

**STUDY OF HUMAN RESPIRATORY FUNCTIONS IN RELATION TO CROP
RESIDUE BURNING**

THESIS

**Submitted for the award of degree of
DOCTOR OF PHILOSOPHY**

by

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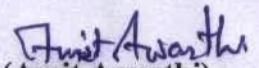
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**Electrical and Instrumentation Engineering Department
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CERTIFICATE

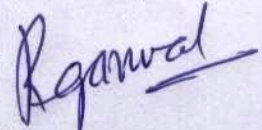
I hereby certify that the work which is being presented in the thesis entitled "*Study of human respiratory functions in relation to crop residue burning*" for the award of degree of **Doctor of Philosophy** in the Electrical and Instrumentation Engineering Department, Thapar University, Patiala, is an authenticate record of my own research work carried out under the guidance and supervision of Dr. Ravinder Agarwal and Mr. Prabhat K. Gupta. The results contained in this thesis have not been submitted, in part or in full, to any other University or Institute for the award of any degree or diploma.


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This is to certify that the above statement made by the candidate is correct and true to the best of my knowledge.



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Dedicated to

My Uncle

Sh. Ashok Awasthi

Thank you for your patience, support and prayers

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Abstract

Human body is the most complex machine in which all the systems can be compared to various parts of the machine which work in a coordinated manner for the proper functioning of the body. As the machine requires energy from fuels, body also requires energy to do work which comes from food and oxygen. Along with fuel, if external material enters inside the machinery, proper functioning is affected which, after some time may stop working. Same thing happens in the case of human body; if external material along with food and air enters inside the body then health of the body is affected. These external materials are mainly the pollutants present in the air. Agriculture Crop Residue Burning (ACRB) plays a major role in causing pollution for a definite period. Crop residue burning activity is as old as human civilization and still considered as the cheapest and easy way of disposing off the agricultural waste.

In present work, affect of ACRB on the ambient air and respiratory system of common healthy people were done by measuring their Pulmonary Function Tests (PFTs) like Force Vital Capacity (FVC), Force Expiratory Volume in first Second (FEV_1), Peak Expiratory Flow Rate (PEF) and Force Expiratory Flow in 25 to 75% ($FEF_{25-75\%}$) *etc.* Ambient levels were considered by measuring the concentration levels of different size particulate matter like Suspended Particulate matter (SPM), Particulate matter of size less than 2.5 and 10 μm ($PM_{2.5}$ and PM_{10}).

Study was carried out at the five sites of Patiala city of Punjab, India for three year of duration from February 2007 to January 2010, which included 50 healthy subjects. Age of 50 subjects lies between 13 to 53 years with mean value of 30 years. Subjects included 40 male and 10 female with mean height of 166 cm (139 - 179 cm) and weight of 62 kg (40 - 85 kg) at the start of the study. Standard methods of American Thoracic Society (ATS) were used to measure the PFTs by using portable Spirometer on the basis of which, subjects whose FEV_1/FVC ratio larger than the 80 % were included in the study. Standard methods were used to measure the concentration of SPM and PM_{10} using High Volume Sampler (HVS) and Anderson Cascade Impactor (ACI).

The results of three year study shows that there is a significant increase in the concentration level of different size particulate matter during the burning episode of wheat and rice crop residue. Rice crop residue burning has more effect on the concentration level in comparison to wheat crop residue burning. PFTs which are considered in the study shows

significant decrease in their values during the ACRB, which is not recovered completely, even after the completion of burning episodes. Linear regression technique was used to authenticate the effect on the volume of air *i.e.*, FVC and FEV₁ was more during ACRB in comparison to other PFTs. Whereas, oxygen saturation level shows no significant change during the burning period of agriculture crop residue. Effect on the PFTs was more during the rice crop residue burning in comparison to wheat crop residue burning period. The maximum effect was observed on the lower and upper age groups as compared to the middle aged group. Contribution of different size particulate matter conclude that effect of smaller size particulate matter (PM_{2.5}) is found to be higher in comparison to larger size particulate matter due to their greater penetration potential.

The present study clearly signifies that ACRB is still a common process which reduced the ambient air quality that poses effects sometime permanent in nature on the PFTs of healthy subjects. Different analyses prove that rice crop residue burning has more effect on the lower and upper age groups due to increase in the concentration level of the particulate matter during the burning episodes. However, the middle age group is affected to a relatively less extent.

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List of Abbreviations

Abbreviations	Name
ACI	<i>Anderson Cascade Impactor</i>
ACRB	<i>Agriculture Crop Residue Burning</i>
ANOVA	<i>Analysis of Variance</i>
ARBP-1	<i>After Rice Crop Residue Burning Period (December'2007- January'2008)</i>
ARBP-2	<i>After Rice Crop Residue Burning Period (December'2008- January'2009)</i>
ARBP-3	<i>After Rice Crop Residue Burning Period (December'2009- January'2010)</i>
ARIMA	<i>Autoregressive Integrated Moving Average</i>
ATS	<i>American Thoracic Society</i>
AWBP-1	<i>After Wheat Crop Residue Burning Period (June-July'2007)</i>
AWBP-2	<i>After Wheat Crop Residue Burning Period (June-July'2008)</i>
AWBP-3	<i>After Wheat Crop Residue Burning Period (June-July'2009)</i>
BMRC	<i>British Medical Research Council</i>
BRBP-1	<i>Before Rice Crop Residue Burning Period (August- September'2007)</i>
BRBP-2	<i>Before Rice Crop Residue Burning Period (August- September'2008)</i>
BRBP-3	<i>Before Rice Crop Residue Burning Period (August- September'2009)</i>
BWBP-1	<i>Before Wheat Crop Residue Burning Period (February-March'2007)</i>
BWBP-2	<i>Before Wheat Crop Residue Burning Period (February-March'2008)</i>
BWBP-3	<i>Before Wheat Crop Residue Burning Period (February-March'2009)</i>
CCN	<i>Cloud-Condensation Nuclei</i>
CH ₄	<i>Methane</i>
CI	<i>Confidence Index</i>
CO ₂	<i>Carbon-dioxide</i>
COPD	<i>Chronic Obstructive Pulmonary Disease</i>
DLCO	<i>Diffusion Capacity of Carbon monoxide</i>
DRBP-1	<i>During Rice Crop Residue Burning Period(October-November'2007)</i>
DRBP-2	<i>During Rice Crop Residue Burning Period (October-November'2008)</i>
DRBP-3	<i>During Rice Crop Residue Burning Period (October-November'2009)</i>
DWBP-1	<i>During Wheat Crop Residue Burning Period (April-May'2007)</i>
DWBP-2	<i>During Wheat Crop Residue Burning Period (April-May'2008)</i>
DWBP-3	<i>During Wheat Crop Residue Burning Period (April-May'2009)</i>
ECD	<i>Effective Cut Diameter</i>
ERS	<i>European Respiratory Society</i>

ERV	<i>Expiratory Reserve Volume</i>
FBPFM	<i>Field Burning and Pulmonary Function Model</i>
FEF _{25%}	<i>Force Expiratory Flow at 25% of FVC</i>
FEF _{25-75%}	<i>Force Expiratory Flow in 25 to 75% of FVC</i>
FEF _{50%}	<i>Force Expiratory Flow at 50 % of FVC</i>
FEF _{75%}	<i>Force Expiratory Flow at 75 % of FVC</i>
FEV ₁	<i>Force Expiratory Volume in 1 second</i>
FRC	<i>Functional Residual capacity</i>
FVC	<i>Force Vital Capacity</i>
H ₂ O	<i>Water</i>
ha	<i>Hectare</i>
Hg	<i>Mercury</i>
hPa	<i>Hectopascals</i>
hr	<i>Hours</i>
HVS	<i>High Volume Sampler</i>
IC	<i>Inspiratory Capacity</i>
IGP	<i>Indo-Gangetic plain</i>
IRV	<i>Inspiratory Reserve Volume</i>
km	<i>kilometre</i>
LEDs	<i>Light Emitting Diodes</i>
MIR	<i>Medical International Research</i>
ml	<i>Millilitre</i>
mm	<i>Millimetre</i>
MT	<i>Metric</i>
MVV	<i>Maximum voluntary ventilation</i>
N ₂	<i>Nitrogen</i>
NAAQS	<i>National Ambient Air Quality Standard</i>
NO _x	<i>Oxides of Nitrogen</i>
NW	<i>North-West</i>
O ₂	<i>Oxygen</i>
O ₃	<i>Ozone</i>
PAHs	<i>Polycyclic Aromatic Hydrocarbons</i>
PEF	<i>Peak Expiratory Flow</i>
PFTs	<i>Pulmonary Function Tests</i>

PM	<i>Particulate Matter</i>
PM ₁₀	<i>Particulate Matter with an aerodynamic diameter of 10 µm or less</i>
PM _{2.5}	<i>Particulate Matter with an aerodynamic diameter of 2.5 µm or smaller</i>
ppb	<i>Parts per billion</i>
QM-A	<i>Quartz Micro Fibre Sheet-A</i>
r	<i>Correlation Coefficient</i>
RCRB	<i>Rice Crop Residue Burning</i>
RH	<i>Relative Humidity</i>
RSPM	<i>Respirable Suspended Particulate Matter</i>
RV	<i>Residual Volume</i>
RWS	<i>Rice Wheat System</i>
SD	<i>Standard Deviation</i>
SO ₂	<i>Sulphur dioxide</i>
SO _x	<i>Oxides of Sulphur</i>
SPM	<i>Suspended Particulate Matter</i>
SpO ₂	<i>Oxygen Saturation Level</i>
SPSS	<i>Statistical Package for Social Sciences</i>
SW	<i>South-West</i>
Temp	<i>Temperature</i>
Tg	<i>Teragram</i>
TLC	<i>Total Lung Capacity</i>
TSP	<i>Total Suspended Particulate</i>
TV	<i>Tidal Volume</i>
VC	<i>Vital Capacity</i>
VOC	<i>Volatile Organic Compounds</i>
WCRB	<i>Wheat Crop Residue Burning</i>
WD	<i>Wind Direction</i>
WHO	<i>World Health Organisation</i>
°C	<i>Degree Celsius</i>
µ	<i>Micro</i>

Chapter I

Introduction

This chapter briefly describes the human respiratory system, its working followed by Agriculture Crop Residue Burning (ACRB), and its effects on lung functions. Although, lots of work has been done in the areas of harmful effects of different aspects of pollution but the study of ACRB is still lagging behind in comparison to other reasons of air pollution. There is a need of systematic study on the effect of ACRB on different respiratory function of Human beings.

Among the variety of factors influencing health of individual, air we breathe play a crucial role. On daily basis, humans inhale around 10000 liters of ambient air, which comes in close contact with a lung surface area of over 100 m² (Heyder, 2004; Koenig, 1999; Salvi, 2007). The respiratory tract comes into close contact with large volume of ambient air and its components. Health risks resulting from environmental effects are a major source of concern all over the world. The relationship between human health and environment has always been matter of debate. Various anthropogenic activities have resulted deviation from the perfect balance of composition of the physical state of environment and has resulted in contamination of the air, water, land *etc* among which air has always been a matter of basic concern due to its direct contact with the human physiological system.

Human body is made up of different systems like skeletal system, muscular system, circulatory system, nervous system, respiratory system, digestive system, excretory system *etc.* (Guyton and Hall, 2006; Barret *et al.*, 2010). Different systems have their own importance like skeletal system provide support for the body, muscular system provide movement to the body, circulatory system to transport nutrients gases through the body *etc.* The smooth working of human body or fitness of body depends on these systems. The human body respiratory system is critical to immediate survival.

Respiratory system is one of the sensitive organ systems of the human body which is affected easily by external environment. The main organs affecting respiratory system are the lungs and these are very delicate, as they interact with the external as well as the internal environment. The respiratory system provides a means of acquiring oxygen (O₂) and eliminating carbon dioxide (CO₂). Respiratory system is made up of organs in body that helps to breathe. The primary function of the respiratory system is to supply the blood with oxygen to all parts of the body for the various cellular functions. Primary mode of entry of pollutants into the human body is through the respiratory system by the process of breathing (Brown and Lawford, 2005; Joseph and Brown, 2004).

1.1 Respiratory system

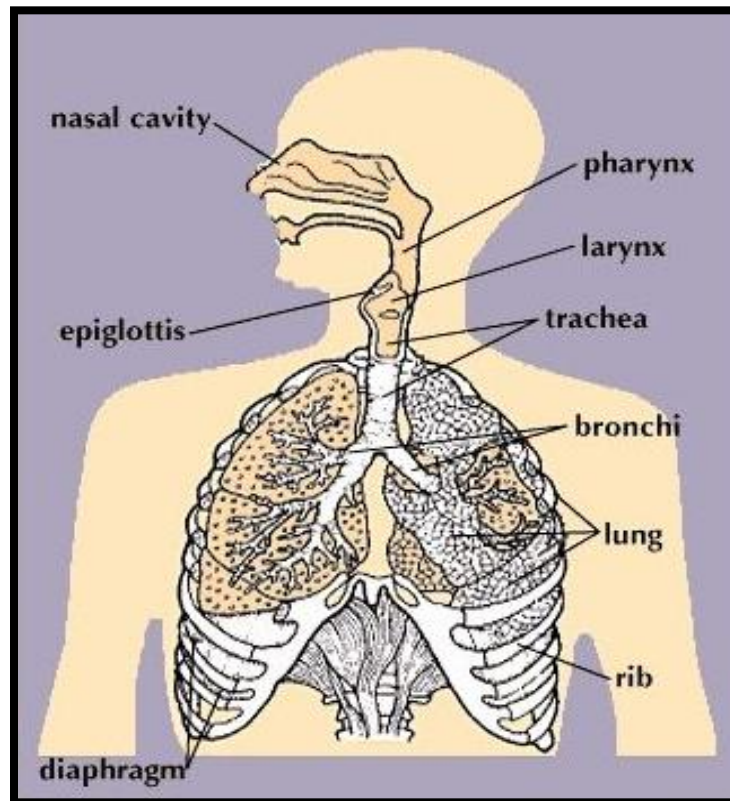


Figure 1.1: Respiratory system of human body

Respiratory system is made up of different organs in the body that help to breath shown in Figure 1.1. The primary function of human respiratory system is to deliver

oxygen to bloodstream and remove CO₂. These two processes occur concurrently as the breathing cycle is repeated. Lungs are the main organs of the respiratory system. In the lungs oxygen is taken into the body and CO₂ is breathed out (Brown and Lawford, 2005; Joseph and Brown, 2004). The extensive interaction of the respiratory system with the surrounding atmosphere, air pollutants or traces of gas other than N₂ and O₂ can be delivered to the respiratory system and this creates health problem. The passage of air from the nose to capillaries is shown as block diagram in Figure 1.2.

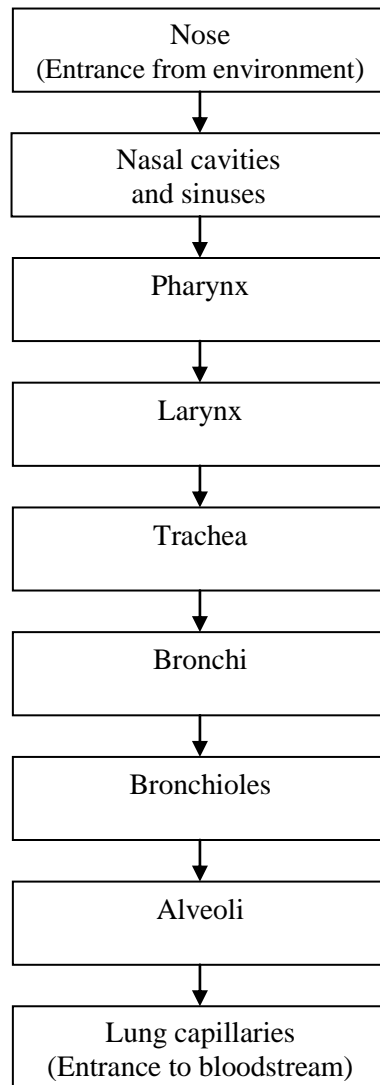


Figure 1.2: Block diagram of the passage of air

Air enters into the body during inspiration. Inhaled air enters in the body by small opening called nostril (nose), which then flows through the nasal cavity. The nasal

passages are lined with tiny hair like structures and a sticky substance called mucus. Dust and dirt entering in the body are to a greater extent trapped in these hairs and mucus preventing their entry in the respiratory system. Through nasal cavity air enters in the pharynx (a small cavity behind the nose) and then to larynx (voice box). The nasal cavity ends in a broad tube structure called trachea which further splits into two tubes called bronchi (bronchus). Each of the bronchus enters in the lungs, where the primary bronchi divide into smaller and smaller tubes. Finally, branching into extremely tiny tubes called bronchioles. Air entering in the body flows from nasal cavity through respiratory tract and ultimately reaches to lungs in bronchioles. The bronchioles end in hundreds of millions of thin-walled bag like structures called alveoli or air sacs. These alveoli (alveolus) contain blood capillaries. Air enters in the blood by diffusion through walls of bronchioles and blood capillaries, and is carried throughout the body. The alveoli give the lungs a tremendously extended surface area. Air sacs provide large surface area for the gas exchange, if due to some reasons this surface area reduced, then proper functioning of respiratory system is affected. The respiratory system with different organs exchange gases by diffusion and transport with the help of respiration. Respiration is a complex collective physiological process of absorption of oxygen from the environment and oxidation food materials in the cells with the release of water, CO₂ and energy and elimination of CO₂ into the environment.

Respiration occurs in two stages, inspiration and expiration. During normal breathing, inspiration is active process and expiration is passive process. In the inspiration (inhalation) process, air enters the lungs from the atmosphere; whereas during expiration, air leaves the lungs. While passing through the lungs, the atmospheric air (inspired air) delivers oxygen to the blood in the pulmonary capillaries and in exchange takes away carbon dioxide from the blood.

Respiration involves two processes, external respiration and internal respiration. External respirations involve the exchange of respiratory gases (O₂ and CO₂) between alveoli of lungs and the blood in the pulmonary capillaries where as internal respirations

involve the exchange of gases between blood and tissues. Phenomenon of respiratory gas exchange takes place inside the body show in Figure 1.3.

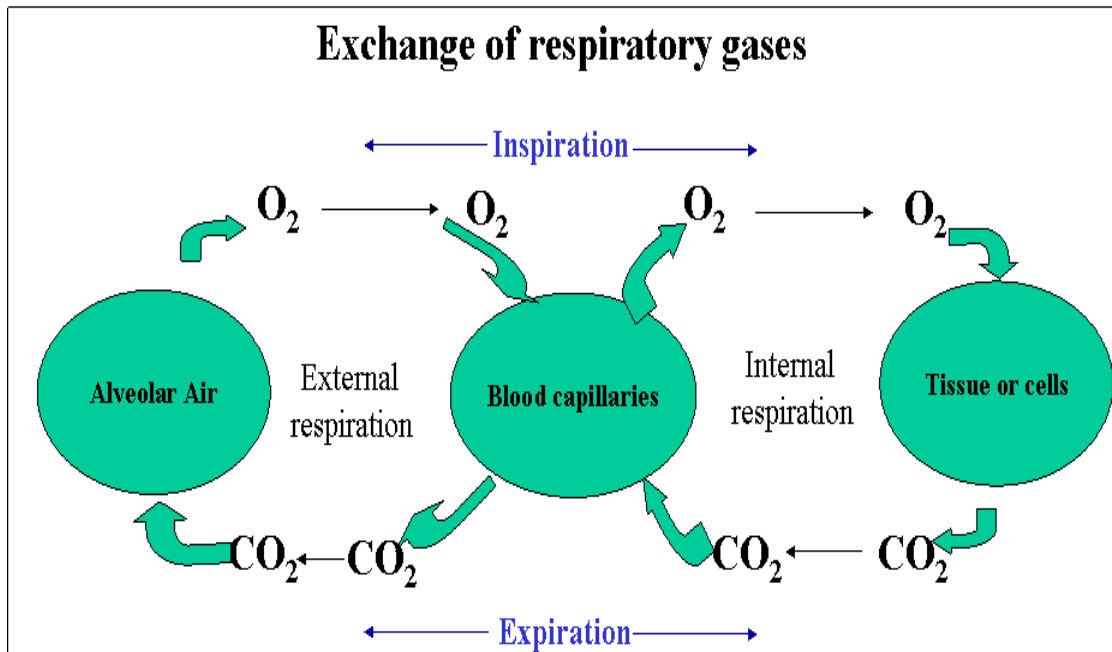


Figure 1.3: Exchange of gases

1.1.1 Exchange of gases

The exchange of gases between blood and alveoli occur in the respiratory unit. The membrane through which the exchange occurs is called the respiratory membrane. The exchanges of gases occur by bulk flow diffusion. The diffusion capacity is defined as the volume of gas that diffuses through the respiratory membrane each minute for pressure gradient of 1 mm Hg. Exchange of gases depend upon the diffusion capacity of the gases.

Factor affecting diffusion capacities are:

1. Pressure gradient:

It is the pressure difference between the partial pressure of a gas in the alveoli and the partial pressure of that gas in the blood capillary. Diffusion capacity is directly proportional to the pressure gradient.

2. Solubility of gas:

If the solubility of a gas is more in fluid medium, a large number of molecules are available for diffusion, results in increase in the diffusion capacity. Diffusing capacity is directly proportional to solubility of the gas.

3. Total surface area of respiratory membrane:

The surface area of respiratory membrane in each lung is about 70m², if the total surface area of respiratory membrane is reduced; the diffusing capacity for gases is reduced. The diffusion capacity is directly proportional to surface area of respiratory membrane.

4. Molecular weight of the gas:

If the molecular weight is more, density is more and rate of diffusion is less. The diffusion capacity is inversely proportion to molecular weight of the gas.

5. Thickness of respiratory membrane:

More the thickness of respiratory membrane lesser is the diffusion. The diffusion capacity is inversely proportional to the thickness of the respiratory membrane.

$$DC \propto \frac{P_G \times S \times A}{M_w \times D}$$

DC = Diffusion capacity

P_g = Pressure gradient

S = Solubility of gas

A = Surface area of respiratory membrane

M_w = Molecular weight

D = thickness of the respiratory membrane

Exchange of gases takes place by the process of diffusion in which gases moves from the area of high concentration to low concentration. Partial pressure of oxygen in

the atmosphere is 159 mm Hg and in the alveoli it is 104 mm Hg, because of pressure gradient of 55 mm Hg, oxygen easily enters the alveoli from the atmosphere air. Partial pressure of oxygen in the blood capillary is 44 mm Hg and in the alveoli 104 mm Hg. Due to pressure gradient of 64 mm Hg oxygen diffuse from alveoli into the blood. The partial pressure of oxygen in arterial blood is 95 mm Hg. The pressure gradient of 55 mm Hg (95 - 40) exist between blood and tissues so that, oxygen can easily diffuse into the tissue.

The partial pressure of carbon dioxide is high in the cells due to its continuous metabolic activity that produced CO₂ constantly in the cells and is about 46 mm Hg. The partial pressure of carbon dioxide in blood is 40 mm Hg. The pressure gradient of 6 mm Hg is responsible for the diffusion of carbon dioxide from tissue to blood. Partial pressure of carbon dioxide in alveoli is 40 mm Hg whereas in the blood it is 45 mm Hg. The pressure gradient of 5 mm Hg is responsible for the diffusion of carbon dioxide blood into the alveoli. In the atmospheric air, the partial pressure of carbon dioxide is about 0.3 mm Hg whereas, in the alveoli, it is 40 mm Hg, so, carbon dioxide leaves alveoli easily. Due to partial pressure differences gases exchange take place by the diffusion on the basis of movement of gases from higher to lower concentration. Diffusion is well described by Fick's law of diffusion. It states that the amount of substances crossing a given area is directly proportional to the area available for diffusion, the concentration gradient and a constant known as diffusion coefficient. According to Fick's law

$$J = -D \times A \times \frac{dc}{dx}$$

Where, J = amount of substance diffused

D = diffusion coefficient

A = area through diffusion occurs

$\frac{dc}{dx}$ = concentration gradient

Negative sign indicates that diffusion occurs from region of higher concentration to a region of lower concentration. The diffusion coefficient reduces when the molecular size of the diffusing substance is increased. It is increased when the size is decreased, *i.e.* the smaller molecules diffuse rapidly than larger ones.

The gaseous exchange is higher when surface area for exchange is large, but with air, if due to some external contamination, particles gets deposited on the gas exchange surface sites the gas exchange mechanism would be affected. Particulate matter along with other gases deposit inside the respiratory tract, which may affect the proper functioning of respiratory system.

1.1.2 Transport of Gases

Oxygen is transport in blood by two forms; as simple physical solution and in combination with hemoglobin. Oxygen dissolves in water of plasma and is transported as simple solution in the physical form. The amount of oxygen transports in this way is very negligible. Oxygen combines with hemoglobin in blood and is transported as oxyhemoglobin. The transport of oxygen in this form is important because maximum of oxygen is transported by this method. Oxygen combines with hemoglobin only as physical combination. No oxidation reaction takes place; oxygen combines with iron in heme part of hemoglobin. Each molecule of hemoglobin contains 4 atoms of iron (Guyton and Hall, 2006; Barret *et al.*, 2010). The iron of the hemoglobin is present in ferrous form, after combination of each iron atom with one molecules of oxygen, iron remain in ferrous form only known as oxygenation. This type of combination of oxygen has some advantages. Oxygen can be readily released from hemoglobin when it is needed. Hemoglobin accepts oxygen readily whenever the partial pressure of oxygen in the blood is more. Hemoglobin gives oxygen whenever the partial pressure of oxygen in blood is less. Oxygen saturation level measures the percentage of oxygen in blood. Oxygen saturation level measures the percentage of hemoglobin binding sites in the bloodstream occupied by oxygen. Oxygen saturation level is the amount of oxygenated hemoglobin present in the blood. Pulse-oximeter is used to measure Oxygen saturation level.

1.2 Respiratory Parameters and Pulmonary Function Tests

Pulmonary Function Test (PFTs) is a valuable tool for evaluating the respiratory system also called as respiratory parameter. Several breathing tests that measure the function of the lungs, including the rate of air flow and the volume of exhaled air, performed to assess lung function and to detect the presence of respiratory disease are called PFTs or respiratory function. PFTs are a group of procedures that measure how well the lungs are functioning (Miller *et al.*, 2005). Pulmonary function tests can help a doctor in diagnosing a range of respiratory diseases which might not otherwise be obvious to the doctor or the patient. The tests are important since many kinds of lung problems can be successfully treated if detected early. Pulmonary function tests help a doctor to diagnose respiratory diseases and disorders such as asthma, Chronic Obstructive Pulmonary Disease (COPD) and emphysema, and mechanical injury by measuring the degree of lung impairment (Barreiro and Perillo, 2004; Baur *et al.*, 1999; Nicod 1999; Stocks and Quanjer, 1995). These tests are also done before major lung surgery to make sure that the patient will not be disabled by having a reduced lung capacity. When performed over time, these tests are helpful in evaluating how a lung disease is progressing, and how serious the lung disease has become.

Spirometry is the most common technique to measure the various PFTs, measuring lung function, specifically the measurement of the amount (volume) and/or speed (flow) of air that can be inhaled and exhaled (Miller *et al.*, 2005; Stanojevic *et al.*, 2008; Stocks and Quanjer, 1995). Spirometry is used in lung function screening study. It is used for diagnosing and monitoring respiratory symptoms and disease, for preoperative risk stratification, and as a tool in epidemiologic and other research studies. Spirometry requires a voluntary maneuver in which a subject inhales maximally from tidal respiration to total lung capacity and then rapidly exhales to the fullest extent until no further volume is exhaled at residual volume. Spirometry is an important tool used for generating pneumotachographs which helpful in assessing conditions such as asthma, pulmonary fibrosis, cystic fibrosis, and COPD (Barreiro and Perillo, 2004).

The spirometry is performed by using a device called a Spirometer, which comes in several varieties including the waterless, rolling seal type and Stead-Wells water seal type *etc.* that directly measure the volume of air displaced or measures airflow by a flow-sensing device, such as a pneumotachometer or a tube containing a fixed resistance to flow. Most of the clinical pulmonary function testing laboratories use a microprocessor-driven pneumotachometer to measure the air flow directly and then derive volume itself mathematically.

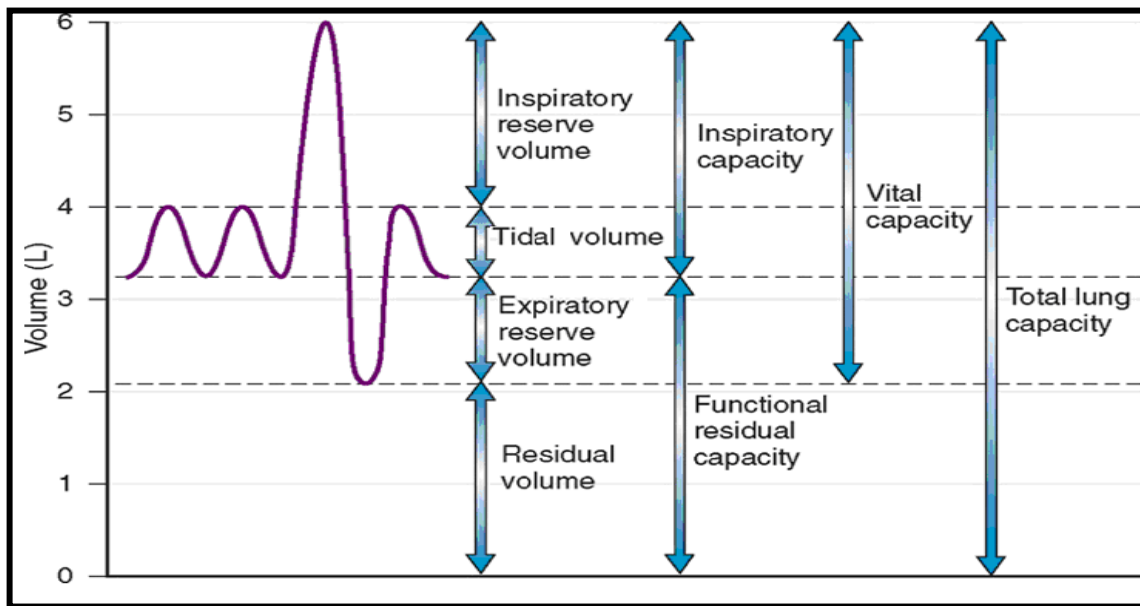


Figure 1.4: Spirogram with lung Volume and capacities

Source: Widmaier *et al.*, 2008

Basic understanding of the measurements produced by spirometry or other pulmonary function tests requires understanding some basic definitions of the compartments of the lung. These are four volumes and four capacities which comprise the air contained in or moved by the lung (Figure 1.4). By definition, a volume is a compartment that cannot be further sensibly subdivided, while a capacity is composed of two or more volumes. The four volumes of the lung are defined as follows:

1. Tidal volume (TV): It is the amount of air or of gas that is inhaled with a normal inspiratory effort from the resting position of the chest and lung. It may be somewhat

difficult to measure due to normal variation between breaths or due to a subject's knowledge that he or she is being observed.

2. Inspiratory Reserve Volume (IRV): It is the additional amount of gas that can be inhaled following this normal inspiratory effort. This is an infrequently used measurement and is somewhat difficult to measure because of variation in tidal volume.

3. Expiratory Reserve Volume (ERV): After completing a normal expiratory effort that returns the lung and chest wall to the resting position, an additional amount of gas can be exhaled with a voluntary effort that is called the expiratory reserve volume. Thus, the ERV is the amount of gas that can be exhaled when the expiratory effort begins at the resting position and ends at maximal expiration.

4. Residual volume (RV): At the point of maximal expiration, there is still a quantity of gas in the lung that cannot be expelled. The remaining volume of gas is known as the residual volume and the space occupied by the gas is known as dead space.

The four capacities of the lung are:

1. Vital Capacity (VC): It is the amount of gas that can be expelled from the lung when exhalation starts at the maximal inspiratory level and proceeds to the maximal expiratory level. It is the sum of the IRV, VT, and ERV (or IC+ERV).

2. Inspiratory Capacity (IC): It is the maximum amount of gas that can be inhaled from the resting position. The IC is the sum of the VT and the IRV.

3. Functional Residual Capacity (FRC): After a normal exhalation to the resting position of the lung and chest wall, the amount of gas remaining in the lung is the FRC, which consists of the ERV plus the RV.

4. Total Lung Capacity (TLC): It comprises all four volumes, *i.e.* $TLC = TV + IRV + ERV + RV$.

Most Spirometer displays the following graph (Figure 1.5), called spiograms: a: volume-time curve, showing volume (liters) along the Y-axis and time (seconds) along the X-axis, b: flow-volume loop, which graphically depicts the rate of airflow on the Y-axis and the total volume inspired or expired on the X-axis

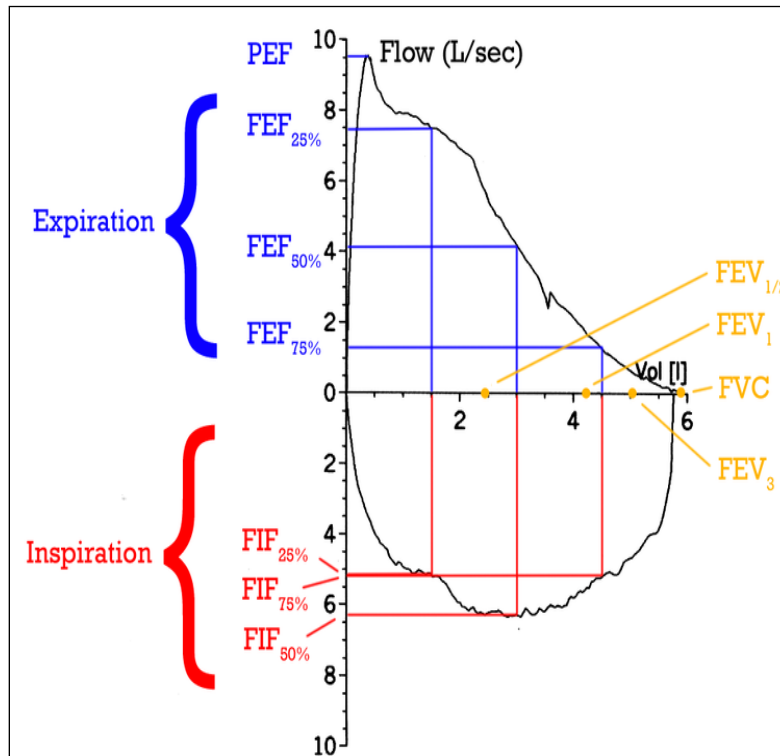


Figure 1.5: Spiograms

The most commonly used guidelines for Spirometric testing and interpretation are set by the American Thoracic Society (ATS) and the European Respiratory Society (ERS) (Miller *et al.*, 2005). There are generally minor differences between the two most recent ATS and ERS statements, except that the ERS statement includes absolute lung volume and ATS does not. On the basis of percentage to predicted values the interpretation has been done (Barreiro and Perillo, 2004; Baur *et al.*, 1999).

Pulmonary function tests (PFTs) measure the capability of lungs to take air in and exhale and how efficiently they transfer oxygen into the blood. There are several different tests.

- Spirometry measures how well the lungs exhale (breathe out).
- Lung volume measures how well the lungs inhale (breathe in).
- Testing of Diffusion Capacity of Carbon Monoxide (DLCO) shows how efficiently the lungs transfer oxygen from the air into the bloodstream.

Dynamic measures are generally used to assess the breathing mechanism. These measures are important because breathing is dynamic process and the rate at which gases can be exchanged with the blood is a direct function of the rate at which air can be inspired and expired. A number of force breathing tests are used to assess the muscle power associated with breathing and the resistance of the airway. Among them, Force Vital Capacity (FVC), Force Expiratory Volume in 1 second (FEV_1), Peak Expiratory Flow (PEF), Force Expiratory Flow in 25 to 75% ($FEF_{25-75\%}$) *etc.* are normally used to see the effects on breathing mechanism.

The ambient air which we breathe may have significant effect on their working and functioning of lung and PFTs (Dockery *et al.*, 1993; Donaldson and Macnee, 2003; Staurt, 1984; Vichet-Vadakan *et al.*, 2001; Wilson and Suh, 1997; Wong *et al.*, 2001). The polluted air when goes inside the body through breathing poses a serious effect on the health especially on the respiratory system (Brunkreef and Holgate, 2002; Donaldson and Macnee, 2003; Vieira and Masacarenhas, 2008; Wong *et al.*, 2001).

1.3 Air pollution

Air pollution is the increased presence of atmospheric solids, liquids, or gaseous compounds within the atmosphere (Crawford, 1976). Mobile and stationary sources emit primary pollutants directly into the atmosphere. Principal pollutants are carbon monoxide, nitrogen oxides, hydrogen sulphide, sulphur oxides, hydrocarbons, particulate matter and heavy metals such as lead. Photochemical reactions in the atmosphere produce

secondary pollutants such as ozone. The concentrations of primary and secondary pollutants determine air quality. The effect of emissions on air quality is strongly mediated by weather and climatic conditions (inversion level height, mixing, wind speed and direction, air pressure, and precipitation). Among other sources, Agriculture Crop Residue Burning (ACRB) is one of the important anthropogenic sources of air pollution (American Thoracic Society, 1998; Badarinath *et al.*, 2004, 2005, 2006; Cachier, 1998; Kaushik *et al.*, 2006; Mittal *et al.*, 2007; Sahai *et al.*, 2007, 2010; Smith and Mehta, 2003; Ulevicius *et al.*, 2010; Vebol and Towprayoom, 2010).

1.3.1 Agriculture Crop Residue Burning



Figure 1.6: View of smoke due to be burning of wheat residue in Patiala, India

Emission of air pollutants due to open burning is of concern to the public as well as local, state, federal and foreign environmental and health regulatory agencies (Crutzen and Andreae, 1990; Dennis *et al.*, 2002; Tipayarom and Oanh, 2007; Wu *et al.*, 2006; Yang *et al.*, 2007). Open burning is defined as the unenclosed combustion of materials in an ambient environment. ACRB involves the open burning of residues of different agricultural crops which are left in the field after cutting, harvesting and threshing of the

crop (Figure 1.6). There are number of crops whose residue are burnt by the farmers during the particular seasons in the open fields like rice, wheat and sugarcane are three major crops on which lot of studies had been done in different countries (Cancado and Sadiva, 2006; Jeffrey *et al.*, 1997; Mohammad *et al.*, 2002; Lara *et al.*, 2005; Sahai *et al.*, 2007, 2010; Santos *et al.*, 2002).

Table 1.1: Residue production (x 10³ tons) by different crops in 1998

Crop	Asia	Africa	South America	World
Rice –straw	771,804	25,968	24,153	844,782
Rice –husk	154,361	5,194	4,831	168,956
Wheat	379,788	27,395	25,539	946,734
Barley	34,097	6,753	2,141	208,229
Sugarcane	53,855	8,561	41,880	125,227
Cotton	6,378	315	69	6,801
Oats	2,424	342	1,604	51,604
Corn	166,205	38,729	54,626	604,013

Source: Singh Y *et al.*, 2005

The amount of agriculture waste produced by countries varies with the type of principal crop grown and management system. Approximately 3.1 billion tons of crop residues are produced every year and about 60 percent originating in the developing world and 40 percent in the developed world (Strehlar and Stutzel, 1987). In South-east Asia, burning is the major disposal method for rice straw, which accounts for 31 percent of the agricultural waste in the developing world (Ponnamperuma *et al.*, 1984). With time, due to modernization and advance instrumentation the percentage of agricultural waste is continually increased.

Asia is the major producer of crop residue. It produces 52.6 percent of the world residues production. Table 1.1 show the residue production by different crops in Asia, Africa and South America indicates that the contribution of Asia in production of residue is comparatively high in comparison to South America and Africa. Rice, wheat and corns are the major crops, contributing about 84 percent of the total production of crop residue

in Asia. In Asia, the annual biomass is burned at a very large scale and the contribution of crop residue burning in total residue is very predominant in China (110.0 Tg) and India (84.0 Tg) (Streets, 2003). In Southeast Asia, burning is the major disposal method for rice straw, which accounts for about 31 percent of the agricultural waste in the developing world. ACRB can produce a large amount of smoke in a short amount of time. There are concerns over the impact to public health, safety and the environment (Singh *et al.*, 2009). This demands a stronger reason for monitoring and assessment of the severity of such activities on health.

Residue generation rises sharply with the rise in production after the adoption of green revolution technologies. Primary crop residues are used as animal fodder, industrial/domestic fuel, thatching, packaging, bedding, wall construction, and green-manuring/compositing/in-situ incorporation *etc.* The amount left over the fields available for field burning. This amount is highly variable and uncertain with local and regional climate, season, livestock distribution, availability fuel wood, availability of fodder, weed infestation, *etc.*

Rice gives two types of residue, straw and husk. Rice straw is a major portion of the rice crop residue and is partially used as fodder for cattle in southern and eastern India and for roof thatching all over the country (Meshram *et al.*, 2002). Husk is a byproduct of rice milling and is the second largest agro-industrial residue after the bagasse produce in India, up to 43 percent of which is consumed in rice mills (Meshram *et al.*, 2002). Although husk is not considered appropriate as fodder due to high silica content, about 5 per cent is used as cattle feed. The major share of husk goes as fuel in parboiling rice mills followed by applications like domestic fuel, bedding for animals (especially poultry) and also for oil extraction (Tyagi *et al.*, 1989). Earlier Husk was not burnt in the field. The introduction of combine harvesters has started to scatter husk in the field, which is subjected to burning. Wheat straw is produced in large quantity and the major share goes into the cattle field, domestic fuel, paperboard making and oil extraction. Rice and wheat are the two major crops responsible for residue generations in India, especially Punjab state (Badrinath *et al.*, 2006; Gupta *et al.*, 2004). In 1994, 150 Tg of dry residue

was generated in India, which is about 74 percent of the total that is available for open burning.

Rice and wheat are the key crops in agricultural biomass burning-related emissions. Rice and wheat is grown widely in India and referred to as the Rice Wheat System (RWS), wherein both the crops are grown one after then other, in a cycle (Thakur *et al.*, 2003). The RWS practice covers most of the areas where these two crops are grown. This system has been followed in U.P. since 1872 and in Punjab and west Bengal, since 1920 (Gupta *et al.*, 2003). RWS account for about one-fourth of the total crop residue production in India (Gupta *et al.*, 2003, Sarkar *et al.*, 1999).

Table 1.2: Rice-wheat crop production and residue generation from major states in 1994(Gg)

States-1994	Rice		Wheat		Total	
	Production	Residue	Production	Residue	Production	Residue
UP	10326	13284	22126	33189	32452	46473
Punjab	7688	9890	13501	20251	21189	30141
MP	6308	8115	7151	10727	13459	18842
Bihar	6251	8041	4296	6443	10547	14484
Haryana	2185	2810	7285	10928	9470	13738
Maharashtra	2419	3112	1097	1646	3516	4758
Gujarat	916	1179	1704	2555	2620	3734
HP	110	141	553	829	663	970
All India	81435	88474	64285	96428	145720	184902

Source: Gupta *et al.*, 2004

Every four tons of rice or wheat grain produced about six tons of straw (Thakur *et al.*, 2003). Large amount of crop residue is produced from RWS in India from major involved States, viz. Uttar Pradesh, Madhya Pradesh, Punjab, Bihar, Maharashtra, Haryana, Gujarat and Himachal Pradesh. The amount of residue generated from rice and wheat from the above-mentioned States is 133 Tg, which includes the highest from Uttar Pradesh (13 and 33 Tg) followed by Punjab (10 and 20 Tg) and Madhya Pradesh (8 and 11 Tg) respectively (Gupta *et al.*, 2004) (Table 1.2).



Figure 1.7: Manual cutting of crops



Figure 1.8: Combine Harvester

The major constraint in the RWS is the short time available between rice harvesting and plantation of wheat. Wheat crop is very sensitive to any delay in planting. This encouraged the introduction and use of combine harvesters in the RWS. In the North-West part of India, most of the cropped area is under combine harvesters that leave behind a large amount of straw in the fields whose sustainable utilization or disposal in the short time between cycles become very difficult. In the early stage, cutting of different crops was done manually (Figure 1.7), but due to the use of combine harvesters

(Figure 1.8), there has been a sharp increase in the share of residue that is left in the field as it leaves major portion of the residue, including husk in the field. According to Gupta *et al* (2003) about 5-7 tons/ha of rice straw is left unused in field. This abundantly produced crop residues needs to be disposed off to prepare land for next growing season. ACRB has been most commonly accepted practice for this crop residue disposal.

Agriculture crop residue disposal is a labor intensive and tedious part of the agriculture practice, thus burning is supposed to be the most convenient, economical and conventional approach by the farmers. ACRB being less time consuming, is widely accepted method for preparing the farm land for the next growing season. Moreover, ACRB does not require any extra labor to take the residue to other place. Due to less laborious and cost effective technique it is extensively accepted by the farmers to clear farm lands. Farmers are also supposed to use this practice to minimize pest and weeds in the fields for the coming crops. Since burning of agriculture crop residue is quick, easy and labor saving crop disposal technique.

For the personal and short term benefits, farmers used the practice of ACRB but it poses a serious, long term hazardous effect on society. ACRB due to less than ideal combustion conditions typically produces soot and Particulate Matter (PM) that are visible as dense smokes that produce ill effect on the ecological system (Ribeiro *et al.*, 2008). ACRB poses extra burden on the ecological system, some are global but mostly are regional on soil, air, visibility, climate and water

a. Degradation of soil properties like

- Loss of soil organics.
- 27-73 percent of N lost.
- 50 percent bacterial population/ soil microbial diversity decreases on repeated burning.
- Increases the carbon contents.
- Exchangeable NH_4^+ N & bicarbonate extractable P contents show immediate increase.

- b. Introduce several compounds into the atmosphere, including carcinogenic/mutagenic compounds like Polycyclic Aromatic Hydrocarbons (PAHs), aerosol and different harmful gases.
- c. Reduce visibility due to scattering and diffraction of light by the aerosol.
- d. Emission of green house gases occur which are responsible for global warming and climate change.
- e. Due to increase in the pollution level ultimately it affects the health of living beings.

1.3.1.1 ACRB and Environment

ACRB produces large amounts of trace gases and aerosol particles, which play pivotal role in troposphere chemistry, climate and health (Dennis *et al.*, 2002; Janhall *et al.*, 2010; Makkonan *et al.*, 2010; Pandey *et al.*, 2005, Seinfeld and Pandis, 1998, Singh *et al.*, 2009; Vanderwerf *et al.*, 2006; Yokelson *et al.*, 2007(a,b)). In urban areas, carbonaceous aerosols associated with vehicular combustion are major sources of pollution and radiative effect of carbonaceous aerosols constitutes one of the largest uncertainties in climate modeling (Andreae *et al.*, 2001, 2005; Ramanathan *et al.*, 2007). Smoke particles from biomass burning have direct radiative impact by scattering and absorbing shortwave radiation and indirect radiative impact by serving as cloud-condensation nuclei (CCN) and changing the cloud microphysical and optical properties (Andreae and Rosenfeld, 2008; Asa-Awuku *et al.*, 2008; Kivekas, 2008, Reutter *et al.*, 2009; Rose *et al.*, 2008; Rosenfeld *et al.*, 2008, Cachier *et al.*, 1998, Cattani *et al.*, 2005). In addition to aerosol particles, biomass burning due to crop residue burning are considered a major source of carbon dioxide (CO₂), carbon monoxide (CO), methane (CH₄), volatile organic compounds (VOC), nitrogen oxides and halogen compounds (Guyon *et al.*, 2005; Andreae and Merlet, 2001). The greenhouse gases CO₂ and CH₄ directly influence the global warming, while changes in oxidizing capacity to CO variability could perturb the growth rates of greenhouse gases (Dennis *et al.*, 2002; Singh *et al.*, 2009). Recent study by Gustafsson *et al.* (2009) highlighted that biomass burning is one of the main causes for dense “brown clouds” in South Asia and 50–90% of the South Asian BC originates from fossil fuel combustion (Stone *et al.*, 2007; Menon *et al.*, 2002).

Biomass burning has been estimated to contribute up to 40% of the annual carbon released into the atmosphere by various anthropogenic sources (Cachier *et al.*, 1998). Atmospheric aerosols have several environmental impacts, some of which are global but mostly are regional (Janhall *et al.*, 2010; Badrinath *et al.*, 2009a). Atmospheric aerosols being poly dispersive, different sizes are significant for different phenomena. The concentrations of aerosols in the atmosphere as well as their size distribution are affected by various source processes like washout and rainout (Cachier *et al.*, 1998; Crutzen and Andreae, 1990). There are different types of harmful substances, particulate matter and gaseous are produced due to ACRB, but here main focus given particulate matter.

About 90 percent of smoke is PM₁₀. The particulate matter produced by burning consists of particles of soot (unburned carbon), ash (unburned minerals), condensed fumes (including toxic and cancer causing aerosols) and other products of incomplete combustion. Particulate matter is an air pollutant consisting of a mixture of particles that can be solid, liquid or both suspended in the air for long time. Particle size is regarded as the most important physical characteristic of particulate matter (Prospero *et al.*, 1981).

Suspended Particulate Matter (SPM) is the particulate having particle's aerodynamic size varying from 0 to 100 µm also called Total Suspended Particulate (TSP). Individual particles cannot be seen with the naked eye, collectively they can appear as black soot, dust clouds, or grey hazes. PM₁₀ represents the particles with an aerodynamic diameter of 10 µm or less, or, more strictly, particles which pass through a size selective inlet with a 50% efficiency cut-off at 10 µm aerodynamic diameter (US Federal Register, 1987). PM₁₀ is also called as Respirable Suspended Particulate Matter (RSPM) as they are able to reach inside the respiratory tract. PM_{2.5} is the mass of aerosol particles with aerodynamic diameter of 2.5 µm or smaller also called as fine particles (Seinfeld and Pandis, 1998).

PM_{10-2.5} represents the particles with an aerodynamic diameter between 10 and 2.5 µm called as the coarse fraction of PM₁₀. The emitted particles have certain falling

velocity (depending on size of particles) due to downward force of gravity, which is opposed by aerodynamic drag of atmosphere. The balance between these forces is readily attained and the particles remain suspended in air for long time (Nicholson *et al.*, 1988). Smaller the size of particles more is the residence time. Due to large residence time, smaller size particulate matters cover a long distance. It becomes global problem rather than local problem depending on the wind speed. Thus assessment of PM₁₀ and PM_{2.5} concentration as well as their share to total PM concentration assumes significance from environmental perspectives.

1.3.1.2 ACRB and Health

As mentioned in earlier sections, ACRB is one of the most important sources of harmful gases and PM. Aerosol particles with aerodynamic diameters less than 10 µm (PM₁₀) and aerodynamic diameters less than 2.5 µm (PM_{2.5}) are of special interest when health problems are concerned, as they are easily inhaled deeply into the lungs where they can be absorbed into the bloodstream or remain embedded within the terminal airways.

Epidemiologic studies suggest that respirable particulate matter (PM₁₀) is a risk factor for respiratory morbidity and cardiopulmonary mortality (Dockery *et al.*, 1993, 1994; Gomiscek *et al.*, 2004; Laden *et al.*, 2000; Mar *et al.*, 2000; Pope *et al.*, 1995, 2002). The health impacts of finest particulate PM_{2.5} is greater because it can penetrate deep into alveolar sections of lung (Agarwal *et al.*, 2006). Various health effects attributable to PM have been documented (WHO, 1999; Brunekreef and Holgate, 2002). It is also known that the fine aerosols are important from health perspective as they can penetrate deeper into the respiratory system. These particles have longer atmospheric residence times. Also due to relatively large surface area, these small particles are associated with them in higher proportion of metals and persistent organic compounds.

PM₁₀ have been shown significant associations with decline in lung function, respiratory and cardiovascular disease deaths from cardiopulmonary disease and lung cancer. Greater the exposure increments greater is the risk of impacts. The most

conclusive evidence has been provided by cohort and time series studies that have linked elevated concentrations of PM to increased morbidity and mortality (Chaloulakou *et al.*, 2003; Dockery *et al.*, 1993, 1994; Gomiscek *et al.*, 2004; Laden *et al.*, 2000; Mar *et al.*, 2000; Pope *et al.*, 1995, 2002; Samet *et al.*, 2000; Schwartz *et al.*, 1996). There are strong evidences which show the harmful effects of short term increase in the concentration of particulate matter on the mortality and health of individuals (Cizao and Tong, 2008; Grass *et al.*, 2010; Jindal *et al.*, 1994; Samet *et al.*, 2000; Wilson and Zereini, 2009; Wu *et al.*, 2010; Yi *et al.*, 2010). Thus, assessment of PM₁₀ and PM_{2.5} concentrations as well as their share to total PM concentration assumes significance from health perspective.

Respiratory diseases associated with agriculture were one of the first recognized occupational hazards (American Thoracic Society, 1998). Although, industrialization and the use of motor vehicles are overwhelmingly the most significant contributors to air pollution but crop residue burning also plays an important role in air pollution as it produces many harmful gases and particulate matter. The investigation of agricultural respiratory hazards has lagged behind the investigation of hazards in mining, automobile and other heavy industries (Contini *et al.*, 2010; Gajghate and Bhanarkar., 2005; Ghasemkhani *et al.*, 2006; Ingle *et al.*, 2005; Jaen *et al.*, 2006; Kaushik *et al.*, 2006; Lim *et al.*, 2010; Long *et al.*, 1998; Osman *et al.*, 2009; Paul *et al.*, 2004 Sharma *et al.*, 2008). The open ACRB emissions are more troublesome than other anthropogenic sources from public health perspectives because open burning emissions are typically released at or near ground level instead of through tall stacks which aid dispersion. Open burning emissions are not spread throughout the year but concise to small interval of time. During this period, people are exposed to higher concentration of harmful gases and particulate matter, hence expected to have more influence (Badarinath *et al.*, 2006, 2009b; Long *et al.*, 2006; Sharma *et al.*, 1995). Due to functioning of respiratory system and different processes involved in respiration make it very sensitive with respect to external environment (Jedrychowski *et al.*, 2008; Long *et al.*, 2006; Lagorio, 2006).

Human exposure to polluted air chiefly affects the lungs, eyes and skin. It also indirectly affects the heart and other organs. Air pollution is of particular concern to

people with asthma, as even low concentrations may increase the risk of developing asthma, or exacerbate existing conditions (Brimblecombe, 1986; Elsom, 1992). The actual biological pathway is not well understood but three respiratory effects are thought to be the result from exposure to air pollution:

- Direct irritation of the sensitive airways.
- A toxic effect, causing cellular damage and inflammation of the airways.
- Modification of the immune system, resulting in greater susceptibility to other asthma triggers, especially entry of allergens (Wardlaw, 1993).

Many epidemiological studies have modeled the effect of air pollution on health and they have been reviewed on several occasions (Dockery and Pope, 1994; Holland *et al.*, 1979; Katsouyanni *et al.*, 1995; Lipfert, 1993; Ostro, 1996; Schwartz, 1994b; Smith *et al.*, 1999; World Health Organization Regional Office for Europe, 1987).

Increased modernization and industrialization has increased the standards of living of the human beings on one side but on the other side it has posed large detrimental effects on the chemical balance of the atmospheric air around us. Since human beings are continuously in direct contact with the air which has adverse effects on them. There is a need to understand the health effects of different types of air pollution on humans. Lot of studies including survey has been done on the air pollution like industrial pollution and vehicular pollution. The pollution arising from these pollutants does not vary appreciably in the atmosphere throughout the year. In the case of health effects due to air pollution arising from crop residues burning, there has been alarmingly increase in their concentration in the atmosphere during particular months as agricultural crop residue burning emissions are not spread throughout the year but it is episodic in time or season. Thus, there is a need of systematic study for estimating the effect on health due to crop residue burning. In the present study, attempts have been made to study the effect due to burning crop residues on human respiratory system by measuring PFTs and SpO₂. For accurate result repeated spirometric measurement had been done for three years. Anderson cascade Impactor and High Volume Sampler were used to measure the

concentration of different size particulate matter and finally on the basis of data collection. Finally, a model has been proposed to predict the effect of ACRB on PFTs.

This chapter is followed by the detailed literature review and the objective of the present work. Third chapter describes various methodology adopted in the present study which includes selection of sampling sites and subjects, collection of different biological and environmental parameters, different instrument involved in the study and analysis of the different parameters. Fourth chapter deals with result and discussions of data collected during February 2007 to January 2010. In Chapter five a model is proposed on the basis of the three year results. Last chapter gives conclusion and future recommendations of the study.

Chapter II

Review of literature

This chapter presents an account of literature on different types of studies in the environmental health perspective. In earlier part of the literature review, different types of investigations conducted in the field of human health status are presented, where as in the later part, different type of studies related to mass concentration of different size particulate matter in the ambient air is discussed. Lot of study has been done to measure the respiratory status by measuring the respiratory symptoms and hospital admissions etc. but not much study was found in the literature with repeated spirometry measurement of respiratory system. Moreover, issues other than Agriculture Crop Residue Burning (ACRB) like industrialisations etc. were investigated but effect of ACRB on the respiratory system lag behind the other type of studies. In retrospection of the literature survey done attempts were made to study the effect of ACRB on the respiratory system by measuring the PFTs of healthy subjects.

2.1 Literature Review

Significant increase in mortality and morbidity due to respiratory and cardiovascular disease has been recognized since few decades by the scientific community to be partly caused by excess ambient pollution levels. Although the health effects of pollution have been experienced since the ancient times of 13th century with the use of coal and wood, but only recently (mid 1900) the scientific community has tried to quantify and assess the human health. The acceptable pollution level by the society is a matter of concern and extremely important for policy makers to establish the minimum standard aims to safeguard human, animal and plant survival.

Rapid urbanization and industrialization with concomitant increase in vehicular and industrial emissions, both in the developed and developing world, have deteriorated the quality of ambient air. It is estimated that, humans inhale around 10, 000 liters of ambient

air on daily basis, which comes in close contact with a lung surface area of over 100 m² (Heyder, 2004; Koenig, 1999; Salvi, 2007). About 350 liters of oxygen diffuses across the alveolar capillary basement membrane into 10, 000 liters of blood flowing through the lungs daily (Heyder, 2004). The respiratory tract comes in close contact with a large volume of ambient air and its component regularly. The harmful substances, especially the fine particles, that we inhale get retained in the lungs and cause harmful effects. It has been estimated by the World Health Organization (WHO) that more than 300 million people die every year due to harmful effects of ambient air (WHO, Health aspects of air pollution, 2004).

Notorious acute air pollution episodes such as London smog episodes (1952, 1962), the Donora smog (1948) and Muese valley smog (1930) resulted in large number of deaths which indicate the short-term elevated levels of PM are associated with variety of pulmonary disorder, including mortality (Faith *et al.*, 1972).

For centuries, human being have been dealing with Suspended Particulate Matter (SPM) from dirt and many other anthropogenic sources like one of the oldest practice of biomass burning for the purpose of cooking, warmth and for other personal benefits (Sint *et al.*, 2008). Human respiratory tract deals with wider variety of ambient particles and gasses, predominantly smoke from vehicle exhaust and industrial sources.

The most detrimental event associated with mortality due to exposure to air pollution occurred during December 5th to the 9th 1952, in London, England (Sunyer *et al.*, 2000). During the London Fog, over 4000 more deaths were observed than normal due to heart and lung conditions. The smog episode in the Ruhr district of West Germany during January 1985 show higher mortality, morbidity rate and hospital admissions during said period (Wichmann *et al.*, 1989). The episode in London, along with many others, brought attention to the impact of air pollution on human health (Sunyer *et al.*, 2000) and focused attention of the scientific community on the need of studying the adverse health effects of ambient air pollution. Tyrolean Iceman discovered in September

of 1991 that before 5300 year ago, dust and carbon retained in his Lung tissue (Pabst *et al.*, 1998).

Exposure to ambient air pollution has been linked to a number of health outcomes, starting from modest transient changes in the respiratory tract and impaired pulmonary function, continuing to restricted activity/reduced performance, emergency room visits and hospital admissions and to mortality. There is lot of evidence for adverse effects of air pollution on the respiratory system (WHO, 2004, Health aspects of air pollution).

2.1.1 Studies related to human health

To understand the effects of air pollution on the human beings literature survey was done on the basis of groups, methods and causes of air pollution which was further divided into subgroups (Figure 2.1).

