

# **CAUSE-EFFECT MODELLING OF CROP RESIDUE BURNING ON URBAN SCHOOL CHILDREN HEALTH**

*Thesis*  
*Submitted for the award of*  
*Doctor of Philosophy*

*by*

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**November, 2018**

## CERTIFICATE

I hereby certify that the work which is being presented in the thesis entitled "Cause-effect modelling of crop residue burning on urban school children health" for the award of degree of Doctor of Philosophy in Electrical and Instrumentation Engineering Department , Thapar Institute of Engineering and Technology (TIET), Patiala, is an authentic record of my own work carried out under the supervision and guidance of Dr. Ravinder Agarwal, Professor, EIED, TIET, Patiala and Dr. Susheel Mittal, SCBC, TIET, Patiala.

The results presented 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 our knowledge and the contents of the thesis has reached the requisite standards.

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*Dedicated to my Grandfather and my  
Parents for blessings and encouragement*

## Acknowledgement

Achievement of goal is possible just with strong determination and guidance. The only way to success and knowledge is constantly doing efforts with zeal and passion. In this journey, the nature plays his role by providing sources and limelight to show the right way. I would like to thanks those persons who helped me to achieve my goals.

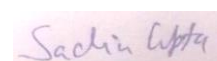
First of all, I would like to express my deep gratitude to my thesis supervisor Dr. Ravinder Agarwal for faith, motivation, patient guidance and every time support. Success can never be attained without proper guidance. I am truly very fortunate to have the opportunity to work with them. I found their guidance to be extremely valuable. I am thankful to him that he has full confidence in my ability. Much of this work has not been completed without his vision and encouragement.

I would like to express my warm and sincere gratitude to Dr. Susheel Mittal, my co-supervisor in this thesis. He always supported me through the work by motivating me from time to time. It would have been very difficult for me to come out with results without his invaluable suggestion. He is like an ocean of knowledge and ideas from where i got inspiration to work and attain the clues for my assignments. It is not enough for me to give few words to my mentors, as they give me wealth of knowledge beyond my expectations.

I would like to thank my family for standing by me through all the joys and sorrows that life had to offer. My heartfelt thanks and life-long gratitude go to my mother and father for all their love, constant support, encouragement and sacrifices and affections that they have showed upon me. I would like to express my heartily thanks to sister Ms. Shivali Gupta for always being supportive.

I would like to thank all my friends and lab mates Mr. Raghav Garg, Mr. Piyush Samant, Mr. Nishant Kumar, Mr. Rohit Gupta and Mr. Sharad Tiwari for their help in every phase of journey. It is impossible for to sustain my patience and mood at every stage of research work without their company.

Although I have tried to express my gratitude to every person who contributed in this work directly or indirectly, there may still be someone hiding behind the veils of my forgetful part of memory. Last but not the least; I would like to thank all such souls.



Sachin Gupta

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## Abstract

Clean air is a need of each human being to survive on planet earth. Due to rapid growth in modernization and life style, the ambient air is getting polluted due to mixture of hazardous substances such as toxic gases and fine suspended particulate matter having size several times lesser than the thickness of human hair. The exposure to these substances for a short or long duration caused chronic disorders such as asthma, shortness of breath and reduction in working capacity of respiratory system. According to previous studies, exposure to increased level of particulate matter having size less than  $10\mu\text{gm}^{-3}$  in ambient air is responsible to affect the health of inhabitants of all age groups. The effects on children are more severe than other age groups due to their body structure and constraints. The children are unaware of their surrounding environment and their organs are under development. Their respiration system is unable to trap these substances due to weak defense system. Particulate matter is generated by improper combustion of fuels or garbage in ambient air. Typically, there are number of sources that are responsible. Agriculture crop residue burning is identified as the second largest source of air contamination in Punjab state (India) that is responsible for releasing of coarse and fine particulate matter in the air. Rice and wheat crop is the main cyclic crop of this area. As per NASA's recent evidences, dense plums are identified in the area that is hypothesized to affect the lung capacity of human subjects. To study the effect of ACRB on human subjects, three schools (in Amritsar, Ludhiana and Mandi Gobindgarh) were selected in the region. Initially, 150 healthy human subjects (50 school going children in age group 10 to 14 years per school) were enrolled in the study. The repeated sampling of particulate matter ( $\text{PM}_{10}$  and  $\text{PM}_{2.5}$ ) and pulmonary function test (FVC,  $\text{FEV}_1$ , PEF,  $\text{FEF}_{25-75\%}$ ) were done for three years from August 2013 to July 2016 using Aerosol spectrometer and spirometer. The sampling frequency was planned to cover non crop residue burning seasons and burning seasons. The sampling was done twice in a fortnight during non crop residue burning seasons and four times in burning seasons in a staggered manner at all sites. After collection of data, statistical analyses were done to observe the trends in physiological parameters of human subjects. Descriptive analyses were done using t-test and ANOVA test to observe the significant difference in categories. Mixed effect model has been used to predict the changes in physiological parameters of human subjects due to increased level of PM with adjustment of confounders and covariates. It has been observed from the results that the level of PM crossed the NAAQS during crop residue burning seasons. The concentration level of PM was higher in rice crop residue burning seasons than in wheat crop residue

burning seasons. During both crop residue burning periods, a sharp increment has been observed in PM levels at all selected sites. It has been seen that the level of PM was higher in Mandi Gobindgarh than Ludhiana and Amritsar. The level of PM was higher in rice seasons due to unfavorable meteorological conditions. BMI wise, the subjects were surrogated in three categories to observe the changes in PFT parameters. All the male and female subjects were grouped separately on the basis of their respective BMI values i.e., either as NBMI (18-23 kgm<sup>-2</sup>), LBMI (less than 18 kgm<sup>-2</sup>) or HBMI (>23 kgm<sup>-2</sup>). FVC of NBMI subjects reduced marginally from 3.2% to 3.4%. The fall in FVC of HBMI subjects were however, greater from 3.6% to 4.2% while for LBMI it varied from 4.1% to 4.3% from their respective baseline values. the FEV<sub>1</sub> of NBMI subjects decreased by 3.5% to 3.8% from their baseline values. The fall in FEV<sub>1</sub> of HBMI subjects varied by 4.1% to 4.9% while that of LBMI it varied from 5.0% to 5.4% from the baseline value. The fall in PEF of HBMI subjects varied by 4.1% to 4.9% while that of LBM,I it varied from 5.0% to 5.4% from the baseline value. It has been observed from the trends that the PEF of all subjects decreased from their baseline values and the fall was greatest in LBMI subjects in comparison to HBMI and NBMI subjects by 50 to 55%. The FEF<sub>25-75%</sub> levels of all categories declined due to burden of PM levels. FEF<sub>25-75%</sub> of NBMI subjects reduced marginally from 1.7% to 1.9%, while the fall in FEF<sub>25-75%</sub> of HBMI subjects varied by 1.6% to 1.9%. The fall in FEF<sub>25-75%</sub> of LBMI subjects varied by 2.3% to 2.6% from the baseline value. It has been observed that the subjects of LBMI were affected more than NBMI and HBMI subjects at all sites. Site wise, the decrement was more in FVC and PEF at Mandi Gobindgarh site due to higher level of PM than Ludhiana and Amritsar site. SAC Theory has been to explain as plateau were observed in FVC levels of all BMI categories. It cannot be supported with experimental observations immediately, yet it is hypothesized that during increase in PM<sub>2.5</sub> levels from 74µgm<sup>-3</sup> till 81µgm<sup>-3</sup>, 82µgm<sup>-3</sup> to 106 µgm<sup>-3</sup>, 107µgm<sup>-3</sup> to 117µgm<sup>-3</sup> and more than 117µgm<sup>-3</sup> the PM<sub>2.5</sub> keeps on depositing in the successive pulmonary sacs in the lungs and the FVC observed does not show any fall in its values corresponding to these periods. Further investigations are required to prove this hypothesis. Hence, the sac theory proposed here is supported amply from the plateau getting noticed for children of all age groups and BMI categories.

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## List of Abbreviations

Abbreviations	Name
ACRB	<i>Agriculture Crop Residue Burning</i>
AMS	<i>Amritsar</i>
ANOVA	<i>Analysis of variance</i>
AOD	<i>Aerosol Optical Depth</i>
ATS	<i>American Thoracic Society</i>
BMI	<i>Body Mass Index</i>
BMRC	<i>British Medical Research Council</i>
CCN	<i>Cloud Condensation Nuclei</i>
CHF	<i>Congestive Heart Failure</i>
CI	<i>Confidence Interval</i>
CO	<i>Carbon monoxide</i>
CO <sub>2</sub>	<i>Carbon dioxide</i>
COPD	<i>Chronic Obstructive Pulmonary Diseases</i>
CRB	<i>Crop Residue Burning</i>
CRWS	<i>Cyclic Rice Wheat System</i>
EC	<i>Elemental Carbon</i>
EF	<i>Enrichment Factor</i>
ELCR	<i>Excess Lifetime Cancer Risk</i>
EN	<i>European Nation</i>
EPA	<i>Environment Protection Agency</i>
ERS	<i>European Respiratory Society</i>
FEF <sub>25-75%</sub>	<i>Force Expiratory Flow in 25 to 75%</i>
FEV <sub>1</sub>	<i>Force Expiratory Volume in 1 second</i>
FN	<i>Fortnight</i>
FVC	<i>Forced Vital Capacity</i>
GIS	<i>Geographical Information Systems</i>
HBMI	<i>High Body Mass Index</i>
HQ	<i>Hazard Quotient</i>
HVS	<i>High volume sampler</i>
Km	<i>Kilometres</i>
L	<i>Liter</i>
LBMI	<i>Low Body Mass Index</i>
LDH	<i>Ludhiana</i>
MEM	<i>Mixed Effect Model</i>
MESA	<i>Multi-Ethnic Study of Atherosclerosis</i>
MGH	<i>Mandi Gobindgarh</i>
ml	<i>Millilitre</i>
MMV	<i>Maximum Voluntary Ventilation</i>
MODIS	<i>Moderate Resolution Imaging Spectroradiometer</i>

Mt/yr	<i>Metric tons per year</i>
NAAQMN	<i>National Ambient Air Quality Monitoring Network</i>
NAAQS	<i>National Ambient Air Quality Standards</i>
NASA	<i>National Aeronautics and Space Administration</i>
NBMI	<i>Normal Body Mass Index</i>
NO <sub>2</sub>	<i>Nitrogen dioxide</i>
NO <sub>x</sub>	<i>Nitrogen oxide</i>
O <sub>2</sub>	<i>Oxygen</i>
OC	<i>Organic Carbon</i>
OR	<i>Odd Ratio</i>
PAHs	<i>Polycyclic Aromatic Hydrocarbons</i>
PCA	<i>Principle Component Analysis</i>
PEF	<i>Peak Expiratory Flow</i>
PFT	<i>Pulmonary Function Tests</i>
PM	<i>Particulate Matter</i>
PM <sub>1</sub>	<i>Particulate matter having fractioned size less than or equal to 1 microgram</i>
PM <sub>10</sub>	<i>Particulate matter having fractioned size less than or equal to 10 microgram</i>
PM <sub>2.5</sub>	<i>Particulate matter having fractioned size less than or equal to 2.5 microgram</i>
ppb	<i>parts per billion</i>
PPCB	<i>Punjab Pollution Control Board</i>
RCRB	<i>Rice Crop Residue Burning</i>
RCS	<i>Rice Crop Season</i>
RR	<i>Relative Risk</i>
RSPM	<i>Respirable Suspended Particulate Matter</i>
RTOLSAM	<i>Real Time Optical Light Scattering Aerosol Monitor</i>
RWRB	<i>Rice Wheat Residue Burning</i>
SD	<i>Standard Deviation</i>
SES	<i>Socio Economic Status</i>
SO <sub>2</sub>	<i>Sulphur dioxide</i>
SO <sub>x</sub>	<i>Sulphur oxide</i>
SPM	<i>Suspended Particulate Matter</i>
TSP	<i>Total Suspended Particulate</i>
UNICEF	<i>United Nations Children's Fund</i>
USEPA	<i>United States Environmental Protection Agency</i>
UV	<i>Ultraviolet</i>
VOCs	<i>Volatile Organic Compounds</i>
WCRB	<i>Wheat Crop Residue Burning</i>
WCS	<i>Wheat Crop Season</i>
WHO	<i>World Health Organization</i>
µm	<i>Microgram</i>

# Chapter-1

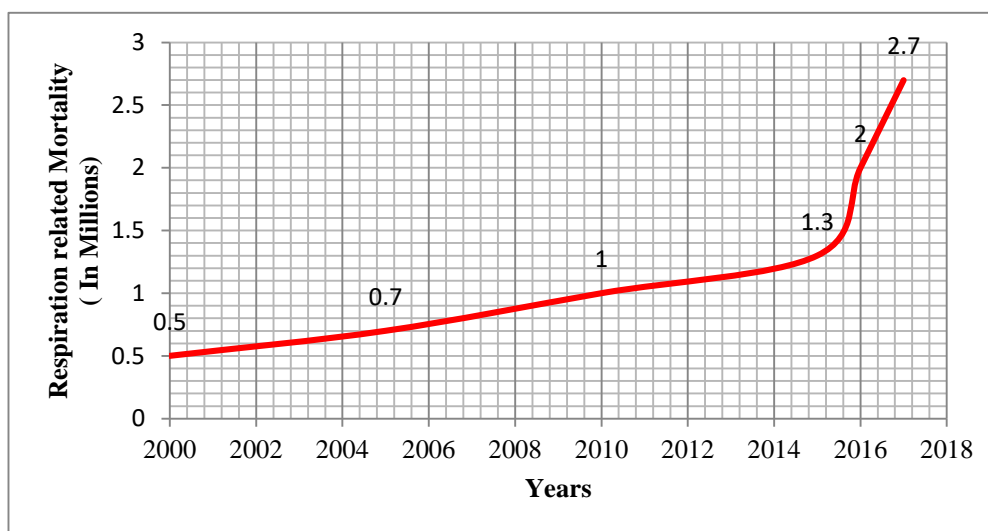
## Introduction

*In this chapter various aspects related to particulate matter pollution and their consequences on health of human are discussed. Various studies have been described the impact of air pollution on physiological parameters of human subjects but still there is a lack of information focusing on Agriculture Crop Residue Burning (ACRB) practices and their effects on lung functions of school going children. Human physiology such as Body Mass Indices (BMI) is an integral part in exposure assessment. The assessment of ACRB on lung function parameters of children are focused in this chapter.*

### 1.1 Particulate Matter Pollution and Human Physiology

Clean air is a fundamental right of each living being for its survival on the earth. This is the most essential element like food and water. A human body consists of several complex and integrated systems comprising of skeletal system, muscular system, respiration system, digestive system and nervous system that are constantly working while coordinating with each other to maintain the health status (Heyder *et al.* 2004; Barret *et al.* 2010). Among these systems, respiratory system has a key role in the life of a human being. Human body organs need oxygen and release carbon dioxide in a cyclic manner due to their natural biological process. This process is called pulmonary functioning of lungs. Through nose, respiratory mechanism takes O<sub>2</sub> through inhalation from ambient environment and transport to different parts of the body by cardiopulmonary organs and exhale CO<sub>2</sub> from the body parts (Salvi *et al.* 2007). Respiratory system is very critical to immediate survival (Koenig *et al.* 1999; Guyton *et al.* 2006). This mechanism regularly comes in close contact with the ambient environment for exchange of gases (Salvi *et al.* 2007; Brown *et al.* 2013). Any kind of impurity in ambient air reduces working capacity of organs and may cause damage to this system (Balakrishnan *et al.* 2002; Atkinson *et al.* 2010). A human body needs only hygienic food, dustless shelter, clean air and water for their healthy life. But due to exponential growth in population, living standards, technology, need of food and socioeconomic security, a rapid growth has been observed in manufacturing units, factories and chimneys, use of fuel for transport by personal or public vehicle, burning of coal furnaces, construction and cement plants, use of artificial fertilizers and pesticides, washing through chemicals. Hence, the environment is getting polluted. These activities are polluting all sources of basic amenities needed by a living being for its survival. Pollution is a collective term for the substances that are responsible for

disturbance of biological and physiochemical compositions of ambient environment. Pollution is identified as the key marker behind the growth of these diseases like cancer, heart attacks, asthma (Cizao *et al.* 2008; Clarka *et al.* 2009; Brauer *et al.* 2012). There are several kinds of pollutions who are polluting water, soil and air, but pollution in air is always an important matter of debate due to its direct effects on lungs and cardiopulmonary system of human subjects (Kim *et al.* 2015; Raanan *et al.* 2016). Every year, more than 2.4 million people lose their life due to exposure to the polluted air (Agarwal *et al.* 2013; Kim *et al.* 2015; Linares *et al.* 2016). The count of morbidity and mortality of human subjects has been rapidly increasing from 2000 by 19% to 67% in 2016 due to ambient air pollution. Figure 1.1 shows worldwide growth of mortality of human subjects due to cause of air pollution in different continents (Kim *et al.* 2015).



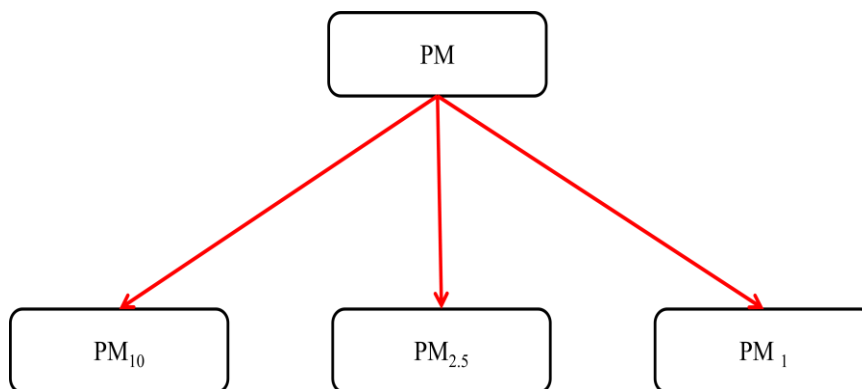
**Figure 1.1: Rapid growth in disorders and mortality rate in human subjects by air pollution**

There are large number of sources that pollute ambient air by releasing hazardous gases ( $\text{SO}_2$ ,  $\text{SO}_x$ ,  $\text{NO}_x$  and  $\text{CO}$  *etc.*) and Respirable Suspended Particulate Matter (RSPM) (having size  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$ ). Both gaseous and RSPM pollutants affect the respiratory system of human subjects with different intensities but RSPM has more statistically significant correlation coefficient value than gaseous pollutants ( $-0.78, p\text{-value} < 0.05$ ) (Gauderman *et al.* 2004; Pope *et al.* 2006; Valavanidis *et al.* 2008; Gupta *et al.* 2017).

### 1.1.1 Suspended Particulate Matter and its Significance

Particulate Matter (PM) is a collection of dust particles, unburned particles of fuel (released during combustion process) and organic tarry matter that remains suspended in the ambient

environment for different time slots from few days to months due to their aerodynamic nature. According to United States Environmental Protection Agency (USEPA) and various NAAQS (National Ambient Air Quality Standards), PM is characterised as per their aerodynamic size in micrometer ( $\mu\text{m}$ ) (shown in Figure 1.2) (US Federal report 1987; Dockery *et al.* 1994; USEPA report 2001).



**Figure 1.2: Classification of RSPM as per EPA and NAAQ standard**

According to pollution control agencies, RSPM of different aerodynamic size are defined as:

**PM<sub>1</sub>** - is defined as ultrafine dust as they reside in the ambient environment for long time (from few weeks to months) and can travel several hundred Kilometers (Km) due to their aerodynamic nature. These particles are 97 times smaller than the thickness of single human hair. Dockery *et al.* (1993) and Donaldson *et al.* (2003) investigations says that these particles are more harmful to human respiration health due to significant increment in Chronic Obstructive Pulmonary Diseases (COPD) cases and hospital admissions at various affected sites. These particles easily enter into blood vessels through alveolar sacs due to their nuclear size and cause cardiopulmonary complications.

