Appendix I - Publications
Climate Change: Forces, Impacts and Mitigation Strategies for Agriculture

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Abstract - Agriculture originated more than 12,000 years back, is one of the major provisions for the mankind. In developing countries like India around 60% of the population is engaged in agricultural practices. With the beginning of industrial revolution there has been modernization in the agriculture techniques contributing to enhanced greenhouse effect. Agricultural sector contributes to 13% of the total greenhouse gas emissions. Global warming and climate change have impacted nature and human society through devastating effects like variability in the rainfall patterns, increased extreme events and disease and pest attack leading to decreased crop yields. There are many methods to mitigate global warming but the secret to cool the planet Earth from global warming lies in some of the traditional agricultural practices like organic farming, agroforestry, no till farming, etc. which not only cut down greenhouse gases but also increase soil fertility and conserve soil ecosystem.

Key words: Agricultural practices, global warming, climate change, mitigation, carbon sequestration.

Introduction - Agriculture is an economic activity highly dependent upon weather and climate to produce food and fiber necessary to sustain human life. It is greatly vulnerable to climatic variability and climate change (Cohen et al., 1992). Agriculture originated more than 12,000 years back contributes food for the sustenance of mankind on the Earth. It marked the beginning of human civilizations like the Harappan, the Mayan and the Nile valley civilization. Developing countries like India have around 60% of the population engaged in agriculture profession. One-fourth of the earth surface is land and has the capacity to hold three times more carbon than the atmosphere. From this about 1600 billion tons of carbon is present in the soil as organic carbon while the vegetation comprises of 540-610 billion ton of carbon. The carbon on the surface and in atmosphere due to its mobility contributes to climate change (Scherr and Sthapit, 2009). Global warming is the increase in the world’s average temperature which is because of the increasing emission of the greenhouse gases (GHGs). Global warming further
leads to climate change. Climate change refers to a statistically significant change in either the mean state of the climate or in its variability (in terms of temperature, precipitation etc.) persisting for an extending period (typically decades or longer) (Scherr and Sthapit, 2009). Climate change results due to both natural and anthropogenic causes (Fig-1).

Table-1: Agricultural GHGs and their CO\textsubscript{2} eq in million tons (Anonymous, 2008)

<table>
<thead>
<tr>
<th>Sources of agriculture GHGs</th>
<th>Million tones CO\textsubscript{2} equivalent (CO\textsubscript{2} eq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N\textsubscript{2}O (soil)</td>
<td>2128</td>
</tr>
<tr>
<td>CH\textsubscript{4} (enteric fermentation of cattle)</td>
<td>1792</td>
</tr>
<tr>
<td>Rice production</td>
<td>616</td>
</tr>
<tr>
<td>Manure</td>
<td>413</td>
</tr>
<tr>
<td>Fertilizer production</td>
<td>410</td>
</tr>
<tr>
<td>Irrigation</td>
<td>369</td>
</tr>
<tr>
<td>Farm machinery</td>
<td>158</td>
</tr>
<tr>
<td>Pesticide production</td>
<td>72</td>
</tr>
<tr>
<td>Land conversion to agriculture</td>
<td>5900</td>
</tr>
</tbody>
</table>

Table-2: Direct and indirect global emissions of GHGs from the agriculture sector (Anonymous, 2008)

<table>
<thead>
<tr>
<th>GHGs from agriculture</th>
<th>Sources</th>
<th>Emission (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH\textsubscript{4}, CO\textsubscript{2}, N\textsubscript{2}O</td>
<td>Direct emissions</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Fertilizers</td>
<td>1.2</td>
</tr>
<tr>
<td></td>
<td>Farming</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Land use change</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>Indirect emissions</td>
<td>17-32</td>
</tr>
</tbody>
</table>

Fig-1: Percent GHG emissions by various sectors (Smith et al, 2007)

Agricultural sector as driver to global warming- Today, to meet the demand of food, fiber and fodder of the increasing population more and more chemicals are being used to increase the yield which has resulted in pollution and increased GHG emission. The change in the land-use management has led to forest being converted to agricultural lands causing an increase in the CO\textsubscript{2} and N\textsubscript{2}O emissions. About 40-50% of the earth’s surface is agricultural land (Nguyen, 2003). With the beginning of industrial revolution there has been modernization in the techniques
of agriculture like introduction of chemical fertilizers, pesticides, tractors, mechanized harvesting etc which has caused rapid pollution. Agriculture is both a sink and source of GHGs. As a sink, it captures the atmospheric CO$_2$, CH$_4$ and N$_2$O into the soil and vegetation. As a source, it contributes to GHG emissions from nitrogen fertilizers, burning of fossil fuels and biomass, enteric fermentation from livestock and waste management (Smith et al, 2007). Agricultural practices contribute to 3.3 Gt CO$_2$-eq/yr of CH$_4$ and 2.8 Gt CO$_2$-eq/yr of N$_2$O and altogether contribute around 13% (5.1-6.1 Gt CO$_2$-eq) of the total GHG emissions (Ruser et al, 2001). CO$_2$ is released mainly from microbial decay, burning of plant litter and soil organic matter. N$_2$O emission occurs due to use of nitrogen fertilizers, manure and denitrification by bacteria. Enteric fermentation through livestock (70%), decomposition of manure (25%) and rice cultivation (5%) contribute to CH$_4$ emission (Anonymous, 2001). The burning of biomass (12%), rice cultivation (11%), and manure management (7%) are other contributors to GHGs emission from agriculture (Table 1 and 2). Even though there is an annual exchange of CO$_2$ between the atmosphere and agricultural lands, (Fig-2) the net flux remains almost balanced, with CO$_2$ emissions of about 0.04 Gt CO$_2$/yr only (Nguyen, 2003).

**Risks of contemporary agricultural practices**- The contemporary agriculture due to exclusive use of agrochemicals has degraded climate, soil, water and natural ecosystems and contributes to climate change causing emissions of GHGs owing to changes in land-use and soil degradation. One-third of the total land is under agriculture. Moreover, 13 million hectare of the land with around 6 million hectare of the forest converted to agricultural lands (Harbinson, 2001) contributes to GHGs emissions.

**i. Agro-chemicals:** In earlier days bio-fertilizers, manures and bio-pesticides were used. It was with the introduction of the chemicals with the start of Green Revolution that the Asian rice fields known for their rich aquatic biodiversity and bio-pest control could not render their true services (Müller-Lindenlauf, 2009). The fertilizer production consumes a lot of energy and adds around 300-600 million tons CO$_2$-eq/yr and contribute 0.6 - 1.2% of the global GHGs. The use of fertilizers has increased from 110 CO$_2$-eq/yr in 1960-61 to 910 million tons CO$_2$-eq/yr in 2004-2005 (Ruser et al, 2001). The nitrogenous chemical fertilizers provide around 40% of nitrogen to the agricultural crops from which only half is used by the plants, the rest is emitted and leads to large amounts of N$_2$O emissions (Anonymous, 2001).

**ii. Livestock management:** The raising of livestock, especially cattle is an important agricultural activity (Cohen et al, 1992). Dairy and cattle operations liberate huge amount of ammonia due to disintegration of urea and manure (Paul et al, 2009). Livestock emissions contribute to 9% of total GHGs and generate 65% of N$_2$O from manure, 37% of methane, and 64% of ammonia (Harbinson, 2001).
iii. Rice cultivation: Rice cultivation emits CH$_4$ during its wet cultivation, which causes anaerobic decomposition of plant wastes after harvest. Rice cultivation causes 11% of the total GHG emissions and 5% of the CH$_4$ emissions (Harbinson, 2001).

iv. Manure: Animal manure is an important soil addendum as a good source of nitrogen. Stored manure emits large amount of GHGs, especially CH$_4$, due to anaerobic decomposition. Factory farms managing manure release 18 million tons of methane yearly (Müller-Lindenlauf, 2009).

Impacts of Global warming on Agriculture- According to the IPCC, 2007 report due to the anthropogenic GHGs emissions the global mean temperature is expected to rise from 2-4.5°C and of India from 2.7-4.3°C by the end of this century. Rainfall over India is predicted to increase (Anonymous, 2000). The rise in temperature is causing the glaciers and ice caps to melt and also thermal expansion of water. This has resulted in a sea level rise of 1.8mm/year from 1961-2003, but from 1993-2003 the pace has almost doubled. The sea level in India is predicted to rise by about 88 cm by 2100. This would cause salinity ingress and the submergence of the low lying areas and islands (Anonymous, 2000). A dynamic interaction exists between various biotic (microbes, flora and fauna) and abiotic elements (soil, water, air) in farming operations and any disturbance in the natural balance may impact crop productivity through damage to the environment. The global warming and simultaneous climate change are not only impacting human and animal health and life style but are also deteriorating the ecosystem including agriculture. This is through devastating effects like variability in the rainfall patterns leading to severe droughts and floods, increase in the extreme events like heat waves, cyclones and increase in the number of pests and weeds. The impacts of climate change on agriculture are already serious. Seasons and weather are becoming increasingly variable and extreme, making it difficult for farmers to decide and cultivate specific crop. The whole agricultural system could collapse if climate change continues (Harbinson, 2001).

i. Precipitation: The monsoon is of great significance in India as it is still a monsoon dependent nation for irrigation. Any change in rainfall pattern is a serious threat to agriculture as it can lead to economic crisis and food security. Water is needed more at the initial stages of plant growth as less precipitation impacts the seeds germination. The production of major grains has declined due to dust storms and droughts (Cohen et al, 1992). The monsoon patterns are predicted to change owing to global warming. It is expected that the semi-arid regions of western India will receive more rainfall as temperature rises, while there will be a decline of 10-20% in the rainfall in central India by 2050s (Lal, 2001). The timing of the rainfall has changed. Rainfall pattern in Chattisgarh of the last few years shows very less pre-monsoon showers in May and June which has impacted the rice fields (Ramakrishna, 2001). In the coastal regions of Gujarat and Maharashtra the agriculture will be worst affected due to

**ii. Enhanced CO₂:** Laboratory experiments for rice, wheat, soybeans, potatoes, vegetables and other C₃ plants concluded that increase in CO₂ increases their yield (Cohen et al, 1992). The soyabean yields could increase as much as 50% if concentration of CO₂ in the atmosphere doubled. But if simultaneously it is accompanied by an increase in temperatures by 1-1.5°C the yield would come down to 35% (Anonymous, 2002). The weeds will migrate and flourish as they respond more positively to increasing carbon dioxide (Smith et al, 2007).

**iii. Temperature:** Increasing temperature will decrease the soil moisture due to more evaporation, which will also increase dust storms (Anonymous, 2006) and droughts (Smith et al, 2007). There will be irregularities in precipitation. Long growing season will lead to earlier planting and earlier harvesting and hence more yield (Anonymous, 2006). In Rajasthan, a 2°C rise in temperature will result in reduction of pearl millet production by 10-15% (Lal, 1999). According to GRID 2000, warming by 2°C would reduce the land area suitable for coffee in Uganda. Similarly, the sensitive cocoa production would suffer heavily due to climate change. On the other hand, the crops like corn and sorghum would flourish (Anonymous, 2006).

**iv. Yield:** Study undertaken by Auffhammer on the rice yields in India provide evidence that GHG and air pollution both have resulted in a decline in the rice yields (Fischer et al, 2005; Cramer, 2006). In climate change scenarios, agricultural land suitable for cereal crop cultivation will increase in North America (40% increase over the 360 million ha), North Europe (16% increase over 45 million ha), the Russian Federation (64% increase over 245 million ha) and East Asia (10% increase over 150 million ha) due to longer growth periods and more favourable growing conditions due to warming (Peskett, 2007; Anim-Kwapong and Frimpong, 2005; Easterling et al, 2007). There will be an increase in GHG emission from 2.3-3.2 Gt of CO₂ eq about three times from 1990 in developing nations. Some poor nations may show about 10-20% decline in their cereal-production. Documents predicted a global increase in cereal production from present 1.8 G ton to 3.7-4.8 G ton, depending on the socio-economic conditions (Peskett, 2007; Anim-Kwapong and Frimpong, 2005; Easterling et al, 2007). Parry and Rosenwieg (1994) stated that food production may decline in the subtropical and tropical regions but, developed countries may be benefited due to newer technologies (Cohen et al, 1992). The crops are not only declining in yield but also in quality. Coffee and tea are losing their aroma and flavour (Rautela, 2011).

**v. Pest, diseases and weeds:** The increasing temperature results in extensive growth of the weeds. Weeds and pests get better adapted to the higher temperatures and reduce the yield of crops. The increase in temperature increases evapo-transpiration, which reduces crop yields and makes crops undernourished and susceptible to diseases (Anonymous, 2008; Anonymous, 2000; Anonymous,
Helopeltis, the tea bug mosquito has caused 20-30% loss to tea production in India. Owing to variable climate rice thrips have declined rice yield in Kuttanad and Palakkad, Kerala (Rautela, 2011).

vi. Migration of some plantations: During the past 50 years the apple growing belt has moved 30 km north and in Bajaura no apple grow today which was once the starting point of apple production. In Kullu valley apples have not been ripening on time, the flowers have decreased resulting in less fruits per tree due to untimely snowfalls and rain. These alterations in traditional cropping cycle of apple have been attributed to climate change and are adversely affecting farmer’s income (Rautela, 2011).

Mitigation strategies- Mitigation deals with the causes of climate change, while adaptation tackles its effects. Mitigation has been defined by the IPCC as an anthropogenic activity to reduce the sources or enhance the sinks of greenhouse gases and adaptation as adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (Anonymous, 2008).

Mitigation strategies involves reducing the intensity of radiative forcings so as to reduce the effect of global warming and it can be made possible by two aspects, Geo-engineering and Carbon sequestration. Geo-engineering are the proposals to manipulate the earth’s climate so as to decrease the impact of global warming from the GHG emission. It comprises (Scherr and Sthapit, 2009; Kunzig, 2008),

a. Sulphur dioxide spraying in the atmosphere to cool the earth,
b. Establishment of artificial trees to suck in excess of CO$_2$ from the atmosphere,
c. Cloud seeding ships which form clouds with albedo more than the normal clouds,
d. Iron fertilization of the oceans,
e. Limestone fertilization of the oceans so as to enhance the CO$_2$ absorption capacity of the oceans,
f. Space mirror to reflect some of the sun rays in space.

