Effect of Crop Residue Burning Emission on Ambient Air Quality of Industrial Estate-MandiGobindgarh

Thesis submitted in partial fulfillment for the requirement of degree of

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DECLARATION/CERTIFICATE

I hereby declare that the work embodied in thesis entitled **"Effect of Crop Residue Burning Emission on Ambient Air Quality of Industrial Estate- Mandi Gobindgarh"** for the award of degree of Master of Technology (EST) submitted in the **"School of Energy And Environment"**, Thapar University, Patiala, is a record of the work carried out by me under the guidance of **Dr Amit Dhir** (Assistant Professor, School of Energy and Environment). The matter presented in this thesis has not been submitted in part or full, to this or any other University/Institute for any degree or diploma.

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ABSTRACT

Urban air pollution, primarily in the form of highly elevated ambient concentrations of small particulate matter, poses a serious threat to the health of urban dwellers in many countries. India, a developing country, is one of the first ten industrial countries of the world. Because of the enhanced anthropogenic activities, India is one of the most polluted country in the world. Various sources reveal that Mandi Gobindgarh and its surrounding areas are polluted with regard to Air pollution, which exceeds the national ambient air quality standards (NAAQS). Mandi Gobindgarh is one of the critically polluted areas with regard to air pollution as designated by CPCB. Air is excessively hot and dry due to furnaces. Air pollution in Mandi Gobindgarh is mainly caused by three sources, namely, industrial, stubble burning and vehicular emissions. Open biomass burning of crop residue is a common practice after harvesting, this activity releases a large amount of air pollutants, which can cause serious effects on the ambient air quality, public health and climate. In crop residue burning there is no stack, no vent or duct, thus all emissions are fugitive. The effect of pollution is much lesser pronounced in rural areas than in urban areas. However the sickness increases in rural areas during paddy and wheat chaff burning due to toxicity of the gases from chaff. In this study, ground-based ambient air monitoring was conducted at five different locations in Mandi Gobindgarh, Punjab, in order to determine the impact of open burning of crop residues on concentration levels of particulate matter (PM_{10} and $PM_{2.5}$). A study was carried out for the measurement of PM_{10} and $PM_{2.5}$ for one rice crop season from October 2012 to January 2013 and one wheat crop season from March 2013 to May 2013, using Respirable Dust Sampler. Levels of PM_{10} and $PM_{2.5}$ showed increase of 86.65% and 53.2% respectively during the rice crop residue burning months, and an increase of 60.4% and 33.1% respectively during wheat crop residue burning months, at an agricultural site. Whereas, an increase of 33.33% and 31.1% respectively during the rice crop residue burning months, and an increase of 23.7% and 9.5% respectively during wheat crop residue burning months, at an Industrial site, where agricultural impact is minimal and at a site with maximum vehicular emission, there was an increase of 33.6% and 25.8% respectively during rice crop residue burning months and an increase of 29.1% and 28% respectively during wheat crop residue burning months.

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CHAPTER 1
INTRODUCTION

1.1 Overview

The air we breathe in is a precious commodity of life. We can refuse to consume adulterated and polluted water and food for a reasonable period of time, until we get the wholesome one. However, when air is concerned we can't afford to stop breathing even for a minute, although we may know it to be polluted. The quality of air we breathe in is an important element in the protection and promotion of our health. There certainly exists a close relation between poor air and poor health, as pollution of air results in breathing difficulties, increased incidence of asthma, cancer and even death. Extensive industrialization and increased transportation has polluted the atmospheric air to such an extent that it is slowly losing its self-cleansing capacity. Deteriorating air quality is exposing even serious threats, of changing the composition of atmosphere (*Khan,2004*).

Air pollution is a mixture of natural and man-made substances in the air we breathe such as fine particles produced by the burning of fossil fuels, ground-level ozone, which is a reactive form of oxygen that is a primary component of urban smog, and noxious gases such as sulfur dioxide, nitrogen oxides, carbon monoxide, and chemical vapors.

Air pollution has become an important factor of environmental degradation. Release of smoke from the chimneys of the industries, burning of fuels like coal, wood as well as the exhausts from automobiles leads to air pollution. In the modern times, rapid industrialization and use of automobiles for transport to cope with the growing demand of the growing human population have become the major sources of air pollution. In most of the 23 Indian cities with a million-plus population, air pollution levels exceed World Health Organization's (WHO) recommended health standards. In every city, the levels are getting worse because of rapid industrialization, growing number of vehicles, energy consumption, and burning of wastes. Several cities face severe air pollution problems, with annual average levels of total suspended particulates (TSP) at least three times as high as the WHO standards. A study conducted by the World Bank indicates premature deaths of people in Delhi owing to high levels of air pollution (*CPCB, 2003*).

1.2 Air quality monitoring program in India

Ambient air quality monitoring provide air quality information that form the basis for identifying areas with high air pollution levels and subsequently, for planning the strategies for control and abatement of air pollution. Ambient air quality monitoring programme are needed to determine the existing quality of air. The ambient air quality monitoring network involves measurement of a number of air pollutants at number of locations in the country so as to meet objectives of the monitoring. Any air quality monitoring network thus involves selection of pollutants, selection of locations, frequency, duration of sampling, sampling techniques, infrastructural facilities, man power operation and maintenance costs.

The air quality monitoring program in India was started in 1967 by the National Environmental Engineering Research Institute (NEERI) (then named CPHERI, Central Public Health Engineering Research Institute).The monitoring was expanded to include regular monitoring at three stations in 1978. The CPCB initiated the National Ambient Air Quality Monitoring (NAAQM) program in the year 1984 with seven stations at Agra and Anpara. Subsequently, the program was renamed as National Air Monitoring Programme (NAMP). The number of monitoring stations under the NAMP has increased, steadily, to 295 by 2000-2001 covering 99 cities/towns in 28 States and 4 Union Territories (*CPCB, 2003*).

Under NAMP, four air pollutants, viz., sulphur dioxide (SO_2), oxides of nitrogen as NO_2 and suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM/PM_{10}), have been identified for regular monitoring at all the locations. Besides this, additional parameters such as respirable lead and other toxic trace metals, hydrogen sulphide (H_2S), ammonia (NH_3) and polycyclic aromatic hydrocarbons (PAHs) are also being monitored in 10 metro-cities of the country since 1990.

The monitoring of meteorological parameters such as wind speed and direction, relative humidity and temperature were also integrated with the monitoring of air quality. Further, for real time data collection, automatic monitoring stations at few places had also been installed. Ambient air quality monitoring was carried out manually using high volume samplers and respirable dust samplers with gaseous attachments. The samples were analysed in the laboratory and sent to the Pollution Assessment Monitoring and Survey (PAMS), division of CPCB.

1.3Air pollution affected areas in India

Air pollution in India is mainly caused by three sources, namely, vehicles, industrial and domestic sources. It is mainly concentrated in the following three areas:

(i) **Major cities**: The problem of air pollution is in major cities where the prominent sources are vehicles and small- and medium-scale industries. These cities include Delhi, Kolkata, Mumbai, Chennai, Ahmedabad, Bangalore, Hyderabad, Pune, Kanpur, etc.

(ii) **Critically polluted areas**: In India, there are as many as 24 areas which have been designated as 'Critically Polluted Areas' w.r.t. air, water pollution by CPCB. These areas are as follows:

Table 1.1: Problem Areas in India *(CPCB, 2003)*

S.No.	Problem Areas in India	Problem Area Type of Industry
1	Singrauli	Power Plants, Mining, Aluminium Industry
2	Korba	Power Plants, Aluminium Industry, Mining
3	Vapi	Chemical Industries
4	Ankaleshwar	Chemical Industries
5	Greater Cochin	Oil Refineries, Chemical, Metallurgical Industries
6	Visakhapatnam	Oil Refinery, Chemical, Steel Plants
7	Howrah	Foundry, Rerolling Mills
8	Durgapur	Chemical Industries, Power Plants, Steel Plants
9	Manali	Oil Refineries, Chemical Industry, Fertilizer Industry
10	Chembur	Refineries, Power Plant, Fertilizer Industry
11	MandiGobindgarh	Secondary Steel Industry
12	Dhanbad	Mining, Coke Oven
13	Pali	Cotton Textile, Dyeing
14	Nagafgarh	Drain Basin Power Plants, Vehicles
15	Angul-Talcher	Mining, Aluminum Plants, Thermal Power Plants
16	Bhadravati	Iron and Steel, Paper Industry
17	Digboi	Oil Refinery
18	Jodhpur	Cotton Textile, Dye
19	Kala-Amb	Paper, Electroplating
20	Nagda-Ratlam	Viscose Rayon, Caustic, Dyes, Distillery
21	North Arcot	Tanneries

22	Parwanoo	Food Processing Unit, Electroplating
23	Patancheru – Bollaram	Organic Chemical, Paints Petrochemical Industry
24	Tarapur	Chemical Industry

Among those, the critically polluted areas with regard to Air Pollution are MandiGobindgarh, Durgapur, Digboi, Greater Cochin, Visakhapatnam etc.

(iii) **Rural areas**: Indoor air pollution exists in rural areas with domestic fuel as the main source of air pollution. In rural areas, cow dung and wood sticks are used as fuel in household. Kitchens are without any proper ventilation, resulting in the build-up of air pollutants in the houses. Indoor air pollution exists in rural areas due to lack of proper ventilation and absence of exhaust fans/ electric chimneys.

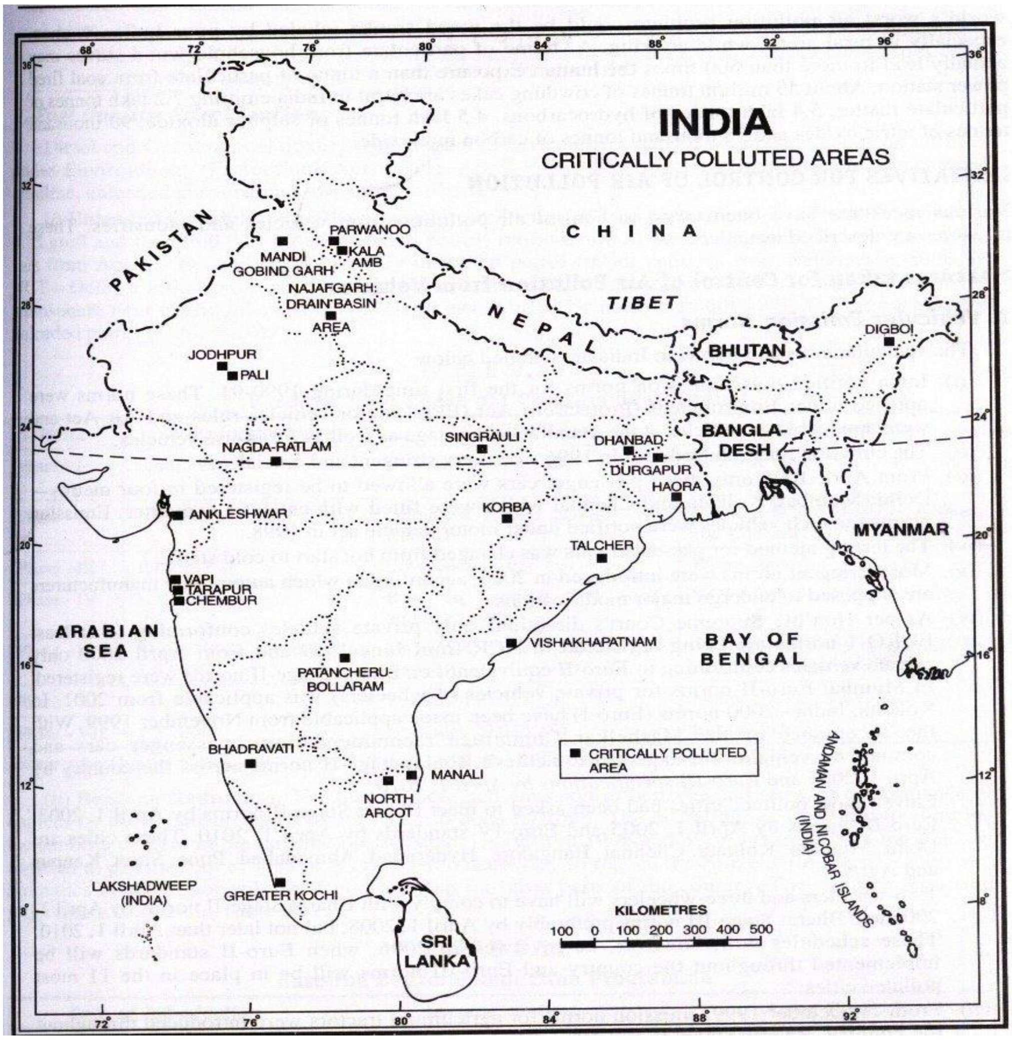


Fig 1.1 Map showing critically polluted areas in India

1.4 Description of study area and its Air quality

MandiGobindgarh is a town and a municipal committee in Fatehgarh Sahib District in the Indian state of Punjab and also known as 'Steel Town of India' as various categories of steel manufacturing units are operating in this town. This town is located on National Highway-I. The town is spread over an area of 10.64 Sq. Kms. and accommodates a population of 55,416 as per 2001 census. Geographically, MandiGobindgarh lies between north latitude 30^o-37'-30" and 30^o-42'-30" and east longitude 76^o-15' and 76^o-20'. It shares common boundaries with several districts such as Mohali, Patiala, Sangrur, Ludhiana and Rupnagar, and is well connected by rail and road *(PPCB, 2010).*

After analysing the Environmental Status of Industrial Clusters of the country, Central Pollution Control Board in consultation with the Ministry of Environment & Forests has identified 88 critically polluted industrial clusters, of which MandiGobindgarh is one of them in the State of Punjab with regard to air pollution. The Ministry of Environment & Forests vide office memorandum No.J-11013/5/2010-IA.II(I) dated 13/1/2010 has imposed a temporary restriction of 8 months on the establishment of the projects in the said critically polluted industrial clusters, which are covered in Schedule-I appended to the EIA notification 2006.