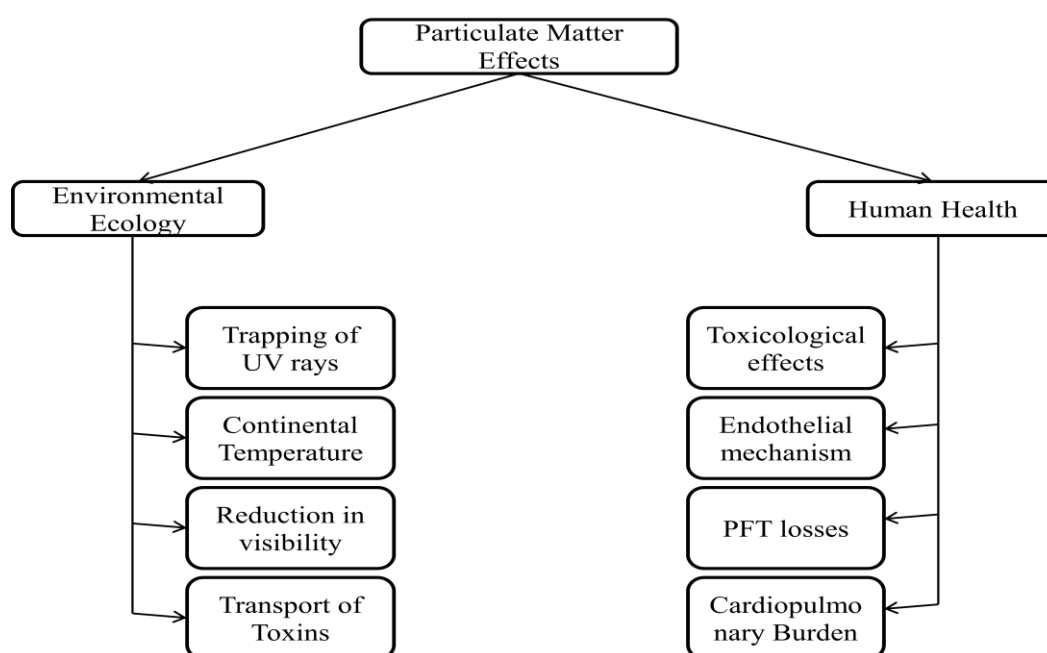
**PM<sub>2.5</sub>** - composition is identified as fine dust. They reside in the ambient environment from few days to months due to their aerodynamic nature and travel several miles. These particles are 63 times smaller than a single human hair width. Brown *et al.* (2013) and Cao *et al.* (2013) study says that these particles are respirable and impacts on endothelial and alveolar sacs in respiration system. The nasal cavity is unable to trap them during inhalation process. They may affect the capacity of lungs due to restrictions in exhalation mechanism in lungs.

**PM<sub>10</sub>** - composition is defined as coarse particles because they are heavier than PM<sub>2.5</sub> and PM<sub>1</sub> constituents. The residence time of PM<sub>10</sub> is very less than fine and ultra fine particulate matters due to unfavorable aerodynamic conditions. Their size is 27 times smaller than a

human hair. Janhall *et al.* (2010) and Janssen *et al.* (2013) described PM<sub>10</sub> as coarse particles that are emitted from diesel vehicles, biomass burning activities and by construction sites. PM<sub>10</sub> is mostly responsible for smoke plumes in the urban and rural areas. During respiration, they are not able to reach deep into lungs, as they are trapped by mucus in the nasal cavity of larynx of wind pipe due to their size (Awasthi *et al.* 2011).

### 1.1.2 Environmental and Health Effects of PM

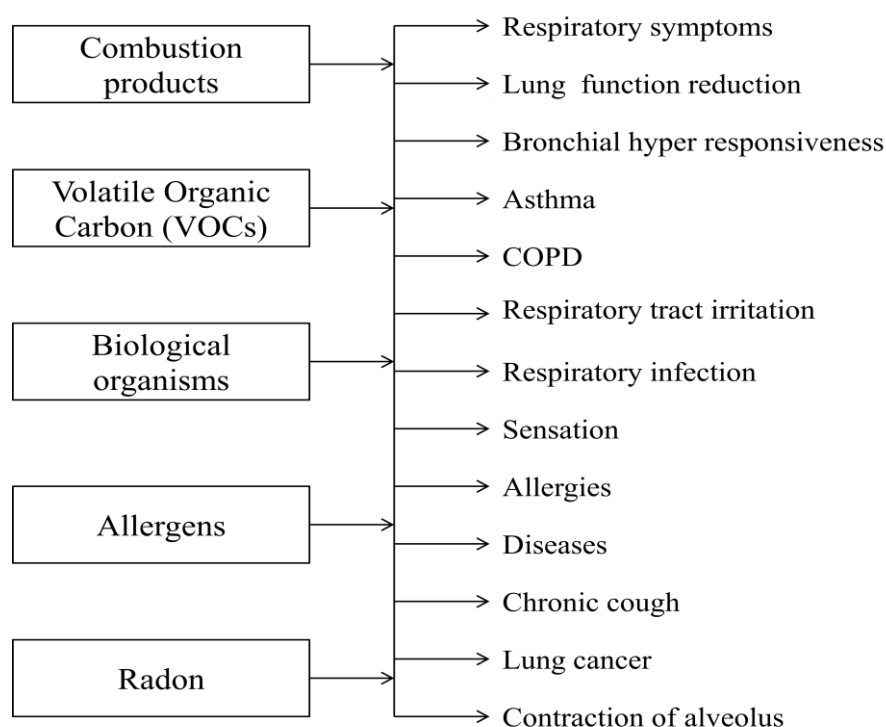
According to aerodynamic size of SPM, PM having smaller size is more dangerous to environmental ecology and human health. Broadly, Figure 1.3 shows different aspects of PM (Seinfeld *et al.* 2016).



**Figure 1.3: Ecological and Health effects of PM**

**Effects on Environmental ecology** - In ambient environment, trace elements of PM absorb the UV (Ultra violet) rays from sun and trap them in the troposphere (Seinfeld *et al.* 2016). Due to trapping of UV rays, the temperature of continent has increased from their existing levels of 9% to 15%. So, they are directly or indirectly responsible for global warming. Badarinath *et al.* (2009) investigated that the emission of PM affects visibility of the areas. The investigation of Gonzalez *et al.* (2004) and Ghio *et al.* (2012) reveals the toxicological aspects of SPM as these are responsible for transport of hazardous toxins and pollens from one place to several miles due to their favorable biochemical and physiological compositions.

**Effects on Human Health** – PM having smaller size affects ambient environmental parameters as well as human health. Respiration and cardiopulmonary organs is the prime target of PM (Gupta *et al.* 2017). Through breathing, PM enters into lungs of human subjects and stresses the endothelial walls. Toxicologically, PM having oxidative nature damages tissues of respiration mechanism (Ghio *et al.* 2012). SPM having size  $PM_{2.5}$  and  $PM_1$  are more harmful to chest compliances as they do affect recoilless of lung walls (Buonanno *et al.* 2012). Figure 1.4 shows health effects due to physiological and toxicological composition of particulate matter (Ghio *et al.* 2012).



**Figure 1.4: Composition of PM and their health effects**

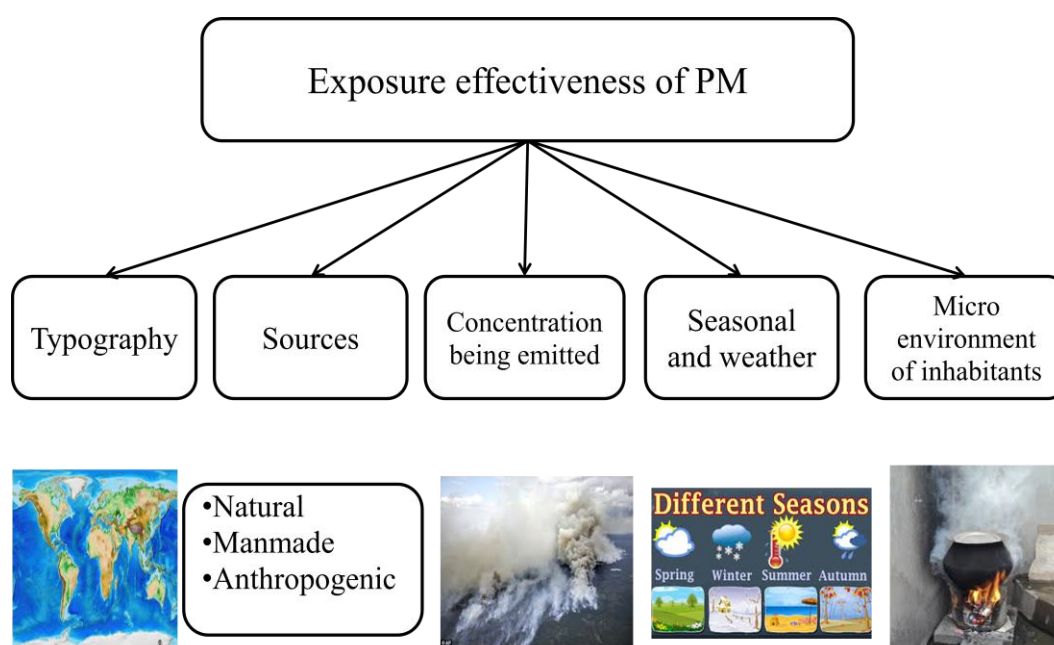
Due to slow cleaning mechanism of lungs, PM affects the capacity and flow of Pulmonary Function Test (PFTs) parameters by deposition on alveolar sacs (Hicran *et al.* 2014).

## 1.2 Exposure Effectiveness of Particulate Matter

Particulate matter is emitted in ambient environment by a number of processes, activities and sources. Figure 1.5 describes different aspects related to exposure effectiveness of PM in the ambient environment.

**Typographical aspects:** On earth, various geographical grids are identified as permanent sources of PM. There are various sites in different continents where unpredictable amount of SPM have been released by particular sources due to geo-typographical reasons like

volcanoes in east Australia and forest fires of Indonesia. The findings of Gauthierab *et al.* (1998) and Andreae *et al.* (2008) found a permanent releasing of trace gases and alkali metals from Mt. Etna Volcano in Sicily and Soufriere Hills Volcano, Montserrat, West Indies as these sites are famous for volcanic activities. The evidences of trace pollutants were even observed several miles far from active sites due to travel of PM with wind directions. This activity is natural and cannot be interrupted to stop releasing of pollutants. There are various manmade sites that are influenced by uncontrolled release of pollutants due to weak and ineffective policies of control agencies. These sites have the constraints of large population, manufacturing units, millions of on road vehicles in cities like Tokyo (Japan), China, New Delhi and Hyderabad of India (Pei *et al.* 2013; Rovira *et al.* 2014; Kim *et al.* 2015). Figure 1.5 shows the effectiveness of various factors on PM compositions.



**Figure 1.5: Exposure effectiveness of PM depending on various factors**

**Sources of PM:** There are various natural and manmade activities that are polluting the environment in an unabated manner (Figure 1.5) (Badarinath *et al.* 2009). These activities are constantly releasing coarse and fine PM. Worldwide, these practices are the main sources of pollution in each area of continents. Regular use of fuel in daily activities by inhabitants is observed as the main sources of SPM in the respective areas (Dvonch *et al.* 2009; Margolis *et al.* 2012). It has been found from the Badarinath *et al.* (2006, 2009) studies that there are various anthropogenic activities (construction of buildings, biomass burning and fuel burning) observed as prime source of PM pollution in areas.

**Concentration of PM being emitted:** The level of pollutants released by the sources is totally different at various sites during different time slots (Gupta *et al.* 2016). The emission is not constant throughout the years. There are a number of activities such as use of fireworks during festivals or carnivals celebrated worldwide that suddenly increases the level of SPM to a hazardous level in the respective areas (Badarinath *et al.* 2009; Gouder *et al.* 2014). Mittal *et al.* (2009) shows that trends of pollutions are episodic in ambient air due to time bound practices and carnivals in India like agriculture practices in Indo Gangatic Plains in the months of March-April and October-November.

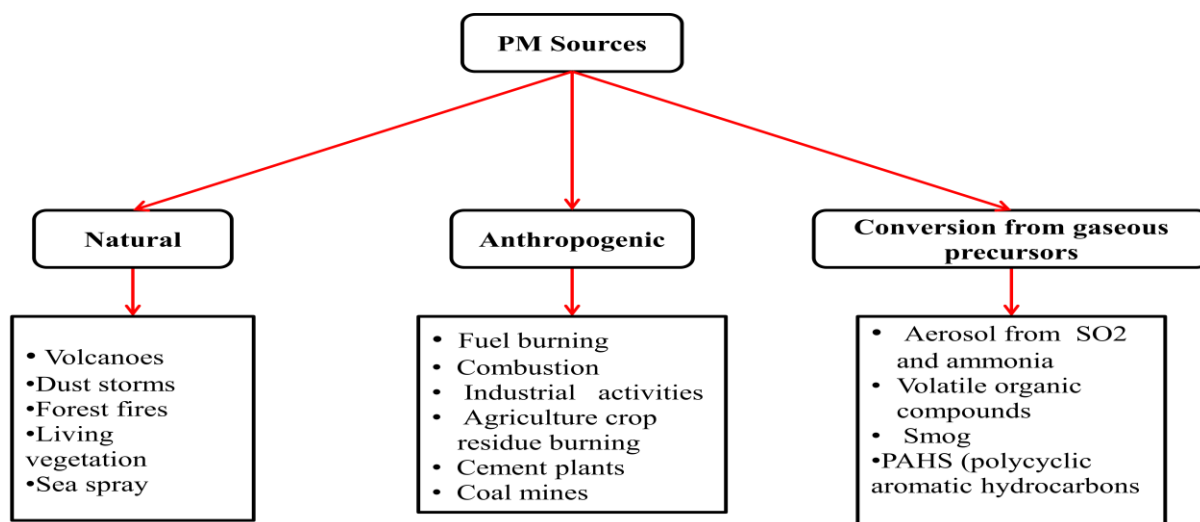
**Season and weather constraints:** Spatial and temporal parameters (speed of blowing air, direction of air, ambient humidity, level of precipitation and temperature) has an important role in the settlement of PM pollutants in the ambient environment (Tecer *et al.* 2008; Zona *et al.* 2015; Ayanlade *et al.* 2016). It has been observed in literature that the areas having low temperature, low precipitation and low wind speed are more prone to PM pollutants than other places having relatively high values. The PM trends are even very sensitive to seasonal variations due to variations in meteorological parameters in the areas. (Karar *et al.* 2006; Giri *et al.* 2008).

**Microenvironment of inhabitants:** The socioeconomic status, daily habits, routine schedules at work place and living standards of inhabitants are also the parameters to be considered during the studies of PM pollutants (Tang *et al.* 2012; Buonanno *et al.* 2013; Altug *et al.* 2014; Gupta *et al.* 2016). Human subjects who are working on construction sites or petrochemical sites are more affected than workers who are working in indoor environment (Pope *et al.* 2006; Rovira *et al.* 2014). Moreover, it has been observed that the persons when come in contact with PM pollutants even for a short duration get affected and suffered from severe health complications (Buonanno *et al.* 2012; Agarwal *et al.* 2013; Gupta *et al.* 2017). Based on factors, PM studies have been emphasized in different domains by various researchers due to their significant effects on environmental ecology and human health. Strong correlations have been found between complications in human health, ecological factors due to burden of PM in local and global regions.

### 1.3 Sources of PM

Particulate Matter having size  $PM_{10}$  and  $PM_{2.5}$  are emitted by various natural and manmade activities and they are broadly categorized into primary and secondary sources (Figure 1.6)

(Uriarte *et al.* 2008; Sharma *et al.* 2010; Singh *et al.* 2010; Strickland *et al.* 2010; Tang *et al.* 2012). Various processes are responsible for regular contamination of ecology of environment by release of pollutants in ambient air. Primary sources are the sources in which PM have been released by burning of fossil fuels or biomass waste in the ambient environment at different topographical locations (Ostro *et al.* 2009; Mittal *et al.* 2009; Gupta *et al.* 2016).



**Figure 1.6: Sources of PM**

Secondary sources of PM pollutants are constituents generated in ambient environment due to various photosynthesis based chemical reactions (Gonzalez *et al.* 2004; Ghio *et al.* 2012). It has been observed in literature (Mittal *et al.* 2009; Gasana *et al.* 2012; Rovira *et al.* 2014; Gupta *et al.* 2016) that secondary pollutants of PM have high rate of oxidative stress on organs of living beings and may have poisonous effects.

Among sources, vehicle and production units are identified as the prime source of PM in surrounding air in rural and urban areas. Studies are focusing the effect of PM on lung functions of human beings that are produced by combustion of fuels in automobiles and factories (Margolis *et al.* 2009; Gasana *et al.* 2012; Rovira *et al.* 2014). ACRB is identified as one of the main sources of particulate matter (Lexieux *et al.* 2004). Agriculture crop residue burning is episodic by nature. In particular months, the level of PM is very high with respect to environmental conditions (Mittal *et al.* 2009; Singh *et al.* 2010). Few studies estimated the effects of ACRB on human beings. (Uriarte *et al.* 2009; Awasthi *et al.* 2010; Agarwal *et al.* 2010).

## 1.4 Agriculture Crop Residue Burning Practice

Open air burning of crop remains are used as easy way to clear the agriculture land. Globally, it is ranked as second largest source of air pollution than after industrial or production units (Paul *et al.* 2004; Badarinath *et al.* 2006; Badarinath *et al.* 2009; Tripathi *et al.* 2013; Agarwal *et al.* 2012). It is a matter of serious concern regarding public health on local as well as global scale. Till now, administrative authorities of the state, country and international agencies are unable to cure this problem due to lack of systematic policies and amendments (Gupta *et al.* 2017). Open burning of biomass waste releases enormous amount of gaseous and SPM pollutants due to unenclosed combustion in ambient air. Globally, crops are yielding in a cyclic manner due to their sensitive biological relations with seasonal and weather constraints.

Crops are very sensitive to environmental factors. Any kind of delay in the sowing process results in economic loss to farmers (Kumar *et al.* 2015). Hence, local and global markets also get affected. During harvesting and threshing, the machines scatter agricultural waste in the fields. The local farmers burn this waste in their fields to save their labor cost and resources as it is tough task to bundle the crop residue waste (Figure 1.7). This practice released a uncountable amount of hazardous gases and fine particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) in the ambient environment.

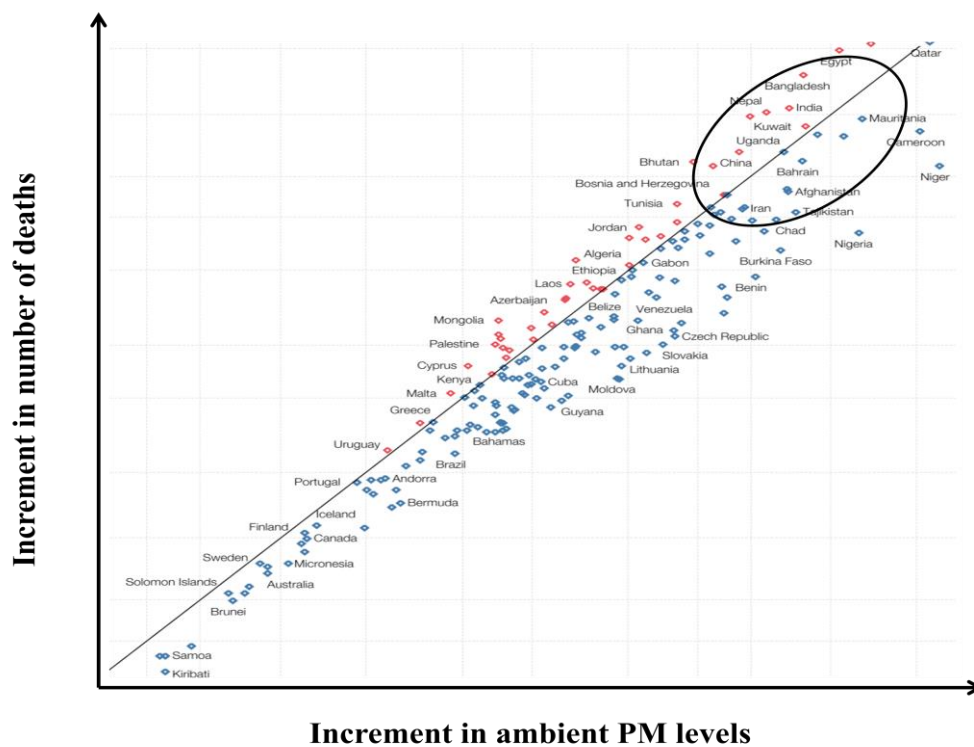


**Figure 1.7: Farmers are burning crop residue in the open fields of Punjab (India)**

There are a number of crops that are responsible for generation of huge amount of crop wastes during threshing process. On global scale, there are three major crops identified by the

researchers (such as rice, wheat and sugarcane) for production of agriculture based biomass residue (Singh *et al.* 2010; Jain *et al.* 2014).

The amount of agriculture waste is depending on types of variety of crop (principal or genetically modified root) and their well managed way of cultivation. Approximately 6.8 billion of crop residue is produced in the open fields having 37% share of well developed nations and rest 63% of the developing countries (Kumar *et al.* 2015). Asia is one of the leading continents where ACRB practice is adopted to dispose of bio-waste in the open fields than other continents (Kumar *et al.* 2015). Rice and wheat are the main cyclic crops. Mainly China and India is responsible for burning of approximately 67 million crop waste in the open fields with yearly growth of 19% due to modernization in the agriculture field (Figure 1.8) (Kumar *et al.* 2015). Out of which, rice and wheat crops are responsible for generation of 84% of total crop residue in the fields. As per recent satellite images the evidences of formation of thick clouds of smoke due to crop residue burning practices in the regions have been identified (Singh *et al.* 2009). Due to ACRB activity, level of PM increases alarmingly in the areas in comparison to permitted scale of pollutants.



**Figure 1.8: Status of different countries in ACRB practice**

After green revolution in India, crop residue production increased sharply with the rise in production of grains. After harvesting process, local inhabitants use crop residues for various purposes such as animal fodder, fuel for thermal plants, raw material for cardboard industry *etc.* Even after harvesting, bulk of amount is still left in the fields that insist farmers for field burning due to lack of resources to manage the residue.