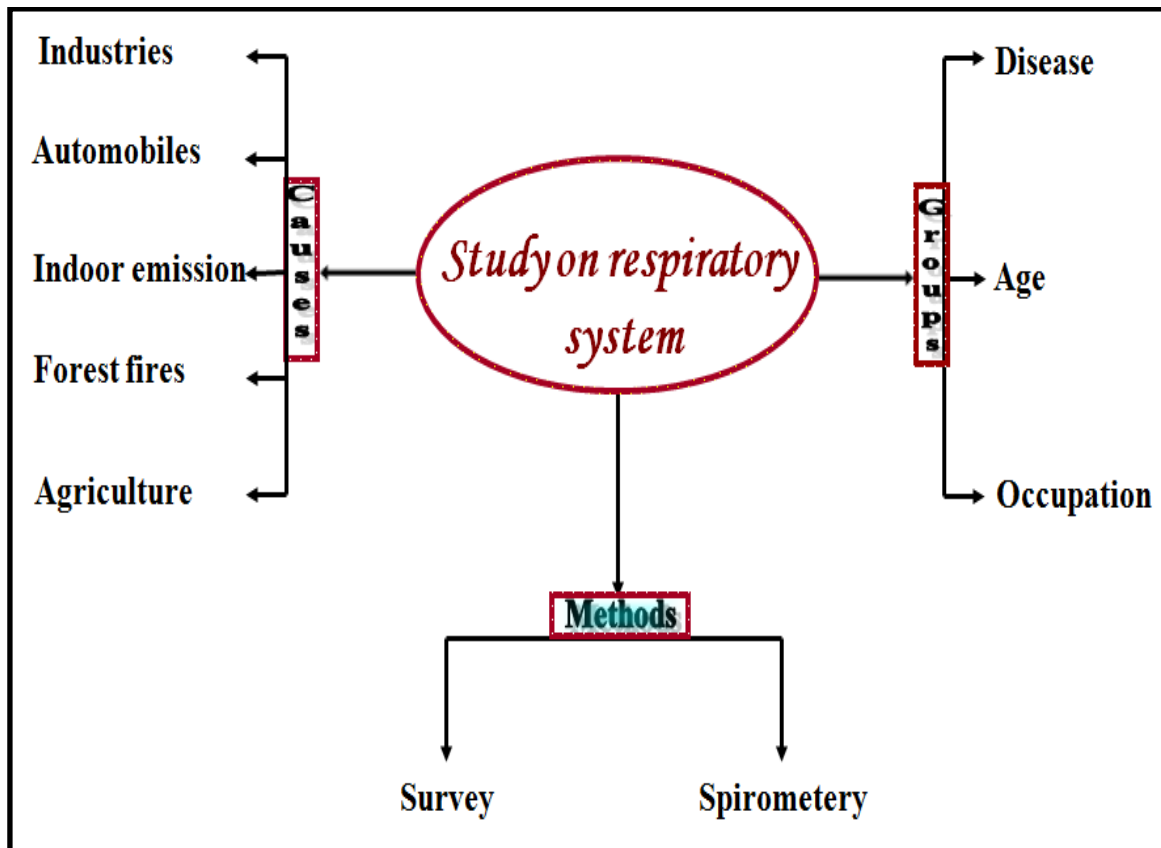


Figure 2.1: Characterizations of different studies in the field of respiratory system

Literature was reviewed for various groups of diseased people like asthmatic persons *etc.*, on the basis of age like children or adults and on the basis of occupational exposure like stone crusher workers, traffic policeman *etc.* for different causes like air pollution due to industries, automobile and biomass burning. On the basis of methodology, study was done on two aspects like survey in hospital admission, respiratory symptoms *etc.* and measurement of different respiratory parameters by using spirometry. Few studies with repeated measurement of PFTs were done on the same subjects for long period. Literature in support of different type of studies on the basis of method, causes and groups has been cited in the coming section.

Lot of study on the sensitive group like children, Asthmatic people were reported in past. Young children seem more sensitive to some pollutants. On comparison with healthy individuals, peoples with respiratory disorder like asthma or chronic bronchitis may react more strongly to given exposure, either as a result of increased responsiveness to a specific dose and/or as a result of a larger internal dose of some pollutants than in normal individuals exposed to the same concentration. Increased particle deposition and retention demonstrate in the airways of people suffering from obstructive lung disease (WHO, Health aspects of air pollution, 2004). These groups were found more sensitive, so lots of studies were done on the children and diseased people specially those suffering from Asthma.

Some studies were carried out in different countries shows the effect of outdoor pollution on children (Edwards *et al.*, 1994; He *et al.*, 1993; Schnabel *et al.*, 2009; Wang *et al.*, 1994). In most of these investigations, pollution arises from industries and traffic was of major concern. Ong *et al.* (1991) studied the respiratory health of primary school children in urban community of Hong Kong. In this case, two-year survey of respiratory morbidity in primary school children was conducted. This study provides the basis for an evaluation of new low sulfur fuel regulations introduced in July 1990.

Ma *et al.* (1991) studied the impact of particulate matter on pulmonary function of children in China. The pulmonary function like FVC, FEV₁, FEF_{25-75%}, and FEF_{75-85%} of

504 children were performed in three regions along with different level of particulate pollution in air. It was observed that when the concentration of total suspended particulate increases to $100 \mu\text{gm}^{-3}$, the odd ratio for respiratory diseases and symptoms increases.

Strachan and Anderson (1992) studied the trend in hospital admission rates for asthma in children. Study showed that rate of admission for childhood asthma in England and Wales increases up to doubled since 1970s.

Wilkin and Mao (1993) studied the trends in rates of admission to hospital and death from asthma among children and young adults in Canada during 1980s. This study was limited to update reports of increases in the rates of admission to hospital and death from asthma among children and young adults in Canada during the 1970s by examining data for the 1980s.

He *et al.* (1993) studied the effects of air pollution on children's pulmonary function in urban and suburban areas of Wuhan, China. In this study, spirometric functions of 604 children of chronic respiratory free conditions were measured. The study of FVC and FEV₁ showed that urban ambient air pollution exposure in china contributes to retardation in the growth of children's lung function.

Edwards *et al.* (1994) studied the Hospital admissions for asthma in preschool children. They examined the relationship between residence near major roads, traffic flow and risk of hospital admission for asthma in children younger than 5 year of age living in Birmingham, United Kingdom. Children admitted with an asthma diagnosis were significantly more likely to live in the area of high traffic flow ($> 24,000$ vehicles/24h) located along the nearest segment of main road than were children admitted for nonrespiratory reasons ($p < 0.02$) or children from the community ($p < 0.002$). Children admitted for nonrespiratory reasons were more likely to be admitted than children in the community sample if they lived within 200 m of a main road ($p < 0.02$), irrespective of traffic flow.

Wang *et al.* (1994) studied relationship between air pollution and changes in children's peak expiratory flow. In this case continuous measurements of PEF for one month of 60 healthy children selected in the city of Beijing were taken along with measurement of SO₂ and NO₂ in air. There was notable correlation between individual exposure to SO₂ and PEF of the children.

Tang *et al.* (1997) studied the predictive pulmonary function of school children in an area of low air pollution in Taiwan. In this study, the effects of different parameters on a predictive model of pulmonary function of 836 elementary school children of aged 7 to 12 years were studied for FVC and FEV₁. Regression analysis showed that all the pulmonary function parameters measured had a positive correlation with height, where as weight correlated only with certain parameters.

Chen *et al.* (1999) studied the short-term effect of ozone on the pulmonary function of children in primary school of Taiwan in three communities (Sanchum, Taihsi and Linyuan). In this study multivariate linear model analysis was used to evaluate pulmonary function effects of each pollutant in addition to determine the indoor air pollution and meteorological conditions. There was significantly negative association of peak O₃ concentration on the day before spirometry test with individual FVC and FEV₁. The decrease in children's lung function occurs at peak hourly O₃ concentration < 80 ppb. The slope of lung function decrease was approximately 1ml/ppb for peak hours of O₃ exposure.

Chew *et al.* (1999) studied the association of ambient air pollution levels with acute asthma exacerbation among children in Singapore. Study suggests that asthmatics children are more susceptible to increased levels of air pollution, particularly SO₂ and total suspended particulate, although the ambient levels are generally within acceptable range.

Aekplakorn *et al.* (2003) studied the acute effect of SO₂ from a power plant on pulmonary function of children in South Asia Thailand. In the asthmatic children, daily

increase in SO₂ was associated with negligible decline in pulmonary function but small negative association was found between PM₁₀ and pulmonary function.

Aekplakorn *et al.* (2004) studied the heterogeneity of daily pulmonary function in response to air pollution among asthmatic children in South East Asia (Thailand). Daily pulmonary function like FVC, FEV₁, PEF_R and FEF_{25-75%} testing were performed for 61 days on 83 asthmatic school children in the Mae Moh district of Thailand. The results indicate evidence of inter-individual variation for subject changes pulmonary function due to effect of SO₂ and PM₁₀ on children. It showed that at low concentration of daily SO₂ and PM₁₀ in the study area, there is evidence of a heterogeneous response to SO₂ and PM₁₀ in children.

Kim *et al.* (2005) studied the effects of particulate matter on the pulmonary function of middle school children in Incheon metropolitan city. In this case FVC and FEV₁ of 368 students were done twice between March 2000 and December 2000. Relationship between PFT and PM₁₀ level were analyzed. PM₁₀ showed some adverse effect on the pulmonary function of normal children.

Ostro *et al.* (2009) studied the effects of fine particle components on respiratory Hospital admissions in children. This study estimates the risks of exposure to PM_{2.5} and several species on hospital admissions for respiratory diseases among children. Components of PM_{2.5} were associated with hospitalization for several childhood respiratory diseases including pneumonia, bronchitis and asthma.

Schnabel *et al.* (2009) studied the Hospital admission in children up to the age of 2 years. Analysis was based on data from the LISA-study, a prospective population based birth cohort study including 3097 full-term infants. The number of hospitalization episodes per person showed that many children were hospitalized only once during the period from 7 to 24 months. This analysis shows that hospital admission is common and not equally distributed concerning sex, parental education and region in German children.

There is lot of evidence in literature in which effect of indoor air pollution due to house hold emissions on health was studied (Bruce *et al.*, 2000; Ezzati *et al.*, 2001; Finkelman *et al.*, 2004; Smith *et al.*, 2000). Emissions from household coal and wood combustion associated with cooking and heating are an important public health issue (Hosgood *et al.*, 2011; McCracken *et al.*, 2007). Use of fuel wood in traditional chulhas and cook stoves creates health problem like eye irritation to serious respiratory diseases (Johnson *et al.*, 2011). Now a day's improved Cook stoves are used for minimizing the health effect due to indoor air pollution (Masera *et al.*, 2007; Romieu *et al.*, 2009).

Chingappa *et al.* (2007) studied the impact of improved cook stoves on indoor air Quality in the Bundelkhand region in India. Results shows that improved cook stoves increased the air quality with the reduction in the concentration level of particulate matter of fine range and carbon monoxide.

Clark *et al.* (2009) studied the impact of improved cook stoves on indoor air pollution and adverse health effects among Honduran women and reported more symptoms in woman using traditional stoves than those using improved stoves.

Some studies does not involved actual measurement of PFTs, rather analysis were done on the basis of survey or collection of data from different hospitals and health institutes. Aditama *et al.* (2000) studied the impact of haze from forest fires in Indonesia to respiratory health. Data was collected from personal reports from pulmonologists working in the area as well as from provincial/district office and hospitals. Data shows that there is significant impact of haze to human lung.

Cho *et al.* (2000) studied the air pollution and hospital admission for respiratory diseases in Korea. In this study, the relationship between levels of air pollution and incidence of respiratory system was examined. No respiratory parameters were studied directly. Respiratory diseases admissions were related to NO₂, CO and Total Suspended Particulate (TSP) concentrations below the environmental standard but the significance of this relationship was area dependent.

Duki *et al.* (2003) studied the effect of air pollution on respiratory health in Indonesia and was analyzed to economic cost. In this case 16,663 pairs of student and their mother were surveyed, using self-administered questionnaire, to measure the effect of air pollution on respiratory health and the cost of associated illness. Multiple regression analysis showed that the prevalence rates of the symptoms of cough, phlegm, persistent cough, wheezing without cold and asthma. Student and mother groups, were significantly correlated with NO₂ emitted along large roads near their residences and to lesser extent with smoking.

Park *et al.* (2005) studied the effects of ambient particulate matter on PFR and respiratory symptoms of asthmatic during Asian dust periods in area. This study provides evidence that Asian dust events are impacting on the respiratory symptoms of subjects with bronchial asthma and ambient air pollution particularly PM₁₀, might be one of the aggravating factors.

Franklin *et al.* (2008) studied the role of particle composition on the association between PM_{2.5} and mortality. This study shows that certain chemical species modify the association between PM_{2.5} and mortality and illustrates that mass alone is not a sufficient metric when evaluating health effects of PM exposure.

In the present decade different studies were done on the basis of occupational criteria like policeman, shopkeepers *etc* which were considered to be more susceptible to ambient air. They form the groups of peoples exposed to other toxic materials which adds to or interacts with air pollutants, and is socioeconomically deprived. Rao *et al.* (1992) studied the pulmonary function status of shopkeepers of Ahmdabad exposed to auto exhaust pollutants. This study deals with evaluation of pulmonary function test like VC, FEV₁ and FEF_{25-75%} in Ahmdabad shopkeepers stationed near different traffic junctions and relating these PFT with levels of oxide of nitrogen near these junctions categorized as heavy, medium and low polluted area junctions. The results indicate significant impairment in FEV₁% and FEF_{25-75%} value in high-polluted area shopkeepers where NO_x levels were much higher than TLV value. This study also denoted that FEF_{25-75%} is an

early indicator of obstruction in smaller airways which is the primary site of deposition of inhaled pollutants.

Karita *et al.* (2001) studied the respiratory symptoms and pulmonary function among traffic police in Bangkok, Thailand. In this case comparison between male traffic police and male non-traffic police was done. FEV₁ and expiratory flow rate in 25% of vital capacity were measured and showed an evidence of increase in prevalence of obstructive changes in the peripheral airways among traffic police in Bangkok.

Tiwari *et al.* (2003) studied the spirometric measurements among quartz stone Ex-workers of Gujarat, India. This cross sectional study was carried out among 134 ex-workers, which contain both male and female from quartz crushing units. Study showed that quartz stone workers exposed to approximately 100% free silica had deteriorated lung function, which can be attributed mainly to respiratory disorders along with other epidemiological factors such as age, sex, duration of exposure and smoking.

Ingle *et al.* (2005) studied the exposure to vehicular pollution and respiratory impairment of traffic policemen in Jalgaon city, India. The ambient air quality monitoring was carried out in Jalogaon city. The average concentration of SO_x, NO_x, particulate matter and respirable dust particulate was reported during the study period. The spirometric analysis of traffic policemen shows significant variation in PEF_R, FEV₁ and FVC. The parameters were significantly affected in the traffic policemen as against the control group of population. It reveals significant respiratory impairment in the traffic policemen due to exposure to vehicular pollution.

Hendryx *et al.* (2009) studied the mortality from heart, respiratory and kidney disease in coal mining areas of Appalachia. Study was carried out for 4 years from 2000 to 2004 for heart, respiratory and kidney disease in relation to tons of coal mined. Results show that higher chronic heart, respiratory and kidney disease mortality in coal mining areas due to environmental exposure to particulate matter or toxic agents present in coal and released in its mining and processing.

Osman and Pala (2009) studied the occupational exposure to wood dust and health effects on the respiratory system in a minor industrial estate in Bursa/Turkey. The study was conducted during October 2006 and May 2007. In this study, 656 persons, 328 woodworker and 328 controls were included and it was pointed out that the exposure to wood dust adversely influenced the workers respiratory functions.

Other types of studies found in the literature were on the diseased group like COPD, asthmatic *etc.* In these cases common or normal healthy person remain untouched. Jing *et al.* (2000) studied the relationship between air pollution and acute and chronic respiratory parameter disease in Benxi, China. In this paper the effect of outdoor air pollution on respiratory system was carried out on chronic expectoration, shortness of breath asthma, chronic bronchitis, chronic obstructive pulmonary diseases and acute respiratory diseases. Respiratory symptoms parameters increased with the increasing levels of outdoor air pollution.

Chhabra *et al.* (2001) studied the ambient air pollution and chronic respiratory morbidity in Delhi. Authors conducted a cross-sectional study among residents of Delhi to determine the role of ambient air pollution in chronic respiratory morbidity in Delhi. Authors concluded that prevalence rates of bronchial asthma, chronic obstructive pulmonary disease and chronic bronchitis among residents in the two pollution zones were not significantly different. Lung functions of asymptomatic non-smokers were consistently and significantly better among male and female residents of the lower-pollution zone.

Kuo *et al.* (2002) studied the effects of air pollution among asthmatic in central Taiwan. Monthly level of PM₁₀, SO₂ and NO₂ were measured along with FVC, FEV₁ and PEF pulmonary functions. Level of NO₂ and PM₁₀ were correlated significantly with monthly hospital admissions. The increased risk of asthma and the frequency of monthly hospital admissions among asthmatics correlated positively with pollution levels especially SO₂ and NO₂.

Pothikamorjorn *et al.* (2002) studied the impact of particulate air pollutant on allergic skin reactivity and lung function. A cross sectional study was taken to compare the prevalence of eye, nose, airway allergic symptoms, allergic skin sensitivity and lung function of 290 high school students. It was observed that chronic exposure to high PM₁₀ levels was significantly associated with increased prevalence of eye and airways symptoms and a decrement of FEF_{25-75%} resulting in increase of school absence and medical expense.

Sekine *et al.* (2004) studied long term effects of exposure to automobile exhaust on the pulmonary function of female adults in Tokyo, Japan. The subjects living in area with high levels of air pollution showed higher prevalence rates of respiratory symptoms and larger decrease of FEV₁ compared with those living in areas with low levels of air pollution.

Agarwal *et al.* (2006) studied the respiratory morbidity through pollution status and meteorological condition for Delhi. The study showed the role of pollutants like SO₂, NO₂, SPM and RSPM and various meteorological factors on respiratory admission on account of COPD asthma and emphysema. Further the study showed that winter months had greater exposure risk and statistical analysis revealed that SPM and RSPM have significant positive correlation with number of COPD cases and metrological factor temperature has a significant negative correlation with COPD.

In past researchers emphasis mainly on the effect of the pollution by automobiles, industries *etc.* on children, characterized group or diseased group. Thereafter, air pollution in urban centers where automotive exhausts and the industrial chimneys are the most important sources of atmospheric pollutants was studied. However, a significant portion of the earth's population is exposed to still another source of air pollution, i.e., biomass burning which includes ACRB and forest fires.

Climate change is one of the major reasons for increase in forest fires incident that ultimately affect the ecological system. Forest fires or the wildfires are differs from other fires by its extensive size, the speed at which it can spread out from its original source, its potential to change direction unexpectedly and can cause extensive damage, both to property and human life. The smoke from these fires can affect individuals differently, based on the duration of smoke exposure, their age and health. Different researcher study the health and environmental perspectives of these wide fires (Fowler, 2003; Hanigan et al., 2008; Joshi, 2003; Mirabelli et al., 2009)

Emmanuel, (2000) studied the impact of haze from forest fires to lung health in Singapore. Findings from the health impact of the haze showed that there was a 30% increase in outpatient attendance for haze-related conditions. An increase in PM₁₀ levels from 50 µgm⁻³ to 150 µgm⁻³ was significantly associated with increases of 12% of upper respiratory tract illness, 19% asthma and 26% rhinitis. During the same period, there was also an increase in accident and emergency attendance for haze-related conditions. Results show a mild health effect from 1997 smoke haze in Singapore.

Künzli et al. (2006) studied the health effect of children due to forest fires during 2003 in South California. All symptoms (nose, eyes, and throat irritations; cough; bronchitis; cold; wheezing; asthma attacks), medication usage, and physician visits were associated with individually reported exposure differences within communities. Risks increased monotonically with the number of reported smoky days. Study concluded that the exposure to wildfire smoke was associated with increased eye and respiratory symptoms, medication use, and physician visits.

Agriculture residue burning is one of the important types of Biomass burning, which have remarkable environmental health hazards. Pollution arising from burning of agriculture residue which is one of the most prevalent practices of the rural sector is not much studied so there is need of investigation in this field. Open burning emissions are not spread throughout the year; rather it is typically episodic in time or season. There are some studies, which had been done by different researchers in different countries like

Iran, California *etc.* to investigate the effect of agricultural burning on respiratory system but generally they emphasis on the survey based on hospital admission and no actual measurement of PFTs had been done continuously for long duration.

Jefferey *et al.* (1997) studied rice burning and asthma hospitalization in California. Investigation on association between rice burning and daily asthma hospitalizations was done. In this study no PFT were measured but this study suggests that rice straw burning may be associated with increased asthma hospitalization. Dose-response effects were seen, risk of asthma hospitalization increasing as the number of acres burned increased.

Jacob *et al.* (1998) studied the effect of rice burning on the asthma hospitalization for 10-year in Butte County, California and noted that hospital asthma admissions were 29 percent higher than average on days when large quantities of rice stubble was been burned.

Long *et al.* (1998) studied respiratory symptoms in a susceptible population due to burning of agricultural residue. 428 adults with mild to moderate and high level of airways obstruction were surveyed. Study on smokers and non-smokers were also done. Not much emphasis has given on FEV₁. Study suggests that people with underlying respiratory disorders such as chronic bronchitis and asthma were susceptible to air pollution caused by burning of agricultural residue.

Arbex *et al.* (2000) studied the effect of sugar cane plantation on hospital respiratory admissions in southern Brazilia. They reported that total air particulates were significantly higher during sugarcane burning periods and the number of patients requiring inhalation therapy also increased significantly during sugarcane burning periods.

Torigoe *et al.* (2000) studied the influence of emission from rice straw burning on bronchial asthma in children. A five-year study in a rice growing area of Japan reported that the average number of childhood asthma hospital visits were more than double

during the rice burning months of September and October as compared to the rest of the year. Average airborne particulate concentrations were also more than double during September and October as compared to the rest of the year. In addition, an adult asthmatic volunteer in this study suffered a 41% drop in peak expiratory flow after being exposed to rice burning smoke for 20 minutes.

Mohammad *et al.* (2002) studied the early effects of burning rice farm residues on respiratory symptoms of villagers in Isfahan, Iran. In this case, cross sectional study was conducted randomly in villagers of Isfahan rural areas. FEV₁, FEV₁/FVC, PEF_R and FEF_{25-75%} were the respiratory parameters were under investigation. The values of these parameters decreased. Increased respiratory morbidity associated with rice burning among all people living in the area was observed.

Cancado *et al.* (2006) studied the impact of sugarcane-burning Emissions at Piracicaba in southeast Brazil on the respiratory System of children and the elderly. Results show that the increase of 10.2 mg/gm⁻³ concentration of PM_{2.5} associated with increase of 21.4% and 31.03% in child and elderly hospital admissions which clearly verify the adverse impact of sugarcane burning emissions on the health of the population at Piracicaba in southeast Brazil.

Arbex *et al.* (2007) evaluated the association between the TSPs generated from pre-harvest sugar cane burning and hospital admission due to asthma (asthma hospital admissions) in the city of Araraquara in Brazil. It was found that 10 µgm⁻³ increases in the TSP concentrations was associated with an increase of 11.6% (95% CI 5.4 to 17.7) in asthma hospital admissions which means the increases in TSP concentrations were definitely associated with asthma hospital admissions in Araraquara.

Ribeiro (2008) review the different articles published during 1996 to 2006 that deals with the health effects of sugarcane burning. These studies suggest that the elderly, children and asthmatics people are more sensitive and effected more by the sugarcane burning. In these studies generally more stress is given to particulate matter of size less

than 10 μm which show more effect on the different studied groups (Vermylen *et al.*, 2005).

Lot of study had been done to study the effect of pollution due to different reasons on human health, but mostly on the basis of collection of data from nearby hospital. Respiratory diseases associated with agriculture were one of the first- recognized occupational hazards from many years ago. In 20th century this problem has been carefully studied. Investigation of agricultural respiratory hazards has lagged behind the investigation of hazards in mining and other heavy industries, but these agricultural hazards are of serious concern.

2.1.2 Studies related to particulate matter

Classification on the basis of size is quite common because size governs the transport and removal of particles from the air and their deposition within the respiratory system. Measurement of Particulate Matter (PM) is important both environment and health point of view as this particulate matter is one of the main factors for global warming. In health point of view, lot of respiratory problem arises due to inhaling of these harmful matters.

World health Organization (WHO) estimates that inhalation of PM is responsible for 50000 excess deaths each year worldwide. Adverse health events have also been observed in a range of air concentrations considered safe according to WHO guidelines (WHO. 1994).

Airborne Particulate Matter (PM) is the recent focus of the world community as it penetrates the respiratory system of human beings and causes many disorders as the particles contained in the PM₁₀ size fraction may reach the upper part of the airways and lung. Several time series and cohort studies have shown that children, elderly and asthmatic people are at higher risk due to air pollution arises due to particulate matter.

Very few studies have used repeated spirometry to examine short term respiratory health effects of particulate matter (From *et al.*, 1992; Hoek *et al.*, 1994; Koenig *et al.*, 1993; Kasamatsu *et al.*, 2006). These studies were focused on school children, and the authors reported small decrease in FVC and FEV₁ in association with elevation of particulate matter. Size and mass distribution of particulate matter is important from both health and environment point of view, hence size/mass distribution studies had been done by different researchers.

Parmar *et al.* (2001) studied the size distribution of atmospheric aerosol in Agra city. Authors used four stages Cascade particle separator to measure size and mass distribution of aerosol. It measured the chemical character of aerosol and found that aerosol is basic in nature and basicity of coarse mode is due to higher concentration of soil-derived alkaline components while the basicity in fine mode is due to neutralization of acidity by NH₃.

Latha *et al.* (2005) measured the seasonal variation of PM₁₀ and PM_{2.5} particles loading over tropical urban environment. Seasonal variation of PM, PM₁₀ and PM_{2.5} suggests that concentration was observed to maximum during winter and minimum during monsoon. The value of PM_{2.5} was found to be higher than the limit suggested by USEAPA.

Das *et al.* (2006) measured the distribution of PM_{2.5} and PM_{10-2.5} in PM₁₀ fraction in ambient air due to vehicular pollution in Kolkata megacity. The concentration of particulate matter was found to be higher as prescribed by the NAAQS. The correlation between PM₁₀ and PM_{2.5} was found higher as PM_{2.5} compared to major portion of PM₁₀ fraction contributed by vehicular emissions.

There is lot of evidence which show that fine PM is able to induce alveolar inflammation by penetrating deep into airways, which is responsible for variation in blood coagulability and release of mediators that induce acute episodes of respiratory and cardiovascular diseases (Seaton *et al.*, 1995). Early research into particulate pollution focused on TSP but was gradually refined to PM₁₀, which are more likely to enter the

lungs. More recently, PM_{2.5} has begun to replace PM₁₀ as the particulate measured (Dockery *et al.*, 1993; Pope *et al.*, 1995b) and there has been some evidence of associations between PM_{2.5} and mortality, rather than the coarse fraction of PM₁₀ (Schwartz *et al.*, 1996). Until about 1980, analyses suggested that mortality and morbidity were not associated with particulates and other pollution until high levels were reached (Holland *et al.*, 1979). A number of recent epidemiological studies have established mortality and morbidity associations even with lower levels of particulate air pollution (Pope *et al.*, 1991; Dockery *et al.*, 1993; Koenig *et al.*, 1993; Pope *et al.*, 1995a). Remarkable consistency and coherence in the results support the evidence for substantial adverse health effects due to air pollution (Bates *et al.*, 1990).

There is good epidemiological evidence that short-term increases in PM₁₀ concentrations are associated with increases in: total mortality, as well as mortality from respiratory or cardiac disease; respiratory and probably cardiac hospitalisations; emergency room visits for asthma and other respiratory conditions; functional limitation as reflected by restricted activity days and school absenteeism; and the daily prevalence of respiratory symptoms (Dockery and Pope, 1994). Short-term increases in PM₁₀ are also associated with small decreases in the level of pulmonary function in children and in adults with obstructive airways disease (Dockery and Pope, 1994). These results have been observed in cross-sectional, cohort, time series, case-control studies and air pollution episodes (Pope *et al.*, 1995a).

Most of the evidence shows increasing mortality due to particles starting above a PM₁₀ concentration of 20 µg m⁻³. Although there is no evidence of a value of PM₁₀ below which no population impacts are detectable (Schwartz and Marcus, 1990). The association is essentially linear in the ranges observed with no plateau. In a major review, it was shown that a 10 µg m⁻³ increase in PM₁₀ concentration is associated with a 1.0% increase in total deaths per day (Dockery and Pope, 1994). Strong associations have been observed with cardiovascular disease (1.4% per 10 µg m⁻³ PM₁₀) and respiratory disease (3.4% per 10 µg m⁻³ PM₁₀). The estimated impacts on mortality, hospitalisation and emergency room visits are relatively small compared to estimates on school absenteeism

and incidence of respiratory illness (Table 2.1).

Table 2.1: Summary of the health effects of PM₁₀ on respiratory outcomes (per 10 µgm⁻³ increase in PM₁₀)

Respiratory outcome	Estimate of effect	
	Overall	Asthmatics
All causes mortality	1.0%	N.A
Respiratory mortality	3.4%	N.A
Cardiac mortality	1.4%	N.A
Respiratory hospital admissions	0.8%	1.9%
Emergency department visits	1.0%	3.4%
Asthma attacks	N.A	3.0%
Bronchodilator use	N.A	3.0%
Lower respiratory symptoms	N.A	3.0%
Upper respiratory symptoms	N.A	0.7%
Cough	1.2%	2.5%
School absenteeism	4.1%	N.A
Peak expiratory flow	0.08%	N.A

N.A.: Not applicable as no results were reported for this outcome.

Source: (Dockery and Pope, 1994)

It is clear from literature that along with the environmental effect of Agriculture Crop Residue Burning (ACRB) there were also some studies in which authors have investigated the health effect of ACRB in different countries (Ribeiro, 2008). In India no such studies has been done to investigate human health effect due to ACRB. Although, ACRB is the common practice of agriculture crop residue disposal from the fields all over India and its environmental effect has been studied by different researchers (Badrinath *et al.*, 2004, 2006; Latha *et al.*, 2004; Gupta *et al* 2004) but its health effect was not studied.

Badrinath *et al.* (2004) characterized aerosols produced as a result of biomass burning in Mizoram (Northeast), India. They concluded that biomass burning have significant effect on their level as compared to other reasons.

Badrinath *et al.* (2006) studied the agriculture crop residue burning in Indo-Gangetic plains using IRS-P6 AWiFS satellite data. Results suggested that crop residue burning is common in the Indo-Gangetic plain which is the significant contributor of trace gases and particulate matter and emissions from wheat crop residues in Punjab are relatively low compared to those from paddy fields.

Sahai *et al.* 2007 developed the emission factor for trace gases and carbonaceous particulate from burning of wheat straw in Northern part of India. It was found that wheat straw burning has significant effect on the concentration of trace gases (CO₂, CO and CH₄) and particulate matter.

Sharma *et al.* (2010) studied the impact of agriculture crop residue burning on atmospheric aerosol in the Patiala city and suggested that there is significant effect on the aerosol properties during October-November months which are associated with rice crop residue burning. They showed the high aerosol loading over central region of India during the rice crop residue burning.

It is understood from the above mention studies that ACRB has adverse effect on the environmental chemistry; hence there is a need to study its health effect.

2.2 Objectives

- ❖ To collect aerosol (SPM) samples, aerosol size and mass distribution before, after and during wheat and rice burning in and around Patiala.
- ❖ To measure human physiological parameters like Force Vital Capacity (FVC), Peak Expiratory Flow (PEF), Forced Expiratory Volume in one second (FEV₁) Force Expiratory Flow at 25 to 75 % (FEF_{25-75%}) and O₂ saturation during the study period.
- ❖ To study the contribution of SPM due to residue burning on various physiological functions

Chapter III

Methodology

This chapter explains different techniques, methods and instrumentation used to study the effect of particulate matter on respiratory parameters of healthy human subjects due to Agriculture Crop residue (ACRB). Different instruments were used for measurement of the different biological and environmental parameter and the selection of site and subject on the basis of the different criteria mentioned in this chapter. The five study areas were chosen for the study will be briefly described (Section 1). Selection of subjects and criteria of their selection will be presented (Section 2). Information regarding the measurement of different parameters are mentioned in section 3 and instrumentation involved and basic principle of working of instruments are described in section 4. Different methods used for the analysis of collected data are mention in the section 5.

To study the effect of ACRB on the respiratory health of common healthy subjects, systematic methodology was adopted. Standard prescribed methods were used and all precautions were taken during the different type of experimentation and analysis. Following steps were followed during the study and are shown diagrammatically in Figure 3.1

- a. Selection of sampling site
- b. Selection of subjects
- c. Data collection
- d. Analysis

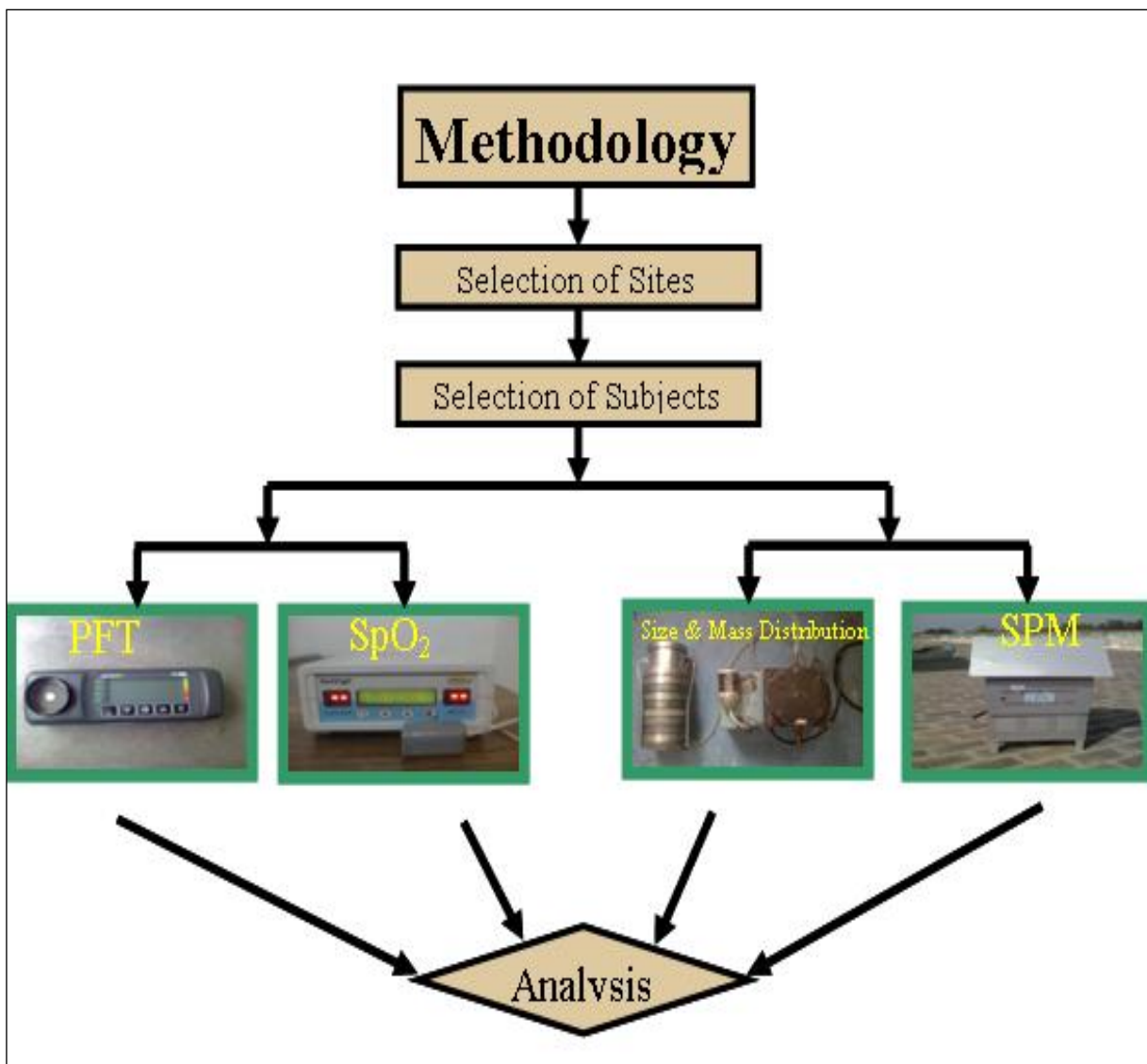


Figure 3.1: Flow diagram of methodology

3.1 Selection of sampling sites

Study was carried out in Patiala city of Punjab, India. Patiala city is located in the southeastern part of the Punjab state of Northern area that lies between north latitude 29° 49' to 30° 47' and east longitude 75°58'to 76°54'.

District Patiala has 5 tehsils, 9 towns and 1084 villages as per the 2001 census. District Patiala has a population of 1,839,056 with a density of population in the district is 507 persons per sq km. Large population of Patiala district residing in rural area, only

35% people of total population residing in urban areas. Geographical area of Patiala District is 368,000 ha out of which 82 percent used for cultivations (Teri Report, 2003). Agriculture is one of the major occupations of Patiala's people and 12 percent is used for residential and commercial purposes. There are two major agricultural seasons in Patiala namely Kharif and Rabi. Punjab has made enormous contributions to the national pool of food grains i.e. around 70 percent of wheat and 50 percent of rice. The state, on an average, accounts for 23 percent of wheat, 14 percent of cotton and 10% of rice production of the whole country (Punia M. *et al.* 2008). Punjab has about 2,647,000 ha under paddy cultivation that yields roughly 100 million tons of rice straw and about three-fourth of crop residue amounting to 70–80 million tons of rice is disposed-off by burning (Badarinath KVS. *et al.*, 2006). At present, about 95% of the total food grain production in Punjab is from rice and wheat (Gupta RK. 2003). The majority of the rice and wheat in Punjab is combine harvested, leaving anchored straw 0.3 - 0.6 m high, and loose straw in windrows (Gajri PR *et al.* 2002). Rice and wheat are the two major crops of Patiala, with a combined cropping area of more than 86 percent. The total biomass generated in district Patiala from all sources like Agriculture crop residues, Forest and other wastelands, and Agro-Industry is 3,792,252 MT/year. Every year, farmers burn the residue and straw after the completion of harvesting. Total biomass generation from agricultural activities was 3,428,373 MT/year out of which about 90 percent generate from crop residue burning (TERI Report, 2003).

Agricultural crop residues are burnt during the months of October-November and April-May each year in the Indo-Gangetic Plains (IGP) which has significant impact on greenhouse gas emissions and aerosol loading (Badarinath *et al.*, 2009). The IGP is a very important agro-eco region in South-Asia, which occupies nearly one-fifth of the total geographic area in four countries (Pakistan, India, Nepal and Bangladesh). The IGP in India covers 20 percent geographical area and contributes 42 percent to the total food grains production and holds nearly 40 percent of the total population (Tripathi *et al.*, 2005). In the IGP region of India, 12 million hectares is accounted for rice-wheat crop rotation and harvesting of these crops with combine harvesters is very popular with the farmers of Punjab, Haryana and western Uttar Pradesh (Badarinath *et al.*, 2009). These

combine harvesting techniques in rice-wheat system leave behind large quantities of straw in the field. The crop residues are subjected to open burning on account of high labor wages and anxiety of the farmers to get the crop produce collected and marketed at the earliest.

Typically, in Punjab, summer is very hot and winter is very cold. The district is generally dry and hot, with monsoon lasting three months. Both summer and winter are severe. The month of May is the hottest with the mean monthly maximum temperature of 43.1°C. January is the coldest month with mean monthly minimum temperature of 2.1°C. The annual average rainfall is 688mm. On an average, there are 61 rainy days. The variation in rainfall is appreciable. Wind direction of Patiala city is generally North-West with some time South-West. Five sites were selected from in Patiala city. These sites were selected in such a way that they cover maximum agricultural area around them in Patiala, so that during burning period influence of increase concentration of pollutant due to ACRB can be clearly checked. The study was conducted in five sites of Patiala city covering the residential, urban, agricultural (rural area), commercial and sensitive areas, shown in Figure 3.2 and their latitude and longitude shown in Table 3.1. All these sites were selected in such a way that the Thapar University lies almost at the centre and other four sites lies within the range of 10 - 15 Km as shown in Figure 3.2. After the selection of five sites in Patiala city, High Volume Sampler (HVS) were installed keeping in mind about the security of instruments, availability of electricity and trend of wind direction (NW). Table 3.2 represents the specific location of the HVS. These sites were closed to the agricultural land and residential area to study the influence of the crop-residue burnt pollution on human health.

Influence of change in the concentration level of pollutants produced in any part of the region were collected in all the sampling site so that an average of all the sampling sites represent concentration level of pollutants of the city. There were no large scale factories close to sampling sites.

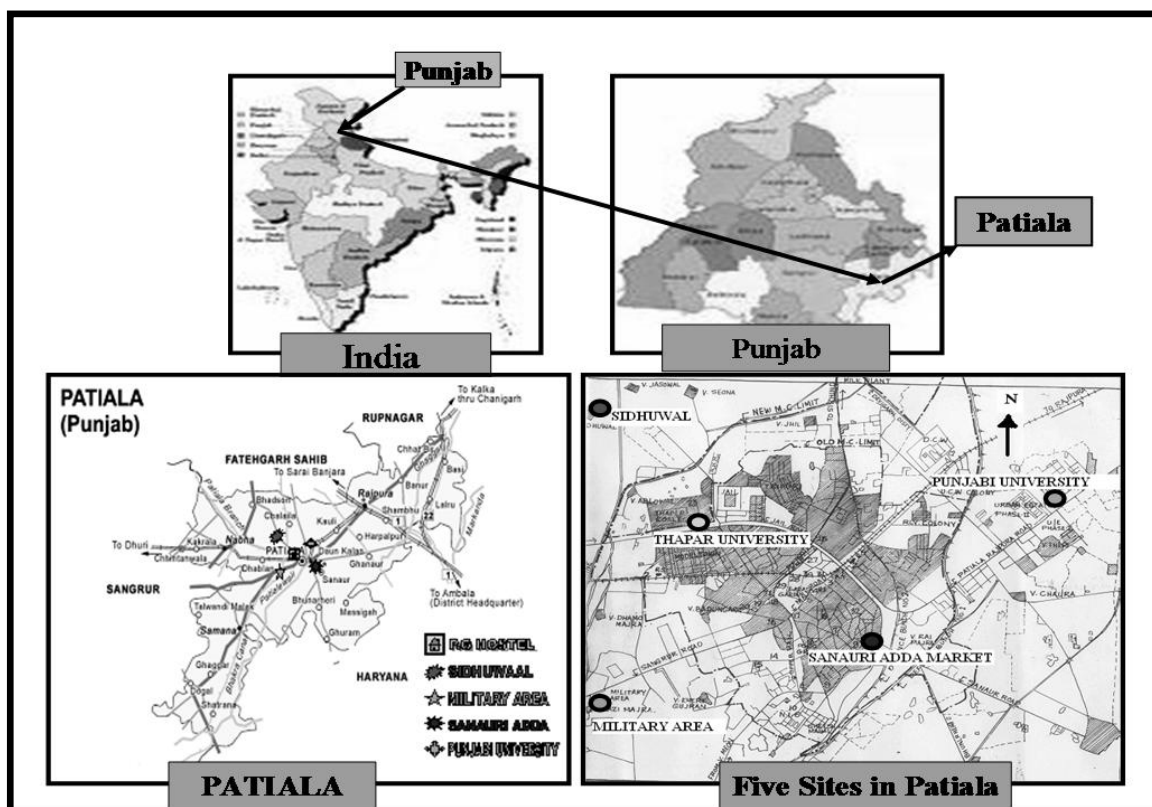


Figure 3.2: Location of study area in India, Punjab and Patiala

Table 3.1: Five monitoring sites with background and grid reference

S. No.	Site	Background	Grid Reference
1.	Thapar University	Urban site	Latitude - 30°21'05.42" N Longitude - 76°21'57.93" E
2.	Punjabi University	Semi-urban site	Latitude - 30°21'28.10" N Longitude - 76°27'02.57" E
3.	Sidhuwal Village	Rural site- cum-agricultural site	Latitude - 30°22'42.14" N Longitude - 76°20'31.52" E
4.	Sanauri- Adda	Residential-cum-commercial site	Latitude - 30°19'23.14" N Longitude - 76°24'23.88" E
5.	Military Area	Sensitive	Latitude - 30°18'41.31" N Longitude - 76°21'12.82" E

Table 3.2: Monitoring sites with specific location of HVS installed

S. No.	Site	Specific location
1	Thapar University	P.G. Hostel
2	Punjabi University	Department of Biotechnology
3	Sidhuwal Village	Government Elementary School
4	Sanauri-Adda	Sarvhitkari High School
5	Military Area	Kendriya Vidyalaya

3.2 Selection of Subjects

The study includes subjects from each five sites. Initially about 25 subjects were selected from each site but with time the number of subjects decreased to 10, due to non-cooperation or reluctance from their side. At last, 50 healthy subjects continued to respond till the end of the present study. For the selection of subjects, a standard respiratory questionnaire (Annexure 1) based on American Thoracic Society (ATS)/ British medical research council (BMRC) was used (Miller *et al.*, 2005; Samet *et al.*, 1978). The questionnaire included both acute and chronic respiratory symptoms information.

On the basis of questionnaire subjects were judged to be healthy on the following criteria

- No history of smoking
- No exertions dyspnoea or general debility.
- No obvious signs of malnutrition or skeletal deformity.
- No obesity.
- A detailed physical examination has been carried out to rule out any cardio-respiratory disorder
- No history of heart disease
- No history of asthma, respiratory and shortness of breath

On the basis of these criteria, non-smoker healthy subjects having no respiratory or lung disease were selected and continuously investigated for three years. Demographic characteristic of 50 healthy subjects is shown in Table 3.4.

Table 3.3: Demographic characteristic of subjects

Sex	N	%
Male	40	78
Female	10	22
Age*	N	%
<18	10	20
18-40	28	56
>40	12	24

N = number of subjects; * age in year

In the initial period of the study, age of 50 subjects varies between 13 to 53 years with mean value of 30 years which included 40 male and 10 female with mean height of 166 cm (139 - 179 cm) and weight of 62 kg (40 - 85 kg) (Table 3.3). Total subjects were characterized into three age groups on the basis of their ages i.e., lower age group (< 18 years), middle age group (18 - 40 years) and upper age group (> 40 years). Male population predominated in the study as only those females were selected who were not using conventional wood fire (chulhas) for domestic purposes so that its smoke does not interfere with the effect due to ACRB. Moreover females were less-cooperating due to introvert character, family restrictions and other social issues and thus were not active in the study. None of the persons had history of asthma respiratory or any other illness and were not on medication. All the subjects were farmers or residents who spent at least two to three hours in the farms for various agricultural works along with nearby local jobs. At the initial stage of the study, only those subjects were selected whose FEV₁/FVC value was found to be greater than 80 %, as one of criterion for normal spirometry on the basis of ATS is that the FEV₁/FVC ratio must be larger than the 75 %.

3.3 Data Collection of biological and environmental parameters

After the selection of sites and subjects, biological (PFTs and SpO₂) and environmental (SPM and PM₁₀) data were collected through standard methods using different instruments.

3.3.1 Measurements of Pulmonary Function Tests (PFTs)

To measure the respiratory status of common people residing within the Patiala, PFTs were measured. PFTs of selected subjects were measured at least two times or maximum of four times in a month during the morning hours between 9 AM to 12 PM from February 2007 to January 2010. PFTs of the subjects were measured in the sitting position by using the portable Spirometer

PFTs were measured after adding their age, height, weight and gender on the basis of American Thoracic Society Standards (ATS). During the Spirometer maneuver, under mentioned precautions were taken throughout the study:

- Before taking test, subjects were allowed to take rest for 5 to 10 min and during this interval; instructions were given to the subjects.
- The mouthpiece was inserted well into the mouth (beyond the teeth) and the mouth was supposed to be closed around the mouthpiece to ensure that air cannot escape from the sides of the mouth.
- Individual mouthpiece was given to subjects.
- Measurements were taken at least thrice to ensure the best possible results from each person.
- From a minimum of three valid maneuvers (difference between two value of FVC not more than 200 ml), Spirometer selected the best possible values of FVC, FEV₁, PEF and FEF_{25-75%} based on the maximum value of FVC+ FEV₁.

Maneuvers done by the subjects during whole study involved different steps

- Take two to three normal breath
- Then take deep possible maximum breath
- Expire all air as fast as possible with force and up to maximum extent

By using this maneuver, following parameters (FVC, FEV₁, PEF, FEF_{25-75%}, FEF_{25%}, FEF_{50%} and FEF_{75%}) were measured throughout the study.

- Force Vital Capacity (FVC): Total amount of air that can be forcefully expired as quickly as possible after taking deep possible breath. It is expressed in liter.
- Force Expiratory Volume in 1 second (FEV₁): Total amount of air blown in 1 second. It is expressed in liter per second.
- Peak Expiratory Flow (PEF): Rate of airflow attained during a forced Expiration. This parameter measures how fast a person can exhale air and it is expressed in liter per second.
- Force Expiratory Flow in 25 to 75% (FEF_{25-75%}): Flow measurement over the middle half of FVC i.e. from the 25% level to 75%. It is expressed in liter per second.
- Force Expiratory Flow in 25% (FEF_{25%}): Flow measurement from the 0 level to 25% of FVC. It is expressed in liter per second.
- Force Expiratory Flow in 75% (FEF_{75%}): Flow measurement from the 0 level to 75% of FVC. It is expressed in liter per second.
- Force Expiratory Flow in 50% (FEF_{50%}): Flow measurement. from the 0 level to 50% of FVC. It is expressed in liter per second.

Spirometer which is used measures above said basic PFTs as these are the most important and informative, which are generally used by the doctors and researchers for the investigation and curing the different respiratory diseases like asthma *etc.* The subject's baseline lung function was compared with the reference value of E.R.S '93/Knudson and expressed as percent of the predicted value (Knudson *et al.*, 1983; Quanjer *et al.*, 1993) and expressed as follow

$$\% \text{ predicted} = \frac{\text{Measured value}}{\text{Pridcted value}} \times 100$$

3.3.2 Measurement of Oxygen saturation level (SpO₂)

Oxygen saturation level measures the percentage of oxygen binding with hemoglobin. SpO₂ of selected subjects were measured at least two times or maximum of four times in a month during morning hours between 9 AM to 12 PM from August 2007 to January 2010. Measurement of SpO₂ was done for the same subject on the same days as that of PFTs by using Pulse-oximeter.

Sampling of SpO₂ and PFTs were done on the same day and same time. Dates of sampling of SpO₂ and PFTs were selected on the basis of availability of subjects in such a way that data was collected two times in a month at a regular interval of 15 days and four times in ACRB. After giving rest time of about 10 minutes to the subjects, SpO₂ were measured and just after these PFTs were measured.

Along with measurement of different biological parameters, environment status was also checked throughout study period by the measurement of concentration of different size particulate matter.

3.3.3 Measurement of Suspended Particulate Matter (SPM)

SPM is the particulate matter of size up to 100 µm produced by different sources, among which ACRB is one of the sources. High Volume Sampler (HVS) was used to measure the concentration of SPM at all the selected five sites. Collection of SPM was done for 24 hrs (9 AM to 9 AM) four times in normal months and alternate days during exhaustive burning period of wheat and rice crop residue during February 2007 to January 2010. SPM samples were taken on pre-fired (≥ 2 h at 500°C), pre-desiccated and pre-weighted Whatman-quartz fibers filters (QM-A). Exposed filters were removed and dried in desiccators for 24 h and then re-weighted. From the weight differences and airflow rate, the mass as well as concentration of SPM in ambient air were measured by prescribed standard methods (IS: 5182 (Part XV), 1974). The mass concentration of suspended particulates in ambient air, expressed in micrograms per cubic meters, was calculated by measuring the mass of collected particulates and the volume of air sampled.

$$W = W_2 - W_1$$

W = Weight of suspended particulate (grams)

W_2 = weight of sampled filter paper

W_1 = weight of fresh filter paper

V = Volume of air sampled (cubic meter) which is obtained as

$$V = Q \times T$$

Q = average sampling rate (cubic meter per minute) which is obtained as

$$Q = \frac{Q_1 + Q_2}{2}$$

Q_1 = Sampling rate indicated by the orifice meter at the start of the sampling

Q_2 = Sampling rate indicated by the orifice meter just before the end of sampling

T = Total sampling time (minutes)

Thus, concentration of particulate matter was calculated by

$$\text{Concentration} = \frac{W}{V} \text{ (grams/cubic meter)}$$

Concentration was expressed at Standard Temperature and Pressure (STP) by calculating the volume at STP and then divides weight of suspended particulate by V_{STP} .

Formula used to measure volume at STP

$$V_{STP} = \frac{P \times 0.75006 \times V \times 298}{760 (273 + t)} \text{ (cubic meter)}$$

Where P = Atmospheric Pressure

V = Volume of air sample

t = Temperature

3.3.4 Measurement of PM₁₀

Particulate matter of size less than 10 μm and their size and mass distribution were measured by using eight stages Anderson Cascade Impactor (ACI) was used. PM₁₀ sampling was done continuously for 72 hours. PM₁₀ sampling was done during August 2007 to January 2010. PM₁₀ sample were collected twice in a non burning months of crop residue and once in a week during exhaustive burning period at Sidhuwal site, as it covers maximum agriculture land.

Filter papers used in eight stages ACI for sampling were weighted and placed in the desiccators before and after the sampling (same as in case of HVS). Mass concentration for each size range were calculated using the same formula used in HVS and by adding the concentration of all stages of ACI, PM₁₀ were measured. PM_{2.5} was not measured directly using ACI as there is no stage which has Effective Cut Diameter (ECD) of 2.5 μm . PM_{2.5} was calculated by the method adopted by Das *et al.* (2006) in which mass concentration for each size range and cumulative mass concentration for respective ECD were calculated. The values obtained were used for plotting graph between log(ECD) verses cumulative mass concentration less than the stated size. An equation for the linear trend of plot was obtained and used for the measurement of PM_{2.5} concentration.

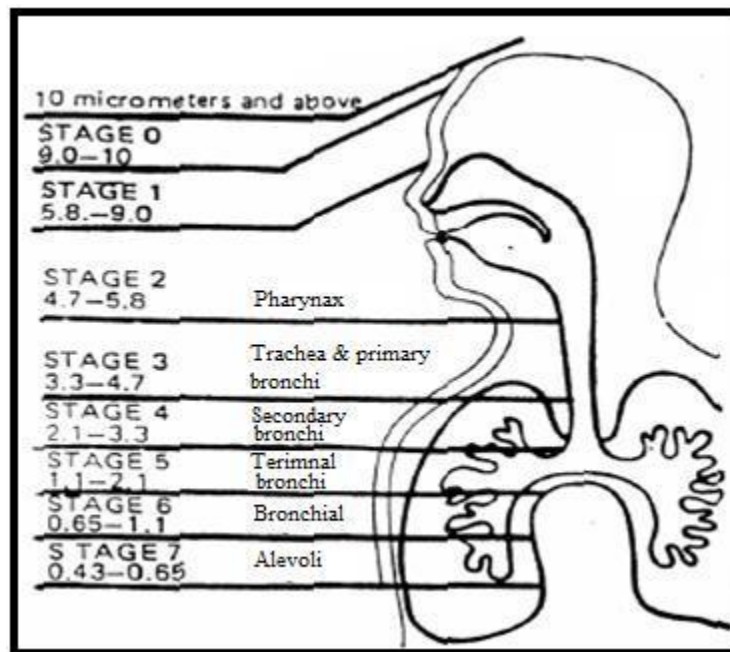


Figure 3.3: Andersen Sampler Simulates Human Respiratory System

Figure 3.3 represents penetration of different sized particles inside the body which deposit at the different parts of the respiratory system. Particulate matter of size less than $10\ \mu\text{m}$ are more important in health point of view because these particles go deep inside the lungs through breathing and deposit in different parts of the body depending upon their size. Figure 3.3 represents that smaller the size of particles more are the chances of positioning deep inside the lungs and thus affecting the proper functioning of the lungs. Particles of size less than $1\ \mu\text{m}$ can go up to alveoli, which may affect the internal gas exchange mechanism of the lung, which influence the proper functioning of respiratory system. Measurement of small sized particulate matter is more significant in health point of view. Now the standard prescribed limit set by different countries give more stress on the $\text{PM}_{2.5}$ (RSPM) in comparison to SPM.

3.4 Instruments used to measure different parameters

3.4.1 Spirometer



Figure 3.4: Spirometer

A Spirometer is a medical apparatus used for the measurement of the volume of air inspired and expired by the lungs. Spirometer records the amount of air and the rate of air which is breathed in and out over a specified time. In the present investigation, PFTs were done according to the American Thoracic Society (ATS) standards (Miller *et al.*

2005). Spirometer used in present study is Spiro bank-G of model MIR (Italy) works on the principle of infrared interruption. Physical diagram of the Spirometer is shown in Figure 3.4.

The turbine (Figure 3.5) has a cylindrical and transparent body, inside which two helicoidally conveyors, located symmetrically at each extremity, hold a very lightweight rotor. The rotor axis rotates on jewels, to minimize the friction. The housing of the turbine is the optoelectronic reader. The data were stored in the Spirometer and was transferred to computer by interfacing with RS232 using winspiroPRO1.3 software. Some basic knowledge and working of the Spirometer used is described below:



Figure 3.5: Technical picture of turbine

As air moves through the helicoidally conveyors, it takes a spiral motion which causes the rotation of the turbine rotor and consequently the interruption of the infrared light beamed by the diodes, at every passage of the blade. Every complete revolution of the rotor represents a known volume of air (24 ml) flowing through the turbine. For each single interruption an impulse is transmitted to a microprocessor, which counts the revolutions and consequently measures air flow and volume. This type of flow meter grants high accuracy of measurement within a wide range of flows, independently by the environmental conditions (Pressure, Humidity, external temperature and expired gas composition). Technically Spirometer which is used throughout the study has volume range of 10 L, flow range of ± 16 L/s, volume accuracy of $\pm 3\%$ or 50 mL and flow accuracy of $\pm 5\%$ or 200 mL/s.

3.4.2 Pulse-oximeter

Pulse-oximeter is a medical device, which measures the oxygen saturation of the blood as well as heart rate. In the present study, SpO₂ were measure by using the Pulse-oximeter. Initially data (August 2007 to July 2008) were collected by the Pulse-oximeter which is correct up to unit place (Oxivigil manufactured by Medline Equipment & Computer Systems (I) Ltd; Figure 3.6.a), after this new Pulse-oximeter with a higher level of accuracy up to one decimal place (Dolphin Voyager Pulse-oximeter, Dolphin Medical, PTE. Ltd; Figure 3.6.b) were used to measured the SpO₂ up to January 2010. Both are user-friendly systems and a compact lightweight design with a long life internal battery. Basic principle and working of both the instrument are same.