The Punjab Pollution Control Board has identified following 6 industrial clusters within the jurisdiction of critically polluted area of MandiGobindgarh. The identified clusters of MandiGobindgarh area are shown in Table 1.2.

Table 1.2: Clusters identified as critically polluted area of MandiGobindgarh *(PPCB, 2010)*

CLUSTER NO.	NAME OF THE INDUSTRIAL CLUSTER
I	Area near RIMT starting from M/s Cold Drip Pvt. Ltd. to M/s JTG Alloys Ltd.
II	Area between RIMT road (upto M/s Pushpanjali Steel) to Talwara Road (upto M/s M.R. Alloys) on one side of G.T. Road and upto Rajwaha on the other side of the G.T. Road
III	Area on G.T. Road (right side - Rajpura to Ludhiana) covered between M/s IMT, M/s Gian Steel Rolling Mills, M/s Baba BalakNath Steel Rolling Mills, M/s Bansal Iron and Steel Rolling Mills (on left side) and area

	starting from M/s Patiala Casting to M/s Bansal Iron upto Rajwaha.
IV	Area bound between M/s Gopal Mills, M/s Kailash Steel Rolling Mills, M/s Northern India Pvt. Ltd. and M/s Aarti Strips in Guru Ki Nagri
V	Area on both sides of Amloh Road covered between M/s Doaba Steel Rolling Mills, M/s Janta Steel & Agro Industries, M.C. disposal point, M/s Vishnu Steels and M/s R.K. Steel and Allied Industry
VI	Area on both sides of G.T. Road on Khanna side starting from M/s Ganesh Steel Industry to M/s Karam Steel to M/s Shri Ganesh Steel Rolling Mills to M/s Dhiman Steel Industry to M/s M.T.C. Steel Industry to M/s Kumar Hammer and Model Town.

The polluted air has affected almost all the population (1,55,416) of MandiGobindgarh in 2012. They are specially affected by high dust and smoke particulate pollutants through industrial units and smoke from vehicles and generators. The population showed a higher prevalence of symptoms of respiratory problems, angina and cardiovascular disease. The rural area around the city too stands polluted due to industrial smoke, dust and the burning of over 20 million tons of paddy husk by Punjab's farmers‘ triggered smog.‘ (Times of India 12 Dec 2012). For Gobindgarh town, out of total area of 9 sq. km. (2223 acs.) 33.74% is occupied by industrial use, 31.49% by residential use, 13.68% by traffic & transportation & 10.66% by agriculture (*PPCB, 2010*).

In order to determine the status of quality of the ambient air in MandiGobindgarh, the PPCB is monitoring the ambient air quality of MandiGobindgarh for the last 15 years. The ambient air quality monitoring analysis of last 7 years reveals that the annual average concentration of Respirable Suspended Particulate Matter (RSPM) is in the range of 214 – 272 $\mu g/m^3$ against annual average prescribed standard of 120 $\mu g/m^3$ for industrial area, 60 $\mu g/m^3$ for residential, rural and other areas, and 50 $\mu g/m^3$ for sensitive area. So, the concentration of RSPM in ambient air is more than the prescribed limits.

CHAPTER 2
HARVESTING AND ITS IMPACT ON ENVIRONMENT

2.1 Wheat and paddy harvesting season

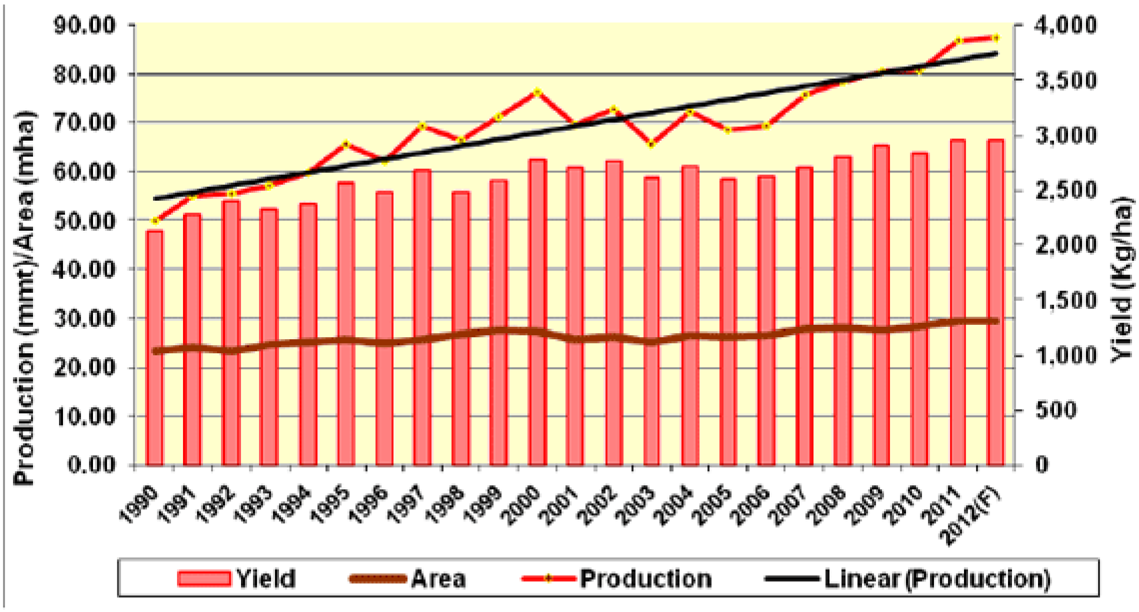
Harvest is the process of gathering mature crops from the fields. *Reaping* is the cutting of grain or pulse for harvest, typically using ascythe, sickle, or reaper. The harvest marks the end of the growing season, or the growing cycle for a particular crop, and social importance of this event makes it the focus of seasonal celebrations such as a harvest festival, found in many religions. On smaller farms with minimal mechanization, harvesting is the most labor-intensive activity of the growing season.

Rabi crops are sown in winter from October to December and harvested in summer from April to June. Some of the important rabi crops are wheat, barley, peas, gram and mustard. Though, these crops are grown in large parts of India, states from the north and north-western parts such as Punjab, Haryana, Himachal Pradesh, Jammu and Kashmir, Uttaranchal and Uttar Pradesh are important for the production of wheat and other rabi crops.

Kharif crops are grown with the onset of monsoon in different parts of the country and these are harvested in September-October. Important crops grown during this season are paddy, maize, jowar, bajra, tur (arhar), moong, urad, cotton, jute, groundnut and soyabean. Some of the most important rice-growing regions are Assam, West Bengal, coastal regions of Orissa, Andhra Pradesh, Tamil Nadu, Kerala and Maharashtra, particularly the (Konkan coast) along with Uttar Pradesh and Bihar. Recently, Paddy has also become an important crop of Punjab and Haryana.

2.1.1 Wheat production in India

Wheat is one of the most important staple food grains of human race. India produces about 70 million tonnes of wheat per year or about 12 per cent of world production. The Major Wheat producing states in India is placed in the Northern hemisphere of the country with UP, Punjab and Haryana contributing to nearly 80% of the total wheat production.



Source: Ministry of Agriculture, GOI; and FAS/New Delhi estimates for MY 2012/13

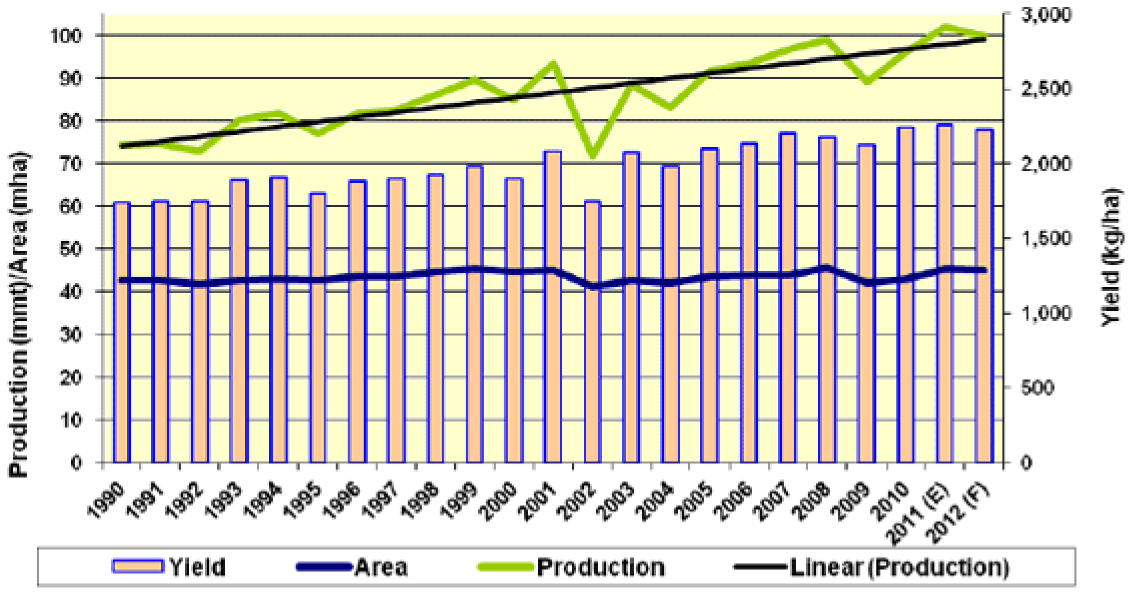
Fig 2.1 Graph showing Wheat production in India

Assuming normal weather conditions through harvest (April), From Fig 2.1, post currently forecasts marketing year (MY) 2012/13 wheat production to increase to a record 87.5 million tons from 29.6 million hectares compared to 86.9 million tons from 29.4 million hectares last year. The government's preliminary 2012 wheat production estimate is higher at 88.3 million tons on slightly optimistic yield expectations as high temperature during harvest may temper yield prospects.

2.1.2 Paddy production in India

Rice is grown in many regions across India. For about 65% of the people living in India, rice is a staple food for them. It is a part of nearly every meal, and it is grown on a majority of the rural farms. West Bengal, Uttar Pradesh, Andhra Pradesh, Punjab, Tamil Nadu, Bihar, Orissa, Assam, Karnataka and Haryana are the major producing states. More than 50% of total production comes from the first four states.

Assuming normal 2012 monsoon rains (June-September) and weather conditions, From Fig 2.2, post forecasts MY 2012/13 rice production at 100 million tons from 45.0 million hectares, marginally lower than the estimated MY 2011/12 record production of 102 million tons.



Source: Ministry of Agriculture and FAS New Delhi estimates for 2010/11 and 2011/12

Fig 2.2 Graph showing Paddy production in India

2.2 Stubble burning

Stubble is the base of the plant and the straw residue remaining on the surface of the soil following the harvest of particular crops. This includes material discharged from the harvester. The stubble and straw remaining in grass seed fields after harvesting seed is known as residue. Burning is one way to dispose of the straw left after harvest so fields can be made ready for seeding the following spring.

However, some farmers find it difficult to deal with straw in the normal ways. For example, a bumper crop can leave a tremendous amount of straw, which can be very difficult to work into the soil or spread evenly across the field. Rainy weather after harvest can leave fields too wet to till. Burning straw is considered a low-cost solution alternative to tilling in the straw. Under such circumstances, farmers may have no choice but to burn the straw.

'Agricultural stubble burning'—or 'crop stubble burning'—is one of several types of prescribed biomass burning'. In some countries, Malaysia for example, high purity silica is produced from rice stubble. Agricultural stubble burning produces broad area emissions of smoke, particulates, breakdown products, dioxins and associated odour. Each of these can have adverse off-site impacts if not properly managed. Burning may also involve the release of pesticides and herbicides that have been used on the crops to be burnt.

The impacts of the emissions, and hence the potential for health effects, are heightened if the burning is conducted during periods when the prevailing weather is conducive to very poor dispersion and poor dilution of the smoke. In the case of broad area stubble burning, poor dispersion occurs when the smoke plume is confined close to the ground and drifts almost intact, rather than dispersing and diluting itself downwind.

The composition and intensity of the smoke produced from the combustion of the biomass is influenced by all of the following factors:

- Crop area burned
- Meteorological conditions
- Soil moisture content
- Nature of the stubble, its density and its moisture content.

It is important to understand how plants utilize nutrients from the soil and how burning affects available soil nutrients. Long-term annual burning results in lower levels of soil organic matter and net N mineralization rates, but higher levels of plant productivity compared with no burning. Microbial biomass is important to crop, pasture, and grass production in that a constant "pool" of microbes is needed to break down straw, stubble, and duff into nutrients that are useable by plants. When there are very few microbes (a small pool), there is less total activity to break down straw and stubble and, thus, less nutrients available for the plant. This in turn relates to reduced production. Fertilizer can be added to somewhat help increase the amount of available nutrients in these cases. However, research has shown that with the reduction of microbial biomass, more and more fertilizer is required to maintain production levels, which may have their own environmental implications. Hence, the size and ratios of biologically active pools of C and N are important indicators of soil health and sustainable production.

CHAPTER 3
MONITORING

3.1 Overview

The monitoring of pollution levels in the atmosphere is of fundamental importance because it measures the extend of existing pollution, effectiveness of air pollution control devices and future efforts required. So, numbers of factors which are considered before starting sampling at study area are as follows *(CPCB, 2003)*:

a) Selection of procedures for sampling and analysis

b) Sampling locations

c) Period of sampling, frequency and duration of sampling

d) Processing of data

3.1.1 Selection of sampling procedures

There are two types of sampling:

- Continuous sampling
- Time averaged in-situ sampling

Continuous sampling is carried out by automatic sensors, optical or electrochemical, and spectroscopic methods which produce continuous records of concentration values. The specific time-averaged concentration data can then be obtained from continuous records. Time-averaged data can also be obtained by sampling for a short time – i.e. by sampling a known volume of air for the required averaging time. Samples are then analysed by established physical, chemical, and biological methods for the concentration values which are the effective average over the period of sampling.