Rice crop has two residues forms (straw and husk). Straw is a main part of rice crop residue and it is used as fodder by inhabitants of southern and eastern parts of India. (Meshram *et al.* 2002). Husk is a waste that is produced by rice mills during separation of cereal from raw form. Although, husk of rice is not found appropriate as fodder for lactic animals due to presence of silica in the waste (Badarinath *et al.* 2006). A large portion of husk is used as fuel in energy production units of mills and a small portion is consumed in domestic stoves as fuel, bedding for poultry products and oil extraction (Tyagi *et al.* 1989). The use of combine harvesters and threshers scatter the straw and husk in the open fields that are subjected to burning in the open fields. Waste of Wheat is also generated in large scale and the major portion is used as cattle field due to favorable and hygienic content, domestic fuel, raw material in paperboard making and oil extraction. Rice and wheat (Table 1.1) are the two major crops responsible for residue generation in India, especially in Punjab (Badrinath *et al.* 2006; Singh *et al.* 2009; Mittal *et al.* 2013; Gupta *et al.* 2016; Gupta *et al.* 2017). Rice and wheat crops contribute main role in agricultural biomass burning-related emissions of pollutants in ambient environment. Rice and wheat are grown widely in India and referred to as Cyclic Rice Wheat System (CRWS), because both of these crops are grown one after then other in a cyclic manner (Thakur *et al.* 2003). Most of the land is under CRWS practice. This system is also adopted by various regions in Indo Gangetic belt.

**Table 1.1: Agriculture crop residue generation in Mt/yr in Indo Gangetic plains (Jain *et al.* 2014)**

<b>Crop</b>	<b>Annual crop waste production in Mt/yr</b>	<b>Dry residue Generation in Mt/yr</b>
Rice	192.8	153.4
Wheat	120.7	80.7
Maize	26.75	19.7
Cotton	90.9	37.9
Sugarcane	18.6	16.8

Thakur *et al.* (2003) and Badarinath *et al.* (2006) reported that about six tons of bio-waste is produced per four tons of rice or wheat grains. Agriculture crop residue disposal is a labor intensive and tedious task of this practice, thus burning is adopted to be an easy, convenient, economical method by the local farmers. ACRB being less time consuming, is widely used practice for preparing a farm land for next seasonal crops. Moreover, ACRB does not require any extra labor to take care of it. Sometimes, farmers are supposed to use this practice as pest and weeds control method in the fields for the coming crops. For the personal and short term benefits, farmers used the practice of ACRB but it poses a serious, long term hazardous effect on environmental ecology and society. Due to lack of proper combustion environment, ACRB practice produces hazardous gases and fine PM in the affected areas. The plumes of dense smoke are visible in the areas that cause ill effects on ecological system (Ribeiro *et al.* 2008). ACRB practice contaminates ecological system that directly affects global and regional ambient air, visibility, climate, soil, weather and seasonal cycles (Singh *et al.* 2009).

#### **1.4.1 Effects of ACRB on Environment**

ACRB practice emits gases and aerosol particles that are playing a pivotal role in contamination of environment composition, climate and health (Vanderwerf *et al.* 2006; Yokelson *et al.* 2007; Singh *et al.* 2009; Janhall *et al.* 2010; Makkonen *et al.* 2010). According to Ramanathan *et al.* (2007) the carbonaceous and acidic aerosols related with automobile fuel combustion are found as main sources of pollution in the areas and have a significant role in radiative effects-based climate modeling. PM of size  $PM_{10}$  and  $PM_{2.5}$  have key radiative impacts due to their ability of absorbing short and harmful radiations to form Cloud Condensation Nuclei (CCN) (Andreae *et al.* 2008; Asa-Awuku *et al.* 2008; Kivekas 2008, Reutter *et al.* 2009). ACRB practice acts as major source of greenhouse gases ( $CO_2$ , CO,  $CH_4$ , VOC and halogen compounds (Guyon *et al.* 2005). The green-house gases have direct influence in causing global warming (Singh *et al.* 2009). Gustafsson *et al.* 2009 and Thumarty *et al.* 2015 highlighted the role of ACRB practice as one of the main contributor to form dense brown clouds in Southern part of Asia and North- western India. ACRB practice has been estimated to contribute up to 44% of the annual carbon released into the ambient atmosphere (Cachier *et al.* 1998; Bond *et al.* 2013). Particulate Matter impacts on global scale but mostly are regional (Badrinath *et al.* 2009; Janhall *et al.* 2010). Atmospheric aerosols being dispersive by nature have different sizes that are significant for different phenomena. There are different types of harmful substances in particulate matter composition

released by ACRB practice. Badarinath *et al.* (2009) and Mittal *et al.* (2009) reported that about 70 percent of thick clouds have PM<sub>10</sub>. The particulate matter produced by burning activity contains remains of ash, soot that are marked as toxic and cancer-causing aerosols.

Particulate matter is an air pollutant having blend of particles that are partially in solid or liquid form and are suspended in the air for long a time. Particle size is an important physical characteristic of PM (Prospero *et al.* 1981; Mittal *et al.* 2009; Singh *et al.* 2009). Human eye is unable to see the composition of PM by naked eyes but collectively PM is observed as black soot, form of clouds and hazy by nature. The falling velocity of emitted particles depends on size of particle due to gravity (Singh *et al.* 2009). The particle having smaller in size takes more time to settle downward. Due to slow residence time, fine PM can travel a long distance with blowing air. It has been identified as global problem rather than local problem depending on the wind speed (Badrinath *et al.* 2009; Janhall *et al.* 2010). Thus, assessment of PM level as well as their share in total PM concentration found suitable from atmospheric and human health perspectives.

#### **1.4.2 Health effects of ACRB practice**

Particulate matter having size PM<sub>10</sub> and PM<sub>2.5</sub> have key interest when health problems are concerned, as they absorbed into the blood-stream and attached into the terminal airways when inhaled by nose (Gupta *et al.* 2016). Various epidemiologic studies observed that the PM<sub>10</sub> is a cause of respiratory ailments and cardiopulmonary related disorders (Dockery *et al.* 1993, Laden *et al.* 2000; Gomiscek *et al.* 2004). Health related impacts of PM<sub>2.5</sub> are greater than coarse particles as it sticking in to alveolar section. (Agarwal *et al.* 2010; Gupta *et al.* 2017). The cohort and longitudinal studies linked elevated level of PM in relation to increased morbidity and mortality counts. The most conclusive evidence has been provided by (Mar *et al.* 2000; Majumder *et al.* 2012; Kelly *et al.* 2015). There are strong evidences that shows harmful effect of short term increase in the concentration of particulate matter on the mortality and health of individuals (Wilson *et al.* 2009; Grass *et al.* 2010; Wu *et al.* 2010; Yi *et al.* 2010; Agarwal *et al.* 2012).

The open ACRB emissions are more troublesome than other anthropogenic sources from public health perspectives because it released near to ground level. Open burning emissions are seasonal that are not released continuously in a 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 (Long *et al.* 1998; Mittal *et al.* 2009; Badarinath *et al.* 2009; Gupta *et al.* 2016). Due to functioning of respiratory system and different processes involved in respiration make it very sensitive with respect to external environment. Research communities found that the increased level of PM, affect working of Lung functioning (Mulli *et al.* 2004; Jacobson *et al.* 2012; Buonanno *et al.* 2012; Hicran *et al.* 2014). It may cause Asthma and other ailments.

PM affects the lungs mechanism of human subjects of all age with diverse intensity. Health effects are more in children than other age groups (Mittal *et al.* 2009; Awasthi *et al.* 2010; Hicran *et al.* 2014; Gupta *et al.* 2016). As compared to adults or elders, children are more prone to PM due to high rate of respiration and their lung organs are not fully development. The endothelial airway is narrow than adults and immunity of body is weak and have unbalanced Body Mass Index (BMI) (Gauderman *et al.* 2004; Valavanidis *et al.* 2008). According to UNICEF's report on malnutrition, BMI is abnormal in children (Hicran *et al.* 2014; Gupta *et al.* 2016). Also, BMI is associated to form recoilless of composition of different body parts such as endothelial mechanism (Khan *et al.* 2001; King *et al.* 2005). The Spirometric parameters FVC, FEV<sub>1</sub>, PEF and FEF<sub>25-75%</sub> are identified as key parameters to measure the health status of respiration system of human subjects.

### **1.5 Respiratory Health Parameters and Pulmonary Function Test**

Pulmonary Function Test (PFTs) is a valuable method for evaluation of respiratory system of human subjects. Respiration volume and flow are the two main components that are further categorized by spirometer. Breathing tests measure the functioning of the lungs performed to assess lung function. These parameters can help to find disease in respiratory system through PFT practice. PFTs are a set of processes that measures the lungs functioning (Miller *et al.* 2005). Pulmonary function test helps doctors and researchers to identify respiratory disorders such as bronchitis, cardiopulmonary ailments, Chronic Obstructive Pulmonary Disease (COPD), mechanical injury by measuring degree of lung impairment (Barreiro *et al.* 2004).

These tests are useful to evaluate whether lung capacity is improving or in critical situation. spirometer is a most versatile and common technique to measure volume and speed of air blowing during breathing. (Miller *et al.* 2005; Stanojevic *et al.* 2008). In spirometry, a human subject performed a pattern of breathing such as inhales maximally from tidal respiration to total lung capacity and then exhales with a full force until no volume of air

remains exhaled. Spirometer is a device that directly measures the volume of inhaled and exhaled air-flow by a sensing device (pneumo-tachometer, fixed resistance-based tube sensor). Now, most of the clinical pulmonary function testing laboratories use a microprocessor operated pneumo-tachometer to evaluate the flowing air directly and then after derive volume itself by using standard mathematical equations (Figure 1.9).



**Figure 1.9: MIR Spirodoc for PFT measurements**

American Thoracic Society (ATS) and the European Respiratory Society (ERS) have proven protocols to perform LFT (Miller et al. 2005). There is a little difference between the two ATS and ERS statements. But the ERS statement includes absolute lung volume in the calculations than ATS. On the basis of percentage to predicted values the interpretation has been done.

Dynamic measures are generally used to assess the breathing mechanism. These measures are important because breathing is a dynamic process. 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. There are few forces breathing tests that are used to evaluate muscle power that is associated with breathing and the resistance of the airway. Force Vital Capacity (FVC), Peak Expiratory Flow (PEF), Force Expiratory Flow in 25 to 75% (FEF<sub>25-75%</sub>), Force Expiratory Volume in 1 second (FEV<sub>1</sub>) are the main parameters that are normally used to see the effects on breathing mechanism.

The ambient air which we breathe has significant effect on the working and functioning of lungs and PFTs. The polluted air when goes inside the body through breathing poses a serious effect on the health of human subject's respiratory system. Studies have been done to scale the effects of PM from various sources such as vehicles, industries or mines on children (Manalia et al. 2008; Cheng et al. 2010; Cheng et al. 2010; Altuğ et al. 2014). There is lack

of studies to perform cause-effect analysis on increased level of PM in ambient atmosphere and physiological parameters of children due to ACRB practice (King *et al.* 2005; Cheng *et al.* 2010). This study presents the trends of PM in different time periods and episodes during six consecutive ACRB periods at three selected sites and their consequences on the different lung function parameters of enrolled school going children.

## **1.6 Background of Cause Effect Analysis**

In biomedical instrumentation, cause effect analysis performed a key role to identify and characterize the relationship among multi factors without speculation (Tylor et al. 2016). This method describes the relationship and possibility of likelihood among the concerned variables. The veracity of quantification and estimation from cause effect analysis is corroborated by research community from past decades due to factual mathematics (Aylward et al. 2013; Gupta et al. 2017). In biomedical and informatics domain, cause effect analysis is a right approach to identify the initial impressions of multilateral independent variables on dependent variables in respect of human health (Liu et al. 2018). This approach helps to identify prognostic risk factors and biological reasons behind the human physiology when exposed to hazardous elements such as pollutants, toxics and crucial conditions. The descriptive and inferential outcomes of cause effect modelling enables the researchers to summarize findings after performing hypothetical trails. Cause effect model is a regression approach that enhances the ability of research community to critically review scientific facts, extrapolate findings and encourages in adopting new approaches in research (Tonne et al. 2017).

It has been observed in various epidemiological studies that the regression is an important mathematical expression to describe certain physiological and biological relations between response and stimulators under hypothetical assumptions (Tonne et al. 2017). In field studies, the data of both dependent variable (Y) and independent variables ( $X_i$ ) are collected in different time slots and conditions i.e., continues, discrete, Binary (Yes or No), socio economic parameters, covariates and confounders. The cause effect modelling is very flexible in adjustment of staggered data with main parameters in form of range of certainty in relation to uncertainly. In epidemiological and panel based studies, there are various regression based modelling techniques to estimate the inducement of changes in dependent variable by various independent variables and covariates (Scotch et al. 2010). Among the regression models, Mixed effect model has been observed as one of the most versatile and accommodative

model that has the flexibility to adjust any form of measured data Lampa *et al.* 2008; Rajeshwaran *et al.* 2014. The comparison of regression models is shown in Table 1 (Schneider *et al.* 2010).

**Table 1.2: Comparative analysis of various regression models**

Regression Model	Area of Application	Type of sampled data		Adjustment of Heterogeneity	Benefits	Limitations
		Dependent variables	Independent variables			
Linear regression	Description of linear relation	Continue	Continues	No	To observe initial strength of relation	Vague in range of certainty
Logistic regression	To identify the probability of relation among the groups in dichotomous outcome (Yes or No)	Continues	Discrete or binary	No	To prove the interdependency of dependent variables in binary form of outcome	Overconfidence in outcomes
Multiple regression	Description of linear relations among parameters	Continue	Continues	Yes	To estimate correlation value of each explanatory variables	Consideration of each variable as independent and range of certainty is over estimated
COX regression	To model the data collected from surveys	Continues	Continues	Yes	To estimate the changes in dependent variables due to independent variables over time	Only proportionality rate has been accessed
Poisson regression	To model counted data	Discrete	Continues or Discrete	Yes	To get the information of hazard from number of cases	This model need certain assumption to be set before estimation e.g., variance should be equal to mean
Mixed effect regression	To quantify changes in percent from repeated trends of data	Continues or discrete	Continues, discrete and binary	Yes	Range of certainty of intercept is more flexible with adjustment of covariates and confounders as fixed and random variable form	Decision to fix covariates and confounder as fixed and random variables

Hence, as compared to other regression models, Mixed Effect Model (MEM) has been adopted for prediction of trends. This model has flexibility to adjust both fixed and random variables with their normal and non-normal distribution over time (Lampa *et al.* 2008; Rajeshwaran *et al.* 2014). In contrast to prediction models, this model also accounts any missing data, heterogeneity between groups, repeated correlations, and variance –covariance relations of individual parameter for accuracy in estimation of sampled group (Lampa *et al.* 2008). Hence, this model fixed the range of certainty by considering clustered relations of parameters.

This chapter is followed by second chapter in which literature is exhaustively reviewed to understand the importance of study and research gaps are identified. The objectives of the present work are also presented in this chapter. Third chapter describes systematic flow chart, methodology, instrumentation and statistical techniques adopted in the present study. International standards and protocols were followed for selection of sampling sites, study subjects and instruments for collection of environmental parameters and PFT tests. Fourth chapter describes result and discussions. This chapter is divided in two parts. First part describes the trends and comparisons in ambient particulate matter at selected sites during different seasons and episodes. Second part illustrates the trends and estimations in various measured physiological parameters of children in different seasons and episodes. Statistical analysis and modeling on collected data has been done to support hypothesis and scaling the consequences due to cause of ACRB practice in the area. In fifth chapter describes conclusions and future recommendations from the study.

*In this chapter, various aspects of ambient particulate matters i.e., significance, exposure effectiveness, sources and their consequences on various physiological parameters of human subjects in early age are discussed to understand the importance of issue. Agriculture crop residue burning is identified as the second largest source for contamination of air quality. From recent decades, this practice is adopted by the farmers due to their personal benefits and lack of sources. Various chronic health effects of PM are identified (Asthma, COPD, heart rate variability) due to hospital reports and field studies. Asthma, shortness of breath, bronchitis, chest pain etc. are few diseases that are hypothesized to be caused by raised level of particulate matter in environment. Human physiology has been discussed in this chapter to understand the working of physiological parameters.*

# Chapter -2

## Review of Literature

*This chapter presents an account of literature that is covering various aspects of particulate matter and their significance in relation to lung functions of human subjects. In literature survey, various incidents of ambient particulate matter and health effects are discussed who raised the attention of research communities to investigate the issue. Further, lot of studies are discussed who evaluated the health effects of PM. Different aspects such as sources, occupations, exposure effectiveness, meteorological factors, socioeconomic factors are exhaustively studied and presented in relation to exposure effectiveness of PM on health of human subjects. Various studies are discussed who demonstrated the consequences of PM on human subjects under clinical trials, hospital entries or controlled experiments. There is still lack of studies in relation to ACRB practice relation with ambient PM concentration level and Spirometric based evidences on human subjects in early stage such as school going children.*

### 2.1 Introduction

Human body has integrated systems which are constantly working in associations for survival. Respiration system of human body is the only mechanism that is continuously working for exchange of gases even in unconscious state of mind. Heyder and Koenig reported that a human body is estimated to inhale around 10,000 litres of ambient air on daily basis (Koenig 1999; Heyder 2004; Salvi 2007). Inhaled air contacts with lung surface area of over 100 m<sup>2</sup> and about 330 litres of oxygen diffuses into alveolar capillary membrane where blood is flowing through the lungs. It has been observed in various studies that any kind of impurity in the air (to be inhaled), affects the working capacity of respiration mechanism (Badarinath *et al.* 2009; Awasthi *et al.* 2013; Gupta *et al.* 2017).

In previous decades, various incidents were happened that accidentally raised the level of pollutants in the ambient air. Air pollution incident in different locations (London smog episodes in 1952 to 1962, Donora smog incident in 1948 and Muese valley smog in 1930) raised astonished number of morbidity and mortality in the respective areas. Those incidents proved that elevated levels of air pollutants such as PM even for a short duration are associated with variety of pulmonary disorder like shortness of breath and asthma (Faith *et al.* 1972). These incidents raised various issues in front of research communities.

- Identification of various sources of air pollution
- Identification of pollutants (Gaseous or SPM)
- Concentration and composition to be released
- Significance in relation to environmental ecology
- Impacts in relation to health prospects of living beings such as human and animals

Various policy making and governing bodies were established worldwide to determine the safely limits of pollutants in ambient environment to be released by sources for establishments of standard values. From few decades, research communities are exhaustively working on various projects to identify the sources of pollutants and their impacts on human subject health (Dockery *et al.* 1993). It has been observed from the studies that the sudden growth in industrialization and urbanization is supposed to be the main source of acute air pollution in the respective areas (Vallius *et al.* 2005). As per WHO reports, various hazardous gaseous and fine particulate matter pollutants are released by the sources. These pollutants have their own impact intensity but raised level of PM is more harmful than gaseous pollutants due to high statistical correlation coefficients (Awasthi *et al.* 2011). Particulate matter having fine size such are PM<sub>2.5</sub> or less is dangerous due to their physiological and toxicological aspects. There is a number of evidences for adverse effects of raised levels of fine PM pollution than standard values on the respiratory system of human subjects (WHO report 2004). Various cohort and cross sectional studies has been surveyed to understand the role of PM on human subjects in different domains such as rapid growth in hospital admissions in relation to respiratory ailments, astonished increment in cardiopulmonary morbidity and mortality, community based surveys, industrial and rapid growth in personal vehicles burden, occupation assessments, physiological parameters of human subjects and their reaction to PM pollutants, socio-economic factor, personal exposures, meteorological aspects in relation to PM levels, research designs and statistical methods.

Very few literatures have observed the health effects of components present in PM<sub>2.5</sub>. Various factors such as particulate size number, area of surface and concentration level mass are also related with chronic health defects (Harrison and Yin 2000).

Rao *et al.* (1992) studied the lung function status of shop-keepers of Ahmadabad (Gujarat, India) in relation to auto wheelers exhausted pollution. The study evaluated the lung function parameter using spirometer and related them with raised levels of oxide of nitrogen near to

these places that are categorized as heavy, medium and low polluted area junctions. Their results concluded with a significant impairment in FEV<sub>1</sub> and FEF<sub>25-75%</sub> parameter values in relation to high level of polluted area shopkeepers where the level of NO<sub>x</sub> was higher than the allowed value.

Ebi *et al.* (2008) investigated the health impacts in relation to climate change and troposphere Ozone and raised level of particulate matter. They reviewed the literature who were focused on climate change, air quality and their impacts on health of inhabitants in form of rate of morbidity and the cases of mortality. They observed that the changes in meteorological parameters significantly affects regional air quality by various kind of chemical reactions such as chemical reactions, variation in height of boundary, mixing of pollutants in vertical positions etc. From the evidences, it was observed that the factors related to climate change may increase concentration of troposphere ozone in developed countries. It was the chief cause of morbidity and mortality.

Nandasena *et al.* (2013) found a significant relation between indoor air pollution and respiration health of children in the developing countries. As per their findings, indoor air pollution caused a massive impact of diseases on inhabitants in these countries. The excess use of fuel and biomass waste for purpose of cooking and heating was the major source of air pollution inside the houses. Other sources of pollution such as smoking and some other substances that are emitted by human interventions also played a key role in daily health cycle of inhabitants. As per their estimation, around 3.8 million deaths were caused with 5.5% of life years in 2011. Children were the sensitive groups for prominent effects of indoor air pollution.