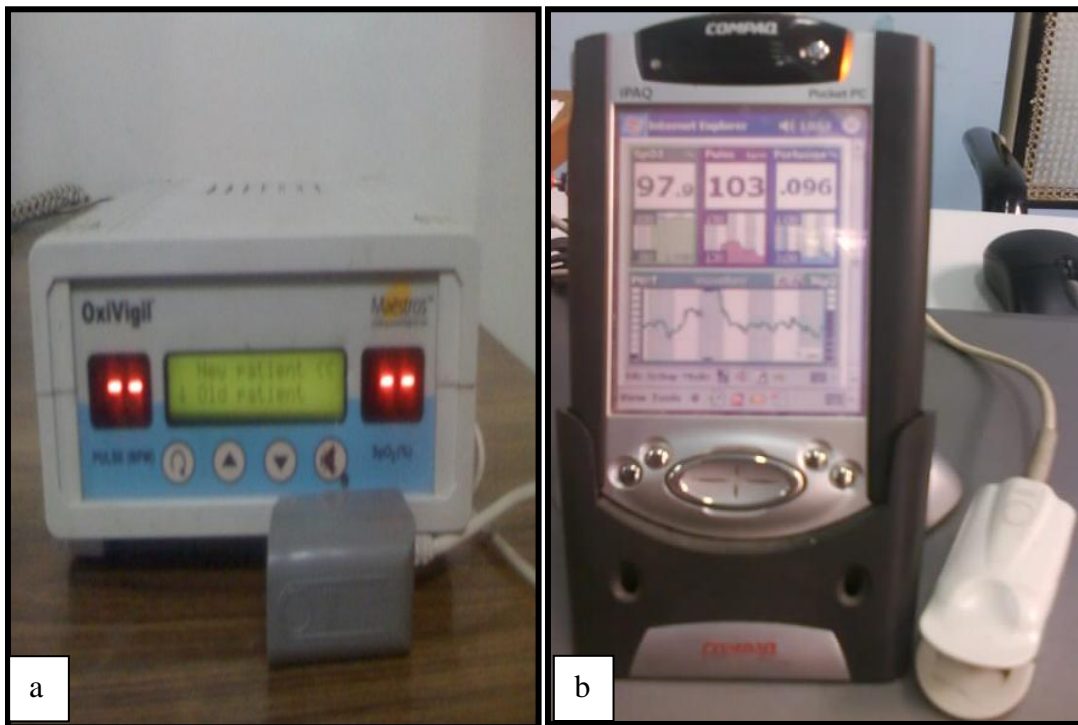


Figure 3.6: Pulse-oximeter: (a) First: August 2007-July 2008; (b) Second: February 2007-July 2010

Pulse-oximeter works on the principle of Beer-Lambert law. It is based on the red and infrared light absorption characteristics of oxygenated and deoxygenated haemoglobin. Oxygenated haemoglobin absorbs more infrared light and allows more red lights to pass through. Deoxygenated (or reduced) haemoglobin absorbs more red lights and allows more infrared light to pass through.

Pulse-oximeter probe contains LEDs, which emit two wavelengths of light, (red and near infrared). A photo-detector on the other side measures the intensity of transmitted light at each wavelength, from which SpO_2 is derived. Red light is in the 600 -750 nm wavelength light band. Infrared light is in the 850 - 1000 nm. In this instrument transmission method is used for sending light through the measuring site. In the transmission method the emitter and photo-detector are opposite to each other with the measuring site in-between. The light can pass through the measuring site. After the transmission, red (R) and infrared (IR) signals pass through the measuring site and are received at the photo-detector, the R/IR ratio is calculated. The R/IR is compared to a “look-up” Table (made up of empirical formulas) that converts the ratio to a SpO_2 value. Manufacturers have their own look-up Tables based on calibration curves derived from healthy subjects at various SpO_2 levels.



Figure 3.7: Picture representing the functioning of probe in Pulse-oximeter

SpO_2 level in blood is measured by inserting the finger inside the probe. Figure 3.7 represents the red and infrared rays transmission through the finger and absorption by the photo-detector.

3.4.3 High Volume Sampler (HVS)

High Volume Sampler (HVS) is a basic instrument used to monitor the ambient air quality and pollution. It is widely used to measure air pollution in industrial areas, urban

areas on shop floor, near monuments and other sensitive areas. The physical design of the sampler is based on the aerodynamic principles, which results in the collection of particles of 100 micron and less. HVS make of Envirotech's APM 430 Dwarf HVS (Figure 3.8) was used in the present study.



Figure 3.8: High Volume Sampler

The instrument collects measures the volume of air sampled, while the amount of particulates collected is determined by measuring the change in weight of the filter paper as a consequence of the sampling. The passage for air reaching the filter is designed (roof type) to prevent heavier settle able dust particles from reaching the filter thus measuring the concentration of Suspended Particulate Matter (SPM) in atmospheric air. The internal diagram of HVS is shown in Figure 3.9.

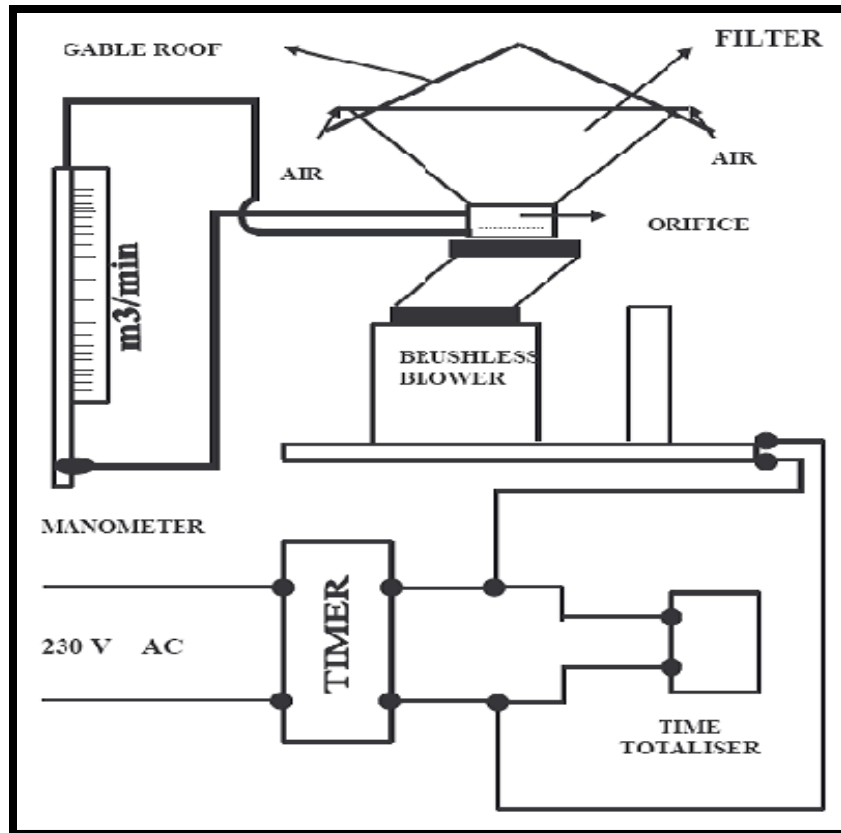


Figure 3.9: Block diagram of HVS

The flow rate of air passing through the filter is monitored by measuring the pressure drop across an orifice plate placed between the filter holder and the blower (Figure 3.9). The scale of the manometer used to measure the pressure drop is calibrated in airflow units of cubic meters per minute. Time totalizer records the time in minutes/hours of the sampling ambient air. Hence, by knowing the volume of air sampled, the mass of particulate matter is measured gravimetrically by using the balance.

3.4.4 Anderson Cascade Impactor (ACI)

Anderson Cascade Impactor (ACI) is the instrument that is used to collect the particulate matter of size less than 10 μm and conduct size and mass distribution of SPM. Anderson Sampler had eight stages (0, 1, 2 ...7 and F, filter holder), multi-jet, multi-stage instrument and were held together by three spring clamps and gascated with “O” ring seals, which separates from 10 micrometers and above down to 0.4 micrometer diameter particles into nine ranges (Figure 3.10) .



Figure 3.10: Anderson Cascade Impactor

Number of orifice, diameter of each orifice, effective cut diameter (ECD) and range of particles size collected in each stage shown in Table 3.5. The size of orifice is constant for each stage but it become smaller in succeeding stages. Stages 0 and 1 have 96 orifices arranged in radial pattern. Stages 2-6 contain 400 orifices. Stage 7 contains 201 orifices. The orifices are progressively smaller from 0.1004" diameter in stage 0 to 0.01" diameter in stage 7 (Table 3.4).

Table 3.4: Number of orifice, their diameter with expected range of collected particles in each stage of Impactor

Stages in Impactor	Orifice diameter (inches)	Number of orifices	Particle range collected (μm)	Effective cut diameter (μm)
0	0.1004	96	> 9.0	9.0
1	0.0743	96	5.8-9.0	5.8
2	0.0360	400	4.7-5.8	4.7
3	0.0280	400	3.3-4.7	3.3
4	0.0210	400	2.1-3.3	2.1
5	0.0135	400	1.1-2.1	1.1
6	0.0100	400	0.7-1.1	0.7
7	0.0100	201	0.4-0.7	0.4
F	0.1100	Filter holder	0.0-0.4	0

Air was drawn through the sampler, multiple jets of orifice in each stage direct particles towards the surface of collection plate for that stage. By varying the velocity (orifice size of the jet), the size of particles collected in each stage was controlled. The range of particle sizes collected on each stage depends on jet velocity of that stage and cut off a previous stage. The size of jet is constant for each stage but for each succeeding stages the jets get smaller. Impaction occurs when the particle's inertia overcome the aerodynamic drag. Any particle not collected on the first stage follow the air stream around the edge of the plate to the next stage, where it was either impacted or passed on to the succeeding stage, and so on.

The combination of constant flow rate and successively smaller diameter orifices increase the velocity of sample air as it cascades through the Impactor, resulting in the impaction of progressively smaller particles in the succeeding stages. Small particles impacted on the last collection plate were collected in the backup filter.

3.5 Analysis

To analyze the different biological and environmental parameters standard statistical methods were used. Statistical Package for Social Sciences (SPSS) for windows, version 15 was used for different statistical analysis. To analyze the difference for different parameters between two different periods, Paired t-test was used and linear regression was used to find the relation of pollutants with PFTs. All statistical significance tests were 2-tailed and confidence index set at 95%. A level of p-value < 0.05 was considered to be statistically significant. Statistical parameters like mean, Standard Deviation (SD), Correlation Coefficient (r), regression analysis and significance level (p value) were used for the analysis purposes.

Monthly mean value of biological parameters were measured by

- Mean of different values of one subject of the month
- Mean of the average value of all 50 subjects of the same month

Monthly mean values of environmental parameters were collected by taking the mean of the concentration at five sites of the same month.

For better interpretation of the results, three years *i.e.*, thirty six months (February 2007 to January 2010): 1st year: February 2007 to January 2008; 2nd year: February 2008 to January 2009; 3rd year: February 2009 to January 2010, were divided into eighteen periods on the basis of burning time of wheat and rice crop residue;

- BWBP-1: before wheat crop residue burning period (February-March'2007);
- DWBP-1: during wheat crop residue burning period (April-May'2007);
- AWBP-1: after wheat crop residue burning period (June-July'2007);
- BRBP-1: before rice crop residue burning period (August- September'2007);
- DRBP-1: during rice crop residue burning period (October-November'2007);
- ARBP-1: after rice crop residue burning period (December'2007- January'2008);
- BWBP-2: before wheat crop residue burning period (February-March'2008);
- DWBP-2: during wheat crop residue burning period (April-May'2008);
- AWBP-2: after wheat crop residue burning period (June-July'2008);
- BRBP-2: before rice crop residue burning period (August- September'2008);
- DRBP-2: during rice crop residue burning period (October-November'2008);
- ARBP-2: after rice crop residue burning period (December'2008- January'2009);
- BWBP-3: before wheat crop residue burning period (February-March'2009);
- DWBP-3: during wheat crop residue burning period (April-May'2009);
- AWBP-3: after wheat crop residue burning period (June-July'2009);
- BRBP-3: before rice crop residue burning period (August- September'2009);
- DRBP-3: during rice crop residue burning period (October-November'2009);
- ARBP-3: after rice crop residue burning period (December'2009- January'2010).

At last the relationship between SPM and PFTs is measured by statistical methods of linear regression. To find the relationship between environmental and biological parameters;

- Monthly mean values of biological and environmental parameters were calculated
- Correlation coefficient between their monthly mean values were calculated

- Taking biological parameters as dependent variable “y” and environmental parameters as independent variable “x” regression lines was found.

e.g.

$$Y (FVC) = a \pm bX (PM_{10});$$

FVC= dependent, PM₁₀= Independent variable

- Regression line was used to measure the change in the value of biological parameters with the increase in concentration of pollutants by 10 µgm⁻³

Finally, multiple linear regression technique is used to develop a model for the prediction of the PFT values.

Chapter IV

Result and discussions

Chapter is divided into three parts. First part of the chapter deals with result and discussion on the measurement of the concentration levels of different size particulate matter in the ambient air. Second part of the chapter consist the results and discussion on Pulmonary Function Tests (PFTs) and Oxygen Saturation (SpO₂) level. Finally, in the third part, relationship between different sized particulate matter and PFTs has been described after considering different biological and environmental parameters.

Suspended Particulate Matter (SPM) were measured continually for 36 months from February-2007 to January 2010, whereas particulate matter of size less than 10 μm measured for 30 months from August 2007 to January 2010 and are shown graphically. The data is divided into different period according to the burning time of wheat and rice crop residue. Results show the contribution of Agriculture Crop Residue Burning (ACRB) on environmental chemistry of Patiala city as ambient air gets polluted due to increase in the concentration of particulate matter during burning episode of wheat and rice crop residue.

In the second part, PFTs like Force Vital Capacity (FVC), Peak Expiratory Flow (PEF), Forced Expiratory Volume in one second (FEV₁) Force Expiratory Flow at 25 to 75 % (FEF_{25-75%}), Force Expiratory Flow at 25% (FEF_{25%}), Force Expiratory Flow at 75 % (FEF_{75%}) *etc.* of 50 subjects of age varies between 13 to 53 years from February 2007 to January 2010 were studied. SpO₂ level was also studied for 12 months with one instrument (correct up to unit place) from August 2007 to July 2008 and next 18 months with other instrument (corrected up to one decimal place) of the same 50 subjects selected from the five sites. The results demonstrate the significant effect of ACRB on PFTs of healthy subjects.

Finally, correlation between various environmental parameters and PFTs of different age group were calculated. Various combination which gives significant correlation were further analyzed by using linear regression. Results show that there was no contribution of ACRB on the SpO₂ of healthy subjects, so no correlation and linear regression was applied on SpO₂. Different statistical analysis shows contribution of different size particulate matter on the PFTs of all age groups, with higher contribution of smaller size particulate matter on upper and lower age group.

4.1 Aerosol data analysis

Measurement of Suspended Particulate Matter (SPM) and Particulate Matter of sizes less than $10\ \mu\text{m}$ (PM_{10}) was carried out by High Volume Sampler (HVS) and Anderson Cascade Impactor (ACI) of eight stages and analysed.

4.1.1 Measurement of suspended particulate matter

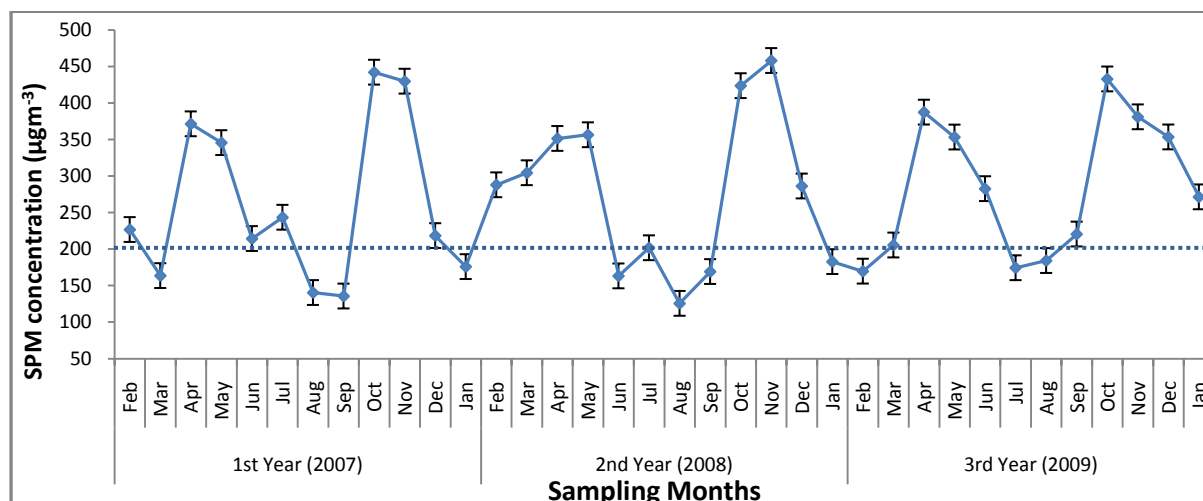


Figure 4.1: Monthly variation of SPM concentration

Suspended Particulate Matter (SPM) concentration (\pm standard error) levels in the atmospheric air of Patiala city from February 2007 to January 2010 is shown in Figure 4.1. Data of 36 months were divided into three years, 1st year: February 2007 to January 2008; 2nd year: February 2008 to January 2009; 3rd year: February 2009 to January 2010. Graph shows that SPM concentrations are not constant throughout the years. In first year of study, initial decrease is observed in March 2007 which tremendously increases during the April month which shows slight decrease during May. After May 2007, further decline is observed during June which followed by a slight increase in July 2007. During August and September 2007 the SPM concentration level goes down and reaches below the concentration level as prescribed by the National Ambient air Quality Standard (NAAQS) of $200\ \mu\text{gm}^{-3}$ (as shown by dotted line). After September 2007, SPM concentration level show abrupt increase in October 2007 and reaches to the maximum level. Then the level decreases slightly during November which further show abrupt decrease in December and values goes below the standard level of NAAQS during January. Almost same trend of abrupt increase in the concentration level were observed in month of April-May and October-November in the 2nd

and 3rd year. It is found that concentration level during April-May and October-November is much higher up to 2 to 2.5 times as per NAAQS. The concentration of SPM increases during the April- May and October-November due to burning of wheat and rice crop residue by the farmer after harvesting the crop. Three year of observations shows that concentration level decreases after the April-May and October-November of each year, which validate the major contribution ACRB on the concentration level of particulate matter as the farmers burned the wheat and rice crop residue in the month of April-May and October-November in the Northern part of India. For analysis purpose the results of thirty six months of study were divided into eighteen periods on the basis of burning time of wheat and rice crop residue (details are mentioned in methodology).

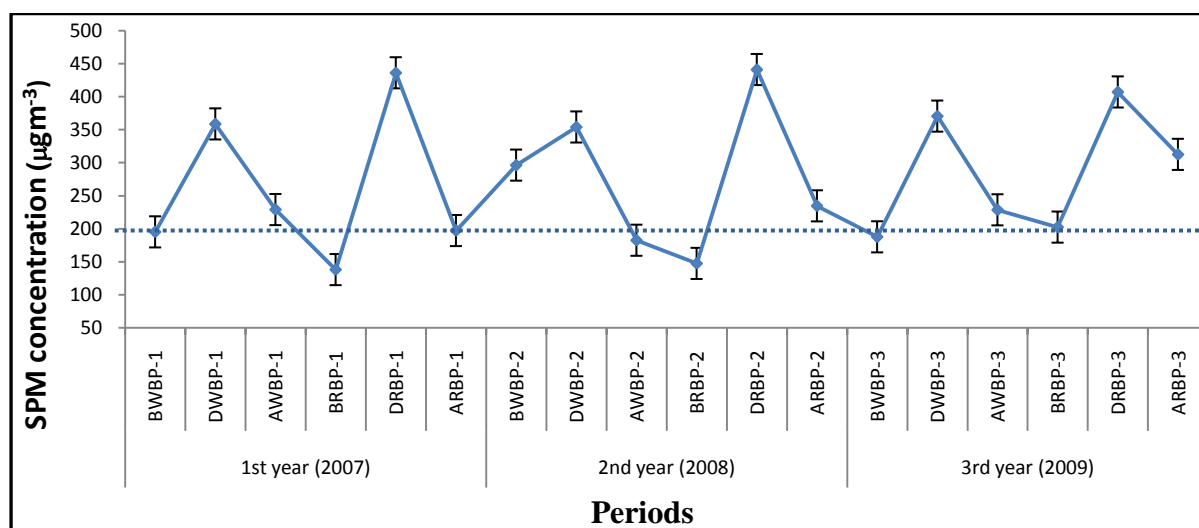


Figure 4.2: Periodical variation of SPM concentration

Figure 4.2 represents the periodical variation of SPM concentration (\pm standard error) from February 2007 to January 2010. Graph shows the increase in SPM levels during wheat and rice crop residue burning like DWBP-1, DRBP-1, DWBP-2, DRBP-2, DWBP-3 and DRBP-3. It is found that during crop residue burning period concentration is much higher *i.e.*, 2 to 2.5 times the standard prescribed limit set by NAAQS. The concentration level during ARBP is found to be above the NAAQS standards every year. This period (ARBP) occur in the coldest months (December-January) of the year. Higher concentration during different burning period is due to ACRB of wheat and rice crop residue.

Slight increase in concentration level was observed in case of non burning periods may be due to other sources like vehicular pollution sources as some sites are commercial, urban and semi-urban background. During burning episodes peoples are exposed to higher concentration levels and have chances of effect on health due to inhaling of contaminated air.

4.1.2 Measurement of different size particulate matter (0 to 10 μm)

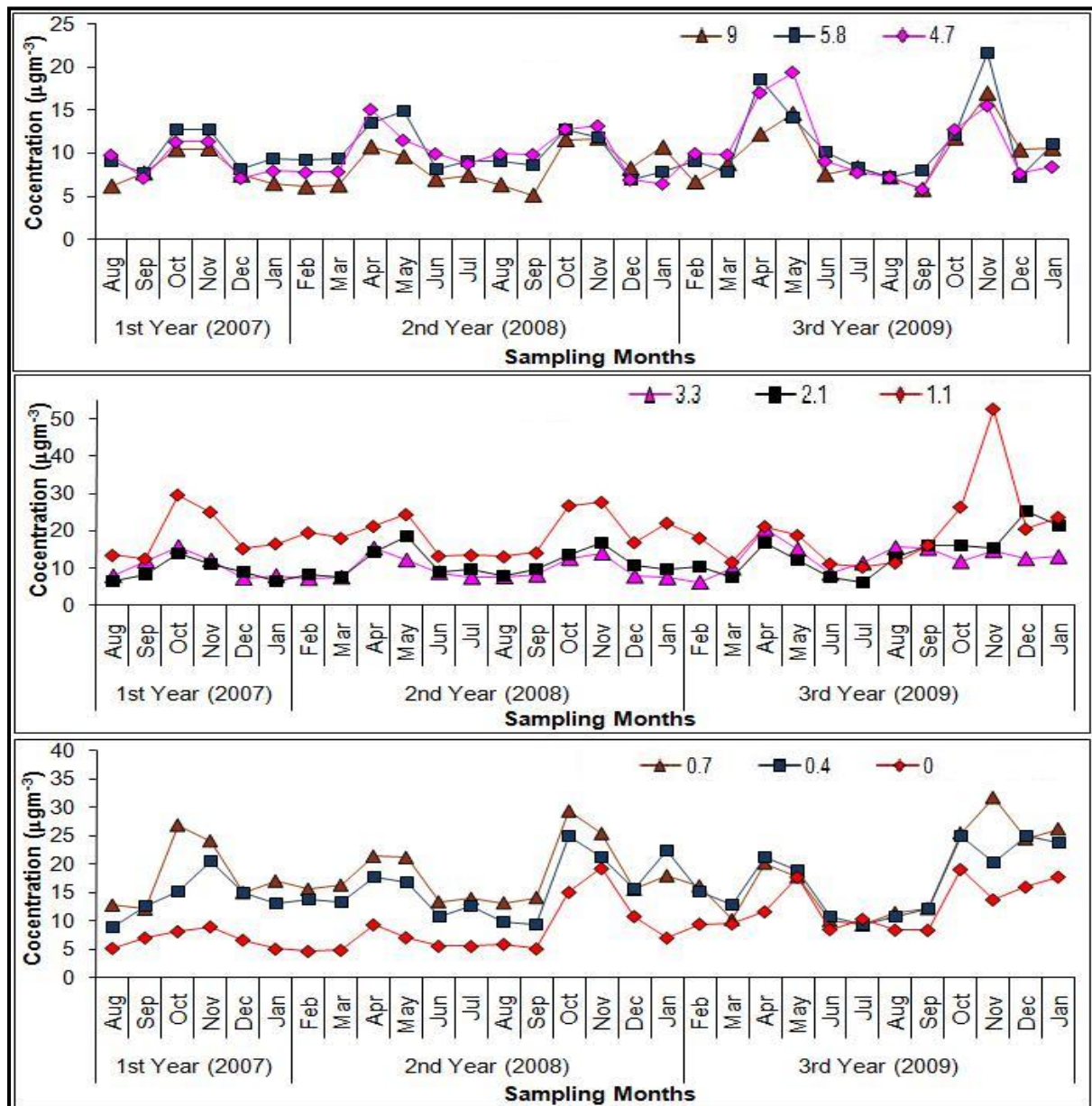


Figure 4.3: Monthly variation of different size particulate

Figure 4.3 shows the average mass-size distribution of different size particulate for different months on the basis of Effective Cut Diameter (ECD) from August 2007 to January 2010. In each month variation of different size particulate matter is shown by different lines with separate symbols. Concentrations of particulate matter in the range of ECD between 0.4-1.1 μm of size were more in comparison to all other ranges during all the months. The particles having ECD 1.1 μm showed a maximum concentration throughout the study period and maximum value in November 2009 ($29.6 \mu\text{gm}^{-3}$). Contributions of different size particulate matter to RSPM were found to be in the range of $11.11 \pm 3.9\%$ with maximum

18% involvement of particles having 1.1 μm ECD. Trends indicate that concentration of coarse fraction remained low in all the months in contrast to particles in the fine range. In the month of October-November of each year, different size particulate matter shows higher concentration as shown by the spikes in the graph as these two months are associated with rice crop residue burning. Similarly in the 2nd and 3rd year, more spikes observed in the month of April and May due to wheat crop residue burning. During burning period either rice or wheat crop, there is more concentration of particulate matters as compared to rest months of the year. Imperative observation shows that the mass concentrations of all size range particulate matter shoot out in the months of October-November and April-May due to burning of rice and wheat crop residue.

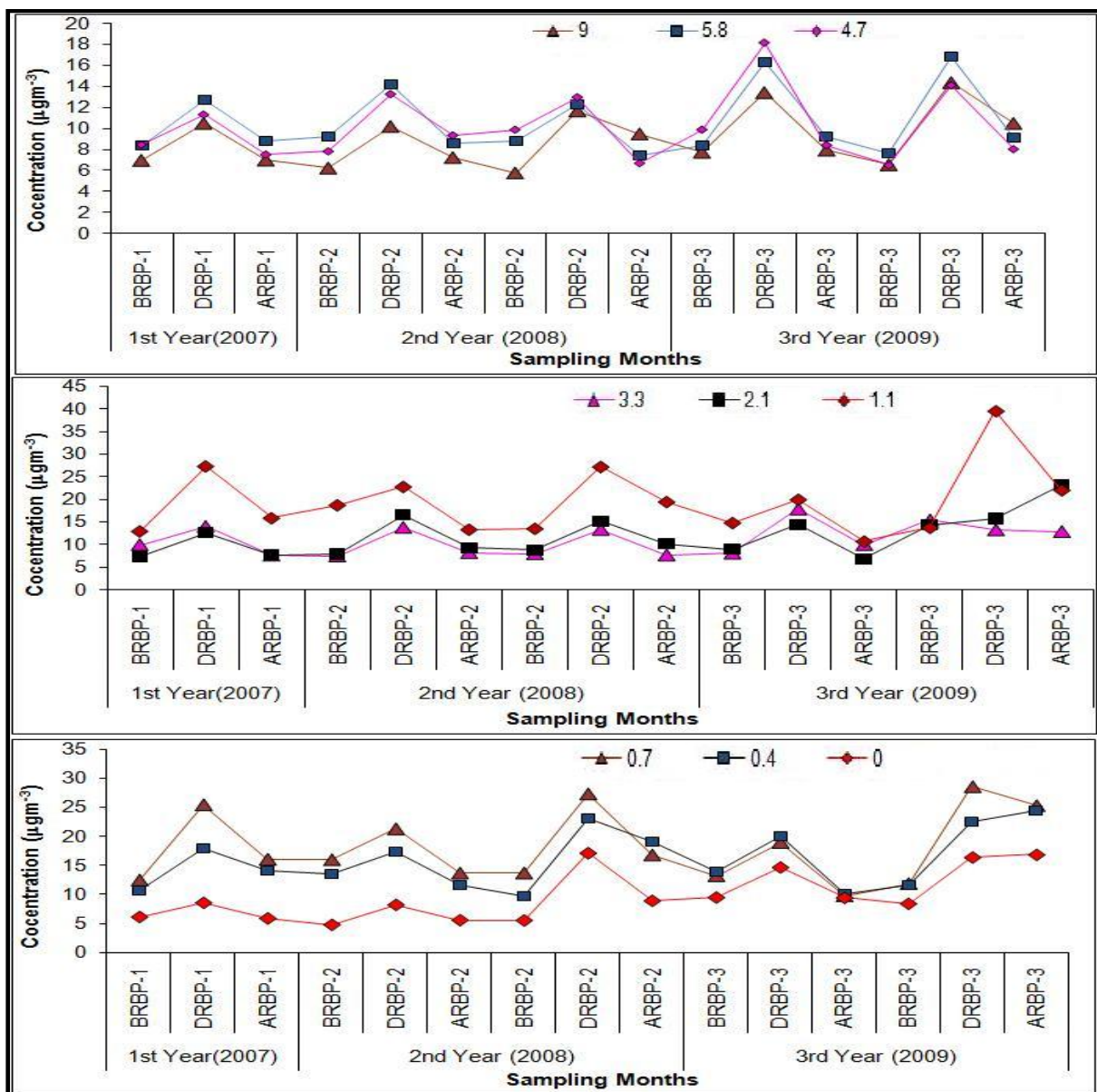


Figure 4.4: Periodical variation of different size particulate (0 to 10 μm)

Figure 4.4 shows the average mass-size distribution of aerosol (different size particulate matter) for different periods on the basis of ECD from August 2007 to January 2010. During burning period there is clear cut increase in the concentration level of all size particulate matter. After the completion of residue burning episode there is a steep decrease in the concentration of all size particulate matter, which remains constant or show small increase or decrease in next period and again show abrupt increase during the next burning period either of rice or wheat. ACRB have drastic effect on the concentration levels of different sizes of Particulate Matter (PM). Fine fraction of PM contribute more in comparison to coarse fraction as the particles in the range of 1.1 to 2.1 μm always remain higher as comparison to other particles during the whole study periods.

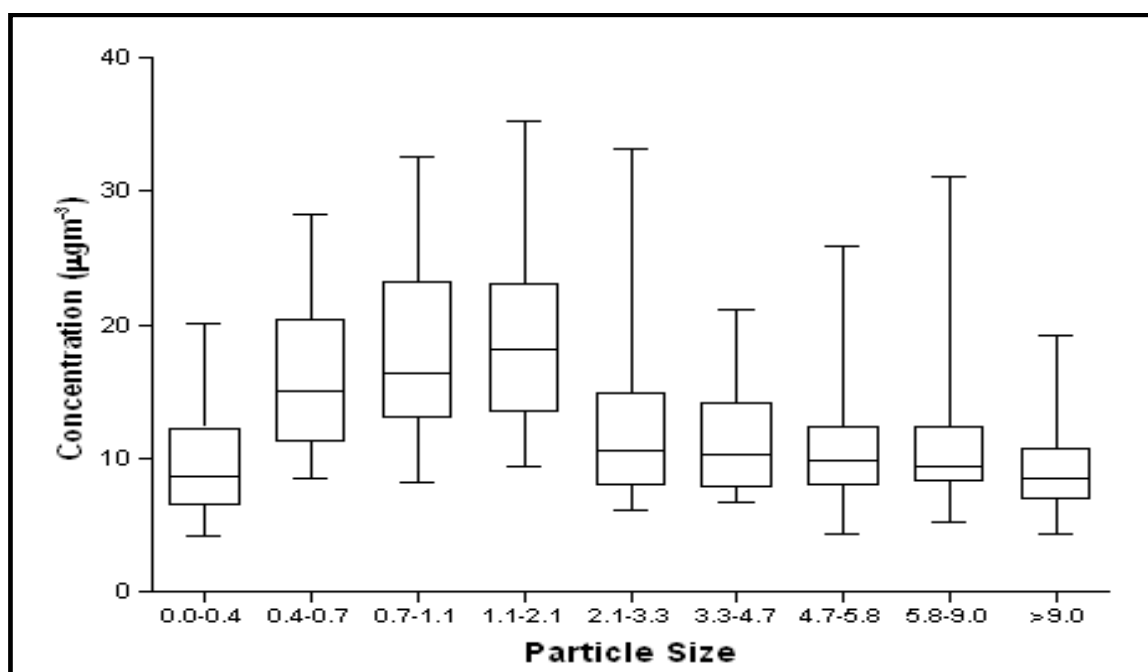


Figure 4.5: Size distribution of PM during the study period

Figure 4.5 shows size distribution of PM during the study period from August 2007 to January 2010. During the study period highest mass fractions of PM was observed in the size range of 1.1 - 2.1 μm and 0.7 - 1.1 μm followed by 0.4 - 0.7 μm . Contribution of different size particulate (0 to 10 μm) vary from 8 to 17% of total PM_{10} with maximum distribution of size range 1.1 - 2.1 μm and minimum in the size range > 9 μm . Fine fractions contributes more in comparison to coarse fraction particles during the whole study period. For comparison of distribution and concentration levels of different size particulate matter during burning and non-burning period box plot (Figure 4.1.6) is plotted for burning (April-May and

October-November of 2007, 2008 and 2009) and non-burning months (except April-May and October-November of studied year).

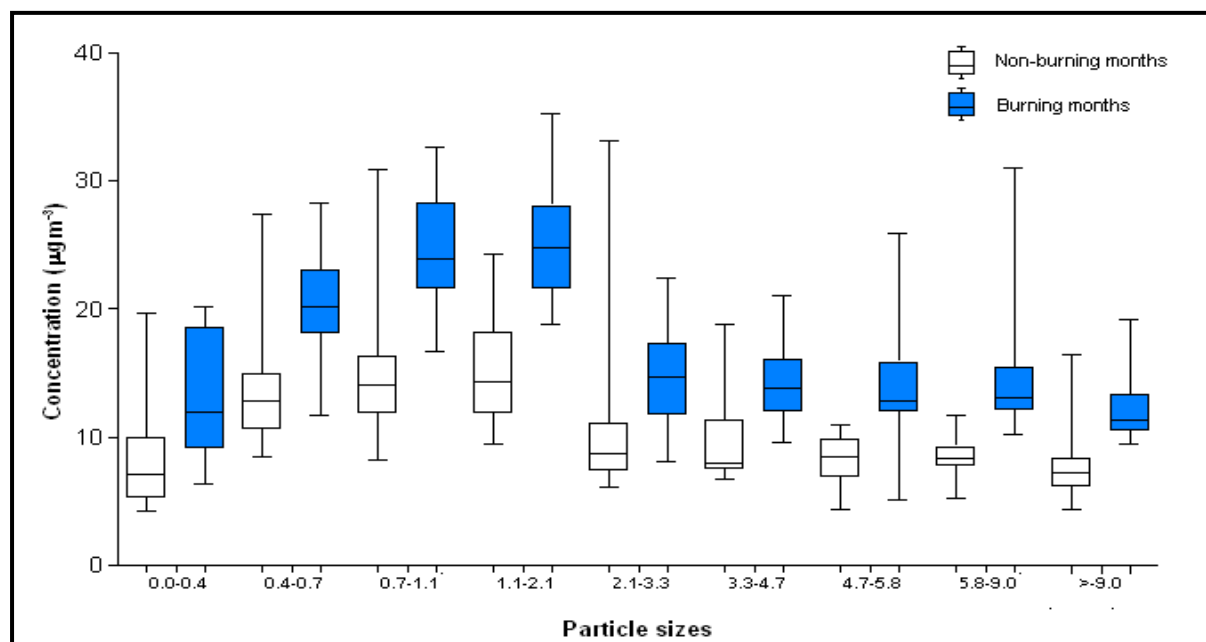


Figure 4.6: Size distribution of PM during the Non-burning and burning months

Figure 4.6 shows size distribution of PM during non-burning and burning months concentrations of all different size particulate matters has higher value during burning period, which signifies that due to burning, concentration of different size PM increased irrespective of their size. Highest mass fractions of PM were observed in the size range of 1.1 - 2.1 µm and 0.7 - 1.1 µm followed by 0.4 - 0.7 µm during non-burning and burning months. Contribution of different size particulate (0 to 10 µm) in total PM₁₀ varies from 8 to 16 % in non-burning months and 8 to 17 % in burning months *i.e.*, burning does not poses much effect on the contribution and distribution of different size particulate matter. Particles in the range between 2.1 - 3.3 µm, 3.3 - 4.4 µm, 4.7 - 5.8 µm, 5.8 - 9.0 µm and > 9.0 µm have same contribution of 8 %, 9 %, 9 % and 10 % respectively, during burning and non burning months. Concentration of the PM is greatly affected by the burning practices but the total distribution of the particulate matter remains almost constant during burning as well as non burning period.

4.1.3 Measurements of PM₁₀ (RSPM)

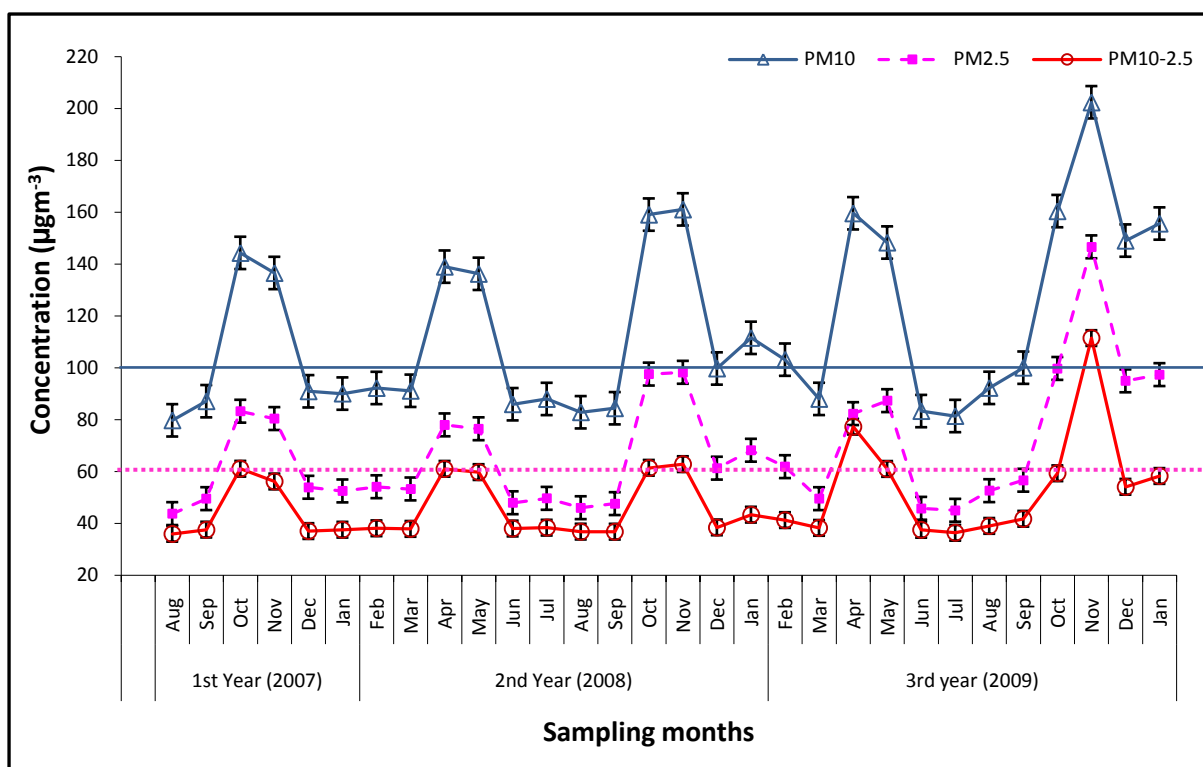


Figure 4.7: Monthly variation of PM₁₀, PM_{2.5} and PM_{10-2.5}

Figure 4.7 represents the monthly variation of PM₁₀, PM_{2.5} and PM_{10-2.5} from August 2007 to January 2010. There is a significant increase in the mean concentration in the month of October which remained high in November 2007. Concentration levels show remarkable decrease in December that does remain almost constant up to March 2008. Concentration again shows significant increase in April 2008, which remaining high in May. In June, the value decreases and remains low in July till September 2008 (Figure 4.7). During the study period, overall average concentrations of PM₁₀ were found $116 \pm 34 \mu\text{gm}^{-3}$ and background (average except burning period months) concentrations were around $96 \pm 20 \mu\text{gm}^{-3}$. Maximum concentration of PM₁₀ was found in the month of November 2009 ($202 \mu\text{gm}^{-3}$), then in October 2009 ($139 \mu\text{gm}^{-3}$) in which exhaustive burning of rice crop residue was occurring. Solid line (upper line) represents the safe limit value of PM₁₀ ($100 \mu\text{gm}^{-3}$) set by National Ambient Air Quality Standard NAAQS and it was found that the concentration levels of PM₁₀ generally remain below NAAQS but crossed the NAAQS level during months of April-May and October-November.

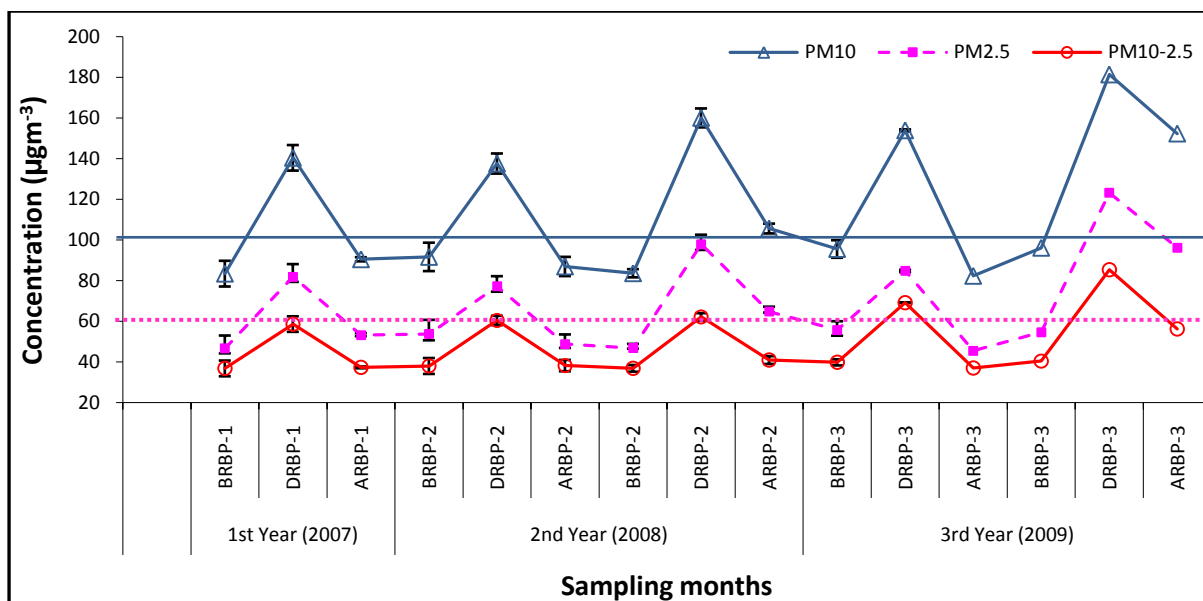


Figure 4.8: Periodical variation of PM₁₀, PM_{2.5} and PM_{10-2.5}

Periodical variations (Figure 4.8) of PM₁₀ show contribution of burning of rice and wheat on the concentration level of PM₁₀. Higher peak values were observed during the burning period of rice and wheat crop residue which crosses the limit set by NAAQS of 100 µgm⁻³. Maximum concentration observed during rice burning period then in the wheat crop residue burning period. In general concentration level remains below the NAAQS during non-burning months except in ARBP-2 and ARBP-3. There was tremendous increase observed in the concentration level of PM₁₀ during rice and wheat crop residue burning with respect to non crop residue burning period indicating a clear cut contribution from the crop residue burning to the PM₁₀ levels.

4.1.4 Measurements PM_{2.5} (Fine Particulate Matter)

Almost same trend were seen in the monthly mean concentration of PM_{2.5} as that of PM₁₀ (Figure 4.7). Same as that of PM₁₀, abrupt increase is observed in the months of October-November then concentration level decreases and then again abrupt increase observed in April-May which were associated the crop residue burning of rice and wheat. Higher concentration was obtained during October- November 2009 (99 and 146 µgm⁻³) followed by October-November 2008 then in April-May 2008 (82 and 87 µgm⁻³). PM_{2.5} varied from 43 to 146 µgm⁻³ with mean value of 68 ± 24 µgm⁻³. Non-burning mean concentration of fine fraction was 56 ± 15 µgm⁻³. Increase in the concentration level of fine particulate matter during rice crop residue burning is more as compared to increase during wheat crop residue burning in comparison to non-burning values. Concentration level of

PM_{2.5} remains below the NAAQS (60 µgm⁻³) during non-burning months except in ARBP-2 and ARBP-3 (Figure 4.8). Maximum concentration observed during rice burning period then in the wheat crop residue burning period.

4.1.5 Measurements of PM_{10-2.5} (Coarse particulate matter)

Variation in coarse fraction of PM₁₀ was almost same as that of PM₁₀ and PM_{2.5} (Figure 4.7 and 4.8) *i.e.*, peak values were observed in the month October-November and April-May of studied period. Concentration of PM_{10-2.5} varied from 36 to 61 µgm⁻³ with mean value of 44 ± 11 µgm⁻³ and background concentration was 38 ± 0.75 µgm⁻³. There were 56% increase during rice crop residue and 60% increase during wheat crop residue burning in the concentration of coarse particulate matter in comparison to non-burning values. It was found that (Figure 4.1 to 4.8) concentration of different size particulate matters show significant increase during the months of October-November and April-May in which exhaustive burning of rice and wheat crop residue take place.

4.1.6 Relationship between PM_{2.5}, PM_{10-2.5} and PM₁₀

Table 4.1: Monthly ratio of fine and coarse to respirable particulate matter

	PM _{2.5} /PM ₁₀			PM _{10-2.5} /PM ₁₀		
	1 st year	2 nd year	3 rd year	1 st year	2 nd year	3 rd year
Feb	---	0.587	0.600	---	0.413	0.400
Mar	---	0.585	0.555	---	0.415	0.445
Apr	---	0.561	0.536	---	0.439	0.434
May	---	0.561	0.589	---	0.439	0.411
Jun	---	0.558	0.550	---	0.442	0.450
Jul	---	0.564	0.553	---	0.436	0.447
Aug	0.549	0.557	0.565	0.451	0.443	0.435
Sep	0.569	0.564	0.585	0.431	0.436	0.415
Oct	0.577	0.610	0.623	0.423	0.390	0.377
Nov	0.589	0.610	0.575	0.411	0.390	0.425
Dec	0.593	0.614	0.638	0.407	0.386	0.362
Jan	0.583	0.611	0.625	0.417	0.389	0.375
Mean	0.577	0.582	0.581	0.423	0.418	0.419
SD	0.016	0.024	0.036	0.016	0.024	0.036
Min	0.549	0.557	0.536	0.407	0.386	0.362
Max	0.593	0.614	0.638	0.451	0.443	0.484

SD: standard deviation; ---measurement started from August-2007

Table 4.1 represents the monthly ratio of fine and coarse fraction of particulate matter to RSPM from August 2007 to January 2010. Data of initial six month *i.e.* from February 2007 to July 2007 are not available as the measurements start from August 2007. The average mass concentration ratios $PM_{2.5}/PM_{10}$ varied 0.54 to 0.64 with an average value of 0.58 ± 0.03 (Table 4.1) during the study period. The ratio of $PM_{2.5}/PM_{10}$ indicates that major part *i.e.* 54% to 64% of the PM_{10} comprises $PM_{2.5}$. $PM_{10-2.5}/PM_{10}$ ratio was found 0.42 ± 0.03 , which was lower than $PM_{2.5}/PM_{10}$ 0.58 ± 0.03 (Table 4.1) and indicate higher contribution of $PM_{2.5}$ in PM_{10} . There was no significant change observed during the burning period months in comparison to non-burning period months on the ratios of particulate matter and contribution of fine fraction always remain high ($> 50\%$) in comparison to coarse fraction. Observed different ratios of particulate matter indicate that RSPM contain more fractions of lower size particulate matter ($PM_{2.5}$) as compared to coarse fraction ($PM_{10-2.5}$) of aerosol.

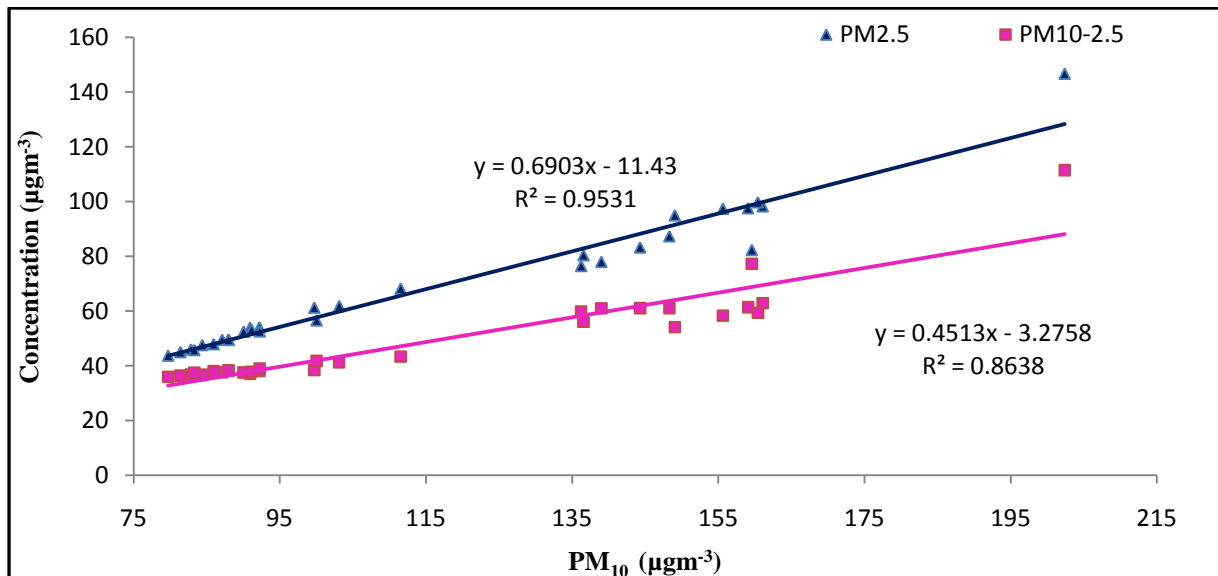


Figure 4.9: Relationship between $PM_{2.5}$, $PM_{10-2.5}$ with PM_{10}

To find the association between the different size of particulate matters, linear regression among $PM_{2.5}$, $PM_{10-2.5}$ and PM_{10} were carried out as shown in Figure 4.9. Both $PM_{2.5}$ and $PM_{10-2.5}$ were significantly correlated with PM_{10} . $PM_{2.5}$ was more strongly associated with PM_{10} ($r = 0.976$) as compared to association between $PM_{10-2.5}$ with PM_{10} (0.929), because $PM_{2.5}$ (fine fraction) contributes more in PM_{10} during all monitoring months irrespective of burning or non-burning period. Results of Table 4.1 and Figure 4.9 show that contributions of smaller fraction of particles are more in comparison to the coarse fraction irrespective of burning and non-burning period.

4.1.7 Comparison between non-burning and burning period

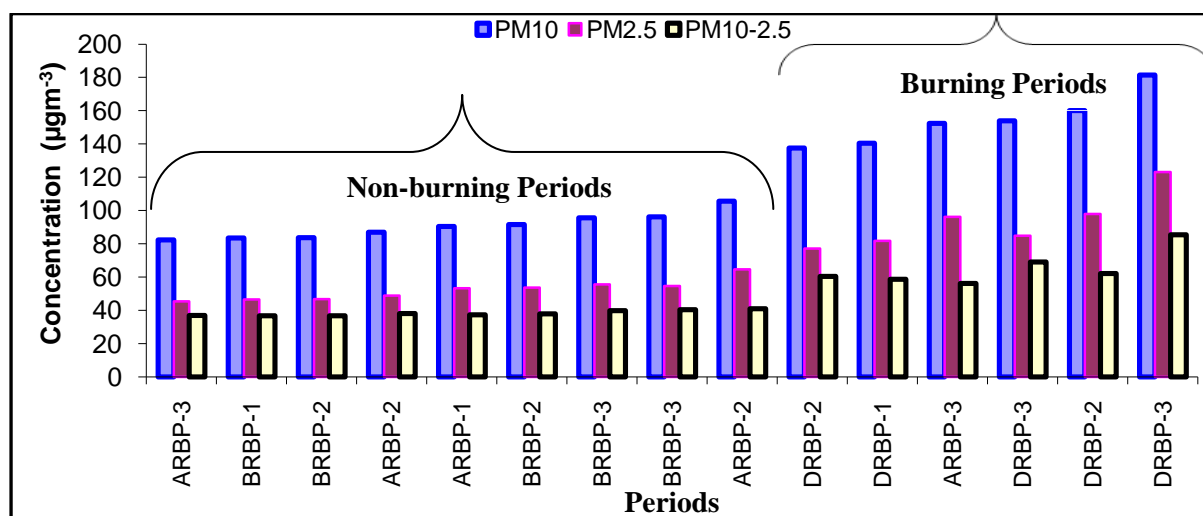


Figure 4.10: Variation of PM₁₀, PM_{2.5} and PM_{10-2.5} during non-burning and burning periods

Figure 4.10 represents periodical variation of PM₁₀, PM_{2.5} and PM_{10-2.5} in terms of different non-burning periods (before and after residue burning of rice and wheat) and burning periods of wheat and rice crop residue. Figure 4.10 shows that the concentration level during the burning period is high as comparison to non-burning periods and during these burning periods level of PM₁₀ and PM_{2.5} is found to be above the safety limit as set by NAAQS (100 µgm⁻³ for PM₁₀ and 60 µgm⁻³ for PM_{2.5}) for industrial, residential, rural and other areas. It is also observed that between the burning and non-burning period, concentration level during non-burning period is mostly below the NAAQS except ARBP-3 and ARBP-2. Statistical analysis show that there is 59 % increase in PM₁₀ concentration and 64 % increase in PM_{2.5} during burning period in comparison to non-burning period concentration. It was observed that during the burning of agriculture crop residue, particulate matter level increases abruptly. Average value of different size particulate matter in rice and wheat crop residue burning period were calculated and tabulated in Table 4.2 to compare the contribution of crop residue burning on the concentration level of the particulate matter.

4.1.8 Comparison between rice and wheat crop residue burning

Table 4.2: Average concentration of particulate matter in burning period of wheat and rice crop residue

	PM ₁₀ (µgm ⁻³)			PM _{2.5} (µgm ⁻³)			PM _{2.5} /PM ₁₀		
	1 st year	2 nd year	3 rd year	1 st year	2 nd year	3 rd year	1 st year	2 nd year	3 rd year
DWBP	---	137.61	153.94	---	77.22	84.81	---	0.57	0.55
DRBP	140.42	160.07	181.40	81.83	97.90	123.18	0.58	0.61	0.60

It was observed that (Table 4.2) RSPM and fine fraction *i.e.* PM₁₀ and PM_{2.5} level were high in rice crop residue burning period as compared to wheat crop residue burning during the study period of all three years. In both burning periods, contribution of PM_{2.5} in PM₁₀ was high (> 50 % ; 54 to 64 %) as compared to PM_{10-2.5} but fraction of PM_{2.5} was 4 to 5% more in rice crop residue as compared to wheat crop residue burning. This indicates that during rice crop residue burning PM₁₀ contain more percentage of PM_{2.5} as compared to wheat crop residue burning. Moreover, percentage increase with respect to background concentration of particulate matter was more during the rice crop residue burning in comparison to wheat crop residue burning. Differences between rice and wheat crop residue burning periods were calculated by using the paired t-test. The total difference between the rice and wheat crop residue burning for the value of PM₁₀ and PM_{2.5} are 4.47 and 8.84 µgm⁻³ respectively, which is statistically significant (p < 0.05) (Awasthi et al., 2011). Hence, among two crop residue burning season, impact of rice crop residue burning was found to be more on the mass concentration of aerosol as compared to wheat crop residue burning.

4.1.9 Seasonal variation or comparison between coldest and hottest months

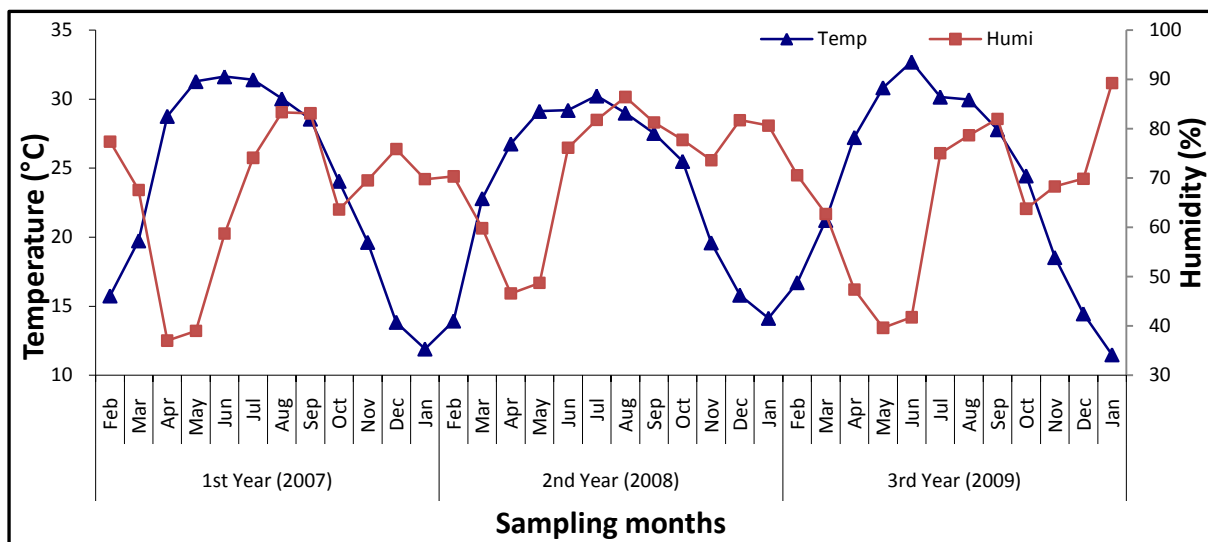


Figure 4.11: Monthly average value of temperature and humidity

For measurement of seasonal variation, meteorological parameter like temperature and humidity were taken from the internet (www.wunderground). Monthly temperature and humidity variations of Patiala city is shown in Figure 4.11.

On the basis of metrological information's, April to August are hottest months of the summer season and December to February are coldest month of the winter season in Patiala. On the basis of meteorological parameters of Patiala city, during study period monthly average value of temperature was 23.7 ± 7 °C with minimum monthly average temperature of 11.9 °C in January 2008 and maximum temperature was 32.7 °C in June 2009. Minimum value of temperature was seen in the month of December to January every year and maximum temperature in three consecutive months observed during June to August (Figure 4.11). During the study period monthly average value of humidity was 68.1 ± 14.6 with minimum value up to 37 % in April 2007 and maximum value up to 89 % in January 2010.

For the comparison of seasonal variation of particulate matter [excluding the effect of burning period months (October-November and April-May)], average value of three consecutive months; December-February for winter and June-August for summer were calculated and shown in Table 4.3 as these three consecutive months shows minimum and maximum temperature during the study period (Figure 4.11).

Table 4.3: Average concentration of particulate matter in summer and winter

Season	PM ₁₀ (µgm ⁻³)		PM _{2.5} (µgm ⁻³)		PM _{2.5} /PM ₁₀	
	June-Aug'08	June-Aug'09	June-Aug'08	June-Aug'09	June-Aug'08	June-Aug'09
Summer	85.58	85.65	47.87	47.81	0.56	0.56
Winter	91.12	104.79	53.29	63.77	0.58	0.61

RSPM and fine fraction have higher value during the winter months as compared to summer months, which show that during winter season concentration of different size particulate matter was high. Ratio of PM_{2.5}/PM₁₀ was also found to be high in the winter month as compared to summer month *i.e.*, PM₁₀ contains up to 61 % of PM_{2.5} in winter and 56 % in summer indicates that fine fraction contributes more during winter season as compared to summer season. Average value of humidity during summer (June to August) is found to be high as compared to the average value during winter months (December to February). Significant ($p < 0.05$) differences of 12.31 µgm⁻³, 10.80 µgm⁻³ and 0.04 were observed in PM₁₀, PM_{2.5} and PM_{2.5}/PM₁₀ between winter and summer which supports the observation that during winter months, concentration levels were higher than in summer months (Awasthi et al., 2011).