3.1.2 Sampling locations

Sampling locations are in general governed by factors like objectives, method of sampling, meteorological conditions and resources available. During ambient air quality sampling, sampling was done for number of pollutants on selected sites. Sampling site must be carefully selected so that it can represent the areas under study. Concentration of pollutants varies with altitude i.e. results obtained on breathing level ground to that obtained on a taller building differs. Number of sampling stations and their location depend on several factors including the objectives of the programmes, the size of the study area, and the proximity of the source of pollution, topographical features, local weather condition and meteorological parameters. A representative number of sampling stations for a given area may be established by means of a preliminary survey, whose objectives should be:

- To gather preliminary information of the study area and principal sources of pollution.
- To review the available climatological and meteorological data.
- To gather data on the concentration of pollutants in areas of severe and slight pollution.

3.1.3 Period of sampling, frequency and duration

Period, frequency and duration of sampling should be appropriate to measure the actual existing ambient air quality. It should be such that the measurable quantities are trapped in the sample at the end of the sampling. It is preferable to observe sampling period consistent with the averaging times for which air quality standards of the given pollutants are specified.

3.2 Chemical characterization

Particulate is the main component of air pollution and its harm to human body has already been proved by epidemiology. The extent of particulate's harm is pertinent to the aerodynamic diameter, chemical composition and the category of the source emission. No chemical analysis method, no matter how accurate or precise, can adequately represent atmospheric concentrations if the filters to which these methods are applied are improperly selected or handled. $PM_{2.5}$ or PM_{10} filter mass deposits are usually measured in micrograms (one-millionth of one gram). These are very small quantities, and even the slightest contamination can bias these mass measurements. Most chemical species that constitute $PM_{2.5}$ or PM_{10} are measured in nanograms (one-billionth of one gram).

The risk of sample contamination when measuring these chemical components is 10 to 1,000 times greater than it is when measuring mass concentrations. Small biases in chemical concentrations can greatly affect the decisions that are made with respect to source apportionment or health effects, so extra precautions are warranted when selecting and using filters. Teflon-membrane and quartz-fiber filters are most commonly used for the $PM_{2.5}$ and PM_{10} chemical analyses. Component analysis was conducted for the $PM_{2.5}$ samples collected through water soluble ions.

The water-soluble portion of suspended particles associates itself with liquid water in the atmosphere when relative humidity increases, thereby changing the light scattering properties of these particles. Different emissions sources may also be distinguished by their soluble and non-soluble fractions, as in the case of soluble potassium. Gaseous precursors can also be converted to their ionic counterparts when they interact with chemicals impregnated on the filter material. Polyatomic ions such as sulfate, nitrate, ammonium, and phosphate must be quantified by methods such as ion chromatography (IC).

Since the city selected for the study is one of a critically polluted city, it becomes necessary to determine the quality of Ambient air on a regular basis and take preventive measures.

3.3Objectives of the Present Study

The objectives of the present study are as follows:

- Selection of sampling sites.
- Monitoring the concentration of PM_{10} and $PM_{2.5}$.
- Chemical characterization of collected dust.

CHAPTER 4

REVIEW OF LITERATURE

Air quality protection is a key element in ensuring sustainable livelihoods for both present and future generations. Pollution from urban atmosphere is due to air pollutant emissions and transmissions. One of the main reasons for deterioration of air quality is the post harvesting burning. The stubble left after harvesting of crop is burned to clear the field for sowing the next crop. The stubble burning affects the air quality, which can be determined by monitoring before and after stubble burning. Literature abounds in studies on air quality and the effect of harvesting on ambient air quality. Below is presented a selection of works that have dealt with this topic and also the main ideas that emerge from these works.

4.1 INTERNATIONAL SCENARIO

Biederbeck et al., 1980 reported that the heat from burning residue penetrated the soil to a depth of one-half inch. This means that many insects and diseases that are soil borne or overwinter in the soil are not affected by burning. While burning can eliminate up to about 314 of the straw from a field burning also oxidizes about 314 of the nitrogen that would occur from the decomposition of the straw, which reduces soil health and soil fertility. Additionally, research is also consistent in findings that burning increases the erodibility of the soil, reduces water intake of the soil, and increases soil density (reducing porosity).

Ojima, 1987 found that microbial biomass C and N were reduced by long-term annual burning, but were affected very little by short-term burning (1 to 2 years).The study also showed that short-term burning created increased active N and N mineralization rates (increase in available N for the plant). However, long-term burning resulted in a decrease of soil organic matter and N mineralization rates.

Doran and Smith, 1987 suggest that changes in nutrient cycling, and thus greater nutrient availability, are associated with changes in the size and activity of labile and stable organic matter "pools" in the soil.

Gupta, Grace, and Roper,1994 completed research on arable soils in Australia associated with cereal grain production, that suffered severe declines in soil organic matter, an important source for plant essential nutrients. The objective of their study was to evaluate crop residue management systems for their ability to improve soil organic matter as well as Carbon and Nitrogen availability. In their study, they compared: 1) residues burned, 2) residues retained, and 3) a mixture of burned and retained residue. The findings of the study showed that different crop residue management systems had a significant impact on C and N levels which would directly affect production levels. Residue retention significantly increased the amounts of mineralizable C and N compared with when residue was burned. The study also showed that continuous retention of high C/N ratio residues (cereal grain residues) increases microbial activity in the soil but not the size of the biomass.

The study conducted by *Jimenez,2002*, was to characterize the air quality impacts from agricultural field burning and to evaluate the Washington Department of Ecology Smoke Management Program. The burn seasons 2000 and 2001 were selected and data collected included: meteorological conditions, burn reports, burn calls and citizen complaints, along with observed air quality data from regional monitoring stations. Backward trajectories were developed for selected smoke episodes. Eight smoke events observed in Pullman, WA were analysed. Results show that in four cases, field burning was found to contribute to the air pollution observed. Occurrences of smoke intrusion were also identified in Pullman on days when agricultural burning was not allowed due to poor ventilation. The year 2001 had a smaller number of acres burned during the Fall (26,652 acres) compared to the Spring (99,633 acres). But it also had fewer burn days (22 days) in Fall. During the Fall 2000 burn season, wildfires in the region had a significant impact on the air quality in Eastern Washington.

In the survey done in China by *Gao et al.,2002*, report that only 6.6% of the crop residue was burned in the field on average and 36.6% of the crop residue was returned to the soil directly. *Streets et al., 2003* prepared a more thorough estimate of trace gas and aerosol emissions from biomass burning in China, including biofuel combustion, crop residue burning in the field, and forest and grassland fires. But in these researches, the proportion of crop residue burned in the field may be understated. *Cao et al., 2005* and *Yan et al., 2006* regarded that with the economic development, crop residue was not one kind of necessary fuel, collecting them was very troublesome, the places to store them were short, and there were few ways to use them were the main reasons why crop residue was burned in the field.

Yang et al., 2007 reported that in China, many pollutants are released because of crop residue burning in the field, resulting in serious pollution of ambient air. Based on the data of crop output from 2001 to 2005, the annual average amount of crop residue generated was estimated as 3.04-106 t. About 82% of wheat straw and 37% of rice straw were burned in the field, so the proportion of crop residue burned in the field was about 43%. The daily average concentration of PM_{10} kept exceeding 0.250mg/m^3.

In Thailand and many other Asian countries, where rice is the major crop, open burning of rice straw after harvesting is a common practice. This activity releases a large amount of air pollutants, which can cause serious effects on the ambient air quality, public health and climate. *Tipayarom et al.,2007* counted the number of hotspots, which represents open fires, detected on the Moderate Resolution Imaging Spectro-radiometer (MODIS) satellite images over the Pathumthani. The results show high numbers of hotspots during the rice straw burning season. Good correlation was obtained between hotspots numbers and the levels of air pollutants, including carbon monoxide and particulate matter.

The influence of 1 years of stubble burning on the carbon storage as well of chemical composition of soil organic matter (SOM) was studied in agricultural soil of a long term field experiment by *Rumpel, 2008*. Additionally, the potential of black carbon (BC) produced by burning of harvesting residues, to be lost by horizontal as well as vertical transport was quantified during a rainfall simulation experiment. Carbon content of the agricultural soils of the Issoudoun field trial ranged between 1.9 and 16. G/kg, the control soil showed slightly higher initial carbon contents. The burned plot showed carbon stocks of 4 Gg/ha after 31 years of stubble burning. These values were not significantly different from those measured before burning.

Guoliang et al.,2008 noted that wheat straw had the top emission factor for the total PM (8.75 g/kg) among the four crop residues, while, highest emission factor of corn stover and wheat straw for EC (elemental carbon) (0.95 g/kg) and OC (organic carbon) (3.46 g/kg) respectively.

The traditional manual sugarcane harvesting requires the pre-harvest burning practice which should be gradually banned by 2021 for most of S˜ao Paulo State, Brazil, on cultivated sugarcane land. To forward the end of this practice to 2014, a “Green Ethanol (GE)” Protocol was established in 2007. *Daniel et al., 2011*analysed five years of continuous sugarcane harvest monitoring, based on remote sensing images, to evaluate the effectiveness of the Protocol, thus helping decision makers to establish public policies to meet the Protocol's expected goals. The conclusion was that the "Green Ethanol" Protocol was effective with a positive impact on the increase of GH, especially on recently expanded sugarcane fields.

Cheewaphongphan and Garivait, 2009 reported that the open Burning of rice residue is the common practice in Thailand that releases pollutants and greenhouse gases emission. He estimated the spatial and temporal distribution of emissions from rice field residues burning during 1998-2009 in Thailand, using questionnaire survey and field experiment. The annual average amount of burned area was estimated as 4.7 Mha (SD 0.2 Mha), included 2.1 Mha (SD 0.2 Mha) in irrigated-area and 2.5 Mha (SD 0.06 Mha) in rain-fed area. The average annual amount of burned rice residue is about 21.7 Mt (SD 1.8 Mt). *Garivait, 2002* studied the Climate Change and reported that open biomass burning constitutes one of the major sources of atmospheric trace gases and particulate matter or aerosols, especially during the dry season. They investigated forest fires and agricultural crop burnings in Thailand using remote sensing data combined to those obtained from field surveys. Preliminary estimations obtained using the emission ratios and factors issued from literature review indicated that an average of 44 Tg of biomass is burnt annually in Thailand on average. This leads to a total emission per year of 69 Tg CO2, 4.5 Tg CO, 0.46 Tg CH4, 0.4 TgNO_x, 0.06 Tg NH3, 0.02 Tg SO_2 and 0.8 Tg NMVOC.

Yu Tai-Yi, 2011 analysed and estimated with measured data the spatiotemporal characteristics and impact of ambient air-quality attributed to open burning of rice straw. In typical air-quality stations, the average hourly incremental concentrations between the episode and non-episodes were greater than 300 mg/m^3 for PM_{10}, 1.0 ppm for CO and 35 ppb for NO_2 during the impact of rice straw burning.

Harnly et al., 2012 studied a winter period in Imperial County when predominantly Bermuda grass stubble was burned. At four locations, $PM_{2.5}$ levels were 23% higher from 4 P.M. on burn days to 8 A.M. the following morning than on days when there were no burns. On days when a burn was within 2 miles of a monitoring site, concentrations were 7 to 8 $\mu g/m^3$ higher than on days when burns were farther away; measured levels lowered air quality, which potentially approached moderate. In monitoring five specific burns, they found that the levels of particulate matter with aerodynamic diameter smaller than 10 micrometers (PM_{10}) were highly elevated and potentially hazardous directly downwind of one field. In addition, $PM_{2.5}$ was composed primarily of carbon, and levels of naphthalene, a respiratory carcinogen, were elevated compared with upwind samples.

Choi et al., 2013 used the model to estimate the emission from open biomass burning. Estimation of emissions from fires, however, has been problematic, primarily because of uncertainty in the size and location of sources and in their temporal and spatial variability. Hence, more comprehensive tools to estimate wildfire emissions and that can characterize their temporal and spatial variability are needed. The BlueSky Framework, which was developed by the USDA Forest Service and US EPA, was used to develop the Asian biomass-burning emissions modeling system. The sub-models used for this study were the Fuel Characteristic Classification System (FCCS), CONSUME, and the Emissions Production Model (EPM). This study suggests a practicable and maintainable methodology for supporting Asian air-quality modeling studies and to help understand the impact of air-pollutant emissions on Asian air quality.

4.2 NATIONAL SCENARIO

One of the major sources of emission of greenhouse gases (GHGs) is biomass burning, thus the space-based observations of global distribution of fire form a key component of climate change is studied by *Singh and Panigrahy, 2003*. This study mainly highlights the spatiotemporal occurrence of agricultural residues burning in Indo-Gangetic plains of India using fire products from space borne satellites. The fire incidents are reported very high in October-December (55%) compared to that in March-May (36%), indicating that burning of rice residue is more prevalent than that of wheat. In the first part, April shows the highest fire events with 18.25% and the in the second part, October shows the highest fire events with 45.59% out of total agricultural fire in the study area. This is due to the burning of leftover crop residues of rice crop before planting of rabi season crop The fact is that, the time-gap available for planting rice is quite high and therefore the farmer may wait for rainfall to get the residues naturally decomposed. On the contrary, the time gap available between rice to wheat cropping is not sufficient for nutrient enrichment.

Singh et al., 2008 conducted a preliminary evaluation of the direct financial benefits and costs to farmers of use of the Happy Seeder (HS) in comparison with the current practices of straw burning followed by direct drilling or conventional tillage prior to sowing. The results of the evaluation suggest that the HS technology is more profitable than conventional cultivation or direct drilling after burning, and that it is viable for farmers from a financial perspective. The net present value (NPV) of the benefits is highly sensitive to yield; a 5% increase in yield with the HS doubles the increase in NPV of the HS over conventional tillage.