Hwang *et al.* (2015) investigated the lungs health of children who were residing in rail yard of California in relation to PM levels. LFT were performed on selected children at two primary schools in which one school was near to rail yard. It was observed from their results that the airway has infections due to raised level of PM in the areas.

Apte *et al.* (2016) identified from the results that PM pollution in houses leading to various complications of children residing in the Southeast Asia. He found various intern factors such as use of tobacco for smoking, construction amenities, fuel for heating, cooking and lighting purpose that were used in houses were great contributor to PM pollution in houses.

Zhang *et al.* (2017) assessed the excess use of diesel engine and their health effects on 137 diesel engine testing labor. Spirometric tests were conducted and measured to observe levels of urinary PAHs in metabolites form. The decline in FEV<sub>1</sub>/ FVC ratio, MMV and FEF<sub>25-75%</sub> parameters were statistically significant when exposed workers were examined than non-exposed workers.

## 2.2 Literature on Particulate Matter

Meteorological factors (such as season, temperature, humidity, level of precipitation, wind speed, wind directions and ventilation coefficients) have significant relations with particulate matter composition and chemical constituents. The volatility and chemical reactions to form photochemical secondary species such as aerosol and PAHs are widely depends on seasonal and temporal trends (Davidson *et al.* 2005). It has been observed in the studies that the environmental factors have both favorable and unfavorable support to PM concentrations in ambient environment. The meteorological factors in winter season are unsympathetic towards settlement of ambient PM concentration levels than rainy and summer season due to poor ventilation coefficient.

Cho *et al.* (2000) studied the raised level of air pollution in relation to hospital entries for respiration diseases in Korea. The significant relationship between increased levels of air pollution and incidence of respiratory system was examined. Respiratory diseases admissions were related to NO<sub>2</sub>, CO and Total Suspended Particulate (TSP) concentrations. Positive associations were observed between TSP and respiratory related number of hospital entries.

Wellenius *et al.* (2005) identified the relation of PM and entries in hospital for congestive heart failure in Pittsburgh, Pennsylvania. During 1987-1999, the data was collected and then using a longitudinal approach, they evaluated the relations. They counted more than 55,000 entries having primary diagnosis of CHF in the respective hospitals and observed adverse effects on respiration system with significant increment in levels of PM<sub>10</sub>, CO, NO<sub>2</sub>, and SO<sub>2</sub>. The results presented that the elevations in PM pollution from traffic caused acute cardiac decompositions.

Satya *et al.* (2005) observed that the seasonal and spatial variabilities had significant relations to form on chemical spices of PM<sub>10</sub> in the highly polluted basins of Los Angeles. They had done sampling for 3 years for size-fractionated ambient particulate matter mass concentration. They identified various spices in PM concentration such as organic and other

types of ions, components of carbon and some metal forms. It was observed that the mass concentration level was lower during winter seasons than in the summer seasons due to less use of vehicles. But the level of ultra-fine PM was much higher in winters due to excess use of organic vapour based condensation released from vehicles in the area at extreme lower temperatures.

Ko *et al.* (2007) observed a statistically proven role of temporal trends between the air pollutants and entries of heart and respiration related patients in the hospitals and complaints in Hong Kong. The study was conducted in 15 hospitals for four years (from 2000 to 2004) in which the collected the data of daily emergency visits in relation to constituents of PM pollutants in the area such as PM<sub>10</sub>, PM<sub>2.5</sub> and other trace gases. They observed a positive association between respiration ailments-based emergency visits in the hospital with all five types of measured air pollutants. The value of relative risk for hospital admission for every 10  $\mu\text{g}\text{m}^{-3}$  increment in PM<sub>10</sub> and PM<sub>2.5</sub> were observed as highest than trace gases by 1.024 and 1.031 respectively. It was found that the PM pollutants had a greater impact to cause COPD admissions in the winter seasons than during warm seasons.

Bell *et al.* (2008) estimated the cardio-based risk assessments of elders in relation to seasonal and regional fine PM (PM<sub>2.5</sub>) in the hospitals of 204 USA. The data was collected from 1998 to 2006. They found statistically significant positive correlation factors of seasonal and regional PM variation in relation to respiration related disorders particularly in cold seasons (1.05%, CI- 0.29- 1.82). Similarly, the prevalence of cardio-vascular diseases was observed to be at peak during winter periods (1.49%, CI-1.09-1.89) with increment in hospital emergency visits per 10 $\mu\text{g}\text{m}^{-3}$  increment in fine PM (PM<sub>2.5</sub>), with associations also observed in other seasons.

Domimici *et al.* (2008) studied the impact of fine PM air pollution on patients who were admitted to nearby hospitals for heart and respiration diseases. They found that the exposure to PM<sub>2.5</sub> significantly raised the risk of medicare enrolments. From a national database (1999 to 2002) on hospital admission rates, they found maximum complaints for cardio-vascular and injuries in respiration system of patients in relation to ambient PM<sub>2.5</sub> levels. The largest association was observed in heart failure patients having risk of 1.38% more than other patients per 10 $\mu\text{g}\text{m}^{-3}$  increment in same day level of PM<sub>2.5</sub>.

Samoli *et al.* (2008) studied the effects of PM on mortality rate of inhabitants in northern part of Europe and America. The rate of cause-mortality in human subjects of all ages of both cities ranged from 0.2% to 0.6% for a  $10\mu\text{gm}^{-3}$  increment in ambient  $\text{PM}_{10}$  levels. In both regions, it was observed that the higher number of older people and unemployed youth were the main reason of risk in association with increased PM level.

Bell *et al.* (2008) investigated the short-term effects of fine PM in relation to season on admission in regional hospitals in USA during 1999 to 2005. They found a strong association between risk of disorders in heart among the elders due to ambient  $\text{PM}_{2.5}$  levels. Episodically, they evaluated the effects of  $\text{PM}_{2.5}$  in different seasons across the year. They concluded with strong evidences that the statistically significant increment in symptoms of respiratory disease in winters than other seasons with 1.05% increment in entries of hospitals per  $10\mu\text{gm}^{-3}$  increase level of  $\text{PM}_{2.5}$ . The number of cases of cardio diseases was highest in winter than other seasons.

Bell *et al.* (2009) investigated the hospital admissions corresponding to identification of different metals in composition fine PM in ambient environment. They surveyed two national datasets (from 2000 to 2005) by country and by season to cover longitudinal mean level of  $\text{PM}_{2.5}$  components and their impact to cause risk for cardio and respiration in persons who were having ages in and around 65 years in US. They observed positive correlations between elemental carbon of  $\text{PM}_{2.5}$  content and increased number of hospitalizations that was associated with short term exposure.

Qian *et al.* (2010) investigated the variability's in ambient air pollution levels due to seasonal pattern and their relations to acute mortality rates. Various pollutants such as  $\text{PM}_{10}$ ,  $\text{SO}_2$  and  $\text{NO}_2$  were examined for 4 years (2001-2004) in Wuhan, China. They found statistically significant positive relations between pollutants and rate of cause of mortality in the selected sites of china. The significant effects were observed during winter seasons for all deaths caused may be in a natural way, cardio strokes or respiration-based ailments. It was estimated that a  $10\mu\text{gm}^{-3}$  increment in  $\text{PM}_{10}$  daily concentration was associated with an increase in all cause of mortality rates by 0.69% (CI: 0.44 to 0.94%) during winter, 0.34% (CI: 0.00 to 0.69%) during spring seasons.

Villarrubia *et al.* (2010) investigated the associations between daily changes in level of pollutants such as  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{SO}_2$ ,  $\text{NO}_2$ , CO and ozone levels with counts of morbidity rate.

The increment in respiratory mortality and heart ailments based rate of mortality in Las Palmas de Gran indicated an important relationship between daily ozone concentration levels and mortality rate from heart diseases.

Fischer *et al.* (2011) estimated the relative risk trends and estimations in mortality of inhabitants due to increased levels of PM pollution in The Netherlands during 1992-2006. They observed daily changes in air pollution levels and the relative associations with daily variations in counts of mortality. They found a statistically proven uplifted trends during the review process of collected data.

Chen *et al.* (2013) investigated seasonal variations in and severe effect of PM pollution on the rate of mortality in the affected sites of China. They collected the data of PM<sub>10</sub> and daily counts of mortality in 17 Chinese sites. They found that a 10 $\mu\text{gm}^{-3}$  increment in PM<sub>10</sub> concentration was related to 0.46% mortality in winter seasons that was 34% more than mortality rates in other seasons such as spring, summer and fall.

Janssen *et al.* (2013) studied the effects of PM<sub>2.5</sub> on daily death counts in the affected regions of Netherlands. They collected data of ambient PM on daily bases from the Dutch Monitoring Network (NAAQMN) and cause-specific mortality rates from the hospitals from 2008 to 2009. As per poisson regression analysis, they proved strong correlations between levels of PM<sub>10</sub> and PM<sub>2.5</sub> with cause specified counts of deaths. A 10 $\mu\text{gm}^{-3}$  increment in previous day level of PM was related with 0.1% (CI: 0.4 to 1.4) having excess risk.

Ostro *et al.* (2016) observed seven years longitudinal association of mortality in the inhabitants of California in relation to fine and ultrafine particles while considering the sources of PM and their respected spices. They followed state-wise cohort of more than 1,00,567 female faculties from the selected sites. The observed statistically significant associations of PM<sub>2.5</sub> mass compositions with levels of different spices such as elemental form of carbons nitrate some other secondary organic metals in the majorly used sulphur based fuel combustion in the area. The mortality rate in selected cohort was estimated to be 1.29 (CI: 1.08-1.31) with a 10 $\mu\text{gm}^{-3}$  increment in PM<sub>2.5</sub> consistent.

Carugno *et al.* (2016) investigated the PM exposure and their specific deaths reasons by counting hospital entries in highly polluted regions of Italy. They examined the effects of PM<sub>10</sub> and NO<sub>2</sub> exposure on the deaths and hospital admissions due to specific reasons such as cardiac, cere-bro vascular and respiration related diseases. They observed that the mortality

was significantly relates both pollutants (0.68% for PM<sub>10</sub> and 0.70% for NO<sub>2</sub>). The effect of pollutants was more for summer seasons than other seasons. They also identified that the level of PM<sub>10</sub> caused respiration-based hospital admissions.

Rapid growth in occupations (such as industries, mode of transports, construction sites, and petrochemical sites) are responsible for emitting significant amount of particulate matter pollutants in the ambient environment. Various potential studies were done in the fields to predict the effects of increased level of fine PM on working capacity of respiration tracts. In reviewed studies, PFTs were done on the children from the duration of few weeks to a couple of years for scaling the consequences.

Ingle *et al.* (2005) had done assessments to observe the traffic pollution on lung functioning of traffic police in Jalgaon city of Maharashtra, India. The ambient air mean concentration level of SO<sub>x</sub>, NO<sub>x</sub>, particulate matter and respirable dust particulate were measured from nearby stations and reported during the study period. Significant decline was observed in PEF, FEV<sub>1</sub> and FVC parameters of enrolled candidates.

Dasgupta *et al.* (2006) found the relationship of worst indoor air quality on poor families. They surveyed 236 households in Bangladesh. They observed that the most of households in Bangladesh were depending on heavy use of biomass fuels such as wood, dung cakes and other for heating and cooking of food. They found that the level of PM<sub>10</sub> was 300µgm<sup>-3</sup> (which was identified as a cause of serious health implications). By using regression-based analysis, a negative relationship between PM<sub>10</sub> level and health effects.

Morgenstern *et al.* (2007) estimated individual exposure of young school going children in relation to levels of PM<sub>2.5</sub> and NO<sub>2</sub> using GIS and predefined questionnaire in the affected areas of Munich, Germany. By fitting multiple linear regression models with adjustment of odds ratios they found a significant positive relation with traffic pollution.

Hendryx *et al.* (2009) estimated the rate of mortality in the workers causes due to heart diseases in coal mining areas of Appalachia. During four years duration, data of both PM pollution and specified death counts were sampled. The results scaled out a high level of disease-based mortality rate in inhabitants of coal mining areas.

Cao *et al.* (2012) investigated the level of fine PM (PM<sub>2.5</sub>) composition and their relation to cardiopulmonary mortality in Chinese cities those were a heavily polluted. The team

collected the data of PM<sub>2.5</sub> and rate of mortality in the selected areas from 2004 to 2008 in staggered way. They observed that the organic carbon, elemental carbon and more than ten water-soluble ions were present in the PM. They observed a statistically significant positive relations between increased level of PM and their consequences on respiration and heart related rate of mortality in the area. In which the correlation was strong with increased levels of carbon content, chlorine and nickel in the ambient environment of respective areas.

Taner *et al.* (2013) investigated indoor elemental compositions in fine PM (PM<sub>2.5</sub>) in restaurants of Turkey where health risk was hypothesized to be positive due to use of coal as fuel inside the hotel. In their study, various trace elements were found in the PM<sub>2.5</sub> such as Cr, As, Cu, Ni, V, Se, Zn and Pb. With the help of component-based Principle Analysis (PCA), they observed various kind of risks in relation to health of workers and customers due to presence of metals in indoor PM. They also scaled out the risk factor for PM<sub>2.5</sub> as 4.10 (five times more when compared to acceptable limit).

Huang *et al.* (2014) investigated the risk of personal household particulate matter (PM<sub>2.5</sub>) exposure and their effects on heart rate variability among housewives. They had done 24 hours ECG and household PM exposure monitoring in fifty houses. They observed that the level of PM<sub>2.5</sub> was alarmingly high during and after cooking and caused 1.25% to 4.31% decrease in heart rate variability from their baseline values.

Wu *et al.* (2014) investigated the associations between cardiopulmonary health effects and source apportioned PM<sub>2.5</sub> levels in Beijing, China for a period of one year (2010 to 2011). They repeatedly measured the LFTs to scale the effects of PM<sub>2.5</sub> from a number of pollution sources in selected sites of Beijing. PM was identified as potential inflammatory biomarkers in relation to raised blood pressure and adverse pulmonary functions of selected inhabitants in winter season than other seasons.

### **2.3 Literature on Methodology**

Literature was reviewed for various groups of people like asthmatic persons on the basis of age (children or adults) and occupation exposure (stone crusher workers, traffic policeman etc.) for different causes like air pollution due to industries, automobile and biomass burning. On the basis of these methodologies, studies were performed on these two aspects i.e., surveying of hospital admissions and evaluation of various respiration parameters by using spirometer. Few studies were found in literature those have done repeated measurement of

PFTs on the same subjects for long period. Lot of study on sensitive groups such as children and communities were reported in past (Roy *et al.* 2012). Children seem more sensitive to raised levels of air pollutants. On comparison with healthy individuals, people with respiratory ailments like asthma or chronic bronchitis may react in a strong way when exposed to pollutants (WHO report 2004). Some studies carried out in different countries show the effect of outdoor pollution on children (He *et al.* 1993; Edwards *et al.* 1994; Wang *et al.* 1994; Schnabel *et al.* 2009). In most of these investigations, pollution released from industries and traffic was of major concern.

In early decades, when scientific communities identified the serious concern of particulate matter pollution, then they got the evidences on health effects by collecting the data. They surveyed regional and community hospitals to count number of respiratory related admissions. Also, they had done meetings with pulmonologists to identify symptoms and disorders in respect of respiration and cardiopulmonary organs.

Thurston *et al.* (1997) investigated the use of medication in asthmatic children in relation to raised PM levels during haze episodes in ambient air. They enrolled 52 to 58 asthmatic children in a summer camp for three summer seasons. Data on level of pollutants such as PM and Ozone were collected from nearly installed pollution measuring devices by pollution control agencies. The level of pollutants was found statistically correlated with acute ailments such as chest symptoms and lung function decrements of sampled subjects. As per their estimations, an increment in the one hour daily O<sub>3</sub> from 84 to 156 ppb was related to this group with an increase from 19 to 27 ( $\pm 3$ ) is the expected number of unscheduled medications administered per day.

Peters *et al.* (1999) investigated the effects of different environmental air pollutants on school going children of 12 different communities in Southern California. They had done a 10 years cohort study while focusing on four major pollutants of area: Ozone, PM<sub>2.5</sub>, acids, and Nitrogen dioxide. They simultaneous surveyed 3,676 children of 150 schools by respiratory related questionnaires. Rates of respiratory illness were higher for males. The exacerbation of wheeze was found positive with the levels of acids (OR - 1.44 (CI: -1.13 to -1.73) and NO<sub>2</sub> (OR = 1.53 (CI: 1.18 to 2.19)).

Osman and Pala (2009) investigated the effects of use of wood fuel and health effects on the lung system in industrial areas of Bursa, Turkey. They sampled the data from 2006 to 2007.

In this study, 656 persons (328 woodworker and 328 controlled persons) were included. They observed the adverse effects of wood coal pollution on health of human subjects in the area.

Xu et al. (2013) investigated the role of diesel in vehicles on the lungs function and sign of inflammation in healthy volunteers in an experimental study. Spirometric tests were conducted on the volunteers before and after exposure. It was observed that the irritation symptoms in upper airways were significantly more common in volunteers after diesel exhaust exposure (odds ratio=3.3).

Song *et al.* (2016) investigated the spatial and temporal based characteristics of ambient PM and their health impacts for two years duration (2014-2016) in China. They observed various disorders such as mortality rate, respiration ailments, cardio-vascular disorders and consequences of bronchitis that are directly attributed to increased level of PM<sub>2.5</sub>. As per their measurements, mean level of PM<sub>2.5</sub> was approximately 73.61  $\mu\text{gm}^{-3}$  but season wise PM<sub>2.5</sub> concentration was variable (January-134.21  $\mu\text{gm}^{-3}$ , December-120.19  $\mu\text{gm}^{-3}$ , July-38.76  $\mu\text{gm}^{-3}$  and August-41.31  $\mu\text{gm}^{-3}$ ). They found that the counts of death were 764,695 and cases of 150,744 cardio-vascular disorders, 447,135 lung diseases got registered in China.

Hong *et al.* (2017) investigated the level of seasonal PM and adverse health outcomes among inhabitants those were impacted by increased level of road dust in British Columbia, Canada. From 2003 to 2015, analyses were done to stratified three seasons such as residential wood smoke in winter, road dust in the periods of spring and forest fire smoke in summer. An inter-quartile increment in daily PM levels was related with a 3.7% [CI: 1.6-5.6] increase in non-accidental mortality during the road dust season, 2.7% [CI: 2.0-3.4] increase in dispensations during the wildfire season and winter season.

## **2.4 Literature on Modelling**

Schwartz *et al.* (1994) studied the health effects of summer air pollution on children of different communities in US. They measured 24 hours concentration of different pollutants such as ambient SO<sub>2</sub>, NO<sub>2</sub>, Ozone, PM<sub>10</sub> and PM<sub>2.5</sub>, scattering of light and aerosol acidity for five consecutive warmth seasons. Simultaneously, they had done survey on 1844 school going children of six communities to count respiratory illness and symptoms. Significant relationships were observed between raised level of PM<sub>2.5</sub> and incidence of coughing symptoms and lower respiratory symptoms.

Aditama *et al.* (2000) studied the impact of haze from forest fires in Indonesia in relation to respiratory health of inhabitants. Data was collected from pulmonologists (that are collecting the data in the areas as well as from district hospitals). Data shows that there is statistically significant impact of haze on human lungs parameters.

Karita *et al.* (2001) investigated a statistically proven positive relationship between extreme levels of PM and respiration symptoms in traffic policeman in Bangkok, Thailand. They separately compared the male and female cop data. When FEV<sub>1</sub> and FEF<sub>25%</sub> parameters of vital capacity were measured and compared then their evidences showed an increase in prevalence of obstructive changes in the airways of lungs of traffic police.

Tiwari *et al.* (2003) studied the spirometric parameters of workers who were working in quartz stone mines of Gujarat state in India. Total 135 workers were evaluated in this study in which both male and female candidates were enrolled from quartz crushing mines. The results indicated very astonished results due to negative association in lung functions in relation to exposure time of worker (who spent maximum time in the bad environment of mine).

Kim *et al.* (2004) estimated that the heavy traffic in California caused pollution nearby schools and affects the respiration health of children in East Bay areas. They observed a strong association between respiration symptoms caused in school children due to heavy traffic in the area. The adjusted odds ratio for asthma in relationship to an inter-quartile gap in NO<sub>x</sub> was 1.17 (CI: 1.10 to 1.14). Even they found spatiotemporal variations in traffic pollutants and have strong relations to LFT.

Cheng *et al.* (2010) proposed the methods for real longitudinal data analysis using mixed effect models. They compared the results from simple regression models and mixed effect models to justify the identification and adjustment of fixed and random variables as effect modifiers. They found that the MEM became very useful when analysis on longitudinal data were performed due to need of model for the adjustment of covariates.

Bell *et al.* (2012) had done investigation in health-related ailments of living beings in relation to fine PM levels when they were characterised and segregated on seasonal and temporal trends in the affected areas of USA. The prime target of their investigation was to find whether the spatial and temporal patterns in PM concentration have health effects. From the database of 187 US counties, 52 chemical components of PM<sub>2.5</sub> were identified. By using

Bayesian hierarchical modelling, they observed a significant risk factors for inhabitants in corresponding changes in seasonal and temporal variation in PM<sub>2.5</sub> specially for the persons over the age more than 65 years. They observed that the winter seasons is responsible for more cases of cardiopulmonary based hospitalization that were higher than other seasons.