Another technology comprises of the various methods of carbon sequestration called Carbon Capture and Storage (CCS). According to IPCC 2007 report major point sources of carbon dioxide include coal-fired power stations, natural gas, fossil fuel–based hydrogen, and synthetic fuel. It is possible that CO$_2$ emissions from such sources can be captured and stored in underground geologic formations. CCS technologies are already being widely used in industries producing fertilizers, hydrogen and natural gas processing (Anonymous, 2006).

Green practices- Agriculture can mitigate about 6 Pg CO$_2$-eq/yr which is equal to 100% of direct emissions from agriculture. The greatest mitigation is also through soil carbon sequestration (5.34 Pg CO$_2$-eq/yr) and CH$_4$ (0.54 Pg CO$_2$-eq/yr) and nitrous oxide (0.12 Pg CO$_2$-eq/yr) emissions. A field with low
carbon content is indicative of a higher potential to sequester carbon (Ruser, 2001). Carbon sequestration refers to the capacity of agricultural lands and forests to remove CO$_2$ from the atmosphere. Trees, plants and crops absorb CO$_2$ through photosynthesis and store it as carbon in biomass (tree trunks, branches, foliage, roots) and soils. The capability of agriculture land to sequester carbon depends on the climate, soil type, type of crop or vegetation cover and management practices (agricultural tillage, crop rotations, livestock waste disposal) (Fig-2) (Paustian et al, 1997).

**Fig-2: Carbon exchanges between vegetation, soil and atmosphere**

The major principles of crop rotation, intercropping, mulching etc which maintain soil health should be encouraged as they minimize the risk of climate change on agriculture.

**i. Organic farming:** Organic agriculture has been defined by Codex Alimentarius Commission as a holistic production management system which avoids the use of synthetic fertilizers, pesticides and genetically modified organisms, minimizes pollution and optimizes the health and productivity of interdependent communities of microbes, plants, animals and people (Smith et al, 2007). Studies (Niggli et al., 2009) have shown that organic agriculture helps in mitigating climate change as it sequesters 0.9-2.4 Gt CO$_2$ per year (Wells et al, 2000). Comparative field study (Stalenga et al, 2008) showed carbon content of organic plots to be higher than conventional managed farms (Watson et al, 2000; Liebig et al, 2005). Organic farming increases biodiversity and reduces the energy use for agricultural production. It totally omits the 1% emission of GHGs from chemical fertilizers (Zundel and Kilcher, 2007); Ruser et al, 2001). Use of biofertilizers like blue green algae *Nostoc, Anaebaena* etc, green algae which have a high NPK content and the mycorrhizal inoculums in the soil provide the plants with macro-and micro-nutrients and hence reduce the GHGs emissions otherwise generated for chemical fertilizer production. Organic farming increases the efficiency of plants to use nitrogen and also increases the water holding capacity of the soil thereby reducing the yield loss by extreme weather events (Flessa et al, 2002). Organic farming sequesters carbon in both above ground (trees, hedges, crops) and below-ground stocks. According to the IPCC (2006) the carbon stock change
varies over 20 year period and to a depth of 30 cm. The carbon sequestration potential of organic agriculture rely upon practices like crop rotations, cultivation of nitrogen fixing plants, reducing erosion by avoiding fallow land, using manure against chemical fertilizers and agroforestry. All these practices are recommended as mitigation strategies by the IPCC (Smith et al, 2007).

**ii. Reducing soil tillage:** Conservation/zero/no-tillage involves growing crops in the residue of crops left on the soil surface. The seeds are drilled and the weeds are removed manually. The soil disturbance is reduced, water is conserved and carbon sequestration capacity of the soil increases (Smith et al, 2007) as soil loss is reduced up to 90% (Burnett et al, 1998) and hence increased yields. The soil carbon sequestration has increased at the rate of 200-600 kg C/hr/yr in areas of annual crop with no tillage depending on variation in soil texture and previous land-use (Agrawala et al, 2005).

**iii. Biochar:** Biochar, the term coined by Peter Read (Harbinson, 2001) is finely ground charcoal produced by pyrolysis and improves soil carbon sequestration on application. It has been in use in traditional agricultural practices, the charcoal applied to soil would lead to permanent carbon storage, improve the soil fertility and water retention capacity and help in mitigating climate change (Harbinson, 2001). The idea of using biochar has originated from Terra Preta a highly fertile soil rich in black carbon created by indigenous farmers in Central Amazonia 500-4500 years ago by incorporating biomass residues, compost, river sediments, manure, fish bones, turtle shells and charcoal (Harbinson, 2001). Biochar interacts with fungi and helps in maintaining soil fertility over long time. North American prairies, Germany and Australia show charcoal residues from wildfires and other sources which date back to thousands of years which confirms the fact that carbon in charcoal can be retained in soils for thousands of years (Harbinson, 2001; Lehmann et al, 2008; Jha, 2010). It has been estimated that more than 500 million hectares of plantations with biochar would be required to mitigate climate change (Harbinson, 2001).

**iv. Agroforestry:** Agro-forestry originated in the Vedic era (1000 B.C.) and it can be defined as the science of designing and developing integrated, self-sustainable, land-management systems that involves the introduction and retention of plants such as trees, shrubs etc along with agricultural crops including pastures, on the same unit of land and time, to fulfill the ecological as well as socio-economic necessities (Rai and Handa, 2001). Agro-forestry enhances agricultural productivity, maintains the nutrient balance and protects the nature. Trees play an important role in agroforestry systems and help in sustaining agriculture, reduce salinity, improve soil fertility, prevents erosion, control water-logging, reduce eutrophication, increase local bio-diversity and reduce the greenhouse effect. The best example of the use of agroforestry is of Ashok Vatika as described by Maharishi Valmiki in Ramayana (Rai and Handa, 2001).

Taungya cultivation system is being practised with teak (*Tectona grandis*)
plantations in Kerala, West Bengal, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Orissa, Karnataka, as well as in the North-east hill region consists of land preparation, tree planting, growing agricultural crops for 1-3 years and then repeating the same method in a different area. In hills of Tamil Nadu, *Eucalyptus globulus*, *Acacia mearensi*, and *Pinus* species are established with potatoes; cashew plantation in Andhra Pradesh with groundnut; cardamom plantations with *Alnus nepalensis* by the indigenous Lepcha and Limbu tribes in eastern Himalayas (Sharma et al, 1997; Watson et al, 2000) and important cereals are being grown with coconut plantations (Rai and Handa, 2001). The species of Bamboo are being used for the plantations by agricultural farmers as they help sequester more carbon in the soil (Fig-3). Bamboos sequester 0.36 t-e-\text{CO}_2\text{ ha}^{-1}\text{ yr}^{-1} of phytolith carbon and globally sequester <1.5 billion t-e-\text{CO}_2\text{ yr}^{-1}, equivalent to 11% of the current increase in atmospheric \text{CO}_2. Agroforestry has been recognized by IPCC to have potential for sequestering carbon as part of climate change mitigation strategies (Agrawala et al, 2005); Paustian et al, 1997; Sharma et al, 1997). Soil restoration by growing trees and cover crops can sequester carbon at the rate of 3 Pg per year which is same as the rate of increase in carbon in the atmosphere (Lal, 1997).

**Fig-3: Bamboo being used for the plantations by agricultural farmers as they help sequester more carbon in the soil**

**v. Rotational grazing and livestock improvement:** FAOSTAT (2006) has estimated that the grazing lands occupy areas larger than croplands but are managed poorly. The GHG emission from grasslands can be reduced by,

a. Limiting the grazing intensity as it influences the removal, growth, carbon capture, and flora of grasslands and hence the amount of carbon in soils.

b. Species introduction especially of grass species with higher productivity and deeper roots sequester more carbon (Anonymous, 2008).

Brazilian Savannah with crop-livestock system has introduced Brachiaria grass and zero tillage. Introduction of legumes into grazing lands can promote soil carbon storage and reduce emissions from nitrogen fertilizer (Nguyen, 2003).
Livestock mainly ruminants like cattle and sheep emit huge amount of \( \text{CH}_4 \) and \( \text{N}_2\text{O} \) which can be reduced by improved feeding practices (less forage, increasing oilseeds to the diet, optimizing protein intake to reduce N emission), using dietary additives (ionophores, condensed tannins, essential oils, probiotics (yeast), saponins, vaccines against methanogenic bacteria) and changing management strategies and animal breeding (Nguyen, 2003).

vi. Biogas generation/Biofuels: GHG emissions can be reduced by substituting fossil fuels with energy produced from agricultural byproducts like crop residues, dung and energy crops (jatropha, corn, sugarcane) either directly or after conversion to fuels such as ethanol or diesel (Nguyen, 2003). They emit \( \text{CO}_2 \) but to a reduced extent. All the agricultural waste, animal waste and dung on being subjected to anaerobic digestion convert all waste to energy by capturing methane and preventing it from being released into the atmosphere. The captured methane can then be used as a fuel (Biogas) and also to generate electricity (Smith et al, 2007).

vii. Irrigation and water management: Improving the water use efficiency through drip irrigation and center-pivot irrigation systems, significantly reduce the amount of water and nitrogen applied to the cropping system and hence will reduce greenhouse emissions of nitrous oxide.

viii. Non-mechanization of agricultural practices: The farmers with small land holdings can use the bulls and ox for the water pumping, pod crushing, small scale oil production, electricity generation, ploughing in place of tractors (Fig-4). This can check the GHG emissions by reducing fuel consumption.

Fig-4: Ox being used in India for ploughing in fields.

GHGs mitigation in agriculture- The technical potential for GHG mitigation in agriculture mostly involves soil carbon sequestration. IPCC (1996) has suggested that 400-800 MtC/yr (1400-2900 MtCO\(_2\)-eq/yr) could be sequestered in global agricultural soils in 50-100 years. Similarly, 300-1300 MtC (1100-4800 MtCO\(_2\)-eq/yr) from fossil fuels could be sequestered by using 10-15% of
agricultural land to grow energy crops. IPCC (1996) estimated that CH\(_4\) emissions from agriculture could be reduced by 15-56%, mainly by improving nutrition of ruminants and better management of paddy rice, which could also reduce N\(_2\)O emissions by 9-26%. Of the technical potentials estimated (Smith et al. 2007) about 89% is from soil carbon sequestration, 9% from mitigation of CH\(_4\) and about 2% from mitigation of soil N\(_2\)O emissions (Nguyen et al., 2003).

**Conclusion:** The agriculture practices though started long back was only with the industrialization that the GHGs started increasing in the atmosphere. The modernization and green revolution contributes to climate change. Due to climate change the cereal production is predicted to decline in the developing and under-developed countries but can be combated by organic farming and cultivating climate tolerant crops and traditional method of cropping. Large agricultural land degraded by excessive erosion, salinization, acidification can be improved and restored by re-vegetation, application of manure and compost, organic farming, reducing tillage and retaining crop residues and conserving water. Agriculture is therefore a tool to sequester sufficient carbon dioxide and promote plants which help sequester more carbon dioxide during agricultural practices and lowers global warming. Carbon sequestration in soils improves its organic matter, nutrient content and moisture holding capacity (Paustian et al, 1997).

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Agriculture and climate change: Real problems, false solutions. Preliminary report by Grupo de Reflexion Rural, Biofuelwatch, EcoNexus and NOAH - Friends of the Earth Denmark.


Growth and chlorophyll levels of selected plants with varying photosynthetic pathways (C₃, C₄ and CAM)

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Abstract: Chlorophyll is the most prominent pigment in plants that participates in the process of photosynthesis. It is an important factor in determining the rate of photosynthesis. Based on the plastochron index, the chlorophyll concentration of the mature leaf was determined in selected plants (Catharanthus roseus (L) G. Don (C₃ plant), Andropogon citratus DC (C₄ plant) and Bryophyllum bipinnatum (Lam) Oken (CAM plant). The plants were grown in earthen pots (diameter 23 cm) under natural conditions in a net-home. The chlorophyll concentration in Catharanthus roseus (L) G. Don (C₃ plants) was found to be more than in Andropogon citratus DC (C₄ plant) and Bryophyllum bipinnatum (Lam) Oken (CAM plant). Based on the plastochron index the growth rate of the C₃ plant was faster than the C₄ and CAM plants. This supports the fact that the C₃ plants are more efficient in growth in comparison to the C₄ and CAM plants.

Key words: C₃, C₄ and CAM plants, chlorophyll concentration,.Arnon's method, Plastochron index, growth rate.

1 INTRODUCTION

The rate of photosynthesis is influenced by two factors: external factors including the light, temperature and carbon dioxide; and internal factors which include chlorophyll (Emerson, 1929). Chlorophyll is confined in the thylakoids of the chloroplast (Taiz and Zeiger, 1998). It is the most prominent pigment in the plants for photosynthesis. It is an important factor in plant determining the rate of photosynthesis (Taiz and Zeiger, 1998). More the concentration of chlorophyll more will be the rate of carbon dioxide capture as there will be more trapping centers and hence more will be the rate of growth. It has been experimentally proved that more is the chlorophyll content per unit volume of cells more will be the rate of photosynthesis and hence more the rate of growth (Emerson, 1929). But the chlorophyll composition alone cannot be taken up as criteria for designating a species to be efficient for carbon fixation and growth. There are other factors like the nature of the plant species. Some plant species are naturally more tolerant to the extremes of the climate conditions like drought/water stress and high temperature. C₄ and CAM plants are known to be of such forms and occur in abundance in hot, dry and arid climatic conditions, unlike C₃ plants.

Considering the climate change scenario with increasing temperature and CO₂ levels the responses of the C₃, C₄ and CAM plants can be compared and the most efficient and tolerant of them can be identified. The C₃ plants have Rubisco which functions as an oxygenase when the concentration of CO₂ is low and as carboxylase when the level of CO₂ is optimum. So, the increasing level of CO₂ will be beneficial as no photorespiration will occur and the net primary productivity of the plant will increase (Taiz and Zeiger, 1998). On the other hand the increasing temperature will cause the ratio of [CO₂] to [O₂] to decrease hence decreasing the ratio of carboxylation to oxygenation and leading to more photorespiration in comparison to photosynthesis. Photorespiration leads to release of CO₂ including consumption of O₂ and loss of carbon in the form of dry matter (Taiz and Zeiger, 1998).