4.1.10 Discussion

Results show the adverse contribution of ACRB on the concentration level of different size particulate matter (SPM, PM₁₀, PM_{2.5} and PM_{10-2.5}) at the Patiala City of Punjab. To support the result statistically, paired t-test was used to calculate the difference between the mean value of SPM, PM₁₀, and PM_{2.5} of the different studied periods with respect to the burning time of ACRB and shown in Table 4.4.

Table 4.4: Difference in SPM, PM₁₀ and PM_{2.5} from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	Difference	SPM	PM ₁₀	PM _{2.5}
1st Year (2007)	BWBP-1 - DWBP-1	-163 (< 0.05)	---	---
	BWBP-1 - AWBP-1	-33 (0.42)	---	---
	BWBP-1 - BRBP-1	57 (0.07)	---	---
	BWBP-1 - DRBP-1	-240 (< 0.05)	---	---
	BWBP-1 - ARBP-1	-1.5 (< 0.05)	---	---
2nd Year (2008)	BWBP-2 - DWBP-2	-157 (< 0.05)	-46 (< 0.05)	-23 (< 0.05)
	BWBP-2 - AWBP-2	113 (0.12)	45 (0.18)	45 (0.05)
	BWBP-2 - BRBP-2	118 (0.06)	8 (0.09)	65 (0.05)
	BWBP-2 - DRBP-2	-145 (< 0.05)	-68 (< 0.05)	-44 (0.23)
	BWBP-2 - ARBP-2	-61 (< 0.05)	-14 (< 0.05)	-11 (< 0.05)
3rd Year (2009)	BWBP-3 - DWBP-3	-182 (< 0.05)	-58 (< 0.05)	-38 (< 0.05)
	BWBP-3 - AWBP-3	-41 (0.25)	13 (0.21)	11 (0.06)
	BWBP-3 - BRBP-3	-14 (0.12)	-10 (0.28)	8 (0.17)
	BWBP-3 - DRBP-3	-219 (< 0.05)	-85 (< 0.05)	-67 (< 0.05)
	BWBP-3 - ARBP-3	-104 (< 0.05)	-36 (< 0.05)	-20 (< 0.05)

Parenthesis represent p-values; --- data not available

Table 4.4 represents the difference between the SPM, PM₁₀ and PM_{2.5} concentration of first period of each year (BWBP) with other five periods (DWBP, AWBP, BRBP, DWBP and AWBP) of the same year for all the three studied years. The low p value with negative difference between the non-burning and burning periods clearly shows that concentration of different size particulate matter significantly ($p < 0.05$) increased during the burning period of wheat and rice crop residue. Hence, results of paired t-test verify that increased concentration observed during burning periods (Figures 4.1 to 4.10) is statically significant.

In northern India, open residue burning of crop residue is common process used by the farmers from a long time due to their different personal benefits (Badarinath *et al.*, 2006, 2009a, b). Increase in levels of particulate matter during agriculture crop residue burning months was due to the production of smoke due to incomplete and improper combustion of residue in open fields. In an ideal combustion condition, sufficient mixing of the fuel and combustion air take place along with sufficient gas-phase residence times at high temperature. This assures a high degree of completeness (conversion to water [H₂O] and carbon dioxide [CO₂]) in the combustion process, which limits pollutant emissions due to incomplete combustion. Open burning due to less than ideal combustion conditions, typically produces soot and particulate matter that are visible as dense smoke (Andreae *et al.*, 2001). Average concentration of SPM, PM₁₀ and PM_{2.5} was 273 ± 102 , 115 ± 34 and 69 ± 24 μgm^{-3} , which is more than the NAAQS of 24 hr for industrial, residential, rural and sensitive area.

Recent study by Gustafsson *et al.*, (2009) highlighted that biomass burning is one of the main causes for dense “brown clouds” in South Asia. Biomass burning is one of the significant global source of atmospheric aerosols and trace gas emissions, which have a major impact on climate and human health (Gogoi *et al.*, 2008; Kharol and Badarinath, 2006; Pandey *et al.*, 2005; Vander werf *et al.*, 2006; Wu *et al.*, 2006; Yang *et al.*, 2007). Smoke particles from biomass burning have direct radiative impact by scattering and absorbing shortwave radiation and indirect radiative impact by serving as Cloud-Condensation Nuclei (CCN) and changing the cloud microphysical and optical properties (Cattani *et al.*, 2005) and hence have local and global effect on the climate (Bellouin *et al.*, 2005; Gogoi *et al.*, 2008; Prasad *et al.*, 2003).

The results of different size range particulate matters signifies that the contribution of small size particulate matter was found to be high as compared to particle size coming in coarse fraction range as PM_{2.5}/PM₁₀ ratio is found to be always greater than 50 % and reached up to 64%. This is due to large surface area and lower settling velocity of small size particles, also supported by number of other studies conducted in different countries that also found PM_{2.5}/PM₁₀ mass ratio higher than PM_{10-2.5}/PM₁₀ (Chan and Kwok, 2001; Harrison *et al.*, 1997, 1999, 2004; Hauck *et al.*, 2004; Wilson and Suh, 1997).

Higher concentration of particulate matter during rice crop residue burning as compared to wheat crop residue was probably due to large quantity of rice crop residue being disposed

of during October-November as compared to wheat crop residue by open field burning because wheat crop residue is used as fodder and other purposes up to greater extent as compared to rice crop residue. The emissions from wheat crop residues in Punjab are relatively low as compared to those from paddy fields (Badrinath *et al.*, 2006). Moreover, burning of rice crop residue takes place in the winter months of October and November, so due to movement of boundary layer toward lower height result in more concentration than in burning of wheat crop residue in the summer months of April and May.

Results of comparison among particulate matter with respect to seasons show that winter month's concentration level was higher as compared to summer. In the summer high solar heating of the land leads to an increase in the boundary layer height that increases the ventilation coefficient which further leads to faster dispersion of aerosols. The increase in ventilation coefficient results in decrease in the concentration of particulate matter. During winter season, low solar heating of land results in slower dispersion of aerosols and boundary height decreases resulting in increase in concentration of particulate matter. Winter season have greater exposure risk as pollutants often get trapped in the lower layers of the atmosphere thereby resulting in high concentration of particulate matter.

Correlation of PM_{10} was found to be higher with $PM_{2.5}$ ($r = 0.976$) in contrast to $PM_{10-2.5}$ ($r = 0.929$) because $PM_{2.5}$ contributes more up to 64 % of the total mass concentration of PM_{10} . Wilson and Suh, (1997) also reported that PM_{10} and $PM_{2.5}$ exhibits a higher degree of correlation where as the lowest correlation between $PM_{10-2.5}$ and $PM_{2.5}$. Higher contribution of $PM_{2.5}$ in PM_{10} is more serious issue as particles of respirable range are responsible for most of the airborne particle threat to human health because of their small size range and pose health hazard due to their inhalation and deep penetration capability in respiratory system during breathing (Hoek *et al.*, 1998, 2002; Laden *et al.*, 2000; Lal *et al.*, 2004; Mar *et al.*, 2000; Pope *et al.*, 1991, 1992, 2002; Schwartz *et al.*, 1996; Shanghai *et al.*, 2007; Zanobetti *et al.*, 2009).

Part-II

4.2 PFTs and SpO₂ data analysis

Various Pulmonary Function Tests (PFTs) like FVC, FEV₁, PEF, FEF_{25-75%} *etc.* and Oxygen Saturation (SpO₂) level of 50 healthy subjects were measured by Spirometer (Spiro bank-G of model MIR) and Pulse-Oximeter (Dolphin Voyager Pulse-oximeter, Dolphin Medical, PTE. Ltd.) respectively and analysed.

4.2.1 Measurement of Pulmonary Function Tests (PFTs)

4.2.1.1 Force vital capacity

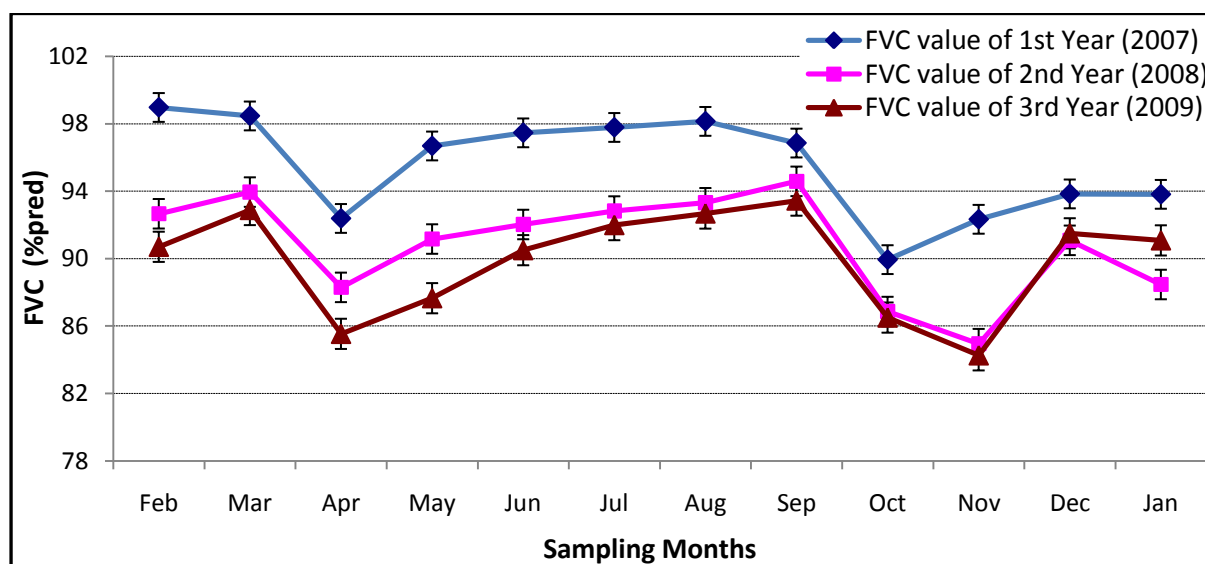


Figure 4.12: Monthly average value of FVC (% predicted) with standard error

Figure 4.12 represents the monthly average values of Force Vital Capacity (FVC) and illustrates the variation of FVC in different months during the three study years from February 2007 to January 2010. Trend of FVC was found to be almost similar in the three years. Small decrease in the average value of FVC was observed during the starting month of the study period of first year *i.e.*, February 2007 to March 2007, whereas in 2nd and 3rd year there is increase in value from February to March. After March, significant decrease were observed in the values of FVC during the month of April and thereafter recovery up to some extent in May but value remain small as comparison to the previous months *i.e.*, February and March. After May, the value gradually increases up to August in 1st year and up to September in 2nd and 3rd year after the completion of burning episode. Increase in values from May to September was more prominent in 2nd and 3rd year with respect to 1st year. Significant

decrease was then observed in the month of October that recovers slightly in the November 2007. Decrease was observed for the month of November in 2008 and 2009, which further increase in December month of all the three studied years with minute decrease in January. Significant decreases were seen in the months of April-May and October-November with minute increase and decrease in other months due to increase in the concentration level of different size particulate matter. Since in Northern parts of India April-May and October-November is usually the time when farmers burn the crop residues in the fields to prepare their land for next growing season (Badrinath *et al.*, 2006; Sahai *et al.*, 2010).

For analysis the effects of crop residue burning results of thirty six months were divided into eighteen periods on the basis of burning time of wheat and rice crop residue (mentioned in methodology).

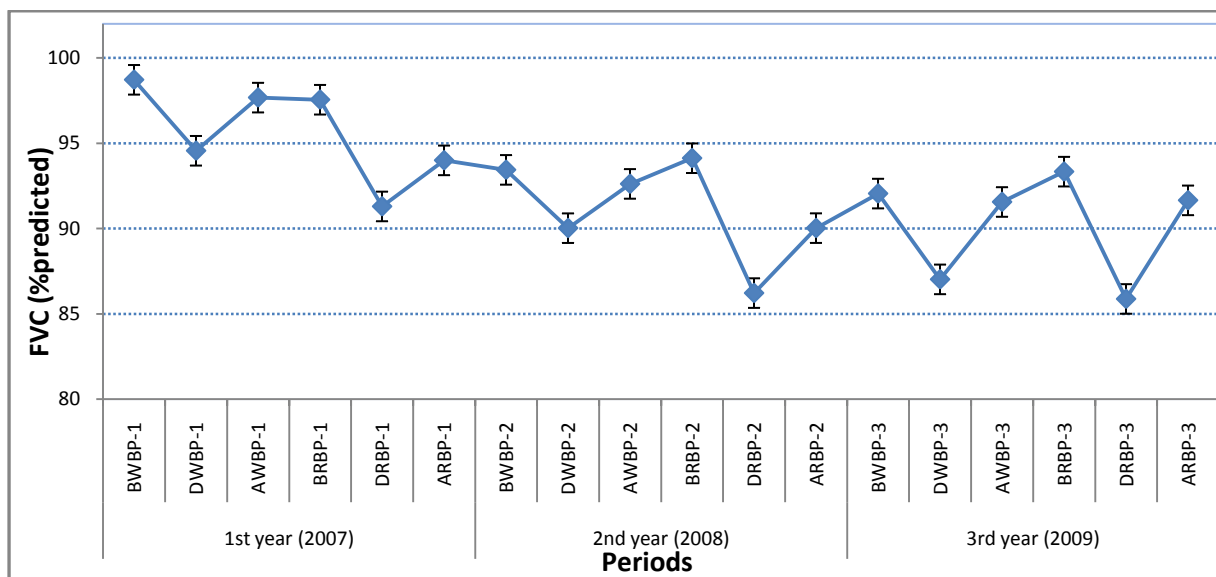


Figure 4.13: Periodical variation of FVC (% predicted) with standard error

Figure 4.13 represents the variation of FVC in different periods with reference to the crop residue burning after harvesting of wheat and rice crop from February 2007 to January 2010. FVC shows maximum value during BWBP-1 that decrease DWBP-1, which increases further and have high value during AWBP-1 and BRBP-1 as compared to DWBP-1, followed by significant decrease during DRBP-1 that recover up to some extent ARBP-1 and BWRBP-2. Again in 2nd year, significant decrease seen in the DWBP-2, which increases in AWRBP-2 and BRBP-2 which further show remarkable decrease in DRBP-2 that recovers slightly during ARBP-2 and BWBP-3. Similar trend was observed for the 3rd year as that that of 2nd year. It is clear from the Figure 4.14 that FVC shows significant decrease during the burning

period that recover up to some extent after the completion of burning residue but complete recovery in comparison to pre-burning period of rice was not seen, that indicates some permanent decrease remains in the FVC of healthy subjects.

Paired t-test was used to calculate the difference between the mean value of FVC before, during and after the burning period of wheat and rice crop residue to check the results, that the decreases in FVC value are significant or not. Table 4.5 represents the difference between the FVC (% predicted) value of first period of each year (BWBP) with other five periods (DWBP, AWBP, BRBP, DWBP and AWBP) of the same year for all the three studied years.

Table 4.5: Difference in FVC % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	FVC	Difference	Lower	Upper	t
1st Year (2007)	BWBP-1 - DWBP-1	4.203	3.697	4.709	16.475
	BWBP-1 - AWBP-1	1.088	0.916	1.260	12.564
	BWBP-1 - BRBP-1	1.212	1.055	1.368	15.380
	BWBP-1 - DRBP-1	7.467	7.039	7.895	34.598
	BWBP-1 - ARBP-1	4.066	3.419	4.524	37.308
2nd Year (2008)	BWBP-2 - DWBP-2	3.417	3.073	3.760	19.725
	BWBP-2 - AWBP-2	0.822	0.681	0.964	11.529
	BWBP-2 - BRBP-2	-0.684	-0.876	-0.493	-7.086
	BWBP-2 - DRBP-2	7.222	6.829	7.615	36.499
	BWBP-2 - ARBP-2	3.414	3.003	3.825	16.496
3rd Year (2009)	BWBP-3 - DWBP-3	5.029	4.884	5.174	68.863
	BWBP-3 - AWBP-3	0.493	0.420	0.565	13.487
	BWBP-3 - BRBP-3	-1.285	-1.431	-1.138	-17.401
	BWBP-3 - DRBP-3	6.176	5.729	6.623	27.425
	BWBP-3 - ARBP-3	0.397	0.142	0.653	3.089

Significant up to $p < 0.05$

In first year, difference between the mean values before the wheat crop residue burning period with all other period was found to be positively significant with maximum value in DRBP (7.467) and then in DWBP (4.203). During second and third year, all the differences are found to be positively significant except with BWBP, which indicate that the value recover up to some extent before rice crop residue burning period. The difference at the end of years was found to be significantly positive (4.066, 3.414, 0.397) which specifies that the

value does not recover completely and some permanent decrease was seen in their value. The results also support mathematically by calculated mean difference using the standard paired t-test. Comparison between wheat and rice crop residue burning shows that the effect during rice crop residue burning is more in comparison to wheat crop residue burning as the numerical value of difference is large in rice crop residue burning period in all the three studied year. Results of different observation prove that ability of person to expire total volume of air forcefully (FVC) reduced due to ACRB.

Figure 4.12 and 4.13 shows that the FVC value of healthy subjects decreased due to wheat and rice crop residue burning. Total subjects were divided in to three groups; lower (< 18 years), middle (18 to 40 years) and upper age group (> 40 years) on the basis of their ages to see the effect of crop residue burning on the different age groups subjects.

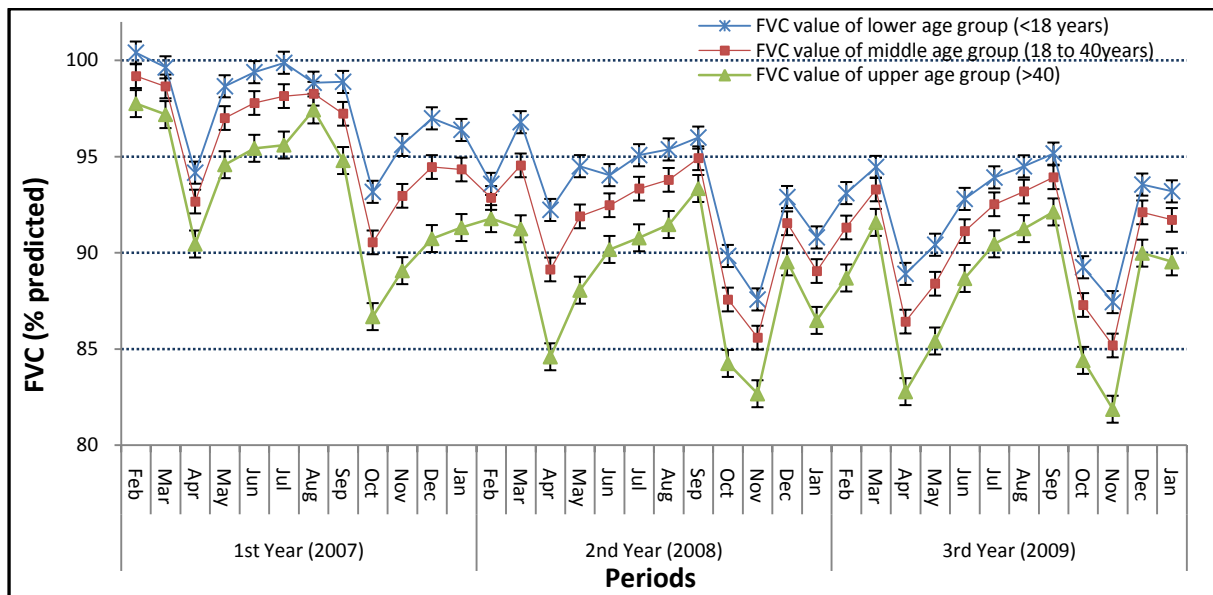


Figure 4.14: Monthly average variation of FVC (% predicted) with standard error for three different age groups

Figure 4.14 shows the monthly variation of FVC for the three different age group subjects. FVC value of all three age group subjects show almost similar trends during the study period of three year especially during the burning period of wheat and rice crop residue. FVC value of lower, middle and upper age group show notable decrease initially in the April-May and then in October-November which is almost similar in the case of total subjects (Figure 4.12), which verify that PFTs of subjects of all age group are affected by the ACRB.

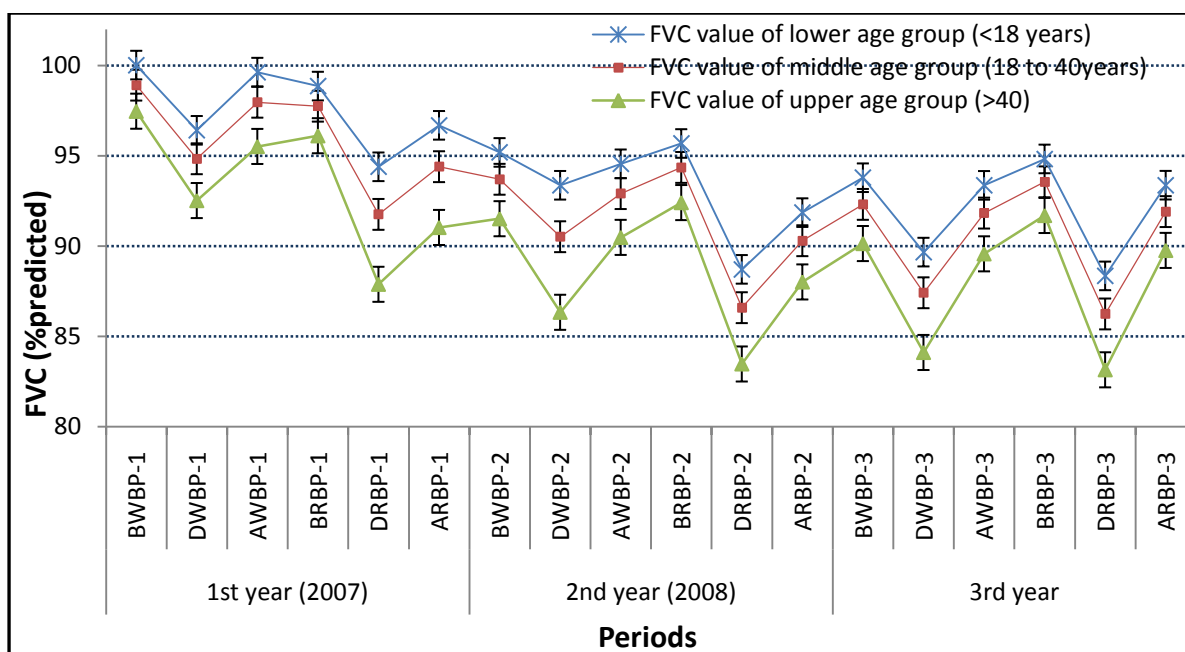


Figure 4.15: Periodical variation of FVC (% predicted) with standard error for the three different age groups

Figure 4.15 represents the periodical variation of FVC for three different age groups during February 2007 to January 2010. All the three different age groups show notable decrease during the burning period of wheat and rice crop residue (DWBP and DRBP) in all the three studied years (Figure 4.16). Similar trend was observed for all three age groups with respect to the periodical variation in the FVC value of all subjects. Figure 4.14 and 4.15 indicates that all the three age groups people were affected by the open wheat and rice crop residue burning which shows slight recovery after the burning period but complete recovery was lost. Paired t-test was used to calculate the difference between first period (BWBP) with other periods of same year to check the decrease in the month of burning periods are statistically significant or not and which age group people show maximum decrease due to open crop residue burning.

Table 4.6 represents the difference of FVC % predicted values of three age groups between the first period of each year (BWBP) with other five periods (DWBP, AWBP, BRBP, DWBP and AWBP) of the same year for all the three studied years. During the burning period of wheat and rice crop residue all the decrease was found statistically significant (Table 4.5), *i.e.*, due to wheat and rice crop residue burning, FVC of all the three age group subjects were affected. Mostly in all cases the difference between different pairs are positively significant that show that the value in different period of each year are

significantly lower to that of the value in starting of year *i.e.*, BWBP. The positive significant value of difference between before wheat with after wheat and rice crop residue burning shows that FVC does not show complete recovery even after the completion of burning episode in all the three age group subjects and poses some permanent effect on their FVC. Negative difference in 2nd and 3rd year of all age group BWBP (Table 4.6) show the recovery up to some extent but difference between first period and last period (BWBP - ARBP) found to be positive which indicates that the value does not recover at the end of the year. Effect on the upper age group seem to be maximum, as in maximum cases, numerical value of difference is more in upper age group as compared to middle and lower age group subjects. Results also indicate that the effect of rice crop residue burning is more in comparison to wheat crop residue burning.

Table 4.6: Difference in FVC % predicted values of lower, middle and upper age group subjects from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	FVC	Difference		
		Lower age	Middle age	Upper age
1st Year (2007)	BWBP-1 - DWBP-1	3.612	4.078	4.949
	BWBP-1 - AWBP-1	0.390	0.947	1.952
	BWBP-1 - BRBP-1	1.163	1.166	1.358
	BWBP-1 - DRBP-1	8.360	7.159	9.587
	BWBP-1 - ARBP-1	3.336	4.517	6.440
2nd Year (2008)	BWBP-2 - DWBP-2	1.819	3.182	5.183
	BWBP-2 - AWBP-2	0.630	0.794	1.034
	BWBP-2 - BRBP-2	-0.495 ^a	-0.656	-0.894
	BWBP-2 - DRBP-2	6.476	7.112	8.046
	BWBP-2 - ARBP-2	3.334	3.402	3.502
3rd Year (2009)	BWBP-3 - DWBP-3	4.121	4.895	6.033
	BWBP-3 - AWBP-3	0.423	0.482	0.569
	BWBP-3 - BRBP-3	-1.040	-1.249	-1.555
	BWBP-3 - DRBP-3	5.437	6.068	6.993
	BWBP-3 - ARBP-3	0.414 ^a	0.400	0.379 ^a

Significant up to $p < 0.05$, ^anon-significant values

4.2.1.2 Force expiratory volume in one second

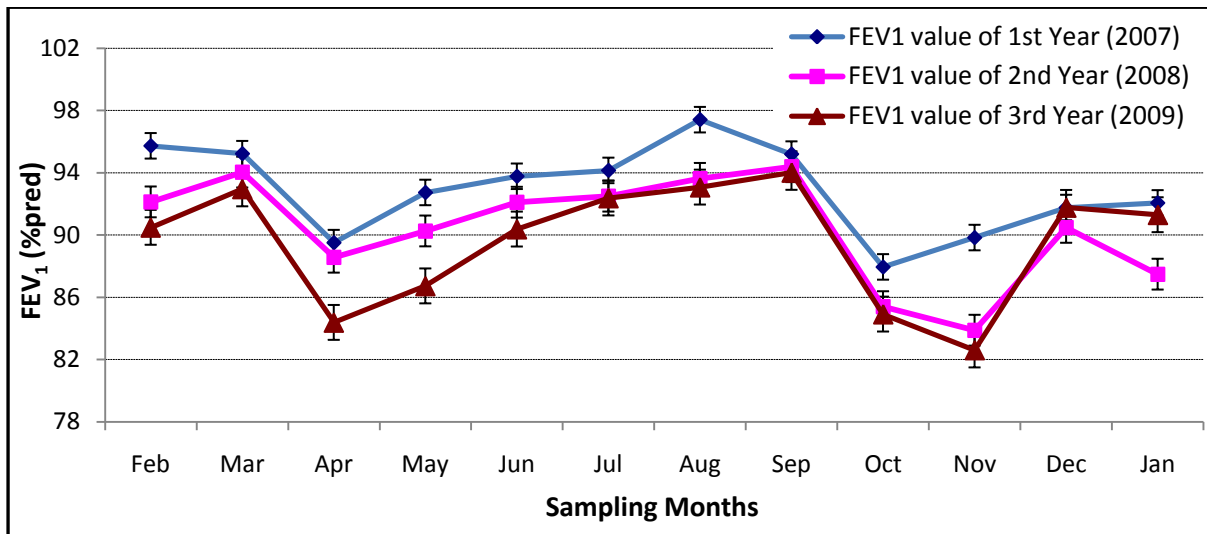


Figure 4.16: Monthly average value of FEV₁ (% predicted) with standard error

Figure 4.16 shows monthly average values of Force Expiratory Volume in one second (FEV₁) during various months from February 2007 to January 2010. Almost similar trend was observed in case of FEV₁ as in case of FVC except that a prominent increase in the monthly average value was observed for FEV₁ from July 2007 to August 2007 which decreases in the month of September 2007. Variation trend for FEV₁ in 2008 and 2009 was almost same as that of FVC. Figure 4.16 shows remarkable decrease in the months of April-May and October-November of all studied period with minute up and down in other months, which show that FEV₁ is also affected in the month of April-May and October-November due to ACRB of wheat and rice.

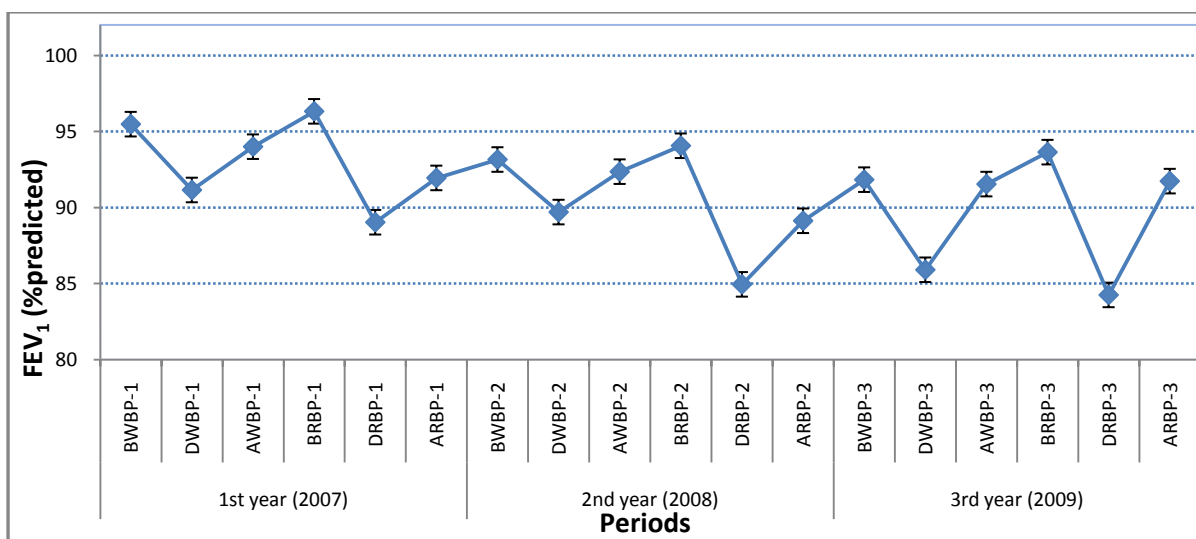


Figure 4.17: Periodical variation of FEV₁ (% predicted) with standard error

Figure 4.17 represents the variation of FEV₁ in different periods with reference to the crop residue burning after harvesting of wheat and rice from February 2007 to January 2010. General trend for values of FEV₁ for periodical variation is same as that of FVC. There is increase in the values of FEV₁ after the burning periods like AWBP-1, ARBP-1, AWBP-2, ARBP-2, AWBP-3 and ARBP-3 which further increases till the next burning periods during 1st, 2nd and 3rd year from 2007 to 2009. It is clear from the graph that there is recovery up to some extent in wheat burning period as their value recover in 2nd consecutive period (BRBP) of DWBP. Drastic decline in the average values of FEV₁ is observed during wheat and rice burning period in all the three years, which clearly signifies the effect of ACRB on it. Paired t-test was used to find the significance level of different changes by taking the difference between different periods. Table 4.7 shows the difference in FEV₁ % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP during the three years of study.

Table 4.7: Difference in FEV₁ % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP during the three years of study (by using paired t-test)

	FEV ₁	Difference	Lower	Upper	t
1st Year (2007)	BWBP-1 - DWBP-1	4.328	3.915	4.741	20.786
	BWBP-1 - AWBP-1	1.480	1.359	1.600	24.362
	BWBP-1 - BRBP-1	-0.844	-1.196	-0.491	-4.753
	BWBP-1 - DRBP-1	6.450	6.076	6.824	34.218
	BWBP-1 - ARBP-1	3.535	3.423	3.647	62.541
2nd Year (2008)	BWBP-2 - DWBP-2	3.457	2.964	3.950	13.917
	BWBP-2 - AWBP-2	0.799	0.495	1.102	5.218
	BWBP-2 - BRBP-2	-0.906	-1.243	-0.568	-5.326
	BWBP-2 - DRBP-2	8.212	7.693	8.730	31.442
	BWBP-2 - ARBP-2	4.029	3.482	4.575	14.634
3rd Year (2009)	BWBP-3 - DWBP-3	5.927	5.698	6.157	51.239
	BWBP-3 - AWBP-3	0.291	0.228	0.355	9.093
	BWBP-3 - BRBP-3	-1.809	-1.963	-1.655	-23.290
	BWBP-3 - DRBP-3	7.581	7.039	8.123	27.741
	BWBP-3 - ARBP-3	0.097 ^a	-0.193	0.387	0.664

Significant up to $p < 0.05$, ^anon-significant value

Difference (Table 4.7) between the mean values before wheat crop residue burning period with periods including DWBP-1, AWBP-1, DRBP-1, ARBP-1 was found to be positively significant with maximum value for DRBP (6.450) and then in DWBP (4.328).

There is one recovery point in every year *i.e.*, have negatively significant value in case of BWBP. The positive difference between first period and last period (BWBP-ARBP) of every studied year clearly shows that complete recovery of FEV₁ is lost, which was same as in case of FVC. Comparison among two crop residue burning period, effect during rice crop seems to be more prominent in comparison to wheat crop residue burning as there is more decrease and less recovery during the burning period of rice crop residue.

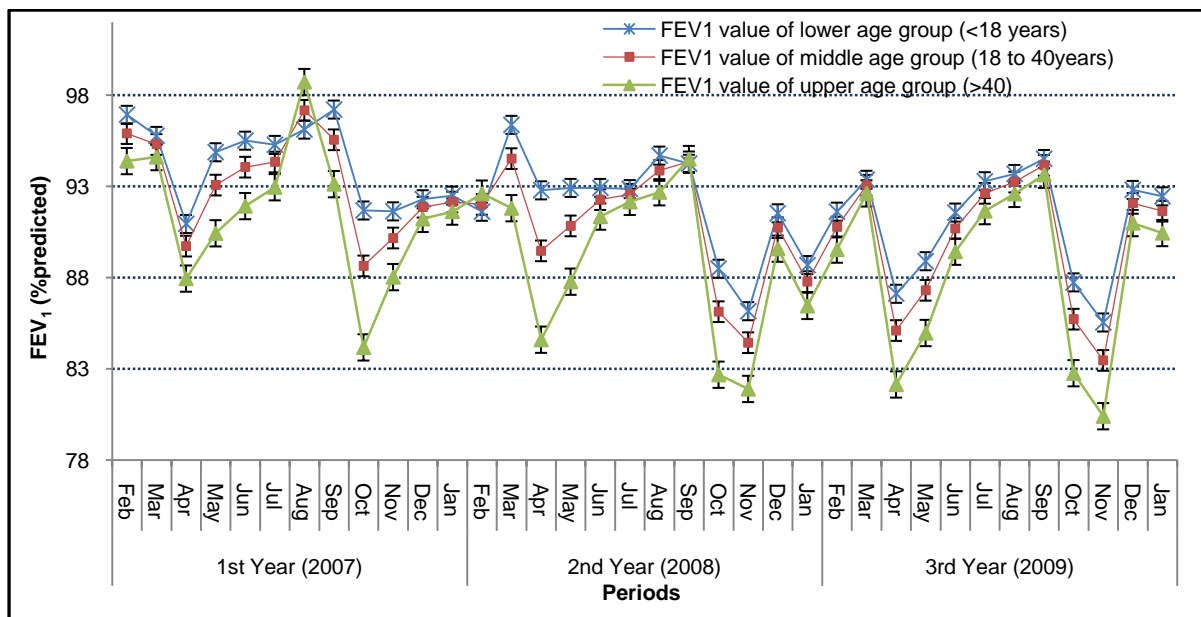


Figure 4.18: Monthly average variation of FEV₁ (% predicted) with standard error for three different age groups

Figure 4.18 shows monthly average variation of FEV₁ for three different age groups from February 2007 to January 2010. Almost similar trend is observed in all the three age groups. Monthly variation of FEV₁ of different age group is almost similar to FVC variation of different age group. Again remarkable decrease in FEV₁ was observed in the month of April-May and October- November of every age group subjects that recovers slightly but complete recovery was not observed in any of the age groups. Almost same trend were observed for three year *i.e.*, FEV₁ reduced during the April- May and October-November of each year with minute up and downs in other months.

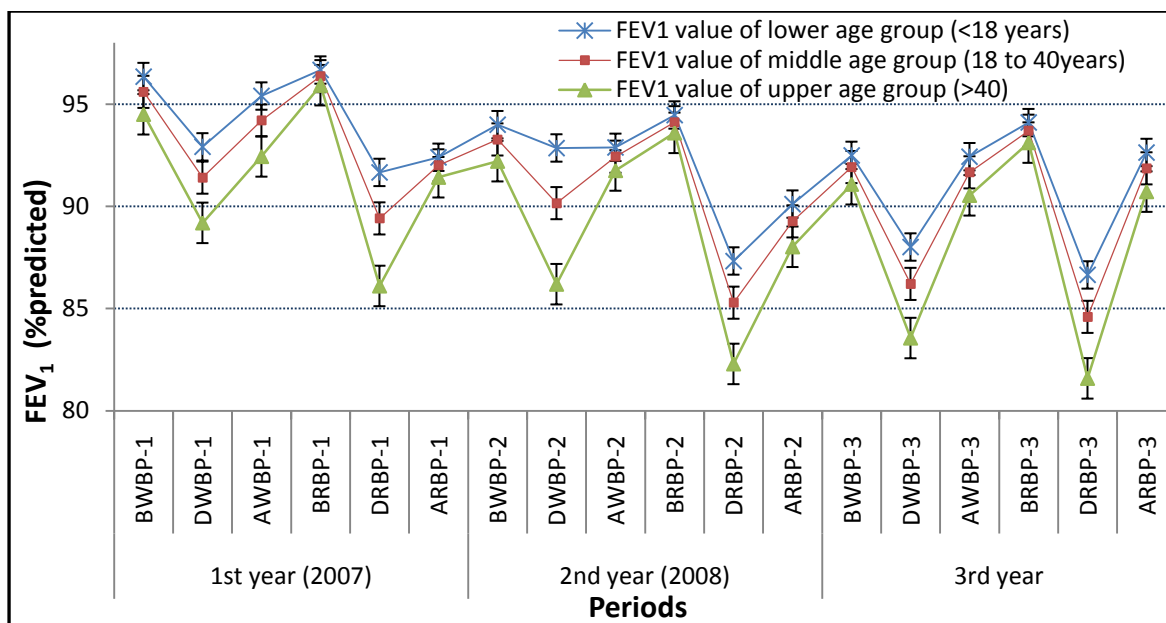


Figure 4.19: Periodical variation of FEV₁ (% predicted) with standard error for three different age groups

Figure 4.19 shows periodical variation of FEV₁ for three different age groups from February 2007 to January 2010. FEV₁ of all the three age groups subjects shows decrease in their value during the burning period of rice and wheat crop residues which gradually increases after the burning period followed by further increase till the next burning period in all the three age groups during three studied years from February 2007 to January 2010. In this case recovery seems to be more in wheat crop residue burning period in comparison to rice crop residue burning period. Paired t-test was used to calculate the difference between different periods to check the significance level of changes observed in the three age group subjects during the burning of wheat and rice crop residue (Table 4.7).

Table 4.8 shows the difference in FEV₁ % predicted values of lower, middle and upper age group subjects from first period of each year (BWBP) with the remaining five period of same year (DWBP, AWBP, BRBP, DRBP and ARBP) during the three years of study. During the burning period of wheat and rice crop residue all the decrease were found to be statistically significant. It indicates that due to wheat and rice crop residue burning FEV₁ of all three different age groups subject were affected (Table 4.7). Mostly in all cases the difference between the different pairs are found to be positively significant. It shows that the value in different period of each year are significantly lower to that of the value in starting of year *i.e.*, BWBP. The positive significant value shows that FEV₁ does not show complete recovery even after the completion of burning episode in all the three age group. Comparison

between wheat and rice crop residue burning period shows that difference of first period with DRBP in all three year is more in comparison to difference with DWBP that indicate more effect of rice crop residue burning on the all the three age groups. Comparison among different age groups show more effect on the upper age group in contrast to lower and middle age group subjects as difference value is found to be maximum in case of upper age group.

Table 4.8: Difference in FEV₁ % predicted values of lower, middle and upper age group subjects from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	FEV ₁	Difference		
		Lower age	Middle age	Upper age
1st Year (2007)	BWBP-1 - DWBP-1	3.439	4.197	5.311
	BWBP-1 - AWBP-1	0.954	1.402	2.061
	BWBP-1 - BRBP-1	-0.319 ^a	-0.767	-1.424
	BWBP-1 - DRBP-1	4.689	6.191	8.397
	BWBP-1 - ARBP-1	3.948	3.596	3.079
2nd Year (2008)	BWBP-2 - DWBP-2	1.140	3.116	6.018
	BWBP-2 - AWBP-2	1.109	0.844	0.456
	BWBP-2 - BRBP-2	-0.472 ^a	-0.842	-1.385
	BWBP-2 - DRBP-2	6.668	7.985	9.918
	BWBP-2 - ARBP-2	3.885	4.008	4.188
3rd Year (2009)	BWBP-3 - DWBP-3	4.483	5.715	7.524
	BWBP-3 - AWBP-3	0.064	0.258	0.543
	BWBP-3 - BRBP-3	-1.603	-1.778	-2.036
	BWBP-3 - DRBP-3	5.849	7.326	9.496
	BWBP-3 - ARBP-3	-0.142 ^a	0.062 ^a	0.361 ^a

Significant up to $p < 0.05$, ^anon-significant values

The results of FEV₁ show that ability of all age group to expire air in first second (FEV₁) was affected during the burning period of wheat and rice crop residue in which upper age group were affected more. Rice crop residue burning seems to have more effect in comparison to wheat crop residue burning. These results are true for both FVC and FEV₁.

4.2.1.3 Peak expiratory flow

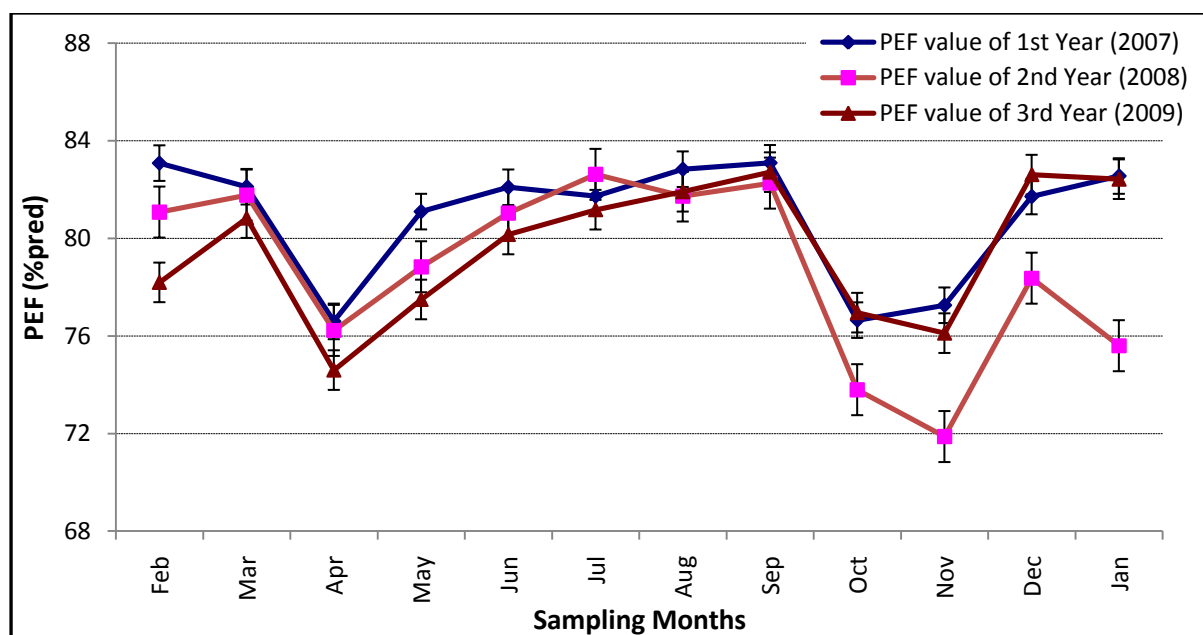


Figure 4.20: Monthly average value of PEF (% predicted) with standard error

Figure 4.20 shows the monthly average values of Peak Expiratory Flow (PEF) during February 2007 to January 2010 as shown by overlapping lines in the graph. Like FVC and FEV₁; PEF values shows approximately similar trends in all the three years with minute deviations. Decrease in the values of PEF was observed during March 2007 whereas in the second and third year increase was observed during March in the PEF values which further decreases in April month of all the years. After April gradual increase in the values of PEF was observed from May to September of all three years with small decrease in July 2007 and August 2008 of 1st and 2nd year. A sudden decline in the PEF value was observed during October months of all the years which further decreases in 2nd and 3rd year but a small increase was observed in 1st year. During December increase in the average values of PEF was observed in all three years, which further decreases in January 2009 and 2010 year. Results show that the value of PEF shows remarkable decrease in the months of April-May and October-November of each year. Periodical variation was calculated and shown in Figure 4.21.

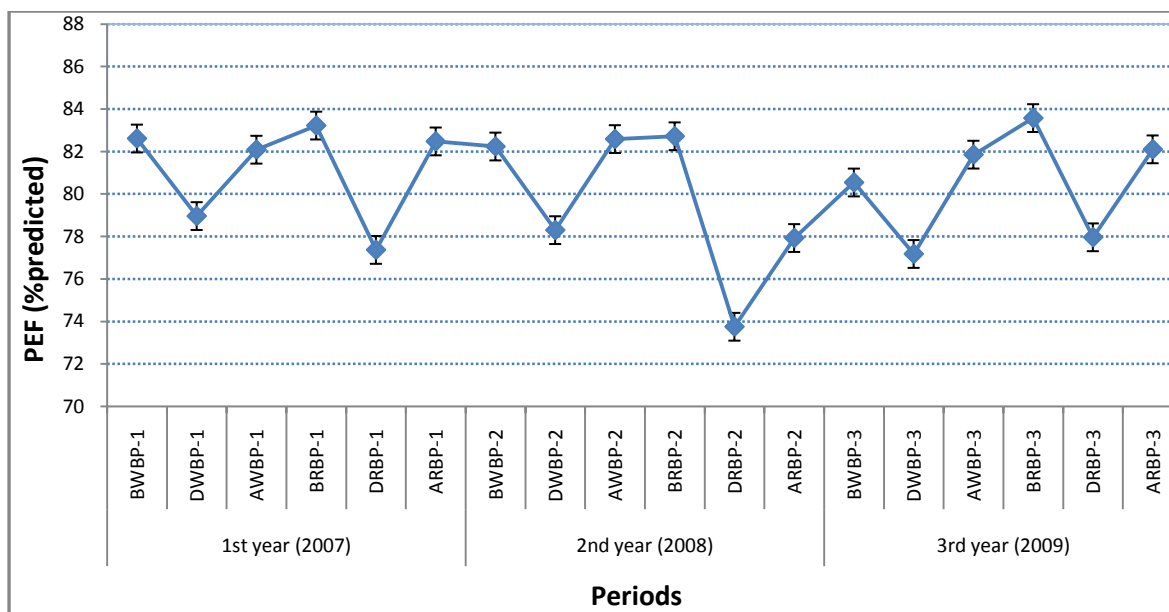


Figure 4.21: Periodical variation of PEF (% predicted) with standard error

Figure 4.21 shows the periodical variation of PEF with respect to wheat and rice crop residue burning period. Initial observation from the graph is same as that of previous graphs for FVC and FEV₁ *i.e.*, remarkable decrease was observed during burning period of wheat and rice crop residue. After the completion of burning episode, there is recovery up to some extent in coming periods in every year, but the recovery in the case of PEF seems to me more in comparison to FVC and FEV₁.

Pared t-test was used to calculate the difference in PEF % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP for three years of study (Table 4.9). It is estimated that the difference between the PEF values of the first period (BWBP) and rest of the burning periods of the same year are positively significant for DWBP and DRBP of all three studied years with maximum in case of DRBP (5.244, 8.486 and 3.581) and then WRBP (3.652, 3.938 and 3.365). These results show that effect of rice crop residue burning is more on PEF in comparison to wheat crop residue burning. Three negative value in 3rd year (-1.310, 3.031 and -1.560) and two value in 2nd year (-0.349 and -0.482) and one negative value (-0.610) in 1st year clearly shows that PEF value recover up to some extend after the completion of burning episode. Significant negative differences in 3rd year indicate that PEF value recovers after the completion of burning episode and ACRB does not pose any permanent effect on PEF. To see the impact on three age groups, the data of total subjects was divided into three groups on the basis of their ages.

Table 4.9: Difference in PEF % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP during the three years of study (by using paired t-test)

	PEF	Difference	Lower	Upper	t
1st Year (2007)	BWBP-1 - DWBP-1	3.652	3.013	4.290	-17.274
	BWBP-1 - AWBP-1	0.527	0.428	0.626	10.556
	BWBP-1 - BRBP-1	-0.610	-0.778	-0.443	-7.239
	BWBP-1 - DRBP-1	5.244	4.992	5.495	41.366
	BWBP-1 - ARBP-1	0.136 ^a	-0.455	0.727	0.456
2nd Year (2008)	BWBP-2 - DWBP-2	3.938	3.511	4.364	18.327
	BWBP-2 - AWBP-2	-0.349 ^a	-0.969	0.270	-1.119
	BWBP-2 - BRBP-2	-0.482 ^a	-1.172	0.209	-1.385
	BWBP-2 - DRBP-2	8.486	7.824	9.149	25.409
	BWBP-2 - ARBP-2	4.309	3.586	5.033	11.821
3rd Year (2009)	BWBP-3 - DWBP-3	3.365	3.335	3.396	217.053
	BWBP-3 - AWBP-3	-1.310	-1.469	-1.151	-16.340
	BWBP-3 - BRBP-3	-3.031	-3.212	-2.851	-33.304
	BWBP-3 - DRBP-3	3.581	3.238	3.923	14.962
	BWBP-3 - ARBP-3	-1.560	-1.922	-1.198	-8.553

Significant up to $p < 0.05$, ^anon significant values

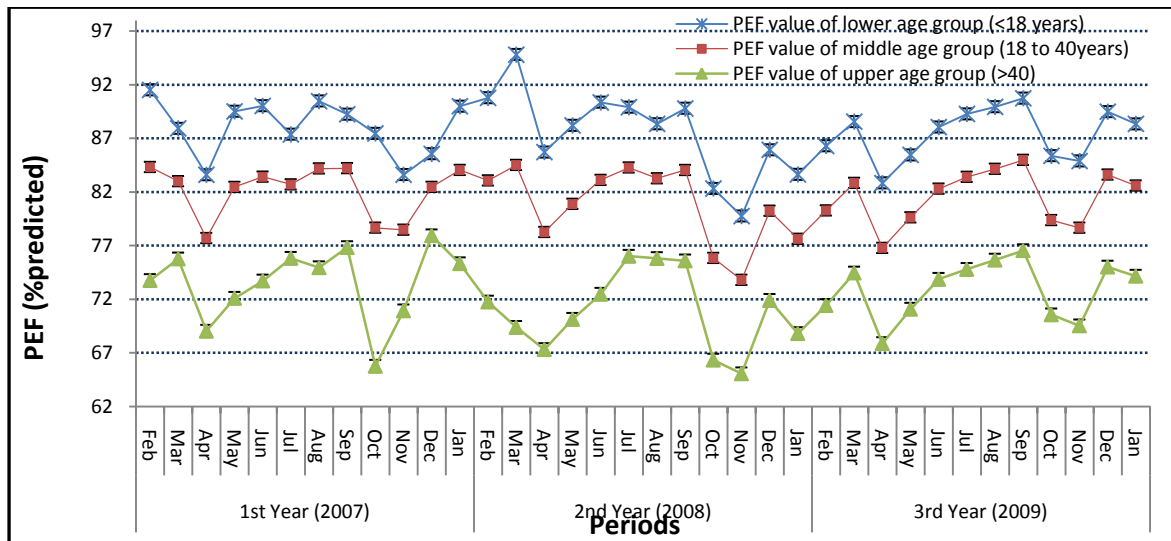


Figure 4.22: Monthly average variation of PEF (% predicted) with standard error for three different age groups

Figure 4.22 shows monthly average variation of PEF for three different age groups from February 2007 to January 2010. Graph shows that just like total monthly variation of PEF values, there is a decrease in the values of PEF during April-May and October-November months of all the study years for all three age groups. Trend of all the three age

groups seems to be similar with respect to different months and it is clear that ACRB have negative effect on the PEF of all age groups (Figure 4.22).

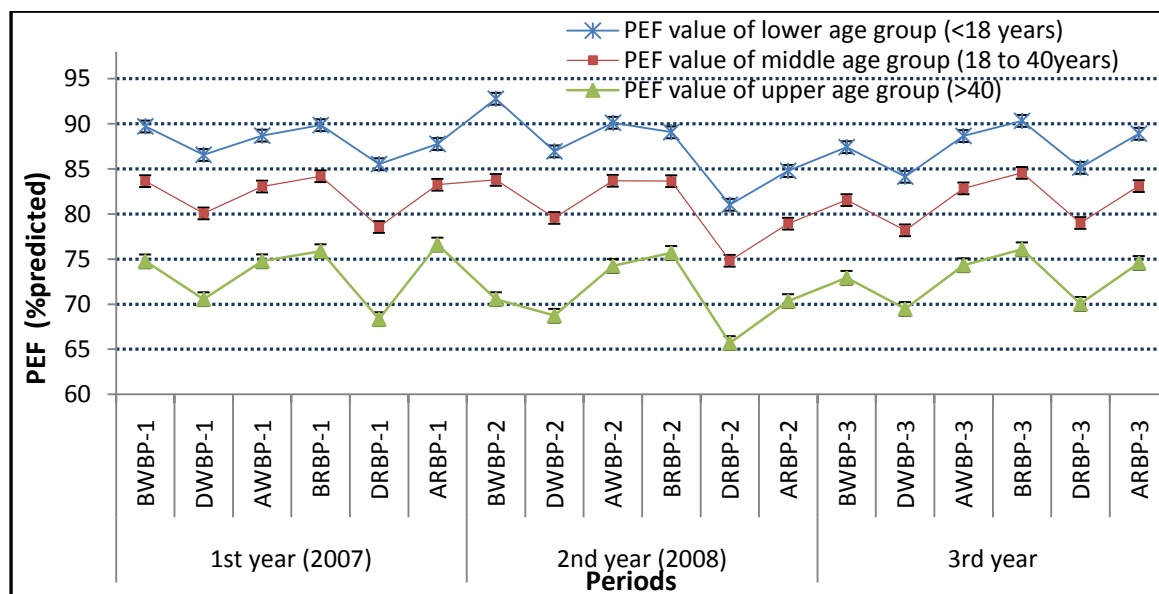


Figure 4.23: Periodical variation of PEF (% predicted) with standard error for three different age groups

Periodical variation of PEF for different age groups during the three study years from February 2007 to January 2010 is shown in Figure 4.23. There is an increase in the value of PEF after the burning periods of wheat crop residue which include AWBP, BRBP in 1st, 2nd and 3rd year. In rice cultivation period there is an increase in the value of PEF after the burning periods of rice crop residue which include ARBP in 1st year and ARBP, BWBP in 2nd year. All the three age groups show almost same trend of increase and decrease in the monthly average values of PEF before, during and after the burning period of ACRB.

Table 4.10 represents the difference in PEF % predicted values of lower, middle and upper age group subjects from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP during the three years of study. Almost same observations, as that of total subjects were found for three different age group (Table 4.8). Table shows that during the burning period, all the decrease were found to be statistically significant which shows the effect of the crop residue burning on different age groups. Negative significant value with ARBP-3 in all the age groups shows that value of PEF of all the age group recovers after the completion of burning period. Comparison of positive significant value of three age groups shows that the values are maximum in case of upper age group in comparison to lower and middle age groups which indicate that effect on upper age group is more in comparison to middle and lower age groups

subject. The results of PEF show that ACRB poses a temporary effect on the flow rate of different healthy subjects which recover after the completion of burning episode.

Table 4.10: Difference in PEF % predicted values of lower, middle and upper age group subjects from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	PEF	Difference		
		Lower age	Middle age	Upper age
1st Year (2007)	BWBP-1 - DWBP-1	3.160	3.579	4.195
	BWBP-1 - AWBP-1	1.012	0.598	-0.008 ^a
	BWBP-1 - BRBP-1	-0.143 ^a	-0.542	-1.127
	BWBP-1 - DRBP-1	4.184	5.088	6.415
	BWBP-1 - ARBP-1	1.944 ^a	0.402	-1.863
2nd Year (2008)	BWBP-2 - DWBP-2	5.836	4.217	1.840
	BWBP-2 - AWBP-2	2.663	0.094	-3.680
	BWBP-2 - BRBP-2	3.720	0.136	-5.127
	BWBP-2 - DRBP-2	11.757	8.967	4.871
	BWBP-2 - ARBP-2	8.015	4.854	0.213 ^a
3rd Year (2009)	BWBP-3 - DWBP-3	3.280	3.353	3.460
	BWBP-3 - AWBP-3	-1.235	-1.299	-1.393
	BWBP-3 - BRBP-3	-2.916	-3.014	-3.158
	BWBP-3 - DRBP-3	2.293	2.538	2.899
	BWBP-3 - ARBP-3	-1.485	-1.549	-1.644

Significant up to $p < 0.05$, ^a non-significant values

4.2.1.4 Force expiratory flow in 25 to 75% of FVC

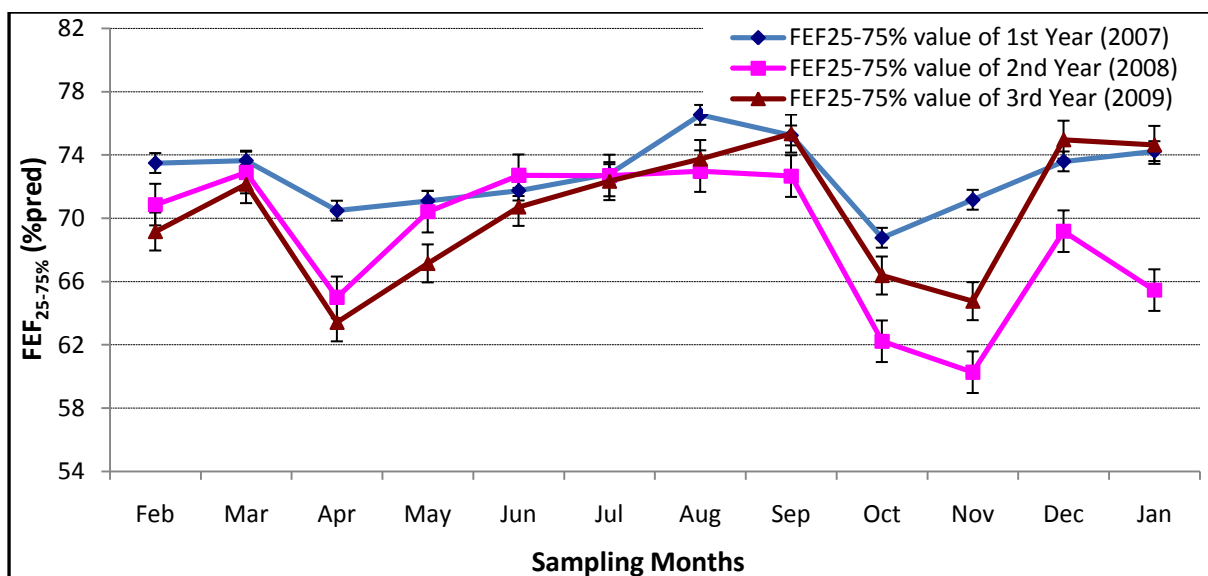


Figure 4.24: Monthly average value of FEF_{25-75%} (% predicted) with standard error

Figure 4.24 shows variation of monthly average values of Force Expiratory Flow in 25 to 75% of FVC ($FEF_{25-75\%}$) in different months from February 2007 to January 2010. Initial increase observed in the March of every year which further decreases in April. This decrease is less in April 2007 as compared to the decrease observed in the next years for April months of 2nd and 3rd year. The values increases gradually till August 2007 and up to June 2008 and up to September 2009, after this significant decrease observed in October month of each year which continue to decrease in 2nd and 3rd year whereas some recovery were observed in the November 2007 of 1st year. After November, value of $FEF_{25-7\%}$ increases up to December during every three years with further decrease observed in January of 2nd and 3rd year. Results (Figure 4.24) show that $FEF_{25-75\%}$ has significant lower values during April-May and October-November months in comparison to other months of every year that are active months for the crop residue burning of wheat and rice.