Rovira *et al.* (2014) found that the raised level of pollution near the petrochemical sites caused symptoms of respiratory ailments and reduced lung function in school going children in the age group 5 to 7 years. The data of prevalence of symptoms was measured using well proven questionnaires. Multivariable analyses were applied on the collected data. It was observed that the children who were residing near petrochemical sites were on high risk to lung function disabilities.

Blanes *et al.* (2015) investigated the effects of air pollution from burning of biodegradable wastes in nonurban residences (n=454) from 2005 to 2010. They fitted logistic regression and mediating methods on questionnaire based data to examine any associations between exposure and non-specific symptoms. After the adjustment of person specific covariates, positive dose-response associations were found.

## **2.5 Cardiopulmonary Effects due to PM Pollution and Socioeconomic Status of Human Health**

According to WHO reports, malnutrition is one of the major problems that is identified in the children of developing nations due to poor socioeconomic conditions such as low birth weight, low income, lack of basic amenities, unhealthy residential areas, unconsciousness of parents, lack of education and awareness. From the investigations, it has been proved that the unbalanced diet and poor socioeconomic constraints may lead to abnormal Body Mass Index (BMI) of human subjects. The BMI has a significant association with performance of physiological parameters in living beings such as respiration system, brain power and physical activities. Under clinical physiological activity trials, it has been found that the performance of persons with abnormal BMI was poor than normal BMI candidates. Very few studies have been done till now to investigate the effects of air pollutant such as PM on respiration health of children with their socioeconomic conditions.

Neidell *et al.* (2004) investigated the level of PM pollution and their asthma causing factors by hospital admissions of children in relation to their socio-economic status. Carbon monoxide was identified as significant pollutant that caused asthma in children (ages 1-18 years). With further investigation, it was concluded that the children of lower socio-economic status were affected a lot than middle and upper status.

Forastiere *et al.* (2006) investigated the role of socio-economic constraints, level of PM<sub>10</sub> and their relations with rate of mortality on regular bases in inhabitants of Rome, Italy. They observed that a rapid increase in PM levels was associated with increased counts of regular mortality and morbidity of inhabitants. Socio Economic Status (SES) was identified as the potential effect modifier with PM<sub>10</sub> mortality association. They recorded 83,253 deaths in a period (1998-2001) due to area based traffic emissions. They found that the people in lower classes had more vulnerable to chronic diseases among persons with lower income and SES (1.9% and 1.4%) compared upper income by (0.0% and 0.1%).

Babin *et al.* (2007) investigated the data of admissions of asthma patients in emergency ward of pediatric department in Washington for four years (from 2000–2004) while considering the socio-economic status (SES) and age group of patients. They observed that the relationship between asthma visits and the level of ozone (O<sub>3</sub>) had a statistical significant and is alarming in the age group 5 to 12 years children. They calculated that the 0.02-ppm increment in O<sub>3</sub> level caused 3.2% increment in patients visits and a mean 9.4% increase in daily asthma patient's admissions.

Zeka *et al.* (2008) investigated the effects of socio-economic level and physical environment of inhabitants of USA on lowered weight of new born baby and preterm births in Eastern Massachusetts. During 1996 to 2002, they observed several factors are responsible such as ethnicity, parental care and their education level and area-based (household income) SES with all birth outcomes. The effects of PM pollutants were more correlated to level of education grades and income of parents. Hence, they concluded that the SES was identified as potential confounders with other primary effect modifiers.

Deguen *et al.* (2010) reviewed the significance of social imbalance caused from health risks related to PM levels in European sites. In studies, they found that the poorer people experienced higher health ailments of air pollution. Hence, they raised issue of health inequalities in relation to increase PM levels.

Hajat *et al.* (2013) investigated PM pollution and socioeconomic status under Multi-Ethnic Study (MESA) project. In this study, 6,140 participants were investigated. Annual mean level of PM<sub>2.5</sub> and NO<sub>x</sub> levels were sampled for each study participant's home address for examination. They also investigated individual level of wealth, level of study or education and their occupation. From statistical treatment, they observed that per unit upraise in the z-score for income was related with 0.04µgm<sup>-3</sup> lower PM<sub>2.5</sub> level (CI: -0.06 to -0.01) and 0.94% lower NO<sub>x</sub> (CI: -1.33 to -0.53) after adjustment for SES covariates.

Pratt *et al.* (2015) synthesize the effects of traffic PM pollution on population in relation to class of minorities and SES to scale out exposure and factor of risks in inhabitants. After investigation they concluded that the populations with lower SES were vulnerable to PM pollution than other inhabitants. They raised an important issue to address the in-equities of society globally.

Cakmek *et al.* (2016) investigated effect of SES on the relationship between traffic PM pollution and respiratory health in 3691 primary school children in Windsor Canada. They investigated the relationships of lungs health related to type and volume of traffic and air pollution by classifying the population based on their per capita income and level of education. They observed that 95% of respiration ailments cases were due to traffic related pollution levels and are reported. They observed that the risk was greater in the lower income /education groups than the higher.

Goodman *et al.* (2017) investigated the role of PM pollution on lungs ailments and infection in relation to SES and their relations between prominent air pollutants (Ozone and PM<sub>2.5</sub>) and asthma-based hospital admissions in New York City from 1999 to 2009. They observed that increased level of ozone and PM<sub>2.5</sub> had a significant relation with increased counts of cases of asthma in children aged from 6 to 18 years per 10 ppb increase in ozone (RR = 1.03, CI: 1.02-1.04) and per 10µgm<sup>-3</sup> increase in PM<sub>2.5</sub> (RR = 1.03; CI: 1.02-1.05)

As per evidences from literature survey, a suddenly raised level of particulate matter pollution in ambient environment can adversely affect respiratory and cardiopulmonary organs of inhabitants especially children than elders. There were lot of anthropogenic sources and natural activities those are responsible to release enormous amount of PM in the troposphere in a short span of time (in a week or fortnight). The ACRB practice by local farmers in the fields and their use as fuel in various household activities is identified as the

second largest threat in front of worldwide pollution control agencies. ACRB practice is episodic by nature due to their cyclic process. Local farmers use this practice as best alternate to clear their fields for next crop. Due to their nescience, the chemistry of atmosphere is getting devastated in concern to ecology and human health. From the studies, it has been observed that this practice is still adopted in various developing countries and the level of PM was several times more than standard permitted levels and their associations with health effects were alarming due to sudden increment in cases like hospital admissions, complaints of cardiopulmonary irritation, Asthma cases, and Pulmonary Function Test parameters imbalances.

Ito *et al.* (2004) scale out the estimations of emissions of pollution from crop residue waste burning by capturing satellite images for a year in 2000. The releasing of poisonous gases and ambient aerosols from biomass burning were identified in the affected areas. They observed that the sharing of pollution from biomass waste was 5713 metric tonnes per year. Their estimation indicated alarming situation to global pollution control agencies.

Cancado *et al.* (2006) investigated the health ailments in under grown children due to sugar cane waste burning in the city of Piracicaba in southeast Brazil for a year in 1998. They had done sampling inhalable PM and then segregated them in two broad categories (fine and coarse PM) to find the traces of black soot/carbon. They also collected the emergency visits in the prominent hospitals of area to scale out the consequences. They figure out that with an increment in  $10.32\mu\text{gm}^{-3}$  in  $\text{PM}_{2.5}$  and  $45.5\mu\text{gm}^{-3}$  in  $\text{PM}_{10}$  increased the visits by 22.4% (CI: 4.3–38.5] and 31.03% (CI: 1.25–60.21) respectively. They conclude the severe effects of PM by burning activities on children and elders than adults in the area.

Arbex *et al.* (2007) investigated cause of PM pollution from bio-mass waste burning and asthma-based admission in hospitals in Brazil during 2003 to 2004 (where plantation of sugar cane is a more than other crops). They observed that the raised level of TSP having inhalable PM had severe complication leads to asthma in inhabitants. A  $10\mu\text{gm}^{-3}$  increase in PM were correlated with an upliftment of 12.7% (CI: 5.54 to 18.9) in hospital admissions due to cause of asthma. Hence, they concluded that the sugar cane husk burning reduced air quality in Brazilian urban centers and affects public health.

Sharma *et al.* (2010) investigated the consequences of ACRB on increased level of ambient aerosol loading in and around areas of Punjab, India during 2006 to 2007. By measuring the

PM level in the area and by collecting satellite images, they observed that AOD angstrom constant ( $\alpha$ ) have a large variation in their respective scale. They concluded that the higher values of  $\alpha$  and  $\beta$  presented a disturbed environmental condition due to unbalanced aerosol in the region.

Awasthi *et al.* (2010) investigated the effects of ACRB on PFTs of children in the age group of 10 to 13 years in the Northern part of West Punjab. They estimated the consequences of smoke generated due to rice and wheat CRB on declined values of various physiological parameters. They found maximum effects of PM pollution on PFTs of enrolled children than young subjects.

Agarwal *et al.* (2012) investigated the ailments in respiration of enrolled candidates due to elevated levels of PM pollution in Patiala city of Punjab from 2006 to 2007. They observed that the increased level of PM declined the PFTs of selected candidates and greatly affects the FVC of selected subjects due to excess burden of PM

Agarwal *et al.* (2012) investigated the ailments and rate of decline in LFTs using spirometric parameters evaluation in and around Patiala city of Punjab. They measured various pollution levels in the concerned area like SPM, SO<sub>2</sub>, NO<sub>2</sub> and respirable PM. They figure out the effect of RWCRB events on LFTs of enrolled candidates. As per their observations a sharp decline was observed in various physiological parameters due to heavy concentration of PM pollution in the concerned area. An increment of 10 $\mu\text{gm}^{-3}$  in PM predicted to be the effect modifier in FVC by -1.75% more than other parameters.

Kaskaoutis *et al.* (2014) investigated the effects of CRB on various prominent physical domains like properties of plums, constituents of aerosol etc. in north India. Using satellite-based MODIS images; they observed that the aerosol emissions from biomass burning produced a hazardous disturbance in environmental chemistry.

Ramos *et al.* (2017) investigated the assessments of ACRB on LFT parameters and sign of inflammation in individuals. They enrolled total 35 subjects for inspection. They observed that the raised level of PM due to biomass burning activity significantly reduced the ratio of FEV<sub>1</sub> over FVC.

Awopejo *et al.* (2017) observed the importance of biomass smoke on occupational risk. A cross-sectional study was done to inspect respiration health of 188 healthy women who are

working as streets of Nigeria. They observed from the results of questionnaire based data that LFT ailments were significantly higher in selected candidates due to elevated level of PM pollution in the streets due to the process of cooking and use of coal.

In epidemiological, behavioral and longitudinal studies, data has been collected and then statistically treated for significant interpretations in relation to aim of experiments. In regression based models, range of uncertainty in response (output) results is identified as the key marker to justify the significance of prediction slope due to effect modifiers. Certainty in uncertain conditions chiefly depends on multi covariates and confounders. While designing epidemiological or time series studies, it is very essential to identify primary parameters and their potential covariates and confounders. According to statistics literature, the range of uncertainty shall be fixed in a certain range due to adjustment of each and every possible potential confounder while treating the data. This practice may lead to more accuracy in certainty of slope to represent the trend in firm and vague constraints of an experiment or condition and reduce biasing.

Peng *et al.* (2006) investigated the role of time series studies and selection of appropriate modal for scaling the relations of air pollution and mortality. They raised various methodological issues concerned to time series analysis that attracted the attention of the researchers and prominent scientific communities. They found that that the biases in the estimations generally decreased with more smoothing of confounders using Log transformed spline methods.

Brookhart *et al.* (2010) raised the issues in relation to potential approaches and challenges to adjust confounding parameters in data base when healthcare research has been performed. They observed the lacking of adjustment of covariates and confounding factors in various statistical analysis that may challenge the results. Hence, they concluded the necessity to adjust possible confounding factors in such studies due to complex and challenging interventions of patient, physician, and healthcare system factors.

Spencer *et al.* (2011) investigated the role of ambient pollutants and their risk to cause fatal coronary heart disease among the patients of kidney transplant recipients. They identified each and every possible potential confounder who had the potential to vary the results while adjustment. The identified total 11 confounders who were individually affect the results.

Hence they design individual model with adjustment of each confounders with prime effect modifiers. They separately presented and discussed the results of Models

Sheppard *et al.* (2012) investigations observed that the results of various studies from air pollution epidemiology may suffer from specific forms of confounding factors that caused errors in exposure measurement.

Roy *et al.* (2012) investigated PM<sub>2.5</sub> and growth in lungs in school going children of china. Their estimations were done with adjustment of potential confounders such as education, age, height, weight, season effects and parental occupations. They observed that an upliftment of 10 $\mu\text{gm}^{-3}$  of PM<sub>2.5</sub> declined the FEV<sub>1</sub> by 2.6 ml. Hence. the results were well recognized by scientific community.

From the literature, it has been observed that the raised level of fine particulate matter is a serious concern in relation human health. School going children are more affected than human subjects of other age groups. So, there is a need to investigate and study the health effects of children in relation to ACRB activity.

## 2.6 Objectives

- To measure Particulate Matter levels in affected urban areas before, during and after ACRB seasons
- To measure physiological parameters of urban school children
- To critically review the existing models
- To develop the cause-effect models between pollutants and health

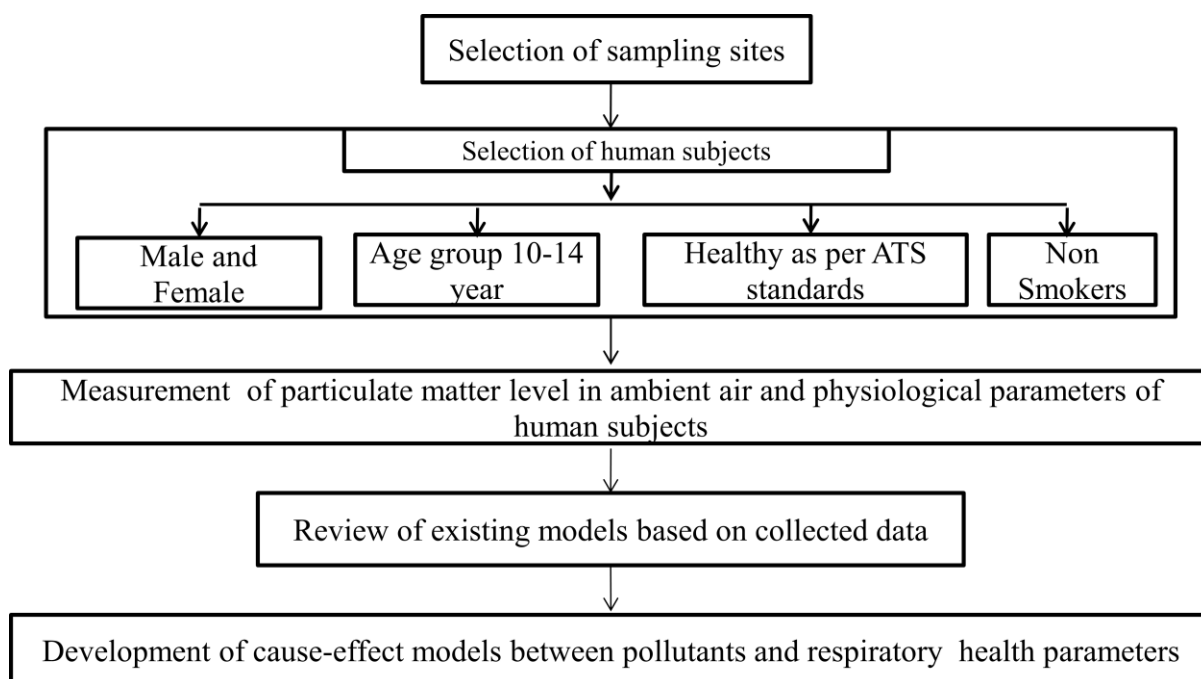
*In this chapter, studies related to health effect of school children due to raised levels of ambient PM are studied and presented. In earlier section, health related studies are presented that scale out the consequences due to raised level of PM in respect of accidental activities, industrial growth, growth in use of vehicles, construction sites etc. Few studies presented on the significance of meteorological conditions, socioeconomic factors and anthropogenic parameters of human subjects in exposure assessment process are included in literature survey. Selection of statistical model has been identified as very important parameter that can influence the inferences from the reported data.*

## Chapter-3

### Materials and methods

*This chapter deals with different methods, techniques, principles and instrumentation used for the research work for the effects of PM on respiratory health school going children due to Agriculture Crop Residue Burning (ACRB) practice in open fields of Punjab. Different national and international standards, procedures and protocols were followed during selection of sites, subjects and instruments. The study areas are briefly elaborated in 3.1 section. Selection of subjects and criteria of their selection is presented in section 3.2. The information of different measurable parameters and their instrumentation is described in section 3.3. The descriptive and statistical analysis techniques are discussed in section 3.4. To study the consequences of ACRB on the respiration health of common healthy subjects, systematic methodology was adopted. Standard prescribed methods were used and all precautions were taken during different type of data collection and analysis.*

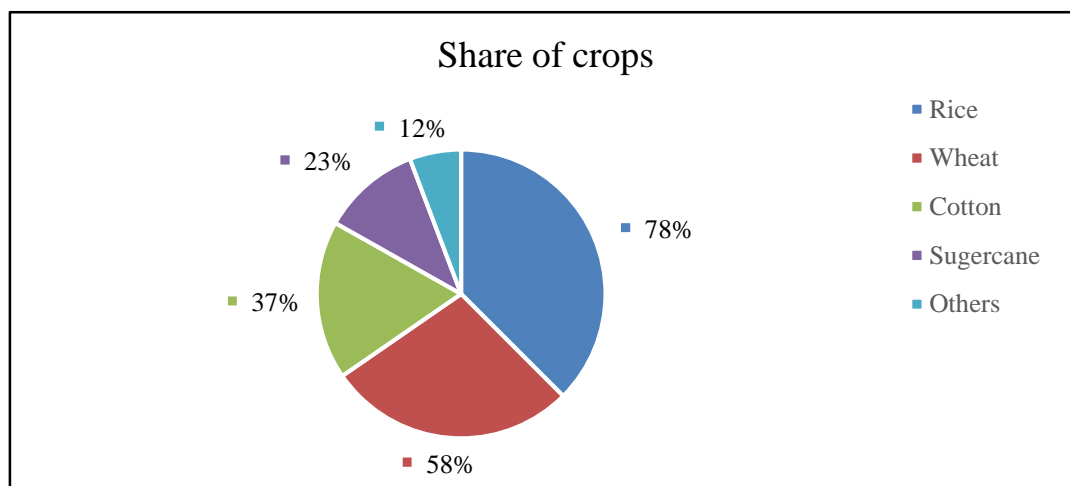
Several steps were followed such as selection of sampling site, selection of subjects, data collection, review of existing models and development and analysis of cause effect models using statistical methods during the study and are shown in Figure 3.1



**Figure 3.1: Flow chart for the study (Methodology)**

### 3.1 Selection of sites

In India, Punjab state is ranked as second biggest food grain producing source of country. This site is a triangular and highly fertile plain area which is located in North -West side of Trans Himalaya Hills (Badarinath *et al.* 2009). In this area rice, wheat, cotton and sugarcane are cultivated on major scale due to the favorable bio-environmental conditions (Jain *et al.* 2014). This state has 50,336 Hectares of area under which 34,756 Hectares area is under cultivation. In this plain, rice and wheat crops are chiefly cultivated as compared to other crops due to lucrative economic benefits given by State and Central Governments. According to Ministry of Agriculture and Farmers Welfare (Government of India) annual report (2017-18), the percentage sharing of different crops in Punjab region is shown in Figure 3.2 (Jain *et al.* 2014).



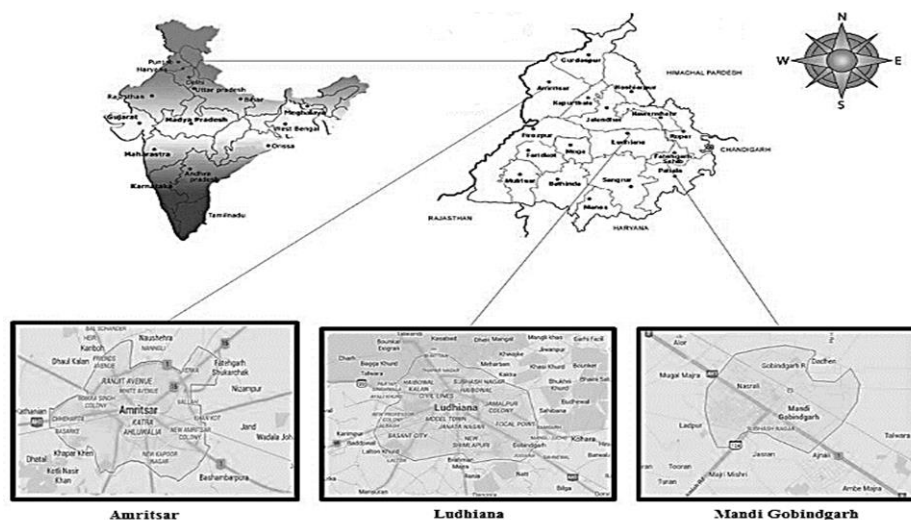
**Figure 3.2: Distribution share of crops in Punjab state**

According to statistical reports, rice crop has highest percentage of production than other crops in the area. Every year, Punjab state adds 37.8% of total rice grains and 57% of wheat grains to food basket of country (Jain *et al.* 2014).