The C₄ plants are more tolerant to high temperature and photorespiration as they have PEP carboxylase with a high affinity for substrate HCO₃⁻. The stomatal aperture get reduced by the activity of PEP carboxylase hence water is conserved and also the concentration of CO₂ in the bundle sheath prevents photorespiration. Because of these reasons the C₄ plants are more abundant in dry and hot conditions (Taiz and Zeiger, 1998).

CAM plants are more efficient in water utilization as they lose only 50-100g of water for 1 gm of CO₂ gained in comparison to the 250-300 and 400-500 gm of water by the C₄ and C₃ plants respectively. They also have another feature, scotoactive stomata, which open only during night
2 MATERIAL AND METHOD
The saplings of Catharanthus roseus (L) G. Don, Andropogon citratus DC and Bryophyllum bipinnatum (Lam) Oken were planted in pots (diameter 23 cm) under natural conditions in net-home. Once established, the leaf plastochron index (LPI) of all the selected plants was determined (Dickson and Larson, 1981; Erickson and Michelini, 1957). The plastochron index was used to study the rate of plant growth.

Based on the LPI, mature leaf was used for chlorophyll quantification by Arnon’s method (Arnon, 1949). The chlorophyll concentration of the mature leaf was also measured by non-destructive method using Apogee Opti-Sciences Chlorophyll Concentration Meter (CCM) 200.

The carbon dioxide concentration was also measured with the help of Carbon Dioxide Meter (Technovation Series 2005; range- 0-5%).

3 RESULT AND DISCUSSION
The chlorophyll concentration in Catharanthus roseus (L) G. Don was 0.373 mg/cm² (Table-1), in Andropogon citratus DC was 0.14 mg/cm² and in Bryophyllum bipinnatum (Lam) Oken was 0.043 mg/cm². This corroborates earlier reports on chlorophyll concentration in Catharanthus roseus (L) G. Don (Karthikeyan et al 2009; Cartmill et al 2008; Pandey et al 2007), Andropogon citratus DC (Karthikeyan et al 2009; Kassem et al 2006) and Bryophyllum bipinnatum (Lam) Oken (Laszlo et al 2007). Moreover, based on unit area the chlorophyll concentration as computed by CCM-200 was 34.42 ± 4.71, 14.82 ± 2.39 and 10.48 ± 0.41 mg/cm² in Catharanthus roseus (L) G. Don, Andropogon citratus DC and Bryophyllum bipinnatum (Lam) Oken respectively. The chlorophyll levels in C₃ plant (Catharanthus roseus (L) G. Don) was found to be more (Table-1) than the C₄ plant (Andropogon citratus DC) followed by the CAM plant (Bryophyllum bipinnatum (Lam) Oken). This justifies the fact that the C₃ plants have more chlorophyll concentration in comparison to the C₄ and CAM plants.

However, chlorophyll concentration of C₄ plants (Cynodon dactylon (L) Pers, Zea mays L, Amaranthus hybridus L) was noted to be more than the C₃ plants (Spinacea oleracea L, Triticum vulgare L, Phytolacca americana L) (Black and Mayne 1970).

Studies on plastochron index revealed that the new apical leaf buds appeared after a week in case of Catharanthus roseus (L) G. Don and developed into a node after two weeks interval. The lateral buds and branches were first to come out in Catharanthus roseus (L) G. Don. The C₄ plant, Andropogon citratus DC took two weeks for the new leaf to appear and reached to maturity by four weeks. While for CAM plant, Bryophyllum bipinnatum (Lam) Oken the growth rate was the slowest and did not show any growth by the end of four weeks. The growth rate of selected C₃ plant was more than the C₄ and CAM plant (Table-2). Earlier, plant growth was studied in Xanthium (Erickson and Michelini, 1957), Pisum sativum (Ade-Ademilua, 2005), Phaseolus vulgaris (Shaik et al 1989), Glycine max (Snyder et al 1983). The carbon dioxide concentration as measured with the CO₂ meter showed variation from 0.06% (in the morning, 6 am) to 0.03 % (after 9 am). The CO₂ concentration was recorded to increase as high as 0.07% (around 10 pm). Similar concentrations of CO₂ have been noted (Wei et al 2003; Ziska et al 2001; Sparling et al 1966).

4 CONCLUSION
The chlorophyll concentration in the C₃ plants was found to be more than the C₄ plants and the CAM plants. The growth rate of the C₃ plant was also more than the C₄ and CAM plants. Hence it indicates that the C₃ plants are more efficient in fixing CO₂ and grow faster in comparison to the C₄ and CAM plants. Doubling the current ambient CO₂ concentration was noted to stimulate the growth of C₄ plants to about 10–20% in contrast to C₃ plants by about 40–45% (Poorter, 1993; Reddy et al 2010) and CAM plants to about 12-16% (Nobel and Hartschok, 1986). This corroborates the fact that C₃ plants are more efficient in sequestering CO₂ as faster growth rate was noted for C₃ plants than the C₄ and CAM plant.

But keeping the climate change scenario into consideration the C₄ and CAM plants are more efficient as they can tolerate high temperature conditions, water stress, inhibit photorespiration and hence lead to the perfect functioning of the photosynthetic pathway. This would help them to survive better in the climate change scenario as they are already tolerant to the harsh climatic conditions while the C₃ plants will need to adapt to the changing climate.

REFERENCE


### TABLE 1

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<th>Plants</th>
<th>Chlorophyll concentration (mg/gm)</th>
<th>Chlorophyll concentration (mg/cm²)</th>
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<tr>
<td><em>Catharanthus roseus</em> (L) G. Don</td>
<td>1.263 ± 0.228</td>
<td>34.42 ± 4.71</td>
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### TABLE 2

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<td>Plants</td>
<td>Growth period (week)</td>
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<tr>
<td><em>Bryophyllum bipinatum</em> (Lam) Oken</td>
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Research Article

URBAN GREEN PATCHES AS CARBON SINK: GUJARAT UNIVERSITY CAMPUS, AHMEDABAD

*Aparna Rathore and Yogesh T. Jasrai
Department of Botany, University School of Sciences, Gujarat University, Ahmedabad, Gujarat- 380009
*Author for Correspondence

ABSTRACT
Vegetation is next only to soil in carbon sequestration capability. Owing to an increase in the concentration of greenhouse gases (GHGs) especially carbon dioxide (CO₂) due to human interventions it has become important that the tree carbon sinks are identified for maximum carbon sequestration. This would help plantations to identify specific tree to bring down the level of CO₂, the main GHG. Gujarat University Campus (GUC) has a rich diversity of both flora and fauna. GUC has 60 tree species total 3379 in number. The total carbon stock of the trees was quantified through GBH and height of each tree was measured with measuring tape and altimeter respectively. Simultaneously, the soil was also analyzed for the organic carbon content. Thus, the total carbon stock in the trees and soil of GUC was calculated.

Key Words: Carbon Stock, Tree Species, Gujarat University Campus

INTRODUCTION
Anthropogenic activities, especially fossil fuel burning and deforestation (Pandey, 2002) have resulted in an increase in the concentration of GHGs particularly CO₂ which is accumulating at an alarming rate of 3.5 billion metric tons per annum (Jina et al., 2008) resulting in global warming (Phani Kumar et al., 2009) and climate change (CC). Since the beginning of the industrial revolution, carbon dioxide concentration in the atmosphere has been rising rapidly. Prior to the industrial revolution carbon concentration was around 270 ppm which increased to 372 ppm in 2005 (Kumar et al., 2006; Ramachandran et al., 2007). Impact of CC on the ecology, economy and society is increasing (Pandey, 2002). There is need to mitigate CO₂ levels in the atmosphere controlling global warming.
Carbon sequestration involves the capture and storage of the carbon from the atmosphere which would otherwise go on accumulating in the atmosphere. Carbon dioxide is captured and stored naturally by the plants through the process of photosynthesis where in CO₂ is sequestered in the form of sugars which contribute to organic matter in the soil (Phani Kumar et al., 2009). Hence, estimation of this C content both in vegetation and in soil becomes imperative to access the Carbon sequestration potential. The trees, as they grow sequester the CO₂ in their body (trunk, branches and roots) and this results in an increase in their biomass, indicative of an increase in carbon sequestered by them (Ramachandran et al., 2007). Soil-vegetation systems play an important role in the global carbon cycle. Soil contains about three times more organic carbon than vegetation and about twice as much carbon than is present in the atmosphere (Dinakaran et al., 2008; Kumar et al., 2006 and Batjes and Sombroek, 1997)). Terrestrial vegetation and soil currently absorb 40% of global CO₂ emission from human activities (Sheikh, 2010).
Global warming risks from emissions of greenhouse gases (GHGs) by anthropogenic activities have increased the need for the identification of ecosystems with high carbon sink capacity as an alternative mitigation strategy of terrestrial carbon sequestration (Phani Kumar et al., 2009). The present study deals with the estimation of the total carbon stock of the trees in Gujarat University campus by non-destructive method. Simultaneously, the soil was also analyzed for the organic carbon and other. Thus, the total carbon stock in the trees and soil of Gujarat University campus was calculated.
MATERIALS AND METHODS

Study Area
Gujarat University, situated in Ahmedabad has a campus which spreads over an area of 1.1 km$^2$. It is situated between 23°02'11.44"N latitude and 72°32'46.63"E longitude at an elevation of 180 feet. It has dry semi-arid type of the climate according to the Koppen system of classification. The average summer minimum to maximum temperature varies from 23 to 45°C. The south-western monsoon results in a humid climate from mid-June to mid-September and the average annual rainfall is about 76.0 cms (Figure 1 and 2).

Methodology
For the carbon stock estimation of each tree, the tree was measured for its height using Haga’s altimeter, bole, GBH (girth at breast height) and canopy diameter with a measuring tape. The total carbon stock of the trees was therefore measured by non-destructive method using equations involving the total volume, total biomass, percentage of carbon sequestered and wood density (Phani Kumar et al., 2009). The GBH of the trees was measured. The total biomass was determined in terms of above ground biomass (AGB), below ground biomass (BGB) and tree canopy biomass values specific to each tree species. The AGB was measured based on the method of Phani Kumar et al., (2009). The BGB is calculated by the method proposed by MacDicken, (1997). The biomass of leaf and branch cover of each tree was calculated with the help of crown volume (Phani Kumar et al., 2009). The total volume was then multiplied by the specific density of the tree to get the total biomass. The specific density of the trees was
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noted from The Indian Woods (Chowdhury and Ghosh, 1958). The carbon percentage of the trees was calculated (Pettersen, 1984; Chan, 1982).

A total of 33 soil samples were collected from different sites by random sampling method. Three soil samples were taken sequentially up to a depth of 20cm (surface sample, sample at a depth of 10cm and at 20 cm). It was dried and sieved through 2mm sieve. The undisturbed soil clumps were used to determine the bulk density. The soil was further ground with pestle and mortar and sieved through the 0.5mm sieve. The soil organic carbon was determined (Walkey and Black, 1934) for each soil sample. The soil was also analyzed for the pH, nitrogen, phosphorous and potassium. The total soil carbon stock was also determined (MacDicken, 1997).

RESULTS AND DISCUSSION

The Gujarat University campus has a rich floral diversity. The main tree species comprise of Azadirachta indica (neem), Peltophorum pterocarpum (copper pod tree), Ailanthus excelsa (arduso), Ficus religiosa, Cassia fistula (amaltas), Polialthia longifolia (asopalav), Limonia acidissima (wood apple) and Pongamia pinnata (karanji).

The tree community in the Gujarat University campus comprised of 3379 individuals belonging to 60 species (Fig-2) and 28 families (Table-1). Azadirachta indica A Juss trees were the most dominant (910) followed by Peltophorum pterocarpum (DC) Baker (752), Polialthia longifolia (Sonner) Thwaites (504), Pongamia pinnata (L) Pierre (132), Ailanthus excelsa Roxb (89) and Eucalyptus globulus Labill (97). Based on the average carbon stock of various tree species, maximum carbon sequestration in trees was found with Terminalia chebula Retz (76.93 t) followed by Pithecellobium dulce (Roxb) Bth (65.88 t) Limonia acidissima L (61.31 t) , Ficus benghalensis L (54.03 t), Tamarindus indica L. (52.84 t), Morus alba L (47.92 t), Ailanthus excelsa Roxb (43.89 t), Syzygium cumini (L) Skeel (43.64 t), Azadirachta indica A Juss (43.11 t), F. religiosa L (42.79 t), Albizia lebbeck (L) Bth (40.57 t) Terminalia arjuna (Roxb) W & A (38.21 t), Eucalyptus globulus Labill (35.9 t), Mangifera indica L (35.75 t) and Casuarina equisetifolia L (34.59 t) such trees with good carbon sequestration capability could be the ideal selections for CO$_2$ sequestration in the present scenario to mitigate climate change. While the trees like Acacia nilotica (L) Del (2.48 t) and the members of family Palmae like Phoenix sylvestris (L) Roxb (2.18 t), Roystonea regia (H B & K) O F Cook (1.24 t), Musa paradisiaca L (0.87 t), Dicrostachys cinerea (DC) (0.63 t) are found to have least carbon stock.

The soil pH is normal (7.8). The electrical conductivity of the soil is normal with a value of 0.72 (Table-2). The soil organic carbon was high (1.06%) indicating a good soil quality. The phosphorous content is very low. However, potassium content is high with nitrogen content being normal. The bulk density of 1.18 g/cm$^3$ is also very high.

The total carbon stock in the soil in GUC was calculated to be 2501.60 t/ha and the total carbon stock in the trees of GUC was found to be 661.30 t/ha. Hence, the total carbon stock of soil and trees of GUC is 3162.9 t/ha. This is in accordance with earlier studies which have demonstrated that soil contains about three times more organic carbon than vegetation and about twice as much carbon that is present in the atmosphere (Dinakaran et al., 2008; Kumar et al., 2006; Batjes and Sombroek, 1997).