Singh, 2009 investigated the use of multi-sensor characteristics for accurate assessment of burned areas at regular intervals for two districts of Punjab. MODIS and AVHRR have been used in the quantitative estimation of burned areas. The study suggested that for crop residue burning, a multi-sensor approach is effective for improving the accuracy of burned area.

Kumarl,2009 measured the value of health effects of air pollution for the Indian rural Punjab, where air pollution problem occurs from crop residue burning. Consumer choice model is used to get the monetary estimates of reduced air pollution level to the safe level. Total annual welfare loss in terms of health damages due to air pollution caused by the burning of rice straw in rural Punjab amounts to Rs.76 million. If one also accounts for expenses on averting activities, productivity loss due to illness, monetary value of discomfort and utility and additional fertilizer, pesticides and irrigation, the losses would be much higher.

Sharma et al.,2010 studied the impact of post-harvest biomass burning on aerosol characteristics of Patiala, Punjab state, India during 2008-09, using ground based and satellite data. There was a gradual increase in the Aerosol Optical Depth (AOD) values more significantly at shorter wavelengths (380-500nm) as compared to longer wavelengths in the first half of October 2008 suggesting additional loading of submicron aerosols over the region as the crop residue burning activity picks up during this period. AOD values reaches to its peak value (3.2 at 380nm) at the end of October followed by a decrease approaching to a minimum in the second half of November when the burning process of straw in the fields almost ceases.

Singh et al.,2010 conducted the ground-based ambient air monitoring at five different locations in and around Patiala city in order to determine the impact of open burning of rice (Oriza sativa) crop residues on concentration levels of SPM, SO_2 and NO_2. Substantially higher concentration was recorded at the commercial area site as compared to the other sampling sites for all the targeted air pollutants. Levels of SPM, SO_2 and NO_2 showed clear increase during the burning months (October–November). *Awasthi et al.,2011* studied the size segregated mass distribution of RSPM was done for 2 wheat and 3 rice crop seasons using eight staged impactor at rural and agricultural sites of Patiala (India) where the RSPM levels remained close to the National Ambient Air quality standards (NAAQS). The levels increased up to 66, 78 and 71% during rice season and 51, 43 and 61% during wheat crop residue burning, respectively. Above scientific literature shows that the studies were focused on the contribution of vehicular and industrial emissions in the increment of air contamination in metropolitan cities. Studies on the concentration of suspended particulate matter with special reference to vehicular exhaust emission were carried out in the year 2004 by *Mittal et al.,*at some commercial and curbside locations in Patiala.

Kothai et al.,2011 collected a Particulate matter samples using a dichotomous sampler at a residential area of Vashi situated in Navi Mumbai, India during the period of 2008. The sampler facilitates the simultaneous collection of atmospheric particulates in coarse and fine size fractions. The filter samples collected were analysed for trace elements using Proton Induced X-ray Emission (PIXE) technique. The particulate matter trends show higher concentration during winter season compared to other seasons. High concentrations of elements related to soil and sea salt were found in the coarse fraction of particulate matter. Enrichment Factor (EF) analysis with respect to Fe showed enrichment of Cu, Cr, and Mn only in the fine fraction suggesting their origin from anthropogenic sources. The EF value was observed to be maximum for As, Pb and Zn in the fine particulates.

Gupta et al., 2013 conducted a study to find out the type and amount of air pollution in Mandi Gobindgarh township and surrounding areas to provide a base for taking counter measures to control and eliminate the various forms of pollution in an effort to make MandiGobindgarh and surrounding areas pollution free and the people saved from the pollution related diseases. Samples were selected from among the residents of MandiGobindgarh (113) and over 20 villages (99) around to know their experience of pollution. Also samples were obtained from the persons involved with sources of pollution i.e., industry managements (45), industry labour (48), farmers (49) and farm labour (40). In rural areas around, one can see billowing smoke from vast rice and wheat fields where the rice stubble is being burnt in October-November and from wheat stubble in April-May. Most dangerous air pollution in the town area is due to the excessive suspended particles in the air. In rural areas air is polluted by particulate matter, CO2, NOx from Stubble burning in fields, Tractors, tube wells run on diesel, brick kilns, generators, coal and firewood burning in sigris and chullahs in homes and offices during winters, wood, grass and gobar burning. The effect of pollution is much lesser pronounced in rural areas than in urban areas. However the sickness increases in rural areas during paddy and wheat chaff burning due to toxicity of the gases from chaff. The presence of all these pollutants is considered alarming and their prolonged exposure has led to various health ailments.

Tripathi et al., 2013 covered the burning of crop residues / biomass and its effect on atmospheric quality and climate and also suggested some management options for crop residue/biomass besides burning which may be reducing the air pollution, climate as well as possibility of risk on human health. Almost all researchers agreed that open burning of crop residue / biomass significantly increases the level of particulate matter, gaseous pollutants (SO_2, NO_x, VOCs, and PAHs etc) in atmosphere. However some researchers believe that impact of crop residue/biomass burning have a minor role in climate change.

4.3 Research Gap

1. Few reports highlight the air quality of metropolitan cities of India but still study is incomplete and partial in comparison to global scenario.
2. Further, no detailed study of the effect of harvesting on the air quality of industrial estate (MandiGobindgarh) has been published.
3. Meteorological parameters have not been included in the studies related to ambient air quality.

CHAPTER 5

MATERIALS AND METHODS

5.1 Instruments used

In this chapter, materials and methods used in this study are described in details, including the instrument, computational techniques and procedures used for site selection, sampling of air, analysis of pollutant concentration and chemical characterization of collected dust.

5.1.1 $PM_{2.5/10}$ sampler

$PM_{2.5/10}$ Sampler i.e. Ambient Fine Dust Sampler, Model no. IPM-FDS-2.5μ/10μ of INSTRUMEX is an advanced sampler conforms to the USEPA and CPCB norms. This sampler uses a set of impactors standardized by USEPA to separate coarse particulates from the air stream. For sampling of $PM_{2.5}$, particles with aerodynamic diameter larger than 10 microns are trapped by using the opposed jet impaction over a filter paper of specified Whatman number 7582-004, 37mm diameter supported on surface by silicon oil and those having a diameter between 2.5 and 10 Microns are trapped over PTFE filters using the WINS Impactor. But for sampling of PM_{10}, WINS Impactor unit is replaced by PM_{10} impactor assembly using a filter paper of Whatman number 1820-047, 47mm diameter.

Finally air stream leaving the WINS Impactor consists of only fine particulates with an aerodynamic diameter smaller than 2.5 microns. The flow is controlled by microprocessor based flow controller for maintaining the flow rate constant at 16.67 LPM. This instrument also has two other sensors for the temperature and pressure measurement. All the parameters like sampling period, flow rate etc. were set in control module. The instrument samples for a specific and pre-determined period. All parameters are available at an interval of every 5 minutes and can be downloaded using a USB interface.

Fig 5.1: $PM_{2.5/10}$ Sampler

5.1.2 Weather Monitoring Station (WMS)

The weather monitoring station used in this study was Watch Dog of Spectrum Series 2000. The WatchDog weather station is a multifunction device to detect as well as to stores even parameters including wind speed, wind direction, temperature, relative humidity, dew point, pressure and solar radiations using different sensor for each. The WatchDog weather station can be used in agriculture and gardening as well as in industry, and in the research sector. Its measurement ranges are wind speed 0 to 281 Km/h, wind direction 0 to 360 deg, air temperature -20 to +70 deg C, air humidity 20 to 100% and rainfall 6.5cm/measurement period.

Weather monitoring station must be installed at site where there is no obstruction in path of wind so that correct data can be collected. It consist of lightweight three cup type anemometer for measuring wind speed ranging from 0 to 150 mph and wind vane for the determination of wind direction. Interval for the data collection can be chosen between 1 to 60 minutes. Data logger allows storage of data for 6 months at a time and the stored data can be transferred to computer using data cable.

Fig 5.2: Weather monitoring station

5.2 Computational techniques

In order to plot wind Rose diagrams, Wind Rose PRO software was used. It is a windows application for analysing and plotting directional variables starting from raw data or from their frequencies and creating wind roses. A wind rose is a chart which gives a view of how wind speed and wind direction are distributed at a particular location over a specific period of time. It is a very useful representation because a large quantity of data can be summarized in a single plot. In wind rose, length of arm represents the frequency of a specific wind direction and its position on polar coordinate represent wind direction. The number of arms can be decided by user, which may be 4, 8, 16 and maximum of 360. It imports data in many formats, analyses them and creates different types of charts. The results can be exported in Microsoft excel format, and charts are automatically created within excel. Wind roses can be saved in raster format (BMP, JPG and PNG), and exported as DXF, shape files (SHP) or KML for Google Earth.

5.3 Methodology

The study was carried out in three steps which are:

- Selection of sampling sites.
- Air sampling and analysis.
- Chemical characterization of collected dust.

5.3.1 Selection of sampling site

On the basis of wind roses, land use and demography and six industrial clusters identified by PPCB, five sampling sites were selected, in order to have representative sampling. The wind data collected for the period September 2011 to June 2012 was used for making wind roses which were used in selecting site for sampling.

Monthly, quarterly and half yearly wind roses were plotted from the wind data i.e. its speed and direction, collected for the period of 21 months i.e. September 2011 to May 2013 by using weather monitoring station. The site for installation of weather monitoring station should be an open area with no obstruction to ensure accurate measurement of wind speed and direction. So for this study, the site selected was Thapar University (30°35'39"N, 76°37'07"E), Patiala as it is nearby to a study area

In diagrammatic representation of wind rose, each concentric circle represents a different frequency, emanating from zero at the centre to increasing frequencies at the outer circles. Using a polar coordinate system of gridding, the frequency of winds over a long time period were plotted by wind direction, with color bands showing wind ranges. In order to plot wind rose diagram, seven different wind speed ranges were taken into consideration. The direction of the wind rose with the longest spoke shows the wind direction with maximum frequency. Calm period was taken for speed range <1Km/h and it was included at the centre of the diagram. Wind rose diagram were plotted using Wind Rose Pro setup from Enviroware.

Site with maximum vehicular emission is selected on the basis of town head country planning of Mandigobindgarh, land use feature is determined by satellite imagery and demography of different clusters.

5.3.2 Air sampling and analysis

Sampling of PM_{10} and $PM_{2.5}$ was carried out for one rice harvesting period from September 2012 to January 2013, and one wheat harvesting period from March, 2013 to May 2013, at all the five selected sites using Fine Dust Sampler. Sampling was done thrice at each site for each crop season viz pre-harvesting, during harvesting and post-harvesting. Duration for sampling for each pollutant was 24hr.

5.3.2.1 Monitoring of $PM_{2.5}$:

Fine dust sampler with WINS impactor assembly was used to find out the concentration of suspended particulate of size between 2.5µm to 10µm. Different steps followed during sampling were:

1. The tripod stand was installed and the instrument case was placed over it by making sure that exhaust pipe at right rear of the instrument was not stuck between the frame of the stand and the instrument body.
2. The instrument case houses the WINS impactor and the filter holder along with the vacuum pump and control module. The WINS impactor on filter holder cover was mounted.
3. The WINS impactor assembly was opened, a fresh 37 mm diameter filter was placed in the well and 1 ml of silicon oil was poured over filter paper using a dropper.
4. Then the filter holder was opened that follows the WINS impactor which had a filter cassette with metal wire mesh inside it. Preconditioned and pre weighed PTFE 46.2 mm filter paper was placed on it and snapped into filter cassette. Then the entire assembly was tighten.
5. Now different parameter like flow rate and sampling period was set in control module and sampling starts.

Calculation of the volume of air sampled was done using following equation:

$$\mathbf{V = (F_1 + F_2) * T/2}$$

Where,

V = volume of air sampled in cubic meter

F_1 = measured flow rate before sampling

F_2 = measured flow rate after sampling

T = time of sampling

$PM_{2.5}$ concentration was calculated by:

$$\mathbf{PM_{2.5} = (W_f - W_i) * 1000 / V_a}$$

Where,

$PM_{2.5}$= Total mass concentration of $PM_{2.5}$ collected during the sampling period, ug/m^3

W_f, W_i= Final and Initial mass of PTFE filter paper, mg

V_a= Total air volume sampled (m^3)

5.3.2.2 Monitoring of PM_{10}:

Fine dust sampler with PM_{10}impactor assembly was used to find out concentration of suspended particulate of diameter higher than 10µm within the air. For this WINS impactor assembly is removed and only one 47mm diameter filter paper was used. Following are the steps followed during air sampling for PM_{10}:

1. The tripod stand was installed and the instrument case was placed over it by making sure that exhaust pipe at right rear of the instrument was not stuck between the frame of the stand and the instrument body.
2. PM_{10}impactor assembly was placed in place of WINS impactor assembly and all the joints are tightened each joint tightly.
3. The filter holder was opened and preconditioned and pre-weighed 47 mm diameter glass fiber filter paper was placed on metal wire mesh present in filter cassette. Then cover the filter holder and tighten the entire assembly.
4. Now different parameter like flow rate and sampling period was set in a control module and sampling started.

Calculation of the volume of air sampled was done using following equation:

$$\boldsymbol{V = (F1 + F2) \times \frac{T}{2}}$$

Where,

V = volume of air sampled in cubic meter

F_1 = measured flow rate before sampling

F_2 = measured flow rate after sampling

T = time of sampling

PM_{10} concentration was calculated by:

$$\boldsymbol{PM = (Wf - Wi) \times \frac{1000}{Va}}$$

Where,

PM_{10}= Mass concentration of PM_{10} collected during the sampling period, µg/m^3

W_f, W_i= Final and Initial mass of glass fibre filter paper, mg

V_a= Total air volume sampled (m^3)

Precaution taken during handling of filters:

- Clear forceps were used to handle the filters and each time the forceps were cleaned with ethanol and then with Milli-Q water to avoid any contamination.
- The exposure of the filters to open air was kept minimum by keeping them covered inside the filter carriers provided with the instrument.
- Since filter papers are fine and fragile materials, so handle with care.
- Filters were inspected against the light source for pinholes and loose contamination before use.