Every year, the rice and wheat crops are cultivated in the area in a cyclic manner. As per their required environmental conditions, rice crop is sown in the middle of June when the weather is hot and humid and is ready to harvest in last week of October month. In this period, environment is moderately cool and dry. Similarly, wheat crop is sown in the month of December when weather is cool and dry and is ready to harvest in the second week of April month when the weather is moderate hot and dry. These crops are very sensitive to their environmental conditions. Any kind of delay between the sowing and threshing process of

these crops may affect their health and productivity (Awasthi *et al.* 2010). In these conditions, local farmers have a challenging task to harvest ripe crop, dispose of the crop residue and prepare their fields for next crop. Due to time constraint, farmers use modern mechanical techniques like combines and threshers to directly collect the grains from ripe crop in trolleys. These machines efficiently helped the farmers but in this process a huge amount of crop waste or residue is left and spread in undisciplined manner in the open fields. Each season, the local government allotted a limited time to farmers for selling their crop grains in the local market to government stores. Due to lack of time and shortage of sources like manpower, financial aids (crop residue deposition machines like rotavator, shifter etc.) insist the farmers to burn agriculture crop residue waste in the open fields. In Punjab, this practice released huge amount of gaseous pollutants and suspended particulate matters in the ambient environment. As per NASA's satellite based pictures, every year approximately 46 Metric tons of crops residue waste is burned in the fields of Punjab (Thumarty *et al.* 2015). As compared to other crops rice and wheat crops have maximum share of crop residue generation. This practice not only affects the environment cycle but also affects the human health on local and global scale. To observe the effect of suspended particulate matters on human health of Punjab state, sites and subjects were selected in a planned manner.

In Punjab region, three agriculturally active sites had been selected to measure the level of suspended particulate matters during crop residue burning seasons. These sites were selected in districts of Punjab which have maximum area under cultivation. Hence, Amritsar, Ludhiana and Mandi Gobindgarh sites were selected for data collection. The map of sites is shown in Figure 3.3.



**Figure 3.3: Geographical location of sites in Punjab region**

For sampling and data collection, three schools were selected (one at each site). The strategic importance and demographic detail of sites is given in Table 3.1.

**Table 3.1: Details of the sampling sites and their grid locations**

S.No	Sampling site	Strategic importance	Location with Grid reference	Area under cultivation (in "000" Hectare)	Population at sites (in Millions)
1	Prabhakarn Public Sen. Sec. School, Chheharta <b>Amritsar (AMS)</b>	Historically important	North West side of Punjab with 31.64° N latitude and 74.86° E longitude	424	5.1
2	Tagore Public School, Agar Nagar <b>Ludhiana (LDH)</b>	Commercial center	Centre of Punjab with 30.91° N latitude and 75.86° E longitude	513	7.2
3	Govt. Matric School, Salani <b>Mandi Gobindgarh (MGH)</b>	Steel Industry	East side of Punjab with 30.41° N latitude and 76.18° E longitude	534	4.7

The distance between any two sites was approximately 100 to 150 km and each sampling site was located at about 0-2 km from the nearest point of crop residue burning activity. Seasonal and temporal trends of meteorological parameters were collected from Punjab Pollution Control Board (PPCB) stations at all the sites. The schools were selected on the following basis:

- Schools should not have other source of pollution in surrounding within 10 km.
- Schools having adequate number of children subjects living near to school for 10 or more years.
- Schools should not have any kind of ventilation obstacle surrounding the periphery.

After inspection, all the three sites were found appropriate for the study. Before sampling of air in the school premises, permissions were taken from concerned authorities.

### 3.2 Selection of Subjects

Before the selection of subjects for pulmonary function tests in study period, American Thoracic Society (ATS) and British Medical Research Council (BMRC) protocols were used (Miller *et al.* 2005). Subjects having spirometer parametric ratio (FEV<sub>1</sub>/FVC) more than 75% of percent predicted value were considered as healthy. Based on this, initial spirometric tests were conducted on the students having age between 10 to 14 years in respective schools. These students were studying in the 5<sup>th</sup> and 6<sup>th</sup> standard of schools. Consent forms were given

to selected subjects to fill their background information related to their socioeconomic status, health status and their relative environment. Based on ATS questionnaires, the subjects have to satisfy the following criteria

- No history of smoking or intoxicant.
- No symptoms of dyspnoea or asthma.
- No history of skeletal deformity.
- No excess obesity or undernourishment.
- No history of cardio pulmonary disorders.

About 60 to 70 students were found eligible for study period at each school. But due to personal interest or some behavior constraints, only 50 students finally participated for the study period at each school (Total 150 students). It has been observed in our previous studies that pulmonary impairments related to structural and functional relationships are broadly classified into muscular factors like ventilation coefficient related to flow and capacity of lungs, muscle strength, compressions and expansion of diaphragm, elasticity of lung walls and thoracic cavity restriction and respiration rate (American Thoracic Society report 1998). These organs are getting imbalanced due to several unaccepted multilateral factors (Moya *et al.* 2004). It has been reported that nutritional status of human body affects the factors related to pulmonary function. According to World Health Organization (WHO), Body Mass Index (BMI) or Broka's index is the key marker to examine the nutritional status of human body (Pelsoi *et al.* 1998). BMI parameter categorizes body composition into three significant categories such as Low BMI (less than  $18 \text{ Kg m}^{-2}$ ), Normal BMI ( $18$  to  $23 \text{ Kg m}^{-2}$ ) and High BMI (more than  $23 \text{ Kg m}^{-2}$ ). Experimental and meta-analysis based studies demonstrate that there is a statistically significant correlation between BMI level and pulmonary function impairments of human subjects under various trials (Jones *et al.* 2006).

Consent Forms were collected from selected subjects. The demographic detail of selected subjects is given in Table 3.2.

Site wise, it was observed that in Mandi Gobindgarh, 70% of total candidates were under low BMI followed by Amritsar (65%) and Ludhiana (62%) due to difference in socioeconomic status of the candidates. At the time of selection, the subjects of Ludhiana were found healthy due to their better BMI index than other subjects of Amritsar and Mandi Gobindgarh.

**Table 3.2: Demographic details of the selected subjects as on start of the study (August 2013)**

Parameters	Amritsar (AMS)	Ludhiana (LDH)	Mandi Gobindgarh (MGH)
Male (Number)	29	30	32
Female (Number)	21	20	18
Average age (Years)	12.5	12.2	13.5
Mean height (cm)	144	147	142
Mean weight (kg)	40	48	35
Mean BMI Index	19.3	21.3	17.9
Tiffeneau Index	> 85%	> 85%	> 85%
Symptoms of Asthma	Nil	Nil	Nil
Previous Medical Record	Nil	Nil	Nil
Passive Smoking	Nil	Nil	Nil
Annual Income	Average	Average	Average
Cooking Appliances at home	LPG	LPG	LPG
Allergic rhinitis, atopic	Nil	Nil	Nil

### 3.3 Data Collection of Environmental Parameters, Physiological Parameters of the Subjects

After selection of three sites in Punjab state and 50 healthy subjects at each site, the process of data collection was started in a planned manner. The sampling frequency and schedule was designed for three years study period after considering various factors.

#### 3.3.1 Sampling frequency and schedules

The data collection was decided to be started for a period of three years from August 2013 to July 2016. This duration covers six consecutive crop seasons having three for rice crop and three for wheat crop in a cyclic manner. Each season was further divided into three periods to cover non- burning episodes, during burning episodes and post-burning episodes. The year wise seasons and respective periods are shown in Table 3.3. Keeping in consideration, the holidays, availability of subjects, exam schedules, burning episodes etc. sampling frequency schedule was decided as once in a fortnight during non-crop residue burning periods and twice in a fortnight during peak crop residue burning periods.

**Table 3.3: Crop seasons and respective sampling schedule**

Duration	Crop Season	Pre-burning Period				During-burning Period				Post- burning Period			
August 2013 to January 2014	Rice	Aug-13 to Sep-13				Oct-13 to Nov-13				Dec-13 to Jan-14			
		FN-1	FN-2	FN-3	FN-4	FN-5	FN-6	FN-7	FN-8	FN-9	FN-10	FN-11	FN-12
February 2014 to July 2014	Wheat	Feb14 to Mar-14				Apr-14 to May-14				June14 to July-14			
		FN-13	FN-14	FN-15	FN-16	FN-17	FN-18	FN-19	FN-20	FN-21	FN-22	FN-23	FN-24
August 2014 to January 2015	Rice	Aug-14 to Sep-14				Oct-14 to Nov-14				Dec-14 to Jan-15			
		FN-25	FN-26	FN-27	FN-28	FN-29	FN-30	FN-31	FN-32	FN-33	FN-34	FN-35	FN-36
February 2015 to July 2015	Wheat	Feb15 to Mar-15				Apr-15 to May-15				June15 to July-15			
		FN-37	FN-38	FN-39	FN-40	FN-41	FN-42	FN-43	FN-44	FN-45	FN-46	FN-47	FN-48
August 2015 to January 2016	Rice	Aug-15 to Sep-15				Oct-15 to Nov-15				Dec-15 to Jan-16			
		FN-49	FN-50	FN-51	FN-52	FN-53	FN-54	FN-55	FN-56	FN-57	FN-58	FN-59	FN-60
February 2016 to July 2016	Wheat	Feb16 to Mar-16				Apr-16 to May-16				June16 to July-16			
		FN-61	FN-62	FN-63	FN-64	FN-65	FN-66	FN-67	FN-68	FN-69	FN-70	FN-71	FN-72

### 3.3.2 Measurement of physiological parameters and PFT on children

At each site, respiratory status of the selected subjects was measured by performing Pulmonary Function Tests (PFTs). As per sampling schedule, PFTs of selected subjects were measured fortnightly in school timings (between 9 AM to 2 PM from August 2013 to July 2016). PFTs of the subjects were measured in the standing position by using the portable Spirometer. Before test, physiological parameters of each subject such as gender, height (in centimeter), weight (in kilogram), Body Mass Index etc. were collected for spirometric requirements. PFTs were measured after adding their age, height, weight and gender on the basis of American Thoracic Society Standards and protocols (Miller *et al.* 2005). spirometric maneuvers were performed with consideration of under mentioned precautions throughout the study period:

- Before taking test, subjects were allowed to take rest for 5 to 10 minutes 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 mouthpiece.
- Separate mouthpiece was used by each subject.

- Each Spirometric measurement was 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 prime factors like FVC, PEF and derived factors like FEV<sub>1</sub> and FEF<sub>25-75%</sub>.

Maneuvers done by the subjects during whole study involved different steps

- Take five to eight normal breaths.
- Then take deep breath as per capacity of subject.
- Expire all air as fast as possible with force and up to maximum extent.

The significance of Spirometric parameters is given below (Miller *et al.* 2005):

- 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 litre. It is used to find capacity of lungs for COPD detection.
- 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 litre per second. This parameter has the significance to observe the restrictions in windpipe.
- Forced Expiratory Volume in 1 second (FEV<sub>1</sub>): Total amount of air blown in 1 second. It is expressed in litre per second. This parameter is used to observe the restrictions in endothelial compliances.
- Force Expiratory Flow in 25 to 75% (FEF<sub>25-75%</sub>): Flow measurement over the middle half of FVC *i.e.*, from the 25% level to 75%. It is expressed in litre per second. This parameter is used to observe the stiffness of lungs mechanism.

These parameters are the most important and informative physiological parameters, which are generally used by the doctors and researchers for the investigation and curing the different respiratory related diseases like asthma *etc.* The subject's baseline lung function was compared with the reference value of European Respiratory Society standards and expressed as percent of the predicted value (Knudson *et al.* 1983)

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

### 3.3.2.1 Working principle of spirometer

A spirometer is a medical apparatus used to measure 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 research work PFTs were done according to the American Thoracic Society (ATS) rules (Miller *et al.* 2005). Spiro Doc of MIR (Italy) is used in this study for PFT's. The device works on the phenomenon of infrared light interruption. Physical diagram of the Spirometer is shown in Figure 3.4.



**Figure 3.4: MIR's SPIRO DOC**

In this device, 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 has electronic reader.



**Figure 3.5: Turbine system in Spirometer**

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, Ambient temperature and expired gas composition). Technically Spirometer which is used throughout the study has volume range of 10 L, flow range of  $\pm 16$  L/s, volume accuracy of  $\pm 3\%$  or 50 mL and flow accuracy of  $\pm 5\%$  or 200 mL/s. The data were stored in inbuilt memory and was transferred to computer by interfacing with RS232 port using Winspiro2.3 software.

### 3.3.3 Measurement of particulate matter concentration

Particulate matter concentration having size  $PM_{10}$  and  $PM_{2.5}$  were measured using Real Time Optical Light Scattering Aerosol Monitor (RTOLSAM, Grimm Technology, Model 1.108, Germany) is shown in Figure 3.6.



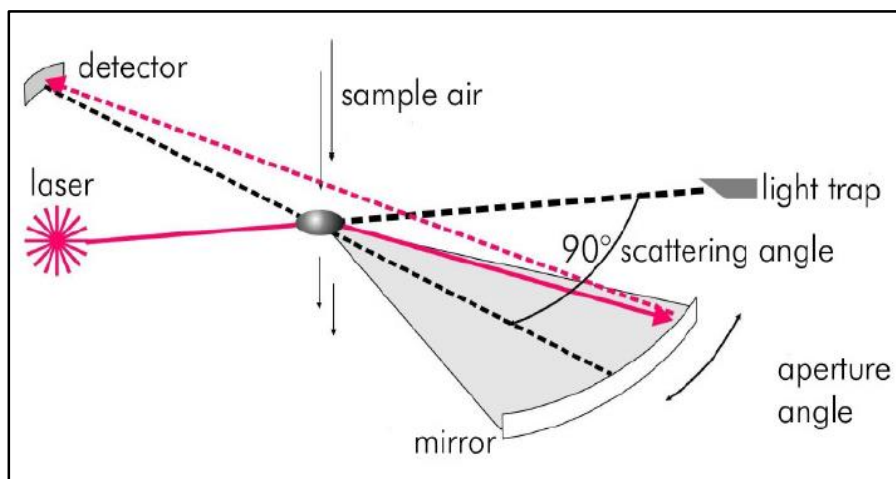
**Figure 3.6: Grimm's Aerosol Spectrometer**

The measurement of  $PM_{10}$  and  $PM_{2.5}$  were observed for 24 hours on same day of PFT test in the school yard. This model is compact portable device which has been built for continuous measurement of airborne particles as well as for measuring the particle count distribution. They possess an integrated gravimetric filter on which all particles are collected after the optical measurement and thus are available for further measurements (Cheng *et al.* 2010). The device has two modes to calculate the PM levels and displayed them as particle concentration in the unit particle/litre (Cheng *et al.* 2010). By means of the Grimm Windows Software additionally different dust mass fractions (smaller than  $PM_{2.5}$ ) can be displayed as well as calculated in particle surface area. The standardized dust mass fractions are scaled in

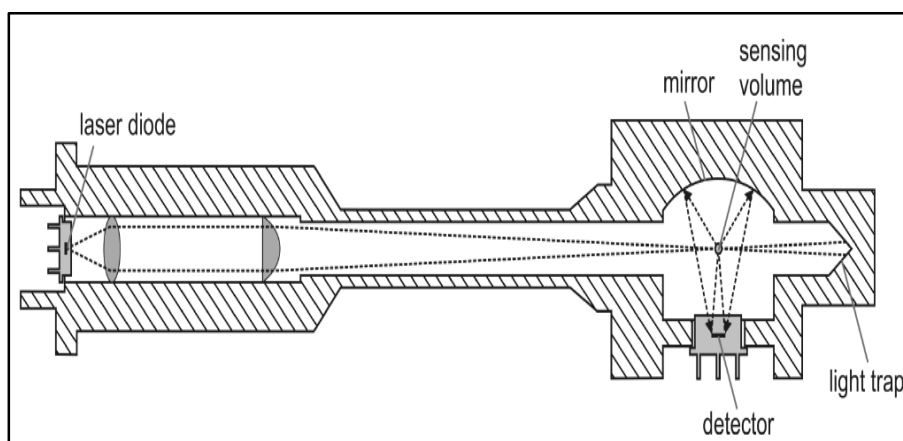
terms of occupational respirable, thoracic and alveolic as per EN 481 protocols (Cheng 2008). These modes are very useful for indoor and outdoor measurements of suspended particulate matter.

### 3.3.3.1 Working Principle of Laser Light Operated Aerosol Spectrometer

The measuring principle of the model 1.108 is the light scattering of single particles with a semiconductor laser as light source. Inside the measuring cell, scattered light is being led directly and via a mirror with a wide opening angle onto the detector (Figure 3.7 and Figure 3.8).



**Figure 3.7: Working principal of laser operated aerosol spectrometer**



**Figure 3.8: Mechanism of Grimm's RTOLSAM**

The detector is positioned at the right angle to the incident laser beam. This setup of the detector is denominated as  $90^\circ$  scattering light detection. This optical alignment increases the

scattering light collected by the detector and optimizes the signal-to-noise ratio. Therefore, even very small particles down to 0.25 $\mu\text{m}$  can be detected. The optical setup moreover abrades the MIE scattering undulations that are caused by monochromatic illumination as it is typical for laser light scattering spectrometers and therefore enables a definite particle sizing. If a particle crosses the laser beam, it creates a light pulse. The particle size distribution can be measured through the calculation of the dust mass. The sample air is sucked through the measuring cell and a gravimetric filter by means of an internal volume flow controlled pump. This filter serves as a dust collector and can be used for gravimetric control of the optical gained measurement results. The pump also conveys the rinsing air, which is gained out of the pump's exhaust air via a zero filter and being held constant by a rinsing air control. The rinsing air protects the laser optics just as other components of the optical measuring cell from pollution and serves during the self-test as particle-free reference air. The signal of the detector diode will be classified into different size channels after accordant amplification of signal. This Model possesses 15 size channels ranges from 0.23 $\mu\text{m}$  to 20 $\mu\text{m}$ .

For standard concentration measurements of  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$ , the device is calibrated as recommended by the manufacturer and needs no pre-preparation as traditional gravimetric methods. Monitoring process, technical aspects, operation modes and gravimetric calibration of test device is well documented in previous studies (Cheng 2008; Cheng *et al.* 2010). The device consists of four modes of operation: Occupational health, Environment, Particle count and Mass concentration. The data were measured using mass concentration mode (15 channels, 0.23 $\mu\text{m}$  to 20 $\mu\text{m}$ ) mainly due to calibration factor of this mode is closer to gravimetric method as compared to other modes and less influence to refractive index, particle shape, density and particle size.

$\text{PM}_{10}$  and  $\text{PM}_{2.5}$  were computed from mass concentration using Grimm Technology equations. According to this method, the  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  concentration were calculated using the equation (3.1) as given below,

$$PM = \sum_{i=1}^{15} (Mi * Fi) \dots\dots\dots 3.1$$

where  $PM$  is  $\text{PM}_{10}$  or  $\text{PM}_{2.5}$  and  $Mi$  indicates channel wise measured mass concentration in  $\mu\text{g}\text{m}^{-3}$ .  $Fi$  is the weighting factor of the  $i$ -th channel of the test device which was further calculated by the given equations (Tang *et al.* 2012).

$$F_{PM10}(i) = 1.0 \quad \text{for } i < 1.5 \mu\text{m} \dots\dots\dots 3.2$$

$$F_{PM10}(i) = 0.9585 - 0.00408 i^2 \quad \text{for } 1.5 < i < 15\mu\text{m} \dots\dots\dots 3.3$$

$$F_{PM10}(i) = 0.0 \quad \text{for } i > 15\mu\text{m} \dots\dots\dots 3.4$$

$$F_{PM2.5}(i) = [1 + \exp(3.233i - 9.495)]^{-3.368} \quad \text{for } 1 < i < 15\mu\text{m} \dots\dots\dots 3.5$$

From the equations, the weighting factors were calculated. For PM<sub>10</sub>, the weighting factor for channels 1 to 7 was taken as 1 while that for 8 to 15 it was taken as 0.942, 0.922, 0.893, 0.8345, 0.724, 0.4486, 0.041, and 0, respectively. For the calculations of PM<sub>2.5</sub>, the weighting factor for channel 1 to 6 was taken as 1 while that for 7 to 9 it was taken as 0.995, 0.855, and 0.48, respectively. For channels 10 to 15, the weighting factor was 0. The real time device measurements were overestimated than actual values. For actual estimation, initially the testing device (RTOLSAM) was calibrated with standard gravimetric method for 24 hours at each site. In this calibration the correction factor was obtained as 0.88 (R<sup>2</sup>= 0.99) for test device (Tang *et al.* 2012).

