Chapter 1

Introduction
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Introduction

Our planet has been witnessing the most profound changes in the brief history of human species. These changes are manifested in terms of climate change, environmental degradation, loss of biodiversity etc., thereby, threatening the very existence of this planet. Among these, climate change has been attributed to the emissions arising from combustion of fossil fuels in thermal power plants, industries and transport sector and also from agriculture and biomass burning (Press 1989). The biomass burning is an uncontrolled combustion process that is inexpensive, widespread and commonly practiced to clear the land (Ryu et al., 2004). The biomass burning has also been a common practice in colder environment for warming the living room and as a fuel in the developing countries. Although the burning of biomass is widespread across the world, it is especially prevalent in the low latitude zones (Crutzen et al., 1990). Some of the locations of biomass burning are tropical forests (Brazil, Indonesia, Colombia, Ivory Coast, Thailand, Laos, Nigeria, Philippines, Burma, and Peru), temperate forests (U.S. and Europe), boreal forests (Alaska, Canada, Siberia, and China), savanna grasslands (Africa) and agricultural field after the harvest (U.S. and Europe). In India, biomass is burnt on large scale especially in the Indo-Gangatic plane in the form of agricultural wastes or crop residues like rice straw, wheat straw and sugar cane husk (Gupta et al., 2004, Badrinath et al., 2006, Punia et al., 2008). In addition, northeastern region of India is also characterized as the region of biomass burning (Habib et al., 2006).

Biomass, the term, is generally used to include phytomass or plant biomass and zoo-mass or animal biomass. Solar energy, when intercepted by plants, is converted into chemical energy by the process of photosynthesis and is fixed or stored in the form of terrestrial and aquatic vegetation. The vegetation when grazed (used as food) by animals gets converted into zoo-mass (animal biomass) and excreta. The excreta from terrestrial animals, especially dairy animals, can be used as a source of energy, while the excreta from aquatic animals gets dispersed as it is not possible to collect and process it for energy production. Further, the agricultural by-products (crop residues) that are part of phytomass are also either burnt on a large scale immediately after the harvesting or used as the source of energy later on. The biomass burning is either initiated by human beings or by natural
events. It is generally believed that more than 90% of biomass burning is initiated by human beings (www.science.larc.gov.in) and this biomass burning has increased significantly over the last century (Mittal et al., 2009). It has been estimated that out of 5613 Tg of dry mass of biomass burnt in year 2000 globally, 2814 Tg of dry mass was attributed to open burning and the rest with bio-fuels (Ito et al., 2004).

[1.1] Crop Residue Burning

After harvesting, the crop residues are burnt in situ by the farmers to speed up the crop rotation. This burning of residues also releases nutrients for the next growing season as the ashes of crop straw contains potassium (Gangwar et al., 2006, Yang et al., 2006). Therefore, the burning of crop residue adds to the fertility of the soil because of the high mineral contents of the ashes. This also controls insects, diseases, and the emergence of invasive weed species. The remaining uncollected crop residues not burnt in the field is subsequently ploughed into the soil. It also serves as a fertilizer for the next cropping season. The anaerobic decomposition of residues in soil directly affects the amount of methane released from the process. Although the soil incorporation of rice straw provides a source of nutrients for the next crop, it has also shown to be conducive to crop diseases (Hrynchuk, 1998). This is one of the reasons why open field burning is often practiced by the farmers for disposal of crop residues.

However, Gupta et al., (2004) pointed out that residue burning causes nutrient and resource loss and adversely affects soil properties. The crop residue burning also affects the pedology. The heat from burning crop residue can penetrate into the soil up to 1 cm, elevating the temperature as high as 33.8–42.2°C. About 32–76% of the straw weight and 27–73% of nitrogen are lost in burning (Hobbs et al., 2002). Bacterial and fungal populations are decreased immediately and substantially only in the top 2.5 cm of the soil upon burning. Repeated burning in the field permanently diminishes the bacterial population by more than 50%, but fungi appear to recover and also decrease soil respiration. Long-term burning reduces total nitrogen and carbon, and potentially mineralized nitrogen in the 0–15 cm soil layer (Biedrbeck 1980).

Thus, the crop residue management is posing a serious problem in the rural areas. The pattern of agriculture has changed now to mechanized and intensive farming from traditional. Practice of intensive farming results in multiple cropping patterns that generate
the exhaustive residues and deplete the soil nutrient contents heavily; e.g. a rice–wheat sequence that yields 7 tons/ha of rice and 4 tons/ha of wheat removes more than 300 kg/ha Nitrogen (N), 30 kg/ha Phosphorus (P) and 300 kg/ha Potassium (K) from the soil (Singh 2003). Though little is known about the effect of burning on nutrient loss and dynamics in the rice and wheat cropping pattern, it has been reported that 40–80% of the Nitrogen is lost as ammonia when wheat crop residue is burnt in the field (Samara et al., 2003). In United Kingdom, it has been observed that the emission of ammonia declined from 20 Giga gm (Gg) N per year in 1981 to 3.3 Gg N per year in 1991, pertaining to imposed ban on the burning of crop residue (Samara et al., 2003). According to them, for every ton of wheat residue burnt, 2.4 kg of N was lost in New Zealand. Likewise, sulphur (S) losses from the burning of high S and low S rice-crop residues in Australia were found 60% and 40% of its content respectively (Lefroy et al., 1994). About 25% of N and P, 50% of S and 75% of K uptake by cereal crops are retained in crop residues, making them viable nutrient sources (Singh 2003). Therefore crop residues are a good source of plant nutrients and are important components for the stability of the agricultural ecosystem. However the burning of crop residues may lead to considerable nutrient loss. Despite the obvious economic and practical benefits of the burning of crop residues, the environmental and health impact of this activity remains uncertain (Hays et al., 2005).

The agricultural practices in India have also experienced significant increasing level of farm mechanization over the last 25 years (Badrinath et al., 2006) that has increased grain production and hence crop residues. As per common agricultural practices in India, crop residues are left standing in the field after harvesting. The residues generated are utilized mainly as industrial/domestic fuel, fodder for animals, packaging, bedding, wall construction, roofing, household heating, green manuring, thatching etc. and the rest is allowed for open burning in the field only. However, in case of combine harvesting almost all the residues generated are left in the field that finally ends up into open burning. The amount of residues left over for burning and other uses differ from crop to crop and are directly related to the yield obtained. For every 4 tons of rice or wheat grain, about 6 tons of straw is produced (Thakur, 2003). In northern India, wheat straw is preferred for fodder while in South India rice straw is fed to livestock (Thakur, 2003). In India too, the crop residues are usually burnt to enable tillage and seeding machinery to work effectively. It is difficult to estimate the quantity of residue used for different uses, which varies largely from year to year and region to region and is therefore characterized by great uncertainty.
The burning of crop residues reduces the availability of straw to livestock, which is already in short supply by more than 40% in India (Thakur, 2003). Around 25 percent of the crop residues generated during the cultivation is burnt in the agricultural fields in India (Reddy et al., 2002). The total agricultural residue production in India in year 2000 was 347 million tons, of which rice and wheat straw accounted for more than 200 million tons (Thakur, 2003) but according to Sarkar et al., (1999), the wheat and paddy cultivation accounts for nearly one-fourth of the crop residues production in India. The major contributing states are Uttar Pradesh, Madhya Pradesh, Punjab, Bihar, Maharashtra, Haryana, Gujarat, and HP. The crop residue generated from wheat and paddy cultivation in 1994 from these states is about 133 million tons (Thakur, 2003). The detailed state-wise generation of rice and wheat crop residue is given in the table 1.1.