Conclusion

The trees to be selected for maximum carbon sequestration in the present scenario with high levels of carbon dioxide in the atmosphere should have high wood specific density. The trees should be fast growing with increasing biomass at a fast rate and should have a huge canopy (Jana et al., 2009). One of the eight national missions included in the India’s National Action Plan on Climate Change comprises on the national mission for a “Green India” to increase forest cover and conserve biodiversity. The CDM, as under the Kyoto Protocol is encouraging the plantation of trees with a high carbon sequestration capability so as to bring down the concentration of CO$_2$ in the atmosphere. In fact the soil-vegetation systems play an important role in the global carbon cycle by sequestering emitted carbon in the atmosphere thereby mitigating global warming.
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<th>S. No.</th>
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Table 2: Physicochemical properties of the soil of Gujarat University

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<th>Mean ± SE</th>
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<tr>
<td>pH</td>
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<tr>
<td>Organic carbon (%)</td>
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<tr>
<td>Nitrogen (%)</td>
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<td>Phosphorous (kg/ha)</td>
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<td>Potassium (kg/ha)</td>
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<tr>
<td>Electrical Conductivity</td>
<td>0.72 ± 0.86</td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENT
I sincerely thank DST Inspire for financial support. I also thank Nisha Patel, Alpesh Ahir, Javed Arambhiya, Alay Mehta and Dhruvi Soni for their sincere support in the field work without whose support my work would not have been a success.

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Research Article


Biodiversity: Importance and Climate Change Impacts

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Abstract: Biodiversity is the variability among living organisms, including genetic and structural difference between individual and within and between individual and within and between species. Biodiversity plays a direct role in climate regulation. Biodiversity conservation will lead to strengthening of ecosystem resilience and will improve the ability of ecosystem to provide important services during increasing climate pressures. This review basically focuses on the importance of biodiversity, the consequences faced by the plants, animals, humans and ecosystem owing to the global warming and climate change and the possible mitigation and adaptation strategies in terms of biodiversity conservation which can protect the planet from the consequences of climate change.

Index Terms: Biodiversity, climate change, mitigation and adaptation

INTRODUCTION

BIODIVERSITY AND ITS IMPORTANCE

Biodiversity is the variability among living organisms, including genetic and structural difference between individual and within and between individual and within and between species. The world biodiversity has a total of 1,263,500 species of plants and animals while India has only 51,828 species (table-1) (1). It provides us with all the necessities of life and sustains and nourishes us. Biodiversity plays a direct role in climate regulation. Climate always changes resulting in evolutionary changes in the species. Biodiversity is important in following ways (3);

i). Soil formation and maintenance of soil quality: The activities of microbes and animal (bacteria, algae, fungi, millipedes, etc) condition soils, break down organic matter, form soil and prevent soil erosion.

ii). Maintain air quality: Plants purify the air and regulate the composition of the atmosphere, by taking in CO₂ during photosynthesis and liberating oxygen in the atmosphere.

iii). Maintain water quality: Trees and forest soils purify water; prevent silting of rivers and reservoirs arising due to soil erosion and landslides.

iv). Pest control: Conserving biodiversity can control 99% of potential crop pests.

v). Detoxification and decomposition of wastes: About 130 billion metric tons of organic waste (including industrial wastes) is processed every year by earth’s decomposing organisms.

vi). Pollination and crop production: Without plant and animal (bees, butterflies, bats, birds) interactions, no pollination will be possible and hence would lead to decline in crop yield.

vii). Climate stabilization: Oceans, soil and vegetation are huge carbon sinks and help reduce the CO₂ in atmosphere. In rainforests the surface temperature is maintained by regular rains, while in cold regions the temperature is regulated by forests acting as insulators and windbreaks.

viii). Prevention and mitigation of natural disasters: Ecosystem biodiversity (forest, salt marshes, mangrove) prevents erosion, nutrient loss, landslides, floods and impacts of storms.

ix). Provision of food security: biodiversity in terms of plants and animals is the ultimate source of food, fiber, fuel and shelter. Biodiversity conservation will lead to strengthening of ecosystem resilience and will improve the ability of ecosystem to provide important services during increasing climate pressures.

GLOBAL WARMING AND CLIMATE CHANGE: DRIVERS AND IMPACTS

Global warming is the increase in the world’s average temperature occurring due to increasing emission of the greenhouse gases (GHGs) which results in an enhanced greenhouse effect. Climate change refers to a statistically significant change in either the mean state of the climate or in its variability persisting for decades or longer (17). Climate change results due to both; natural and anthropogenic drivers.

Natural drivers: It involves the contribution of plants, animals and humans naturally by processes of respiration, death and decomposition. Earth’s climate variability is also caused by changes in the solar radiations, Milankovitch cycle, volcanic eruption, plate tectonics, ocean circulations, earthquakes and so on (18).

Anthropogenic drivers: It involves the human activities leading to climate change (table-2) (20). The concentration of CO₂ has increased from pre-industrial concentration of 280ppm to 392ppm in 2010. It is all due to the burning of fossil fuel to generate the electricity in power plants, industrialization, deforestation, mechanization of agricultural practices, increasing vehicular transportation (In India, vehicles have increased from 350 million to 40 billion since 1947) (21), land use changes, urbanization, industrialization and the disposal of subsequent waste generated out of it all.

Impacts: Millennium Ecosystem Assessment (MEA) predicts climate change to be the principal threat to the biological diversity (2). The average global temperature has increased by 0.6°C since mid 1800s and is predicted to rise by 1.4-5.8°C by the year 2100. The global mean sea level has risen by 10 to 20 cm (8) and may further rise to 88 cm. Thickness of Arctic ice has
decreased by about 40%. Many areas are facing problem of water shortage. Alaska’s boreal forest has moved about 100 km for every 1°C rise in temperature. Climate change has resulted in extinction of animals like golden toad and Monteverde harlequin frog (8). Many communities have already become climate refugees to evade rising sea level (2). The rainfall is predicted to increase in Southeast Asia and decrease in Central Asia, Australia, New Zealand, Mediterranean region and Africa. Extreme climatic events (heat waves, storms and hurricanes) and tropical vector-borne diseases (malaria, dengue etc) are predicted to increase.

IMPACTS OF CLIMATE CHANGE ON BIODIVERSITY

[1] Vegetation: The vegetation is exhibiting the following changes;

a). Migration of vegetation towards a higher altitude: In Nainital, species such as Berberis asiatica, Taraxacum officinale, Jasminum officinale etc have shifted from 1000 to 2000m height (4). Teak dominated forests are predicted to replace the Sal trees in central India and also the conifers may be replaced by the deciduous types. According to climatologists and palynologists, temperature change of 3°C may lead to forest movement of 250 km at a rate of 2.5 km/year which is ten times the rate of natural forest movement (6, 7).

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d). Forest fires have increased in number due to high temperature conditions.

e). Increase in the pest attacks: Due to climate change, pests (Pine wood nematode-Bursaphelenchus xylophilus, Pitch canker-Gibberellacircinata, Red palm weevil-Rhynchophorus ferrugineus, virus, aphids, fungi) have increased in number. Variation in temperature and precipitation patterns can result in more frequent droughts and floods making indigenous plants more vulnerable to pests and diseases (rots, blights) (5).

[II] Animals: Sensitivity of the species to even a slight change in the climate leads to their extinction as in case of the golden toad. Polar bears are in danger due to reduction in Arctic ice cover. North Atlantic right whale may become extinct, as planktons, its main food have shown decline due to climate change. The sex of sea turtles depends on temperature and more female turtles are produced as a result of high temperature. Some threatened species (frogs, toads, amphibians, tigers and elephants) are vulnerable to the impacts of climate change like sea level changes and longer drier spells. Changes in ocean temperature and acidification may lead to loss of 95% of the living corals of Australia’s Great Barrier Reef (2).

[III] Ecosystem

a). Marine and Coastal: 70% of the Earth’s surface is covered by oceans comprising some of the world’s most diverse and unique ecosystems (mangroves, coral reefs, sea grass beds) (10). Climate change is leading to sea level rise, increased coastal erosion, flooding, higher storm surges, sea salinity ingress, increased sea-surface temperatures, ocean acidification, coral bleaching, mangroves and millions of climate change refugees. Species composition and distribution will surely be affected by such changes. Indian coastal areas vulnerable to climate change are Sundarbans, Maharashtra, Goa and Gujarat (Rann of Kutch) (15, 16). The distribution and composition of the species is bound to be effected.

b). Island ecosystem: Islands are the most fragile with rich biodiversity and a high economic importance. 23% of island species are at present endangered (11). Islands have small and endemic species (corals) (11) sensitive to the changing climate. Climate change leads to an increase in the sea level, frequency and intensity of storms, variability in rainfall and intolerably high temperatures affecting the endemic species and hence economic loss in the tourism sector.

c). Inland water ecosystem: Inland water systems include the fresh water systems and are only 0.01% of the world’s water source comprising 0.8% of the Earth’s surface, but support 6% of the total species (12). They are rich source of food, income, employment and biodiversity. Changing rainfall patterns will lead to change in the course of the streams affecting breeding and food habits of many species. The ice cover is bound to decrease causing an increase in the number of flood and drought. This would further lead to changes in the phenology, physiology and migration trends of some organisms like migratory birds.

d). Forest: Forest area is about one-third of the Earth’s surface and comprises two-thirds of all the known terrestrial species. They are also rich biodiversity hotspots. Half of the original forest cover has been cleared up till now. The increased level of CO₂ has led to increase in the growth of some forest. Increased temperature (even 1°C) has resulted in significant migration of tree species, increased attack of pest, invasive species and wild fires, hence modifying the composition of forest. Many animals, primates and 9% of all known tree species (woody trees, white spruce) are at risk of extinction (13).

e). Agriculture: About one-third of the world’s area is under cultivation (2). Climate change leads to variability in rainfall patterns, heat stress, spread of pests and diseases and shortening of the crop cycle and affecting plant growth and production.

f). Dry lands and Grassland: They support 35% of the world population and comprise of the arid and semi-arid areas, grasslands and savannahs. They have localized species (wild ass, Kutch etc) and have varied crops and livestock. The desertification is expanding and so is the temperature making them drier and intolerable for the threatened species. The risk of wild fire is increasing which could change the species biodiversity. Climate change is a threat to the diverse hotspots (Succulent Karoo, South Africa) (2).

g). Mountain: One-third of the Earth’s surface is covered by the mountains which supports one-third of the world population. Many species are very specific and endemic to this ecosystem and are rich natural reservoirs of goods. Climate change is leading to the glacier retreat, change in the course of rivers, migration of the tree species northward (13) and subsequent extinction of
some species.

h). Polar ice/Glacier: They are diverse ecosystem facing extremes of the cold temperature with the flora (planktons) and fauna (migratory birds, whales) and Arctic people modified to such conditions (2). Climate change has resulted in an increase in the temperature to about 5°C to the normal and has resulted in the melting of the ice, increase in sea level which is threatening the endemic species (polar bears, walruses, seals, emperor penguins, krill, ringed seal). Studies show a decline in the weight of the polar bears from 325 kg in 1980 to 253 kg in 2004 (14).

Biodiversity loss has impacted the fishing and hunting practices by indigenous people (Saami and Inuit of Canada) posing an implication on their only source of food (2). (ref. table-3)

[IV] Humans

Climate change leads to an increase in temperature, melting of the ice and increased extreme events. All the extreme events like floods, droughts, cyclones displace the humans from their home and lead to outbreak of water borne diseases like cholera, typhoid etc; spread of tropical and vector borne diseases like malaria, dengue etc and rodent borne diseases like plague. These diseases have shown a persistent increase in the past 50 years. The incident of heat waves has registered an increase throughout the world taking away a heavy toll of the people life every year (5). The increasing sea level rise has already submerged many islands and will soon leave millions of refugees for the world to provide shelter. The sea salinity ingress in the fresh water sources has made land barren and will soon be a threat to the food security.

PREVENTION OF CLIMATE CHANGE: MITIGATION AND ADAPTATION STRATEGIES

Mitigation deals with the causes of climate change, while adaptation tackles its effects. Global warming mitigation involves reducing the intensity of radiative forcings so as to reduce the effect of global warming and it can be made possible by two aspects: Geo-engineering and Carbon sequestration. Geo-engineering are the proposals to manipulate the earth’s climate so as to decrease the impact of global warming from the greenhouse gas emission. It comprises of Sulphur dioxide spraying, artificial trees, cloud seeding ships, iron and limestone fertilization of the oceans and space mirrors (19).

Another technology comprises of the various methods of carbon sequestration called CarbonCapture and Storage (CCS). According to a 2005 IPCC report major point sources of carbon dioxide include coal-fired power stations, natural gas, fossil fuel–based hydrogen, and synthetic fuel. CO₂ emissions from such sources can be captured and stored in underground geologic formations. CCS technologies are already being widely used in industries producing fertilizers, hydrogen and natural gas processing (21). Carbon sequestration can also be made practically possible by methods of organic farming using natural manures, fertilizers (algae- Nostoc, Anaebeana, mycorrhizae) and pesticides and bringing a halt on the application of chemical fertilizers and pesticides and promoting tree plantations and agroforestry practices (20).

Environment Impact Assessment (EIA) of the industrial areas, checking vehicular pollution by the use of biofuels and using the clean technology, reducing over-exploitation of resources (over-fishing, land-use-changes); preventing poaching of rare, endangered and endemic species; preventing habitat fragmentation. The biodiversity can be conserved by management programmes including ecosystem conservation and restoration. The forest need to be conserved with practices of reforestation and afforestation as they have 80% of the total carbon stored in terrestrial vegetation. The indigenous knowledge can also be used to prevent climate change or adapt to it (2).

Strategies by the United Framework Convention on Climate Change (UNFCCC) focuses on cutting down greenhouse gas emissions to prevent climate change. Kyoto protocol has brought into existence joint implementation, emission trading and Clean Development Mechanism (CDM) to reduce greenhouse gas emission. Like all other countries National Action Plan on Climate Change of India was released in Delhi in 2009 and involves eight missions on solar mission, enhanced energy efficiency, sustainable habitat, water mission, sustaining Himalayan ecosystem, Green India through massive tree plantation, sustainable agriculture and strategic knowledge for climate change by establishing a knowledge platform on climate change (22). Successful implementation of all these plans would surely help reduce global warming and conserve biodiversity.

CONCLUSION

The increase in the greenhouse gases is leading to climate change at a faster rate and impacts the people and ecosystems. Every change in the ecosystem process works on the principle of Newton’s law of motion (Every action has an equal and opposite reaction) which may be damaging or complimentary. Even a small change in the climate can lead to the extinction of some vulnerable and sensitive species. Climate change results in the impact on the biodiversity like change in their distribution pattern, migration of species, invasion of invasive species, change in the phenological behaviour like breeding period, migration time etc, increase in the forest fires and pest attacks.

