “4 per mille Soils for Food Security and Climate” in Paris climate accord (Minasny et al., 2017). The 4 per mille (4 parts per thousand) aims to increase the global soil carbon stock by 0.4 % per year (~2.5 Gt C yr<sup>-1</sup>) to compensate the global emissions of GHGs by anthropogenic origins (Minasny et al., 2017).

**Check Your Progress 1**

**Note:** i) Use the space given below for your answers.

ii) Check your answers with those given at the end of the unit.

1) What are Tier 1 and Tier 2 approaches for GHG emission inventories?

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2) What is Tier 3 approach for GHG emission inventories?

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**12.6 GLOBAL CARBON RESERVOIRS**

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There are five different carbon reservoirs existing on our planet Earth (Eswaran et al., 1993; Batjes, 1996; IPCC, 2001; Lal, 2008). Among them, oceans are the largest carbon reservoir and they store about 38400 Pg C. The second largest carbon reservoir is a geological reservoir (includes coal, oil, gas, and peat) and it contains 4130 Pg C. The third carbon reservoir is soil and they store about 2550 Pg C (1550 Pg C as organic and 950 Pg C as inorganic form in soils). The organic form of carbon in the soils is active and more dynamic in nature. The organic matter, which includes derivatives of plants, animals and microbes, in the soil is called as soil organic matter (SOM). Though, SOM contains the materials in all stages, from partial to highly decomposed materials. By mass weight basis, SOM contains about 58% of carbon and the remaining would be the water and nutrients. The inorganic forms of carbon in the soil comprise of the elemental carbon and carbonate forms (calcite and dolomite). The fourth carbon reservoir is an atmosphere which contains 800 Pg C. The CO<sub>2</sub>-C is increasing alarmingly at the rate of 3.5 Pg C yr<sup>-1</sup> due to anthropogenic activities (Lal, 2008). The fifth carbon reservoir is biotic, comprises of living biomass and detritus, contain 560 Pg C. More importantly, the oceans absorb CO<sub>2</sub>, via diffusion process, at the rate of 92.3 Pg C yr<sup>-1</sup> and release 90 Pg yr<sup>-1</sup> (Lal, 2008). Thus the atmosphere and terrestrial ecosystems exchange 120 Pg C yr<sup>-1</sup> via the photosynthesis process and release most of the absorbed CO<sub>2</sub>-C to the atmosphere by plant and soil respiration process (Lal, 2008). The soil and biotic reservoir, combined together have stored about 3110 Pg C which is fourfold higher than in the atmosphere. The strong interactions between atmosphere, biotic, soil and ocean reservoirs are important in regulating the global carbon cycle. So any changes in these reservoirs, due to anthropogenic activities, disturb the carbon cycle from regional to global scale. Thus, understanding and managing these carbon reservoirs by any strategies would be a basis to sequester more CO<sub>2</sub> in the soil and biotic pool. The enrichment of CO<sub>2</sub> can be alleviated by sequestering them in biotic and soil pools for a longer period of time.



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## 12.7 CARBON SEQUESTRATION

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The rate of CO<sub>2</sub> concentration in the atmosphere could be reduced as a mitigation options by transferring them to some other reservoirs in terrestrial ecosystems. The term ‘carbon sequestration’ is defined as the capture and storage of atmospheric CO<sub>2</sub> into the vegetation, soils, geologic basalts and oceans for a longer period (Lal, 2004b). There are two different types of strategies to capture and storage of CO<sub>2</sub> in the above-mentioned reservoirs. They are 1) abiotic strategies (engineered) and 2) biotic strategies.