Table 1.1(a): Rice and wheat crop production and residue generation from major states in 1994 (Gg)

<table>
<thead>
<tr>
<th>State</th>
<th>Rice Production</th>
<th>Rice Residue</th>
<th>Wheat Production</th>
<th>Wheat Residue</th>
<th>Total Production</th>
<th>Total Residue</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP</td>
<td>10326</td>
<td>13284</td>
<td>22126</td>
<td>33189</td>
<td>32452</td>
<td>46473</td>
</tr>
<tr>
<td>Punjab</td>
<td>7688</td>
<td>9890</td>
<td>13501</td>
<td>20251</td>
<td>21189</td>
<td>30141</td>
</tr>
<tr>
<td>MP</td>
<td>6308</td>
<td>8115</td>
<td>7151</td>
<td>10727</td>
<td>13459</td>
<td>18842</td>
</tr>
<tr>
<td>Bihar</td>
<td>6251</td>
<td>8051</td>
<td>4296</td>
<td>6443</td>
<td>10547</td>
<td>14484</td>
</tr>
<tr>
<td>Haryana</td>
<td>2185</td>
<td>2810</td>
<td>7285</td>
<td>19928</td>
<td>9470</td>
<td>13738</td>
</tr>
<tr>
<td>Maharashtra</td>
<td>2419</td>
<td>3112</td>
<td>1097</td>
<td>1646</td>
<td>3516</td>
<td>4758</td>
</tr>
<tr>
<td>Gujrat</td>
<td>916</td>
<td>1179</td>
<td>1704</td>
<td>2555</td>
<td>2620</td>
<td>3734</td>
</tr>
<tr>
<td>HP</td>
<td>110</td>
<td>141</td>
<td>553</td>
<td>829</td>
<td>663</td>
<td>970</td>
</tr>
<tr>
<td>All India</td>
<td>81435</td>
<td>88474</td>
<td>64285</td>
<td>96428</td>
<td>1457720</td>
<td>184902</td>
</tr>
</tbody>
</table>

In the year 2000, about 78 million tons dry rice and 85 million tons wheat straw were generated in India, out of which about 17 million tons and 19 million tons respectively may end up in open field-burning (Gupta et al., 2003). As far as total biomass consumption in India is concerned, bio-fuels accounts for 93 percent and forest fires contributing only 7 percent (Reddy et al., 2002). In bio-fuel segment, about 281 million tons (Mt) of fuel-wood, 62 Mt of dung-cakes, 36 Mt of agricultural residues and 39 Mt of forest biomass were consumed annually as the traditional bio-fuels and about 70–80 %
energy requirement in rural India is met by combustion of these traditional bio-fuels (Parashar et al., 2005, Venkataraman et al., 2006, Reddy et al., 2002). The national average of bio-fuel mix is 56%, 21% and 23% of fuel-wood, crop waste and dung-cake respectively (Reddy et al., 2002). According to Sixth Five Year Plan (1980-85), India, about 1000 million tons of organic waste in the form of crop residue and about 300 to 400 million tons of animal excreta are available annually. It is estimated that if all these materials are utilized, about 70,000 millions cubic meters of methane gas equivalent to about 160 millions of tons of fuel-wood can be produced. This can meet nearly 50% of the rural domestic fuel requirements of the country. This total biomass might yield approximately 6 millions tons of nitrogen, 2.5 millions tons of potassium and 50 millions tons of compost fertilizer.

Agriculture is the basis of sustainability in India, particularly in rural India. As per as agricultural activities are concerned, the following are the major contributors to the atmospheric aerosols:

(a) Tillage operations (that prepare the farm for planting) expose the base soil to possible erosion which adds soil particles to the atmosphere by the wind.

(b) During the crop growth, pesticides (commonly used to control the pests, weeds etc.) and allergic pollens (from plant that spread to the atmosphere) add aerosols to the ambient air.

(c) Thrashing of crops adds fine trash to the lower part of the atmosphere, which ultimately reduces the visibility in surrounding areas and also creates respiratory problems to the farmers working in the field.

(d) After cultivation, bare field is allowed for cattle grazing which results in loosening the upper profile of soil and finer particles are carried away by wind to the atmosphere.

(d) Burning of stubbles, crop residues, weeds, bushes etc. that affect the air quality of surrounding areas which is later transformed into regional haze.

The burning of crop residues is associated with conversion of ligneous bio-mass to the fire. In recent years, the area under the open burning of crop residues has significantly increased. The agricultural wastes burning periods are often characterized by smoke hanging above and near the farmland. This is particularly noticeable when there is a temperature inversion aloft, preventing the smoke from dissipating upwards. Therefore, the agricultural waste burning is important in the harvesting season as it causes the
emissions of the harmful air pollutants, including gases and particulates matter to the atmosphere, which can cause severe impacts on human health along with regional and global climate change (Lemieux et al., 2004).

[1.2] Impact of Biomass Burning on Climate

The impact of biomass burning on air pollution and climate has been recognized in the late 1970s (Langmann et al., 2009). The biomass burning is a significant global source of greenhouse gases (carbon dioxide and methane, etc.), chemically active gases (nitric oxide, carbon monoxide, hydrocarbons and methyl bromide) and atmospheric aerosols that can substantially influence the atmospheric chemical composition and may modify the weather and climate (Crutzen et al., 1990, Press, 1989, Langmann et al., 2009)). It also affects the bio-geo-chemical cycling of nitrogen and carbon compounds from the soil to the atmosphere, the hydrological cycle, i.e., run off and evaporation, the reflectivity and emissivity of the land, and hence the stability of ecosystems and ecosystem biodiversity etc. Therefore, biomass burning has both short-term and long-term impacts on the environment (Fact Sheet; NASA; 2001-02). Thus, the large amount of particulates and gases, including greenhouse gases emitted from burning biomass to the atmosphere influencing the earth’s atmosphere and global climate. Simmonds et al., (2005) revealed a strong correlation of biomass burning with the emission of CO2, CO, CH4, H2, O3, CH3Cl and aerosols.