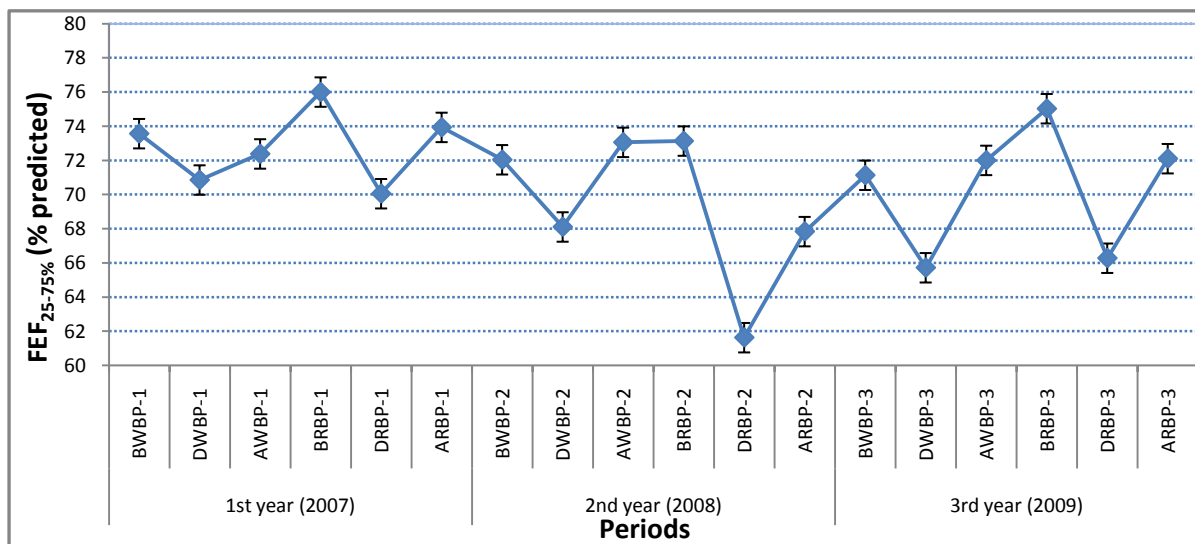


Figure 4.25 Periodical variation of $FEF_{25-75\%}$ (% predicted) with standard error

Figure 4.25 shows periodical variation of $FEF_{25-75\%}$ during three year of study from February 2007 to January 2010 with respect to the burning of the crop residues. Trend of increase and decrease was similar as in case of PEF which shows increase in the monthly average values of $FEF_{25-75\%}$ after the burning period of wheat and rice crop residue. Usual increase is observed after the burning periods which further increases till the next burning period of crop residue. In this case, similar to PEF recovery in the value of $FEF_{25-75\%}$ observed after the completion of burning episode. Paired t-test was used to calculate the difference between different periods to check the significance level of decrease observed in burning period of wheat and rice crop residue.

Table 4.11: Difference in FEF_{25-75%} % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	FEF _{25-75%}	Difference	Lower	Upper	t
1st Year (2007)	BWBP-1 - DWBP-1	2.714	2.392	3.035	16.765
	BWBP-1 - AWBP-1	1.187	1.083	1.291	22.689
	BWBP-1 - BRBP-1	-2.434	-3.141	-1.726	-6.827
	BWBP-1 - DRBP-1	3.514	2.999	4.029	13.548
	BWBP-1 - ARBP-1	-0.368 ^a	-0.974	0.239	-1.202
2nd Year (2008)	BWBP-2 - DWBP-2	3.933	3.413	4.452	15.033
	BWBP-2 - AWBP-2	-1.019	-1.394	-0.644	-5.387
	BWBP-2 - BRBP-2	-1.097	-1.401	-0.792	-7.146
	BWBP-2 - DRBP-2	10.413	9.918	10.908	41.734
	BWBP-2 - ARBP-2	4.204	3.527	4.881	12.320
3rd Year (2009)	BWBP-3 - DWBP-3	5.415	5.291	5.539	86.460
	BWBP-3 - AWBP-3	-0.869	-1.040	-0.698	-10.094
	BWBP-3 - BRBP-3	-3.893	-4.064	-3.723	-45.341
	BWBP-3 - DRBP-3	4.856	4.402	5.309	21.233
	BWBP-3 - ARBP-3	-0.969	-1.434	-0.504	-4.132

Significant up to $p < 0.05$, ^anon-significant values

Table 4.11 represents the difference in FEF_{25-75%} % predicted values of lower, middle and upper age group subjects from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP during the three years of study. Results are almost similar to PEF. Table 4.10 shows that during the burning period of wheat and rice crop residue, all the decrease were found to be statistically significant which shows the effect of the crop residue burning on the FEF_{25-75%} of total subjects. Negative values between the different periods give indication of recovery in the value of FEF_{25-75%} after the completion of burning period as in case of ARBP-3. Comparison of the positive significant value during wheat and rice crop residue burning shows that the values are higher during the burning period of rice crop residue as compared to wheat crop residue burning during the three years of study, which indicate that rice crop residue burning may have more effect on the FEF_{25-75%} of all the three age group subjects. In general, effect on upper age group subject is found to be large in comparison to lower and middle age group subjects.

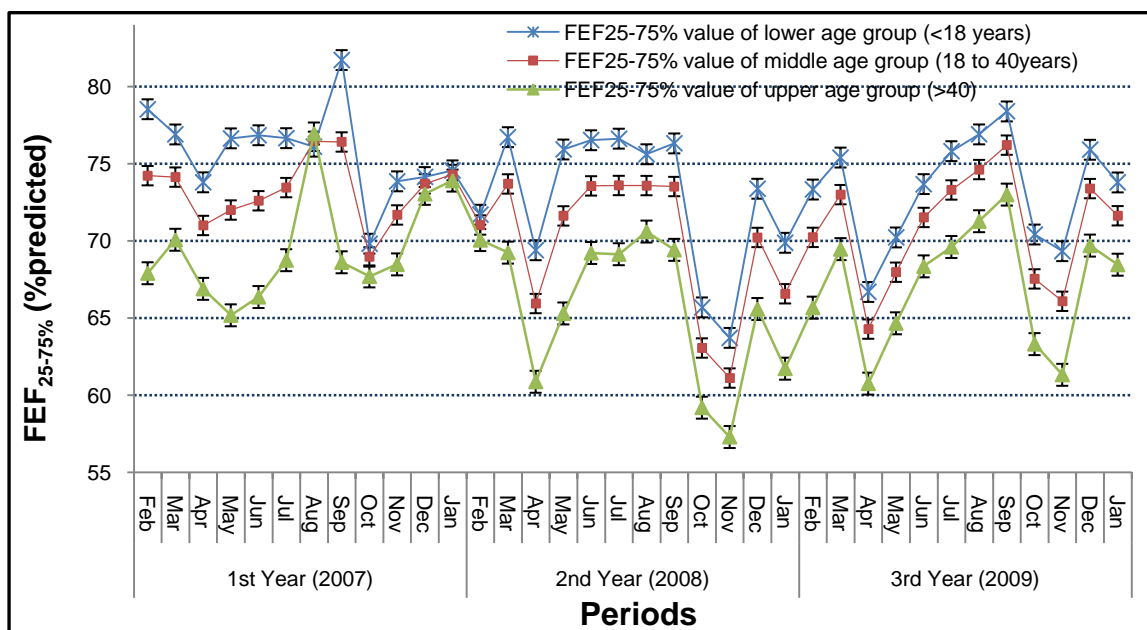


Figure 4.26: Monthly average variation of FEF_{25-75%} (% predicted) with standard error for three different age groups

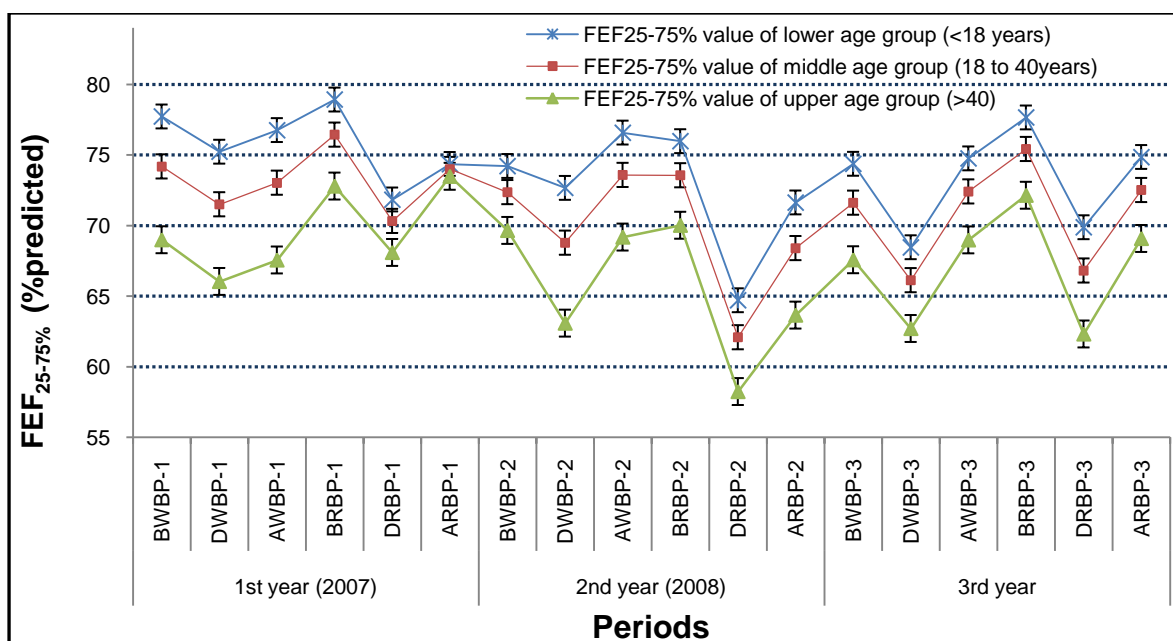


Figure 4.27: Periodical variation of FEF_{25-75%} (% predicted) with standard error for three different age groups

To check the effect of ACRB on FEF_{25-75%} value of different age groups, data of total subjects divided into three groups on the basis of their ages, and then monthly and periodical variation were calculated and shown graphically in Figure 4.26 and 4.27. Figure 4.26 shows monthly average variation of FEF_{25-75%} for three different age groups from February 2007 to

January 2010. Almost similar trend was observed in all the three age groups *i.e.*, remarkable decrease observed in the month of April-May and October- November of every age group. After the completion of burning episode, recovery observed in the case of FEF_{25-75%} seems to be more as compared to FVC and FEV₁

Periodical variations were calculated for FEF_{25-75%} with respect to age factor and shown in Figure 4.27. In case of other PFTs, decrease in the FEF_{25-75%} observed in all the age groups during April-May and October-November months, during exhaustive burning of wheat and rice crop residue Unlike FVC or FEV₁, FEF_{25-75%} shows recovery after the burning period which is same as that of PEF. Trend in the value of FEF_{25-75%} is same for all the age group. Differences between before burning period with other periods were calculated by using paired t- test to see the effect of ACRB on different age groups (Table 4.12).

Table 4.12: Difference in FEF_{25-75%} % predicted values of lower, middle and upper age groups from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	FEF _{25-75%}	Difference		
		Lower age	Middle age	Upper age
1st Year (2007)	BWBP-1 - DWBP-1	2.496	2.681	2.954
	BWBP-1 - AWBP-1	0.964	1.154	1.433
	BWBP-1 - BRBP-1	-1.197 ^a	-2.252	-3.801
	BWBP-1 - DRBP-1	5.878	3.862	0.900
	BWBP-1 - ARBP-1	3.363	0.181 ^a	-4.492
2nd Year (2008)	BWBP-2 - DWBP-2	1.550	3.582	6.566
	BWBP-2 - AWBP-2	-2.366	-1.217	0.470
	BWBP-2 - BRBP-2	-1.758	-1.194	-0.366
	BWBP-2 - DRBP-2	9.510	10.280	11.411
	BWBP-2 - ARBP-2	2.581	3.965	5.997
3rd Year (2009)	BWBP-3 - DWBP-3	5.909	5.488	4.868
	BWBP-3 - AWBP-3	-0.383	-0.798	-1.407
	BWBP-3 - BRBP-3	-3.283	-3.804	-4.568
	BWBP-3 - DRBP-3	4.493	4.802	5.257
	BWBP-3 - ARBP-3	-0.483 ^a	-0.897	-1.506

Significant up to $p < 0.05$, ^anon significant values

Table 4.12 shows difference in FEF_{25-75%} % predicted values of lower, middle and upper age group subjects from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP during the three years of study by using t-test. Trend of observation of the Table 4.11 is almost similar to observation seen in PEF (Table 4.8), difference is only in their numerical values.

Table 4.12 shows that during the burning period of wheat and rice crop residue, the decrease was found to be statistically significant which shows the affect of the crop residue burning on different age groups. Negative significant value of ARBP-3 in all the age groups shows that value of FEF_{25-75%} of all the age group were recover after the completion of burning period. Comparison of the positive significant value of three age groups, it is found that difference is more in upper age group in comparison to lower and middle age which shows that effect on upper age group is more in comparison to middle and lower age group. Comparison among wheat and rice give indication that effect of rice crop residue burning may have more effect on the PEF of three age groups. Results indicate that ACRB have temporary effect on the FEF_{25-75%} that recovers after the completion of burning episode.

4.2.1.5 Force expiratory flow 25% of FVC

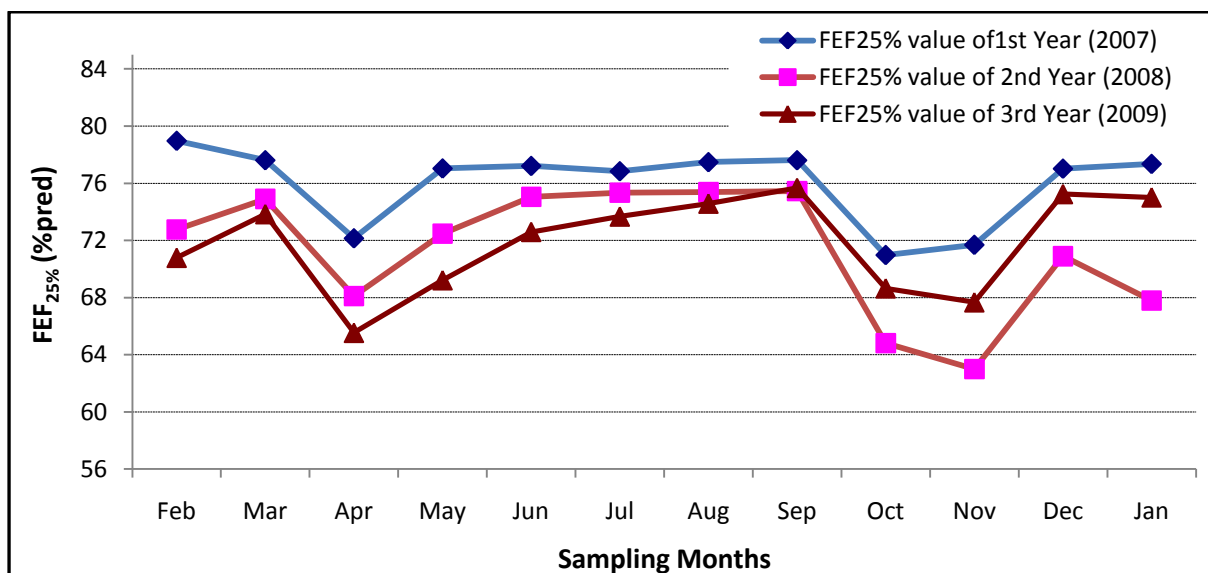


Figure 4.28: Monthly average value of FEF_{25%} with standard error

Figure 4.28 shows the monthly variation in the average values of FEF_{25%} from February 2007 to January 2010. Trends of FEF_{25%} are same as that of other PFTs with respect to April-May and October-November of the study years. Variation from February to March is similar to all the other parameter that decrease in first year and increase from February to march in the 2nd and 3rd year. Significant decrease observed in the month of April in all the three year which increases up to some extent in the May. After May again decrease was observed in October which continued during the month of November in the 2nd and 3rd year. After November, value increased up to December and January of 1st year, where as in 2nd and 3rd year value decrease from December to January.

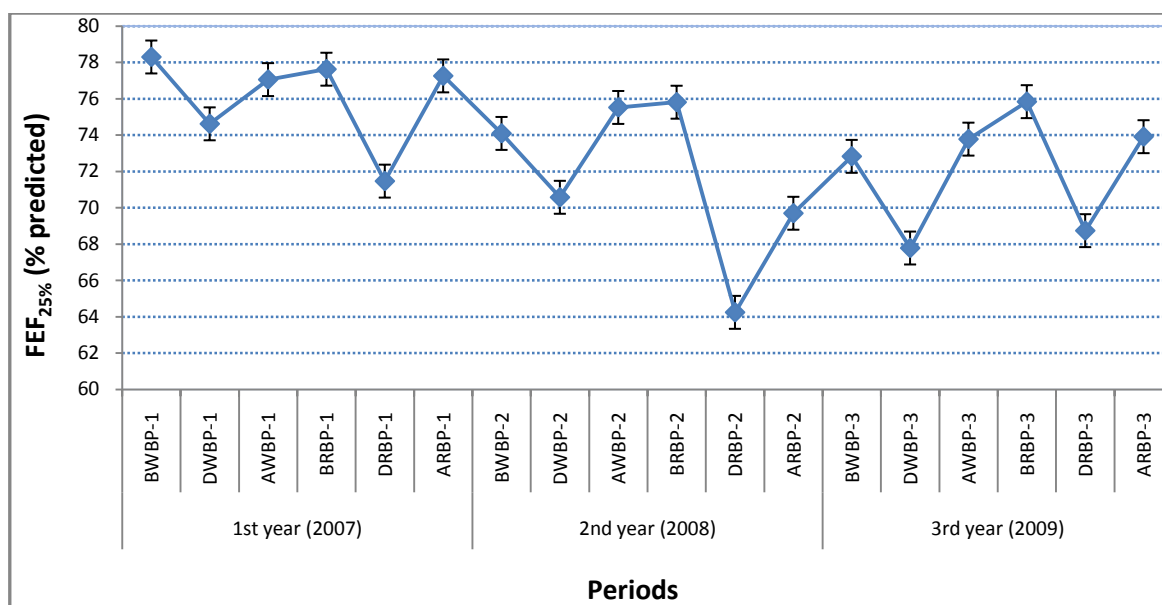


Figure 4.29: Periodical variation of FEF_{25%} (% predicted) with standard error

Periodical variation of FEF_{25%} clearly signifies the effect of burning on the FEF_{25%} of total subjects (Figure 4.29). General trend for values of FEF_{25%} for periodical variation is that there is increase in the values of FEF_{25%} after the burning periods like AWBP-1, ARBP-1, AWBP-2, ARBP-2, AWBP-3 and ARBP-3 which further increases till the next burning periods during 1st and 3rd year but there is decrease observed BWBP of 2nd year. Again in this case, same as that of PEF and FEF_{25-75%} value recover after the completion of burning episode.

To check the significance level of decrease observed in FEF_{25%} during the burning period, paired t-test was used to find the difference between different pairs. Table 4.13 represents the difference in FEF_{25%} % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP by using paired t-test. It is found that difference between the FEF_{25%} values of the first period (BWBP) with the burning periods of the same year are positively significant for DWBP and DRBP of all three studied years with maximum in case of DRBP (6.833, 9.848, 4.089) and then WRBP (3.680, 3.515 and 5.045) in 1st, 2nd and 3rd year. These results show that effect of rice crop residue burning is more on FEF_{25%} in comparison to wheat crop residue burning. Three significant negative value in 3rd year (-0.948, -3.011, -1.083) and two value in 2nd year (-1.429, -1.718) clearly shows that PEF value recover after the completion of burning episode and ACRB does pose only temporary effect on FEF_{25%}. Again data of total subject divided into three groups on the basis of their ages to see the effect on all age groups.

Table 4.13: Difference in FEF_{25%} % predicted values from BWBP to DWBP, AWBP, BRBP, DRBP and ARBP (by using paired t-test)

	FEF _{25%}	Difference	Lower	Upper	t
1st Year (2007)	BWBP-1 - DWBP-1	3.680	3.039	4.320	11.405
	BWBP-1 - AWBP-1	1.244	1.088	1.400	15.830
	BWBP-1 - BRBP-1	0.672	0.509	0.836	8.149
	BWBP-1 - DRBP-1	6.833	6.505	7.161	41.296
	BWBP-1 - ARBP-1	1.041	0.733	1.350	6.700
2nd Year (2008)	BWBP-2 - DWBP-2	3.515	3.269	3.761	28.396
	BWBP-2 - AWBP-2	-1.429	-1.693	-1.165	-10.729
	BWBP-2 - BRBP-2	-1.718	-1.996	-1.440	-12.278
	BWBP-2 - DRBP-2	9.848	9.355	10.342	39.581
	BWBP-2 - ARBP-2	4.394	3.816	4.972	15.094
3rd Year (2009)	BWBP-3 - DWBP-3	5.045	4.882	5.208	61.361
	BWBP-3 - AWBP-3	-0.948	-1.154	-0.742	-9.137
	BWBP-3 - BRBP-3	-3.011	-3.223	-2.799	-28.176
	BWBP-3 - DRBP-3	4.089	3.673	4.505	19.487
	BWBP-3 - ARBP-3	-1.083	-1.512	-0.653	-5.005

Significant up to $p < 0.05$

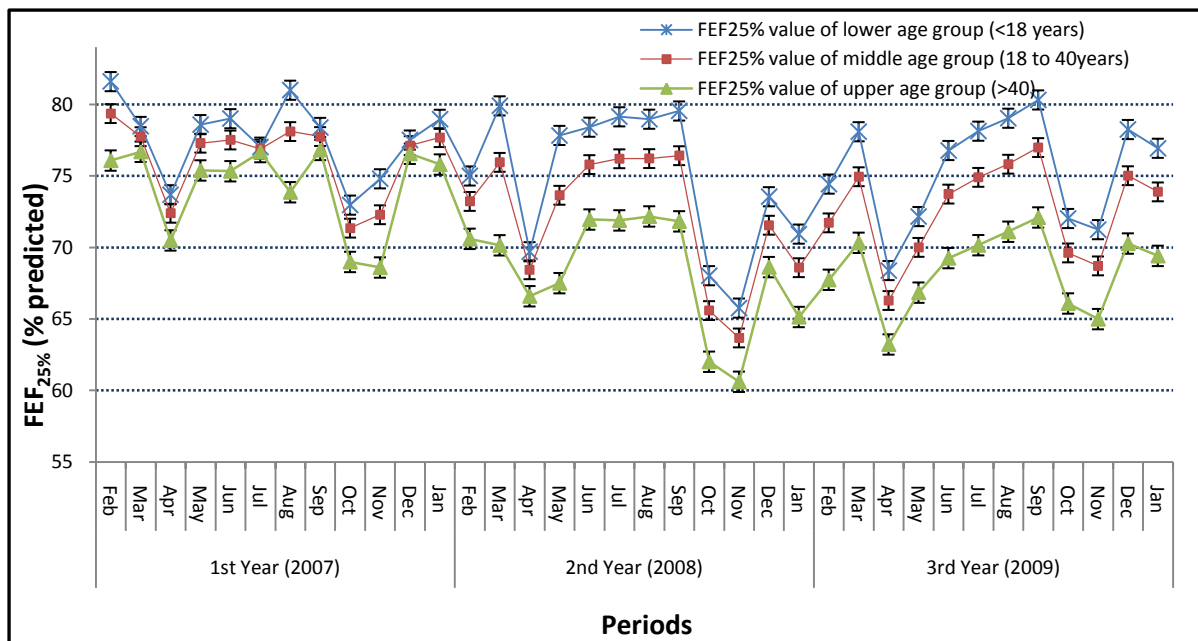


Figure 4.30: Monthly average variation of FEF_{25%} (% predicted) with standard error for three different age groups

Figure 4.30 show age wise variation of FEF_{25%} for different age groups of subjects. FEF_{25%} shows almost same trend as observed in case of FEF_{25-75%}. Variation in the value of FEF_{25%} is same for all the age group *i.e.*, remarkable decrease observed in the April-May and October-November months of all the three years that signifies the effect of ACRB on the FEF_{25%} of all age group subjects. In place of monthly average, periodical average value of FEF_{25%} were calculated on the basis of burning period of wheat and rice crop residue as shown in Figure 4.31.

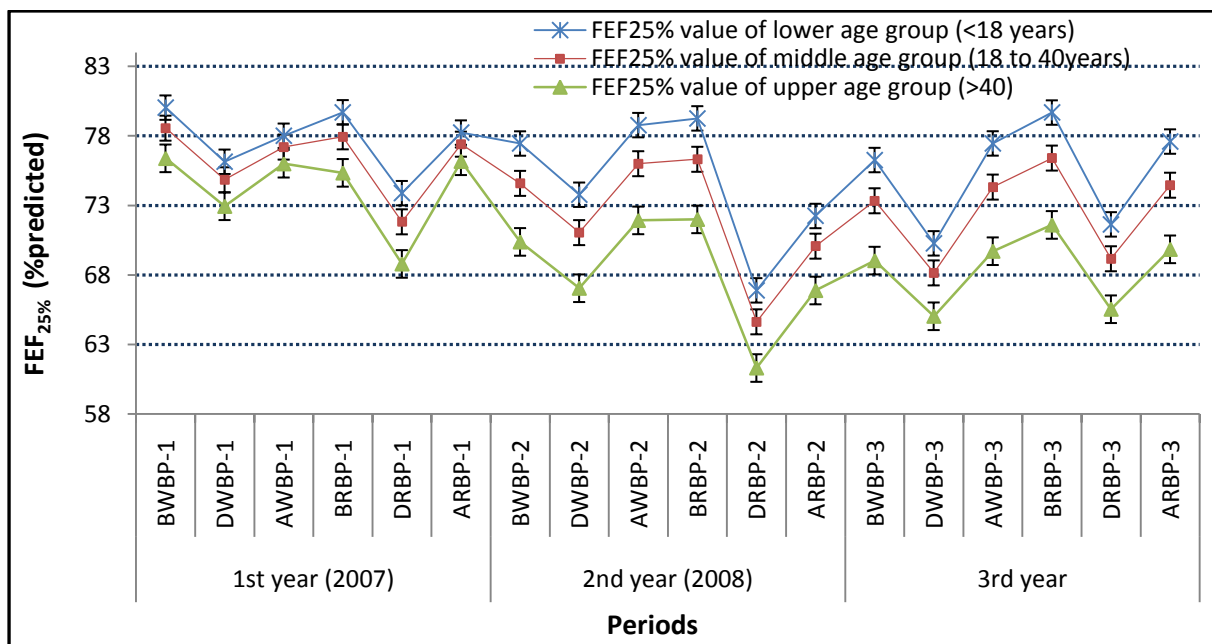


Figure 4.31: Periodical variation of FEF_{25%} (% predicted) with standard error for three different age groups

Figure 4.31 shows the periodical variation of FEF_{25%} for different age groups to understand the age wise effect of crop residue burning on different subjects. All the age groups shows almost same trend in the values of FEF_{25%}. All age group subjects show significant decrease during the burning period of wheat as well as rice crop residue and increase in the average values of FEF_{25%} is observed after the burning period of crop residue during all the three years of study. Sharp decrease observed in burning period seems to be more in DRBP as compared to decrease in DWBP. To check the significance level of decrease observed during the different period, paired t-test was used to calculate difference between different periods.

Table 4.14: Difference in FEF_{25%} % predicted values of lower, middle and upper age group subjects from BWBP to DWBP, AWBP, BRBP, DRBP and (by using paired t-test)

	FEF _{25%}	Difference		
		Lower age	Middle age	Upper age
1st Year (2007)	BWBP-1 - DWBP-1	3.892	3.711	3.445
	BWBP-1 - AWBP-1	2.022	1.359	0.385
	BWBP-1 - BRBP-1	0.336	0.623	1.044
	BWBP-1 - DRBP-1	6.148	6.732	7.591
	BWBP-1 - ARBP-1	1.793	1.152	0.210 ^a
2nd Year (2008)	BWBP-2 - DWBP-2	3.682	3.540	3.331
	BWBP-2 - AWBP-2	-1.323	-1.413	-1.546
	BWBP-2 - BRBP-2	-1.806	-1.731	-1.621
	BWBP-2 - DRBP-2	10.555	9.952	9.066
	BWBP-2 - ARBP-2	5.209	4.514	3.494
3rd Year (2009)	BWBP-3 - DWBP-3	5.988	5.184	4.002
	BWBP-3 - AWBP-3	-1.194	-0.984	-0.675
	BWBP-3 - BRBP-3	-3.414	-3.070	-2.565
	BWBP-3 - DRBP-3	4.625	4.168	3.496
	BWBP-3 - ARBP-3	-1.329	-1.119	-0.810

Significant up to $p < 0.05$, ^anon-significant values

Table 4.14 shows difference in FEF_{25%} % predicted values of lower, middle and upper age group subjects from BWBP to other five periods. Results are almost similar to the results observed in PEF and FEF_{25-75%} with only difference is in their numerical values. Decrease observed DRBP and DWBP were found to be statistically significant which shows the negative effect of the crop residue burning on different age groups. Negative significant value shows that FEF_{25%} was recover after the completion of burning period. Comparison of the positive significant value shows that difference are more in upper age group in comparison to lower and middle age which indicates that effect on upper age group is more in comparison to middle and lower age group.

4.2.2 Oxygen saturation level

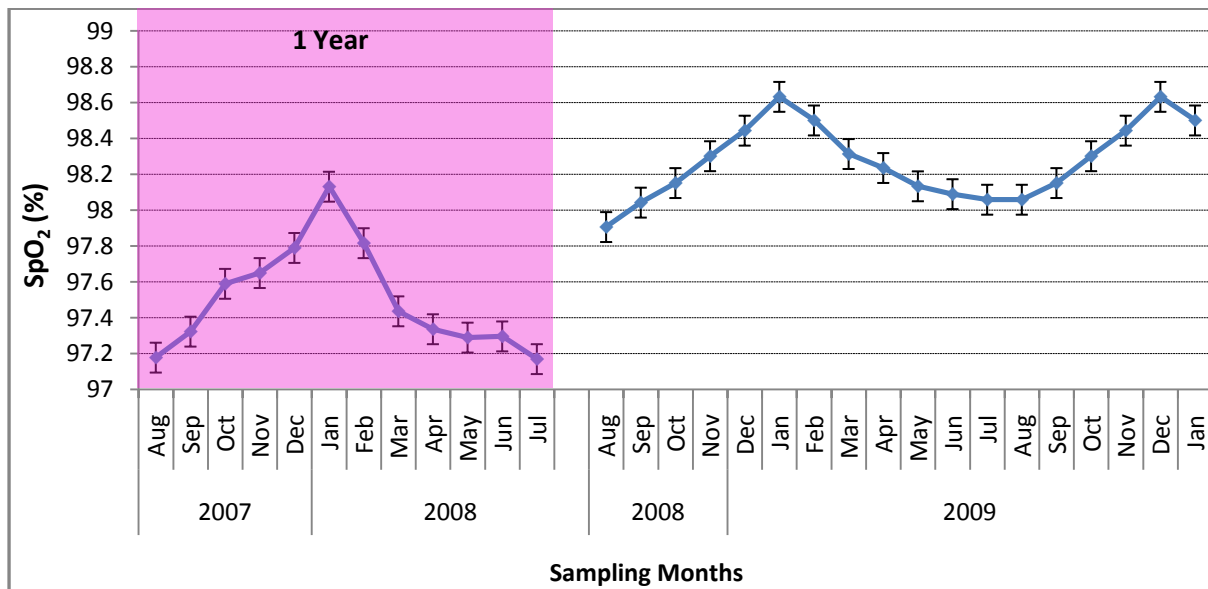


Figure 4.32: Monthly average value of SpO₂ with standard error

Figure 4.32 shows variation of monthly average values of Oxygen saturation level (SpO₂) from August 2007 to January 2010. Graph indicates that there is gradual increase in the value of SpO₂ from August 2007 to January 2008 which then gradually decreases till July 2008. There is no significant increase or decrease seen in the burning period months *i.e.*, during October-November or April-May. However, SpO₂ show gradual increase from August 2007 to January 2008 which starts decreasing after January up to July 2008. Initially up to July 2008, data was collected by the Pulse-oximeter (Oxivigil manufactured by Medline Equipment & Computer Systems (I) Ltd) which is correct up to unit place. It was presumed that there was some experimental error and later on new Pulse-oximeter (Dolphin Voyager Pulse-oximeter, Dolphin Medical, PTE. Ltd) with a higher level of accuracy up to one decimal place was used. Now, this pulse-oximeter shows same increase in the value of SpO₂ from August 2008 to January 2009 which, then gradually decreases till July 2009 but there after show increase in their value up to January 2010. Reoccurrence of same trend of variation with other instrument verified that there is no effect of ACRB on the SpO₂ of total subjects. There may be other factors which show their effect on SpO₂. If we consider the monthly variation with the seasonal variation the value of SpO₂ is usually higher in case of colder months. Although human beings are cold blooded animals which do not show physiological changes with external temperature but since measurement of SpO₂ involved the contact with the external surface of finger, it may affect the values of SpO₂. Oxygen affinity

for blood increases with decrease in temperature, if oxygen affinity increases means SpO₂ also increases. Above trend was more justified by studying the increase or decrease SpO₂ in level with different period.

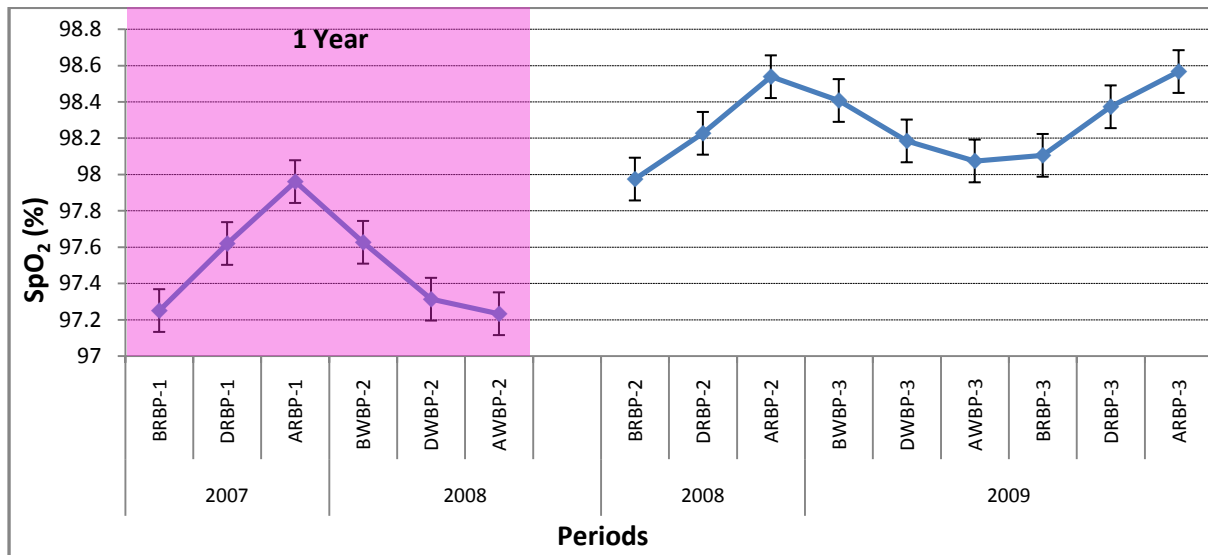


Figure 4.33: Periodical variation of SpO₂ with standard error during the study periods

Figure 4.33 shows periodical variation of SpO₂ during the study years. There was increase in the values of SpO₂ during burning period of rice which continues after the burning period of rice but the trend was reversed in case of burning period of wheat where the values shows decrease during the burning period. Since the result were not as expected and included some other factors other than burning hence the difference between different periods was not calculate. Figure 4.32 and 4.33 shows that SpO₂ of total subjects were not affected by ACRB. There is possibility that particular age group may have some effect of ACRB. To check this, total subjects divided into three groups on the basis of age as did in earlier case for various PFTs.

Figure 4.34 shows monthly average variation of SpO₂ for three different age groups from August 2007 to January 2010. Overall trend of SpO₂ is same as in case of monthly wise and period wise variation of total subjects. Trend of all age group is similar to each other and no effect of ACRB seen on the SpO₂ of any age group, as same increase is observed from August to January in all the studied years and in all the three age groups, which gradually decreases after January till July of all the studied years.

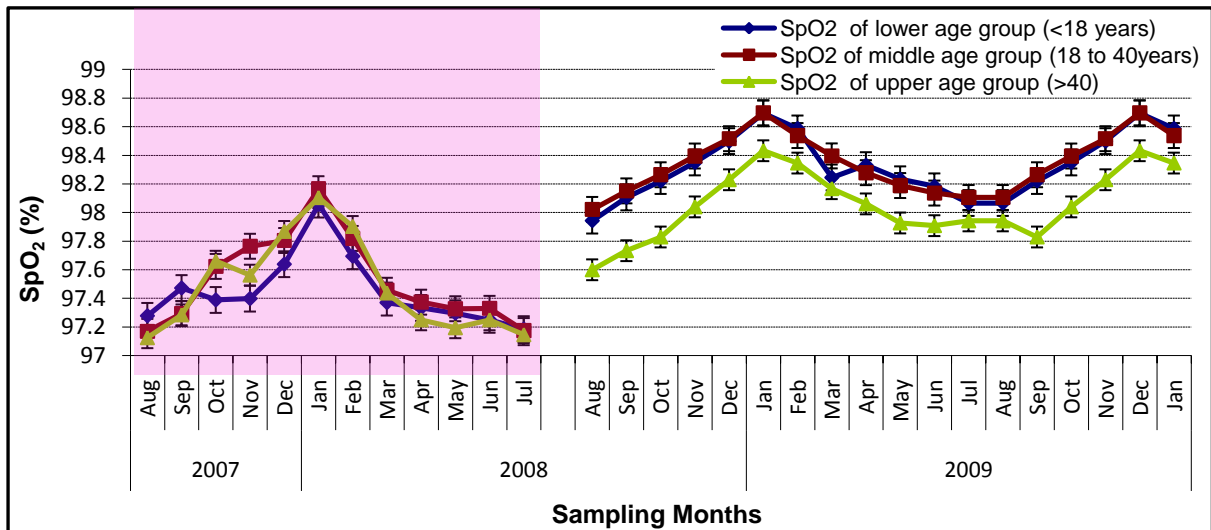


Figure 4.34: Monthly average variation of SpO₂ with standard error for three different age groups

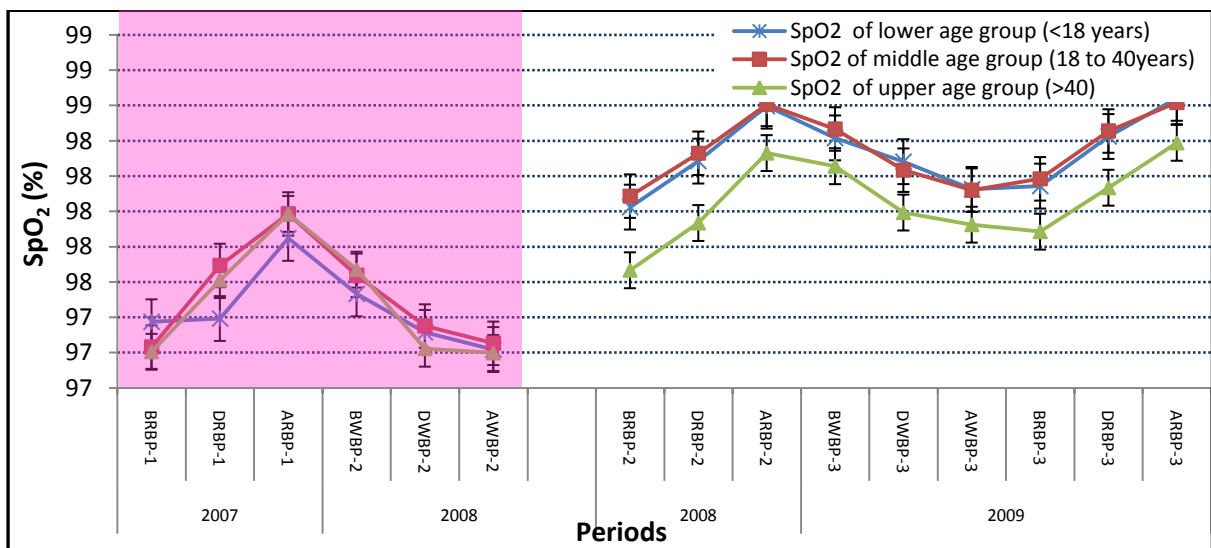


Figure 4.35: Periodical variation of SpO₂ with standard error for three different age groups

Figure 4.35 depicts the variation of SpO₂ during different burning periods for three different age groups. Variation shows that values increase during rice crop residue burning period whereas decreases during the wheat crop residue burning for all the age groups of the subjects. Since the results were not as per ACRB i.e., neither increasing nor increasing during the burning period of wheat and rice crop residue. Different results of SpO₂ clearly authenticate the there is no any effect of ACRB on the SpO₂ of any age group.

4.2.3 Comparison of rice and wheat crop residue burning

Comparison of difference between first period of each year with burning period of wheat and rice crop residue of different PFTs shows that decrease is more in case of rice crop residue burning, but it is not very much accurate to give any conclusion on the basis of these differences since difference of BRBP with DRBP of each year include some value/effect of wheat crop residue burning. To overcome this and evaluate the effect of wheat and rice crop residue burning and to strengthen the results, deference between before and during wheat crop residue burning is compared with the difference between before and during rice crop residue burning of each year.

Table 4.15: Difference in PFTs percent predicted values from BWBP to DWBP and BRBP to DRBP (by using paired t-test)

Year	PFTs (%pred)	Difference (%pred)	
		BWBP - DWBP	BRBP - DRBP
1st Year (2007)	FVC	4.203	6.255
	FEV ₁	4.328	7.294
	PEF	3.652	5.854
	FEF _{25-75%}	2.714	5.947
2nd Year (2008)	FVC	3.417	7.906
	FEV ₁	3.457	9.117
	PEF	3.938	8.968
	FEF _{25-75%}	3.933	11.509
3rd Year (2009)	FVC	5.029	7.461
	FEV ₁	5.927	9.390
	PEF	3.365	5.612
	FEF _{25-75%}	5.415	8.749

Differences are significant up to p-value 0.001; %pred: percentage of predicted value

Table 4.15 represent the difference in PFTs % predicted values from BWBP to DWBP, and BRBP to DRBP during the three years of study from February 2007 to January 2010. Comparison of differences of PFT values indicate that the effect of rice crop residue burning is more in comparison to wheat crop residue burning as the value of difference is found to be higher during rice crop residue burning period. It is confirmed from the results (Table 4.15) that ACRB have significant effect on the PFTs with higher contribution during rice crop residue burning.

4.2.4 Comparison between different PFTs

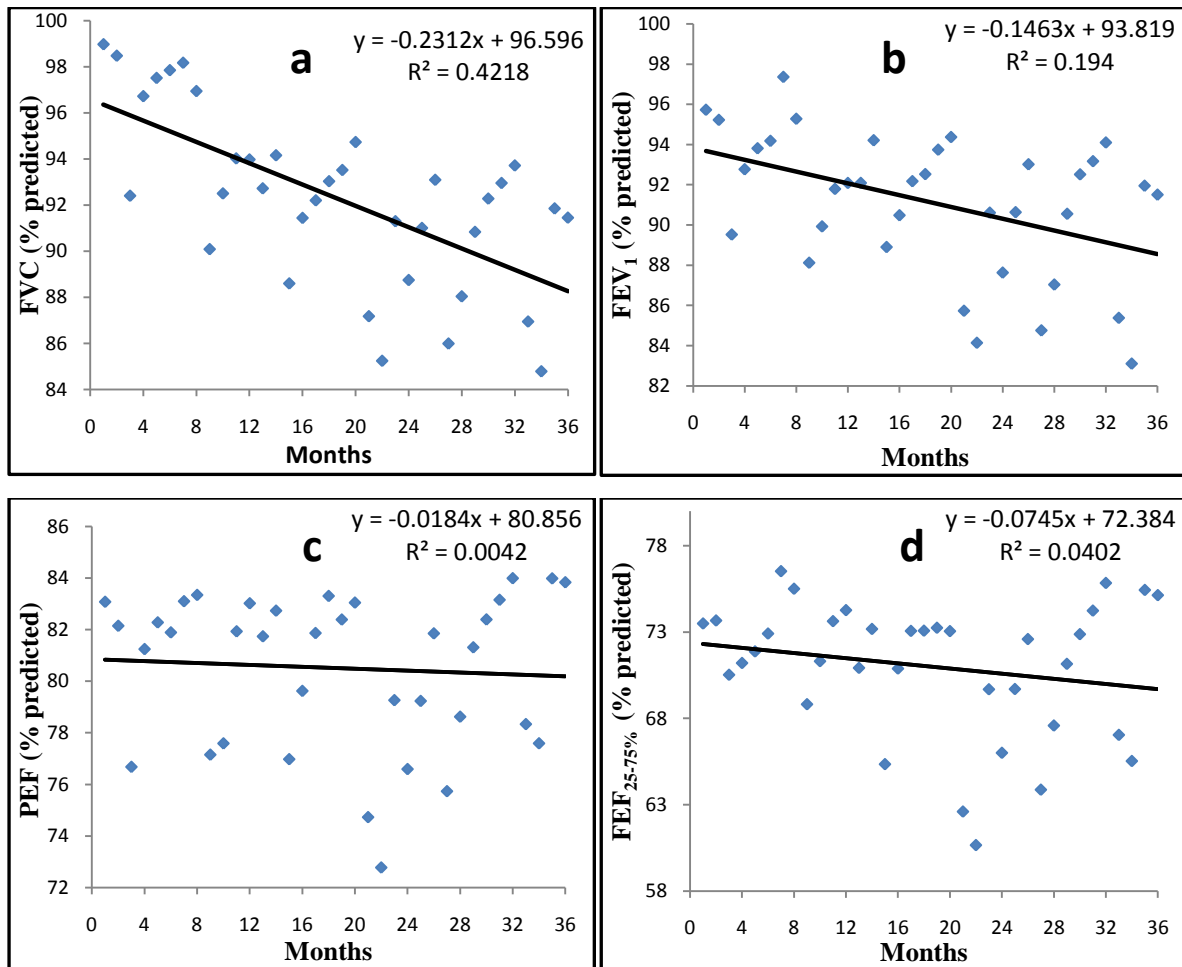


Figure 4.36: Linear regression among different PFTs; (a): FVC, (b): FEV₁, (c): PEF and (d) FEF_{25-75%} versus different months from February 2007 to January 2010

From the results of difference between periods and on the basis of monthly and periodical variations it is difficult to say about the actual order of the decrease in PFTs and it is not possible to give any conclusion/inference about the maximum affected PFTs. To measure the actual order of effect on the PFT values, linear regression between monthly average values of PFTs with time has been done and the trends with equation of line with R^2 value are shown in Figure 4.36. Regression results (Figure 4.24) of PFTs on time showing that with increase in one month, permanent decrease observed in the FVC, FEV₁, PEF and FEF_{25-75%} are 0.231%, 0.146%, 0.018% and 0.074% respectively. Maximum decreases were observed in the FVC followed by FEV₁, FEF_{25-75%} and minimum in PEF. Numerical value of change in the PFTs shows that decrease in the volume of air (FVC and FEV₁) per month is

more in comparison to the rate of air flow (PEF and FEF_{25-75%}). Hence, ACRB have more permanent effect on the FVC and FEV₁ as compared to PEF and FEF_{25-75%}.

4.2.5 Discussion

PFTs of healthy subjects are affected by ACRB episodes of wheat and rice crop residue during February 2007 to January 2010. It is found that the all pulmonary function values were low in the burning period as compared to values for pre and post periods. The possible factors affecting pulmonary functions include not only environmental factors but also individual attributes, such as gender, age and height (Knudson *et al.*, 1976, 1983; Stocks *et al.*, 1995). These factors were taken into consideration while assessing the effects of air pollution on pulmonary functions by measuring the data in % predicted value on the basis of E.R.S' 93 Knudson (Knudson *et al.*, 1983; Quanjer *et al.*, 1993) and adjusted according to age and height. PFTs investigation was carried out on same subjects throughout the study period and the data was recorded as per standard method prescribed by American Thoracic Society Standard (Miller *et al.*, 1995). Other possible factor for the decrease of PFTs could be the quality of the lung function maneuvers that might have decreased over time because of decreasing efforts of the subjects. If decreasing efforts was the only reason of declining in the value of PFTs, then the values should have continued to be decline after the wheat and rice crop residue burning period but results showed that all PFTs increased up to some extent after the wheat-rice crop residue burning. Variation in PFTs over the time was not influenced due to technical effects, because necessary cares like minimum of three maneuvers with less than 5% difference between two consecutive maneuvers were done during the whole study period of measurement. Decline in the PFTs were may be due to biological changes takes place in the respiratory tract due to increase in the concentration of particulate matter during ACRB. Exact mechanism was not understood but decrease in lung functions in relation with exposure to higher levels of particulate matter was due to the inflammation of lung or fibrous tissue formation in the alveolar septa and fibrotic lesion of the small airways.

Open residue burning (due to less than ideal combustion conditions) produces smoke which contains harmful gases and particulate matter. During breathing, when smoke reached inside the respiratory system it affects the proper functioning of respiratory system due to decrease in the available surface area for gas exchange. Smoke inhalation is an important cause of acute lung injuries as endothelial and epithelial barriers are affected. Smoke contains

large number of constituents which are toxic to bronchial mucosa and alveoli because of their physical and chemical properties or their ability to form free radicals. The smoke constituents when inhaled in sufficient concentration tend to produce acute neutrophilic airway inflammation associated with symptoms of cough, dyspnea and wheezing (Boopathy *et al.*, 2002) and hence pulmonary function affects. Due to all these physiological factors it is clearly observed that ACRB has potential effect on PFTs of healthy subjects. There was no direct effect seen on the SpO₂ of different age group as it was assumed that there were other factors also which shows their effect on SpO₂. If we consider the monthly variation with the seasonal variation, the value of SpO₂ is usually higher in case of colder months. Although human beings do not show physiological changes with external temperature but since measurement involved contact with the external surface it may affect the values of SpO₂.

Human body has its inborn ability to adjust itself according to the changing external environment. But with ageing like after the age of 40 years it loses its capability of self adjustment under stress condition which even increases more after the age of 60 years. In higher age group although body carry out normal physiological functions but as demand of body increases under stressed conditions, their body is unable to meet the demand of the body as their volume of air inspired or expired as well the air flow decreases. Thus it has direct effect on the PFTs of the individual but does not affect the oxygen saturation level which involves maximal activity rather than normal breathing.

PFTs is a forced process as it involves volumes and flow rates measured by asking the person to perform or breathe forcefully and maximally, on the other hand SpO₂ is a normal process measured under normal respiration. Forced expiration can be effected with the increase in the concentration of pollutants thus effecting the PFTs but SpO₂ being a normal process remains unaffected. Example; even a single kidney can be sufficient and can excrete various normal function except hard work or exercise, 10% of liver can keep the normal functioning of body. Moreover, the increase in concentration of pollutants can affect forced expiration but this increase is not to an extent that it enters the blood and affects the oxygen saturation level which remains normal under all circumstances. Also PFTs are observed to be decrease with age because with age a person becomes more susceptible to stressful conditions like exercise *etc* but this decrease in pulmonary function in which peak capacity is measured does not affect oxygen saturation of blood under normal circumstances.

Findings of the present study also show that effect of Rice Crop Residue Burning (RCRB) is more in comparison to Wheat Crop Residue Burning (WCRB). The probable reason may be higher concentrations of different size particulate matter in case of RCRB with respect to WCRB. As RCRB occurred in the months of winter season (October-November), hence effects are expected to be more pronounced during this period. In winter season due to lowering of depletion layer, the concentrations of pollutant are dense so more effect was seen on the subjects. Along with higher concentration during RCRB period, subjects also inhale colder air during RCRB period in comparison to WCRB period. Two factors: colder air and higher concentration during RCRB effect concurrently on the same subjects poses more effect of RCRB in comparison to WCRB.

In previous studies inhalation of cold air has been cited as potential risk factor (Rode *et al.*, 1994). In healthy subjects due to exposure to cold air, some of the normal physical responses, such as a runny nose, are very apparent, but changes in airway physiology have also been detected. These include constriction of the airways (Fontanari *et al.*, 1996) and an increased sensitivity to irritants (Amirav *et al.*, 2002). A high rate of breathing in a cold environment may also accentuate the risk of sustaining permanent lung damage. In one of the Canadian arctic study show the premature lung aging due to deep inhalation of cold air (Schaefer *et al.*, 1980). Cold air triggers these asthmatic attacks. Exact mechanism is not clear but lot of literature supports the effect of cold air on lungs. It is well known that cold air can trigger breathing problems in those already susceptible, and in fact is used as a challenge for assessing exercise-induced asthma (Sinclair *et al.*, 1995; Steinbrugger *et al.*, 1990; Nicoli *et al.*, 1993). However, still much argument to understand and support to why this occurs. Cooling of the airways may directly initiate broncho-constriction (Kaminsky *et al.*, 2007; Thorpe *et al.*, 1997) although chilling of the nasal cavity (Fontanari *et al.*, 1996), that further support to reduce various PFTs. Thus, the results of present study is in accordance with previous studies and supports that effect of RCRB is more due to the combine effect of low temperature and higher concentration of particulate matter during the rice crop residue burning in winter season.

Effects on higher age group people were also found to be high in comparison to middle and lower age group. This is because with ageing like after the age of 40 years it loses its capability of self adjustment under stress condition which even increases more with further increase in the age. In higher age group although body carry out normal physiological

functions but as demand of body increases under stressed conditions, their body is unable to meet the demand of the body as their volume of air inspired or expired as well the air flow decreases. The reason may be because with age immune system and defence mechanism of adult are weak due to which it is more sensitive to external environmental. As their defence mechanism does not fight much against the pollutant hence during the exposure of different pollutant during burning it show more decrease in their PFTs.

4.3 Contribution of different size particulate matter on PFTs

In this part, effect of different sizes particulate matter (SPM, PM₁₀ and PM_{2.5}) during ACRB on the PFTs (FVC, FEV₁, PEF, FEF_{25-75%} and FEF_{25%}) of healthy subject has been analysed by using linear regression technique.

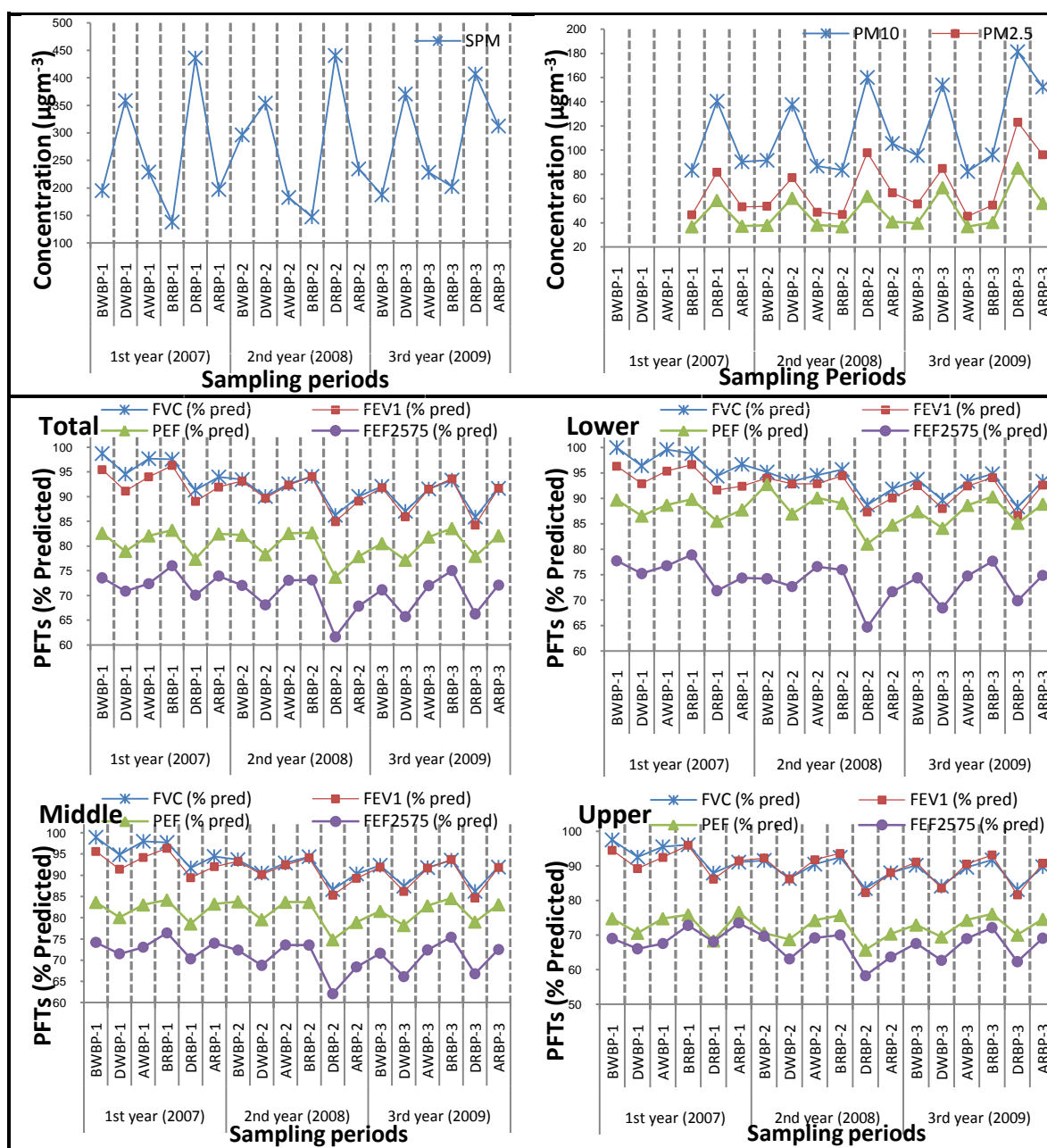


Figure 4.37: Periodical variation of environmental parameters (SPM, PM₁₀, PM_{2.5}, PM_{10-2.5}) and PFTs (% predicted) like FVC, FEV₁, PEF and FEF_{25-75%} of total, lower, middle and upper age group subjects

Figure 4.37 represents the combined periodical variation of different size particulate matter and PFTs of total and different age groups subjects from February 2007 to January 2010. Different PFTs and environmental parameters have opposite trend during the burning period of wheat and rice crop residue burning (Figure 4.37), *i.e.*, there may be a negative relation between them. To check the significance of meteorological parameters on PFTs, correlations with meteorological parameters were also calculated.