### 12.7.1 Abiotic Strategies

The abiotic strategies (engineered) of carbon sequestration involve capture, separation, transport and inject the CO<sub>2</sub> into the geologic basalts and ocean (IPCC, 2005). Also injecting the CO<sub>2</sub> into the old or abandoned oil field can enhance the oil recovery (Lal, 2011). Though the geologic and oceanic carbon sequestration techniques still work in progress for certain regions of the world (Ridgwell and Edwards, 2007; Goldthorpe, 2017). Several scientists around the world are looking for some reasonable technology for capturing the CO<sub>2</sub> and storing it into the oceans. Besides, the abiotic techniques of capturing of CO<sub>2</sub> should be monitored and verified regularly before implementing into a certain region. Moreover, the oceans are becoming more acidic and coral reefs are bleaching due to the effect of more CO<sub>2</sub> diffusion into the oceans (Goldthorpe, 2017). So, thus oceans are becoming more acidic and it creates a threat to the marine life. Thus injecting the CO<sub>2</sub> into the oceans would ultimately affect the marine life.

### 12.7.2 Biotic Strategies

In contrast to abiotic strategies, the biotic strategies of CO<sub>2</sub> capture and storage occur naturally in terrestrial ecosystems and oceans. The atmosphere and oceans have a powerful exchange of carbon. There are two different processes involved in the exchange of carbon from the atmosphere to the oceans. They are 1) solubility pump (a physical process), here the CO<sub>2</sub> dissolved in oceans naturally based on local climatic conditions (preferably cold oceans) (Bates et al., 2011) and 2) biological pump, here the phytoplankton do the carbon fixation process via photosynthesis. In the oceans, the phytoplankton could fix about 45 Pg C yr<sup>-1</sup> via photosynthesis (Falkowski et al., 2000). The fixed carbon (i.e. carbon materials) is deposited in the deeper oceans after the organisms die and thus sequestered. Several studies have suggested that the availability of Fe plays a greater role in the biotic sequestration of carbon in the oceans (Gregg et al., 2003). In terrestrial ecosystems, the plants are playing a significant role in CO<sub>2</sub> capture and storage processes. Plants capture the atmospheric CO<sub>2</sub> via photosynthesis and stored the fixed carbon into biomass and soil organic matter (SOM). The terrestrial carbon sequestration is considered as a win-win approach because it has many additional benefits such as improving soil and water quality, increased crop yield, and restoration of degraded ecosystems (Lal, 2003). So, the ability of the plants in terrestrial ecosystems to sequester atmospheric CO<sub>2</sub> has received more interest in recent decades.

### 12.7.3 Carbon Sequestration Potential of Biomes

Table 12.3 shows the total carbon stock of the major biomes of the world. Forest ecosystems are considered as a major carbon reservoir in terrestrial

ecosystems. Globally, forest ecosystems cover about 4.17 billion hectares on our earth's surface (Dixon et al., 1994; Prentice, 2001). Thus, forest ecosystems sequester about 1146 Pg C in their vegetation biomass and soil (Dixon et al., 1994). In forests, soils are considered as a major sink and source for carbon. The carbon allocation between vegetation biomass and soils differs by latitudes and altitudes (Dixon et al., 1994; Dinakaran and Rao, 2012). Thus the larger portion of the carbon in vegetation and soils are located in temperate and tropical forest ecosystems. The amount of carbon exchanged (gross primary production, GPP) between vegetation and the atmosphere is estimated at about 120 Pg C yr<sup>-1</sup> (Denman et al., 2007). Global forests alone exchange about 75 Pg C yr<sup>-1</sup> between atmosphere and forests (WBCSD, 2007). Besides, forests stored about 85% and 74% of carbon in aboveground and belowground respectively (Robinson, 2007). The ratio of carbon stock in the soil to vegetation varies from 5: 1 in boreal, 2:1 in temperate and 1:1 in a tropical forest ecosystem (Jarvis et al. 2005). Since the carbon sequestration potential of different tree species differs because of variations in the properties (tree phenology, litter properties, and decomposition rate) that drive the carbon sequestration and their dependence on climatic conditions (Purves and Pacala, 2008). The total carbon uptake of boreal, temperate and tropical forest ecosystems was about 0.49 – 0.7 Pg C yr<sup>-1</sup>, 0.37 Pg C yr<sup>-1</sup> and 0.72 – 1.30 Pg C yr<sup>-1</sup> respectively (Lorenz and Lal, 2010). Thus the carbon sequestration potential rate of the global forest ecosystem is estimated about 1.7 ±0.5 Pg C yr<sup>-1</sup> (Fan et al., 1998). Lal (2004c) estimated the global carbon sequestration potential about 0.4-1.2 Pg C yr<sup>-1</sup> from an arid region to cultivated lands. Globally, the soil organic carbon (SOC) storage in the top 3 meters depth was estimated about 2344 Pg C (Jobbagy and Jackson, 2000). Therefore, the estimates of carbon stocks in different biomes and their carbon sequestration potential are uncertain because still there is a paucity of information with regard to the data of plant species contribution towards the cycling of carbon.