Globally, 40% of carbon dioxide, 38% of tropospheric ozone, 39% of particulate organic carbon, and more than 86% of elemental carbon is emitted from the biomass burning (Levine et. al, 1995). The total global emission from the biomass burning are 2290 Tg of carbon per year as CO2, 496 Tg of CO per year, 32.2 Tg CH4 per year, 38 Tg NMHC per year, 11.5 Tg HCHO per year, 9.2 Tg of CH3OH per year, 21.7 Tg CH3COOH per year, and 38.3 Tg of PM2.5 per year (Ito et al., 2004). In Asia, about 0.37 Tg of SO2, 2.8 Tg of NOx, 1100 Tg of CO2, 67 Tg of CO and 3.1 Tg of CH4 are estimated to be released annually from the open burning of the biomass. In which crop residue burning alone contributes about 0.10 Tg of SO2, 0.96 Tg of NOx, 379 Tg of CO2, 23 Tg of CO, and 0.68 Tg of methane (Streets et al., 2003).

The agriculture sector in India contributed 83% of the total methane emissions in 2005; out of which about 10% of methane were emitted from biomass burning. While more than
80% of the total N₂O emissions were coming from agriculture sector out of which about 12% came from agriculture residues burning during the same period (Garg et al., 2006). The field-burning of rice and wheat straw in India resulted the emissions of 102, 2138, 2.2 and 78 Gg of CH₄, CO, N₂O and NOₓ respectively in 1994 that went up to 110, 2306, 2.3 and 84 Gg respectively in 2000 (Gupta et al., 2003, Gupta et al., 2004). In this estimate it was assumed that the one-fourth of the available residue is burnt in the field. According to Ministry of Environment and Forests, rice and wheat straw burning contribute about 1.24% of N₂O and 0.56% of CH₄ in India’s net national emission of N₂O and CH₄ from all the sources in 1994 respectively. Thus, the biomass burning plays a vital role in the regional as well as global climate change. The atmospheric aerosols, in particular, affect the global radiation balance (Lee et al., 2005), climate and hydrologic cycling (Andreae et al., 2001, Kaufman et al., 2002) and visibility (Chan et al., 1999). The two major chemical components of aerosols coming out from biomass burning are black carbon and organic carbon (Reddy et al., 2002, Lethehead et al., 2006). On the global basis, the major source of carbonaceous aerosols is the biomass burning and it is estimated to be 23-27% of total aerosol mass concentration (Sengupta, 2002; Ramanathan, 2001). Black carbon absorbs solar radiation whereas organic carbon scatters the solar radiation. The strongest negative force is associated with regions of intense biomass burning activities and differs from regions where the sulphate radiative force is the strongest. The global annual, mean radiative force caused by biomass burning aerosols is estimated as −0.2 Watt m⁻² (IPCC 2001). The dust particles contained in the smoke of biomass combustion frequently induce spontaneous convection resulting in the production of rain, but this usually evaporates before reaching the ground. The finer smoke particles are eventually widely distributed through the global troposphere; some enter the stratosphere, where they remain suspended for longer duration. In the stratosphere, they serve to scatter incoming short wave radiation, and can thus exert a cooling effect on the planetary temperature.

[1.3] Impact of Biomass Burning on Human Health

Many toxicological and epidemiological studies have established adverse impact of particulates matter and gaseous emission on the human health. The effects of the aerosols that include ultra fine particles, fine particles and coarse particles on the health depend on
their size. There is increasing evidence of several adverse effects of ultra fine particles on health and sometimes it can penetrate the cell membranes and pulmonary alveoli, enter into the blood and even reach the brain ((Brown et. al., 2001; Oberdorster et al., 2004; Yang et. al., 2006). The particulates matter can also induce inheritable mutations (Somers et al., 2004). Smoke, from biomass burning, is particularly dangerous, since most of the particulates are smaller than 10 microns in size (PM$_{10}$), and are easily able to travel deep into lungs and may penetrate the respiratory system beyond the larynx (Curtis et al., 2002). Both long and short-term exposures to ambient levels of particulates matter in the air are associated with respiratory and cardiovascular illness and mortality. People with pre-existing lung and heart disease, the old and the children are particularly sensitive to particulate air pollution (COMEAP 1998). Wu et al., (2006) assessed the personal exposures to PM$_{2.5}$ emitting from agricultural burning smokes for asthmatic adults in Pullman, USA. The average personal exposure to PM$_{2.5}$ was found to be 13.8 µg m$^{-3}$, which was on average 8.00 µg m$^{-3}$ higher during the agricultural burning episodes (19.0 µg m$^{-3}$) than non burning episodes (11.0 µg m$^{-3}$). Thus, the aerosols generated from burning adversely affect the human health especially respiratory system (Schwartz, 1993, Pandey et al., 2005, Mohanraj et al., 2004).

[1.4] Literature Review

One of the earliest significant works on the emission from crop residue burning has been done by Boubel et al., in 1969 titled “Emission from burning grass stubble and straw”. Later on, a number of studies were carried out to evaluate the impact of biomass burning on the ambient air quality. Darley et al., (1974), and Carroll et al., (1977), showed that gaseous and particulates emissions from forest and agricultural burning are affected by the stubble characteristics including straw and crop type as well as moisture content. They found that total particulate emissions (by mass) are directly proportional to moisture content. Dasch, (1982), measured the particulate and gaseous emissions from wood burning and estimated that an average of 10 gm of particulates, 110 gm of CO and 0.7 gm of NO$_2$ is emitted from per kg of wood burning. The emitted particulates were found to be spherical with a mass median diameter of about 0.12 µm. This study also revealed that wood burning accounted for 20-30% of the Denver (USA) wintertime fine particulate load.
Trimble et al., (1984) highlighted the environmental impact of biomass energy which is a renewable, low-sulphur fuel and supposed to be relatively cleaner fuel. They concluded that bio-chemical and thermo-chemical conversion of biomass produced air pollutants including particulates, carbon monoxide, hydrogen sulphide, polycyclic aromatic hydrocarbon (PAH), solid wastes, and wastewater which might adversely impact the environment. Therefore, they favoured the implementation of careful planning and conservation practices and employment of appropriate environmental control technology that will enhance the attractiveness of this renewable resource as a source of energy.

Curtzen et al., (1990) studied the impact of biomass burning on the atmospheric chemistry and biological cycles in the tropics. About 50 percent of the nitrogen in the biomass fuel was found to be released as molecular nitrogen that caused a significant loss of fixed nitrogen in tropical ecosystem, in the range of 10 to 20 Tg per year. According to them, biomass burning containing 2 to 5 Petagram (Pg) of carbon was burnt annually, producing large amounts of trace gases and aerosol particles that played important roles in the atmospheric chemistry and climate.

Andreae (1991) estimated the release of 1.6 Giga tons of carbon per year in the atmosphere just by burning savanna grasslands. If the amount from burning agricultural residues were included, it raised to 2.5 Giga tons of carbon per year that was significant because the fossil fuel burning adds 5.5 Giga tons of carbon per year.