4.3.1 Correlation results

Table 4.16: Correlation matrix between environmental parameters and PFTs of total subjects

	SPM	PM ₁₀	PM _{2.5}	Temp	Pressure	Humidity	FVC	FEV ₁	PEF	FEF _{25-75%}	FEF _{25%}
SPM	1										
PM ₁₀	0.827	1									
PM _{2.5}	0.762	0.976	1								
Temp	-0.05 ^a	-0.21 ^a	-0.29 ^a	1							
Pressure	-0.49 ^a	-0.30 ^a	-0.20 ^a	-0.34 ^a	1						
Humidity	0.26 ^a	0.40 ^a	0.46 ^a	-0.952	0.21 ^a	1					
FVC	-0.635	-0.815	-0.782	0.13 ^a	0.21 ^a	-0.27 ^a	1				
FEV ₁	-0.749	-0.838	-0.806	0.14 ^a	0.32 ^a	-0.31 ^a	0.940	1			
PEF	-0.715	-0.661	-0.592	0.04 ^a	0.35 ^a	-0.24 ^a	0.746	0.858	1		
FEF _{25-75%}	-0.672	-0.664	-0.608	0.03 ^a	0.33 ^a	-0.21 ^a	0.806	0.890	0.935	1	
FEF _{25%}	-0.698	-0.756	-0.695	0.12 ^a	0.23 ^a	-0.29 ^a	0.923	0.922	0.901	0.926	1

Data are significant up to $p < 0.001$; ^anon-significant value

Table 4.16 represents correlation matrix which describes the correlation among 11 variables. It is a square 11 x 11 matrix with the (ij)th element equal to the correlation coefficient r_{ij} between the i^{th} and the j^{th} variable. The diagonal elements (correlations of variables with themselves) are always equal to 1.00. Table 4.16 represents the Pearson correlation (2-tailed) between the monthly variations of different pollutants (SPM, PM₁₀ and PM_{2.5}), meteorological parameters (temperature, humidity and pressure) and PFTs (FVC, FEV₁, PEF, FEF_{25-75%}, FEF_{25%} and FEF_{50%}). The correlations between different PFTs are found significantly positive, which indicates the same trends of all PFTs *i.e.* with the increase of one PFT other PFTs also increased. Different size particulate matter (SPM, PM₁₀, PM_{2.5}) also have significant ($p < 0.001$) positive correlation among themselves, which indicates that all the PFTs have same trend. Metrological parameters have non-significant correlation among themselves except temperature and humidity. Significant negative correlation ($r = -0.952$; $p < 0.001$) between temperature and humidity indicate that the trend of

temperature is opposite to humidity. Meteorological parameter does not show any significant ($p > 0.05$) correlation with PFTs and different size particulate matter. Correlation between PFTs with different size particulate matters (SPM, PM_{10} and $PM_{2.5}$) were found to be significantly negative ($P < 0.001$). Negative correlation between the PFTs and different size particulate matter prove that with increase in the concentration of different size particulate matter there is a decrease in PFTs parameter. Linear regression technique was used to measure the contribution of different size particulate matter on the PFTs after demonstrating the negative significant relation between them by the preliminary test of correlation (r value) and significant level (p value).

4.3.2 Relationship between PFTs with different size particulate matter

Table 4.17: Change in PFTs with $10 \mu\text{gm}^{-3}$ increase in different size particulate matter (SPM, PM_{10} and $PM_{2.5}$)

Particulate Matter	PFTs (% pred)	Changes	(95% CI)		p value
			(Lower)	(Upper)	
SPM (Increment $10 \mu\text{gm}^{-3}$)	FVC	-0.221	-0.303	-0.140	<0.001
	FEV ₁	-0.254	-0.336	-0.171	<0.001
	PEF	-0.207	-0.287	-0.127	<0.001
	FEF _{25-75%}	-0.267	-0.380	-0.154	<0.001
	FEF _{25%}	-0.270	-0.365	-0.174	<0.001
PM_{10} (Increment $10 \mu\text{gm}^{-3}$)	FVC	-0.777	-0.991	-0.563	<0.001
	FEV ₁	-0.866	-1.084	-0.647	<0.001
	PEF	-0.603	-0.868	-0.338	<0.001
	FEF _{25-75%}	-0.820	-1.177	-0.462	<0.001
	FEF _{25%}	-0.863	-1.153	-0.574	<0.001
$PM_{2.5}$ (Increment $10 \mu\text{gm}^{-3}$)	FVC	-1.054	-1.379	-0.728	<0.001
	FEV ₁	-1.178	-1.513	-0.843	<0.001
	PEF	-0.763	-1.166	-0.361	<0.001
	FEF _{25-75%}	-1.052	-1.599	-0.525	<0.001
	FEF _{25%}	-0.863	-1.153	-0.574	<0.001

Table 4.17 represents the change in the PFTs values of total subjects with respect to the $10 \mu\text{gm}^{-3}$ increment of each type of particulate matter. Association between different size particulate matter and PFTs were calculated between their monthly average by using linear regression and taking PFTs as dependent and particulate matter as independent variable. Increase in the concentration of SPM, PM_{10} and $\text{PM}_{2.5}$ by $10 \mu\text{gm}^{-3}$ was related significantly ($p < 0.001$) to all PFTs. Negative value of change shows that with the increase in the concentration of particulate matter, there is significant decrease in the value of all PFTs. However, difference observed only in the numerical value of change in PFTs with the increase in $10 \mu\text{gm}^{-3}$ of different size particulate matter. Concentration of particulate matter generally increases in the burning period of either wheat or rice crop residue, which shows that with the increase in the concentration of different size particulate matter during burning episode PFT values of subjects decreases.

Results shows that, increase in $\text{PM}_{2.5}$ by $10 \mu\text{gm}^{-3}$ decreases the FEV_1 up to 1.178 %, FVC upto 1.054 %, $\text{FEF}_{25-75\%}$ up to 1.062 %, $\text{FEF}_{75\%}$ up to 0.863 %, PEF up to 0.763 % and decrease up to 0.866 %, 0.777 %, 0.820 %, 0.863 %, 0.603 % with PM_{10} and minimum up to 0.254 %, 0.221 %, 0.267 %, 0.270 %, 0.207 % with SPM in FEV_1 , FVC, $\text{FEF}_{25-75\%}$, $\text{FEF}_{25\%}$ and PEF respectively. Results show that decrease in values of PFTs resulting from increase in pollutant levels of SPM, PM_{10} and $\text{PM}_{2.5}$ indicates the following order in all PFTs; $\text{PM}_{2.5} > \text{PM}_{10} > \text{SPM}$

It confirms from the results that $\text{PM}_{2.5}$ shows a maximum decrease in the values of PFTs with minimum contribution shows by SPM.

A close look on the result of Table 4.17 shows that for;

- Increase in SPM, trend of decrease in PFTs are $\text{FEF}_{25-75\%} > \text{FEF}_{25\%} > \text{FEV}_1 > \text{FVC} > \text{PEF}$
- Increase in PM_{10} , trend of decrease in PFTs are $\text{FEV}_1 > \text{FEF}_{25\%} > \text{FEF}_{25-75\%} > \text{FVC} > \text{PEF}$
- Increase in $\text{PM}_{2.5}$, trend of decrease in PFTs are $\text{FEV}_1 > \text{FVC} > \text{FEF}_{25-75\%} > \text{FEF}_{25\%} > \text{PEF}$

The trend of PFTs is not same for different size particulate matter, hence on the basis of these observations it can be concluded that PEF have minimum effect among all other PFTs.

Different size particulate matters are significantly associated with the PFTs of total subjects with minimum contribution with SPM (Table 4.17). Total subjects were divided in to three age groups; lower (< 18 years), middle (18 to 40 years) and upper age group (> 40

years) on the basis of their ages to see the effect of PM due to ACRB on the different age groups. Again the correlation between PFTs of different age groups and different sizes PM were calculated and then linear regression is used to calculate the association between PFTs and different size particulate matter.

4.3.3 Relationship between PFTs of different age groups with different sizes of PM

Table 4.18: Correlation matrix between environmental parameters and PFTs of (a) lower; (b) middle; (c) upper age group subjects

(a)											
	SPM	PM ₁₀	PM _{2.5}	Temp	Pressure	Humidity	FVC	FEV ₁	PEF	FEF _{25-75%}	FEF _{25%}
SPM	1.000										
PM ₁₀	0.827	1.000									
PM _{2.5}	0.762	0.976	1.000								
Temp	-0.05a	-0.21a	-0.29	1.000							
Pressure	-0.49a	-0.30a	-0.20a	-0.34a	1.000						
Humidity	0.26a	0.40a	0.46a	-0.952	0.210	1.000					
FVC	-0.632	-0.760	-0.720	0.02a	0.24a	-0.17a	1.000				
FEV ₁	-0.691	-0.718	-0.686	0.15a	0.30a	-0.30a	0.891	1.000			
PEF	-0.653	-0.679	-0.592	-0.01a	0.33a	-0.16a	0.751	0.828	1.000		
FEF _{25-75%}	-0.703	-0.771	-0.722	0.18a	0.24a	-0.32a	0.900	0.847	0.727	1.000	
FEF _{25%}	-0.682	-0.751	-0.695	0.12a	0.26a	-0.28a	0.916	0.846	0.791	0.960	1.000

(b)											
	SPM	PM ₁₀	PM _{2.5}	Temp	Pressure	Humidity	FVC	FEV ₁	PEF	FEF _{25-75%}	FEF _{25%}
SPM	1.00										
PM ₁₀	0.827	1.00									
PM _{2.5}	0.762	0.976	1.00								
Temp	-0.05 ^a	-0.21a	-0.29 ^a	1.00							
Pressure	-0.49 ^a	-0.30 ^a	-0.20 ^a	-0.34a	1.00						
Humidity	0.26 ^a	0.40 ^a	0.46 ^a	-0.952	0.210	1.00					
FVC	-0.648	-0.790	-0.758	0.19 ^a	0.24 ^a	-0.32 ^a	1.00				
FEV ₁	-0.726	-0.837	-0.811	0.15 ^a	0.33 ^a	-0.31 ^a	0.927	1.00			
PEF	-0.630	-0.717	-0.669	0.10 ^a	0.27 ^a	-0.31 ^a	0.713	0.824	1.00		
FEF _{25-75%}	-0.599	-0.674	-0.626	0.10 ^a	0.24 ^a	-0.26 ^a	0.767	0.830	0.852	1.00	
FEF _{25%}	-0.609	-0.703	-0.648	0.10 ^a	0.16 ^a	-0.26 ^a	0.877	0.863	0.848	0.927	1.00

(c)											
	SPM	PM ₁₀	PM _{2.5}	Temp	Pressure	Humidity	FVC	FEV ₁	PEF	FEF _{25-75%}	FEF _{25%}
SPM	1										
PM ₁₀	0.827	1.000									
PM _{2.5}	0.762	0.976	1.000								
Temp	-0.05 ^a	-0.21 ^a	-0.29 ^a	1.000							
Pressure	-0.49 ^a	-0.30 ^a	-0.20 ^a	-0.34a	1.000						
Humidity	0.26 ^a	0.40 ^a	0.46 ^a	-0.952	0.21 ^a	1.000					
FVC	-0.638	-0.834	-0.797	0.11 ^a	0.22 ^a	-0.251	1.000				
FEV ₁	-0.736	-0.863	-0.831	0.11 ^a	0.29 ^a	-0.287	0.968	1.000			
PEF	-0.706	-0.636	-0.554	0.14 ^a	0.26a	-0.285	0.784	0.801	1.000		
FEF _{25-75%}	-0.684	-0.790	-0.746	0.07 ^a	0.25 ^a	-0.235	0.886	0.929	0.835	1.000	
FEF _{25%}	-0.653	-0.706	-0.636	0.12 ^a	0.17 ^a	-0.258	0.902	0.876	0.936	0.871	1.000

Data are significant up to $p < 0.001$; ^anon-significant value

Table 4.18 represents correlation matrix between environmental parameters and PFTs of (a) lower; (b) middle; (c) upper age group subjects. Negative significant ($P < 0.001$) correlation is found between different size particulate matters with PFTs of all three age groups. It was found that correlation between different sizes particulate matter and PFTs was stronger in case of upper and lower age groups as compared to middle age group. No significant correlation observed between various metrological parameters with any age group's PFTs. Significant correlation was observed between particulate matter of different sizes and PFTs of three age group subjects. Further, the association between particulate matter and PFTs of different age group subject was calculated with linear regression technique by taking PFTs as dependent and different size particulate matter as independent variable.

Table 4.19: Change in PFTs of lower, middle and upper age group with $10 \mu\text{gm}^{-3}$ increase in different size particulate matter (SPM, PM_{10} and $\text{PM}_{2.5}$)

Particulate matter	PFTs (% pred)	Changes			P value
		Lower (<18 year)	Middle (18 to 40 year)	Upper (>40 year)	
SPM (Increment $10 \mu\text{gm}^{-3}$)	FVC	-0.289	-0.156	-0.319	<0.001
	FEV ₁	-0.285	-0.189	-0.374	<0.001
	PEF	-0.341	-0.143	-0.302	<0.001
	FEF _{25-75%}	-0.535	-0.173	-0.377	<0.001
	FEF _{25%}	-0.413	-0.199	-0.309	<0.001
PM_{10} (Increment $10 \mu\text{gm}^{-3}$)	FVC	-1.039	-0.525	-1.137	<0.001
	FEV ₁	-0.929	-0.670	-1.294	<0.001
	PEF	-1.063	-0.511	-0.794	<0.001
	FEF _{25-75%}	-1.700	-0.611	-1.305	<0.001
	FEF _{25%}	-1.328	-0.887	-0.903	<0.001
$\text{PM}_{2.5}$ (Increment $10 \mu\text{gm}^{-3}$)	FVC	-1.393	-0.712	-1.400	<0.001
	FEV ₁	-1.255	-0.918	-1.650	<0.001
	PEF	-1.311	-0.674	-0.824	<0.001
	FEF _{25-75%}	-2.252	-0.803	-1.615	<0.001
	FEF _{25%}	-1.328	-0.687	-0.920	<0.001

Table 4.19 represents the change in the PFTs with respect to the $10 \mu\text{gm}^{-3}$ increment of each type of particulate matter among different age groups. Increase in the concentration of SPM, PM_{10} and $\text{PM}_{2.5}$ by $10 \mu\text{gm}^{-3}$ was related significantly ($p < 0.001$) to all PFTs and negative value shows that with the increase in the concentration of particulate matter, there is significant decrease in the value of PFTs of all the three age group subjects. However, the difference is only change in numerical value of PFTs with the increase in $10 \mu\text{gm}^{-3}$ of particulate matter.

It is found that upper and lower age group are more affected than middle age group subjects (Table 4.19). Among different size particulate matter $\text{PM}_{2.5}$ has greater effect as compared to PM_{10} and SPM on PFTs *i.e.*, $\text{PM}_{2.5} > \text{PM}_{10} > \text{SPM}$. It can be observed from regression results that the effect on lower and upper age group subject is maximum and again smaller fraction of particles show more effect on the PFTs of each group.

4.3.4 Discussion

The investigation of the effects of inhaled air pollutants on human health has followed a multidisciplinary approach using animal toxicology, molecular and cellular biology, controlled human exposure studies, and epidemiology. Each approach has specific strengths and weaknesses in evaluating the human health effects of air pollution. Epidemiological studies of air pollution have largely focused on the association between exposure and health effects in the community setting. Accurate estimation of exposure to a pollutant is usually difficult, as it is often estimated from fixed monitoring sites. The health effects associated with ambient air quality in epidemiological studies can be divided into short-term and long-term effects, according to the investigated period of exposure. Short-term effects usually concern changes in mortality, symptoms and pulmonary function in association with assessed hourly peak, daily or weekly exposure. Long-term effects are mainly reported as the prevalence of symptoms or disease in association with annual exposure.

Epidemiological study designs used to explore the short-term effects of pollution have included time series and longitudinal studies. In time series studies, daily counts of mortality or hospital admissions are compared to daily concentrations of air pollutants. In longitudinal studies, a cohort of symptomatic people are followed over a period of time and daily reports of symptoms or peak flow are compared to daily concentrations of air pollutants. Longitudinal studies are often referred to as panel studies.

The present study comes under the category of epidemiological short term studies in which exposure of particulate matter due to ACRB on the healthy subjects of northern western region of Punjab were studied for three years. Monthly variations of PFTs are compared with monthly variation of particulate matter. The potential relationship between particulate matter concentration and pulmonary function values was analyzed and found that there is significant decrease in pulmonary function values when particulate matter concentration gets elevated. The association between the different size particulate matter and PFTs were found to be significant for all groups of subjects and results show that effect of SPM is least in comparison to PM₁₀ and PM_{2.5}.

Lot of studies proves that particulate pollution contributes to excess mortality and hospitalizations for cardiac and respiratory tract diseases. These studies also show that daily changes in mortality rates and numbers of people hospitalized are linked to changes in particulate air pollution (Dockery and Pope, 1994; Schwatrz *et al.*, 1994; US Environmental Protection Agency, 2001). These studies and others have estimated that for every 10 μgm^{-3} increase in PM₁₀, there is an increase in the daily mortality rate between 0.5% and 1.6%. Effects were seen even in cities with mean annual PM₁₀ concentrations between 25 and 35 μgm^{-3} . These studies also suggest that even the current federal standards for PM_{2.5} (24-hour standard 60 μgm^{-3}) and PM₁₀ (24-hour standard 150 μgm^{-3}) should be lowered to protect public health. In 2002, California adopted more stringent standards for particulate matter: the annual average standard for PM_{2.5} is 12 μgm^{-3} and for PM₁₀ is 20 μgm^{-3} . In present study, concentration of particulate matter goes above the NAAQS two times in a year for 4 months, means one third of the year people exposed to higher level of pollution level. There is also much evidence which have shown that short term increase in the particulate matter concentration give rise to various respiratory problem, respiratory symptoms and hospital admission. Hence results are in accordance to these types of studies.

Different size particulates have significant effect on the human health. While trying to understand the role of particles and composition in terms of its health risks, there are strong evidences supporting the fact that smaller particles are more harmful as compared to the larger ones. Studies have also shown that particles of different size vary in respiratory tract deposition, movement, clearance and consequent retention time in the human body. Smaller the particles size, greater is the fraction of particles deposited in airways and lings, and greater is the surface area available for interaction with biological system. In contrast the

larger particles (larger than 10 μm) get deposited in the upper region of the respiratory tract (www.worldbank.org/sarurbanair).

The associations of SPM of size more than 10 μm with PFTs were found to be less as compared to PM_{10} and $\text{PM}_{2.5}$. Respiratory defence mechanism is so strong that particles of size less than 10 μm is not allowed by it goes inside the respiratory but respiratory filtration system could not entrap particulate matter with a size less than 2.5 μm well, particles less than 1 μm pass the respiratory filtration system and enter the alveoli, diffuse against the walls of the alveoli and adhere to the alveolar fluid. Due to this, available surface area for gas exchange mechanism gets affected and hence PFTs show a significant decrease in their values. An excess of particles can cause growth of fibrous tissue in the alveolar septa, leading to permanent debility (Kelly *et al.*, 1997). Decrease in lung functions in relation with exposure to higher levels of particulate matter was due to the fibrous tissue formation in the alveolar septa and fibrotic lesion of the small airways (Chattopadhyaya *et al.*, 2006; Fereidoun *et al.*, 2007).

Because of their weight, particulates larger than 10 micrometres (μm) are affected by gravity and velocity. If inhaled, they tend to collect in the throat or get caught by nasal hairs, and are eliminated from the body by sneezing, coughing, nose blowing or through the digestive system. The measurement of particulates matter with a mass median aerodynamic diameter less than 10 μm have more effect in comparison to large size particles, hence in the present study strong negative association is found with so called PM_{10} . $\text{PM}_{2.5}$ is sometimes referred to as the fine fraction of PM_{10} and can remain suspended in the air for days or weeks and can travel long distances. They are of special concern to the protection of lung health as they are easily inhaled deeply into the lungs where they can be absorbed into the bloodstream or remain embedded within the terminal airways and affect the respiratory system and PFTs.

Particles of size range 4.6 – 9 μm normally deposit in the region of tracheo-pharynx; 1.1 – 4.6 μm in the bronchi and 0 – 1.1 μm in the alveoli. Penetration of these particles into the lung airways is determined primarily by convective flow, *i.e.* motion of the air in which particles are suspended. Particles deposit within the respiratory tract by five mechanisms: inertial impaction, sedimentation, diffusion, electrostatic precipitation and interception. Particles deposited inside the lungs are cleared by several mechanisms. These different mechanisms are weekend with age, so upper age group show more effect in comparison to

middle age group. Particles deposited in the bronchi and bronchioles (ciliated airways) are captured on the layer of the mucus lining and are carried out of the lungs on the mucociliary ladder for expulsion through coughing or they are swallowed. Particles deposited deeper, in the nonciliated airways, are engulfed by lung macrophages and cleared more slowly, as the macrophages transport the particles onto the mucociliary ladder or into the lymphatic system. In human beings, chronically inhaled PM was retained mainly in interstitium of lungs (57–91%) and its percentage increased with increase in dose. Clearance mechanisms themselves may be adversely affected by inhaled toxicants, so that clearance may take even longer because of the influence of the particles and co-pollutants such as ozone.

The effects of air pollutants on lung function depend largely on the type of pollutants and its environmental concentration, the duration of pollutant and its environmental concentration, the duration of pollutant exposure and the total ventilation of exposed persons. The ill-health effects of biomass burning are well-established. Smoke from biomass burning is particularly harmful since most of the particulates are smaller than 10 microns in size (PM₁₀) and easily travel deep into the lungs. Numerous studies have noted that increasing levels of PM₁₀ (even if below the USEPA standard of 50 micrograms PM₁₀ per cubic meter of air) can significantly increase levels of respiratory and heart problems (Morris, 2001; Schwela *et al.*, 1994) and are linked with a sudden death rate of approximately 5 percent at that level.

Results clearly shows that effect on the PFTs of upper age group is more in comparison to middle and lower age group, minimum association were found in the case of middle age group subjects. The reason of large decrease in the value of PFTs in case of upper age group with the increase in the concentration of different size particulate matter is because with increase in age, immune system and defence mechanism weaken, hence adults are most susceptible to the external environment as a result of which, it is most affected by the pollution arises due to the increase in concentration of different size particulate matter during the burning period of wheat and rice residue. Association with middle age group is found to be least because defence mechanism of young subjects are fully developed and have a strong capability to fight against the external contaminants. Hence effect on the middle age group during the burning season found to be minimum.

Effect on the lower age group is more in comparison to middle age group subjects. Lower age group comes in the category of children and middle age group comes in the category of young subject. In other way, results shows that effect on children is more in comparison to young subjects. Children are often more susceptible to the health effects of air pollution because their immune systems is in the stage of development and the organs are still immature. Irritation or inflammation caused by air pollution is more likely to obstruct their narrower airways (Awasthi *et al.*, 2010). It may also take less exposure to a pollutant to trigger an asthmatic attack or other breathing ailment due to the sensitivity of a child's developing respiratory system. The airways epithelium of growing children is more permeable to air pollutants and lung defences against particulate pollution and gaseous pollution are not fully evolved. Eighty percent of alveoli are formed postnatal, and changes in the lung continue through adolescence (Dietert *et al.*, 2000). During the early post neonatal period, the developing lung is highly susceptible to damage after exposure to environmental toxicants (Dietert *et al.*, 2000; Pinkerton *et al.*, 2000; Plopper *et al.*, 2000). Children also have a differential ability to metabolize, detoxify and excrete environmental agents (Schwartz *et al.*, 2000).

In addition, children perform a greater level of physical activity; hence their intake of air into the lungs is much greater than other age groups, which increase their exposure to any pollutant in the air (Plunkett *et al.*, 1992; Stanojevic *et al.*, 2008; Ulrik *et al.*, 1999). Higher intake of air increases the rate at which ambient air pollutants enter in the body. Children often breathe through their mouths, bypassing the filtering effect of the nose and allowing more pollutants to be inhaled. Children spend more time outside the home, particularly in the late afternoon, which significantly increases their exposure to ambient air pollutants, as compared to young and adult (Wiley *et al.*, 1991(a, b)). Children have higher resting metabolic rate of oxygen consumption per unit body weight than other age group because they have large surface per unit body weight and because they are growing rapidly. An additional consideration is the smaller lung surface area /kg in the early stages of development, thus higher amounts of inspired air will affect a relatively smaller area of lungs tissue. On the basis of body weight, the volume of air passing through the lungs of a child is more than that of young and adult under the same conditions and more atmospheric pollutant could reach the lung of lower age group. Moreover, children have narrower airways, thus irritation caused by air pollution would produce only slight response in other age groups

which can result potentially significant obstruction in the airway of child (Moya *et al.*, 1999; Staurt *et al.*, 1984).

Thus all the conditions like immature organs, developing stage of bodys defence system, longer exposure time, high metabolic rate, physical and physiological state of respiratory system contributes for the greater effect of air pollution specially the increase concentration of particulate matter on children in comparison to other age groups. Thus PFTs of lower age group shows more decrease in the values with respect to the middle age group.

Decrease in PFTs may not be only due to the particulate matter as some other underlying causes may be present but it is confirmed by three year study that due to ACRB, PFTs of healthy subjects gets reduced. The association of particulate air pollution and pulmonary function found in this study is also consisted with others studies in the US and Europe.

Chapter V

Development of mathematical model for the prediction of PFTs

In this Chapter, Field Crop Residue Burning and Pulmonary Function Model (FCRBPFM) is proposed, designed, developed as well as tested to predict/forecast the value of Pulmonary Function Tests (PFTs). Initially, scatter plots between same months for each PFT were drawn with explanatory variables and observed that there is linear trend with correlation coefficient showing the same result. Then PFTs was regressed on explanatory variable by multi linear method. All variables were found insignificant relation and showing less variation, hence explanatory variables were modified by taking lag i.e., PFTs were regressed on 12th lag value of explanatory variables. Then model was improved, showing more variation (R-square increased) with all significant variables. Model was developed which could predict next one year value of PFTs on the basis of available values of explanatory variables.

Pulmonary Function Test (PFT) values of 50 healthy subjects (age between 13 to 53 years) and pollutants like SPM, PM₁₀, PM_{2.5} were continually investigated for three years from February 2007 to January 2010 at the Patiala city of Punjab and found a significant decrease in the PFTs and increase in the concentration of pollutants during the field burning months of wheat and rice crop residue. By using this data, in the present paper, Field Crop Residue Burning and Pulmonary Function Model (FCRBPFM) has been developed as well as tested. FCRBPFM is the hybrid of four models, developed by multiple ordinary least squares regression method, proposed to predict the value of Pulmonary Function Tests (PFTs) in term of percentage predicted as a function of air pollutants and temperature. Monthly average values of different variables were used for the purpose of the designing of four models for FVC, FEV₁, PEF and FEF_{25-75%} by taking different PFTs as dependent and SPM, PM₁₀, PM_{2.5} and temperature as independent or explanatory variables.

5.1 Study the relationship of FVC with SPM, PM₁₀, PM_{2.5} and temperature

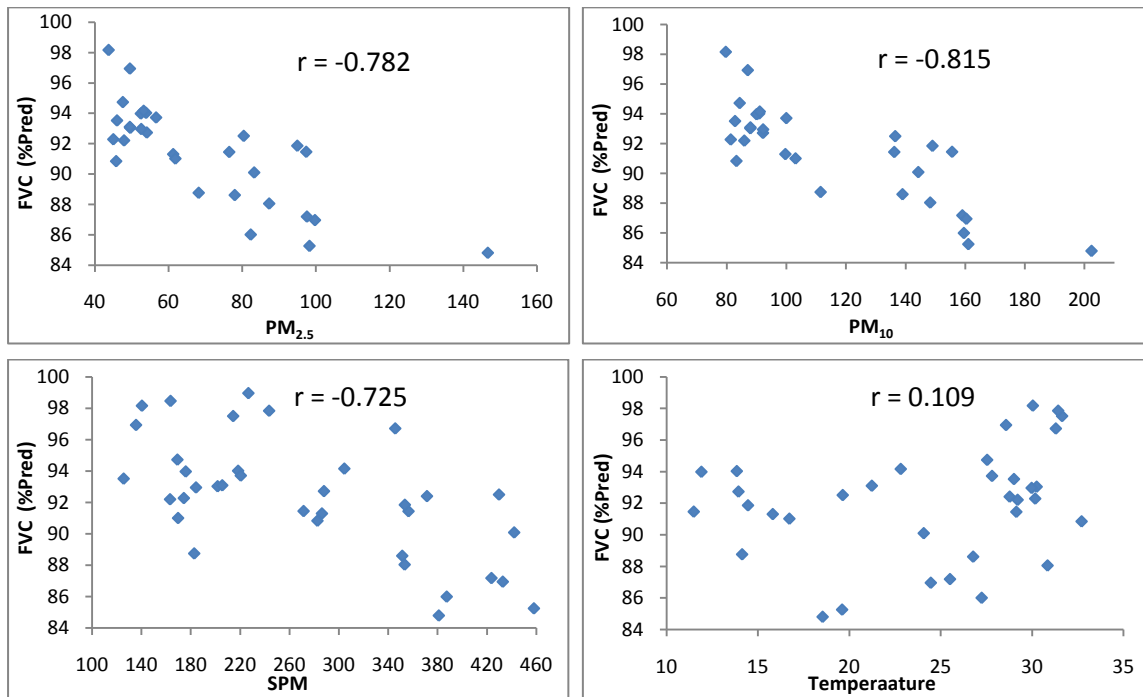


Figure 5.1 Scatter Plot of FVC versus PM_{2.5}, PM₁₀, SPM and temperature

Scatter plot (Figure 5.1) of FVC with PM_{2.5}, PM₁₀, SPM and temperature reveals that there is high negative correlation (negative linear relationship) between FVC with PM_{2.5}, PM₁₀ and SPM but there is very low positive correlation between FVC and temperature. It means that with increase in each of SPM, PM₁₀ and PM_{2.5} there is decrease in FVC. Though there exist low positive correlation between FVC and temperature; temperature is added in the regression model because it has importance in the model on the basis criterion for variable selection. Based on those results, multiple ordinary least squares regression method was used to developed model, as shown in Table 5.1.

Table 5.1: Regression results of FVC on SPM, PM₁₀, PM_{2.5} and temperature

	Coefficient	Std. Error	t-ratio	p- value
Constant	101.162	2.116	47.788	<0.00001
SPM	-0.004 ^a	0.006	-0.647	0.523
PM ₁₀	-0.074 ^a	0.065	-1.131	0.268
PM _{2.5}	0.009 ^a	0.082	0.113	0.910
Temperature	-0.026 ^a	0.062	-0.430	0.670
R-squared	0.676		Adjusted R squared	0.624

^a: Non-significant value as p-value > 0.05

Table 5.1 represents the coefficient and significance level calculated by using multiple linear regressions between the monthly averages values of FVC as dependent and PM_{2.5}, PM₁₀, SPM and temperature as independent variable of same months. By using the coefficient values of independent variables and constant equation for FVC can be written as

$$FVC_{(t)} = 101.6 - 0.004 * SPM_{(t)} - 0.74 * PM_{10(t)} + 0.009 * PM_{2.5(t)} - 0.026 * Temp_{(t)} \quad \dots(1)$$

It is found that (Table 5.1) the coefficient of all independent variables i.e., SPM, PM₁₀, PM_{2.5} and temperature are insignificant. Value of R-squared showed that SPM, PM₁₀, PM_{2.5} and temperature explain 67 percent variation in the FVC. The coefficients of all dependent variables are insignificant which is not accepted statistically for the prediction of FVC. Hence model 1 (equation 1), which are developed by using the monthly average value of same months is not accepted. Then explanatory variables were modified by taking lag i.e., FVC were regressed on 12th lag value of explanatory variables. To develop the model for the prediction of FVC values, relationship between the FVC and lag of 12 month's dependent variable were calculated.

Table 5.2: Regression results of FVC on the 12th lag value of SPM, PM₁₀, PM_{2.5} and temperature

FVC	Coefficient	Std. Error	t-ratio	p- value
Constant	98.3	1.747	56.266	<0.00001
SPM _(t-12)	-0.001 ^a	0.006	-0.276	0.786
PM _{10(t-12)}	-0.377	0.118	-3.194	0.007
PM _{2.5(t-12)}	0.463	0.182	2.541	0.024
Temp _(t-12)	0.178	0.064	2.766	0.016
R-squared	0.876		Adjusted R squared	0.838

^a: Non-significant value as p-value > 0.05

Table 5.2 represents the coefficient and significance level of different models calculated by using multi-linear regression between the 12th lag values of dependent variables with the monthly FVC value. It is observed that coefficient of all dependent variables are found to be significant except SPM_(t-12) (Table 5.2). Results shows that SPM_(t-12), PM_{10(t-12)}, PM_{2.5(t-12)} and Temp_(t-12) explaining 87 percent variation in the FVC.

Comparison of Table 5.1 and 5.2 shows that modification in the explanatory variables result in improvement of R-square value in comparison to model 1, so the improved model 2 can be written in the form of equation:

$$FVC_{(t)} = 98.3 - 0.001 * SPM_{(t-12)} - 0.37 * PM_{10(t-12)} + 0.46 * PM_{2.5(t-12)} + 0.17 * Temp_{(t-12)} \quad \dots(2)$$

The coefficient of SPM is found to be non-significant. Further multiple regressions between dependent and independent variable is calculated after excluding the SPM variable. Table 5.3 represents the coefficient and significance level of FVC's model calculated by using multi-linear regression between the 12th lag values of dependent variables with the monthly independent variables after excluding the SPM variables.

Table 5.3: Regression results of FVC on the 12th lag value of PM₁₀, PM_{2.5} and temperature

FVC	Coefficient	Std. Error	t-ratio	p- value
Constant	98.445	1.609	61.1546	<0.00001
PM _{10(t-12)}	-0.387	0.108	-3.5541	0.003
PM _{2.5(t-12)}	0.468	0.175	2.6757	0.018
Temp _(t-12)	0.182	0.060	3.0359	0.008
R-squared	0.876		Adjusted R squared	0.849

Multiple linear regression results reveal that (Table 5.3); coefficients of all dependent variables are significant and explain up to 87 percent variation in FVC. Comparison of Table 5.2 and 5.3 shows that R-squared value of FVC (Model: 3) is found to be same as that in the Table 5.2 (Model 2) but adjusted R-squared value increased from 83 to 84 % in model 3 after excluding SPM from equation 2. The final accepted equation to predict the value of FVC does not include SPM and written as

$$FVC_{(t)} = 98.4 - 0.38 * PM_{10(t-12)} + 0.46 * PM_{2.5(t-12)} + 0.18 * Temp_{(t-12)} \quad \dots(3)$$

Equation 3 is the final accepted model which could predict next one year value of PFTs on the basis of available values of explanatory variables i.e., PM₁₀, PM_{2.5} and temperature.

5.1.1 Validation of FVC's model

To check the results of models different tests were applied on the residuals like normality, randomness and its relationship with dependent variable.

5.1.1.1 Test for normal distribution of residuals for FVC of model 3

Figure 5.2 represents the normality plot for residual of FVC by using equation 3. Test for null hypothesis of normal distribution gives Chi-square (2) = 0.712 with p-value 0.70. Since p value is found to be greater than 0.05. Hence, null hypothesis is accepted and residuals are following normal distribution.

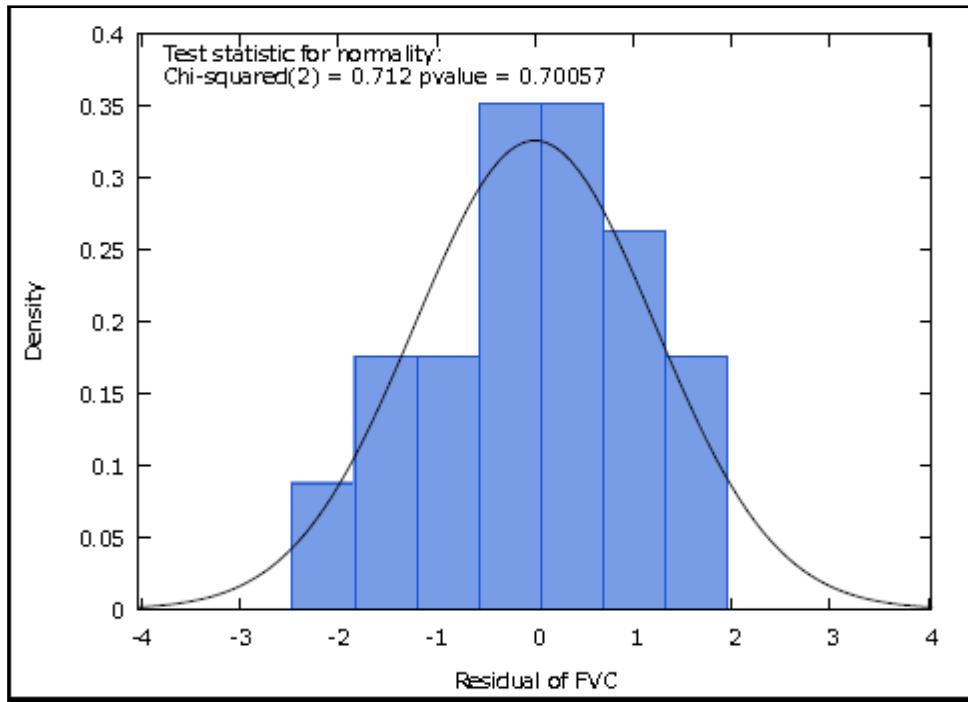


Figure 5.2: Histogram to test normality of residual for FVC of model 3

5.1.1.2 Test for randomness of residuals for FVC of model 3

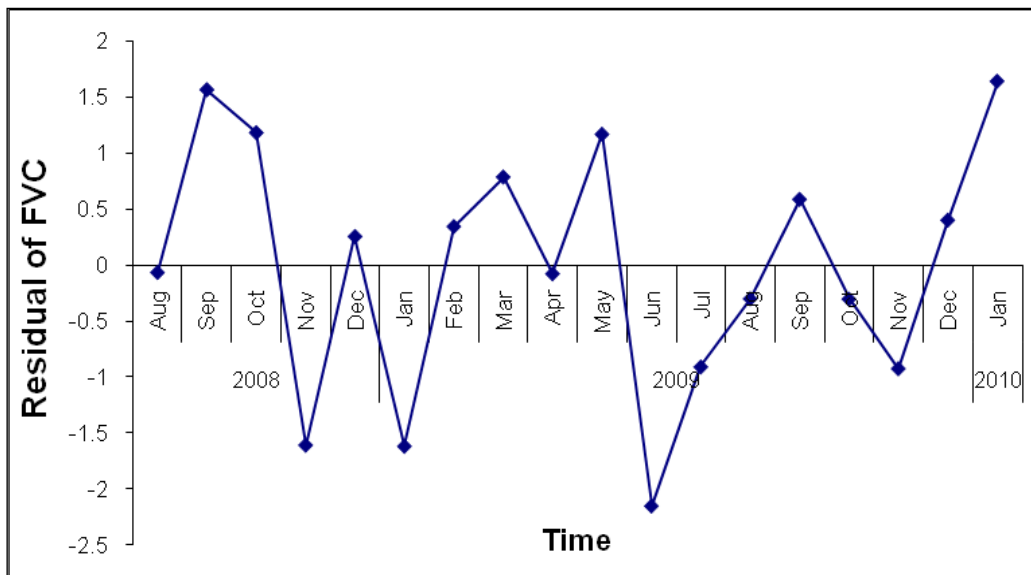


Figure 5.3: Residual plot of FVC versus time for model 3

Figure 5.3 represents the residuals plot of FVC versus time for the model 3. Residuals are randomly oriented having no relationship with time. Thus residuals are following the assumption of randomness.

5.1.1.3 Test for relationship of residuals with explanatory variables for FVC of model 3

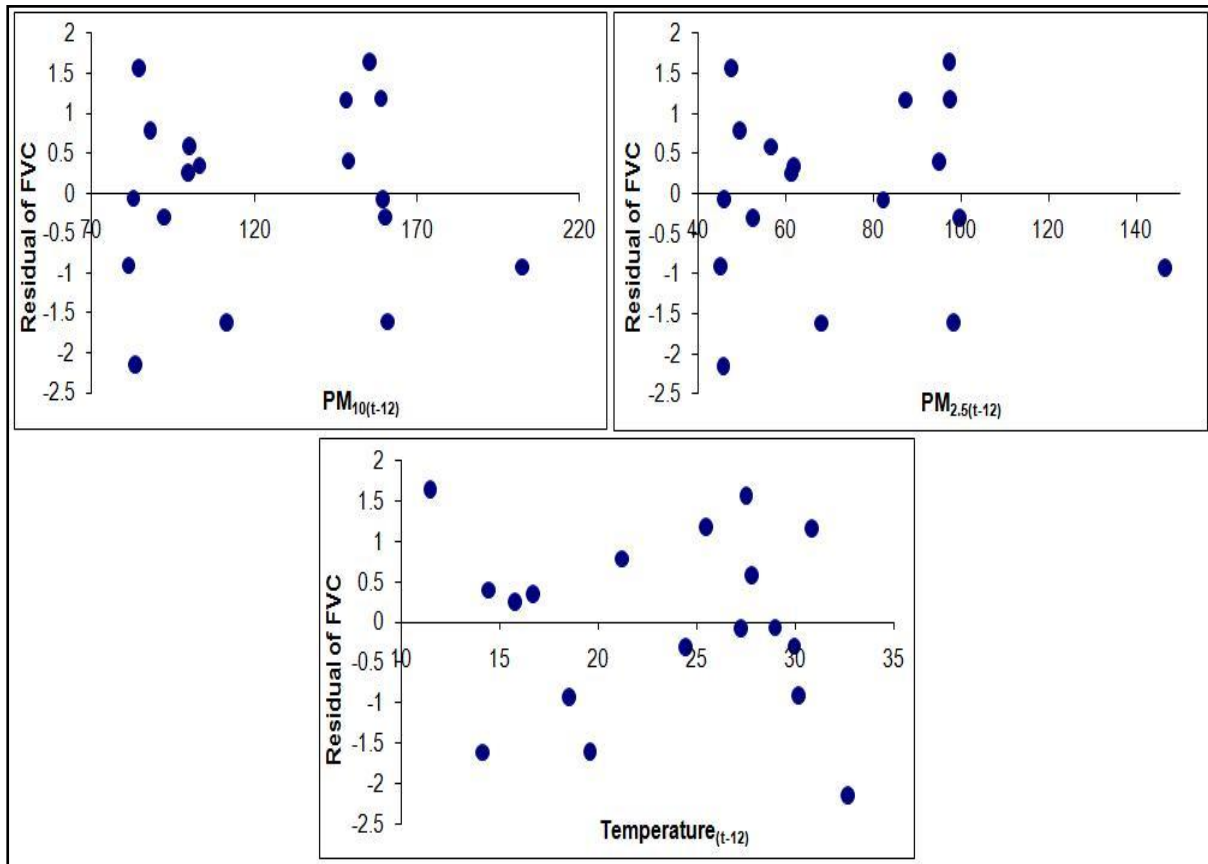


Figure 5.4: Residual plot of FVC versus each independent variable for model 3

Figure 5.4 represents the residuals plot of FVC with different explanatory variable. Residuals have no relationship with explanatory variables (Figure 5.4). Residual of the equation 3 satisfied the different conditions like normality, randomly orientation and independent variation with respect to explanatory variable. Equation 3 is the statistically valid model for the prediction of FVC on the basis of explanatory variable like PM_{10} , $PM_{2.5}$ and temperature.

7.2 Study the relationship of FEV₁ with SPM, PM₁₀, PM_{2.5} and temperature

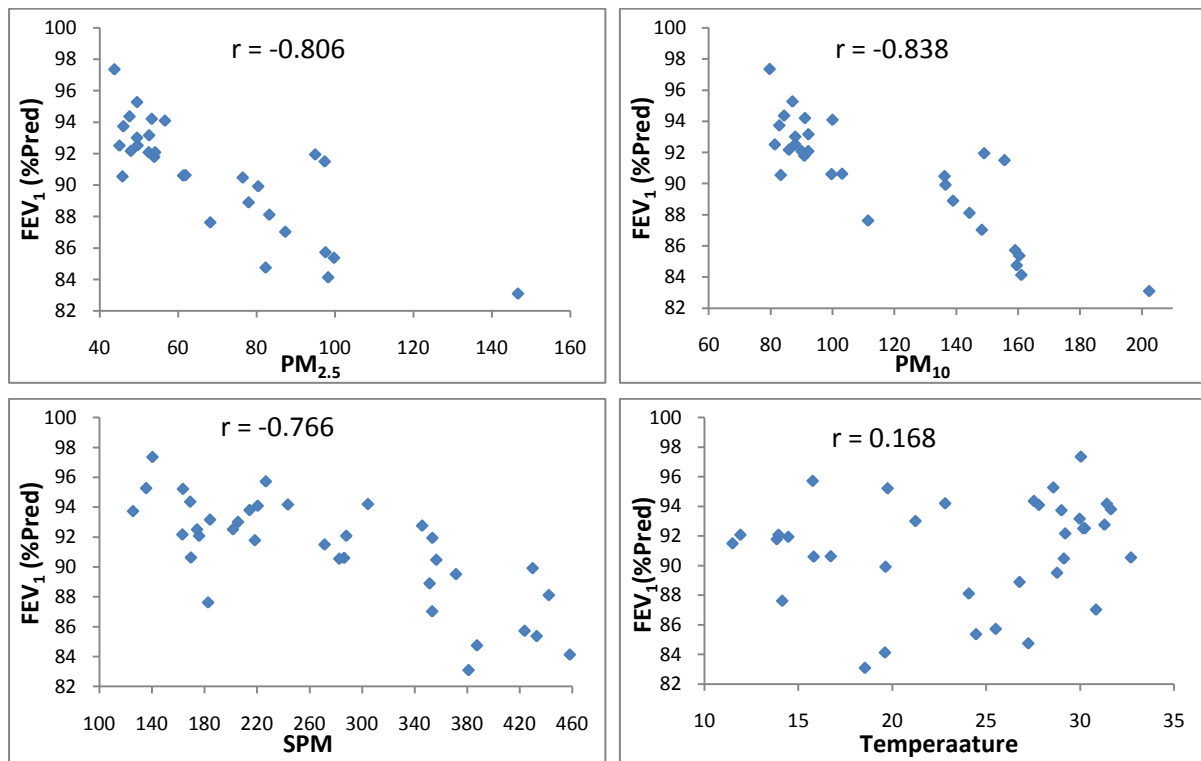


Figure 5.5 Scatter Plot of FEV₁ versus PM_{2.5}, PM₁₀, SPM and temperature

Scatter plot (Figure 5.5) of FEV₁ with PM_{2.5}, PM₁₀, SPM and temperature reveals that there is high negative correlation (neegative linear relationship) between FEV₁ with PM_{2.5}, PM₁₀ and SPM but there is very low positive correlation between FEV₁ and temperature. It means that with increase in each of SPM, PM₁₀ and PM_{2.5} there is decrease in FEV₁. Though there exist low positive correlation between FEV₁ and temperature. Temperature is added in the regression model because it has importance in the model on the basis criterion for variable selection. Based on those results, multiple ordinary least squares regression method was used to developed model, as shown in Table 5.4.

Table 5.4: Regression results of FEV₁ on SPM, PM₁₀, PM_{2.5} and temperature

	Coefficient	Std. Error	t-ratio	p- value
Constant	100.503	2.141	46.939	<0.00001
SPM	-0.007 ^a	0.006	-1.111	0.277
PM ₁₀	-0.071 ^a	0.066	-1.076	0.292
PM _{2.5}	0.006 ^a	0.083	0.072	0.942
Temperature	0.002 ^a	0.062	0.037	0.970
R-squared	0.718		Adjusted R-squared	0.673

^a: Non-significant value as p-value > 0.05

Table 5.4 represents the coefficient and significance level calculated by using multiple linear regressions between the monthly averages values of FEV₁ as dependent and PM_{2.5}, PM₁₀, SPM and temperature as independent variable of same months. By using the values of coefficient (Table 5.4) equation for FEV₁ can be written as

$$FEV_{1(t)} = 100.5 - 0.007 * SPM_{(t)} - 0.07 * PM_{10(t)} + 0.006 * PM_{2.5(t)} + 0.002 * Temp_{(t)} \quad \dots(4)$$

From Table 5.4 it is found that the coefficient of all independent variables i.e., SPM, PM₁₀, PM_{2.5} and temperature are insignificant. Value of R-squared showed that SPM, PM₁₀, PM_{2.5} and temperature explain up to 71 percent variation in the FEV₁ but since the coefficient of all dependent variables are insignificant hence this is not accepted statistically for the prediction of FEV₁. Hence model 4 (equation 4), which is developed by using the monthly average value of same months of dependent and independent variable is not accepted. Then explanatory variables were modified by taking lag i.e., FEV₁ were regressed on 12th lag value of explanatory variables. To develop the model for the prediction of FEV₁ values, relationship between the FEV₁ and lag of 12 month's dependent variable were calculated and shown in Table 5.5.

Table 5.5: Regression results of FEV₁ on 12th lag value of SPM, PM₁₀, PM_{2.5} and temperature

	Coefficient	Std. Error	t-ratio	p- value
Constant	99.496	2.018	49.284	<0.00001
SPM _(t-12)	-0.001 ^a	0.007	-0.219	0.829
PM _{10(t-12)}	-0.452	0.136	-3.314	0.005
PM _{2.5(t-12)}	0.550	0.210	2.613	0.021
Temp _(t-12)	0.215	0.074	2.892	0.012
R-squared	0.885	Adjusted R squared		0.850

^a: Non-significant value as p-value > 0.05

Table 5.5 represents the coefficient and significance level of model for FEV₁, calculated by using multi-linear regression between the 12th lag values of dependent variables with the monthly FEV₁ value. It is observed that coefficient of all dependent variables are found to be significant except SPM_(t-12). Results shows that SPM_(t-12), PM_{10(t-12)}, PM_{2.5(t-12)} and Temp_(t-12) explaining up to 88 percent variation in the FEV₁. Comparison of Table 5.4 and 5.5 shows that modification in the explanatory variables result in improvement of R-square values in comparison to model 4, so the improved model 5 can be written in the form of equation:

$$FEV_{1(t)} = 99.4 - 0.001 * SPM_{(t-12)} - 0.45 * PM_{10(t-12)} + 0.55 * PM_{2.5(t-12)} + 0.21 * Temp_{(t-12)} \quad \dots(5)$$

The coefficient of SPM is found non-significant. Multiple regressions between dependent and independent variable is calculated after excluding the SPM variable. Table 5.6 represents the coefficient and significance level of model calculated by using multi-linear regression between the

12th lag values of dependent variables with the monthly value of FEV₁ after excluding the SPM variable.

Table 5.6: Regression results of FEV₁ on 12th lag value of PM₁₀, PM_{2.5} and temperature

	Coefficient	Std. Error	t-ratio	p- value
Constant	99.63	1.858	53.615	<0.00001
PM _{10(t-12)}	-0.461	0.125	-3.669	0.002
PM _{2.5(t-12)}	0.555	0.202	2.747	0.015
Temp _(t-12)	0.219	0.069	3.159	0.006
R-squared	0.885		Adjusted R-squared	0.861

Multiple linear regression results reveal that (Table 5.6) coefficients of all dependent variables are significant and explain up to 88 percent variation in FEV₁. Comparison of Table 5.5 and 5.6 shows that R-squared value of FEV₁ (Model 6) is found to be same as that in the Table 5.5 (Model 5) but adjusted R-squared value increased from 85 to 86% in model 6 after excluding SPM from equation 5. The final improved equation to predict the value of FEV₁ does not include SPM and written as

$$FEV_{1(t)} = 99.6 - 0.46 * PM_{10(t-12)} + 0.55 * PM_{2.5(t-12)} + 0.21 * Temp_{(t-12)} \quad \dots(6)$$

Equation 6 is accepted model which could predict next one year value of FEV₁ on the basis of available values of explanatory variables i.e., PM₁₀, PM_{2.5} and temperature.

5.2.1 Validation of FEV₁'s model

To check the results of model, different tests were applied on the residuals like normality, randomness and its relationship with dependent variable.

5.2.1.1 Test for normal distribution of residuals for FEV₁ of model 6

Figure 5.2 represents the normality plot for residual of FVC by using equation 3. Test for null hypothesis of normal distribution gives Chi-square (2) = 0.526 with p-value 0.76. Since p value is found to be greater than 0.05. Hence, null hypothesis is accepted and residuals are following normal distribution.

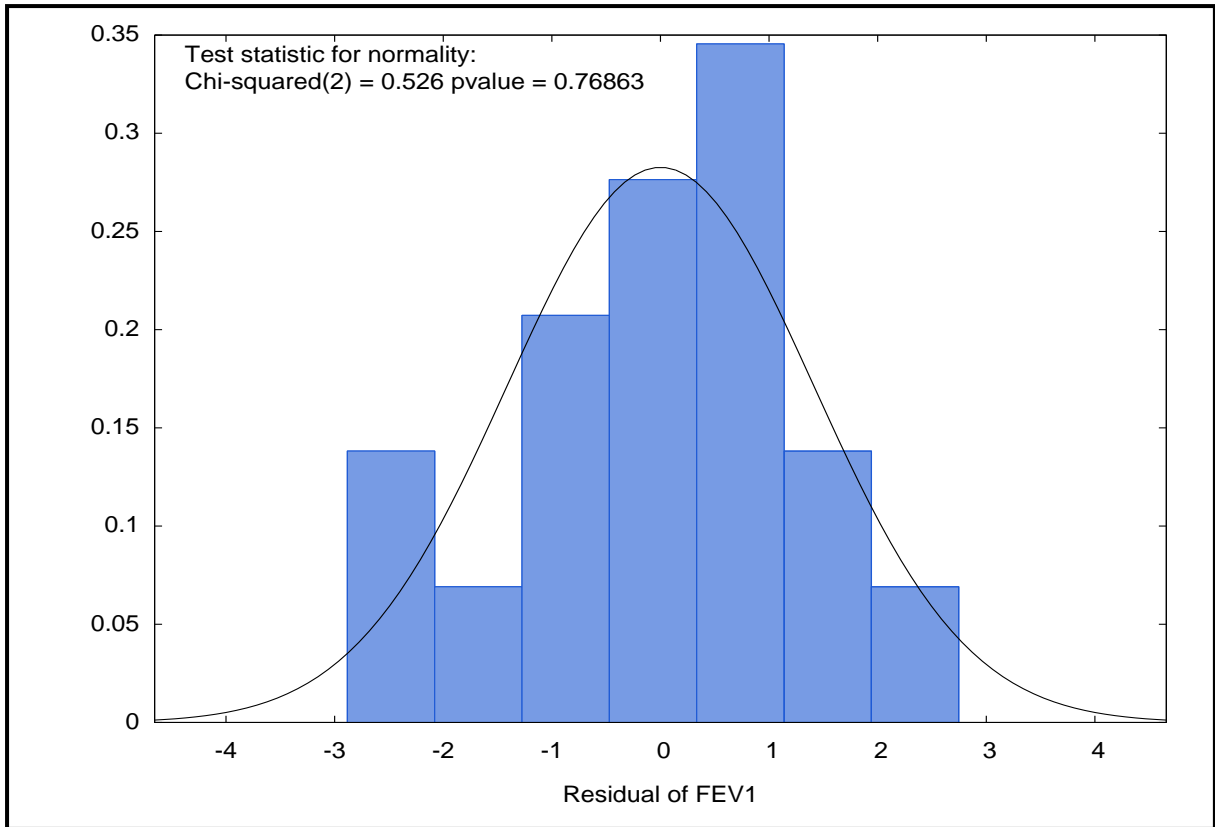


Figure 5.6: Histogram to test normality of residual for FEV₁ of model 6

5.2.1.2 Test for randomness of residuals for FEV₁ of model 6

Figure 5.7 represents the residuals plot of FEV₁ versus time for the model 6. Residuals are randomly oriented having no relationship with time. Thus residuals of FEV₁ are following the assumption of randomness.

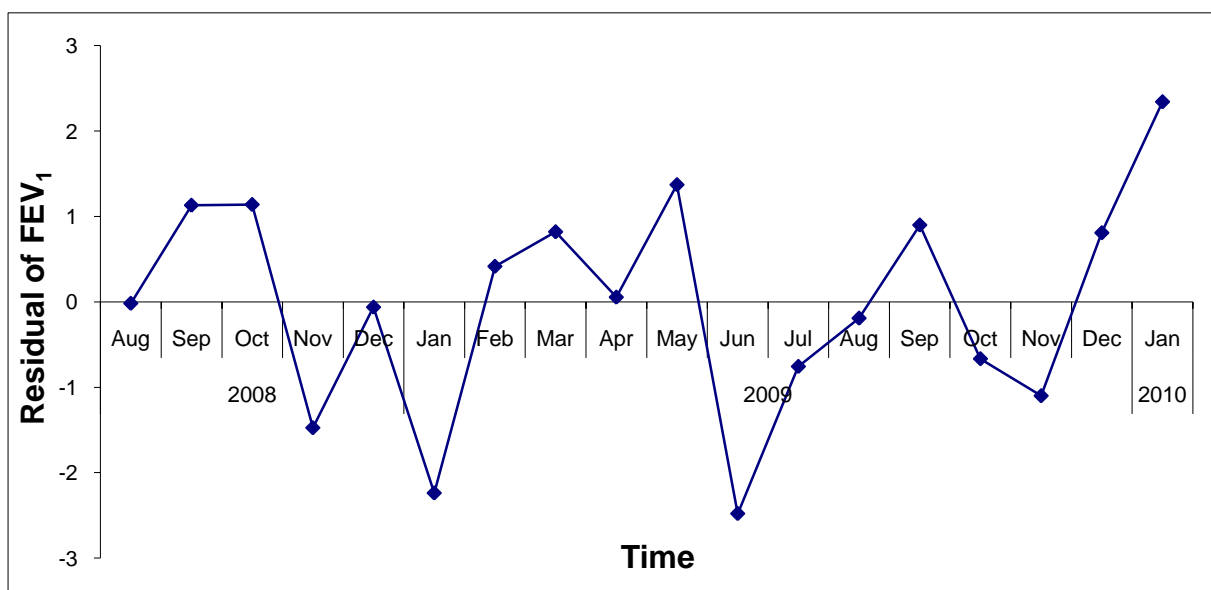


Figure 5.7: Residual plot of FEV₁ versus time for model 6

5.2.1.3 Test for relationship of residuals with explanatory variables for FEV₁ of model 6

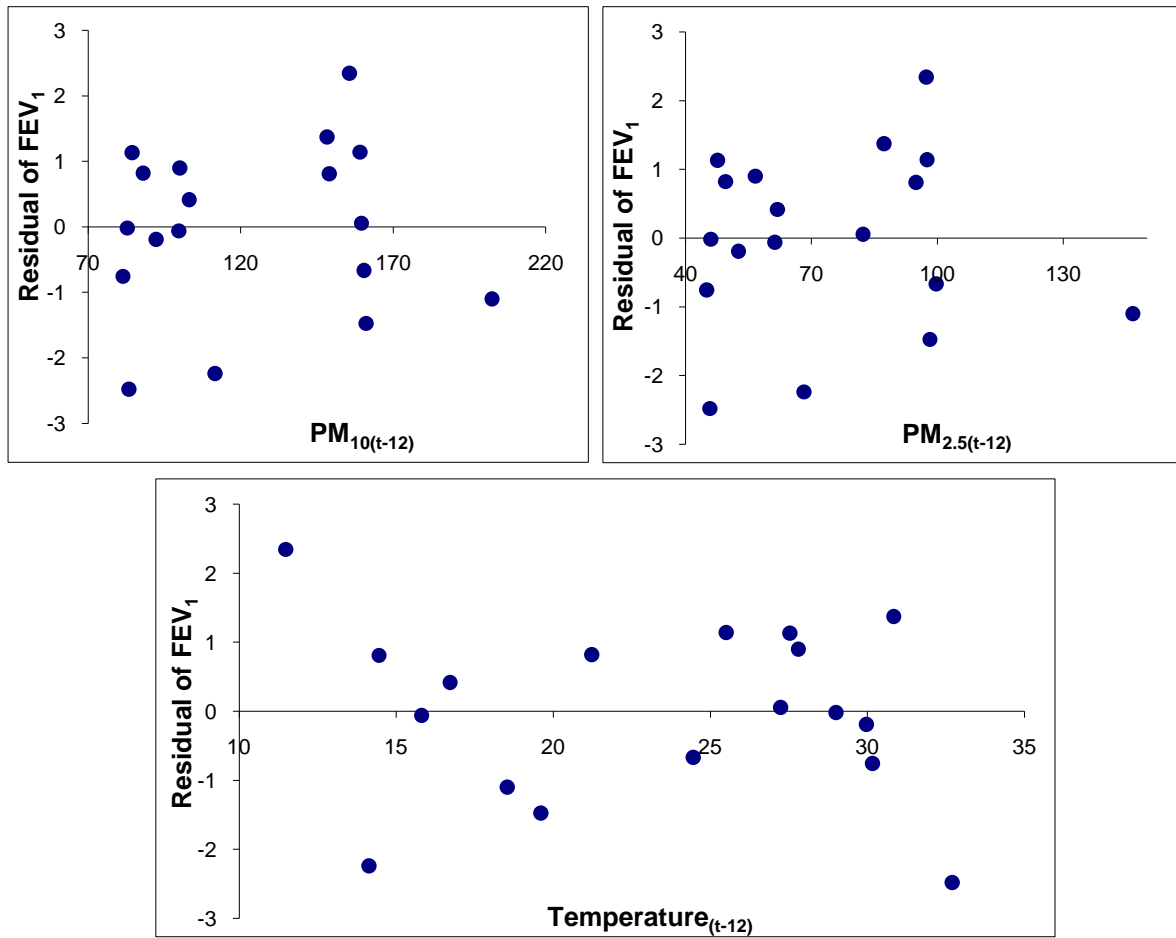


Figure 5.8: Residual plot of FEV₁ versus each independent variable for model 6

Figure 5.8 represents the residuals plot of FEV₁ with different explanatory variable. It is clear that residuals have no relationship with explanatory variables (Figure 5.4). Residual of the equation 6 satisfied the different conditions like normality, randomly orientation and independent variation with respect to explanatory variable. Equation 6 is statistically valid model for the prediction of FEV₁ on the basis of explanatory variable like PM₁₀, PM_{2.5} and temperature.