### 3.4 Statistical analysis

To observe seasonal and episodic trends in ambient PM levels and physiological parameters, descriptive analysis were done i.e., mean and standard deviations. The difference between the sites and within the sites was observed by ANOVA and student's t test. BMI wise, Pearson correlation coefficients were measured to observe the relationship between measured PM pollutants and physiological parameters in both rice and wheat crop residue burning seasons. By critically reviewing estimation based statistical models, it has been observed that the simple linear regression based models adjust the repeatedly measured parameters (Independent parameters) while considering independency between them, may cause false estimation to results of dependent parameters (Boucher *et al.* 1998). These models had been discerned for vague limits of uncertainty in intercept of dependent parameter. In repeated measurements, it is necessary to account correlations within and between the independent parameters in the prediction models for accurate outcomes (Cheng *et al.* 2010).

In this study, Mixed Effect Model (MEM) has been adopted for prediction of trends. This model has flexibility to adjust both fixed and random variables with their normal and non-normal distribution over time (Lampa *et al.* 2008; Rajeshwaran *et al.* 2014). In contrast to prediction models, this model also accounts any missing data, heterogeneity between groups, repeated correlations, and variance –covariance relations of individual parameter for accuracy in estimation of sampled group (Lampa *et al.* 2008). During the longitudinal period of study,

both dependent variables (Physiological parameters - FVC, FEV<sub>1</sub>, PEF and FEF<sub>25-75%</sub>) and independent variables (PM, covariates like anthropometric parameters of selected subjects and meteorological parameters) were repeatedly measured and adjusted in Mixed-effects regression model (Liu *et al.* 2006). The effect estimates were expressed as the increase in lung function per 10µgm<sup>-3</sup> increase in PM<sub>10</sub> and PM<sub>2.5</sub> concentration during both CRB seasons. Site wise, the model was adjusted for age, sex, BMI, temperature and relative humidity. The equation 3.6 presents the mixed effect model based regression approach.

$$Y_{mn} = \beta_0 + \beta_1 * PM + \beta_2 * X_{1mn} + \dots + \beta_a * X_{amn} + \zeta_n + e_{mn} \dots \dots \dots (3.6)$$

where  $Y_{mn}$  represents the PFT parameters (FVC, FEV<sub>1</sub>, PEF and FEF<sub>25-75%</sub>),  $\beta_0$  is intercept,  $\beta_1$  presents the regression coefficient for PM<sub>10</sub> and PM<sub>2.5</sub> levels,  $\beta_2$  to  $\beta_a$  presents the regression coefficients for the covariates in the model,  $\zeta_n$  is the random effect for the study participant,  $n$  represents the study participants,  $m$  identifies the sampling period and  $e_{mn}$  is the residual error term. The statistical analyses were done using Statistical Package for the Social Sciences (SPSS) version 22.0, 2013 and considered significant if p-value < 0.05.

*In this chapter, various international standards and protocols were adopted during selection of sites and human subjects and selection of instruments for study duration. Three schools were selected for data collection in different sites of Punjab. Total 150 students were enrolled in study. Sampling of data has been done from August 2013 to July 2016 to cover six consecutive seasons of rice and wheat crop seasons. The sampling frequency was decided as twice per fortnight at each site during CRB episodes. The instruments were calibrated timely by the suppliers to avoid errors. Statistical techniques and models are briefly explained for statistics based estimations. The significance of Mixed Effect Model (MEM) is also described.*

# Chapter-4

## Results and discussion

*This chapter is divided into three parts. In first part, trends and comparison of  $PM_{10}$  and  $PM_{2.5}$  concentration levels are discussed at different sites. Second part presents seasonal, episodic trends and estimation of the measured physiological parameters. The statistically significant relations and estimations are also presented in second section. Statistical models are proposed to simulate cause effect analysis of the data. FVC levels of selected subjects were stratified in relation to  $PM_{2.5}$  concentration levels at each site. The unusual plateau behavior of FVC as a function of  $PM_{2.5}$  levels observed for each category of school children are discussed in section 4.3.*

In Punjab region, agriculture crop residue burning practice is extensively used by local farmers to clean their fields to prepare their land for next crop. Due to lack of resources and cost factor in disposing excess quantity of crop residue, farmers are using this method since last few decades. This issue is being identified as a global threat in concern to ambient air pollution due to satellite based evidences and health outcomes. In this study, three agriculturally active sites (Amritsar-AMS, Ludhiana-LDH and Mandi Gobindgarh-MGH) were selected in the region. To observe the effect of particulate matter pollution on physiological parameters of children in age group 10 to 14 years, a school was selected at each site. From August 2013 to July 2016, ambient particulate matter having respirable ( $PM_{10}$ ) and inhalable ( $PM_{2.5}$ ) size were measured in the school yards as per sampling plan using portable aerosol spectrometer. Simultaneously, total 150 healthy human subjects also participated in the study for Spirometric tests. Before participation, subjects were inspected by questionnaire and consent form was signed by each subject in respect to their cooperation and continuation for the study duration. According to International standards and protocols, Spirometric maneuvers were performed on each subject to measure their physiological parameters such as FVC,  $FEV_1$ , PEF and  $FEF_{25-75\%}$  in percent predicted scale. Various cofactors and covariates such as meteorological parameters and anthropogenic parameters were also measured on the same day of sampling to estimate their influence on dependent variables during statistical analysis. The collected data of PM and physiological parameters of school going children has been sorted in multi dimensions (year wise, season wise, episode wise, BMI wise) to exhaust analysis. Statistical models have been developed for cause effect estimations and trends. During modeling, various factors have been considered for

comparisons. The analysis were done in two parts (first part describes PM<sub>10</sub> and PM<sub>2.5</sub> trends and second part describes trends in physiological parameters of children). In each part, season wise, episode wise and site wise comparisons have been done and percent changes are reported.

## Part 1: PM concentration level analysis

Respirable particulate matter having size PM<sub>10</sub> and PM<sub>2.5</sub> were monitored continuously during sampling period at all the selected sites. Data was collected two to three times (in a staggered manner) per fortnight to cover each site while considering school schedules and constraints. The data of both PM<sub>10</sub> and PM<sub>2.5</sub> is arranged in different events and time slots for exhaustive analysis and conclusions.

### 4.1 PM<sub>10</sub> concentration level

#### 4.1.1 Trends and comparison in rice and wheat crop residue burning periods

PM<sub>10</sub> concentration levels were measured in school yards for three years to cover six consecutive ACRB seasons. Figures 4.1 to 4.3 show yearly trends of PM<sub>10</sub> in ACRB periods during rice and wheat crop seasons at the selected sites.

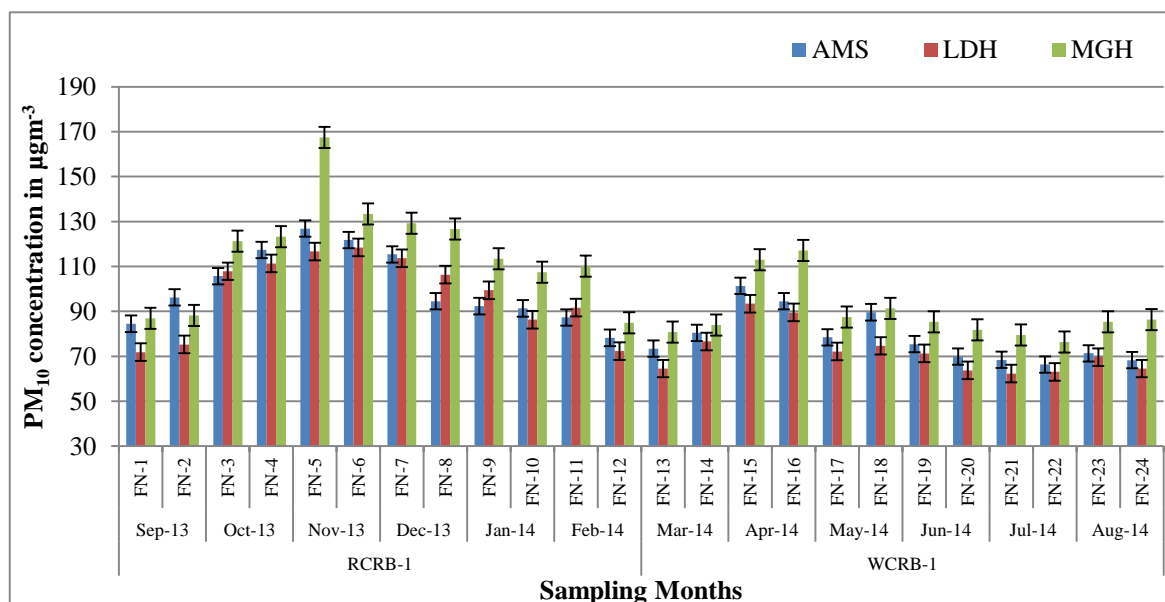
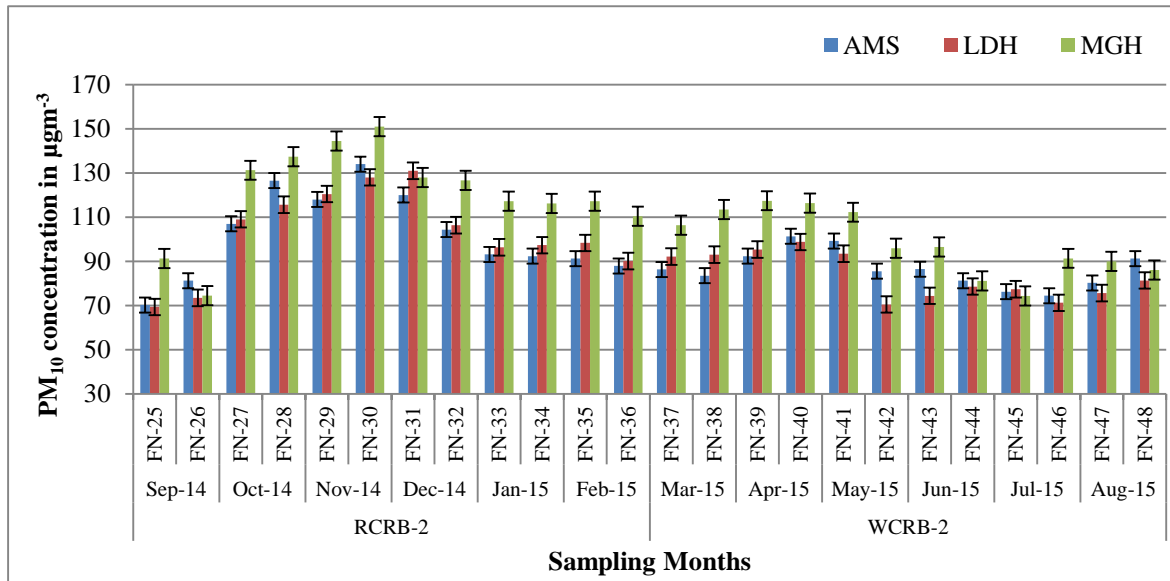
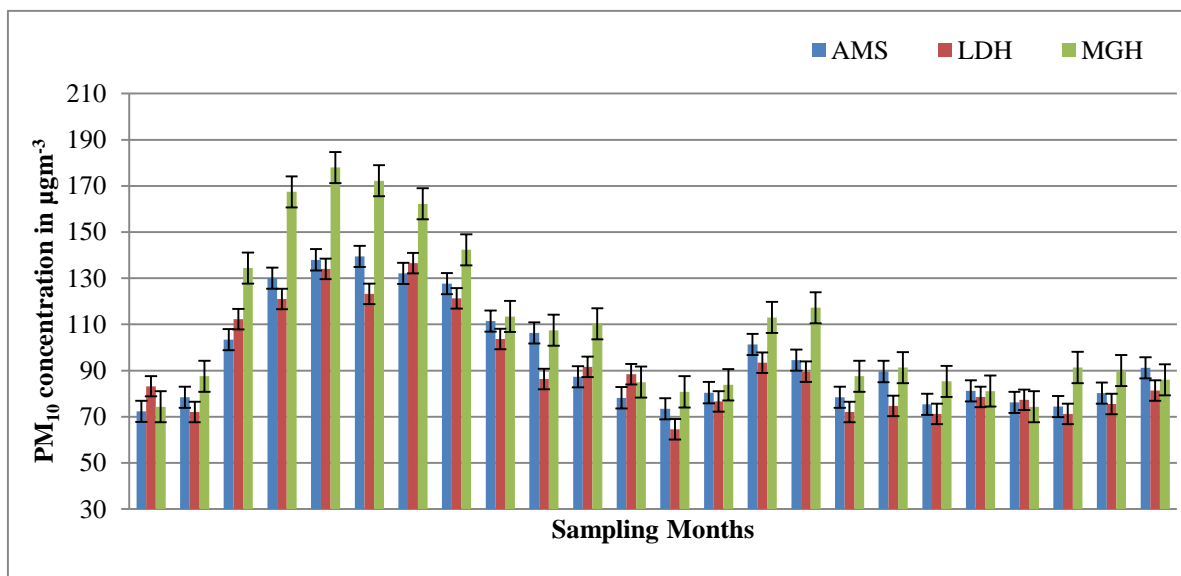


Figure 4.1: Fortnightly averaged trends of PM<sub>10</sub> at all sites during 2013-14 RWRB periods



**Figure 4.2: Fortnightly averaged trends of PM<sub>10</sub> at all sites during 2014-15 RWRB periods**



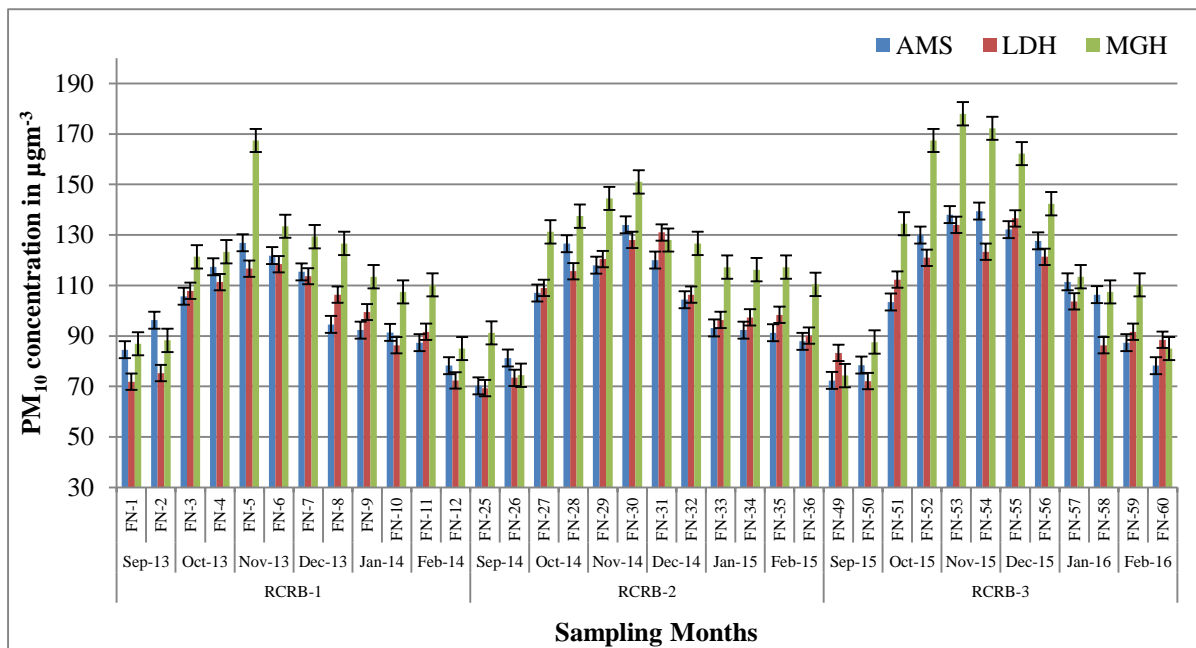
**Figure 4.3: Fortnightly averaged trends of PM<sub>10</sub> at all sites during 2015-16 RWRB periods**

Figures 4.1 to 4.3 show that during the sampling period (2013 to 2016), ambient concentration levels of PM<sub>10</sub> were higher than the baseline levels as well as standard limits of National Ambient Air Quality Standard ( $100\mu\text{gm}^{-3}$  for PM<sub>10</sub>) at all sampling sites. During the whole study period from 2013 to 2016, the fortnightly averaged levels of PM<sub>10</sub> varied from  $64\pm 19\mu\text{gm}^{-3}$  to  $180\pm 37\mu\text{gm}^{-3}$ . The levels of PM<sub>10</sub> varied from  $64\pm 21\mu\text{gm}^{-3}$  to  $167\pm 34\mu\text{gm}^{-3}$ ,  $69\pm 23\mu\text{gm}^{-3}$  to  $180\pm 31\mu\text{gm}^{-3}$  and  $65\pm 16\mu\text{gm}^{-3}$  to  $180\pm 24\mu\text{gm}^{-3}$ , respectively during crop seasons in 2013-14, 2014-15, 2015-16. Due to ACRB activity in the state, the concentration

of PM<sub>10</sub> rapidly increased at all sites. It has been estimated that the concentration level of PM<sub>10</sub> was more than the NAAQS standards by 50% to 80% whereas it was more than permitted levels by 50%, 67% to 80% in consecutive years at all sampling sites. During the sampling period (2013-16), ambient PM<sub>10</sub> concentration levels were higher than national and international standards for more than 30 fortnights (out of total 72 fortnights). Each year, the ambient PM<sub>10</sub> levels were observed higher in particular months (October-November and March-April) than other months during the study period. During 2015-16, the level of PM<sub>10</sub> was estimated to be higher than the previous years by 19% to 27%. The trends of increase in PM<sub>10</sub> levels were more or less the same at all sampling sites. The level of PM<sub>10</sub> was higher in rice crop seasons than wheat crop seasons. Even from the trends, it has been seen that before the beginning of burning episodes, the concentration levels of PM<sub>10</sub> was almost stable and lesser than the standard limits. A sharp rise in PM<sub>10</sub> was observed during the beginning of rice and wheat crop residue burning events. The difference in both seasons is further investigated to found significant observations.

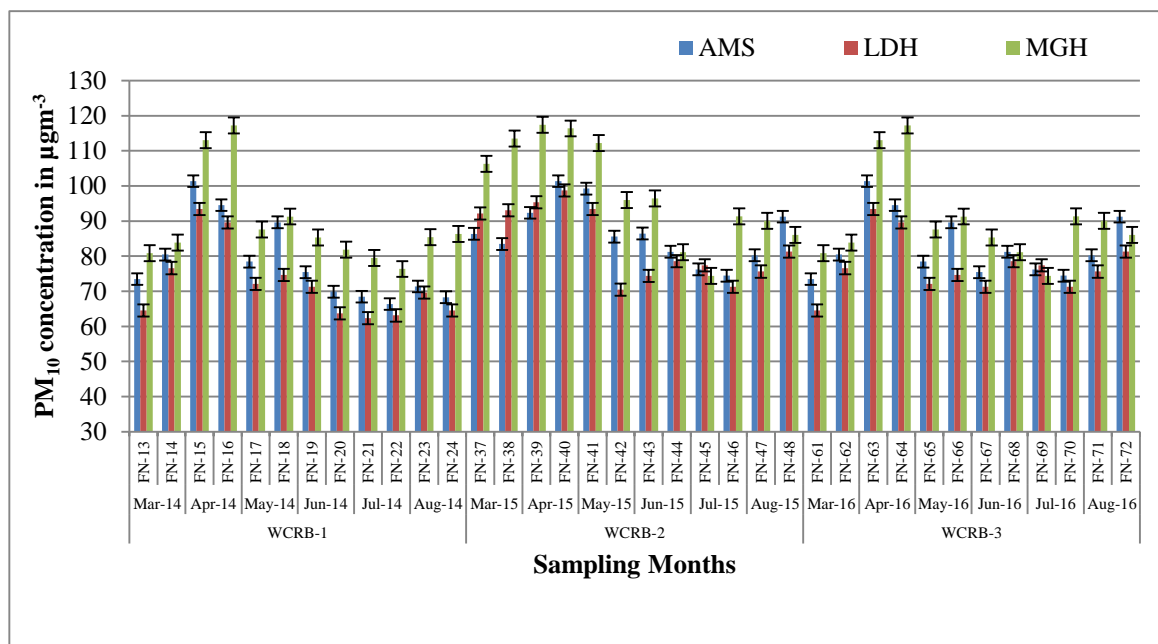
#### **4.1.2 Seasonal trends and comparison**

Each year, rice crop is ready for harvesting in the early days of October month and the practice of ACRB is held in the last days of October and continued till the middle of November. Similarly, wheat crop is ready for harvesting in the end of March and the practice of ACRB is held in the middle of April and finished at the middle of May. The Rice Crop Residue Burning (RCRB) seasons for three consecutive sampling years are shown in Figure 4.4. During RCRB-1 season (Period: 2013-14, FN-1 to FN-12), the ambient concentration level of PM<sub>10</sub> varied from  $70 \pm 16 \mu\text{g m}^{-3}$  to  $170 \pm 41 \mu\text{g m}^{-3}$  (which is estimated to be 70% more than the permitted level). Similarly, in RCRB-2 season (During: 2014-15, FN-25 to FN-36), the concentration level of PM<sub>10</sub> varied from  $74 \pm 14 \mu\text{g m}^{-3}$  to  $150 \pm 23 \mu\text{g m}^{-3}$ . The level of PM<sub>10</sub> was observed to be 50% more than the NAAQS ambient PM<sub>10</sub> standard at all sampling sites. In RCRB-3 season (During: 2015-16, FN-49 to FN-60), the concentration level of PM<sub>10</sub> varied from  $75 \pm 24 \mu\text{g m}^{-3}$  to  $180 \pm 38 \mu\text{g m}^{-3}$  (80% more than safety limits). It has been observed from the trends (shown in the 4.4) that the level of PM<sub>10</sub> suddenly exceeds the permitted levels in the month of October and stays till the last weeks of January in all RCRB seasons (approximately 7 fortnights out of 14 fortnights). In each RCRB season, concentration level of PM<sub>10</sub> increased by about 37% to 64% than previous seasons.