An air sampler draws ambient air at a constant flow rate into a specially shaped inlet where the particulate matter is inertially separated into one or more size fractions within the PM size range. Each size fraction in the PM size range was then collected on a separate filter over the specified sampling period. The total volume of air sampled, measured at the actual ambient temperature and pressure, and was determined from the measured flow rate and the sampling time.

5.3.2.3 Chemical characterization

All ion analysis methods require a fraction of the filter to be extracted in Double distilled water and then filtered to remove insoluble residues prior to analysis. The extraction volume needed to be as small as possible, lest the solution become too dilute to detect the desired constituents at levels typical of those found in $PM_{2.5}$ or PM_{10}. Each square centimeter of filter was extracted in no more than 2 ml of solvent for typical sampler flow rates of 16.7 L/min and sample durations of 24 hours. This often results in no more than 20 ml of extract which was submitted to the different analytical methods, thereby giving preference to those methods which require only a small sample. Sufficient sample deposit must be acquired to account for the dilution volume required by each method.

The major sampling requirement for analysis of water-soluble species was that the filter material be hydrophilic, allowing the water to penetrate the filter and fully extract the desired chemical compounds. Small amounts of ethanol or other wetting agents were sometimes added to the filter surface to aid the wetting of hydrophobic filter materials, such as Teflon-membrane. The filter section was placed in an extraction vial which was capable of allowing it to be fully immersed in ~10 ml of solvent (the Falcon #2045 16 H 150 mm polystyrene vials were good choices). Each vial was properly labeled with the sample ID and capped. Since much of the deposit was inside a fiber filter, agitation was needed to extract the water soluble particles into the solution. Experiments showed that sonication for ~1 hour, shaking for ~1 hour, and aging under refrigeration for ~12 hours assured complete extraction of the deposited material in the solvent (*Chakraborty, 2010*).

The sonicator bath water needed to be periodically replaced or recirculated to prevent temperature increased from the dissipation of ultrasonic energy in the water. After extraction, the solutions were stored under refrigeration prior to analysis. The sample extracted was passed through an ion-exchange column which separates the ions in time for individual quantification, usually by an electro-conductivity detector.

Prior to detection, the column effluent entered a suppressor column where the chemical composition of one element was altered, which resulted in a matrix of low conductivity. The ions were identified by their elution/retention times and were quantified by the conductivity peak area or peak height.

Ion Chromatography (IC) was especially desirable for particle samples because it provides results for several ions with a single analysis and it uses a small portion of the filter extract with low detection limits. In IC, approximately 2 ml of the filter extract were injected into IC system. The resulting peak integrals were converted to concentrations using calibration curves derived from solution standards.

CHAPTER 6

RESULTS AND DISCUSSION

This chapter presents the wind roses, concentration of different pollutants such as PM_{10}, $PM_{2.5}$, and their chemical characterization for all the sampling sites for each crop season. As discussed in methodology, first step was to decide sampling sites on the basis of wind roses, demography and industrial clusters of the study area. Wind roses were plotted for period from September 2011 to August 2012. Wind data was collected at mentioned site at an interval of 1 hr and Wind speeds were grouped into seven categories.

Then conventional wind roses were plotted for the study period of 9 months i.e. from September 2012 to May 2013 by taking wind speed <1km/h as calm period. The conventional wind rose diagram can only depict wind frequencies from different directions at a location but it does not give a pictorial view of the downwind distance up to which wind can cause pollutant to travel. Although, the predominant wind direction can be determined and wind speed during different seasons can be known.

6.1 Wind roses for selection of sampling sites

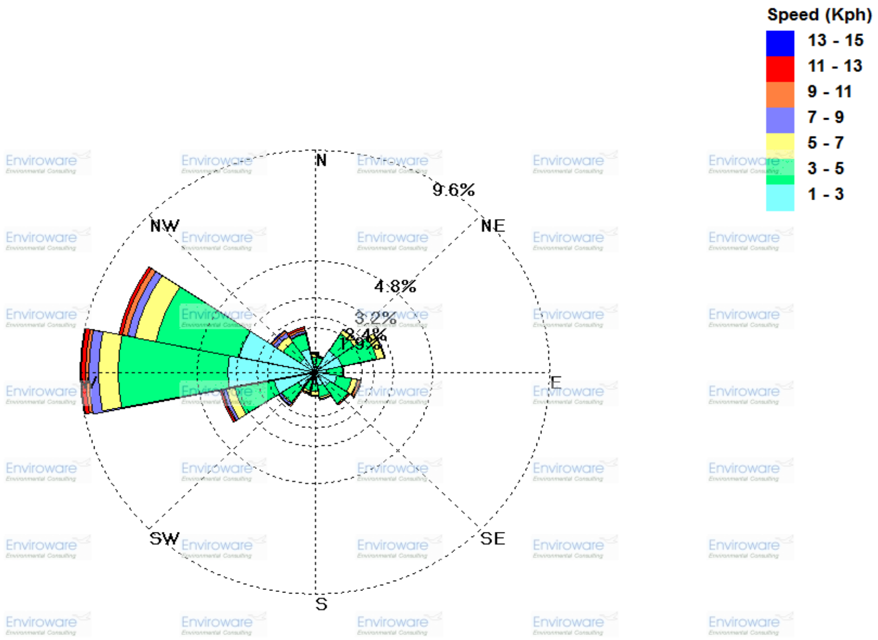


Fig 6.1: Windrose for period September 2011 to August 2012

As it can be observed from the figure 6.1,that during period September 2011 to August 2012 the predominant wind direction was western wind i.e. winds blowing from west to east direction. On the basis of these wind roses, five sampling sites were selected, which are mentioned below

Site 1, is an agricultural area, which is 20 kms South-East MandiGobindgarh bus stand. The site is a broad open area with no side buildings (30°34'23.16"N, 76°21'47.43"E). It is represented as "*Agri site*".

Site 2, is designated as an industrial focal point which is 2 kms South-west from MandiGobindgarh bus stand. This area is less populated as land use of the area is totally industrial (30°38'34.97"N,76°18'27.03"E). It is represented as "*Ind site*".

Site 3, is Guru ki nagri which is south-east on GT road from MandiGobindgarh bus stand. It is a semi- urban site, having mixed land use comprising of industrial, residential and agricultural area (30°40'18.77"N, 76°17'38.29"E). It is represented as "*Mixed-Ind site*".

Site 4, is an area near RIMT, based on national highway 1, with a high proportion of vehicular emission. The site is a broad open area with no side buildings and it is a mixed use area (30°39'5.91"N, 76°19'24.53"E). It is represented as "*Vehi site*".

Site 5, is a partially industrialized area near Saliani village, 2kms North from Amloh Chowk. It represents a site with major proportion of agriculture and to small extent industrial use (30°38'45.86"N, 76°16'1.97"E). It is represented as "*Mixed-Agri site*".

On the basis of predominant wind direction i.e. western winds, Site 1 as shown in the map was selected, it is an agricultural site, Site 2, 3 and 5 were selected on the basis of demography and land use, whereas, Site 4 was selected on the basis of vehicular emissions.

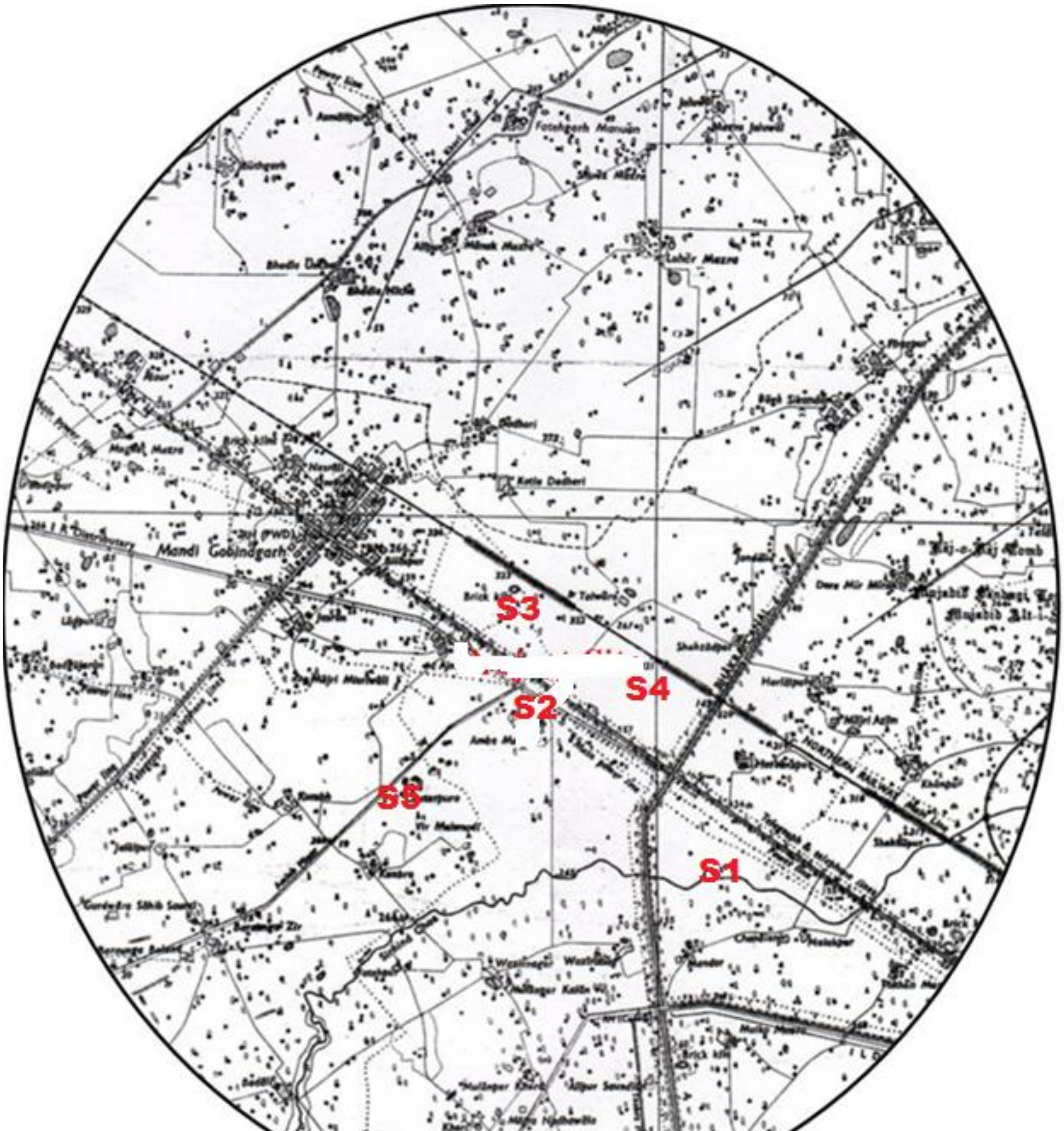


Fig6.2: Location map of different sampling sites.

6.2 Effects due to paddy harvesting

Fig 6.3, 6.4 and 6.5 shows the wind roses plotted for the three sampling periods for paddy i.e. Pre-harvesting (September 2012), harvesting (October- November 2012) and Post- harvesting (December 2012 – January 2013) respectively.

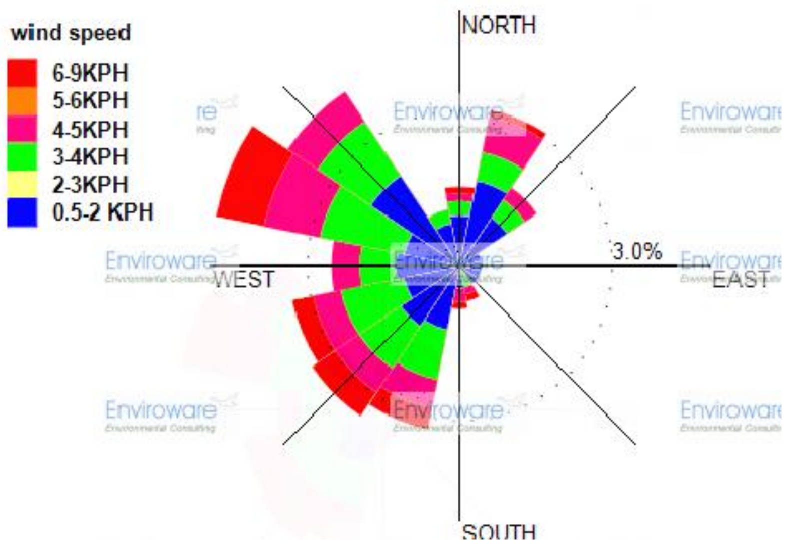


Fig 6.3: wind rose for Paddy Pre-harvesting period (September 2012)

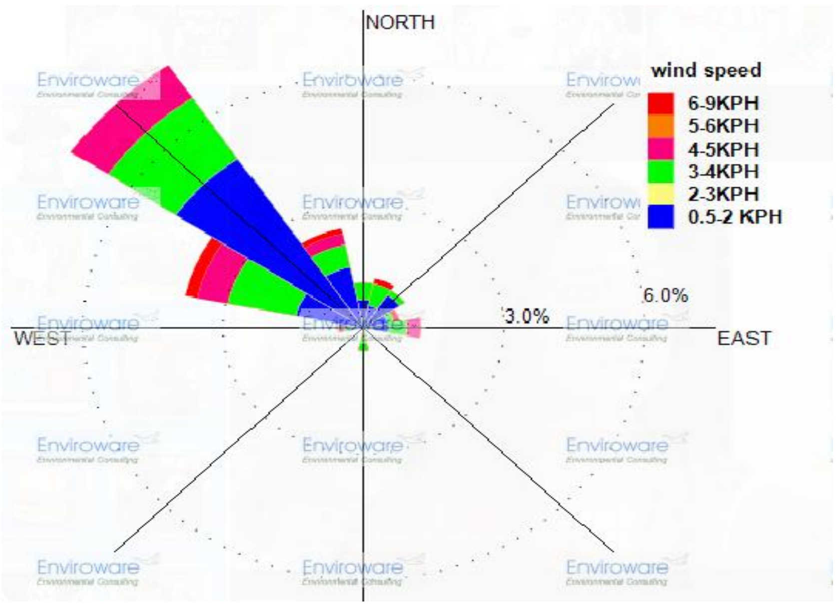


Fig 6.4: wind rose for Paddy harvesting period (October 2012-November 2012)