To maintain the balance of ecosystem, interaction between the plants, animals and biodiversity needs to be understood, hence promoting its conservation and protection by designating the hotspots as biosphere reserves, increasing afforestation, reforestation and agroforestry practices. Biodiversity-based adaption and mitigation strategies will enhance the resilience of ecosystems and prevent damage to human and natural ecosystems.

Table-1: Species biodiversity in India and World

<table>
<thead>
<tr>
<th>Species</th>
<th>Number in India</th>
<th>Number in world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammals</td>
<td>410</td>
<td>4,000</td>
</tr>
<tr>
<td>Birds</td>
<td>1,228</td>
<td>10,000</td>
</tr>
<tr>
<td>Reptiles</td>
<td>447</td>
<td>10,500</td>
</tr>
<tr>
<td>Amphibians</td>
<td>197</td>
<td></td>
</tr>
<tr>
<td>Fishes</td>
<td>2,546</td>
<td>19,000</td>
</tr>
<tr>
<td>Plants</td>
<td>47,000</td>
<td>2,70,000</td>
</tr>
</tbody>
</table>

Table-2: Percent GHGs emissions by various sectors (Smith et al., IPCC, 2007)

<table>
<thead>
<tr>
<th>Anthropogenic sectors</th>
<th>Percentage</th>
</tr>
</thead>
</table>

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### Table 3: Ecosystem vulnerability, impacts, mitigation and adaptation with respect to climate change

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Polar ice/Glaciers, Marine and Coastal, Inland water, Island, Forest, Dry lands/Grassland, Mountain and Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vulnerability</strong></td>
<td>Climate sensitivity of flora and fauna, low resilience power</td>
</tr>
<tr>
<td><strong>Impacts</strong></td>
<td>Rising temperature, Melting ice, Sea level rise, Altering stream flow, Ocean acidification, Increased extreme events like floods, storms, Sea salinity ingress, Increased pest attacks and diseases, Wildfires, Invasion of invasive species, Endemic species like polar bears, penguin, walruses, seals, krill are threatened, Changes in phenological, physiological and migration pattern of species, Reduced agricultural yield</td>
</tr>
<tr>
<td><strong>Mitigation and Adaptation</strong></td>
<td>Reducing pollution both industrial and vehicular, Environment impact assessment, CDM, using clean and renewable energy and biofuels, Biodiversity conservation: Forest conservation, reforestation, afforestation, agro-forestry, avoiding deforestation, sustainable and efficient management of water resources, ecosystem management and restoration, preventing habitat fragmentation, over-exploitation of resources and land-use-change, Agriculture: Organic farming, biological pest control, improving rice farming, no-till practices and in-situ and ex-situ gene preservation, Consideration of suggestion on methods to conserve biodiversity from indigenous people observing climate change</td>
</tr>
</tbody>
</table>

**ACKNOWLEDGMENT**

I am very much thankful to DST, INSPIRE for their financial support.

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10. 10. IUCN. New strategy to help corals and mangroves survive climate change, accessed on 30-7-2010 online at [http://www.iucn.org/](http://www.iucn.org/) 31 clima te.htm

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Biodiversity: Importance and Climate Change Impacts

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**IMPACTS OF CLIMATE CHANGE ON BIODIVERSITY**

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PREVENTION OF CLIMATE CHANGE: MITIGATION AND ADAPTATION STRATEGIES

Mitigation deals with the causes of climate change, while adaptation tackling its effects. Global warming mitigation involves reducing the intensity of radiative forcings so as to reduce the effect of global warming and it can be made possible by two aspects: Geo-engineering and Carbon sequestration. Geo-engineering are the proposals to manipulate the earth’s climate so as to decrease the impact of global warming from the greenhouse gas emission. It comprises of Sulphur dioxide spraying, artificial trees, cloud seeding ships, iron and limestone fertilization of the oceans and space mirrors (19).

Another technology comprises of the various methods of carbon sequestration called Carbon Capture and Storage (CCS). According to a 2005 IPCC report major point sources of carbon dioxide include coal-fired power stations, natural gas, fossil fuel–based hydrogen, and synthetic fuel. CO₂emissions from such sources can be captured and stored in underground geologic formations. CCS technologies are already being widely used in industries producing fertilizers, hydrogen and natural gas processing (21). Carbon sequestration can also be made practically possible by methods of organic farming using natural manures, fertilizers (algae- Nostoc, Anaebaena, mycorrhizae) and pesticides and bringing a halt on the application of chemical fertilizers and pesticides and promoting tree plantations and agroforestry practices (20).

Environment Impact Assessment (EIA) of the industrial areas, checking vehicular pollution by the use of biofuels and using the clean technology, reducing over-exploitation of resources (over-fishing, land-use-changes); preventing poaching of rare, endangered and endemic species; preventing habitat fragmentation. The biodiversity can be conserved by management programmes including ecosystem conservation and restoration. The forest need to be conserved with practices of reforestation and afforestation as they have 80% of the total carbon stored in terrestrial vegetation. The indigenous knowledge can also be used to prevent climate change or adapt to it (2).

Strategies by the United Framework Convention on Climate Change (UNFCCC) focuses on cutting down greenhouse gas emissions to prevent climate change. Kyoto protocol has brought into existence joint implementation, emission trading and Clean Development Mechanism (CDM) to reduce greenhouse gas emission. Like all other countries National Action Plan on Climate Change of India was released in Delhi in 2009 and involves eight missions on solar mission, enhanced energy efficiency, sustainable habitat, water mission, sustaining Himalayan ecosystem, Green India through massive tree plantation, sustainable agriculture and strategic knowledge for climate change by establishing a knowledge platform on climate change (22). Successful implementation of all these plans would surely help reduce global warming and conserve biodiversity.

CONCLUSION

The increase in the greenhouse gases is leading to climate change at a faster rate and impacts the people and ecosystems. Every change in the ecosystem process works on the principle of Newton’s law of motion (Every action has an equal and opposite reaction) which may be damaging or complimentary. Even a small change in the climate can lead to the extinction of some vulnerable and sensitive species. Climate change results in the impact on the biodiversity like change in their distribution pattern, migration of species, invasion of invasive species, change in the phenological behaviour like breeding period, migration time etc, increase in the forest fires and pest attacks. To maintain the balance of ecosystem, interaction between the plants, animals and biodiversity needs to be understood, hence promoting its conservation and protection by designating the hotspots as biosphere reserves, increasing afforestation, reforestation and agroforestry practices. Biodiversity-based adaption and mitigation strategies will enhance the resilience of ecosystems and prevent damage to human and natural ecosystems.

Table-1: Species biodiversity in India and World

<table>
<thead>
<tr>
<th>Species</th>
<th>Number in India</th>
<th>Number in world</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mammals</td>
<td>410</td>
<td>4,000</td>
</tr>
<tr>
<td>Birds</td>
<td>1,228</td>
<td>10,000</td>
</tr>
<tr>
<td>Reptiles</td>
<td>447</td>
<td>10,500</td>
</tr>
<tr>
<td>Amphibians</td>
<td>197</td>
<td></td>
</tr>
<tr>
<td>Fishes</td>
<td>2,546</td>
<td>19,000</td>
</tr>
<tr>
<td>Plants</td>
<td>47,000</td>
<td>2,70,000</td>
</tr>
</tbody>
</table>

Table-2: Percent GHGs emissions by various sectors (Smith et al., IPCC, 2007)

<table>
<thead>
<tr>
<th>Anthropogenic sectors</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table-3: Ecosystem: vulnerability, impacts, mitigation and adaptation with respect to climate change

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>Polar ice/Glaciers, Marine and Coastal, Inland water, Island, Forest, Dry lands/Grassland, Mountain and Agriculture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vulnerability</td>
<td>Climate sensitivity of flora and fauna, low resilience power</td>
</tr>
<tr>
<td>Impacts</td>
<td>Rising temperature, Melting ice, Sea level rise, Altering stream flow, Ocean acidification, Increased extreme events like floods, storms, Sea salinity ingress, Increased pest attacks and diseases, Wildfires, Invasion of invasive species, Endemic species like polar bears, penguin, walruses, seals, krill are threatened, Changes in phenological, physiological and migration pattern of species, Reduced agricultural yield</td>
</tr>
<tr>
<td>Mitigation and Adaptation</td>
<td>Reducing pollution both industrial and vehicular, Environment impact assessment, CDM, using clean and renewable energy and biofuels, Biodiversity conservation: Forest conservation, reforestation, afforestation, agro-forestry, avoiding deforestation, sustainable and efficient management of water resources, ecosystem management and restoration, preventing habitat fragmentation, over-exploitation of resources and land-use-change, Agriculture: Organic farming, biological pest control, improving rice farming, no-till practices and in-situ and ex-situ gene preservation, Consideration of suggestion on methods to conserve biodiversity from indigenous people observing climate change</td>
</tr>
</tbody>
</table>

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Abstract
Climate of the earth is continuously changing due to natural and anthropogenic reasons. For predicting future climate it is imperative to know how climate changed in the past, especially during the past few centuries. High resolution long term climate data during the recent past about 1000 years are needed to understand natural climate variability and the magnitude of human impact on it. Terrestrial proxies available for climate reconstruction are ice cores, lake sediments, corals, speleothems and tree rings. Among these tree rings have specific advantages: they have a wide geographic distribution, are annually resolved, show a continuous record and are easily dated by ring-counting. With their high resolution and reliability, tree rings play an important role in global change studies.

In the present study tree ring samples were collected using increment corer from different teak dominant areas of Gujarat and the tree ring widths were correlated with temperature and precipitation data and drought years. The results so obtained show a sharp correlation of the ring width development with the drought years. Hence, the drought condition has a prominent effect on the growth rate of the teak trees.

Key words: Climate change, tree rings, ring width, crossdating, dendrochronology.

INTRODUCTION
Climate of the earth is continuously changing due to natural and anthropogenic reasons. For predicting future climate it is imperative to know how climate changed in the past, especially during the past few centuries. High resolution long term climate data during the recent past about 1000 years are needed to understand natural climate variability and the magnitude of human impact on it (Bradley et al., 1996; Yadav et al., 2002; Ram et al., 2008). Terrestrial proxies available for climate reconstruction are ice cores, lake sediments, corals, speleothems and tree rings. Among these tree rings have specific advantages: they have a wide geographic distribution, are annually resolved, show a continuous record and are easily dated by ring-counting. Seasonality in the growth rate of trees driven by variability in the climatic factors can result in well defined growth rings in trees. Individual tree rings faithfully record contemporary climatic signatures hence provide an opportunity to decipher the variation in climatic parameters for a duration equivalent to the life span of the tree (Managave et al., 2010).

In addition, tree ring research can also provide great insights into the mechanisms of climate change (Briffa et al., 2004). Tree rings have been used in various applications to reconstruct past climates as well as to access the effect of recent climatic and environmental changes on tree growth. Temperature changes based on the tree ring records suggests that climate swings in the last 1000 years were greater than the IPCC estimates (Pandey, 2002).

Teak (Tectona grandis) and its significance in Tree Ring Analysis
Teak, Sag, Sagwan is the common name for the tropical hardwood deciduous tree species Tectona grandis L.f. belonging to the family Verbenaceae. Tectona grandis is native to south and south-east Asia, mainly India, Indonesia, Malaysia and Myanmar. Tectona grandis is found in a variety of habitats and climatic conditions from arid areas with only 500 mm of rain per year to very moist forests with up to 5,000 mm of rain per year. Teak (Tectona grandis) is one of the few tropical species showing distinct and reliable growth rings and holds potential for reconstructing monsoonal precipitation over India. Annual nature of growth rings in teak trees was established by Berlage (1931) and Chowdhary (1939). Several studies (Berlage, 1931; Bhattacharyya et al., 1992), D’Arrigo et al., 1994, Pumijumnong et al., 1995, Priya and Bhat, 1999, Borgaonkar et al., 2007; Buckley et al., 2007, Shah et al., 2007, Ram et al., 2008) have reported reconstruction of past climate, especially rainfall, using variations in ring-widths of teak. Sudheendrakumar et al., (1993) have observed a bellshaped teak growth curve with higher growth rates during the months of higher rainfall. These studies indicate high potential of Tectona grandis in reconstruction of regional climate (monsoon) related...
parameters (e.g., rainfall, drought frequencies and intensities, ENSO/El Niño, etc.).

The present study deals with the dendrochronological and dendroclimatological analysis of Tectona grandis L.F. The tree-ring-width chronologies of teak (Tectona grandis L.F.) were analysed from the teak dominated areas of Gujarat (Waghai, Purna, Shoolpaneshwer, Ratanmahal, Jambughoda, Ahmedabad, Gandhinagar, Balaram and Gir) to evaluate their dendroclimatic potential in relation to rainfall, temperature and drought condition over the region.

MATERIAL AND METHOD

Study area

Gujarat is situated at latitude of 20°01’ 24.07”N and longitude of 68°04’ 74.04”E with a total area of 196,077 km². On the basis of rainfall received Gujarat has been divided into 7 agro-climatic zones. The tree rings were sampled from the agroclimatic zones of Gujarat where teak trees (Tectona grandis) are prominent (Fig-1). From the Southern hill zone the tree ring were sampled from Waghai Botanical Garden, Dangs (0.24 km²; 20°45’ 26.34”N and 73°29’ 58.35”E; 181.66 m a.s.l.) and Purna Wild Life Sanctuary, Dangs (160.84 km²; 20°56’ 12.99”N and 73°40’ 21.64”E; 390.45 m a.s.l.). From the South Gujarat zone the Teak samples were collected from Shoolpaneshwer Sanctuary, Narmada (607.07 km²; 21°45’ 44.34”N and 73°45’ 47.60”E; 479.75 m a.s.l.). For these locations the climatic data recorded at Surat Meteorological Station (21°11’ 42.86”N and 72°50’ 06.76”E; 10.97 m a.s.l.) were used.

From the Middle Gujarat zone the Teak samples were collected from Ratanmahal Sanctuary, Dahod (55.65 km²; 22°29’ 37.51”N and 73°04’ 55.75”E; 239.88 m a.s.l.) and Jambughoda Sanctuary, Panchmahal (130.38 km²; 22°21’ 14.71”N and 73°40’ 32.63”E; 184.4 m a.s.l.). For these locations the climatic data recorded at Dahod Meteorological Station (22°49’N and 74°15’E; 305 m a.s.l.) were used.