Isermann. K. (1994) discussed the contribution of agricultural activities like fertilization, cultivation and burning of biomasses in the global emissions of climate affecting gases and in the global warming potential (GWP). These agricultural activities contributed about 95% of NH₃, 81% of N₂O, 70% of CH₄, 52% of CO, 35% of NOₓ, and 21% of CO₂ in global emissions. As far as GWP is concerned, this study estimated about 63% of the GWP of energy sector or 80% of the GWP of its CO₂ emissions. The main contributors in the GWP of agriculture were CO₂ and CH₄, which amounts to about 34% and 32% respectively. This CH₄ mainly originated from animal husbandry, rice cropping and biomass burning. The contribution of NO₂, CO and NOₓ in the GWP of agriculture were estimated to be 15%, 10% and 9% respectively. The major sources for the NO₂ were found to be nitrogen fixation, cultivation and biomass burning.

Cachier et al., (1995) observed that aerosols emitted during Savanna fire was primarily of carbonaceous nature (70 percent of total aerosol mass) and consisted predominantly of submicron particles (more than 90 percent).
Ballentine et al., (1996) studied the analysis of fatty acids and PAHs in aerosols from biomass burning in South Africa. In this study fatty acids extracted from unburnt sugar cane plants, particulate aerosols collected during laboratory burns of sugar cane under smoldering and flaming conditions, and fatty acids and PAH produced during the burning of a sugar cane field had been chemically and isotopically characterized. They found that the vegetative combustion produced organic species which might serve as suitable tracers for biomass burning.

Jenkins et al., (1996) burnt four cereal crop residues and four wood fuels in a combustion wind tunnel to simulate the open burning of biomass. They found that the concentration for 19 PAH species in particulates matter in the range between 120 and 4000 mg per kg of biomass burning, representing between 1-70% of total PAH emission.

Marofu et al., (1997) conducted a questionnaire survey to estimate bio-fuel consumption rates in rural and urban households in Zimbabwe and found that agricultural residues were the second most popular form of fuel after wood in rural part of Zimbabwe. On average, both rural and urban consumption of agricultural residues during studied year were found to be 1.5 kg/capita/day and 0.04 kg/capita/day respectively.

Fang et al., (1999) observed 91-98% increase in concentration of solvent-extractable organic compounds in smoke in Indonesia from less intense biomass burning in early September to heavy biomass burning in late September.

Abbasi et al., (2000) focused the attention on the adverse environmental impacts of renewable energy sources and they broadly divided the impact of biomass burning in different categories. Some of them were air pollution (emissions of particulates, carbon oxides, sulphur oxides, and nitrogen oxides), organic emissions (dioxin hydrocarbons, toxic irritants such as acid, aldehyde, phenol, and carcinogenic compounds such as benzopyrene), household hazards (accidental fires), and occupational hazards (prolonged exposure to toxic aerosols).

McDonald et al., (2000) also quantified the particulates and volatile organic compounds coming out from the wood combustion. About 4 gm to 9 gm of particulates matter (PM_{2.5}) and 5 gm to 22 gm of volatile organic compounds were emitted from per kg of wood combustion.

Yamasoe et al., (2000), studied the chemical composition of aerosol particles from direct emissions of vegetation fire in the Amazon Basin and found that the dominant species
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were black carbon, $K^+$, $Cl^-$, $SO_4^{2-}$ and the aerosols having size less than 2 $\mu$m were mostly organic matter (70-92%).

Ezcurra et al., (2001) studied pollution in the town of Vitoria (northern Spain) caused by cereal waste burning. The mean hourly flux of pollutants produced by cereal waste burning fires was 1.4 kt of $CO_2$, 13 t of total particulate matter (TPM) and 3 t of $NO_x$ in the area around Vitoria. The results relating to aerosol composition collected in Vitoria during burning periods showed an increase in the concentration of $K^+$, $NO_3^-$ and $Cl^-$ ions and a high correlation was found among them. The concentrations of $K^+$ and $NO_3^-$ had increased by a mean factor of 2 during the burning period.

Jingjing et al., (2001) signified biomass as major source of energy in rural areas of China that caused detrimental effects on indoor air pollution and associated adverse health impacts. At the same time, sustainable use of biomass leads to no net increase in $CO_2$ emissions, there will be global climate benefits arising from the widespread use of biomass. Therefore, modernized biomass technologies could significantly help to reduce the air pollution and could provide clean and low-cost fuels to the rural areas.

Conny M. Joseph et al., (2002) determined the black carbon and organic carbon in aerosols particles from crown fires in the Canadian boreal forest by the thermal optical method. They found that $BC/TC$ were $0.085 \pm 0.032$ and $0.0087 \pm 0.0046$ during flaming stage based on aerial sampling and during smoldering stage from ground based sampling respectively.

Curtis et al., (2002) referred the biomass burning as a problem of long standing. According to them, about 3 billion metric tons of biomass such as wood, leaves, trees, grass and trash were burnt annually. About 40 percent of the carbon dioxide, 32 percent of the carbon monoxide, 20 percent of the particulates, and 50 percent of the highly carcinogenic polynuclear aromatic hydrocarbons produced by all sources were globally produced annually. Biomass burning is supposed to be the largest source of air pollution in many rural areas of the developed and developing world. They also discussed the ill effect of biomass burning on the human health.

Dickerson et al., (2002) analyzed the black carbon and carbon monoxide observed over the Indian Ocean and found that there was release of 40 Tg of CO from biomass burning in India. They further pointed out high emission of Black Carbon (2 to 3 Tg) in the atmosphere from South Asia with biomass burning as a major source.
Fine et al., (2002) found 20 to 30% of the ambient fine particles' concentrations in the atmosphere were just because of wood smoke emitted from residential wood combustion in USA.

Mayol-Bracero et al., (2002), during the Indian Ocean Experiment (INDOEX), observed that BC/TC, BC/OC, SO\(_4^{2-}\)/BC and K\(^+\)/BC ratios were fairly constant through out the period and suggested that 60 to 80 percent of the aerosol in the polluted layers originated from fossil fuel and 20 to 40 percent from bio-fuel combustion. Reddy et al., (2002), compared emissions from fossil fuels and biomass burning and observed that biomass burning was a minor source of SO\(_2\) and the same being a major source of carbonaceous aerosols. They further estimated that 2.04Tg emission of PM\(_{2.5}\) in one year from biomass burning. It was also observed that crop residues along with fuel wood were the primary contributors to Black Carbon in India.

Jenkins et al., (2003) estimated a releases of 3 kg particulate matter, 60 kg carbon mono oxide, 1460 kg carbon dioxide, 199 kg ash, 2 kg sulphur dioxide, and varying amounts of other obnoxious greenhouse gases like methane, nitrogen dioxide and nitrous oxide in the atmosphere due to burning of one ton of crop residue.

Roberts et al., (2003) tried to assess the impact of aerosols emitted from biomass burning on cloud properties and to identify the physical and chemical properties of the aerosol that influenced the droplet growth in the Amazon Basin by using one dimensional cloud parcel model. They found that during the dry season, smoke aerosols from biomass burning dramatically increased CCN concentrations and during wet seasons the concentrations were low. Therefore, there was a larger inter annual variation of cloud properties during the wet season than dry season.