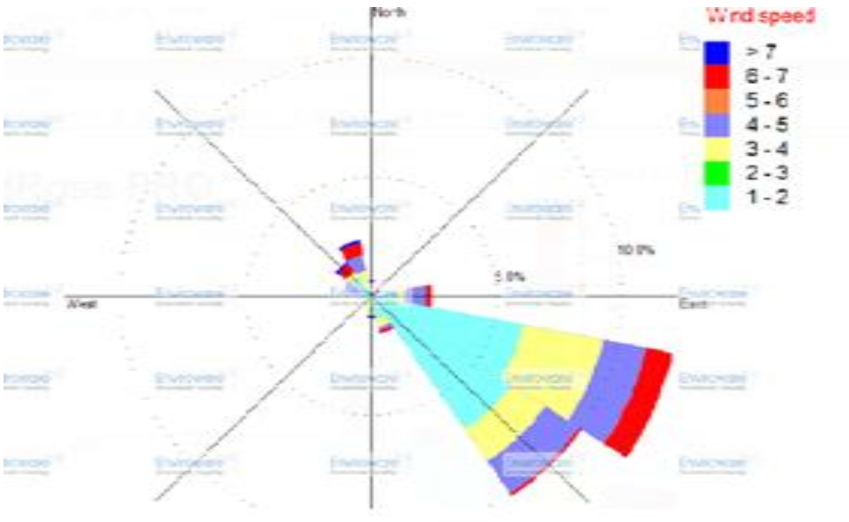


Fig 6.5: wind rose for Paddy Post harvesting period (December 2012-January 2013)

In order to adjudge the effect of Paddy crop residue harvesting on air quality, the concentration of PM_{10} and $PM_{2.5}$ were plotted against three sampling periods i.e. pre-harvesting, harvesting and post-harvesting for all the five sampling sites.

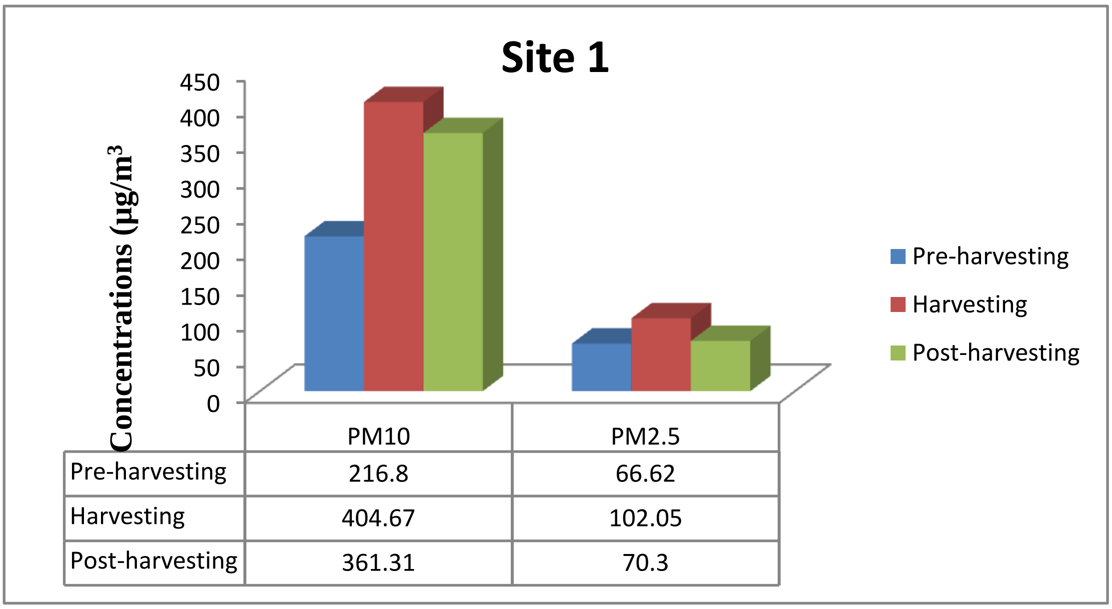


Fig 6.6: Particulate matter concentration at Site 1 for Paddy.

Agri site, where industrial emission impacts are minimal.Fig 6.6 shows, thatthere is more increase in PM_{10} concentration as compared to $PM_{2.5}$ due to stubble burning. During harvesting there was an increase of 86.65% in PM_{10} concentration and 53.2% in $PM_{2.5}$ concentration as compared to pre-harvesting. This substantial increase in PM_{10} and $PM_{2.5}$ concentration is attributed to stubble burning. Whereas, for Post-harvesting, there was an increase of 66.6% and 5.5% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 10.7% and 30.9% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season. Fig 6.3 and 6.4 shows that the predominant wind direction during pre-harvesting and harvesting season is North-west i.e. wind blowing from North-west to South-east. Wind coming from North-west is already polluted from industrial emissions, which further increases the $PM_{10}$and $PM_{2.5}$ concentration level Site 1. Fig 6.5 shows that the predominant wind direction is South-East for post-harvesting i.e. wind blowing from South-east to North-west. The pollutant concentration for post-harvesting is less than during harvesting because of two reasons –less stubble burning impact and due to dispersion of pollutants to North-west.

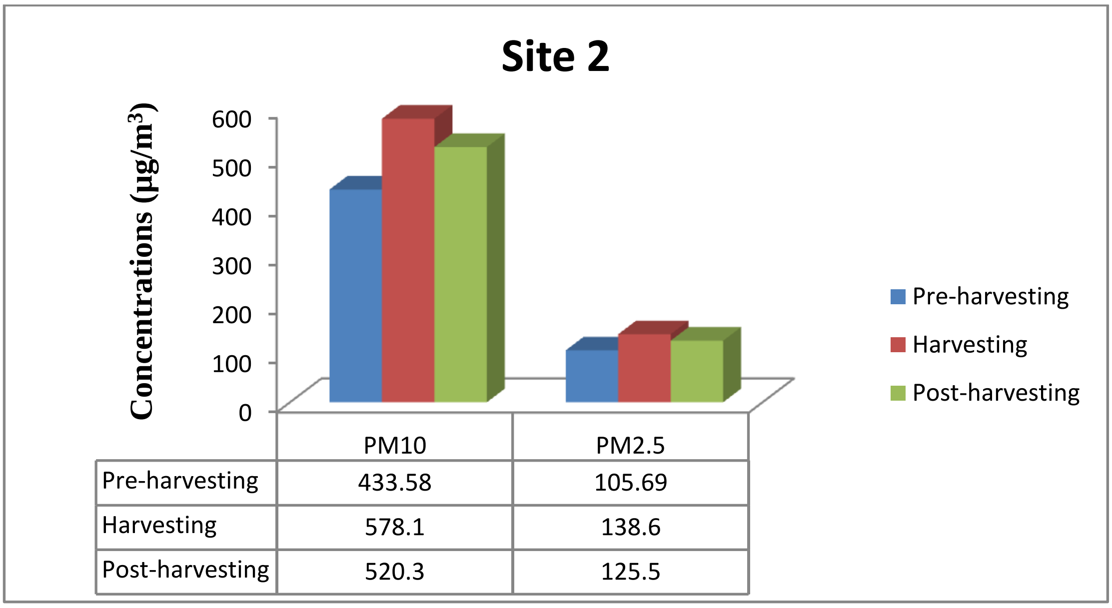


Fig 6.7: Particulate matter concentration at Site 2 for Paddy.

Ind site, where agricultural burning impact is minimal. Fig 6.7 shows, that $PM_{10}$and $PM_{2.5}$ concentration were much higher than at *AgriSite*, due to industrial emissions. During harvesting there was an increase of 33.33% in PM_{10} concentration and 31.1% in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 20% and 18.7% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 10% and 9.5% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season. There is not much increase in $PM_{10}$and $PM_{2.5}$concentration after stubble burning as there is no biomass burning impact.

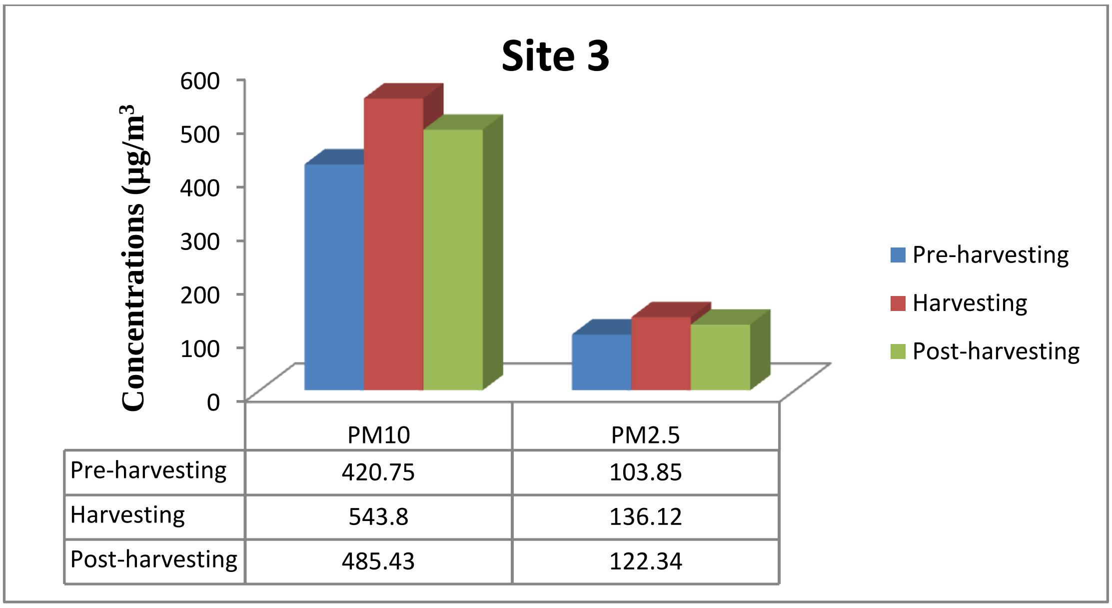


Fig 6.8: Particulate matter concentration at Site 3 for Paddy.

Fig 6.8 shows, that at *Mixed-Ind site*, there is increase in PM_{10} and $PM_{2.5}$ concentration more than at Site 2 but less than at *AgriSite*. During harvesting there was an increase of 29.2% in PM_{10} concentration and 31.07% in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 15.37% and 17.8% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 10.7% and 10.1% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season.

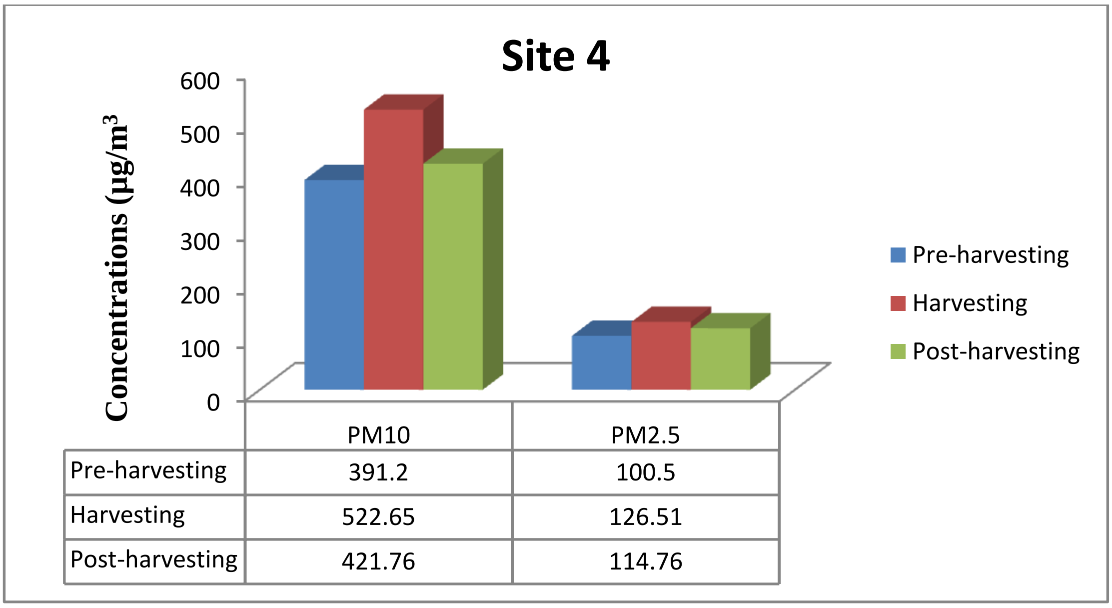
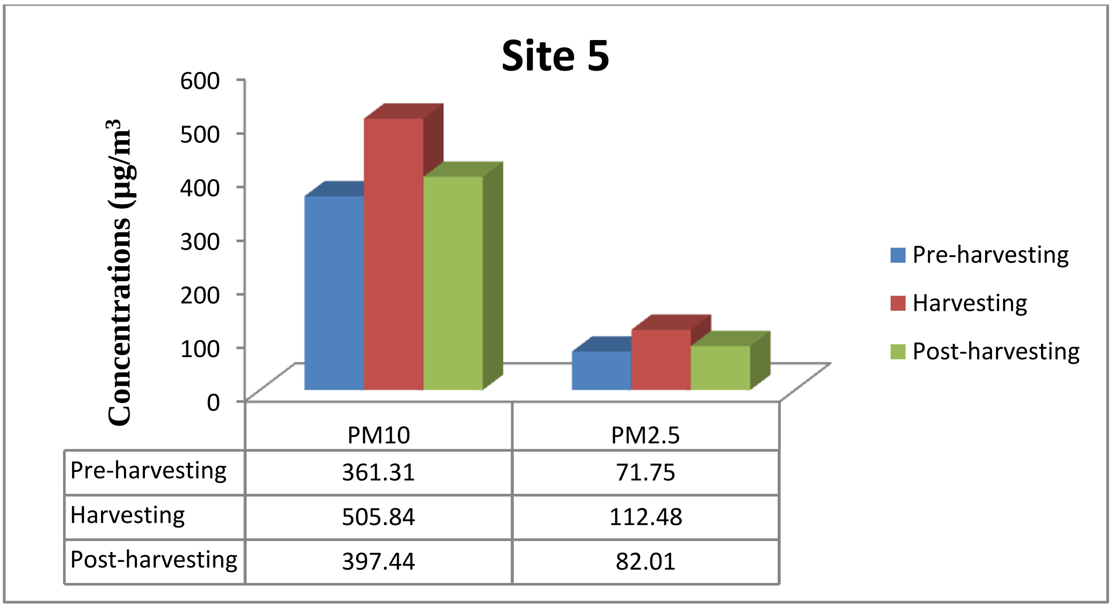


Fig 6.9: Particulate matter concentration at Site 4 for Paddy.