**Table 12.3: Terrestrial carbon stock (Pg C) in the world's major biomes (Source: Dixon et al., 1994; Prentice, 2001)**

Biome	Area (Mha)	Terrestrial carbon stock (Pg C)		
		Plant biomass	Soil	Total
Tundra	0.95	06	121	127
Boreal forests	1.37	88	471	559
Temperate forests	1.04	59	100	159
Tropical forests	1.76	212	216	428
Tropical savannas and grasslands	2.25	66	264	330
Temperate grasslands & shrublands	1.25	09	295	304
Deserts and semi-deserts	4.55	08	191	199
Croplands	1.60	03	128	131
Wetlands	0.35	15	225	240
<b>Total</b>	<b>15.12</b>	<b>466</b>	<b>2011</b>	<b>2477</b>

**Check Your Progress 2**

**Note:** i) Use the space given below for your answers.

ii) Check your answers with those given at the end of the unit.

1) What are the carbon reservoirs on our Earth?

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2) What is carbon sequestration?

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**12.8 ESTIMATION OF SOIL CARBON**

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The loss on ignition (LOI) and Walkley- Black methods are commonly used to estimate the carbon concentration in soils and sediments. The LOI method calculates the carbon percentage based on the weight loss of a dry soil sample after it is heated in an oven or a muffle furnace with a temperature not greater than 440°C (Schumacher, 2002). The Walkley-Black method uses sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) and potassium dichromate (K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub>) as oxidation agents and the remaining Cr<sup>3+</sup> will be determined by titration with ferrous ammonium sulfate (Schumacher, 2002). The LOI and Walkley-Black methods are having limitations for accurate estimation of carbon concentration in soils. Recently, the carbon concentration in soils, sediments, and the litter is determined by dry combustion using an elemental analyzer. The elemental analyzer combusts the sample at around 1100°C and subsequently measure the CO<sub>2</sub> gas coming from the sample. Thus the results are expressed as the percentage of carbon in the analysed samples. If the samples contain carbonates, then it must be treated with hydrochloric acid (HCl) to remove the carbonates. Subsequently, the samples are subjected to combustion using an elemental analyzer to measure the organic carbon.

**Calculation of soil carbon stock**

Soil carbon stock at a particular depth (30 cm) can be calculated by the following equations.

$$\text{Soil carbon stock (g C m}^2\text{)} = \text{soil carbon} \times \text{BD} \times \text{depth} \times 10000$$

where soil carbon (%) concentration of a particular depth (here is 30cm), BD is bulk density (g cm<sup>-3</sup>) of the layer, depth in meter, and 10000 is the factor used to convert the soil carbon value from 1cm<sup>2</sup> to 1 m<sup>2</sup> (100 × 100 cm<sup>2</sup> =1 m<sup>2</sup>). Thus the soil carbon content further converted into tonnes per hectare (t ha<sup>-1</sup>). The BD values should be corrected by the volume occupied by the >2mm particle in the soil samples of a particular layer. Thus, one can estimate the accurate soil carbon stock of a particular ecosystem.

## Calculation of carbon sequestration potential of reforested or restoration site soils

The change in soil carbon stock (t C ha<sup>-1</sup>) from a reference site (it may be the restoration site or converted land from forests, grasslands, and others) to the recently occupied vegetation communities can be calculated by the following equation.

$$\text{Soil carbon stock change (t C ha}^{-1}\text{)} = C_f - C_r$$

Where  $C_f$  represents soil carbon stock (t C ha<sup>-1</sup>) of the forested site or restoration site and  $C_r$  is the soil carbon stock (t C ha<sup>-1</sup>) of reference sites. Thus the change in soil carbon stock values would tell us the carbon sequestration potential of the particular ecosystem.