5.3 Study the relationship of PEF with SPM, PM₁₀, PM_{2.5} and temperature

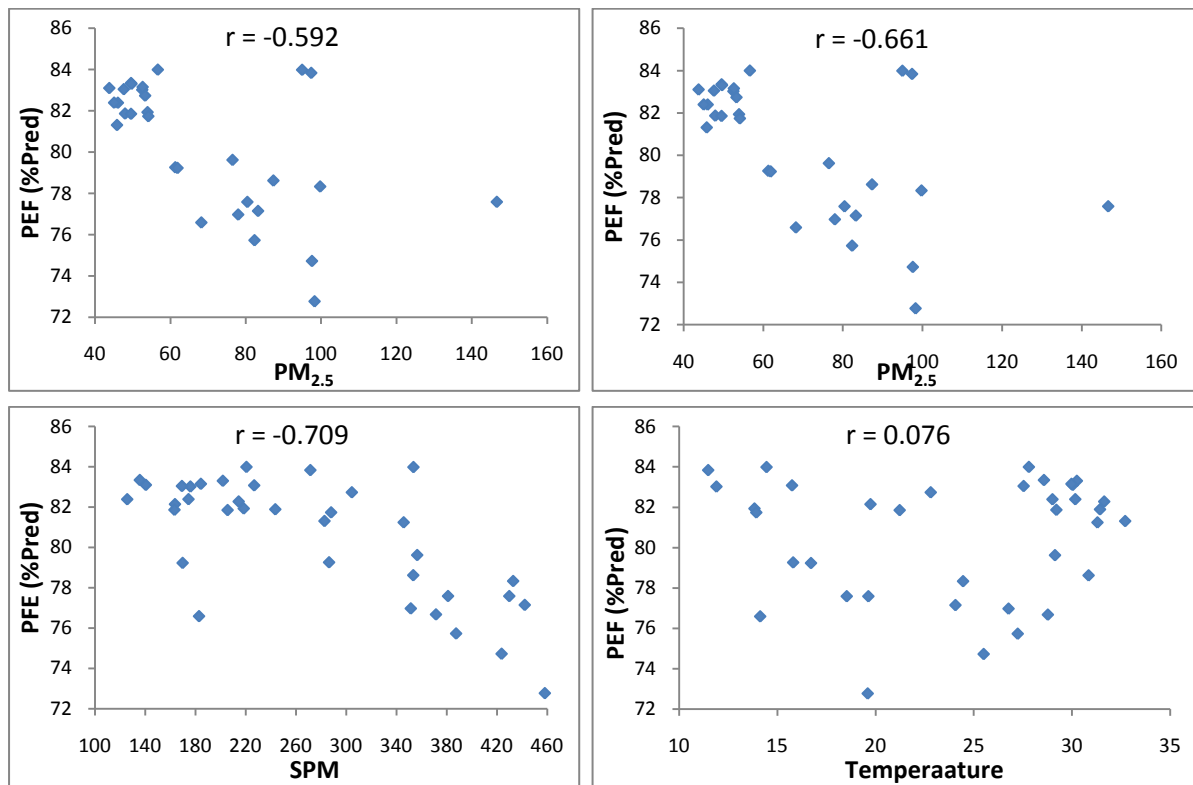


Figure 5.9 Scatter Plot of FEV₁ versus PM_{2.5}, PM₁₀, SPM and temperature

Scatter plot (Figure 5.9) of PEF with PM_{2.5}, PM₁₀, SPM and temperature reveals that there is high negative correlation (negative linear relationship) between PEF with PM_{2.5}, PM₁₀ and SPM but there is very low positive correlation between PEF and temperature. It means that with increase in each of SPM, PM₁₀ and PM_{2.5} there is decrease in PEF. Though there exist low positive correlation between PEF and temperature; temperature is added in the regression model because it has importance in the model on the basis criterion for variable selection. Based on those results, multiple ordinary least squares regression method was used to developed model, as shown in Table 5.7.

Table 5.7: Regression results of PEF on SPM, PM₁₀, PM_{2.5} and temperature

	Coefficient	Std. Error	t-ratio	p- value
Constant	87.914	2.407	36.511	<0.00001
SPM	-0.011 ^a	0.007	-1.548	-0.011
PM ₁₀	-0.101 ^a	0.074	-1.347	-0.101
PM _{2.5}	0.103 ^a	0.094	1.091	0.103
Temperature	0.012 ^a	0.071	0.176	0.012
R-squared	0.542		Adjusted R squared	0.469

^a: Non-significant value as p-value > 0.05

Table 5.7 represents the coefficient and significance level calculated by using multiple linear regressions between the monthly averages values of PEF as dependent and PM_{2.5}, PM₁₀, SPM and temperature as independent variable of same months. By using the different values of coefficient (Table 5.7) equation for PEF can be written as

$$PEF_{(t)} = 87.9 - 0.011 * SPM_{(t)} - 0.101 * PM_{10(t)} + 0.103 * PM_{2.5(t)} + 0.012 * Temp_{(t)} \quad \dots(7)$$

It is found that (Table 5.7) the coefficient of all independent variables i.e., SPM, PM₁₀, PM_{2.5} and temperature are insignificant. Value of R-squared showed that SPM, PM₁₀, PM_{2.5} and temperature explain 67 percent variation in the PEF but since the coefficient of all dependent variables are insignificant hence this is not accepted statistically for the prediction of PEF. Model 7 (equation 7), which are developed by using the monthly average value of same months is not accepted. Then explanatory variables were modified by taking lag i.e., PEF were regressed on 12th lag value of explanatory variables and new equation were developed by using the multiple linear regression technique.

Table 5.8: Regression results of PEF on 12th lag value of SPM, PM₁₀, PM_{2.5} and temperature

PEF	Coefficient	Std. Error	t-ratio	p- value
Constant	84.07	2.604	32.286	<0.00001
SPM _(t-12)	-0.013 ^a	0.009	-1.419	0.172
PM _{10(t-12)}	-0.642	0.176	-3.649	0.002
PM _{2.5(t-12)}	0.988	0.271	3.636	0.003
Temp _(t-12)	0.296	0.096	3.082	0.008
R-squared	0.773		Adjusted R squared	0.70

^a: Non-significant value as p-value > 0.05

Table 5.8 represents the coefficient and significance level of PEF model calculated by using multi-linear regression between the 12th lag values of dependent variables with the monthly PEF value. It is observed that Coefficient of all dependent variables are found to be significant except SPM_(t-12) (Table 5.8). Results show that SPM_(t-12), PM_{10(t-12)}, PM_{2.5(t-12)} and Temp_(t-12) explaining 77 percent variation in the PEF. Comparison of Table 5.7 and 5.8 shows that modification in the explanatory variables result in improvement of R-square values and significance of more dependent variable in comparison to model 7, so the improved model 8 can be written in the form of equation:

$$PEF_{(t)} = 84.07 - 0.013 * SPM_{(t-12)} - 0.64 * PM_{10(t-12)} + 0.98 * PM_{2.5(t-12)} + 0.29 * Temp_{(t-12)} \quad \dots(8)$$

The coefficient of SPM is found to be non-significant; therefore multiple regressions between dependent and independent variable is calculated after excluding the SPM variable. Table 5.9 represents the coefficient and significance level of different models calculated by using multi-linear

regression between the 12th lag values of dependent variables with the monthly independent variables after excluding the SPM variables.

Table 5.9: Regression results of PEF on the 12th lag value of PM₁₀, PM_{2.5} and temperature

PEF	Coefficient	Std. Error	t-ratio	p- value
Constant	85.193	2.571	33.132	<0.00001
PM _{10(t-12)}	-0.717	0.174	-4.123	0.001
PM _{2.5(t-12)}	1.029	0.279	3.678	0.002
Temp _(t-12)	0.331	0.096	3.441	0.003
R-squared	0.738		Adjusted R squared	0.682

Multiple linear regression results reveal that (Table 5.9) coefficients of all dependent variables are significant and explain up to 73 percent variation in PEF and by using the value of different coefficients, equation can be written as

$$PEF_{(t)} = 84.07 - 0.013 * SPM_{(t-12)} - 0.64 * PM_{10(t-12)} + 0.98 * PM_{2.5(t-12)} + 0.29 * Temp_{(t-12)} \dots (9)$$

Comparison of Table 5.8 and 5.9 shows that R-squared value decreased from 77 to 73% and adjusted R-squared value decreased from 70 to 68% in model 9 after excluding SPM from model 8 by multi linear regression technique, so there is no need to exclude SPM as dependent variable to predict PEF. Equation 8 is the final accepted model which could predict next one year value of PEF on the basis of available values of explanatory variables i.e., SPM, PM₁₀, PM_{2.5} and temperature.

5.3.1 Validation for PEF's model

To check the results of model different tests were applied on the residuals like normality, randomness and its relationship with dependent variable.

5.3.1.1 Test for normal distribution of residuals for PEF of model 8

Figure 5.10 represents the normality plot for residual of PEF by using equation 8. Test for null hypothesis of normal distribution gives Chi-square (2) = 0.044 with p-value 0.978. Since p value is found to be greater than 0.05. Hence, null hypothesis is accepted and residuals are following normal distribution.

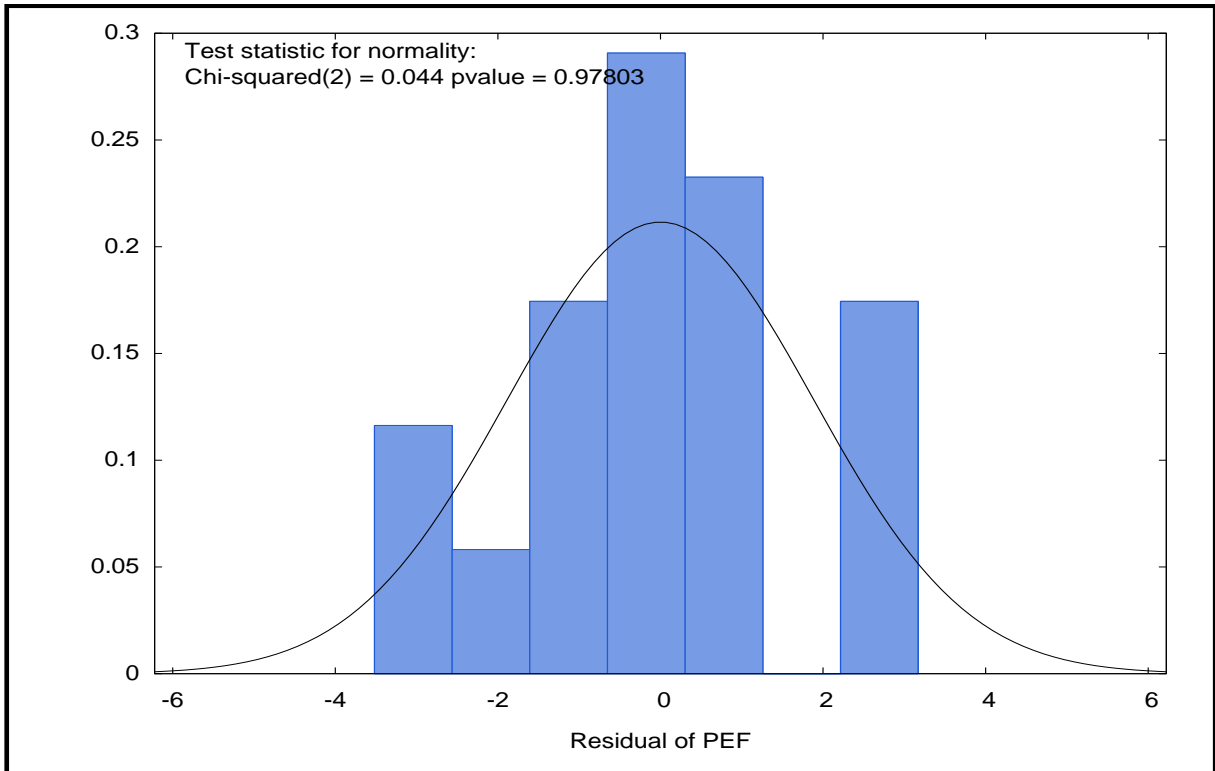


Figure 5.10: Histogram to test normality of residual for PEF of model 8

5.3.1.2 Test for randomness of residuals for PEF of model 8

Figure 5.11 represents the residuals plot of FVC versus time for the model 8. Residuals are randomly oriented having no relationship with time. Thus, residuals are following the assumption of randomness.

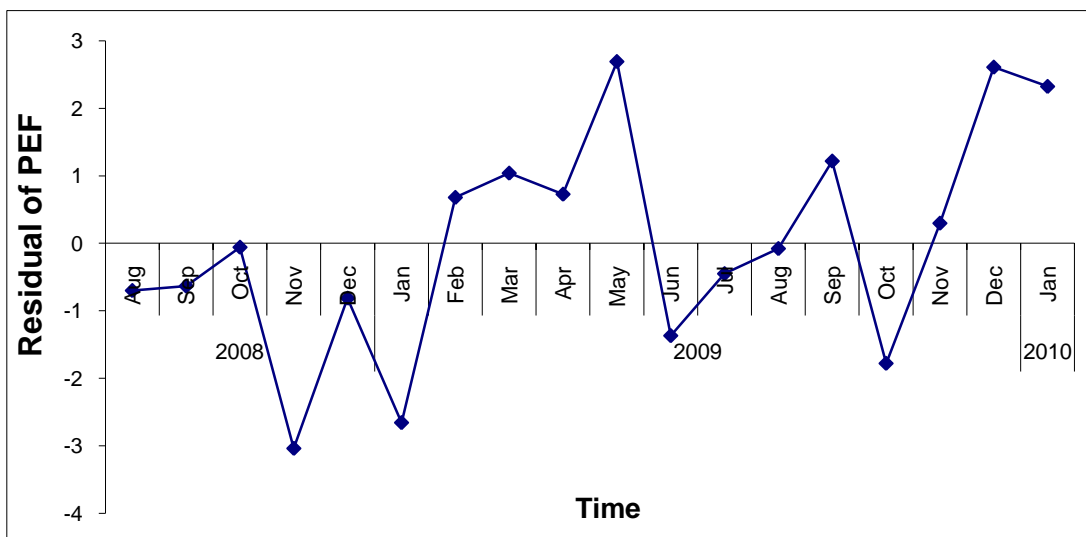


Figure 5.11: Residual plot of PEF versus time for model 8

5.3.1.3 Test for relationship of residuals with explanatory variables for PEF of model 8

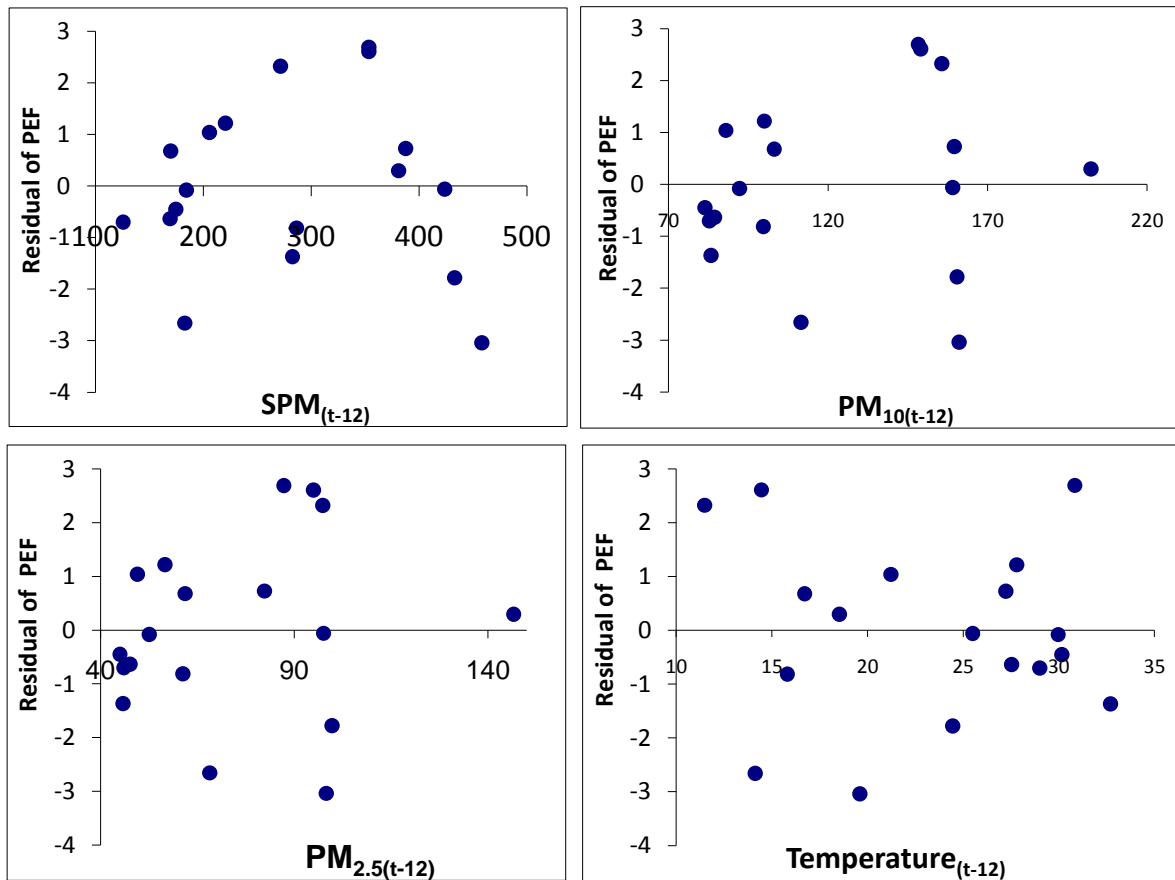


Figure 5.12: Residual plot of PEF versus each independent variable for model 8

Figure 5.12 represents the residuals plot of PEF with different explanatory variable. It is clear that residuals have no relationship with explanatory variables (Figure 5.12). Residual of the equation 8 satisfied the different conditions like normality, randomly orientation and independent variation with respect to explanatory variable; hence equation 8 is the statistically valid model for the prediction of PEF on the basis of explanatory variable like SPM, PM₁₀, PM_{2.5} and temperature.

5.4 Study the relationship of FEF_{25-75%} with SPM, PM₁₀, PM_{2.5} and temperature

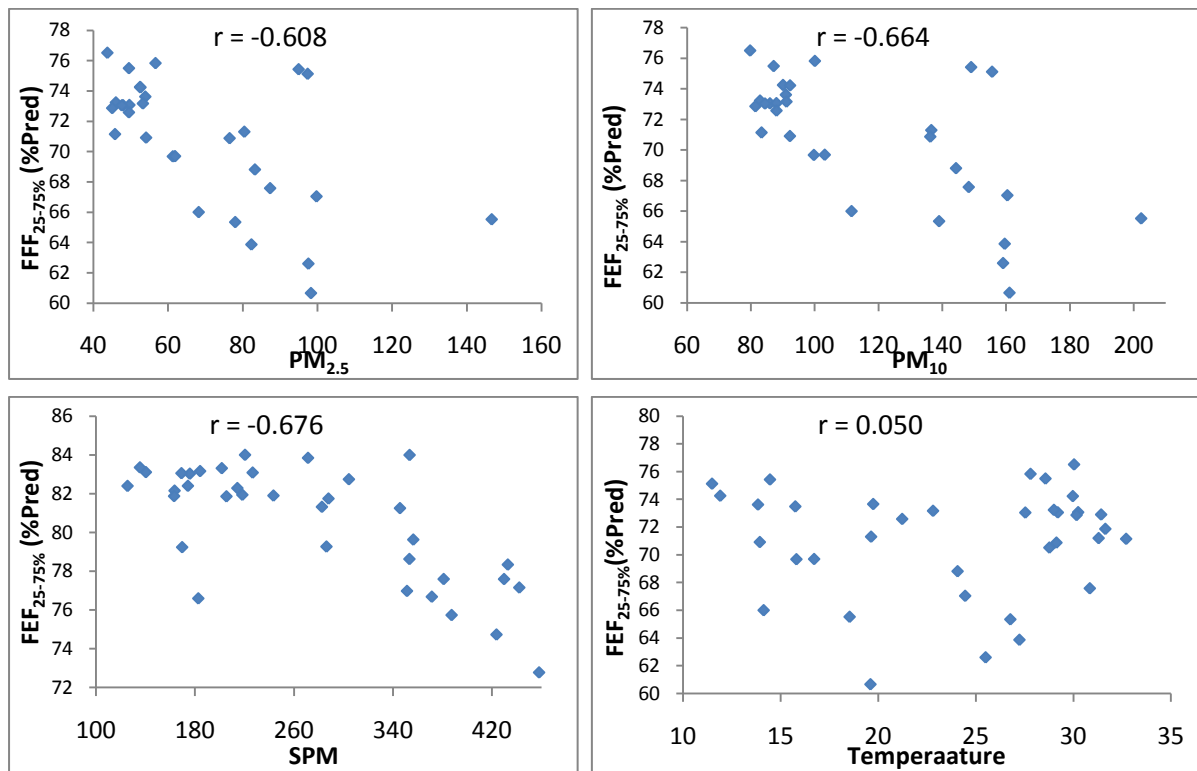


Figure 5.13 Scatter Plot of FEF_{25-75%} versus PM_{2.5}, PM₁₀, SPM and temperature

Scatter plot (Figure 5.13) of FEF_{25-75%} with PM_{2.5}, PM₁₀, SPM and temperature reveals that there is high negative correlation (neagative linear relationship) between FEF_{25-75%} with PM_{2.5}, PM₁₀ and SPM but there is very low positive correlation between FEF_{25-75%} and temperature therefore with increase in each of SPM, PM₁₀ and PM_{2.5} there is decrease in FEF_{25-75%}. Though there exist low positive correlation between FEF_{25-75%} and temperature; temperature is added in the regression model because it has importance in the model on the basis criterion for variable selection. Based on those results, multiple ordinary least squares regression method was used to developed model, as shown in Table 5.10.

Table 5.10: Regression results of FEF_{25-75%} on SPM, PM₁₀, PM_{2.5} and temperature

	Coefficient	Std. Error	t-ratio	p- value
Constant	81.520	3.396	24.003	<0.00001
SPM	-0.012 ^a	0.011	-1.205	0.239
PM ₁₀	-0.106 ^a	0.105	-1.016	0.319
PM _{2.5}	0.083 ^a	0.133	0.623	0.538
Temperature	-0.021 ^a	0.099	-0.219	0.827
R-squared	0.504		Adjusted R squared	0.424

^a: Non-significant value as p-value > 0.05

Table 5.10 represents the coefficient and significance level calculated by using multiple linear regressions between the monthly averages values of FEF_{25-75%} and SPM, PM₁₀, PM_{2.5} and temperature as independent variable of same months. By using the coefficient values of independent variables and constant (Table 5.10) equation for FEF_{25-75%} can be written as

$$FEF_{25-75\%(t)} = 81.5 - 0.01 * SPM_{(t)} - 0.106 * PM_{10(t)} + 0.083 * PM_{2.5(t)} - 0.021 * Temp_{(t)} \dots(10)$$

It is found that (Table 5.10) the coefficient of all independent variables i.e., SPM, PM₁₀, PM_{2.5} and temperature are insignificant. Value of R-squared showed that SPM, PM₁₀, PM_{2.5} and temperature explain 50 percent variation in the FEF_{25-75%} and the coefficient of all independent variables are insignificant which is not accepted statistically for the prediction of FEF_{25-75%}. Hence, model 10 (equation 10), which are developed by using the monthly average value of same months is not accepted. Then explanatory variables were modified by taking lag i.e., FEF_{25-75%} were regressed on 12th lag value of explanatory variables and new equation were developed by using the multiple linear regression technique.

Table 5.11: Regression results of FEF_{25-75%} on the 12th lag value of SPM, PM₁₀, PM_{2.5} and temperature

FEF25	Coefficient	Std. Error	t-ratio	p- value
Constant	77.913	3.471	22.441	<0.00001
SPM _(t-12)	-0.015 ^a	0.012	-1.220	0.243
PM _{10(t-12)}	-0.826	0.234	-3.520	0.003
PM _{2.5(t-12)}	1.235	0.362	3.410	0.004
Temp _(t-12)	0.334	0.128	2.605	0.021
R-squared	0.779	Adjusted R squared		0.712

^a: Non-significant value as p-value > 0.05

Table 5.11 represents the coefficient and significance level of different models calculated by using multi-linear regression between the 12th lag values of dependent variables with the monthly FEF_{25-75%} value. From, it is observed that coefficient of all dependent variables are found to be significant except SPM_(t-12)(Table 5.11). Results shows that SPM_(t-12), PM_{10(t-12)}, PM_{2.5(t-12)} and Temp_(t-12) explaining up to 77 percent variation in the FEF_{25-75%}. Comparison of Table 5.10 and 5.11 shows that modification in the explanatory variables result in improvement of R-square values from 50 to 77 percent in comparison to model 10, so the improved model 11 can be written in the form of equation:

$$FEF_{25-75\%(t)} = 77.9 - 0.01 * SPM_{(t-12)} - 0.82 * PM_{10(t-12)} + 1.23 * PM_{2.5(t-12)} + 0.33 * Temp_{(t-12)} \dots(11)$$

Coefficient of SPM (Table 5.11) is found non-significant. Multiple regressions between dependent and independent variable is calculated after excluding the SPM variable.

Table 5.12: Regression results of FEF_{25-75%} on 12th lag value of PM₁₀, PM_{2.5} and temperature

	Coefficient	Std. Error	t-ratio	p- value
Constant	79.191	3.367	23.516	<0.00001
PM _{10(t-12)}	-0.912	0.227	-4.002	0.001
PM _{2.5(t-12)}	1.283	0.366	3.500	0.003
Temp _(t-12)	0.374	0.126	2.966	0.01
R-squared	0.754	Adjusted R squared		0.702

Table 5.12 represents the coefficient and significance level of FEF_{25-75%} model calculated by using multi-linear regression between the 12th lag values of dependent variables with the monthly independent variables after excluding the SPM variables. Multiple linear regression results reveal that (Table 5.12); coefficients of all dependent variables are significant and explain up to 75 percent variation in FEF_{25-75%} and by using the value of different coefficients, equation can be written as

$$FEF_{25-75\%(t)} = 77.9 - 0.01*SPM_{(t-12)} - 0.82*PM_{10(t-12)} + 1.23*PM_{2.5(t-12)} + 0.33*Temp_{(t-12)} \dots(12)$$

Comparison of Table 5.11 and 5.12 shows that R-squared value decreased from 77 to 75% and adjusted R-squared value decreased from 71 to 70% in model 12 after excluding SPM from model 11 by multi linear regression technique, so there is no need to exclude SPM as dependent variable to predict FEF_{25-75%}. Hence, equation 11 is the final accepted model which could predict next one year value of FEF_{25-75%} on the basis of available values of explanatory variables i.e., SPM, PM₁₀, PM_{2.5} and temperature.

5.4.1 Validation of FEF_{25-75%}'s model

5.4.1.1 Test for normal distribution of residuals for FEF_{25-75%} of model 11

Figure 5.14 represents the normality plot for residual of FEF_{25-75%} by using equation 11. Test for null hypothesis of normal distribution gives Chi-square (2) = 1.925 with p-value 0.381. Since p value is found to be greater than 0.05. Hence, null hypothesis is accepted and residuals are following normal distribution.

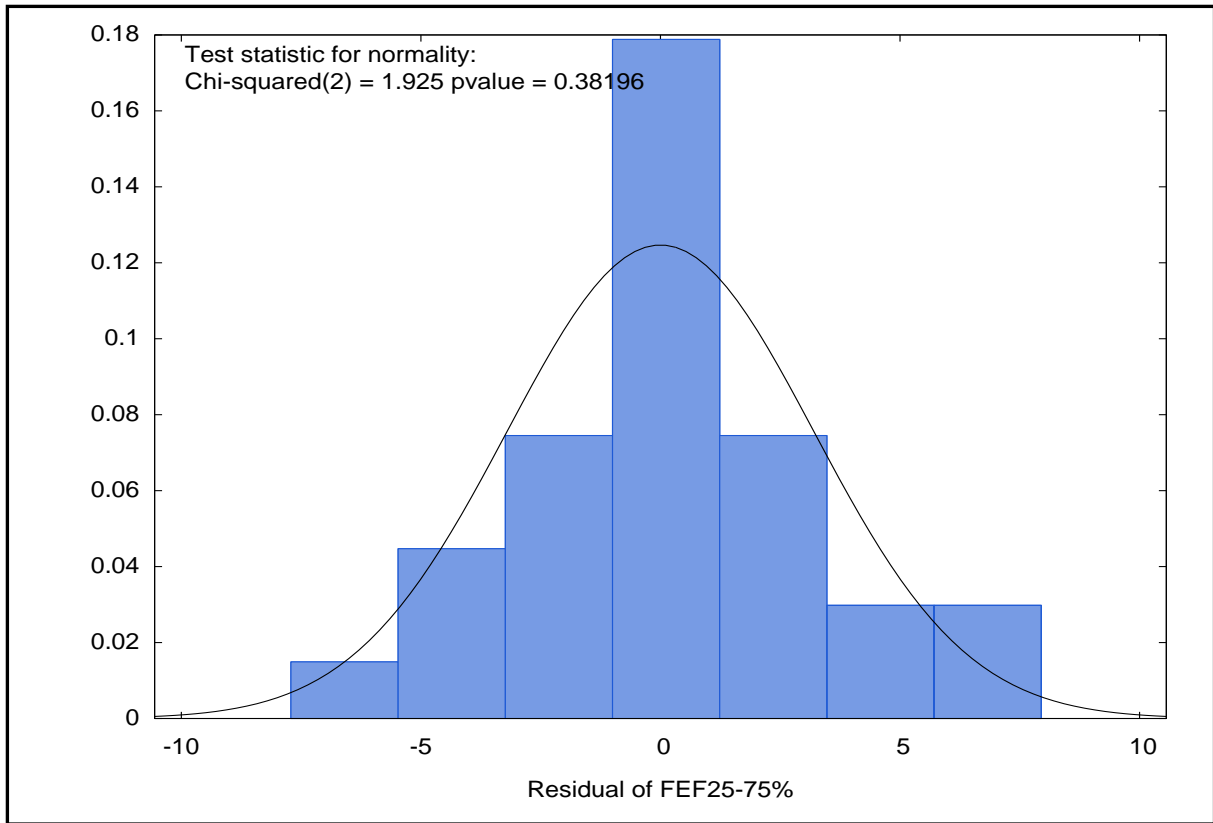


Figure 5.14: Histogram to test normality of residual for FEF_{25-75%} of model 11

5.4.1.2 Test for randomness of residuals for FEF_{25-75%} of model 11

Figure 5.15 represents the residuals plot of FVC versus time for the model 11. Residuals are randomly oriented having no relationship with time. Thus, residuals are following the assumption of randomness.

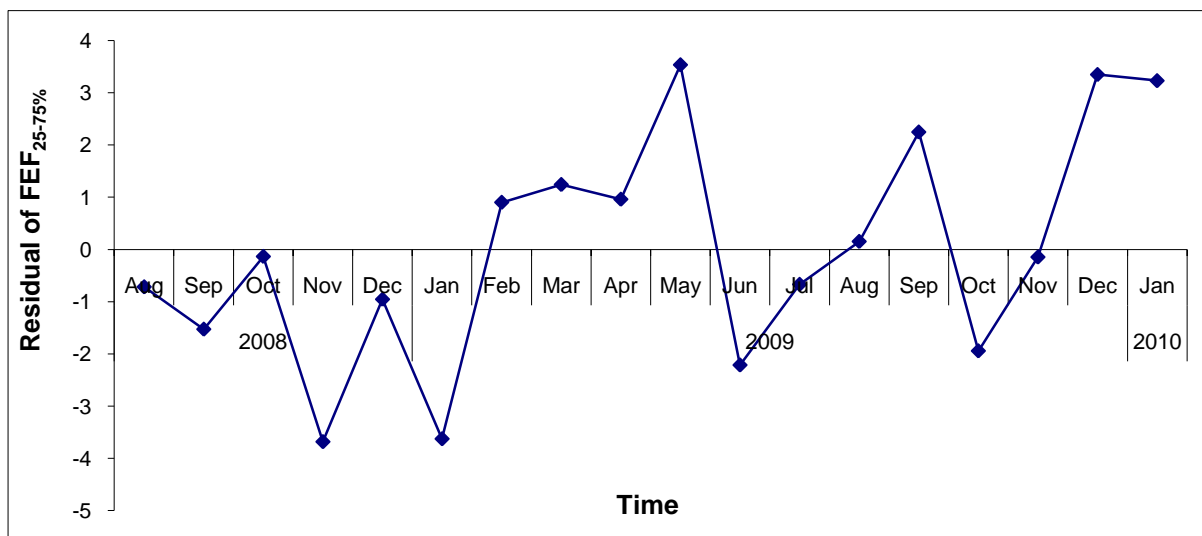


Figure 5.15: Residual plot of FEF_{25-75%} versus time for model 11

5.4.1.3 Test for relationship of residuals with explanatory variables for FEF_{25-75%} of model 11

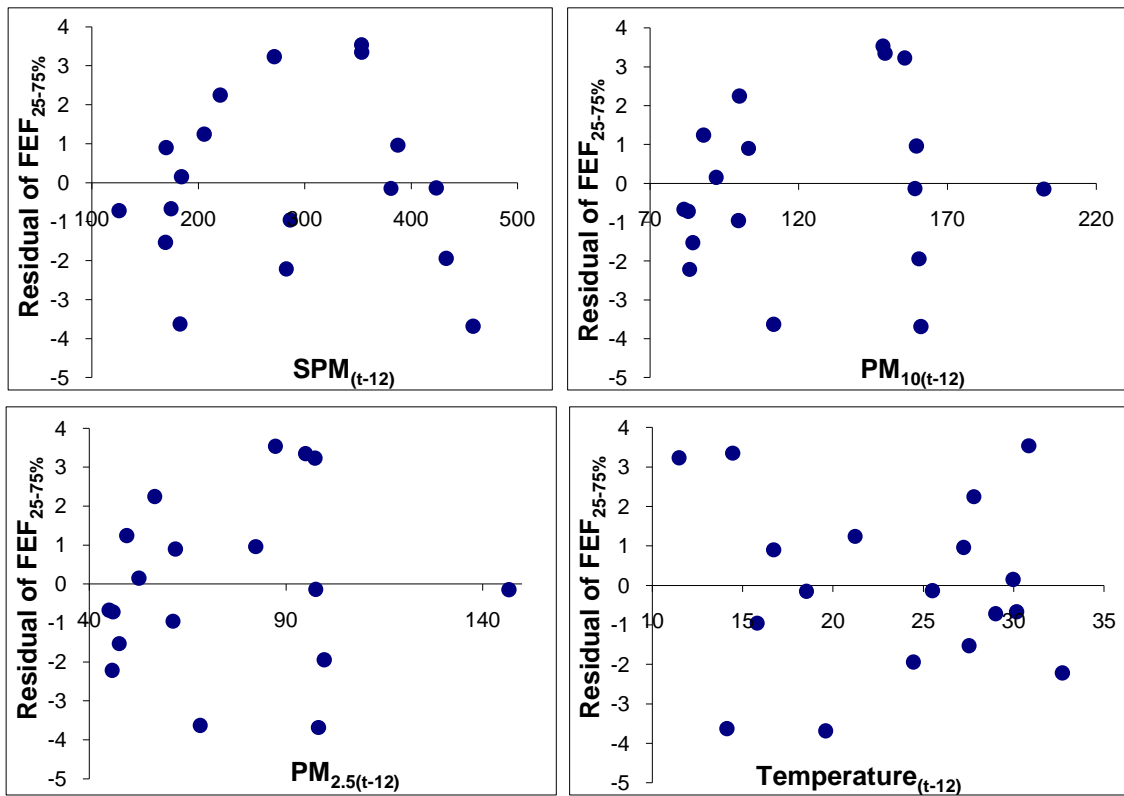


Figure 5.16: Residual plot of FEF_{25-75%} versus each independent variable for model 11

Figure 5.16 represents the residuals plot of FEF_{25-75%} with different explanatory variable. It is clear that residuals have no relationship with explanatory variables (Figure 5.16). Residual of the equation 11 satisfied the different conditions like normality, randomly orientation and independent variation with respect to explanatory variable; hence equation 8 is the statistically valid model for the prediction of FEF_{25-75%} on the basis of explanatory variable like SPM, PM₁₀, PM_{2.5} and temperature.

By using multi-linear regression technique final accepted models which may use to predict the value of different PFTs

$$FVC_{(t)} = 98.4 - 0.38 * PM_{10(t-12)} + 0.46 * PM_{2.5(t-12)} + 0.18 * Temp_{(t-12)} \quad \dots(a)$$

$$FEV_{1(t)} = 99.6 - 0.46 * PM_{10(t-12)} + 0.55 * PM_{2.5(t-12)} + 0.21 * Temp_{(t-12)} \quad \dots(b)$$

$$PEF_{(t)} = 84.07 - 0.013 * SPM_{(t-12)} - 0.64 * PM_{10(t-12)} + 0.98 * PM_{2.5(t-12)} + 0.29 * Temp_{(t-12)} \quad \dots(c)$$

$$FEF_{25-75\%(t)} = 77.9 - 0.01 * SPM_{(t-12)} - 0.82 * PM_{10(t-12)} + 1.23 * PM_{2.5(t-12)} + 0.33 * Temp_{(t-12)} \quad \dots(d)$$

These four set of equations is named as Field Crop Residue Burning and Pulmonary Function Model (FCRBPFM), which might be used to predict the value of different PFTs of next 12 months on the basis of given value of dependent variables. Differences in these equations are that FVC and FEV₁

are explained on the basis of three explanatory variable i.e., PM_{10} , $PM_{2.5}$ and temperature, whereas in PEF and $FEF_{25-75\%}$, SPM is also involved.

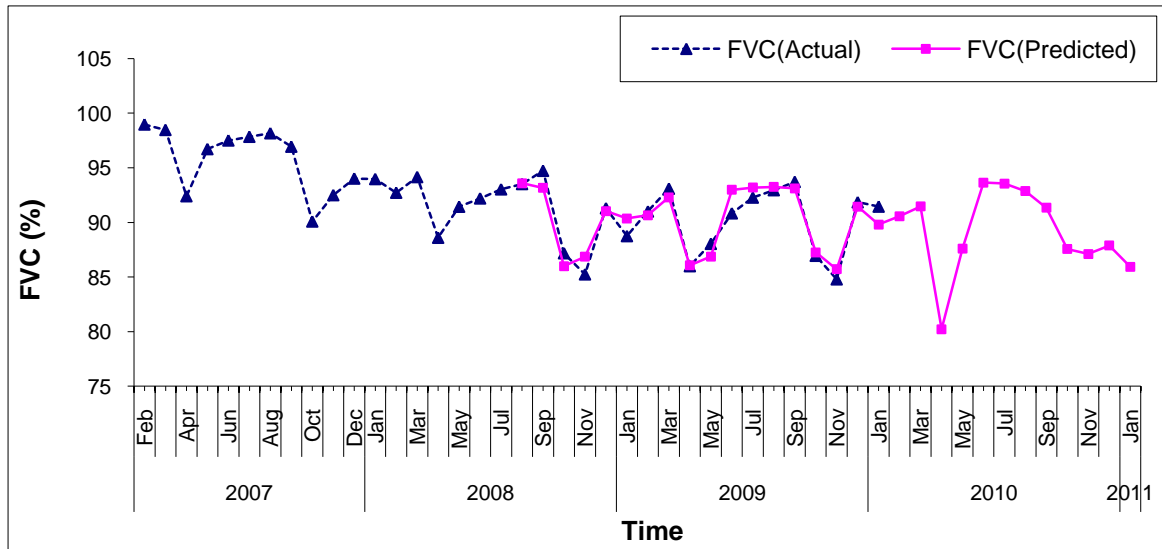


Figure 5.17: Monthly average variation of FVC (%) from February’2007 to January’2011
(a) Triangle notation represents actual values from February’2007 to January’2010;
(b) Square notation represents predicted values on the basis of accepted model from August’2008 to January’2011

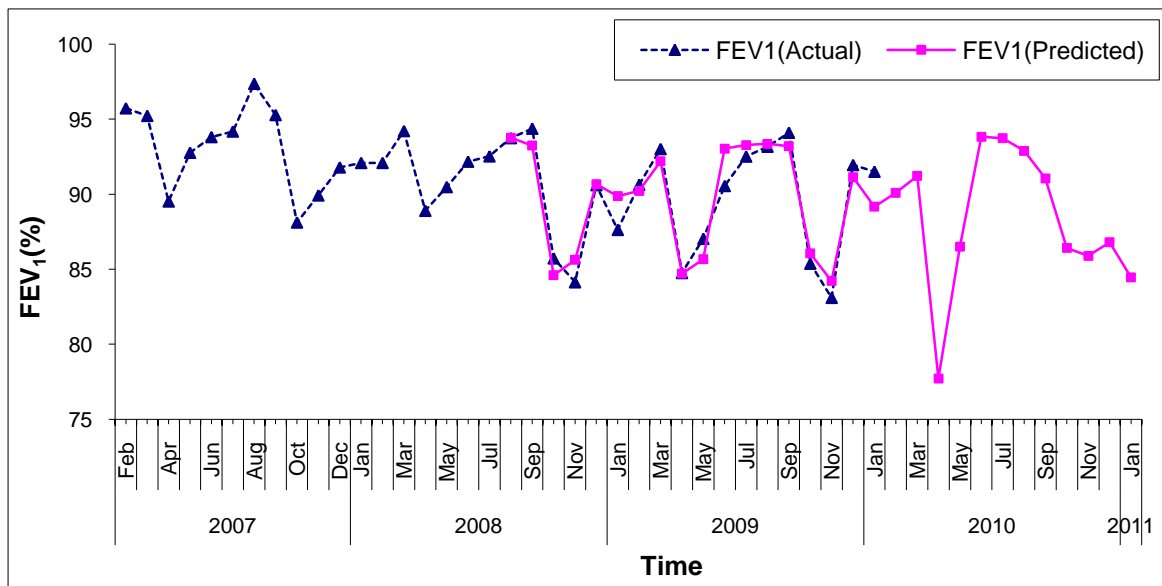


Figure 5.18: Monthly average variation of FEV₁ (%) from February’2007 to January’2011.
(a) Triangle notation represents actual values from February’2007 to January’2010;
(b) Square notation represents predicted values on the basis of accepted model from August’2008 to January’2011

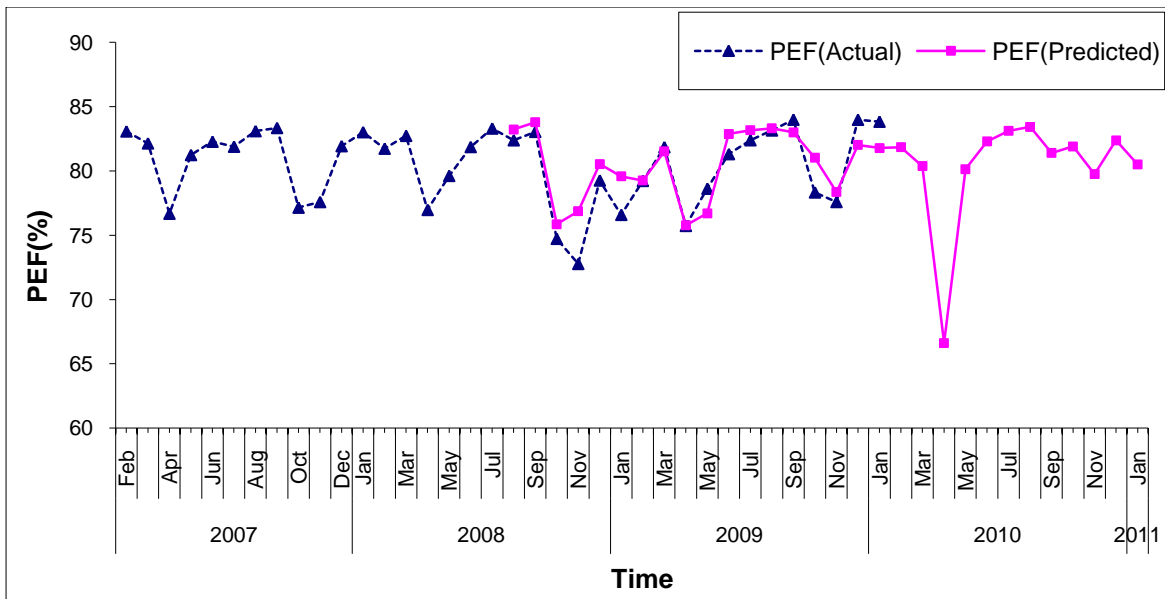


Figure 5.19: Monthly average variation of PEF (%) from February'2007 to January'2011. (a) Triangle notation represents actual values from February'2007 to January'2010; (b) Square notation represents predicted values on the basis of accepted model from August'2008 to January'2011

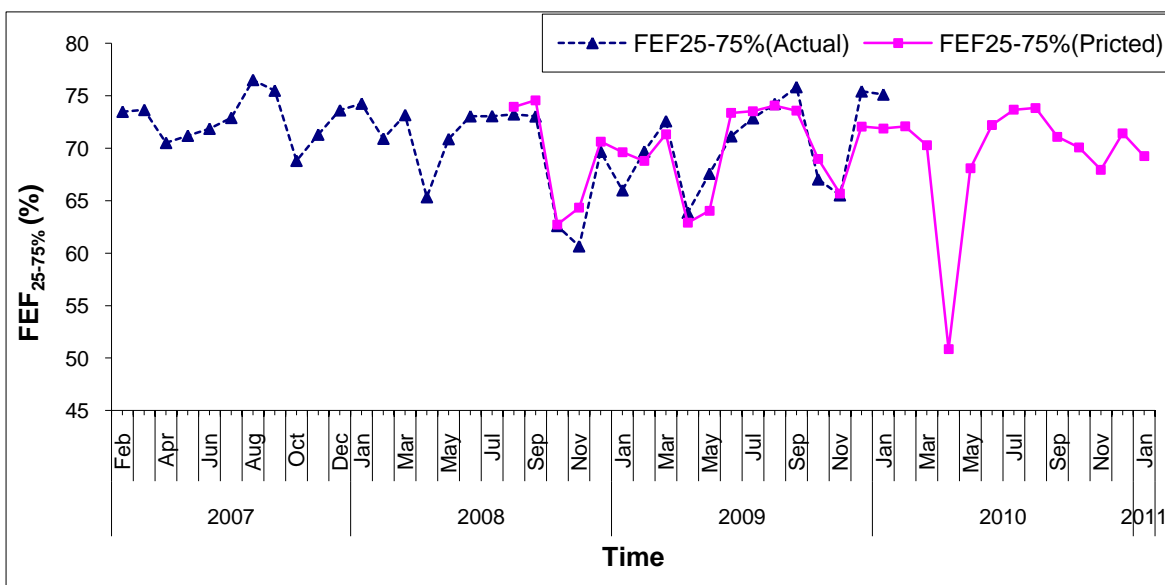


Figure 5.20: Monthly average variation of FEF_{25-75%} (%) from February'2007 to January'2011. (a) Triangle notation represents actual values from February'2007 to January'2010; (b) Square notation represents predicted values on the basis of accepted model from August'2008 to January'2011

Figures 5.17 to 5.20 represent the monthly average variation of PFTs of 50 subjects from February 2007 to January 2010 along with the predicted value of PFTs from August 2008 to January 2011 by using model 7 to 9 (shows by squares). Figure 5.17 to 5.20 shows that remarkable decrease in different pulmonary functions during the month of April-May and October-November which infer

that during the field burning of wheat and rice crop residue, PFTs of even healthy subjects decreased. Models clearly signify the effect of field burning of wheat and rice crop residue on the PFTs. Collective name given to the four models (equation 7 to 9) as FCRBPFM.

FCRBPFM is used to predict the value of different PFTs for the next 12 months on the basis of available value of explanatory variable, hence to increase the efficiency of model, values of explanatory variables were predicted by using an Autoregressive Integrated Moving Average (ARIMA) model, which can be used further to predict the PFT values of succeeding years.

ARIMA model is a generalization of an Autoregressive Moving Average (ARMA) model. These models are fitted to time series data either to better understand the data or to predict future points in the series (forecasting). They are applied in some cases where data show evidence of non-stationarity, where an initial differencing step (corresponding to the "integrated" part of the model) can be applied to remove the non-stationarity.

The model is generally referred to ARIMA (p,d,q) model where p, d and q are integers greater than or equal to zero and refer to the order of the autoregressive, integrated and moving average parts of the model respectively.

In the present study SPM, PM₁₀, PM_{2.5} and temperature are the explanatory variables. By using the ARIMA models prediction of SPM has been done and shown in Table 5.13.

Table 5.13: Results for ARIMA models for SPM

S. No.	Models	Log-likelihood	Akaike Information criterion
1	ARIMA(1,0,0)	-214.9805	437.9611
2	ARIMA(1,0,1)	-211.8105	433.6210
3	ARIMA(0,0,2)	-207.2644	424.5287
4	ARIMA(2,0,0)	-208.1496	426.2991
5	ARIMA(6,0,0)	-199.9226	417.8452

Table 5.13 represents the result of ARIMA model for the prediction of SPM. ARIMA(6,0,0) has highest Log-likelihood and minimum Akaike Information Criteria. ARIMA (6,0,0) is the best accepted model for the prediction of SPM values.

Table 5.14: Forecasted value of SPM by using the ARIMA (6,0,0)

Observation	Prediction	std. error	95% interval
2010:02	155.823	60.0747	(38.0785, 273.567)
2010:03	211.940	60.5949	(93.1763, 330.704)
2010:04	348.672	68.8453	(213.738, 483.607)
2010:05	374.041	70.3307	(236.196, 511.887)
2010:06	344.785	71.0838	(205.463, 484.107)
2010:07	279.619	71.1955	(140.078, 419.160)
2010:08	202.640	78.5587	(48.6682, 356.613)
2010:09	227.886	79.4936	(72.0817, 383.691)
2010:10	320.316	81.6723	(160.242, 480.391)
2010:11	361.344	83.3271	(198.026, 524.662)
2010:12	344.203	83.8500	(179.860, 508.546)
2011:01	291.143	83.9457	(126.612, 455.673)
2011:02	235.405	86.6377	(65.5984, 405.212)
2011:03	244.462	87.4254	(73.1111, 415.812)
2011:04	307.216	87.9742	(134.790, 479.642)
2011:05	348.760	89.1545	(174.020, 523.500)
2011:06	342.543	89.5834	(166.963, 518.123)
2011:07	301.950	89.6256	(126.287, 477.613)
2011:08	259.301	90.8061	(81.3240, 437.277)
2011:09	259.848	91.3691	(80.7676, 438.928)
2011:10	302.437	91.4882	(123.123, 481.750)
2011:11	339.146	92.1870	(158.462, 519.829)
2011:12	340.375	92.5298	(159.020, 521.730)
2012:01	310.967	92.5393	(129.594, 492.341)
2012:02	277.682	93.0962	(95.2168, 460.147)
2012:03	273.715	93.4748	(90.5082, 456.923)
2012:04	302.443	93.4910	(119.204, 485.682)
2012:05	332.904	93.8647	(148.932, 516.875)
2012:06	338.468	94.1193	(153.998, 522.938)
2012:07	318.203	94.1194	(133.732, 502.673)
2012:08	292.279	94.3863	(107.285, 477.273)
2012:09	286.116	94.6323	(100.640, 471.592)
2012:10	305.235	94.6324	(119.759, 490.711)
2012:11	329.625	94.8184	(143.785, 515.466)
2012:12	337.286	94.9946	(151.100, 523.472)
2013:01	324.047	94.9966	(137.857, 510.237)
2013:02	304.123	95.1221	(117.687, 490.559)
2013:03	297.189	95.2773	(110.449, 483.929)
2013:04	309.639	95.2802	(122.893, 496.385)
2013:05	328.714	95.3671	(141.798, 515.630)
2013:06	337.023	95.4821	(149.881, 524.164)
2013:07	328.944	95.4881	(141.791, 516.097)
2013:08	313.922	95.5445	(126.658, 501.185)
2013:09	307.089	95.6396	(119.639, 494.540)
2013:10	314.948	95.6465	(127.484, 502.412)
2013:11	329.606	95.6845	(142.068, 517.144)
2013:12	337.701	95.7557	(150.023, 525.379)
2014:01	333.272	95.7641	(145.578, 520.967)
2014:02	322.203	95.7878	(134.463, 509.944)
2014:03	315.977	95.8443	(128.126, 503.829)
2014:04	320.726	95.8529	(132.858, 508.594)
2014:05	331.831	95.8682	(143.933, 519.729)
2014:06	339.249	95.9104	(151.268, 527.230)
2014:07	337.310	95.9192	(149.312, 525.308)
2014:08	329.375	95.9282	(141.359, 517.391)
2014:09	324.007	95.9607	(135.928, 512.086)
2014:10	326.704	95.9689	(138.608, 514.799)
2014:11	335.019	95.9744	(146.913, 523.126)
2014:12	341.555	95.9984	(153.401, 529.708)
2015:01	341.247	96.0061	(153.079, 529.416)

Thirty six data point used for the development of ARIMA (6,0,0) for SPM. This model is used efficiently for the prediction of SPM till January 2015. ARIMA (6,0,0) may be used for prediction of more year but due to less available data points, standard error increases and variation or difference between the SPM value during different month decreases. Thus, the proposed model should be updated with new available data, which will improve the forecast of SPM and consequently the PFTs.

By using ARIMA (6,0,0) value of SPM is predicted and value up to January 2015 is shown in Table 5.14. This can be further advanced or modified, it is only proposed and further work may be done in this area.

Similarly, by choosing the best ARIMA model on the basis of Log-likelihood and minimum Akaike Information Criteria, other explanatory variables were also predicted and used for the forecasting of the PFTs for more years. Another method may be used but in the present study ARIMA is proposed.

Hence by using the technique to forecast the value of explanatory variable importance of the FCRBPFM increase as PFTs can be predicted for more years on the basis of given three year data. Health depends not only on environmental factors, but also on several other factor like hereditary, nutritional, economic *etc.* which may add error in the proposed model's, as these factor were not taken into account which need to be assimilated for the future application of this model.

Chapter VI

Conclusion and future recommendations

Open burning of crop residues is episodic but still a serious issue for both health and environment perspective as it causes momentous increase in the concentration of particulate matter that even cross the standard limits set by national and international standards which ultimately affect health of the individuals.

The effect of rice crop residue burning on the ambient air quality is found to be higher in comparison to wheat crop residue burning, as the concentration of different size particulate matter and the percentage of fine fraction in total RSPM were found to be higher during rice crop residue burning period. Percentage of small size particulate matter *i.e.*, $PM_{2.5}$ in PM_{10} is greater in comparison to coarse size particles *i.e.*, $PM_{10-2.5}$ irrespective of burning and non-burning periods. ACRB poses significant effect on the concentration levels of particulate matter in the ambient air but not much effect on their distribution.

Monthly variation of different Pulmonary Function Test (PFTs) and Oxygen saturation level (SpO_2) indicates that the values of various PFTs decreases during the months of ACRB but does not pose any change on the SpO_2 and it was considered that deviations in the values of SpO_2 may be due to the environmental factors like temperature. Among different PFTs, FVC and FEV_1 do not show complete recovery whereas other subsequent PFTs like PEF, $FEF_{25-75\%}$, $FEF_{50\%}$ and $FEF_{25\%}$ shows partial recovery after the completion of burning episode. Among different age groups, upper (> 40 years) and lower age group (< 18 years) are most affected by the burning of crop residues in comparison to middle (18 to 40 years) age group subjects.

All the analyses are well supported with large significant levels obtained by calculating the difference using paired t-test. Significant negative association between different size particulate matter and PFTs indicate that exposure of low air quality for definite period of time results in decrease in the PFTs of healthy subjects. Effect of small size particulate matter *i.e.*, $PM_{2.5}$ shows maximum contribution in the decrease of different PFTs.

Field Crop Residue Burning and Pulmonary Function Model (FCRBPFM) has been developed by using the data of three years as well as tested which could be used to predict the value of PFTs of next 12 months. Further, FCRBPFM may be used to predict the value of pulmonary functions of next year if monthly levels of SPM, PM_{10} , $PM_{2.5}$ and temperature of current year are known.

Future recommendations

Open field burning of agriculture crop residue is episodic which covers one-third period of the whole year during which ambient air quality is low which poses permanent effect on the PFTs of even healthy subjects. ACRB is a serious environmental health hazards, hence attempts should be made to lower the effects of ACRB by adopting some realistic regulation which may include steps like total ban or permitting it with proper guidance or educate the farmers with alternate methods for disposal of agricultural residues.

Different results of the present study clearly shows the ill effects of ACRB on the health of the healthy individuals and thus the strategy can be used to study the effect on the diseased group considering other PFTs also and the model developed could be used as an effective tool for risk assessment, although certain uncertainty need to be addressed in future refinement of this model for better prediction compatibility.

Study of PFTs can be extended for children (< 14 years) and adults (> 40 years), as they are more affected by the ACRB.

List of Publications

1. Amit Awasthi, Nirankar Singh, Susheel Mittal, Prabhat K Gupta and Ravinder Agarwal. Study of size and mass distribution of particulate matter due to crop residue burning with seasonal variation in rural area of Punjab, India. **Journal of Environment monitoring, 2011, DOI: 10.1039/c1em10019j.**
2. Amit Awasthi, Nirankar Singh, Susheel Mittal, Prabhat K Gupta and Ravinder Agarwal. Effects of Agriculture Crop Residue Burning on Children and Young on PFTs in North West India. **Science of Total Environment, 408:4440-4445, 2010.**
3. Ravinder Agarwal, Amit Awasthi, Susheel Mittal, Nirankar Singh and Prabhat K. Gupta Effects of air pollution on respiratory parameters during the wheat-residue burning in Patiala. **Journal of Medical Engineering and Technology, 34:23-28, 2010.**
4. Nirankar Singh, Susheel K Mittal, Ravinder Agarwal, Amit Awasthi and Prabhat Kumar Gupta. Impact Assessment of Rice Crop Residue Burning on Levels of SPM, SO₂ and NO₂ in ambient air of Patiala city in India. **International Journal of Environmental Analytical Chemistry, 90(10):829-843, 2010.**
5. Nirankar Singh, Ravinder Agarwal, Amit Awasthi, Prabhat K Gupta and Susheel K Mittal. Characterization of atmospheric aerosols for organic tarry matter and combustible matter during crop residue burning and non-crop residue burning months in Northwestern region of India. **Atmospheric Environment, 44:1292-1300, 2010.**
6. Susheel K Mittal, Nirankar Singh, Ravinder Agarwal, Amit Awasthi and Prabhat K Gupta. Ambient air quality during wheat and rice crop stubble burning episodes. **Atmospheric Environment, 43:238-244, 2009.**
7. Amit Awasthi, Ravinder Agarwal, Nirankar Singh, Prabhat K Gupta and Susheel K Mittal. Effects of exposure to rice-crop residue burning smoke on pulmonary functions and oxygen saturation level of human being in Patiala (communicated).
8. Amit Awasthi, Ravinder Agarwal, Susheel K Mittal, Nirankar Singh and Prabhat K Gupta. Statistical model to quantify the effect of pollution loading due to field crop residue burning on the PFTs of healthy subjects (communicated).