Fig 6.9 shows, at *Vehi Site*, during harvesting there was an increase of 33.6% in PM_{10} concentration and 25.8% in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 7.8% and 14.2% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 19.3% and 9.3% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season.



	PM10	PM2.5
Pre-harvesting	361.31	71.75
Harvesting	505.84	112.48
Post-harvesting	397.44	82.01

Fig 6.10: Particulate matter concentration at Site 5 for Paddy.

Fig 6.10 shows, at *Mixed-Agri site*, during harvesting there was an increase of 40% in PM_{10} concentration and 56.8% in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 10% and 14.3% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 21.4% and 27.1% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season.

6.3 **Effects due to wheat harvesting**

Fig 6.11, 6.12 and 6.13 shows the wind roses plotted for the three sampling periods for wheat i.e. Pre- harvesting (February - March 2013), harvesting (April 2013) and Post- harvesting (May 2013) respectively.

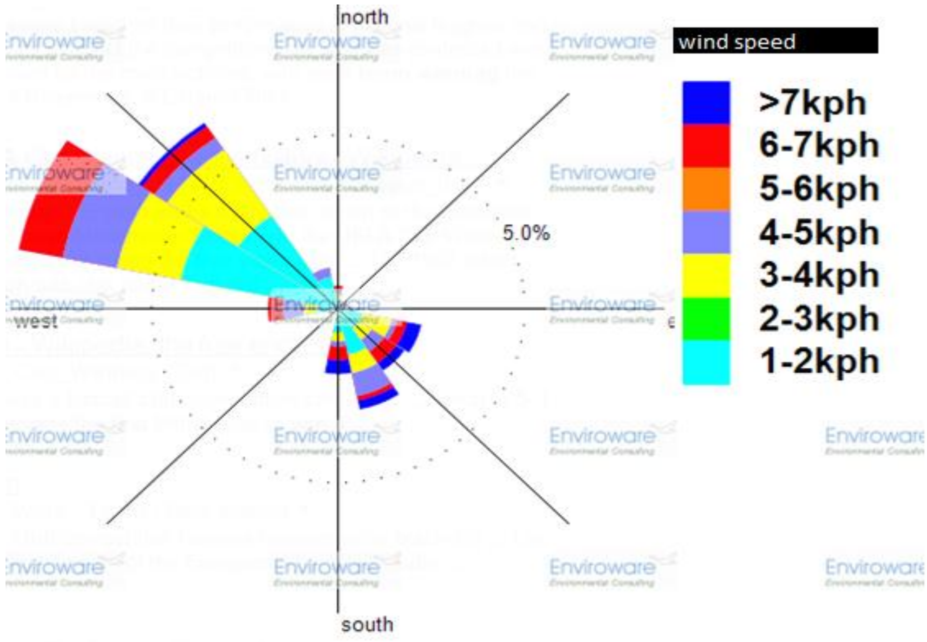


Fig 6.11: wind rose for Wheat Pre- harvesting period (February 2013 - March 2013)

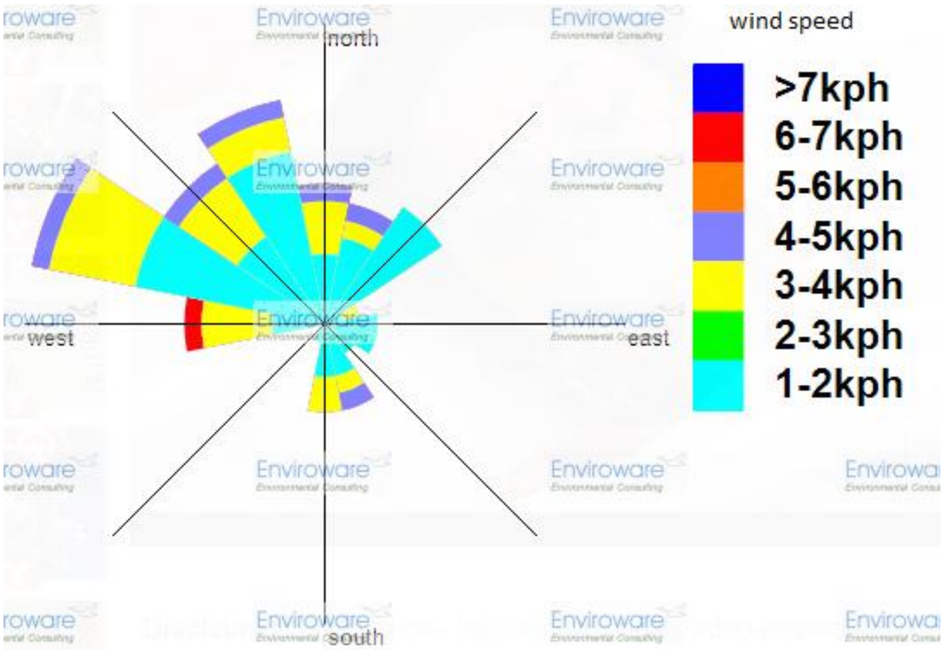


Fig 6.12: wind rose for Wheat harvesting period (April 2013)

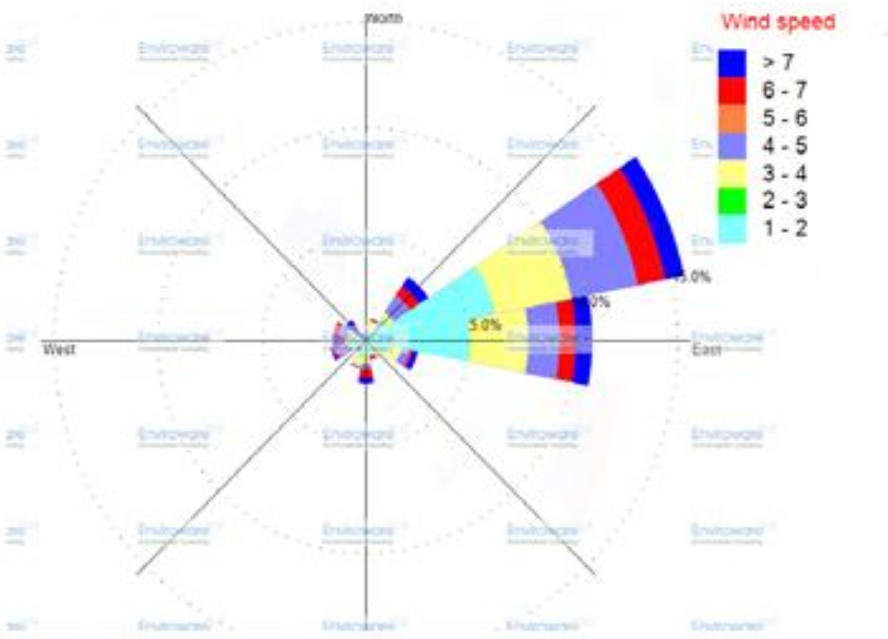


Fig 6.13: wind rose for Wheat Post- harvesting period (May 2013)

In order to adjudge the effect of wheat crop residue harvesting on air quality, the concentration of PM_{10} and $PM_{2.5}$ were plotted against three sampling periods i.e. pre-harvesting, harvesting and post-harvesting for all the five sampling sites.

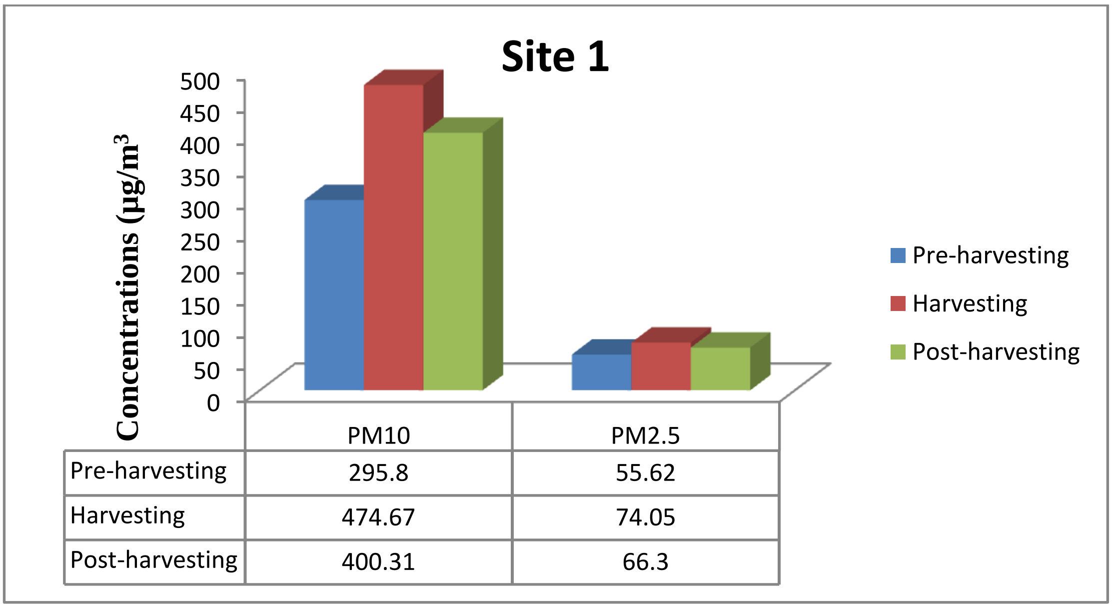
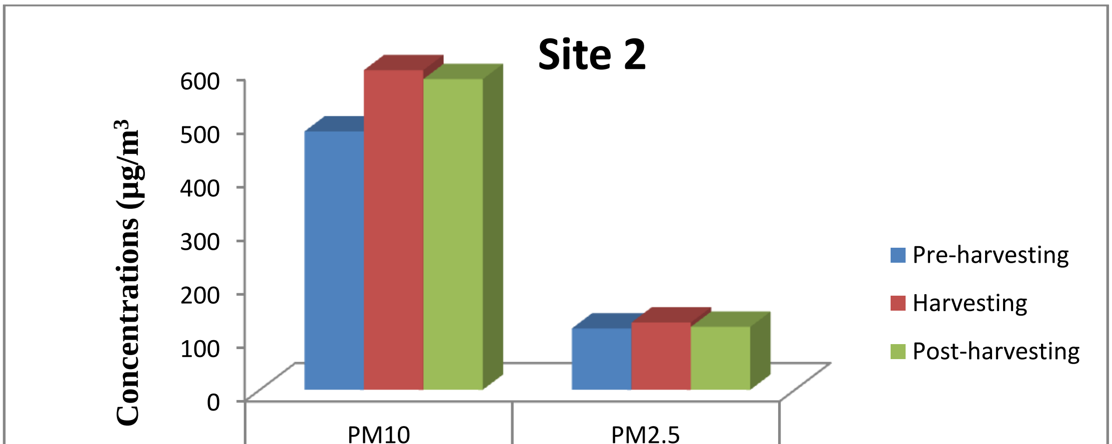


Fig 6.14: Particulate matter concentration at Site 1 for Wheat.

Fig 6.14 shows, that there was more increase in PM_{10} concentration as compared to $PM_{2.5}$ at *Agri site*due to stubble burning. During harvesting there was an increase of 60.4% in PM_{10} concentration and 33.1% in $PM_{2.5}$ concentration as compared to pre-harvesting. This substantial increase in PM_{10} and $PM_{2.5}$ concentration was attributed to stubble burning. Whereas, for Post-harvesting, there was an increase of 35.33% and 19.2% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 15.7% and 10.4%in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season. Fig 6.11 and 6.12 shows, the predominant wind direction during pre-harvesting and harvesting season is North-west i.e. wind blowing from North-west to South-east. Wind coming from North-west is already polluted from industrial emissions, which further increases the $PM_{10}$and $PM_{2.5}$ concentration level at *Agri site*. Fig 6.13 shows that the predominant wind direction is North-East for post-harvesting i.e. wind blowing from North-east to South-west. The pollutant concentration for post-harvesting is less than during harvesting but percent reduction is less as compared to Paddy because dispersion due to wind is not much favourable.



	PM10	PM2.5
Pre-harvesting	482.58	114.69
Harvesting	597.1	125.6
Post-harvesting	580.3	117.5

Fig 6.15: Particulate matter concentration at Site 2 for Wheat.