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## 12.9 LET US SUM UP

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An unprecedented increase in concentrations of GHGs such as CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, CFCs, HFCs, PFCs SF<sub>6</sub>, in the atmosphere due to anthropogenic activities in the recent decades has accelerated the rise in global temperature. Under the UNFCCC, all the ratified countries in the UN climate accord, have been publishing, regularly, the national inventories of GHGs emissions and removals from five different sectors according to the IPCC guidelines. The GHGs emissions inventories are very useful to identify and quantify the sources and sinks of GHGs to combat climate change. According to Kyoto Protocol and Paris climate accord, the developed and developing countries have agreed to reduce the global warming to less than 2°C compared to pre-industrial levels and make efforts to limit the increase to 1.5°C. All the parties at COP21 meeting have agreed to increase the soil carbon stock by 0.4 % (~2.5 Gt C yr<sup>-1</sup>) to compensate the anthropogenic emissions of GHGs. The excess amount of CO<sub>2</sub> in the atmosphere can be captured and stored in the oceans and terrestrial ecosystems via abiotic (engineering) and biotic strategies. However, the terrestrial sequestration of carbon via biotic strategies are widely considered as a plausible option to combat climate change.

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## 12.10 KEY WORDS

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- Anthropogenic GHGs Emissions** : The GHGs emissions are due to human activities such as industrialization, transportation, cultivation, and others.
- Biogeochemical Cycle** : It is a pathway by which the molecules or chemical elements flow between biotic and abiotic components of an ecosystem. For example water cycle, carbon cycle, nitrogen cycle, oxygen cycle, and sulfur cycle.
- COP** : Conference of the parties. It is a decision making body at climate convention.
- IPCC** : Intergovernmental Panel on Climate Change. The World Meteorological Organization (WMO) and the United Nations Environment

Programme (UNEP) jointly created the IPCC in the year 1988 to provide suitable science related to climate change.

**NOAA** : National Oceanic and Atmospheric Administration. It is an American agency within the control of the U.S. Department of Commerce. NOAA share the scientific knowledge about the change in climate, weather, and oceans with the world.

**Ozone** : It is a molecule that contains three oxygen atoms. The ozone layer in the Earth's atmosphere (23-31 km above the Earth's surface) protects the life on earth by blocking the ultraviolet rays that come from the sun.

**Soil Carbon 4 per mille** : The ratio of global anthropogenic carbon emissions (8.9 Gt) and the total soil organic carbon stock (2400).  $8.9/2400 = 0.4\%$  or 4 per mille (parts per thousand)

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## 12.11 SUGGESTED FURTHER READING/ REFERENCES

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## 12.12 ANSWERS TO CHECK YOUR PROGRESS

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### Check Your Progress 1

1. The tier 1 approach for GHG emission inventories employs the coarse data obtained from the global land use and land cover maps, deforestation rates,

agricultural production data from statistics and other parameters provided by the IPCC. The tier 2 approach employs the emission factors and other parameters more specific to the country.

2. The tier 3 approach uses higher-order methods which include models and data from the national forest inventory measurement systems tailored to address national circumstances.

### **Check Your Progress 2**

1. There are five different carbon reservoirs existing on our Earth. Oceans are the largest carbon reservoir and they store about 38400 Pg C. The second carbon reservoir is a geological reservoir that includes coal, oil, gas, and peat, and it contains 4130 Pg C. The third carbon reservoir is soil which store about 2550 Pg C. The fourth carbon reservoir is the atmosphere which contains 800 Pg C. The fifth carbon reservoir is biotic, comprises of living biomass and detritus.
2. Carbon sequestration is defined as the capture and storage of atmospheric CO<sub>2</sub> into the vegetation, soils, geologic basalts and oceans for a longer period.



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