From the North Gujarat zone the Teak samples were collected from various sites at Ahmedabad (23°02’ 10.28”N and 72°32’ 48.11”E; 55.78 m a.s.l.), Gandhinagar (23°11’ 53.64”N and 72°38’ 14.51”E and 75 m a.s.l.) and Balaram Ambaji Sanctuary, Sabarkantha (542.08 km²; 24°18’ 23.77”N and 72°46’ 49.98”E; 428.24 m a.s.l.). For these locations the climatic data recorded at Ahmedabad (23°03’N and 72°58”E; 53 m a.s.l.), Gandhinagar (23°13’N and 72°38’E; 82 m a.s.l.) and Idar Meteorological Station (23°49’N and 72°59”E; 213 m a.s.l.) respectively were used. From the South Saurashtra zone the teak samples were collected from the Gir Wild Life Sanctuary, Junagadh (1153.42 km²; 21°06’ 57.88”N and 70°47’ 32.39”E; 289.56 m a.s.l.). For this location the climatic data recorded at Rajkot (22°18’N and 70°48”E; 133 m a.s.l.) was used.

For these investigations the climatic data (Monthly rainfall and temperature data) obtained for all the stations of Gujarat from the IMD, Pune has been applied. The average monthly temperatures and monthly precipitation are usually treated as the main factors influencing tree ring formation (Fritts, 1976; Cook, 1987; Juknys et al., 2002).

METHOD

Dendroclimatological analysis of Tectona grandis

Dendroclimatological investigations were carried out on teak (Tectona grandis L.f.) collected from various teak dominant areas in Gujarat (Fig-1). To minimize non-climatic influences on ring growth, only healthy trees with no obvious injury or disease were sampled (Zhu et al., 2009). Two tree ring cores per live trees were acquired using a standard non-destructive increment borer at the base or breast height (1.4 m) to remove a 5 mm diameter core from the tree with the aim to extract all the growth-rings present in the tree (Fig-2). Core samples were carefully removed, stored and transferred for laboratory analysis using standard dendrochronological techniques (Fritts 1976; Ram et al., 2008; Zhu et al., 2009). The increment bores were air dried and glued onto wooden mounts in transverse position (Fig-2). The transverse surfaces of the cores were cut with a sharp razor and then polished using different grades of sand paper until the cellular details became clear under a hand held microscope (Di’Az et al., 2001; Yadav et al., 2002).
The tree rings were counted and ring widths were measured using a hand held microscope to a precision of 0.1 mm. Skeleton plot method was used to assign exact year of growth to each and every ring (Stokes and Smiley, 1968). The site ring width index chronologies were prepared by averaging all the tree-ring index series over the individual site (Diáz et al., 2001) and the standard deviation (Table-1) was also calculated (Ram et al., 2008). Tree ring chronologies were developed (Meldahl et al., 1999).

### Table 1: General statistics of tree-ring chronologies

<table>
<thead>
<tr>
<th>Area</th>
<th>Purna</th>
<th>Waghai</th>
<th>Shoolpaneshwar</th>
<th>Jambughoda</th>
<th>Ratanmahal</th>
<th>Balsam</th>
<th>Gandhinagar</th>
<th>Ahmedabad</th>
<th>Gir</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years</td>
<td>59</td>
<td>58</td>
<td>58</td>
<td>58</td>
<td>58</td>
<td>58</td>
<td>58</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>No. of series</td>
<td>14(7)</td>
<td>12(6)</td>
<td>12(6)</td>
<td>6(3)</td>
<td>22(11)</td>
<td>6(6)</td>
<td>12(6)</td>
<td>5(5)</td>
<td>12(6)</td>
</tr>
<tr>
<td>Standard</td>
<td>0.24</td>
<td>0.29</td>
<td>0.20</td>
<td>0.19</td>
<td>0.31</td>
<td>0.36</td>
<td>0.35</td>
<td>0.35</td>
<td>0.23</td>
</tr>
<tr>
<td>deviation</td>
<td>(0.15)</td>
<td>(0.15)</td>
<td>(0.15)</td>
<td>(0.15)</td>
<td>(0.12)</td>
<td>(0.23)</td>
<td>(0.19)</td>
<td>(0.23)</td>
<td>(0.24)</td>
</tr>
<tr>
<td>Correlation</td>
<td>0.04</td>
<td>0.049</td>
<td>0.047</td>
<td>0.270</td>
<td>0.108</td>
<td>0.977</td>
<td>0.139</td>
<td>0.015</td>
<td>0.06</td>
</tr>
<tr>
<td>with rainfall</td>
<td>R²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation</td>
<td>0.05</td>
<td>0.003</td>
<td>0.04</td>
<td>0.24</td>
<td>0.453</td>
<td>0.146</td>
<td>0.075</td>
<td>0.105</td>
<td>0.081</td>
</tr>
<tr>
<td>with temperature</td>
<td>R²</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ring width so observed were then analysed and correlated with the temperature and precipitation data of the particular place to know the impact of climate on the tree growth. Temperature and rainfall data were available from the Indian Meteorological Department. Correlation coefficients were calculated between ring widths of each tree with the ambient temperature and precipitation respectively. Coefficient of correlation was calculated for seasonal and monthly precipitation, minimum and maximum temperature. Monthly minimum temperature and precipitation significantly influence total ring development (Meldahl et al., 1999).

### Correlation of ring widths with drought events in Gujarat

The tree ring widths of the sample from all the sites were plotted against the year of their formation. The trend in tree ring width size fluctuation was then analysed for all the severe drought years in Gujarat. This analysis was done to study what influence the drought period has on the tree ring formation in various agroclimatic zones of Gujarat.

### RESULT AND DISCUSSION

#### Tree ring analysis of *Tectona grandis*

Teak is a tropical species and found over the entire monsoon belt of south and south-east Asian region. Dendroclimatological studies of teak from India, Myanmar, Thailand, Indonesia (Pant and Borgaonkar, 1983; Bhattacharyya et al., 1992; Murphy and Whetton, 1989; Pumijumnong et al., 1995; Jacoby and D’Arrigo, 1990; D’Arrigo et al., 1994) suggested its suitability to understand the past vagaries of monsoon. In teak, local climate effect is more prominent than the regional or global signals (Ram et al., 2008).

Growth of trees is primarily controlled by the most growth limiting factor; rainfall, in case of teak trees from India. Priya and Bhatt (1999) have demonstrated that the cambial activity of teak is influenced by rainfall. Hence, ring-width variations are expected to show a good correlation with rainfall amount. However, widths of all the samples analyzed in the present study do not show any significant relationship with the amount of rainfall except for the samples from Jambughoda and Ratanmahal. The lack of correlation could be attributed to different reasons. The results of the present study show that *Tectona* trees at most sites do not respond to either temperature or rainfall variations. In a few places however, *Tectona* trees respond to temperature and rainfall albeit with a low sensitivity. The tree ring samples of Purna, Waghai and Shoolpaneshwar show negligible or no correlation with rainfall as well as temperature pattern (Fig- 3-8 respectively). This is because of the fact that they have access to permanent source of ground water for their growth. Another reason is that climate of South Gujarat is moderate, not impacted by temperature extremes and...
drought conditions and the seasonal rainfall always occurs in adequate amounts ranging from 1000-1500 mm. Normal or above normal rainfall is not reflected as a significant higher growth. This is mainly because of moisture available at the root zone of the tree (Ram et al., 2008).

Figure 3: Graph showing correlation between ring width size of Tectona tree and rainfall in Purna, Gujarat

Figure 4: Graph showing correlation between ring width size of Tectona tree and temperature in Purna, Gujarat

Figure 5: Graph showing correlation between ring width size of Tectona tree and rainfall in Waghai, Gujarat

Figure 6: Graph showing correlation between ring width size of Tectona tree and temperature in Waghai, Gujarat

Figure 7: Graph showing correlation between ring width size of Tectona tree and rainfall in Shoolpaneshwar, Gujarat

Figure 8: Graph showing correlation between ring width size of Tectona tree and temperature in Shoolpaneshwar, Gujarat

However a few trees did show significant correlation with their ambient temperature and rainfall data. Jambughoda and Ratanmahal show good correlation with ambient temperature (Fig-10 & 12 respectively). The trees from Balaram, Gandhinagar, Ahmedabad and Gir show a less significant relation with ambient temperature (Fig-14, 16, 18 & 20 respectively). Though the temperature is an important parameter in photosynthesis, the correlation analysis indicates the least effect of direct influence of temperature on tree-ring variations. Higher temperature always accelerates evaporation and evapotranspiration which
creates a severe moisture stress condition causing the below normal growth (narrow rings) (Ram et al., 2008).

Jambughoda, Ratanmahal and Gandhinagar show good correlation with rainfall (Fig-9, 11 & 15 respectively). DíAz et al., (2001) found that the winter rainfall enhances the tree ring growth in comparison to the summer rains in Pine trees of Baja, Mexico. The trees from Balaram and Gir also were related less significantly to ambient rainfall (Fig-13 & 19 respectively), while, Ahmedabad showed negligible correlation with rainfall pattern (Fig-17). Borgaonkar et al., (2007) and Ram et al., (2008), based on analysis of teak trees from central and southern India, demonstrated a significant correlation between ring-width and pre-monsoon and post-monsoon climate and suggested role of a moisture index rather than total rainfall as a major factor controlling ring-width variations. This demonstrates that, depending on the locality, rainfall during some months is more important than the other. In this context, it is important to know whether trees are over-irrigated i.e. rainfall is not a growth limiting factor during the periods of higher intensity rainfall. In the first case soils would be filled up to field capacity and excess water would move to the deeper soil layers while the latter implies more surface runoff. This would partly explain low correlation between total rainfall and ring-width variations.
In addition to the climatic factors, tree growth, and hence ring-width, is also controlled by parameters such as soil quality, age of tree, competition between trees, gravity stress, crown position of tree. Attack by teak defoliator (*H. puera*) is also reported to reduce the growth of teak (*Sudheendrakumar et al.*, 1993).

**Correlation of ring widths with drought events in Gujarat**

The ring width chronologies so obtained were plotted against the total years of their formation and correlated with the major drought years in Gujarat (Fig-21). Droughts occurred in Gujarat in the years 1956, 1985, 1986, 1987, 1998, 1999, 2000, 2001, 2002, 2008 and 2009 (*Parmar et al.*, 2005; *Attri and Tyagi, 2010*) from which drought during the years 1985, 1987, 1998, 2000, 2002, 2008 and 2009 were most severe. The relation of narrow ring width to the drought years is more pronounced in the rings of Central Gujarat (Ratanmahal and Jambughoda), North Gujarat (Balaram, Ahmedabad and Gandhinagar) and South Saurashtra (Gir) while, the tree rings of South Gujarat (Purna, Waghai and Shoolpaneshwar) do not show any relation with the drought years. *Deepak et al.*, (2010) have concluded that
teak has been found to have good potential to know rainfall pattern, mostly the drought years. According to Therrell et al., (2006) typically drought years are better estimated than extremely wet conditions because moisture deficit is normally the most important limiting factor to tree growth. Ram et al., (2008) in his general observations on relationship between the teak ring width variations and climatic parameters revealed that the low growth years (narrow ring) are significantly associated with deficient rainfall (drought condition) in most of the cases. Higher rainfall during any particular year helps in maintaining the normal growth of the tree for the next two-three years even though the rainfall during these years could be less. The reverse process is also true when very less rainfall during any particular year creates moisture stress condition at root zone which may continue in the next one-two years resulting in below normal tree growth in successive years.

CONCLUSION
The results show that Tectona trees at most sites do not respond to either temperature or rainfall variations because they have permanent source of ground water for their growth. In a few places (Ratanmahal and Jambughoda) however, trees respond to temperature and rainfall albeit with a low sensitivity. The Tectona tree ring width of Gir, Ahmedabad, Gandhinagar, Balaram, Ratanmahal and Jambughoda showed good relation to the drought years in Gujarat. The rings formed in these particular years were very narrow in comparison to other years. While the rings formed in the tree samples of South Gujarat showed no relation to the drought years in Gujarat as these areas are not affected by climate extremes such as drought.

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Evaluating temperature and precipitation variability over Gujarat, India from 1957-2007

Aparna Rathore* and Yogesh T Jasrai

ABSTRACT
The anthropogenic activities like industrialization, power production, deforestation, land use changes have all resulted into emissions of excess amounts of the greenhouse gases mainly carbon dioxide (CO₂), nitrous oxide (N₂O), methane (CH₄), water vapour which have disturbed the normal energy balance of the Earth resulting into Enhanced greenhouse effect. This has caused the global mean temperature to rise by about 0.7°C and it is predicted that it will increase by 2.5°C by the year 2100. The rainfall has become more variable and the extreme events like cyclones, tsunamis, droughts, floods, heat and cold waves etc have also increased. All such climatic variability has a direct or indirect impact on the ecosystem involving plants, animals and humans. Climate change is likely to impact all the natural ecosystems as well as socio-economic systems. Climatic variability in terms of changes in temperature and precipitation pattern and their extremity pose a threat to the ecosystem and its services and therefore should be analysed in the past and present scenario to predict the future climate. In this paper past 50 years data of all IMD observatories in Gujarat state of India as obtained from IMD, Pune has been analyzed. The moving averages of maximum temperature during summer season and minimum temperature during winter season have been analysed and a significant increasing trend has been observed. The mean maximum temperature has been found to increase by 0.1°C and the mean maximum temperature has increased by 0.4°C over the past 50 years. Similarly the rainfall has also registered an increase in the past 50 years.

Key words: Gujarat, climate, temperature, precipitation data

INTRODUCTION
Meteorological data compiled over the past century suggests that the earth is warming, but there are significant differences at regional level [13]. Over the last 100 years (1906-2005) the average temperature of the Earth’s surface has risen by 0.74±0.18°C [6,7,17] with two main periods of warming, between 1910 and 1945 and from 1976 onwards [21] and by 0.19°C per decade during 1979-1998 [10]. The rate of warming during the latter period has been approximately double that of the first and, thus, greater than at any other time during the last 1,000 years [21]. The IPCC predicts that, under business-as-usual scenarios mean temperatures worldwide will increase 1.4 to 5.8°C by 2100 as a result of growing GHG concentrations in the atmosphere [10,14]. The surface air temperature over India are going up at the rate of 0.4°C/hundred years particularly during the post monsoon and winter season [1]. Indian subcontinent has been predicted to experience an annual mean surface warming in the range between 3.5 and 5.5°C during 2080s [10].