Duan et al., (2004) identified the impact of biomass burning on urban aerosols and concluded that aerosols might be heavily influenced by different types of biomass burning all the year long in the Beijing. The emissions coming out from biomass burning might sometimes account for almost 50% of organic carbon during severe pollution episodes, and probably more for respirable PM\(_{2.5}\) particles. Their result also showed that the influence of biomass burning was maximum during the wheat harvest season, although some important influences might be detected during field preparation burnings, maize crop burning and fallen dead leaves burning.

Jacobson, Mark Z. (2004) studied the short term and long term impact of gaseous emissions (e.g., CO\(_2\), CO, CH\(_4\), NO\(_x\), SO\(_2\), C\(_2\)H\(_6\), C\(_2\)H\(_4\), C\(_3\)H\(_8\), and C\(_3\)H\(_6\)) and aerosol
particle components (e.g., black carbon, organic matter, K\(^+\), Na\(^+\), Ca\(^{2+}\), Mg\(^{2+}\), NH\(_4^+\), H\(^+\), Cl\(^-\), H\(_2\)SO\(_4^-\), HSO\(_4^-\), SO\(_4^{2-}\), and NO\(_3^-\)) by biomass burning on Global warming. They pointed out that the aerosol particles were short-lived and gases were short- and long-lived. The major gas emitted during burning was CO\(_2\). The other gases that could lead to climate change were CH\(_4\), N\(_2\)O, SO\(_2\), Reactive Organic Gases, and NO\(_x\). He also highlighted that aerosols emitted during burning might cause a short-term cooling of global climate, whereas longer-lived greenhouse gases might cause warming (or cancel the cooling) after several decades. As such, reducing biomass burning might cause short-term warming but long-term cooling or no change in temperature. The eventual cooling might be as large as 0.6\(^0\) K after 100 yr. Though controlling biomass burning might not be so efficient at slowing global warming in terms of the speed and magnitude of its effect, as controlling fossil-fuel black carbon, it became necessary to address multiple causes of Climate change simultaneously. Because aerosol particles might be the most damaging and costly components of air pollution.

Ryu et al., (2004), investigated the chemical characteristics of aerosols from burning of barley straw and rice straw in Gwangju, a rural area of Korea and found an exceptionally high PM\(_{2.5}\) concentration (157.8 \(\mu\)g/m\(^3\)) during biomass burning under stagnant atmospheric conditions. Chlorine and Potassium concentration were observed to be very high and both organic and elemental carbons were increased during biomass burning period.

Sinha et al., (2004) studied the transport of biomass burning emissions from Southern Africa to the neighboring Atlantic and Indian oceans during the dry season of May-October, 2000. Their model shows a positive bias of 20% for CO and a negative bias of 10-25% for O\(_3\) at oceanic sites downward of fire emissions. Near the areas of active fire emissions the model shows a negative bias of 60% and 30% for CO and O\(_3\), respectively. On average, from year 1994 to 2000, 60 Tg of CO from biomass burning in southern Africa was transported eastward to the Indian Ocean across the latitude band 0\(^0\)- 60\(^0\)S during the six months of dry season. Over the same period of time 40 Tg CO from the southern African biomass burning was transported westward to the Atlantic Ocean over the latitudes 0\(^0\)-20\(^0\)S during the six months of the dry season, but most of that amount was transported back eastward over higher latitudes to the south (21\(^0\)-60\(^0\)S).

Conde et al., (2005) quantified the emissions of 28 parents and substituted PAHs from burning of pine wood, pine needles, prickly pear, and almond; and found a great
variability in the total concentrations of the PAHs, while their proportions in the different samples were practically independent of the types of biomass burnt.

Hays et al., (2005), characterized the physical and chemical properties of PM$_{2.5}$ emitted from simulated agricultural fires of residuals of rice and wheat. The mean PM$_{2.5}$ mass emission factors from replicate burns of the wheat and rice residues were 4.7±0.04 and 13±0.3 gm per kg of dry mass respectively. They further estimated that particulate emission from wheat were enriched in K (31% w/w) and Cl (36% w/w), whereas the particulates emissions from rice were carbonaceous (84% w/w).

Kannan et al., (2005), measured the particulates matter emitted from the combustion of garden biomass in a controlled simulation fire test chamber and found lowest particulates emission from grass burning (1.51 gm/kg) that contained 10 percent of fine particulates and a significant quantity (70 percent) of respirable fraction. On the other hand, particulates emission from leaves burning was 32.3gm/kg contributing mostly in non-respirable fractions (around 40 percent).

Lal, (2005), estimated the amount of crop residues produced in US being 367×10$^6$ Mg/year for 9 cereal crops, 450×10$^6$ Mg/year for 14 cereals and legumes, and 488×10$^6$ Mg/year for 21 crops. The amount of crop residue produced in the world was estimated at 2802×10$^6$ Mg/year for cereal crops, 3107×10$^6$ Mg/year for 17 cereals and legumes and 3758×10$^6$ Mg/year for 27 food crops.

Lara et al., (2005), observed that sugar-cane burning in Piracicaba (Brazil) was the main source of PM$_{2.5}$ representing 60% of the PM$_{2.5}$.

Lee et al., (2005) studied the impact of Russian forest fires in 2003 and its long range transport of smoke aerosols plume over Korea. The smoke aerosol plume resulted in a decrease in solar visible irradiance of up to 57% and increased the surface PM$_{10}$ concentration up to 258 µg/m$^3$.

Molnar et al., (2005) estimated the fine particulates matter and gaseous emissions from the residential wood burning. They found that wood-smoke particles were significant contributors of K, Ca, and Zn. In addition, Cl, Mn, Cu, Rb, and Pb were found to be possible markers of wood smoke.

Ogawa et al., (2005) burnt the dried rice straw in grate-type test furnace and observed that nitrous oxide was formed mainly in the flaming stage that diffused quickly and was quenched by the surrounding air.
Ortiz et al., (2005) measured the pollution due to cereal waste burning in Spain and estimated that almost 3.3 Tg of carbon and nearly 25 Gg of nitrogen elements were emitted into the atmosphere by cereal waste burning. The combustion process on the cereal fields produced a mean value of 11 Tg of CO\textsubscript{2}, 23 Gg of NO\textsubscript{x} and 80 Gg of total particulates matter. Further, about 46% of CO\textsubscript{2} and 23% of NO\textsubscript{x} emitted by all sources of Spanish pollution came from cereal waste burning. Finally, they deduced that the production of 1 kg of cereal crop implied that 410 g of carbon and 3.3 g of nitrogen were going to be introduced into the atmosphere by this pollutant process.

Parashar et al., (2005), estimated 2.4 Tg of carbonaceous aerosols, mainly OC and BC, emission per year from India, out of which 80% were originated from the use of biomass as energy. They determined the emission factor for OC and BC for fuel wood (3.5±1.9/1.1±0.5), dung cake (12.6±4.5/4.4±2.2) and agricultural residue (3.9±3.4/1.3±1.1).

Wierzbica et al., (2005) found high emissions of Zn, Cr, Cd, and Pb from the burning of forest residues; very high emissions of Zn and Cd from the burning of pellets; whereas the lowest emissions of heavy metals from the combustion of sawdust.