QUESTIONNAIRE

(For those 13 years of age and older)

**Thank you for your willingness to participate.
You are considered for the study by a scientific sampling procedure, and
your cooperation is very important for the success of this study.**

**This is a questionnaire which you are asked to fill.
Please answer the questions accurately as possible without hesitation**

**ALL INFORMATION OBTAINED IN THE STUDY WILL BE KEPT
CONFIDENTIAL AND USED FOR MEDICAL RESEARCH
PURPOSE ONLY**

Part -2 Chronic Respiratory Symptoms questionnaire

Part A: Identification Data

1. Identification Number
2. Name
3. Name of the Father/spouse
4. Name of the Head of the family
5. Age
6. Sex
7. Address

Part B: General Information of Household and family

8. Distance from the mail road (in meters)
9. Any local sources of outdoor pollution (eg. Factory *etc.*)
10. Floor of residence : Yes () / No ()
11. Number of rooms
12. Number of household members : Yes () / No ()
13. Type of fuel used: (tick the response, one or more)
a. Gas b. Kerosene c. wood d. cow dung cake e. coal
14. Is there a separate kitchen? Yes () / No ()
15. Do you use mosquito coils/liquid repellants? Yes () / No ()
16. Total family income per month per capita (**divide total by number of persons & tick the response**)
 - a. Below Rs 1000
 - b. Rs 1000 – 3000
 - c. Rs 3000 – 5000
 - d. Rs 5000 – 10, 000
 - e. Rs 10, 000 and above

Part C: Personal Information

17. Marital status (**Tick the response**)
- a. Unmarried
 - b. Married
 - c. Divorced
 - d. Widowed
18. Number of years staying at given address
19. Where did you live before this?
If yes then for how long
20. Educational status (**Tick the response**):
- a. Primary/Middle School
 - b. High school
 - c. Graduate
 - d. Post graduate/ Professional
 - e. Illiterate
21. Occupational status (**Tick the response**):
- a. Employed
 - b. Student
 - c. Housewife
 - d. Unemployed
 - e. Previously employed but now unemployed

If the response is = a; continue with the following questions

If the response is = b; continue with question number – 25

If the response is = c, d or e; continue with question number – 28

22. What is your occupation?
23. Do you work indoors? Yes () / No ()
If yes (**Tick the response**)
- a. Shop
 - b. Office
 - c. Factory
 - d. Other (Please specify)
24. Do you work outdoors? Yes () / No ()
If yes (**Tick the response**)
- a. At one place
 - b. Moving from one place to another
 - c. Others (Please specify)

25. How do you usually get to work/School/ College? (**Tick one or more**)
- a. Bus
 - b. Train
 - c. Car
 - d. Three wheelers
 - e. Scooter/Motor cycle
 - f. Bicycle
 - g. On foot
26. What are your work/school/ college timing?
From _____ to _____
27. Where is your place of work/ study located (address)
28. Are you regularly exposed to any kind of irritant such as dust, smoke or fumes at work/home/study? Yes () / No ()
29. If you had another job earlier, did you have similar exposure in your job? Yes () / No ()
30. How much time you spend in the kitchen?
31. Smoking Status:
- a. Never smoked
 - b. Ex-smoker
 - c. Current smoker
- If ex-smoker or current smoker, continue with the following questions.
If non smoker, go to question no. 36*
32. What do you or did you smoke?
- a. Bidi
 - b. Cigarettes
 - c. Hukka
 - d. Others (Please specify)
33. At what age did you start smoking?
34. How many Bidis/Cigarettes etc. Do you smoke or used to smoke every day?
35. If ex-smoker, reason for stopping
36. If a nonsmoker, does anybody smoke in your presence at home or at work?

Additional Information :

37. Height:
38. Weight:
39. Overall socioeconomic status
- a. Low
 - b. Medium
 - c. High

Part D: Question related to respiratory diseases and allergies

A. COUGH

1. Do you frequently get a cough? Yes () / No ()
2. Do you usually cough you get up in the morning? Yes () / No ()
3. Do you usually cough at other times during the day or night? Yes () / No ()

If “No” go to “C”

If “Yes” ask the following questions:

4. Do you cough like this on most days for 3 months or more during the year? Yes () / No ()

B. PHLEGM

5. Do you frequently bring up phlegm or sputum from your chest? Yes () / No ()
6. Do you frequently bring up phlegm or sputum from your chest when you get up in the morning? Yes () / No ()
7. Do you frequently bring up phlegm or sputum from your chest at other times during the day or night? Yes () / No ()
8. Do you frequently bring up phlegm or sputum from your chest on most days for as much as 3 months in a year? Yes () / No ()

C. SHORTNESS OR BREATH

9. Do you get short of breath when you hurry (walk fast) on level ground or walk up a slight incline? Yes () / No ()
10. Do you get short of breath walking with other people of your age on level ground? Yes () / No ()
11. Do you have to stop or reduce your pace to catch breath? Yes () / No ()

D. WHEEZING

12. Do you ever get breathing difficulty with wheezing or whistling sound in your breathing? Yes () / No ()
13. Did you ever get wheezing or whistling sound in your breathing during the: (**Tick the response**)
 - a. Last week
 - b. Last months
 - c. Last 3 months
 - d. Last 6 months
 - e. Last 1 year

14. Does this wheezing or whistling sound occur:
- a. After “cold”? Yes () / No ()
 - b. After running or exercise or playing? Yes () / No ()
 - c. When you are exposed to dust/smoke/smells? Yes () / No ()
 - d. When the weather or season changes? Yes () / No ()
 - e. At night, waking you up from sleep? Yes () / No ()
15. If you have a breathing problem, has your doctor diagnosed it as asthma? Yes () / No ()
16. If you have a breathing problem, have you ever taken a medicine that makes breathing easier? Yes () / No ()

E. CHEST ILLNESSES

17. During the past 2 years have you had any chest illnesses that have kept you off work, indoor at home or in bed? Yes () / No ()
18. Have you ever had or do you currently have any chronic heart or chest disease (**Chronic mean disease of long duration**) Yes () / No ()
- If yes is it tuberculosis? Yes () / No ()
 - If not tuberculosis, do you know what is it? Yes () / No ()
19. Have you ever get a chest X ray taken? Yes () / No ()
- If yes was it abnormal? Yes () / No ()

F. QUESTION ON SKIN ALLERGY & CONJUNCTIVITIS

20. Do you often have itching or rash? Yes () / No ()
21. Do you often have sneezing, runny or blocked nose? Yes () / No ()
22. Do you often have watering and itching in the eyes? Yes () / No ()

Signature of Interviewer

Signature of Supervisor

References

- Aditama, T.Y. Impact of haze from forest fires in Indonesia to respiratory health. *Respirology*, 5:169-174, 2000.
- Aekplakorn, W., Loomis, D, Vichit–Vandakan, N, and Bangdiwala, S. Heterogeneity of daily pulmonary function in response to air pollution among asthmatic children. *Southeast Asian Journal of Tropical Medical Public Health*, 35: 990-998, 2004.
- Aekplakorn, W., Loomis, D., Vichet-Vadakan, N., Shy, C., and Vityayanon, P. Acute effect of sulphur dioxide from a power plant on pulmonary function of children, Thailand. *International Journal of Epidemiology*, 32:854-861, 2003.
- Agarwal, R., Jayaraman, G., Anand, S., and Marimuthu, P. Assessing respiratory morbidity through pollution status and meteorological condition for Delhi. *Environment Monitoring and Assessment*, 114:489-504, 2006.
- American Thoracic Society. Respiratory Health Hazards in Agriculture. *American journal of Respiratory and critical care medicine*, 158:1-76, 1998.
- Amirav, I., Balanov, I., Gorenberg, M., Luder, A.S., Newhouse, M.T., and Groshar, D. β -Agonist Aerosol Distribution in Respiratory Syncytial Virus Bronchiolitis in Infants. *Journal of Nuclear Medicine* 43: 4, 487-491, 2002.
- Andre, D., Kosatsky, T., and Bonnier, J.G. Problems and intervention schemes for carbon monoxide intoxication in arenas. *Canadian Journal of Public Health*, 79, 124-129, 1988.
- Andreae, M. O. and Merlet, P. Emission of trace gases and aerosols from biomass burning. *Global Biogeochemical Cycles*, 15:955– 966, 2001.
- Andreae, M. O. and Rosenfeld, D. Aerosol-cloud-precipitation interactions. Part 1. The nature and sources of cloud-active aerosols. *Earth Science Review*, 89:13–41, 2008.
- Andreae, M. O., Jones, C. J., and Cox, P. M. Strong present-day aerosol cooling implies a hot future. *Nature*, 435:1187–1190, 2005.
- Arbex, M.A., Bohm, G.M., Saldiva, P.H.N., Conceicao, G.M.S., Pope, A.C. III, and Braga, A.L. Assessment of the effects of sugar cane plantation burning on daily counts

of inhalation therapy. *Journal of Air Waste and Management Association*, 50:1745-1749, 2000.

Arbex, M.E., Martins, L.C., Oliveira, R.C.D., Pereira, L.A.A., Arbex, F.F., Cançado, J.E.D., Saldiva, P.H.N.S., Braga, A.L.F. Air pollution from biomass burning and asthma hospital admissions in a sugar cane plantation area in Brazil. *Journal of Epidemiology Community Health*, 61:395-400, 2007.

Asa-Awuku, A., Sullivan, A. P., Hennigan, C. J., Weber, R. J., and Nenes, A. Investigation of molar volume and surfactant characteristics of water-soluble organic compounds in biomass burning aerosol. *Atmospheric Chemistry and Physics*, 8:799–812, 2008.

Awasthi, A., Agarwal, R., Singh, N., Gupta P.K., and Mittal S.K. Study of size and mass distribution of particulate matter due to crop residue burning with seasonal variation in rural area of Punjab, India. *Journal of Environment monitoring*, 2011 DOI: 10.1039/c1em10019j.

Badarinath, K. V. S., Kharol, S. K., Sharma, A. R., and Krishna Prasad, V.: Analysis of aerosol and carbon monoxide characteristics over Arabian Sea during crop residue burning period in the Indo-Gangetic Plains using multi-satellite remote sensing datasets, *Journal of Atmospheric Solar-Terrestrial Physics*, 71:1267–1276, 2009a.

Badarinath, K. V. S., Kharol, S. K., Sharma, A. R., Ramaswamy, V., Kaskaoutis, D. G., and Kambezidis, H. D.: Investigations of an intense aerosol loading during 2007 cyclone SIDR – A study using satellite data and ground measurements over Indian region, *Atmospheric Environment*, 43: 3708–3716, 2009b.

Badarinath, K.V.S., Kharol, S.K., and Sharma, A. R. Long-range transport of aerosols from agriculture crop residue burning in Indo-Gangetic Plains – A study using LIDAR, ground measurements and satellite data. *Journal of Atmospheric Solar-Terrestrial Physics*, 71:112–120, 2009a.

Badarinath, K.V.S., Kiran Chand, T.R., and Prasad V. K. Agriculture crop residue burning in the Indo-Gangetic Plains – A study using IRS-P6 AWiFS satellite data. *Current Science*, 91:1085-1089, 2006.

Badarinath, K.V.S., Latha, K.M., Kiran-Chand, T.R., Gupta, P.K., Ghosh, A.B., Jain,

- S.L., Gera, B.S., Singh, R., Sarkar, A.K., Singh, N., Parmar, R.S., Koul, S., Kohli, R., Nath, S., Ojha, V.K., and Singh, G. Characterization of aerosols from biomass burning - a Case Study from Mizoram (North East), India. *Chemosphere*, 54:167-175, 2004.
- Badrinath, K.V.S., Latha, K.M., Chand, T.R.K., and Gupta, P.K., Impact of biomass Burning on Environmental Aerosol Concentration over Tropical Wet evergreen Forests– Arunachal Pradesh, India. *Atmospheric research*, 91: 87-93, 2009c.
- Barreiro, T.J., and Perillo, I. An Approach to Interpreting Spirometry. *American Family Physician*, 2004.
- Barrett, K.E., Barman, S.M., Boitano, S., and Brooks, H.I. *Reviews of Medical Physiology*. Tata McGraw-Hill, 23rd edition, 2010.
- Bates, D.V., Baker-Anderson, M., and Sizto, R. Asthma attack periodicity: a study of hospital emergency visits in Vancouver. *Environmental Research*, 51:51-70, 1990.
- Baur, X., Isringhausen-Bley, S., and Degens, P. Comparison of lung-function reference values. *International Archives of Occupational Environmental Health*, 72:69-83, 1999.
- Bellouin, N., Boucher, O., Haywood, J., and Reddy, M. S.: Global estimate of aerosol direct radiative forcing from satellite measurements, *Nature*, 438:1138–1141, doi:10.1038/nature04348, 2005.
- Boopathy, R., Asrabadi, B.R., and Ferguson, T.G. Sugar cane (*Saccharum officinarum* L) burning and asthma in Southeast Louisiana, USA, *Bulletin of Environmental Contamination Toxicology*, 68:173-179, 2002.
- Brimblecombe, P. *Air: composition & chemistry*. Cambridge, New York: Cambridge University Press; 1986.
- Brown B.H., and Lawford P.V, *Respiration Function*. Medical Physic and biomedical engineering. Series in Medical physics. First Indian edition. 2005.
- Bruce, N., Perez-Padilla, R. and Albalak, R. Indoor air pollution in developing countries: A major environmental and public health challenge. *Bull WHO*. 78(9):1078–1092, 2000.
- Brunekreef, B., and Holgate, S.T. Air pollution and health. *Lancet*, 360:1233-1242,

2002.

Cachier, H., Ruellan, S., and Liousse, C. Biomass Burning Aerosols in Tropical Africa. *Journal of Aerosols Science*, 29:523- 524, 1998.

Cancado, J.E.S., Saldiva, P.H.N., Pereira, L.A.A., Lara, L.B.L.S., Artaxo, P., Martinelli, L.A., Arbex, M.A., Zanobetti, A., and Braga, A.L.F. The impact of sugarcane-burning Emissions on the respiratory System of children and the elderly. *Environmental Health Perspectives*, 114:725-729, 2006.

Cattani, E., Costa, M.J., Torricella, F., Levizzani, V., and Silva, A.M. Influence of aerosol particles from biomass burning on cloud microphysical properties and radiative forcing. *Atmospheric Research*, 82:310–327, 2005.

Chabra, S.K., Chabra, P., Rajpal, S., and Gupta, R.K. Ambient air pollution and chronic respiratory morbidity in Delhi. *Archives of Environmental Health*, 56:58-64, 2001.

Chaloulakou, A., Kassomenos, P., Sporellis, N., Demokritou, P., and Koutrakis, P. Measurements of PM₁₀ and PM_{2.5} particle concentrations in Athens Greece. *Atmospheric Environment*, 37:649- 660, 2003.

Chan L.Y., and Kwok, W.S. (2001). Roadside suspended particulates at heavily trafficked urban sites of Hong Kong–Seasonal variation and dependence on meteorological conditions. *Atmospheric Environment*, 35:3177–3182.

Chattopadhyaya, Y.B.P., Gangopadhyay, P.K., Bandopadhyaya, Y.T.S., and Alam, J., Comparison of pulmonary function test abnormalities between stone crushing dust exposed and nonexposed agricultural workers. *Environmental Health and Preventive Medicine*, 11:191–198, 2006.

Chen, P., Lal, Y., Chan, C., Hwang, J., Yang, C., and Wang, J. Short- term effect of ozone on the pulmonary function of children in primary school. *Environmental Health Perspective*, 106:331-335, 1999.

Chengappa, C., Edwards, R., Bajpai, R., Shields K.Y., and Smith, K.R. Impact of improved cookstoves on indoor air quality in the Bundelkhand region in India. *Energy for Sustainable Development*, 11:32-44, 2007.

Chew, F.T., Goh, D., Ooi, B., Saharom, R., Hui, J.K.S., and Lee, B.W. Association of ambient air– pollution levels with acute asthma exacerbation among children in Singapore. *Allergy*, 54:320-329, 1999.

Cho, B., Cho, J., and Yum, Y-T. Air pollution and hospital admissions for respiratory diseases in certain areas of Korea. *Journal of Occupational Health*, 42: 185-191, 2000.

Cizao Ren C., and Tong S. Health effects of ambient air pollution – recent research development and contemporary methodological challenges. *Environmental Health*, 7:1-10, 2008.

Clarka, M.L., Peela, J. L., Burchb, J. B., Nelsona, T. L., Robinsona, M. M., Conwayc, S., Bachanda, A. M., and Reynoldsd, S. J. Impact of improved cookstoves on indoor air pollution and adverse health effects among Honduran women. *International Journal of Environmental Health Research*, 5:357-368, 2009.

Contini D., Genga A., Cesari D., Siciliano M., Donateo A., Bove M.C., and Guascito M.R. Characterization and source apportionment of PM10 in an urban background site in Lecce. *Atmospheric Research*, 95:40-54, 2010.

Crawford M. *Air pollution control theory*. New York: McGraw-Hill; 1976.

Crutzen, P.J., and Andreae, M.O. Biomass Burnings in the tropics: Impact on Atmospheric Chemistry and Biogeochemical Cycles. *NPL*, 250, 21, 1990.

Das, M., Maiti, S.K., Mukhopadhyay, U. Distribution of PM2.5 and PM10-2.5 in PM10 fraction in ambient air due to vehicular pollution in Kolkata Megacity. *Environmental Monitoring and Assessment*, 122:111-123, 2006.

Dennis, A., Fraser, M., Anderson, S., and Allen, D. Air pollutant emissions associated with forest grassland, and agricultural burning in Texas. *Atmospheric Environment*, 36:3779-3792, 2002.

Dietert, R.R., Etzel, R.A., and Chen, D. Workshop to identify critical windows of exposure for children’s health: immune and respiratory systems work group summary. *Environmental Health Perspective*, 108:483–490, 2000.

Dockery, D.W., and Pope, C.A. III. Acute respiratory effects of particulate air pollution. *Annual Review of Public Health*, 15:107–132, 1994.

- Dockery, D.W., Pope, C.A., and Xu, X.P., Spengler, J.D., Ware, J.H., Fay, M.E., Ferris, B.G., and Speizer, F.E. An Association between Air-Pollution and Mortality in 6 United- States Cities. *New England Journal of Medicine*, 329:1753-1759, 1993.
- Donaldson, K., and Macnee, W. Mechanism of lung injury caused by PM₁₀ and ultrafine particles with special reference to COPD. *European Respiratory Journal*, 21: 47-51, 2003.
- Duki MI, Suzuki S, Kawada T, and Tri-Tugaswati A. Effect of air pollution on respiratory health in Indonesia and its economic cost. *Archives of Environmental Health*, 58:135-143, 2003.
- Edwards, J., Walters, S., and Griffiths, R.K. Hospital admissions for asthma in preschool children: relationship to major roads in Birmingham, United Kingdom. *Archives of Environmental Health*, 49:223-227, 1994.
- Elsom, D.M. *Atmospheric pollution: a global problem*. 2nd ed. Oxford, UK ; Cambridge, Mass., USA: Blackwell Publishers; 1992.
- Emmanuel, S.C. Impact to lung health of haze from forest fires: the Singapore experience. *Respirology*, 5(2):175-82, 2000.
- Ezzati, M., and Kammen, D. Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: an exposure-response study. *Lancet*, 358:619-24, 2001.
- Faith, W.L., and Atkission, A.A. *Air Pollution*, Wiley-Interscience, 1–348, 1972.
- Fereidoun, H., Nourddin, M.S., Rreza, N.A, Mohsen, A., Ahmad, R., and Pouria, H. The effect of long-term exposure to particulate pollution on the lung function of Teheranian and Zanzjanian students. *Pakistan Journal of Physiology*, 3:4-8, 2007.
- Finkelman R.B. *International Journal of Coal Geology*, Potential health impacts of burning coal beds and waste banks. 59:19-24, 2004.
- Fontanari P, Burnet H, Zattara-Hartmann MC, Jammes Y 1996. Changes in airway resistance induced by nasal inhalation of cold dry, dry, or moist air in normal individuals. *Journal of Applied Physiology: Respiratory, Environmental & Exercise Physiology*. 81:1739-1743, 1996.
- Fowler, C.T. *Human Health Impacts of Forest Fires in the Southern United States: A*

- Literature Review. *Journal of Ecological Anthropology*, 7: 39-63, 2003.
- Franklin, M., Koutrakis, P., and Schwartz, P. 2008. The role of particle composition on the association between PM_{2.5} and mortality. *Epidemiology* 19:680-689.
- From, L.J., Bergen, L.G., and Humlie, C.J. The effects of open leaf burning on spirometric measurement in asthma, *Chest*, 101:1236-1239, 1992.
- Gajghate D. G., and Bhanarkar A. D. Characterisation of particulate matter for toxic metals in ambient air of Kochi City, India. *Environment Monitoring and Assessment*, 102:119-129, 2005.
- Ghasemkhani M., Firouzbakhsh S., Rezaei M., and Sadeghipour H.R. Pulmonary Function Status among Workers in Industries of South Tehran, *Journal of Medical Science*, 6:63 – 67, 2006.
- Godish T. *Air Quality*. Lewish Publisher, New York Third edition.
- Gogoi, M. M., Bhuyan, P. K., and Krishna Moorthy, K.: Estimation of the effect of long-range transport on seasonal variation of aerosols over northeastern India, *Annals of Geophysics*, 26, 1365–1377, 2008.
- Gomiscek, B., Hauck, H., Stopper, S., and Preining, O. Spatial and temporal variation of PM₁, PM_{2.5}, PM₁₀ and particle number concentration during the Auphep – project. *Atmospheric Environment*, 38:3917-3934, 2004.
- Grass D.S., Ross J.M., Family F., Barbour J., Simpson H.J., Coulibaly D., Hernandez J., Chen Y., Slavkovich V., Li Y., Graziano J., Santella R.M., Brandt-Rauf P., and Chillrud S.N. Airborne particulate metals in the New York City subway: A pilot study to assess the potential for health impacts. *Environmental Research*, 110:1-11, 2010.
- Gupta P. K., Sahai Shivraj, Singh Nahar., Dixit C. K., Singh, D. P., Sharma, C., Tiwari M. K., Gupta, R. K. and Garg, S.C. Residue burning in rice–wheat cropping system: Causes and implications. *Current Science*, 87:1713-1717, 2004.
- Gupta, R. K., Naresh, R. K., Hobbs, P. R., Jiaguo, Z. and Ladha, J. K. Sustainability of post-green revolution agriculture: The rice–wheat cropping systems of the Indo-Gangetic Plains and China. In *Improving the Productivity and Sustainability of Rice–Wheat System: Issues and Impacts*, ASA Special Publication 65, Wisconsin, USA,

2003.

Gustafsson, O., Krusa, M., Zencak, Z., Sheesley, R. J., Granat, L., Engstrom, E., Praveen, P. S., Rao, P. S. P., Leck, C., and Rodhe, H. Brown Clouds over South Asia: Biomass or Fossil Fuel Combustion? *Science*, 323:495–498, 2009.

Guyon, P., Frank, G. P., Welling, M., Chand, D., Artaxo, P., Rizzo, L., Nishioka, G., Kolle, O., Fritsch, H., Silva Dias, M. A. F, Gatti, L. V., Cordova, A. M., and Andreae, M. O. Airborne measurements of trace gas and aerosol particle emissions from biomass burning in Amazonia. *Atmospheric Chemistry and Physics*, 5:2989–3002, 2005.

Guyton A.C. and Hall J.E. *Text book of Medical Physiology*. Elsevier, 11th edition, 2006.

Hanigan, I.C., Johnston, F.H., and Morgan, G.G. Vegetation fire smoke, indigenous status and cardio-respiratory hospital admissions in Darwin, Australia, 1996-2005: a time-series study. *Environmental Health*, 5:7-42, 2008.

Harrison, R.M., Deacon, A.R., Jones, M.R., and Appleby, R.S. Sources and process affecting concentrations of PM10 and PM2.5 particulate matter in Birmingham, UK. *Atmospheric Environment*, 31:4103–4117, 1997.

Harrison, R.M., Jones, A.M., Lawrence, R.G. Major component composition of PM10, PM2.5 from roadside and urban background sites. *Atmospheric Environment*, 38:4531– 4538, 2004.

Harrison, R.M., Shi, J.P., Jones, M.R. Continuous measurements of aerosol physical properties in the urban atmosphere. *Atmospheric Environment*, 33:1037–1047, 1999.

Hauck, H., Berner, A., Frischer, T., Gomiscek, B., Kundi, M., Neuberger, M., Puxbaum, H., Preining, O., Team, A. AUPHEP – Austrian project on health effects of particulates – general overview. *Atmospheric Environment*, 38:3905 – 3915, 2004.

He, Q.C., Lioy, P., Wilson, W., and Chapman, R.S. Effects of air pollution on children's pulmonary function in urban and suburban areas of Wuhan, People's Republic of China. *Archives of Environmental Health*, 48:382-391, 1993.

Hendryx, M. Mortality from heart, respiratory, and kidney disease in coal mining areas of Appalachia, *International Archives of Occupational and Environmental Health*

82:243-249, 2009.

Heyder, J. Deposition of inhaled particles in the human respiratory tract and consequences for regional targeting in respiratory drug delivery. *Proceedings of the American Thoracic Society*, 1:315-320, 2004.

Hoek, G., and Brunekreef, J., effects of low-level winter air pollution concentrations on respiratory health of Dutch children. *Environmental Research*, 64:136-150, 1994.

Hoek, G., Brunekreef, B., Goldbohm, S., Fischer, P., and Vanden Brandt, P.A. Association between mortality and indicators of traffic-related air pollution in the Netherlands: a cohort study. *Lancet*, 360:1203-1209, 2002.

Hoek, G., D.W. Dockery, A. Pope, L. Neas, W. Roemer, and B. Brunekreef.: Association between PM10 and decrements in peak expiratory flow rates in children: reanalysis of data from five panel studies. *European Respiratory Journal*, 11:1307–1311, 1998.

Holland, W.W., Bennett, A.E., Cameron, I.R., Florey, C.V., Leeder, S.R., and Schilling, R.S. Health effects of particulate pollution: reappraising the evidence. *American Journal of Epidemiology*, 110:527-659, 1979.

Hosgood III, H. D., Wei, H., Sapkota, A., Choudhury, I., Bruce, N., Smith, K. R., Rothman, N., and Lan, Q. Household coal use and lung cancer: systematic review and meta-analysis of case–control studies, with an emphasis on geographic variation. *International Journal of Epidemiology*, 1–10, 2011. doi:10.1093/ije/dyq259.

Ingle S.T., Paschpande B.G., Wagh N.D., Patel V.S., and Attarde S.B. Exposure to Vehicular Pollution and Respiratory impairment of traffic policemen in Jalgaon city, India. *Industrial Health*, 43:656-662, 2005.

IS: 5182 (Part XV), (1974). Mass concentration of particulate matter in the atmosphere, Indian standard methods for measurement of air pollution.

Jacobs, J., Kreutzer, R., and Smith, D. Rice burning and asthma hospitalizations, Butte County, California, 1983-1992. *Environmental Health Perspectives*, 105:980-985, 1998.

Jaen A., Zock J.P., Kogevinas M., Ferrer A., and Marin A. Occupation, smoking, and

chronic obstructive respiratory disorders: a cross sectional study in an industrial area of catalonia, spain, *Environmental Health: A Global Access Science Source*, 5:1-7, 2006.

Janhall S., Andreae M.O., and Oschl U.P. Biomass burning aerosol emissions from vegetation fires: particle number and mass emission factors and size distributions. *Atmospheric Chemistry and Physics*, 10:1427–1439, 2010

Jedrychowski, W., Perera, F., Maugeri, U., Spengler, J.D., and Mroz, E. Effects of prenatal exposure to fine particles and postnatal indoor air quality on the occurrence of respiratory symptoms in the first two years of life. *Environmental and Health perspective*, 2:3-4, 2008.

Jeffrey, J., Richard, K., and Danial S. Rice burning and asthma hospitalization, Butte country, California 1983-1992. *Environmental Health Perspectives*, 105:980-985, 1997.

Jindal S.K., Gupta D., and Singh A. Indices of Morbidity and control of Asthma in adult patients exposed to environmental tobacco smoke. *Chest*, 106:746-749, 1994.

Jing, L.B., Qin, Y., and Xu, Z. Relationship between air pollution and acute and chronic respiratory parameter disease in Benxi, China. *Journal of Environmental Health*, 17:268-270, 2000.

Johnson , M., Lam, N., Brant , S., Gray C., and Pennise, D. Modeling indoor air pollution from cookstove emissions in developing countries using a Monte Carlo single-box model. *Atmospheric Environment xxx*: 1-7, 2011.

Joseph J.C., and Brown J.M. *The Human Respiration System and its measurement. Introduction to Biomedical Equipment Technology. Fourth edition.*

Joshi, S.C. Impact of forest fires on the regional climate. *Current Science*, 85(1): 41-45, 2003.

Kaminsky, D.A., Irvin, C.G., Lundblad, L.K., Thompson-Figueroa, J., Klein, J., Sullivan, M.J., Flynn, F., Lang, S., Bourassa, L., Burns, S., and Bates, J.H. Heterogeneity of bronchoconstriction does not distinguish mild asthmatic subjects from healthy controls when supine. *Journal of Applied Physiology* 104:10-19, 2008.

Karita, K., Yano, E., Jinasart, W., Boundoung, D., and Tamura, K. Respiratory symptoms and pulmonary function among traffic police in Bangkok, Thailand.

Archives Environmental Health, 56:467-470, 2001.

Kasamatsu, J., Shima, M., Yamazaki, S., Tamura, K., and Sun, G. Effects of winter air pollution on pulmonary function of school children in shenyang, china, International Journal of Hygiene and Environmental Health, 209: 435-444, 2006.

Katsouyanni, K., Zmirou, D., Spix, C., Sunyer, J., Schouten, J.P., and Ponka, A. Short-term effects of air pollution on health: a European approach using epidemiological time-series data. The APHEA project: background, objectives, design. European Respiratory Journal, 8:1030-8, 1995.

Kaushik C.P., Khaiwal R., Yadav K., Mehta S., and Haritash. A.K. Assessment of ambient air quality in urban centers of Haryana (India) in relation to different anthropogenic activities and health risks. Environment Monitoring and Assessment, 122:27-40, 2006.

Kelly, Keith, W., and Morgam, C. Occupational Lung Diseases Caused by Asbestos, Silica, and other Silicates, and Occupational Lung Diseases: Coal Workers', Beryllium, and other pneumoconiosis. In: G L. Baum, J D. Crapo, B R. Celli, J B. Karlinky, Editor, Textbook of Pulmonary Diseases, 6th Edition, Lippincott-Raven company, Philadelphia, USA, 683-706, 1997.

Kharol, S. K., and Badarinath, K. V. S.: Impact of biomass burning on aerosol properties over tropical urban region of Hyderabad, India, Geophys. Res. Lett., 33, L20801, doi:10.1029/2006GL026759, 2006.

Kim, J.H., Lim, D.H., Kim, J.K., Jeong, S.J., and Son B.K. Effects of particulate matter (PM₁₀) on the pulmonary function of middle school children. Journal of Korean Medical Science, 20:42-45, 2005.

Kivekas, N.: Parameterization of cloud droplet activation using a simplified treatment of the aerosol number size distribution, Journal of Geophysical Research, 113(D15), D15207, doi:10.1029/2007JD009485, 2008.

Knudson R.J., Lebowitz M.D., Holberg C.J., and Burrows B. Changes in the normal maximal expiratory flow-volume curve with growth and aging. American Review of Respiratory Disease, 127:725-734, 1983.

Knudson, R.J., Slatin, R.C., Lebowitz, M.D., and Burrows, B. The maximum

expiratory flow-volume curve: Normal standards, variability and effects of age. *American Review of Respiratory Disease*, 113:587-600, 1976.

Koenig J.Q., Larson, T.V., Hanely, Q.S., Rebolledo, V., Dumler, K., Chekaway, H., Wang, S.Z., Lin, D., and Pierson, W.E. Pulmonary function changes in children associated with fine particulate matter. *Environmental Research*, 63:26-38, 1993.

Koenig, J.Q. *Health Effects of Ambient Air Pollution: How Safe is the Air We Breathe?* Springer, 1st edition, 1999.

Künzli, N., Avol, E., Wu, J., Gauderman, W.J., Rappaport, E., Millstein, J., Bennion, J., McConnell, R., Gilliland, F.D., Berhane, K., Lurmann, F., Winer, A., and Peters, J.M. Health effects of the 2003 Southern California wildfires on children *American Journal of Respiratory and Critical Care Medicine*, 174(11):1221-8, 2006.

Kuo, H.W., Lai, J.S., and Lee, M.C. Respiratory effects of air pollution among asthmatics in central Taiwan. *Archives of Environmental Health*, 57:194-200, 2002.

Laden F, Neas L.M., Dockery D.W., and Schwartz J. Association of fine Particulate matter from different sources with daily mortality in six U.S. cities. *Environmental Health Perspective*, 108:941- 947, 2000.

Lagorio, S., Forastiere, F., Pistelli, R., Iavarone, I., Michelozzi, P., Fano, V., Morconi, A., Ziemacki, G., and Ostro, B.D. Air pollution and lung function among susceptible adult subjects: a panel study. *Environmental Health A global Access Science Source*, 5:1-12, 2006.

Lal, R., Kendall, M., Ito, K., and Thurston, G.D. Estimation of historical annual PM_{2.5} exposures for health effects assessment. *Atmospheric Environment*, 38:5217–5226, 2004.

Lara, L.L., Artaxo, P., Martinelli, L.A., Camargo, P.B., Victoria, R.L., and Ferraz, E.S.B. Properties of aerosol from sugarcane burning emissions in south eastern Brazil. *Atmospheric Environment*, 39:4627-4637, 2005.

Latha, K.M., and Badarinath, K.V.S. Seasonal variations of PM₁₀ and PM_{2.5} particles loading over tropical urban environment, *Environmental Health Research*, 15:63-68, 2005.

- Latha, K.M., Badarinath, K.V.S., Gupta, P.K., Ghosh, A.B., Jain, S.L., Gerab, B.S., Singh, R., Sarkar, A.K., Singh, N., Parmar, R.S., Koul, S., Kohli, R., Nath, S., Ojha, V.K., and Singh, G. Impact of biomass burning aerosols on UV erythema—a case study from northeast region of India. *Journal of Atmospheric and Solar-Terrestrial Physics*, 66: 981-986, 2004.
- Lim J.M., Lee J.H., Moon J.H., Chung Y.S., and Kim K.H. Source apportionment of PM10 at a small industrial area using Positive Matrix Factorization. *Atmospheric Research*, 95:88-100, 2010.
- Lipfert, F.W. A critical review of studies of the association between demands for hospital services and air pollution. *Environmental Health Perspectives*, 101:229-68, 1993.
- Long, W., Tate, B. R., Newman, M., Manfreda, J., Becker, A.B., and Anthonisen, N.R. Respiratory symptoms in a susceptible population due to burning of agricultural residue. *Chest*, 113:351-357, 1998.
- Ma, H.B., and Hong, C.J. Multifactor analysis of particulate pollution in air on pulmonary function of children. *Chinese Journal of Public Health*, 10:75-77, 1991.
- Makkonen U., Hellén H., Anttila P., and Ferm M. Size distribution and chemical composition of airborne particles in South-Eastern Finland during different seasons and wildfire episodes in 2006. *Science of the Total Environment*, 408:644–651, 2010.
- Mar, T.F., Norris, G.A., Koenig, J.Q., and Larson, T.V. Associations between air pollution and mortality in Phoenix, 1995-1997. *Environment Health Perspectives*, 108:347-353, 2000.
- Masera, O., Edwards, R., Armendariz, A.C., Berrueta, V., Johnson, M., and Rojas, B.L. Impact of Patsari improved cookstoves on indoor air quality in Michoacan, Mexico. *Energy for Sustainable Development*, 11(2):45–56, 2007.
- McCracken, J.P., Smith, K.R., Diaz, A., Mittleman, M.A., and Schwartz, J. Chimney stove intervention to reduce long-term wood smoke exposure lowers blood pressure among Guatemalan women. *Environmental Health Perspective*, 115:996–1001, 2004.
- Menon, S., Hansen, J.E., Nazarenko, L., and Luo, Y. Climate effects of black carbon

- aerosols in China and India. *Science*, 297:2250–2253, 2002.
- Meshram, J.R. Biomass resources assessment programme and prospects of biomass as energy resource in India. *IREDA News*, 13:21-29, 2002.
- Miller M.R., Hankinson J., Brusasco V., Burgos F., Casaburi R., Coates A., Crapo R., Enright P., Grinten C.P.M.V.D., Gustafsson , Jensen R., Johnson D.C., MacIntyre N., McKay R., Navajas D., Pedersen O.F., Pellegrino R., Viegi G., and Wangeret J. Standardization of spirometry. *European Respiratory Journal*, 26:319-338, 2005.
- Mirabelli, M.C., Künzli, N., Avol, E., Gilliland, F.D., Gauderman, W.J., McConnell, R., and Peters, J.M. Respiratory symptoms following wildfire smoke exposure: airway size as a susceptibility factor. *Epidemiology*, 20(3):451-9, 2009.
- Mittal M.L., Sharma C., Pandey R. Air Pollutants and Agriculture Productivity. *Physiology Molecular Biology Plants*, 13:235-241, 2007.
- Mohammad, G., Mehri, F., Tooraj, R.Z., Mahammud, M.M., Behnoosh, E., Payam, D., Hoshmand, F.F., Sharareh, R., and Firouzen, I. Early effects of burning rice farm residues on respiratory symptoms of villagers in suburbs of Isfahan, Iran. *International Journal of Environmental Health Research*, 12:125-131, 2002.
- Morris, R. Airborne particulates and hospital admissions for cardiovascular disease: a quantitative review of evidence. *Environmental Health Perspectives*, 109:495-500, 2001.
- Nicholson K.W. A review of particle resuspension. *Atmospheric Environment*, 22: 2639-2651, 1988.
- Nicod, L.P. Pulmonary defense Mechanisms. *Respiration*, 66:2-11, 1999.
- Nicolai T, Mutius EV, Reitmeir P, Wjst M. Reactivity to cold-air hyperventilation in normal and in asthmatic children in a survey of 5,697 school children in southern Bavaria. *American Review of Respiratory Disease* 147:565-572, 1993.
- Ong, S.G., Liu, J., Wong, C.M., Lam, T.H., Tam, A.Y.C., Danial, L., and Hedley, A.J. Studies on the respiratory health of primary school children in urban community of Hong Kong. *Science of Total Environment*, 106:121-135, 1991.
- Osman, E., and Pala, K. Occupational exposure to wood dust and health effects on the respiratory system in a minor industrial estate in Bursa/Turkey. *International Journal of*

- Occupational Medicine and Environmental Health, 22:43-50, 2009.
- Ostro, B., Roth, L., Malig, B., and Marty, M. The effects of fine particle components on respiratory Hospital admissions in children. *Environmental Health Perspectives*, 117:475-480, 2009.
- Ostro, B., Sanchez, J.M., Aranda, C., and Eskeland, G.S. Air pollution and mortality: results from a study of Santiago, Chile. *Journal of Exposure Analysis and Environmental Epidemiology*, 6:97-114, 1996.
- Pabst, M., and Hofer, F. Deposits of different origin in the lungs of the 5300 year old Tyrolean Iceman. *American Journal of Physical Anthropology*, 107:1-12, 1998.
- Pandey, J. S., Kumar, R., and Devotta, S. Health risks of NO₂, SPM and SO₂ in Delhi. *Atmospheric Environment*, 39:6868–6874, 2005.
- Park, J.W., Lim, Y.H., Kyung, S., An, C.H., Lee, S.P., Jeong, S.H., and Ju, Y.S. Effects of ambient particulate matter on PEF rates and respiratory symptoms of asthmatic during Asian dust periods in Korea. *Respirology*, 10:470-476, 2005.
- Parmar, R.S., Satsangi, G.S., Kumari, M., Lakhani, A., Srivastava, S.S., and Prakash, S. Study of size distribution of atmospheric aerosol at Agra. *Atmospheric Environment*, 35:693-702, 2001.
- Paul M.L, Christopher C.L, and Dawn A.S. Emissions of organic air toxics from open burning: a comprehensive review. *Progress in Energy and Combustion Science*, 30:1-32, 2004.
- Pinkerton, K.E., and Joad, J.P. The mammalian respiratory system and critical windows of exposure for children's health. *Environmental Health Perspective*, 108:457–462, 2000.
- Plopper, C.G., and Fanucchi, M.V. Do urban environmental pollutants exacerbate childhood lung diseases? *Environmental Health Perspective*, 108:252–253, 2000.
- Plunkett, L.M., Turnbull, D., and Rodricks, J.V. Differences between adults and children affecting exposure assessment. In: Guzelian PS, Henry CJ, Olin SS, eds. *Similarities and Differences between Children and Adults: Implications for Risk Assessment*. Washington, DC: ILSI Press; 79–96, 1992.

- Ponnamperuma, F.N., Straw as source of nutrient wetland rice. In orhanic matter and rice. International Rice research Institute, Los Banos, Philipipines, 117-135, 1984.
- Pope, C. A., and Dockery, D.W. Acute health effects of PM₁₀ pollution of symptomatic and asymptomatic children. *American Review of Respiratory Disease*, 145:1123–1128, 1992.
- Pope, C. A., Dockery, D.W., Spengler, J.D., and Raizenne, M. Respiratory health and PM₁₀: a daily time-series analysis. *American Review of Respiratory Disease*, 46:90–97, 1991.
- Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., and Thurston, G.D. Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Journal of American Medical Association*, 287:1132-1141, 2002.
- Pope, C.A., Dockery, D.W., and Schwartz, J. Review of Epidemiological Evidence of Health-Effects of Particulate Air-Pollution. *Inhalation Toxicology*, 7:1-18, 1995a.
- Pope, C.A., Thun, M.J., Namboodiri, M.M., Dockery, D.W., Evans, J.S., Speizer, F.E, and Heath, C.W. Particulate Air-Pollution as a Predictor of Mortality in a Prospective-Study of us Adults. *American Journal of Respiratory Critical Care Medicine*, 15:669-674, 1995b.
- Pope, C.A.-III., Dockery, D.W., Spengler, J.D., and Raizenne, M.E. Respiratory health and PM₁₀ pollution. A daily time series analysis. *American Review of Respiratory Disease*, 144:668-674, 1991.
- Pothikamorjorn, S.L., Ruxrungham, K., Thampanitchawong, P., Fuangthong, R., Srasuebkul, P., Sangahsapaviriyah, A., Suttithavil, W., Klaewsongkram, J., Parisuthikul, V., Viraavan, T., Rumsaeng, V., Kana, K., Direkwattanachai, C., Kamchaisathien, VB, and Phanupak, P. Impact of particulate air pollutant on allergic skin reactivity and lung function. *Asian Pacific Journal of Allergy Immunology*, 20:77-83, 2002.
- Prasad, V.K., Lata, M., and Badarinath, K.V.S. Trace Gas Emissions from Biomass Burnings from Northeast Region in India- Estimates from Satellite Remote Sensing Data and GIS. *The Environmentalist*, 23:229 – 236, 2003.

Prospero, J.M., Glaccum, R.A., and Nees, R.T. Atmospheric transport of soil dust from Africa to South America. *Nature*, 289:570-572, 1981.

Quanjer, Ph.H, Tammeling, G.J., Cotes J.E., Pedersen, O.F., Peslin, R., and Yernault, J.C. Lung volumes and forced ventilatory flows. Report Working Party Standardization of lung function tests; Official Statement of European Community for Coal and Steel, and European Respiratory Society. *European Respiratory Journal*, 6:15-40, 1993.

Ramanathan, V., Ramana, M. V., Roberts, G., Kim, D., Corriganam, C., Chung, C., and Winker, D. Warming trends in Asia amplified by brown cloud solar absorption. *Nature*, 448:575–578, 2007.

Rao, N.M., Patel, T.S., Raiyani, C.V., Aggarwal, A.L., Kulkarni, P.K., Chatterjee, S.K., and Kashyap, S.K. Pulmonary function status of shopkeepers of Ahmdabad exposed to auto exhaust pollutants. *Indian Journal of Physiology Pharmacology*, 36:60-64, 1992.

Reinhardt, T.E., Ottmar, R.D., Castilla, C. Smoke impacts from agricultural burning in a rural Brazilian town. *Journal of the Air and Waste Management Association*, 51:443-450, 2001.

Reutter, P., Su, H., Trentmann, J., Simmel, M., Rose, D., Gunthe, S. S., Wernli, H., Andreae, M. O., and Poschl, U. Aerosol- and updraft-limited regimes of cloud droplet formation: influence of particle number, size and hygroscopicity on the activation of cloud condensation nuclei (CCN). *Atmospheric Chemistry and Physics*, 9:7067–7080, 2009.

Ribeiro, H. Sugar cane burning in Brazil: respiratory health effects. *Revista de Saúde Pública*, 42: 1-6, 2008.

Rode A., and Shephard, R.J. The ageing of lung function: cross sectional and longitudinal studies of an Inuit community. *European Respiratory Journal*, 7:1653-1659, 1994.

Romieu, I., Riojas-Rodriguez, H., Marron-Mares, A.T., Schilman, A., Perez-Padilla, R., and Masera, O. Improved Biomass Stove Intervention in Rural Mexico Impact on the Respiratory Health of Women. *American Journal of Respiratory and Critical Care Medicine*, 180:649–56, 2009.

- Rose, D., Nowak, A., Achtert, P., Wiedensohler, A., Hu, M., Shao, M., Zhang, Y., Andreae, M. O., and Poschl, U. Cloud condensation nuclei in polluted air and biomass burning smoke near the mega-city Guangzhou, China – Part 1: Size-resolved measurements and implications for the modelling of aerosol particle hygroscopicity and CCN activity. *Atmospheric Chemistry and Physics*, 8:17343–17392, 2008.
- Rosenfeld, D., Lohmann, U., Raga, G. B., O’Dowd, C. D., Kulmala, M., Fuzzi, S., Reissell, A., and Andreae, M. O. Floodor drought: How do aerosols affect precipitation? *Science*, 321:1309–1313, 2008.
- Sahai S., Sharma C., Singh D.P., Dixita C.K., Singh N., Sharma P., Singh K., Bhatta S., Ghude S., Gupta V., Gupta R.K., Tiwari M.K., Garg S.C., Mitra A.P., and Gupta P.K. A study for development of emission factors for trace gases and carbonaceous particulate species from in situ burning of wheat straw in agricultural fields in India. *Atmospheric Environment*, 41:9173–9186, 2007.
- Sahai, S., Sharma, C., Singh S.K., and Gupta, P.K. Assessment of trace gases, carbon and nitrogen emissions from field burning of agricultural residues in India. *Nutrient Cycling in Agroecosystems*, DOI 10.1007/s10705-010-9384-2
- Salvi, S. Health effects of ambient air pollution in children. *Paediatric Respiratory Reviews*, 8:275-280, 2007.
- Samet, J.M. A historical and epidemiologic perspective on respiratory symptoms questionnaires. *American Journal of Epidemiology* 108:435-46, 1978.
- Samet, J.M., Dominici, F., Curriero, F.C., Coursac, I., and Zeger, S.L. Fine particulate air pollution and mortality in 20 US Cities, 1987-1994. *New England Journal of Medicine*, 343:1742-1749, 2000.
- Santos, C.Y.M.D., Azevedo, D.D.A., and Neto, F.R.D.A. Selected organ compounds from biomass burning found in the atmospheric particulate matter over sugarcane plantation areas. *Atmospheric Environment*, 36:3009-3019, 2002.
- Sarkar, A., Yadav, R. L., Gangwar, B., and Bhatia, P. C., *Crop Residues in India. Technical Bulletin. Project Directorate for Cropping Systems Research, Modipuram, India*, 34, 1999.

- Schaefer, O., Eaton, R.D.P., Timmermans, F.J.W., and Hildes, J.A. Respiratory function impairment and cardiopulmonary consequences in long-time residents of the Canadian Arctic. *Canadian Medical Association Journal* 123:997-1004, 1980.
- Schnabel, E., Sausenthaler, S., Liese, J., Herbarth, O., Borte, M., Schaaf, B., Krämer, U., and Berg, A.V., Wichmann, H.E., and Heinrich, J. Hospital admission in children up to the age of 2 years. *European Journal of Pediatrics*, 168:925-931, 2009.
- Schwartz J, Dockery DW, and Neas LM. Is daily mortality associated specifically with fine particles? *Journal of Air Waste Management Association*, 46:927-939, 1996.
- Schwartz, J, and Marcus, A. Mortality and air pollution in London: a time series analysis. *American Journal of Epidemiology*, 131:185-194, 1990.
- Schwartz, J. Air pollution and daily mortality: a review and meta analysis. *Environmental Research* 64:36-52, 1994b.
- Schwela, D. Air pollution and health in urban areas. *Reviews in Environmental Health*, 15:13-42, 2000.
- Seaton, A., Macnee, W., Donaldson, K., and Godden, K. Particulate air pollution and acute health effects. *Lancet*, 345:176-178, 1995.
- Seinfeld, J.H., and Pandis, S.N. *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change*. John Wiley & Sons, Inc., New York, 1998.
- Sekine, K., Shima, M., Nitta, Y., and Adachi, M. Long term effects of exposure to automobile exhaust on the pulmonary function of female adults in Tokyo, Japan. *Occupational Environmental Medicine*, 61:350-357, 2004.
- Shanghai, C., Kan, H., London, S.J., Chen, G., Zhang, Y., Song, G., Zhao, N., Jiang, L., and Chen, B. Differentiating the effects of fine and coarse particles on daily mortality. *Environmental international*, 33:376–384, 2007.
- Sharma C., and Pundir R. Inventory of Green House Gases and other Pollutants from the Transport Sector: Delhi. *Iranian Journal of Environmental health Science Engineering*, 5:117-124, 2008.
- Sharma C., Gupta P.K., and Parashar D.C. Nitrous oxide emission estimates from paddy fields & forests in India. *Indian Journal of Radio & Space Physics*, 24:311- 313,

1995.

Sinclair, D.G., Sims, M.M., Hoad, N.A., and Winfield, C.R. Exercise-induced airway narrowing in army recruits with a history of childhood asthma. *European Respiratory Journal* 8:1314-1317, 1995.

Singh, G., Kant, Y., and Dhadwal, V.K. 2009. Remote sensing of crop residue burning in Punjab (India): a study on burned area estimation using multi-sensor approach. *Geocarto International*, 24:273-292, 2009.

Singh, Y., Singh, B., and J. Timsina. Crop residue management for nutrient cycling and improving soil productivity in rice-based cropping systems in the tropics. *Advances in Agronomy* 85:269-407, 2005.

Sint, T., Donohue, J.F., and Ghio, A.J. Ambient air pollution particles and the acute exacerbation of chronic obstructive pulmonary disease. *Inhalation Toxicology*, 20:25-29, 2008.

Smith K.R, Samet J.M, Romieu, I., and Bruce, N. Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax*. 55(6):518-32, 2000.

Smith, K.R., and Mehta, S. The burden of disease from indoor air pollution in developing countries: comparison of estimates. *International Journal of Hygiene and Environmental Health*, 206:279-289, 2003.

Smith, R.L., Davis, J.M., and Speckman, P. Assessing the human health risk of atmospheric particles. *Novartis Found Symposium* 220:59-72, 1999.

Stanojevic, S., Wade, A., Stocks, J., Hankinson, J., Coates, A.I., Pan, H., Rosenthal, M., Corey, M., Lebecque, P., and Cole, T.J. Reference ranges for spirometry across all ages. *American Journal of Respiratory Critical Care Medicine*, 177:253-260, 2008.

Staurt, B.O., Deposition and clearance of inhaled particles. *Environmental Health Perspective*, 55:369-390, 1984.

Steinbrugger, B., and Zach M. Nonspecific bronchial reactivity in symptom-free adolescent asthma patients. *Monatsschr Kinderheilkd*, 138:389-391, 1990.

Stocks, J, and Quanjer, H. Reference values for residual volume, functional residual

capacity and total lung capacity. *European Respiratory Journal*, 8:492-506, 1995.

Stone, E.A., Lough, G.C., Schauer, J.J., Praveen, P.S., Corrigan, C.E., and Ramanathan, V. Understanding the origin of black carbon in the atmospheric brown cloud over the Indian Ocean, *Journal of Geophysical Research*, 112:1-10, 2007.

Strachan, D.P. and Anderson, H.R. Trend in hospital admission rates for asthma in children. *Biomedical Journal*, 304:819-820, 1992.

Streets, D.G. An inventory of gaseous and primary aerosol emissions in Asia in the year 2000. *Journal of Geophysical Research*, 108:8809, 2003.

Strehlar, A, and Stutzel, W. Biomass residues. In Hall, D.O. and Overend, R.P., *Biomass regenerable Energy*, John Wiley, Chichester, UK, 75-102, 1987.

Sunyer, J., Schwartz, J., Tobias, A., Macfarlane, D., Garcia, J., and Anto, J.M. Patients with chronic obstructive pulmonary diseases are at increased risk of death associated with urban particle air pollution: A case-crossover analysis. *American Journal of Epidemiology*, 151:50-56, 2000.

Tang, F.C., Chen, P.C., Chan, C.C., Yau, K.I.T., and Wang, J.D. Predictive pulmonary function of school children in an area of low air pollution in Taiwan. *Journal of Formos Medical Association*, 96:397-404, 1997.

Thakur, T. C., Crop residue as animal feed. *Addressing Resource Conservation Issues in Rice–Wheat Systems of South Asia, A Resource Book*. Rice Wheat Consortium for Indo-Gangetic Plains (CIMMYT), 2003.

Thorpe, C.W., and Bates, J.H.T. Effect of stochastic heterogeneity on lung impedance during acute bronchoconstriction: a model analysis. *Journal of Applied Physiology*, 82:1616-1625, 1997.

Tipayarom, D, and Oanh, N.T.K. Effects from Open Rice straw Burning Emission on Air Quality in the Bangkok Metropolitan Region. *Science Asia*, 33:339- 345, 2007.

Tiwari, R.R., Narain, R., Patel, B.D., Makwana, I.S., and Saiyad, H.N. Spirometric measurements among quartz stone Ex-workers of Gujarat, India. *Journal of Occupational Health*, 45:88-93, 2003.

Torigoe, K., Hasegawa, S., Numata, O., Yazaki, S., Matsunaga, M., Boku, N., Hiura,

M., and Ino, H. Influence of emission from rice straw burning on bronchial asthma in children. *Pediatrics International*, 42:143-150, 2000.

Tyagi, P.D., Fuel from wastes and weeds. Btra Book Servecs, New Delhi, 1989.

Ulevicius V., Bycenkiene S., Remeikis V., Garbaras A., Kecorius S., Andriejauskiene J., Jasineviciene D., and Mocnik G., 2010. Characterization of pollution events in the East Baltic region affected by regional biomass fire emissions. *Atmospheric Research* doi:10.1016/j.atmosres.2010.03.021.

United Nations Environment, WHO, 1994

US Environmental Protection Agency. Air Quality Criteria for Particulate Matter, Vol. II. Research Triangle Park, NC: Environmental Protection Agency; Publication No. EPA/600/P-99/002bB, 2001.

US Federal Register (1987). Ambient monitoring reference and equivalent methods. United States Environmental Protection Agency. Federal Register 40 CFR Part 53, 1 July 1987.

Van der Werf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Kasibhatla, P. S., and Arellano Jr., A. F.: Interannual variability in global biomass burning emissions from 1997 to 2004, *Atmos.Chem. Phys.*, 6, 3423–3441, 2006

VanderWerf, G. R., Randerson, J. T., Giglio, L., Collatz, G. J., Kasibhatla, P. S., and Arellano Jr., A. F. Interannual variability in global biomass burning emissions from 1997 to 2004. *Atmospheric Chemistry and Physics*, 6:3423–3441, 2006.

Vermeylen, J., Nemmar, A., Nemery, B., and Hoylaerts, M.F. Ambient air pollution and acute myocardial infarction. *Journal of Trombosis Haemostasis*, 3:1955-1961, 2005.

Vibol S., and Towprayoon S. Estimation of methane and nitrous oxide emissions from rice field with rice straw management in Cambodia. *Environment Monitoring and Assessment*, 161:301-313, 2010.

Vichet-Vadakan N., Ostro B.D., Chestnut L.G., Mills D.M., Aekplakorn W., Wangwongwatana S., and Panich N. Air pollution and respiratory symptoms: results from three panel studies in Bangkok, Thailand. *Environmental Health Perspective*, 109:381-387, 2001.

Vieira, L.C., and Masacarenhas, M.D.M. Anthropogenic air pollution and respiratory disease- related emergency room visits in Rio Branco, Brazil. *Jornal Brasileiro de Pneumologia* 34:42- 46, 2008.

Wang, L.H., Xu, X., Zhou, L., Zhang, B., Du, X., Chen, A., and Huang, X. Relationship between air pollution and changes in children's peak expiratory flow. *Chinese Journal of Environmental Health*, 11:243-246, 1994.

Wardlaw, A.J. The role of air pollution in asthma. *Clinical & Experimental Allergy* 23:81-96, 1993.

WHO, 2004, Health aspects of air pollution

Wichmann, H.E., Mueller, W., Allhoff, P., Beckmann, M., Boctor, N., Csicsaky, M.J., Jung, M., Molik, B., and Schoeneberg, G. Health effects during a Smog episode in West Germany in 1985. *Environment Health Perspective*, 79:89-99, 1989.

Widmaier, E.P., Raff, H., and Strang, K.T. *Vander's Human Physiology: The mechanisms of Body Function*. McGraw-Hill, 11th Edition, 2008.

Wiley, J.A., Robinson, J.P., Cheng, Y.T., Piazza, T., Stork, L., and Pladsen, K. *Study of Children's Activity Patterns: Final Report*. Sacramento, CA: California Air Resources Board; Publication No. A733-149, 1991.

Wilkins, K., and Mao, Y. Trends in rates of admission to hospital and death from asthma among children and young adults in Canada during the 1980s. *Canadian Medical Association Journal*, 48:185-190, 1993.

Wilson C.L.S., and Zereini F. Airborne particulate matter, platinum group elements and human health: A review of recent evidence. *Science of Total Environment*, 407:2493-250, 2009.

Wilson, W.E., and Suh, H.H. Fine particles and coarse particles: Concentration relationship relevant to epidemiological studies. *Journal of Air and Waste Management Association*, 47:1238-1249, 1997.

Wong, C.M., Ma, S., Hedley, A.J., and Lam, T.H. Effect of air pollution on daily mortality in Hong Kong. *Environmental Health Perspective*, 109:335-340, 2001.

World Health Organization Regional Office for Europe. *Air quality guidelines for*

Europe. Copenhagen Albany, NY: World Health Organization Regional Office for Europe ; WHO Publications Centre USA, 1987.

World Health Report. WHO publication, 1999.

World Health Report. WHO publication, 2000.

Wu C.W., Kuo I.C., Su T.C., Li Y.R., Lin L.Y., Chan C.C., and Hsu S.C. Effects of Personal Exposure to Particulate Matter and Ozone on Arterial Stiffness and Heart Rate Variability in Healthy Adults. *American Journal of Epidemiology*, 171:1299-1309, 2010.

Wu, C.H., Jimenez, J., Claiborn, C., Gould, T., Simpson, C.D., Larson, T., and Li, L.J.S. Agricultural burning smoke in Eastern Washington: Part II. Exposure assessment. *Atmospheric Environment*, 40:5379- 5392, 2006.

www.wunderground.com

Yang, S., He, H., Lu, S., Chen, D., and Zhu J., Quantification of crop residue burning in the field and its influence on ambient air quality in Suqian, China. *Atmospheric Environment*, 42:1961-1969, 2008.

Yi O., Hong Y-C., and Kim H. Seasonal effect of PM₁₀ concentrations on mortality and morbidity In Seoul, Korea: A temperature-matched case-crossover analysis. *Environmental Research*, 110:89-95, 2010.

Yokelson, R. J., Karl, T., Artaxo, P., Blake, D. R., Christian, T. J., Griffith, D. W. T., Guenther, A., and Hao, W. M. The Tropical Forest and Fire Emissions Experiment: overview and airborne fire emission factor measurements. *Atmospheric Chemistry and Physics*, 7:5175–5196, 2007(a).

Yokelson, R. J., Urbanski, S. P., Atlas, E. L., Toohey, D. W., Alvarado, E. C., Crouse, J. D., Wennberg, P. O., Fisher, M. E., Wold, C. E., Campos, T. L., Adachi, K., Buseck, P. R., and Hao, W. M. Emissions from forest fires near Mexico City. *Atmospheric Chemistry and Physics*, 7:5569–5584, 2007(b).

Zanobetti A and Schwartz J. The Effect of Fine and Coarse Particulate Air Pollution on Mortality - A National Analysis. *Environ Health Perspective*, 117:898–903, 2009.