The monsoons are becoming quite uncertain with periods of droughts and floods. The frequency, intensity and duration of rainfall are also likely to change, with increased production risks, especially in semi-arid and arid rain-fed production areas [9,15]. There are already changes in the monsoon pattern with floods in Maharashtra, Gujarat and Rajasthan and drought in the North-East [2]. India may experience between 5 and 25% decline in winter rainfall leading to droughts in the dry summer months. On the other hand the average summer monsoon over Indian subcontinent is bound to increase by 10-15%. The date of onset of monsoon has also become variable [10,16]. The present paper reports changes in the climatic parameters (temperature and rainfall) in Gujarat over five decades of independent India.

MATERIAL AND METHOD

Study Area
Gujarat is in the extreme West part of India (Figure-1). It has tropical climate, namely sub-humid, arid and semi-arid spread over different regions of the state. North Gujarat region comprising of Kutch, part of Banaskantha, Mehsana and North Western part of Saurashtra have arid climate while the South Gujarat have sub-humid climate and in the rest of the state, semi-arid climate. Temperature varies from 6 to 45°C. Annual rainfall varies from 250 mm in the North-West and to more than 1500 mm in South Gujarat.
Climatic Data
Monthly temperature data (including monthly mean temperature, monthly minimum temperature and monthly maximum temperature), annual average minimum and maximum temperature and seasonal rainfall data for IMD observatories of Gujarat state, India, for the period 1957-2007 has been utilized for the analysis.

Data Analysis
The variability in various temperature parameters for selected observatories of Gujarat with complete climate data from 1957-2007 was studied. Seasonal rainfall data was also analyzed during the above period for various observatories. Thirty years and ten years moving averages [11,12] were also calculated for all parameters in order to deduce the extent of climatic variability in the past fifty years. The climatic data was procured from IMD, Pune.

RESULT AND DISCUSSION
The climatic data for various stations of Gujarat state for Maximum, Minimum and Mean temperature and annual rainfall was analysed. There is a significant and steady increasing trend in the past 50 years (Figure-2). The observed warming was predominantly due to an increase in maximum temperature and also due to a significant increase in minimum temperature during winter season as compared to day temperatures in summer (Figure-3 and 7).

1. Average annual temperature of Gujarat
The differences in average annual temperature revealed increasing trend in temperature during past 50 years (1957–2007) in Gujarat. The average annual temperature of Gujarat during 1957 was 26.8°C, which increased to 27.8°C by 2007, with an increase of about 1°C (Fig-2).

2. Minimum Temperature
The annual average minimum temperature of Gujarat during 1957 was 20.8°C which increased to 22.0°C, which shows an increase in the minimum temperature of Gujarat by about 1.2°C (Fig-3). The annual average minimum temperature for winter months (November, December, January and February) of Gujarat has also increased by 1.28°C over the past 50 years (Fig-4).

Decadal and 30 years moving averages of mean minimum temperature during winter season (November, December, January, February) was also studied for Gujarat state.
In general, a steady increasing trend for annual minimum temperature along with decadal and 30 years moving averages during winter season in Gujarat was observed. The rise of temperature was steady and highly linear. The decadal and the 30 years moving averages of mean minimum temperature during winter season increased over almost all the IMD stations (Bhuj, Kandla, Okha, Rajkot, Anand, Baroda, Bhavnagar and Surat by about 1°C) in Gujarat. However, a constant winter temperature over Ahmedabad, Porbandar and a decrease in winter temperature over Deesa, Idar and Dahod by about 0.3°C was noted. But on an average the decadal and the 30 years moving averages of mean minimum temperature during winter season over Gujarat demonstrated show an increase of 0.4°C (Fig-5 & 6). The results so obtained are in accordance with the earlier work [11,12] where the trend showed a steady increase over the years. In case of moving averages of 10 years the increase was 0.25°C. In general, the temperature rise was found to be highest in Saurashtra and Kutch as compared to North and central Gujarat region.

3. Maximum Temperature

The annual average maximum temperature of Gujarat during 1957 was 32.7°C which increased to 33.4°C, with an increase in the maximum temperature of Gujarat by about 0.7°C (Fig-7). The annual average maximum temperature for summer months (March, April, May and June) of Gujarat exhibited an increase of about 1.2°C over the past 50 years (Fig-8).

Most of the observatories showed a steady increasing trend in mean maximum temperature, decadal and 30 years moving averages during summer season in Gujarat. The decadal and the 30 years moving averages of mean maximum temperature during summer season increased
over almost all the IMD stations (Idar, Okha, Rajkot and Porbander by about 1°C) in Gujarat. In contrast, a constant summer temperature over Bhuj, Ahmedabad, Baroda, Dahod and Bhavnagar and a decrease in summer temperature over Deesa, Anand and Surat by 0.3°C was noted. On an average there was an increase of 0.1°C (Fig-9 & 10) shown by the decadal and 30 years moving averages during summer season over Gujarat. Earlier [11,12] the annual mean maximum temperature was found to have increased by 0.11°C and the rise in normals of annual mean temperatures over Gujarat state was 0.07°C with 10 years averages a rise being 0.3°C for the summer months.

4. Rainfall

Seasonal rainfall for various observatories for over 50 year’s period (1957-2007) was analyzed. The annual average rainfall over Gujarat has increased by about 400 mm over the past 50 years (Fig-11). The rainfall shows a very high variability over Gujarat with an average rainfall of 700 ± 231 mm (Mean ± SD). The standard variation over all the stations varies around 230 to 500 mm.

Decadal as well as 30 years moving averages of seasonal rainfall indicate an increase in rainfall normals for all the stations except for Dahod. The decadal moving average of seasonal rainfall shows that the rainfall increased by 116 mm over Gujarat as a whole (Fig-12 & 13).
The coefficient of correlation and regression analysis of 30 years moving averages of seasonal rainfall was done which showed positive linear correlation but the coefficient of regression for Gujarat was, \( R^2 = 0.058 \) (Fig-13). According to other findings Inspite of high year to year variation and high interstate variation the seasonal rainfall normals showed an increasing trend over Gujarat [12].

4.1. August Shift

The rainfall data was also analysed for shift in the beginning of rainfall and shift in the rainfall month for a period of 50 years (1957-2007). The rainfall in Gujarat follows a normal trend of getting initiated from mid-June. The maximum rainfall occurs in the month of July and August even till date. Initially since the 1957 the maximum rainfall occurred in the month of July (225 mm) followed by August (138), but since 1987 there was a steep decline in the amount of July rainfall (56 mm) and started increasing in the month of August (89 mm) and by 2007 it was more in the month of August (436) followed by July (350) (Fig-14). Study by Vedwan & Rhoades (2001) reported a shift in the distribution of rain across time and slight displacement of monsoon rains to the period beyond mid-August [20]. Maikhuri et al. (2003) also recorded the climate changes felt in the recent decades in the form of shift in peak rainfall time from July/August to August/September and winter precipitation from December/January to January/February, increase in frequency of cloud-burst and warming [8]. This rainfall shift has also been supported by the report of Guhathakurta and Rajeevan (2006) where in they have found that the contribution of June, July and September rainfall to annual rainfall is decreasing for few subdivisions while contribution of August rainfall is increasing in few other subdivisions in India [5].

4.2. Declining winter rains

The rainfall data was also analysed for the trend in winter rainfall pattern in Gujarat for the past 50 years (1957-2007). The winter rainfall which was found to occur in the months of November, December, January and February in Gujarat shows a diminishing trend. The winter rainfalls were at peak in 1960s, which declined in 1970s followed by further decline in 1980s and were shown to diminish in the 1990s as per the data analysed (Fig-15).

Inspite of declining winter rains, decrease in the number of rainy days and rainfall period the rainfall across Gujarat has increased as shown by the data analysed. This proves the fact that the intensity of rainfall has increased and the overall average rainfall of an area is compensated and occurs within a short period of the rainfall season.

CONCLUSION

Annual variation in temperature and rainfall was analysed for Gujarat during the period of 1957-2007. The differences in average annual temperature reveal increasing trend in temperature during past 50 years (1957–2007). The average annual temperature of Gujarat has increased by about 1°C,
the mean minimum temperature by about 1.2°C and the mean maximum temperature by about 0.7°C in the last 50 years.

The increase in the decadal and the 30 years moving averages of mean maximum temperature during summer temperature over Gujarat was only 0.1°C. While, the increase in decadal and the 30 years moving averages of mean minimum temperature during winter season was 0.4°C.

The rise in minimum temperature during winter season was found to be higher (more than double) than the rise in maximum temperature in summer season.

The annual rainfall over Gujarat has increased. The rainfall was found to increase most in the Saurashtra followed by South Gujarat and was normal in Central Gujarat, North Gujarat and Kutchh. From the data analysed it was also found that the rainfall which occurred more in the month of July is now occurring in the month of August. It was also found that the winter rainfall which was prominent in the 1960s has now diminished and period of rainfall has reduced. Inspite of all these the rainfall over Gujarat has increased as the intensity of rainfall has increased. So, it can be concluded that temperature and rainfall have both increased during the past 50 years (1957-2007).

It is worthwhile to note that the developmental activities in Gujarat are tremendous with many fold increase in vehicular traffic, road connectivity, commercial and housing projects, industrial expansion and city limits.

Extensive plantations, urban forestry, clean-green technologies with sustainable development and much reduced carbon footprint is the need of the hour for limiting the temperature variability.

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AIR POLLUTION, CLIMATE CHANGE AND MITIGATION STRATEGIES: A REVIEW

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ABSTRACT
Air pollution is the addition of unwanted component of gases and particles into the atmosphere by human activities like burning of fossil fuels, industrial pollution etc and natural phenomenon like volcanic eruptions, forest fires, etc. All these activities release harmful gaseous and particulate components like CO₂, CH₄, CO, N₂O, SO₂, dust, soot etc into the atmosphere. The major gaseous components of CO₂, CH₄, N₂O, etc contribute to the phenomenon called as Greenhouse effect, leading to Global warming. The global warming leads to rising temperatures, melting ice caps, climatic variability contributing to Climate change. This review basically deals with air pollution, its causes, types, air pollution as major cause of climate change, its impacts and mitigation strategies to reduce air pollution and simultaneous climate change.

Key words: Air pollution, climate change, greenhouse gases, global warming, mitigation strategies.
INTRODUCTION

Atmosphere is a complex system of gases and suspended particles. However, the composition of the atmosphere keeps on changing and hence, its structure is variable in time and space. The atmosphere is mainly composed of gases like nitrogen (N₂) (78.8%), oxygen (O₂) (20.95%), argon (0.93%), and other trace gases like carbon dioxide (CO₂) (387ppm), methane (CH₄) (2ppm), nitrous oxide (N₂O) (0.3ppm), water vapour etc. Pollution is the presence of undesirable substance in any segment of the environment, primarily due to human activity discharging by products, waste products or harmful secondary products, which are harmful to man and other organisms. Air pollution is the addition of unwanted component of gases and particles into the atmosphere by human activities like burning of fossil fuels, industrial pollution etc. and also some natural phenomenon like volcanic eruptions, forest fires, etc (1). All these activities release harmful gaseous and particulate components like CO₂, CH₄, CO, N₂O, SO₂, dust, soot etc. into the atmosphere hence polluting it. The changes that are occurring now have their origin in the industrial revolution.

Air pollution results due to both natural as well as anthropogenic causes. Natural causes like volcanic eruptions, dust from dust storms, wild forest fires and pollens released by the plants, spores of the fungi, bacteria and viruses suspended in the atmosphere and death and decomposition of organic matter. Anthropogenic causes include the activities of the man like deforestation, modern agricultural practices, industrial activities etc (27).

Types of air pollution

Air pollution can be of various types on the basis of their sources.
1. **Vehicular air pollution**: The internal combustion engine contributes to the air pollution by exhaust like carbon monoxide, unburnt hydrocarbons, nitrogen oxides, sulphur oxides, lead compounds, smoke, particulates and odour. Baumert et al. (2005) in their global survey of the emissions from the transportation have estimated that GHG emissions from the transport sector account for 14% of total GHG emissions, with domestic and international road transport contributing 72%, domestic and international air transport 11%, international marine transport 8% and others 8% (4).

2. **Industrial air pollution**: Among the various categories of industries nine prominent groups of industries are considered to be the major pollutant generating industries (1) (Table 1).

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Industries</th>
<th>Pollutants released</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Steel mill</td>
<td>Particulates, smoke, CO, fluoride</td>
</tr>
<tr>
<td>2</td>
<td>Petroleum refinery</td>
<td>SO$_2$, hydrocarbon smoke, particulates and odour</td>
</tr>
<tr>
<td>3</td>
<td>Acid plant</td>
<td>SO$_2$, acid mist</td>
</tr>
<tr>
<td>4</td>
<td>Paper mill</td>
<td>SO$_2$, particulates, odour</td>
</tr>
<tr>
<td>5</td>
<td>Soap and detergent plant</td>
<td>Particulates and odour</td>
</tr>
<tr>
<td>6</td>
<td>Fertilizer plant</td>
<td>Particulates, ammonia, SO$_2$, NO$_x$, fluoride</td>
</tr>
<tr>
<td>7</td>
<td>Cement plant</td>
<td>Cement dust, SO$_2$, smoke</td>
</tr>
<tr>
<td>8</td>
<td>Thermal power plant</td>
<td>NO$_x$, SO$_2$, particulates</td>
</tr>
<tr>
<td>9</td>
<td>Metal smelter</td>
<td>SO$_2$, NO$_x$, particulates, smoke</td>
</tr>
</tbody>
</table>

3. **Air pollution due to agricultural activities**: Agriculture contributes to about 60% of the N$_2$O, 40% of the CH$_4$ and 1% of CO$_2$ of the total GHG emissions. The main
Contributors of the air pollution due to agriculture are application of chemicals, use of tractors, the operation of water pumps, burning of dead plant parts, livestock management, shifting cultivation by clearing and burning forest (25) (Fig. 1).

![Pie chart showing emissions from agricultural sector]

**Fig-1: Emissions from agricultural sector (25).**

4. **Biological air pollution:** Biological air pollution results from the natural causes of pollens and spores leading to allergies and asthma, wild fires, melting permafrost releasing CH\(_4\) and volcanic eruptions adds CO\(_2\), CH\(_4\), SO\(_2\), smoke, soot etc to the atmosphere (10). The correlation between the CO\(_2\) fluxes of the atmosphere–land and atmosphere–ocean are dependent on the climatic conditions. Bousquet et al. (2000) proposed that the amount of CO\(_2\) in the atmosphere varies with the El Niño–Southern Oscillation (11,12,13,14).