Cao et al., (2006) observed a strong seasonal dependence for emission of BC and OC from the open burning of agricultural waste.

Choi et al., (2006) studied the effect of biomass burning on the regional pollution on CO levels in Northeast Asia from Measurement of Pollution in the Troposphere (MOPITT) in year 2000 and recommended the long-range transport of CO emitted from biomass burning. They found CO levels over the east China in the first two weeks of April 2000 were enhanced more than 35 ppb by biomass burning in Myanmar and Indo-China and high CO levels over the East/Japan Sea for the last two weeks of April 2000 were affected by both anthropogenic emissions and biomass burning. There was a difference of 31 ppb of the concentration of CO level over the East/Japan Sea between fire days and non fire days. They established the impact of CO level in Korea and Japan and the biomass burning in the Central Siberia. Winkler et al., (2008) too provided the evidence for large-scale transport of biomass burning aerosols at a remote South African site.

Dhammapala et al., (2006) studied the particulates emissions from wheat and Kentucky bluegrass stubble burning in eastern Washington and northern Idaho (USA) and estimated the emission ratios of PM\textsubscript{2.5}/CO for wheat (0.05±0.01) and Kentucky bluegrass (0.23±0.02).
Habib et al., (2006) analyzed the spatial, seasonal and inter annual variability of regional-scale aerosol load over India during 1981-2000 and characterized Northeastern part of India, Bengal and Orissa region as biomass burning region. Aerosols emitted from biomass burning in this region were dominated by carbonaceous aerosols and a good correlation between OM and BC and biomass burning was established. The aerosols emissions from the Indo-Gangatic plain and central India in April and May were considered from forest fires and open burning of crop residues.

Jimenez et al., (2006) characterized the air quality in Pullman, USA, during burning season in year 2002 and found vegetative burning as the second largest source of PM$_{2.5}$ (about 35%).

Jordan et al., (2006a) provided very strong evidence that wood smoke far exceeded automobile exhaust and other contemporary carbon sources as the principal contributor to the ambient particulates matter in Launceston, Australia, during winter. In another study of same region, Jordan et al. (2006b) used Levoglucosan (1, 6 hydro-β-d-glucopyranose) as an atmospheric tracer for wood smoke and observed that wood smoke comprises about 95% of wintertime air pollution in Launceston.

Venkataraman et al., (2006) found a strong regional variation in the open biomass burning in India and it ranged from 18 to 30% on an all-India basis, that contributed about 25% to black carbon, organic matter and carbon monoxide emissions, about 9-13% to PM$_{2.5}$ and CO$_2$ emissions, and negligibly (about 1 percent) to SO$_2$ emissions.

Yan et al. (2006) assessed the emissions from biomass burning in mainland China by using statistical data, survey data, expert’s estimates and a satellite data set. They observed fuel wood and crop residue burning for fuel and open burning in the field were the major sources of biomass burning in China, accounting nearly 90% of the total biomass burning on dry weight base. The emission of carbon monoxide (CO) from open biomass burning (field burning of crop residue and forest and grassland fires) in 2000 was found to be 16.5 Tg. They also found that 19.4% of the crop residues were burnt in the year 2000 in China.

Yang et al., (2006) found that rice straw burning was the significant contributor to the particulate and gaseous PAH; and the average total PAH concentrations of particulates and gaseous phase were 33.0 and 1160 ng m$^{-3}$ respectively in the burning period that were higher than those on non burning days. During the burning periods, 70.9% of PAH mass was distributed in the sizes smaller than 2.5μm. They also established that the particulates
and particulate phase PAHs from rice straw burning were coarser than those from vehicular exhaust. Keshtkar et al., (2007) burnt rice straw and almond pruning in a combustion chamber and found that PAH composition and its emission from these residue burning was also temperature dependent. Total PAH emission from rice straw and almond pruning burns was 18.6 mg kg\(^{-1}\) and 8.03 mg kg\(^{-1}\) of fuel respectively. They also calculated the emission factors for particulate matter, organic carbon and elemental carbon in aerosol having nuclei mode (PM\(_{0.1}\)), the accumulation mode (PM\(_{0.1-1.8}\)) and the coarse mode (PM\(_{1.8}\)). The total emission factors (summing all aerosol modes) of particulates matter (PM), organic carbon and elemental carbon were found to be 7.22 g kg\(^{-1}\), 0.83 g kg\(^{-1}\) and 0.49 g kg\(^{-1}\) respectively for rice straw and 5.43 g kg\(^{-1}\), 2.37 g kg\(^{-1}\) and 0.17 g kg\(^{-1}\) respectively for almond pruning.

Sahai et al., (2007) tried to estimate the emission factors for trace gases and carbonaceous particulate species from in situ burning of wheat straw in agricultural fields in India. According to them, 7.5% of total generated wheat straw was subjected to on-site burning, that was expected to emit large amounts of trace gases and particulates matter (PM) to the atmosphere. They tried to estimate the India specific emission factors (EFs) for CO\(_2\), CH\(_4\), CO, N\(_2\)O, NO\(_x\), NO, NO\(_2\), Organic Carbon (OC), Black Carbon (BC), and Total Carbon (TC) emitted from wheat straw burning. Their results showed that the EFs of CO\(_2\), CH\(_4\), CO, N\(_2\)O, NO\(_x\), NO, NO\(_2\), OC, BC, and TC were found to be 1787±36, 3.6 ±2.7, 28.1± 20.1, 0.74 ±0.46, 1.70± 1.68, 0.78± 0.71, 0.56 ± 0.47, 0.3 ±0.1, 0.2 ±0.1, and 0.5 ± 0.2 g kg\(^{-1}\) respectively. With this EFs, they estimated the total emissions of CH\(_4\), CO\(_2\), CO, N\(_2\)O, NO\(_x\), NO, NO\(_2\), OC, BC, and TC from wheat straw burning in India for year 2000 were found to be 68±51, 34435±682, 541±387, 14±9, 33±32, 15±14, 11±9, 6±2, 3±1 and 10± 4 Gg respectively. They further found that the emissions of CH\(_4\), CO\(_2\), CO, NO\(_x\), OC, and BC were almost 16%, 17%, 5%, 6%, 1%, and 4% of the emissions of these species from all types of biomass burning in India.

Cao et al., (2008) estimated the emission factors of particulates matter and gaseous pollutants from rice straw, wheat straw, corn stover, and cotton stalk burning in rural china by using combustion tower. They examined the emission factors of PM, element carbon (EC), organic carbon (OC), SO\(_2\), NO\(_x\), CO, and CO\(_2\); and ten ions, Na\(^+\), NH\(_4^+\), K\(^+\), Mg\(^{2+}\), Ca\(^{2+}\), F\(^-\), Cl\(^-\), NO\(_2^-\), NO\(_3^-\), and SO\(_4^{2-}\). Their results showed that wheat straw had the highest
emission factor for the total PM \((8.75 \text{g/kg})\) among the four crop residues, whereas, corn stover and wheat straw had the highest emission factor for EC \((0.95 \text{ g/kg})\) and OC \((3.46 \text{ g/kg})\) respectively. Corn stover had the highest emission factors of NO, NO\(_x\) and CO\(_2\), whereas, wheat straw, rice straw, and cotton stalk had the highest emission factors of NO\(_2\), SO\(_2\) and CO. The water soluble ions, K\(^+\) and Cl\(^-\), had the highest emission factors from all the crops. Wheat straw had a relatively higher emission factor for cation species and F\(^-\), Cl\(^-\), NO\(_2^+\) than other residues.