Fig 6.15 shows, that $PM_{10}$and $PM_{2.5}$ concentration at *Ind site* were much higher than at *Agri site*, due to industrial emissions. During harvesting there was an increase of 23.7% in PM_{10} concentration and 9.5%in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 20.24% and 2.4% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 2.8% and 6.4% in $PM_{10}$and $PM_{2.5}$

concentration respectively as compared to harvesting season. There is not much increase in $PM_{10}$and $PM_{2.5}$concentration after stubble burning as there is no biomass burning impact.

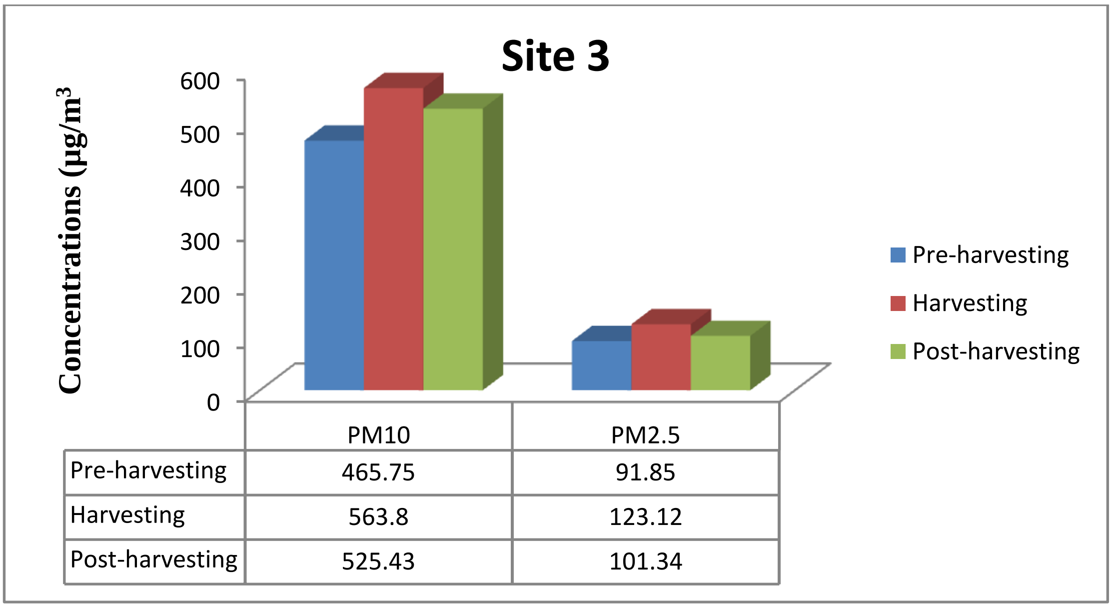
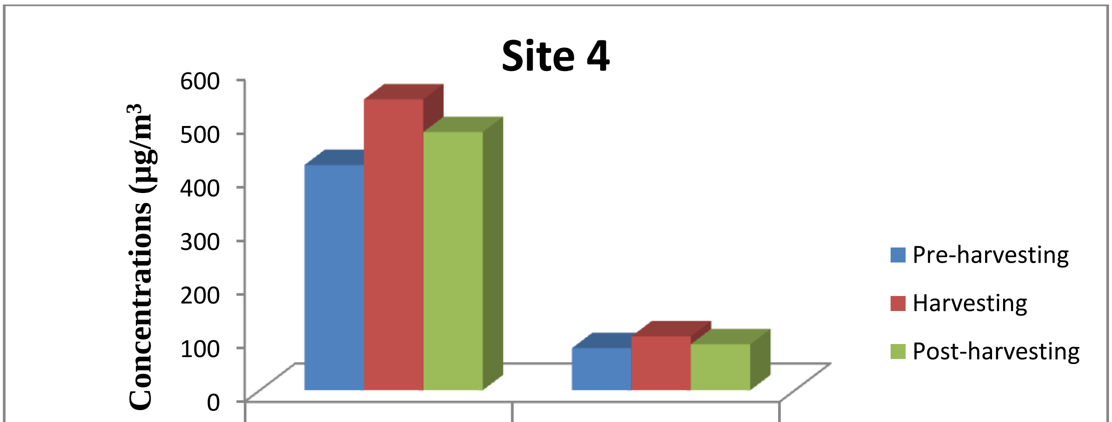


Fig 6.16: Particulate matter concentration at Site 3 for Wheat.

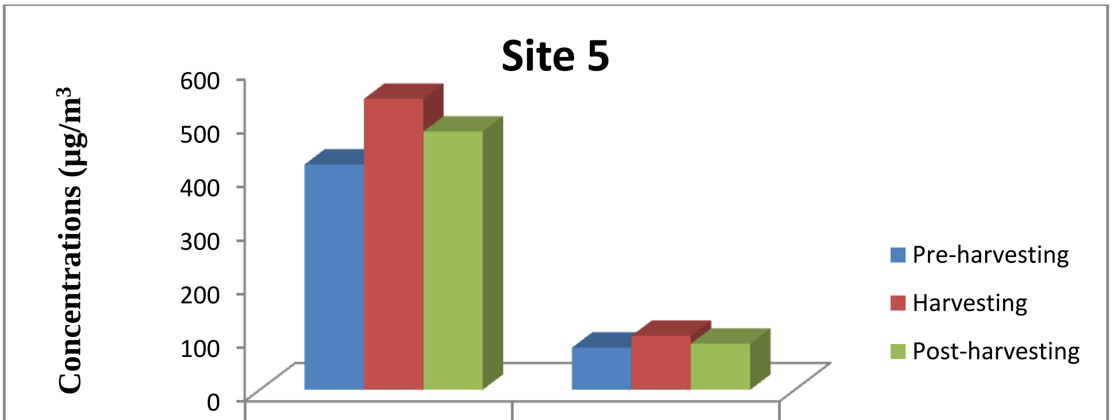
Fig 6.16 shows, at *Mixed-ind site*, there was increase in PM_{10} and $PM_{2.5}$ concentration more than at *IndSite*but less than *AgriSite*. During harvesting there was an increase of 21% in PM_{10} concentration and 34% in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 12.8% and 10.33% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 6.8% and 17.7% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season.



	PM10	PM2.5
Pre-harvesting	420.2	78.5
Harvesting	542.65	100.51
Post-harvesting	481.76	85.76

Fig 6.17: Particulate matter concentration at Site 4 for Wheat

Fig 6.17 shows, that during harvesting at *Vehi site*, there was an increase of 29.1% in PM_{10} concentration and 28% in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 14.65% and 9% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 11.2% and 14.7% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season.



	PM10	PM2.5
Pre-harvesting	420.2	78.5
Harvesting	542.65	100.51
Post-harvesting	481.76	85.76

Fig 6.18: Particulate matter concentration at Site 5 for Wheat

Fig 6.18 shows, that during harvesting at *Mixed-agri site*, there was an increase of 36.54% in PM_{10} concentration and 34.1% in $PM_{2.5}$ concentration as compared to pre-harvesting. Whereas, for Post-harvesting, there was an increase of 8.6% and 16.1% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to pre-harvesting season, and reduction of 20.4% and 13.5% in $PM_{10}$and $PM_{2.5}$ concentration respectively as compared to harvesting season.

6.4 Chemical characterization

Chemical characterization of the sample was done to know the water soluble ions composition in it.

Table 6.1: concentration of water soluble ions

STUDY PERIOD	CONCENTRATION OF IONS (PPM)								
	SO_4^{2-}	Cl^-	NH_4^+	Ca^{2+}	Na^+	NO_3^-	K^+	Mg^{2+}	F^-
PADDY									
PRE-HARVESTING	1.98	4.61		2.76	2.38		0.98	0.38	0.28
HARVESTING	7.07	10.87	6.53	3.53	5.37	1.76	2.56	1.04	0.34
POST HARVESTING	5.68	9.61	12.39	3.26	5.09	1.23	1.47	0.76	0.27
WHEAT									
PRE-HARVESTING	3.62	9.02	14.61	3.26	6.39	0.95	1.67	0.65	0.25
HARVESTING	2.68	7.15	4.17	2.84	4.74		1.34	0.74	0.29
POST HARVESTING	2.82	5.58	11.99	2.65	4.64	0.21	1.05	0.51	0.26

Water soluble ions are chemical species which are easily soluble in water in the lower troposphere under certain conditionsand theyare usually significant components by mass of atmospheric particulate matter. The trend for the mean water soluble ionic concentrations for samples collected during paddy harvesting study period was Cl^-> NH_4^+> SO_4^{2-}> Na^+> Ca^{2+}> K^+> NO_3^-> Mg^{2+}> F^-. The concentration of total water soluble inorganic ions for study period of paddy crop ranged from 0.27 ppm to 12.39 ppm with mean concentration of 3.688 ppm. The major ions species for paddy wereCl$^-$, NH_4^+ and $SO_4^{2-}$and their concentrations varied from 4.61 ppm to 10.87 ppm, 6.53 ppm to 12.39 ppm, 1.98 ppm to 7.07 ppm for Cl$^-$, NH_4^+ and SO_4^{2-}respectively.

The trend for the mean water soluble ionic concentrations for samples collected during wheat harvesting study period was NH_4^+>Cl$^-$> Na^+> SO_4^{2-}> Ca^{2+}> K^+> Mg^{2+}> NO_3^-> F^-. The concentration of total water soluble inorganic ions for study period of paddy crop ranged from 0.21 ppm to 14.61 ppm with mean concentration of 3.62 ppm. The major ions species for paddy wereNH$_4^+$, Cl$^-$ and $Na^+$and their concentrations varied from 4.17 ppm to 14.61 ppm, 4.61ppm to 5.58 ppm and 4.64 ppm to 6.39 ppm for NH_4^+, Cl$^-$ and Na^+ respectively.

Seasonal variation of major water soluble ions show similar trend for both paddy and wheat harvesting seasons. Mass total water soluble ionic species were higher in Winter i.e. during and post harvesting period of paddy (39.07 ppm and 39.76 ppm respectively) and Spring i.e. pre harvesting period of wheat (40.42 ppm) and lower during Summer i.e. during and post harvesting period of wheat (23.95 ppm and 29.71 ppm respectively) and Fall i.e. pre harvesting period of paddy (13.37 ppm). Concentrations of chloride (Cl$^-$) and potassium (K^+) ions were highest in winter and lowest during summer and fall seasons. The seasonal variation of $K^+$was similar to Cl$^-$, indicating that both K^+ and Cl$^-$ were primarily related to the burning activities, which were enhanced in the cold season.

The results obtained during characterization of water soluble ions present in particulates during wheat and paddy harvesting are in agreement with the previous studies (*Wang et al., 2006; Kumar et al., 2007; Deshmukh et al., 2011*). The main reason for highest concentrations of water soluble ionsduringwintercan be attributed to lower temperature whichfavored the transformation of ions from gas phasetoparticle phase and alsodueto lower mixing height and increased anthropogenic activities (*Wang et al., 2006*).Lower concentrations measured during fall period can beattributed to thewashoutof PM containing water soluble ions by rainfall while for summer months (April, May and June) ventilation effect of high wind movements could be the possible reason (*Bhaskar et al., 2010*).

CHAPTER 7
CONCLUSION

Wind data collected over a study period from September 2012 to January 2013 and February 2013 to May 2013, the mostpredominant wind direction was South-East.Results obtained from the study have shown significant increase in PM_{10} and $PM_{2.5}$ concentrations during crop residue burning periods in MandiGobindgarh. Before harvesting, the concentration of PM_{10} and $PM_{2.5}$ was minimal at Site 1, which is an agricultural area, as compared to other four sites, which are industrial and partially industrialized areas respectively. During harvesting, there was a substantial increase in the magnitude of PM_{10} and $PM_{2.5}$ at all the five sites because of three reasons. Firstly, due to Threshing process, which leads to entrainment of rice husk particles in air,secondly, The Shattering process which leads to entrainment of dry shell of wheat seed and lastly,stubble burning. During post-harvesting season, the values of PM_{10} and $PM_{2.5}$ showed a decline trend because of the reduced impact of stubble burning and dispersion. So the present study clearly manifests the effect of stubble burning on the ambient air quality of an industrial estate (MandiGobindgarh).Therelationship between PM_{10} concentration and wind velocity was studied. The results show that the PM_{10} concentration was high in the condition of static and slight wind. PM_{10} concentration descend as wind velocity increases, and the concentration reaches to the minimum value when the wind velocity reach to 1.0-2.0 m/s, then with the wind velocity increasing (> 1.0-2.0 m/s), the PM_{10} concentration increases quickly. The emission flux increased with the increase in wind velocity, and the speed increment become more after the wind velocity was faster than 2.0 m/s. The time duration in between paddy harvesting and wheat sowing is less than wheat harvesting and paddy sowing, so the pollutant concentration is much more during sampling periods of wheat as compared to sampling periods of paddy.

The PM_{10} and $PM_{2.5}$ concentrations obtained at all the sites were above the National Ambient Air Quality Standards (NAAQS) set by CPCB, 2009 (100 µg m^{-3} for PM_{10} and 60 µg m^{-3} for $PM_{2.5}$). Thus it can be concluded from the study that the open burning of crop residue caused great deterioration in the air quality of MandiGobindgarh.

The trend for the mean water soluble ionic concentrations for samples collected during paddy harvesting study period was SO_4^{2-}>Cl^-> NH_4^+> Ca^{2+}> Na^+> NO_3^-> K^+> Mg^{2+}> F^- and for wheat it was SO_4^{2-}>Cl^-> NH_4^+> Ca^{2+}> Na^+> NO_3^-> K^+> Mg^{2+}> F^-.

Some suggestive measures for managing crop residue includepower generation from biomass which has huge potential to provide electricity for rural energy with sustainable environmental benefits. Crop like cotton leaves, woody residue (stalks) need a different type of arrangement for collection which is not available. Crop residue once collected then be utilized with different technologies available both at the national and international level for the valuable utilization of biomass such as thermo-chemical conversion and biochemical conversion.

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