5. **Domestic air pollution:** The domestic pollution results due to use of the aerosols, CFCs and HFCs releasing electric products and smoking. Pollution also occurs from fuels like coal, fuel wood, kerosene and other biomass fuels used for cooking in urban and rural areas (23).
India and air pollution

In a study conducted in 2010 by 80 scientists from 17 institutes confirmed on that India is the world's fifth-biggest polluter with more than 3% increase in its greenhouse gas emissions annually from 1994 to 2007 which has been attributed to the rapid industrialization, urbanization and vehicular growth (26). India ranked 101 in 2005 according to the Environmental Sustainability Index among 146 countries on the basis of its air quality (26).

Population: India is very mysterious in terms of population dynamics as it supports 15% of the global population having only 2.4% of the world's land area. The present population of India is around 1.15 billion and stands next only to China. It is estimated that by 2030, the population of India will be largest in the world. Population of India at the time of Independence was only 350 million and since then it has increased more than three times. The present rate of increase in population is 21.34% which was earlier as much as 30-35% (Fig-3) (27).

![Population of India in billions since independence](image)

Fig-3: The rapid increase in the population of India since independence (27).

Industries: Industrial pollution has quadrupled in the past 20 years. The carbon emissions in India have increased nine times over the past 40 years due to use of coal
as the major energy source (26). IIT Delhi and Central Pollution Control Board (CPCB) have shown 10 industrial centers, Ankleshwar and Vapi in Gujarat, Ghaziabad and Singrauli in Uttar Pradesh, Korba in Chhattisgarh, Chandrapur in Maharashtra, Ludhiana in Punjab, Vellore in Tamil Nadu, Bhiwandi in Rajasthan and Angul Talcher in Orissa to be causing maximum environmental pollution (26).

**Vehicles:** In India, the vehicular population is growing at a rate of 5% per annum and today the vehicle population is approximately 40 million with the two-wheelers accounting for a share of 76% of the total vehicular population (23,24,29). 70% of the country’s air pollution result due to the vehicular emissions. There has been an eight time increase in the vehicular exhausts over the last 20 years (26).

![Fig-2: The increase in the vehicular population in India since 1950 (23).](image)

**Impact of air pollution**

The most important impact of air pollution is that it increases the level of GHGs to exceed the optimum limit and causes enhanced greenhouse effect leading to global warming. Other than this it is hazardous to health of plants and animals. Exposure to particulate matter from combustion-related sources can aggravate chronic respiratory (asbestosis, silicosis and bronchitis) and cardiovascular diseases, alter host defenses,
damage lung tissue, lead to premature death and possibly contribute to cancer. In addition, changes in green plant distribution or pollen production could affect the timing of hay fever and other seasonal allergies. The air pollution also impacts the plants and causes chlorosis, necrosis, bleaching and bronzing. The animals are also influenced by the air pollution which results in suffering due to lung infections and other diseases (10). Sulfur dioxide, nitrogen dioxide and ozone cause a decrease in crop yield, acidification of lakes, damage to certain metals and monuments by acid rain. The Taj Mahal, Agra is turning yellow due to the oxidation of the CaCO$_3$ (limestone/calcium carbonate) reacting with other noxious chemicals. It also causes acidification and eutrophication of soil, lakes, pond etc damaging the fisheries and affecting animal and human health (23).

Air pollution causing climate change
Climate system is a complex interactive system consisting of atmosphere, land surface, snow and ice, oceans and other water bodies or in other words a climate system is an interactive system comprising of the atmosphere, lithosphere, cryosphere and hydrosphere. Climate change refers to a statistically significant change in either the mean state of the climate or in its variability (in terms of temperature, atmospheric pressure, precipitation status etc.) persisting for an extending period (typically decades or longer) (19). Climate change results due to both natural and anthropogenic causes.

Natural causes: The contribution of plants, animals, and humans naturally to global warming by respiration and also due to their death and decomposition come under this category. A significant part of the earth’s climate variability is also caused by changes in the solar emissions, which are due to changes in the sun-earth geometry (Milankovitch cycles). The volcanic eruptions liberate a huge amount of smoke and contribute in increasing the global temperature. Simultaneously, contradictory to the fact that the sulphur oxides so released has a high albedo and hence cools the Earth by reflecting
the solar radiations. The 1991 volcanic eruption of Mount Pinatubo in Philippines had released 20 million tons of SO$_2$ into the atmosphere cooling the Earth by 1°F (0.33°C) (15,28).

**Anthropogenic causes:** The human activities imparting a negative impact on the existing climate resulting in climate change are included under this category (Fig-5). It involves *Industrialization* which contributes about 19.4% of the total GHG emission (3). *Deforestation* contributes to 17.4% of the total GHGs emissions (3) released into the atmosphere each year which is more than from planes, trains and automobiles (33). *Transportation* accounts for 13.1% of the total GHGs emissions (3,22,23). *Urbanization* is responsible for 7.9% of the total GHGs emission (3). *Agricultural practices* contribute about 13.5% in the total emission of the GHGs (3). *Energy supply* sector is the major contributor of GHGs to the atmosphere contributing to 25.9% of the total emissions (3) as a result of power generation by coal burning (26).

![Fig-5: The percent GHGs emissions by the various sectors (3).](image)

**Greenhouse gases from air pollution**
The main natural greenhouse gases are CO$_2$, CH$_4$, N$_2$O, water vapour (H$_2$O), and ozone (O$_3$) (1). Further human activities in recent decades have also added HFCs (hydrofluorocarbons).

[Fig-3: Global Emissions of GHGs (3).]

Carbon dioxide (77%), nitrous oxide (8%), and methane (14%) are the three main greenhouse gases along with 1.1% of the fluoro gases that trap infrared radiation and contribute to climate change (3,5,6,7,17) (Fig-2). The earth’s global temperature in the past years has increased due to an increase in the greenhouse gas concentrations, hence causing what is called as Global warming (1,2).

Another pollutant ‘black carbon’ a product of incomplete combustion of fossil fuels and biofuels causes global warming by darkening the surface of ice and snow by getting deposited on them. It has been revealed that black carbon on snow warms earth three times more than that by carbon dioxide (8). The CO$_2$ levels in the pre-industrial time were only 270 ppm which increased to 385 ppm in 2009. In the last four hundred thousand years, the amount of CO$_2$ concentration has never been larger than 290 ppm.
The speed with which it is increasing clearly states that human influence is the cause (20).

**Global warming potential of the greenhouse gases**
Global warming potential (GWP) may be defined as a gas’s heat-trapping power relative to CO$_2$ over a particular time period. Global warming potential allows the observers to compare the contribution to global warming made by various greenhouse gases that have a varying warming effects and life spans (Table-2) (3).

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Greenhouse gases</th>
<th>Global warming potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carbon dioxide, CO$_2$</td>
<td>1 (=100 years)</td>
</tr>
<tr>
<td>2</td>
<td>Methane, CH$_4$</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>Nitrous oxide, N$_2$O</td>
<td>298</td>
</tr>
<tr>
<td>4</td>
<td>Hydro fluoro carbons, HFCs</td>
<td>124 – 14,800</td>
</tr>
<tr>
<td>5</td>
<td>Per fluoro carbons, PFCs</td>
<td>7,390 – 12,200</td>
</tr>
<tr>
<td>6</td>
<td>Sulphur hexa fluoride, SF$_6$</td>
<td>22,800</td>
</tr>
</tbody>
</table>

**Impacts of climate change**
The GHG emissions have increased by 70% from 1970 to 2005 due to which the global temperature has risen by about 0.74°C from 1906-2005 (9). The change in hydrological cycle and ENSO (El Nino Southern Oscillation) (23) is impacting the monsoon circulation and resulting in extreme events like floods and droughts. The general circulation models have predicted that if the atmospheric concentration of carbon dioxide doubles, the mean annual temperature may increase from about 2 to 4.5°C. The rise in temperature at higher latitudes will be greater than at low latitudes and that the
temperature changes will be greater in winter than in summer (9, 15). The rise in
temperature is leading to melting of the glaciers and ice caps and also thermal
expansion of water which has resulted in a sea level rise of 1.8mm/year from 1961-
2003, but from 1993-2003 this pace has almost doubled (9). This is resulting into the
salinity ingress and also the submergence of the low lying areas and islands. Around 2
million square km of the permafrost has declined by the year 2000. An increase in the
incidence of heat waves, thunderstorms, cyclones, hurricanes etc have also been
registered (9). The Scientists believe that global warming resulting in a rise in the
temperature, will lead to cooling of the stratosphere along with the ozone leading to a
slow pace of ozone hole repairing (32). Crop and rice yields have declined owing to
GHG and air pollution (21). The desertification will increase (9). There will be water
crises and the human health is also going to suffer due to an increase in the tropical
diseases like vector borne diseases (malaria, dengue, chikangunia), rodent borne
diseases, water borne disease (cholera, diarrhoea, dysentery) (10).

Controlling air pollution
Air pollution can be reduced either by switching over to renewable sources for energy
generation which will lead to energy efficiency and would reduce emissions of GHGs to
100%. India has established small hydropower projects of 1,423 MW capacity. The
photovoltaic (PV) system using solar energy is being used for rural electrification,
railway signaling, microwave repeaters, solar lanterns, home and street-lighting
systems, standalone power plants, pumping systems, power to border outposts and TV
transmission and reception. Until now 9,20,000 Solar PV systems, with a total capacity
of 82 MWp have been established in India. India stands fifth in the world in wind power
generation with a total capacity of 1,507 MW (9).
By using efficient fuels like biofuels, substituting coal and petrol by natural gas and by installing mechanical devices by the industries to reduce particulate pollutants (by gravity settling chambers, cyclone collector, dynamic precipitators, spray towers) and to reduce gaseous pollutants (by spray/packed towers and venturi scrubbers with absorbent like activated alumina, silica gel, activated carbon) (1).

Air pollution control for automobiles can suitably be done by installing catalytic convertors, diesel particulate filter and also changing fuel quality. According to a report of RCEP (2000) increasing the fuel prices has lead to the energy savings as in case of UK where a 10% increase in fuel price lead to decrease in the vehicular consumption of the fuel by 6% (16,17,18). PCRA (Petroleum Conservation Research Association) has been established to increase awareness and to develop fuel-efficient equipments (9).

Comparison of fuels supports biofuels to be most efficient (Table-4) (33). Introduction of BRTS (Bus Rapid Transport System) in Ahmedabad, Gujarat is another major initiative to combat climate change.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Carbon content (kg C/kg fuel)</th>
<th>Energy content (kWh/kg fuel)</th>
<th>CO₂ emissions (kgCO₂/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>0.9</td>
<td>12.5</td>
<td>0.27</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.86</td>
<td>11.8</td>
<td>0.24</td>
</tr>
<tr>
<td>LPG-Liquefied Petroleum Gas</td>
<td>0.82</td>
<td>12.3</td>
<td>0.24</td>
</tr>
<tr>
<td>Natural gas</td>
<td>0.75</td>
<td>12</td>
<td>0.23</td>
</tr>
<tr>
<td>Bioenergy</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The government of India has formulated a number of legislations, policies, and programmes for protecting the environment. Some of them related to air pollution are
the Air (Prevention and control of pollution) Act, 1981 and the Environment (Protection) Act, 1986. Ambient air quality standards (both short term for 24 hours and long-term for a year) have been put forward for industrial, urban and other sensitive areas with respect to pollutants such as SO\textsubscript{2}, NO\textsubscript{X}, SPM (Suspended Particulate Matter), RPM (Respiratory Particulate Matter), Pb (lead), CO (Carbon mono-oxide) and NH\textsubscript{3} (ammonia). Environmental impact assessment (EIA) of the various industries and SEZ (Special Economic Zone) is done prior to its establishment (23).

Increasing the plantation of fast growing trees help improve environmental condition by acting as lungs of the city purifying the air (31) as some trees act as sinks of air pollutants like SO\textsubscript{2}, N\textsubscript{2}O, CO and O\textsubscript{3} (30).

**Global warming mitigation strategies**

Global warming mitigation involves reducing the intensity of radiative forcings so as to reduce the effect of global warming and it can be made possible by two aspects; Geo-engineering and Carbon sequestration. Geo-engineering are the proposals to manipulate the earth’s climate so as to decrease the impact of global warming from the greenhouse gas emission. It comprises of a) sulphur dioxide spraying in the atmosphere to cool the earth; b) establishment of artificial trees to suck in excess of CO\textsubscript{2}; c) cloud seeding ships; d) iron fertilization of the oceans; e) limestone fertilization of the oceans; f) space mirror in the space to reflect sun rays (2, 28).

Another technology comprises of the various methods of carbon sequestration. Carbon dioxide emissions can be captured and stored in underground geologic formations, helping in lowering the severity of climate change. Carbon Capture and Storage (CCS) technologies are already in use widely in industries producing fertilizers, hydrogen and in natural gas processing (10). The world’s largest plant for geological CO\textsubscript{2} sequestration has been established as Otway project in Australia. The oldest CCS plant
in the world to store CO\textsubscript{2} on industrial scale is Sleipner gas field in Norway. The carbon capture and storage technology is also being implemented in the Badarpur power plant, Delhi (9,10).

The National Action Plan of India on Climate Change as released in Delhi (2009) involves eight missions; national solar mission, national mission for enhanced energy efficiency, national mission on sustainable habitat, national water mission, national mission for sustaining the Himalayan ecosystem, national mission for a Green India through massive tree plantation, national mission for sustainable agriculture and national mission on strategic knowledge for climate change by establishing a knowledge platform on climate change (9). Successful implementation of all these plans would surely help reduce global warming.

**CONCLUSION**

Air pollution and climate change are thus correlated. An increase in the practices like large scale industrialization, deforestation, urbanization, changing agricultural practices and other human practices add to air pollution. Air pollution enhance the level of greenhouse gases in the atmosphere resulting in global warming which simultaneously causes climate change owing to the changes in the variability in the temperature ranges, precipitation levels and increasing number of cyclones, hurricanes, heat spells, cold waves, droughts and floods. Reducing the level of air pollution at the grass root level by cutting off industrial and vehicular emissions will surely bring down the levels of greenhouse gases in the atmosphere and thus make earth a better place to live in.

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