Cheng et al., (2008) examined the characteristics of the particulates matter having aerodynamic diameter of 2.5 \(\mu\text{m}\) and in between 2.5 \(\mu\text{m}\) and 10 \(\mu\text{m}\) during agricultural waste burning in Taichung City, Taiwan. Their results showed that the average PM\(_{2.5}\) and PM\(_{2.5-10}\) concentrations were 123.6 \(\mu\text{g/m}^3\) and 31.5 \(\mu\text{g/m}^3\) during agricultural waste burning periods respectively and 32.6 \(\mu\text{g/m}^3\) and 21.4 \(\mu\text{g/m}^3\) during non-waste burning periods respectively. The fine aerosol ionic species including Cl\(^-\), K\(^+\) and NO\(_3^-\) increased 11.0, 6.7 and 5.5 times respectively during agricultural burning periods compared with periods when agricultural waste burning was not performed. K\(^+\) was found mainly in the fine mode during agricultural burning. They also concluded that agricultural waste burning with low dispersion often caused high PM\(_{2.5}\) and gases pollutant events. The gaseous CO, SO\(_2\) and NO\(_2\) are also increased 2.4, 2.6 and 2.3 times respectively during agricultural waste burning periods compared to non-waste burning periods. The highest concentration of PM\(_{2.5}\) reached up to 234.1 \(\mu\text{g/m}^3\). The average concentrations of fine OC, EC, SO\(_4^{2-}\), NO\(_3^-\), NH\(_4^+\), K\(^+\), Ca\(^{2+}\), Na\(^+\), and Cl\(^-\) were 35.1, 8.9, 16.9, 9.8, 8.3, 2.8, 0.3, 0.4, and 3.1 \(\mu\text{g/m}^3\) respectively during waste burning; and 9.7, 3.1, 5.7, 1.8, 2.2, 0.4, 0.2, 0.3, and 0.3 \(\mu\text{g/m}^3\) respectively during non-waste burning periods. Organic carbon and sulphate were the major components of PM\(_{2.5}\) representing on average 28% and 14% of PM\(_{2.5}\) during waste burning and 30% and 17% of PM\(_{2.5}\) during non-waste burning periods respectively.

Coelho et al., (2008) studied the Dissolved Organic Carbon (DOC) concentrations in rainwater from two cities, Ribeira o Preto and Araraquara in Brazil, located in the “Brazilian sugar cane belt” arose from a car fuel combustion (particularly due to the large use of ethanol fuel), soil resuspension, industrial activities, long-range transport, and biomass burning; and a good linear correlation between DOC and biomass burning were found. They also found that the average DOC concentrations increased by 62% and 144% in Araraquara and Ribeira o Preto respectively during the harvest period. Highest DOC
concentrations were obtained when air masses traversed sugar cane fields burnt on the same day as the rain event.

Liua et al., (2008) reported the distribution, utilization structure and potential crop residues in China. China produces some 630 million tons of crop residues per year. The amount of crop residues generated in China is 1.3 times of the total yield of crops. Crop residues of corn, wheat and rice amounts to 239, 137 and 116 million tons respectively, accounting for nearly 80% of the total crop residues. About 37% of the crop residues being directly combusted by farmers, 23% was used for forage, 20.5% discarded and directly burnt in the field, 15% lost during collection, 4% for industry materials and 0.5% for biogas.

Yang et al., (2008) quantified the residues burning in the field and tried to examine its influence on ambient air quality in Suqian, China. The annual average amount of crop residue generated was estimated as $3.04 \times 10^6$ tons; out of which 43% of the residue was burnt in the field. About 82% of wheat straw and 37% of rice straw were assumed to be burnt in the field. The total amount of TSP, PM$_{10}$, SO$_2$, NO$_x$, NH$_3$, CH$_4$, EC, OC, VOC, CO, and CO$_2$, emitted from crop residue burning in the field were estimated as 11051, 7572, 525, 3280, 1707, 3544, 905, 4331, 20,606, 120747, and 1988376 tons respectively; and about 78% of them were emitted in summer harvest. During the summer harvest the daily average concentrations of PM$_{10}$, NO$_2$ and SO$_2$ were 0.266, 0.051 and 0.063 mg/m$^3$ respectively.

Zang et al., (2008) investigated gaseous pollutants and particle number emitted from burning of different types of agricultural crop residues like Rice, Wheat, and Corn straw by using a burning stove and aerosol chamber in China. The average emission factors of CO$_2$, CO, NO, NO$_2$, and NO$_x$ were measured to be 791.3, 64.2, 1.02, 0.79, and 1.81 g kg$^{-1}$ for rice straw; 1557.9, 141.2, 0.79, 0.32, and 1.12 g kg$^{-1}$ for wheat straw; and 1261.5, 114.7, 0.85, 0.43, and 1.28 g kg$^{-1}$ for corn straw respectively. Accordingly, the mean emission factors of particle number (PN) were $1.8 \times 10^{13}$, $1.0 \times 10^{13}$ and $1.7 \times 10^{13}$ particles kg$^{-1}$ for rice, wheat, and corn straws respectively. It was observed that the percentages of CO, CO$_2$ and NO$_x$ to the total emissions were 13.9%, 15.3% and 31.4% for rice straw; 32.9%, 32.5% and 20.9% for wheat straw; and 53.2%, 52.2% and 47.6% for corn straw respectively.

Badarinath et al., (2009) observed the variations in aerosol properties due to crop residues burning in Indo Gangatic Plains in India and estimated related radiative forcing using ground measurements, radiative transfer model and satellite data. They also favoured the
long range transport of aerosols emitted from crop residue burning. The radiative forcing under normal conditions was found to be $-53 \text{Wm}^{-2}$ that was reduced to the range of $-107.81 \text{Wm}^{-2}$ due to enhanced loading of aerosols associated with crop residue burning. Beegum et al., (2009) examined the spatial distribution of aerosol black carbon over India during pre-monsoon season and found an abnormal increase in the concentration of BC in Hyderabad and Delhi due to biomass burning.

Gadde et al., (2009) estimated the rice straw produced, mass of rice straw subjected to open burning and emission coming out from this burning in India, Thailand and Philippines. In India, 15% of rice straw is subjected to open field burning that amounts to 13.92 Tg. For the estimation of pollutants emitted from the open burning of rice straw, they followed the IPCC 2006 guide line and took the emission factor from different literature.

Kansal et al., (2009) found biomass burning as one of the major anthropogenic sources of non methane hydrocarbons that played a significant role in tropospheric ozone production in presence of adequate concentration of oxides of nitrogen in the atmosphere.

Li et al., (2009) tried to estimate the economic cost of the biomass viz. straw, grass, firewood, and animal dung by using standard coal equivalents which their materials were converted into by the energy substitution method when used as fuels. Their unit prices were: straw 0.286 yuan/kg, grass 0.277 yuan/kg, firewood 0.336 yuan/kg, and animal dung 0.357 yuan/kg (dry weight). They also compared their thermal efficiencies with LPG and electricity. The thermal efficiencies of crop residues and grass were 15%, firewood and animal dung 18%, coal 22%, and biogas, LPG and electricity 60%.

Li Mei et al., (2009) quantified the mass concentrations of three-ring (Acenaphthylene), four-ring (Fluoranthene & Pyrene), five-ring (Dibenzo[a,h]anthracene), and six-ring (Benzo[ghi]perylene & indeno[1,2,3-cd]pyrene) PAHs in laboratory-made rice straw burning aerosols by Desorption Electrospray Ionization Mass Spectrometry (DESI-MS). The average value of the four PAHS viz. Acy, Flu & Pyr, DbA, and InP & BgP are 11.1, 126.8, 36.8, and 82.9 $\mu$g per gm respectively of the Total Suspended Particulate (TSP) matter. The high concentrations of four-, five-, six ring PAHs in the rice straw burning aerosols were observed in this study suggested that the crop residue combustion was an important source of PAHs in the atmosphere.

Lu et al., (2009) also examined the emission of PAHs from burning of rice and bean straw by a simulated burning experiment. Total emission amounts of 16 PAHs from the burning of rice and bean straw ranged from 9.29 to 23.6 mg g$^{-1}$ and from 3.13 to 49.9 mg g$^{-1}$
respectively. They tried to find out the dependency of the emission of PAHs on temperature, humidity and Oxygen supplied to the furnace chamber. The PAHs emission was generally increased with the increase of burning temperature, whereas moisture content in straw had a negative effect on PAH formation, especially on PAHs with low molecular weight. PAHs emission amounts decreased by 78.2% for bean straw with a moisture content of 30% in comparison with that for dried straw. In addition, PAH emission amounts increased with increase of Oxygen content in supplied air and then decreased; and the maximum emission of PAH was observed when Oxygen content was 40%. Among the 16 PAHs emitted in this observation, Naphthalene (NA) had the largest contribution to PAHs and it accounted for 35.0 ±7.4% of total PAHs, followed by Phenanthrene and Fluorine.

Mittal et al., (2009) have shown a significant increase in the ambient aerosols concentration during the burning of wheat and rice crop stubble from their respective harvesting seasons in the Patiala city of Punjab, India, in the year 2007. The average aerosols concentration in Patiala during non-burning season was found in between 136 µg m⁻³ and 243 µg m⁻³. The mean aerosols load during wheat stubble burning season increased from 217 µg m⁻³ to 317 µg m⁻³, whereas during rice stubble burning season the average monthly aerosols concentration varied between 430 µg m⁻³ and 442 µg m⁻³. The aerosols load during wheat stubble burning and rice stubble burning increased about 40% and 70% respectively from their respective previous non burning periods. The SO₂ and NO₂ concentration during non burning periods varied from an average monthly concentration of 4µg m⁻³ to 17µg m⁻³ and 12µg m⁻³ to 18µg m⁻³ respectively. NO₂ concentration ranged from a minimum 14 µg m⁻³ to a maximum 40 µgm⁻³, whereas SO₂ concentration varied from 16 µg m⁻³ to 22µg m⁻³. A high NO₂ concentration was obtained during wheat stubble burning periods (28 µg m⁻³) and during the rice stubble burning periods (20 µg m⁻³). A high SO₂ concentration was obtained during wheat stubble burning periods (22µg m⁻³) and rice stubble burning periods (21µg m⁻³). In other part of the Punjab too, the emissions from the burning of crop residue during wheat season was relatively low compared to the paddy season (Badrinath et al., 2006). Punia et al., (2008) estimated the district-wise burnt area from agriculture residue burning in Punjab by MOIDS and AWiFS data.
Tian et al., (2009) have observed elemental carbon and primary organic aerosol being the major components, whereas sulphate and nitrate ions are minor components of PM$_{2.5}$ coming out from biomass burning.

From the foregoing, it is clear that although crop residues are a source of feedstock and biofuel but their open burning is a major contributor to aerosols (including smoke) and gases in nearby areas along with regional haze formation. The release of aerosols and gases may play an important role in atmospheric chemistry and radiative forcing, thus affecting regional and global climate. Hence, it is imperative that the burning of crop residue be investigated in all its attendant aspects because of its impact in particular on rural health, environmental quality in general and climate change.

Despite the serious implications of the burning of crop residues, studies in India have been rather limited (e.g. Kannam et al., 2005; Sahai et al., 2007; Mittal et al., 2009; etc.). The study of Kannam et al. (2005) was based on the controlled burning of garden biomass. Sahai et al. (2007) developed emission factors for CO$_2$, CH$_4$, CO, N$_2$O, NO$_x$, NO, NO$_2$, Organic Carbon, Black Carbon, and Total Carbon (TC) from in situ burning of wheat straw. Mittal et al. (2009) examined the impact of burning of crop (rice and wheat) residues on the ambient air quality in terms of total SPM, SO$_2$ and NO$_2$. In these studies, no attempt was made to monitor and characterize aerosols in various size fractions. Thus, the lack of studies on examining the effect of open crop residue burning on the concentration of ambient aerosols in various size ranges having implications for the health of rural communities in India and regional climate has prompted this study with following objectives:

**[1.5] Objectives**

1. To study the mass size distribution of aerosols and its variations during harvesting, non harvesting and crop residue burning periods.
2. To quantify the concentrations of alkali and alkaline earth metals (Na, K, Rb, Mg, Ca, and Ba), heavy metals (Sc, Ti, V, Mn, Fe, Co, Ni, Cu, Zn, Y, Nb, Mo, La, and Hf) and poor metals (Al, Ga, Ge, Sn, and Pb) in aerosols of different size ranges.
3. To quantify the concentrations of Carbon, Nitrogen, Silicon, Phosphorous, Sulphur and Chlorine in aerosols of different size ranges.
4. To evaluate the relative impact on the ambient aerosols concentrations arising out of the burning of rice and wheat residues.
The structure of the present thesis is as follows: Chapter 2 deals with materials and methods containing the details of sampling site, monitoring procedures and analytical techniques. Chapter 3 deals with the measurement of size fractionated mass concentrations of aerosols. The estimation of various metals associated with different size ranges of aerosols have been discussed in the chapter 4. The non metal analysis pertaining to carbon, nitrogen, silicon, phosphorus, sulphur and chlorine in size fractionated aerosols have been given in chapter 5. Conclusions of the thesis are presented in chapter 6.