**Figure 4.4: Rice crop residue burning seasons during 2013-2016**

During RCRB-3, the level of  $PM_{10}$  was estimated to be higher than previous years by 27% to 41%. The Wheat Crop Residue Burning (WCRB) seasons for three consecutive sampling years are shown in Figure 4.5.



**Figure 4.5: Wheat crop residue burning episodes during 2013-2016**

During WCRB-1 season (During: 2014, FN-13 to FN-24), the ambient concentration level of  $PM_{10}$  was varied from  $62 \pm 19 \mu\text{gm}^{-3}$  to  $117 \pm 35 \mu\text{gm}^{-3}$  (which is estimated to be 17% more than the permitted level). Similarly, in WCRB-2 season (During: 2015, FN-37 to FN-48), the

concentration level of  $PM_{10}$  increased from  $63 \pm 18 \mu g m^{-3}$  to  $118 \pm 28 \mu g m^{-3}$ . The level of  $PM_{10}$  was observed 18% more than the NAAQS ambient  $PM_{10}$  standard. In WCRB-3 season (During: 2016, FN-61 to FN-72), the concentration level of  $PM_{10}$  varied from  $64 \pm 19 \mu g m^{-3}$  to  $119 \pm 22 \mu g m^{-3}$  (19% more than safety limits). It has been observed from the trends (shown in Figure 4.5) that the level of  $PM_{10}$  suddenly exceeds the permitted levels in the middle of April and stays till the middle weeks of May in all WCRB seasons (approximately 3 to 5 fortnights out of 12 fortnights). In each WCRB season, concentration level of  $PM_{10}$  increased by about 17% to 28% than previous seasons. During WCRB-3, the level of  $PM_{10}$  was estimated to be higher than previous years by 13% to 23%.

Overall, it has been observed from the trends that the ambient  $PM_{10}$  levels were remained higher than permitted levels for more fortnights in rice seasons than wheat seasons. The ambient concentration level of  $PM_{10}$  was estimated to be about 57% to 67% more in RCRB seasons than WCRB seasons. In each ACRB period, the concentration level of  $PM_{10}$  was higher during and after CRB periods than non CRB periods. The episodic trends are further investigated to find significant observations.

#### 4.1.3 Trends and comparison in non-burning and burning harvesting periods

In each crop season, a sharp rise in  $PM_{10}$  concentration level was observed at each sampling site. The levels were observed to be higher several times more than permitted levels and sustained in the ambient air for long time. To investigate the episodic trends, the data has been presented in pre, during and post CRB episodes. The trends are shown in Figure 4.6 to Figure 4.8.

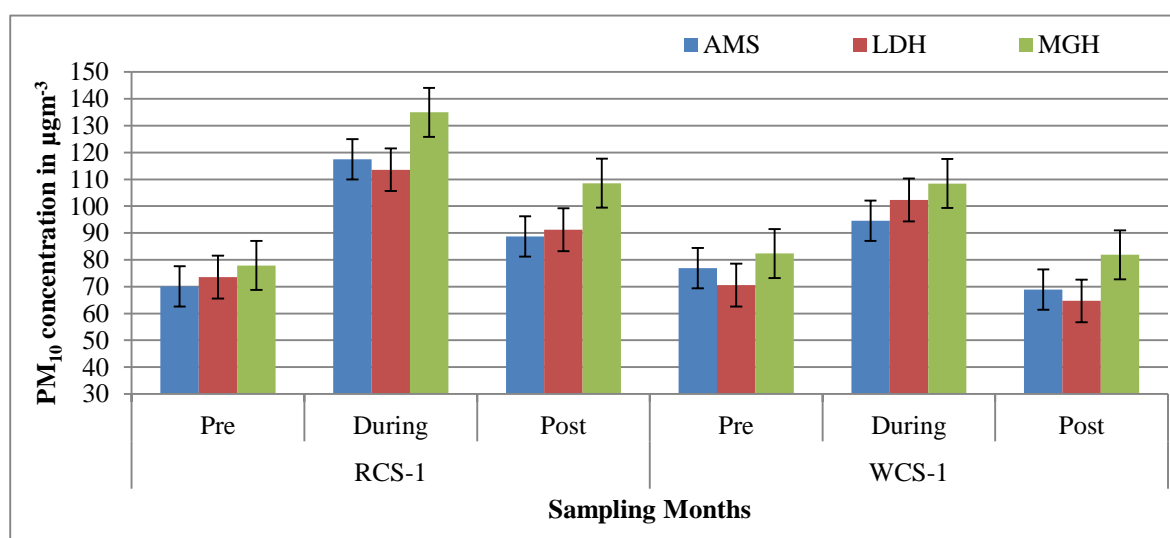
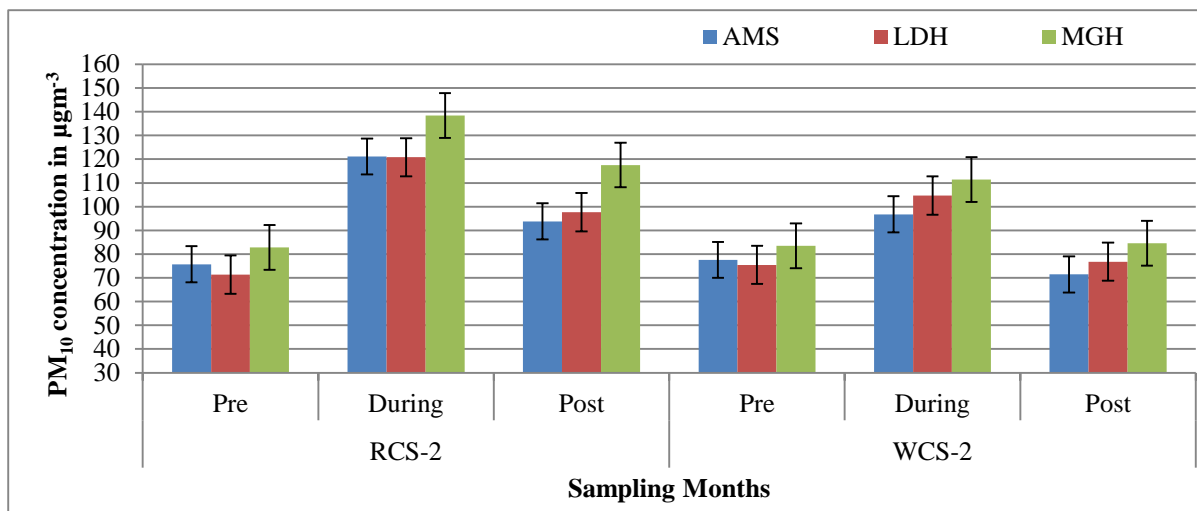
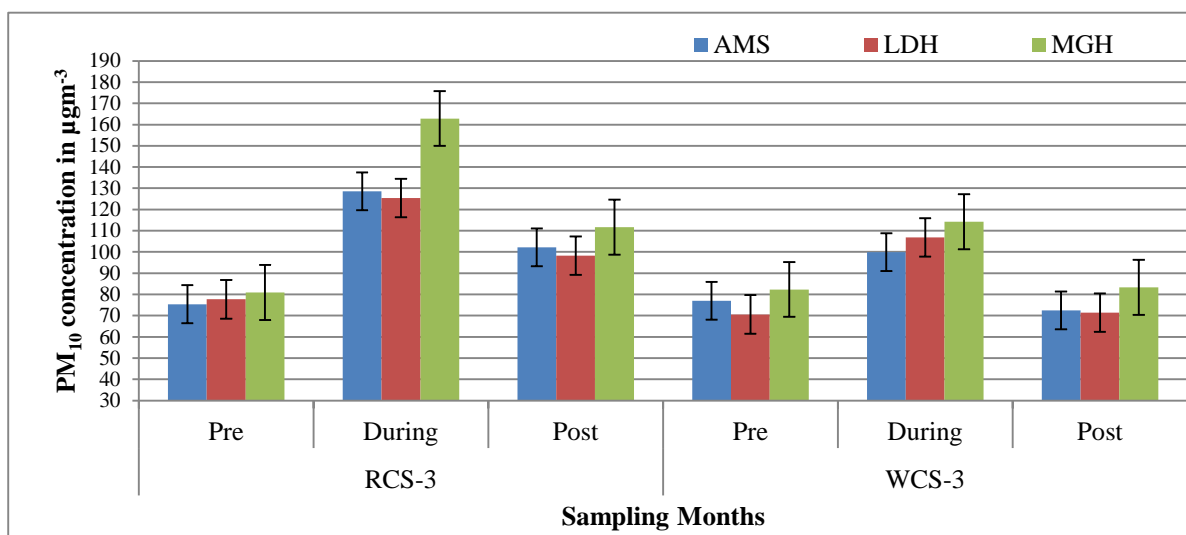


Figure 4.6: Episodic trends in Rice and Wheat crop seasons during 2013-14



**Figure 4.7: Episodic trends in Rice and Wheat crop seasons during 2014-15**



**Figure 4.8: Episodic trends in Rice and Wheat crop seasons during 2015-16**

During 2013-16 rice crop seasons, the PM<sub>10</sub> concentration level before burning episodes (pre episodes) varied from 70µgm<sup>-3</sup> to 76µgm<sup>-3</sup> at all sites. During CRB episodes, a sharp rise in PM<sub>10</sub> concentration levels was observed and higher by 54% to 80% higher than the permitted level. A gradual fall is observed in post CRB episodes and the concentration levels stay more or less near to the permitted level. Similarly, in 2013-16 during pre burning episodes of wheat crop seasons, the level of PM<sub>10</sub> concentration varied from 67µgm<sup>-3</sup> to 72µgm<sup>-3</sup> at all sites. During CRB episodes, again a sharp rise in PM<sub>10</sub> concentration levels was observed (18% to 23% higher than National and International Safety standards). After CRB episodes, a sharp fall was observed in post CRB episodes and PM<sub>10</sub> concentration levels were observed less than the permitted level. It has been observed from the trends that the levels of PM<sub>10</sub> were

below permitted limit in pre CRB episodes of both crop seasons but a sharp rise in PM<sub>10</sub> concentration levels were observed due to CRB practice by farmers. During post RCRB episodes, PM<sub>10</sub> concentration level was still higher than WCRB season by 14% to 24%. It has been observed from the Figure 4.6 to Figure 4.8 that the levels of PM were low before the beginning of rice and wheat crop residue burning episodes and almost constant till the beginning of the burning episodes. Again, a sharp increase in PM was observed during the crop residue burning episodes. In these durations, PM<sub>10</sub> concentration levels were more than the standard values by approximately 35% to 70% in all crop seasons. It is clear from the trends that the increase in PM concentrations was more in rice residue burning periods than during the wheat crop residue burning periods, at all sites. The raised levels of PM stayed more number of FNs after the burning episodes in rice crop periods as compared to the wheat crop periods.

#### **4.1.4 Site wise comparison**

Consistently high PM levels were observed at Mandi Gobindgarh site as compared to that of Ludhiana and Amritsar site during crop residue burning fortnights (Figures 4.1 to 4.8). Further, among the three sites, the level of PM was higher in both crop seasons at MGH by 25-50 % than LDH and AMS, while at LDH and AMS sites the levels of PM<sub>10</sub> had not much difference from those of rice to wheat seasons. Overall trends of both periods indicated that the levels of PM were higher at all sites due to agriculture crop residue burning practice by the local farmers that may significantly affect the health level of human subjects.

## **4.2 PM<sub>2.5</sub> concentration level**

### **4.2.1 Trends and comparison in wheat and rice crop residue burning periods**

PM<sub>2.5</sub> concentration levels were also measured in school yards for study duration to cover six consecutive ACRB seasons. Figures 4.9 to 4.11 show the yearly trends of PM<sub>2.5</sub> in ACRB periods during rice and wheat crop seasons at the selected sites.

From the Figures 4.9 to 4.11, it can be observed that during the sampling period (2013 to 2016), ambient concentration levels of PM<sub>2.5</sub> were higher than the baseline levels as well as standard limits of National Ambient Air Quality Standard ( $60\mu\text{g}\text{m}^{-3}$  for PM<sub>2.5</sub>) at all sampling sites. During the whole study period from 2013 to 2016, the fortnightly averaged levels of PM<sub>2.5</sub> varied from  $33\pm 14\mu\text{g}\text{m}^{-3}$  to  $134\pm 32\mu\text{g}\text{m}^{-3}$ . The levels of PM<sub>2.5</sub> varied from  $38\pm 15\mu\text{g}\text{m}^{-3}$

to  $108 \pm 26 \mu\text{gm}^{-3}$ ,  $33 \pm 11 \mu\text{gm}^{-3}$  to  $116 \pm 25 \mu\text{gm}^{-3}$  and  $39 \pm 11 \mu\text{gm}^{-3}$  to  $134 \pm 29 \mu\text{gm}^{-3}$ , respectively during crop seasons in 2013-14, 2014-15 and 2015-16. Due to ACRB activity in the state, the concentration of  $\text{PM}_{2.5}$  rapidly increased at all sampling sites. It has been estimated that the concentration level of  $\text{PM}_{2.5}$  was 120% to 127% more than the NAAQS standards where as 80%, 93% and 123% more than permitted levels in consecutive years at all sampling sites.

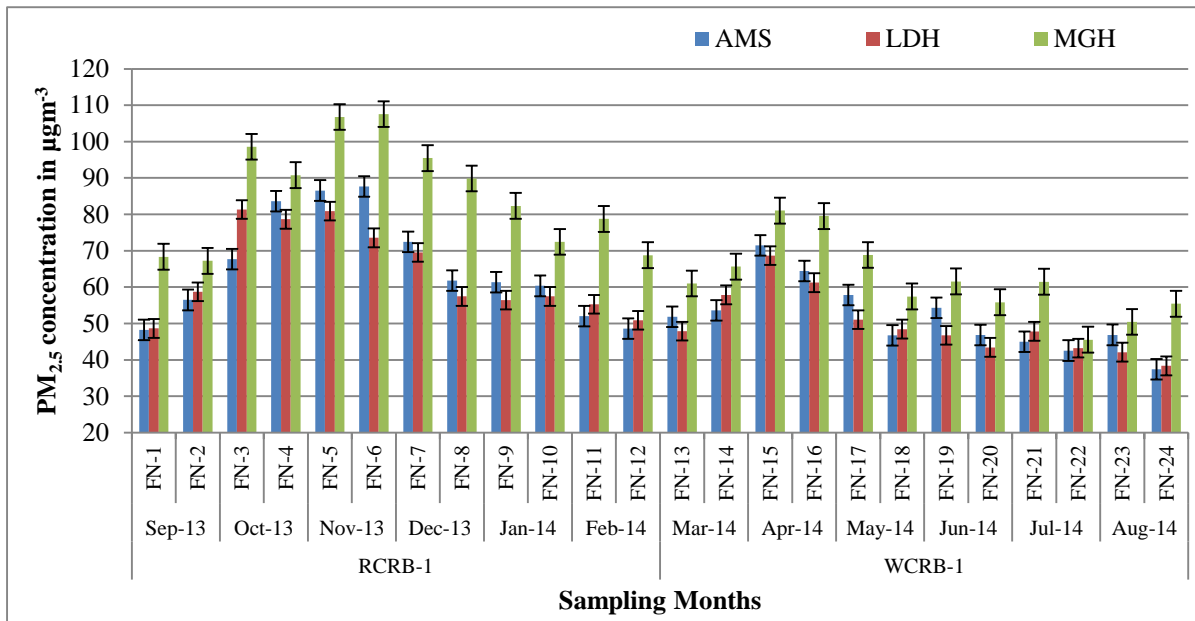


Figure 4.9: Fortnightly averaged trends of  $\text{PM}_{2.5}$  at all sites during 2013-14 RWRB periods

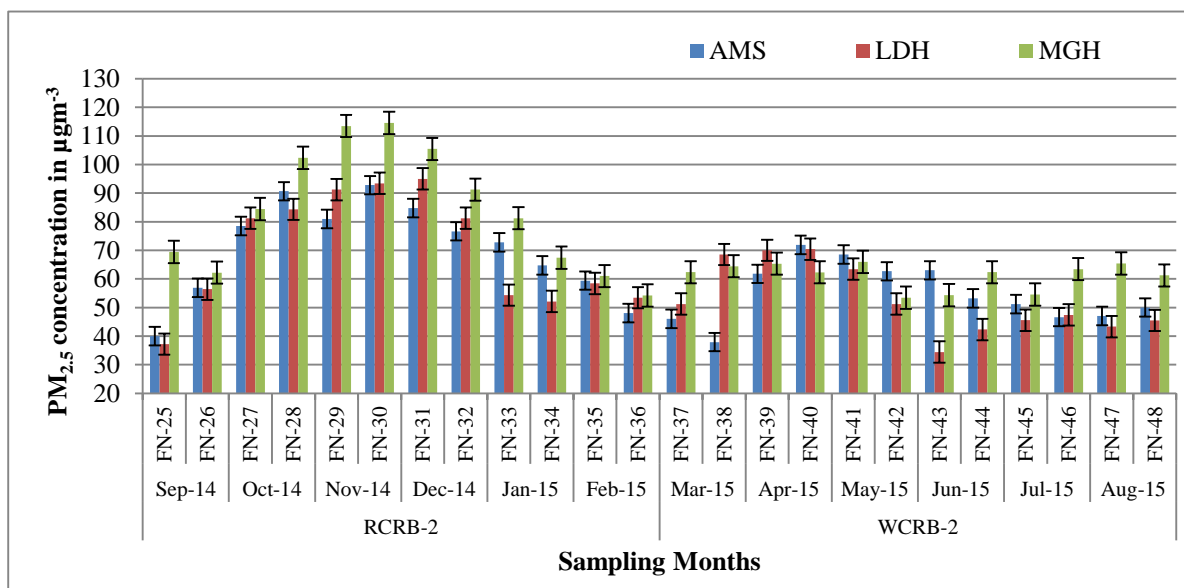
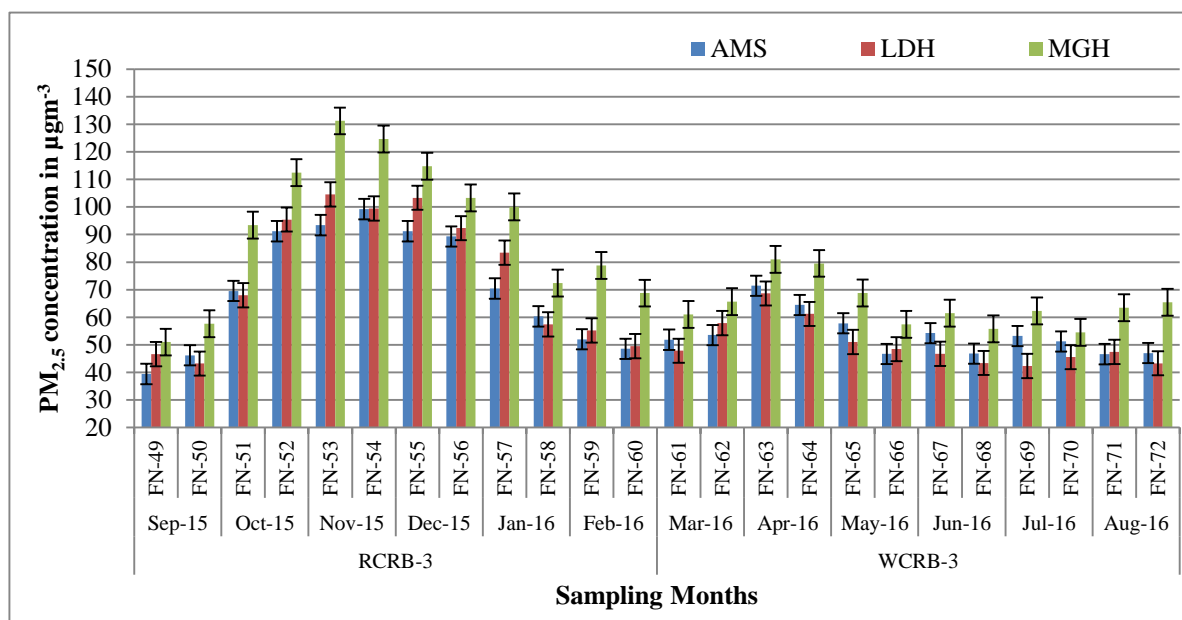


Figure 4.10: Fortnightly averaged trends of  $\text{PM}_{2.5}$  at all sites during 2014-15 RWRB periods

During sampling period (2013-16), ambient PM<sub>2.5</sub> concentration level was higher for more than 46 fortnights (out of total 72 fortnights). In 2013-14 it has been seen that the concentration level of PM<sub>2.5</sub> were higher for more than 15 fortnights. In 2014-15 the ambient PM<sub>2.5</sub> concentration level was higher for 12 to 14 fortnights.



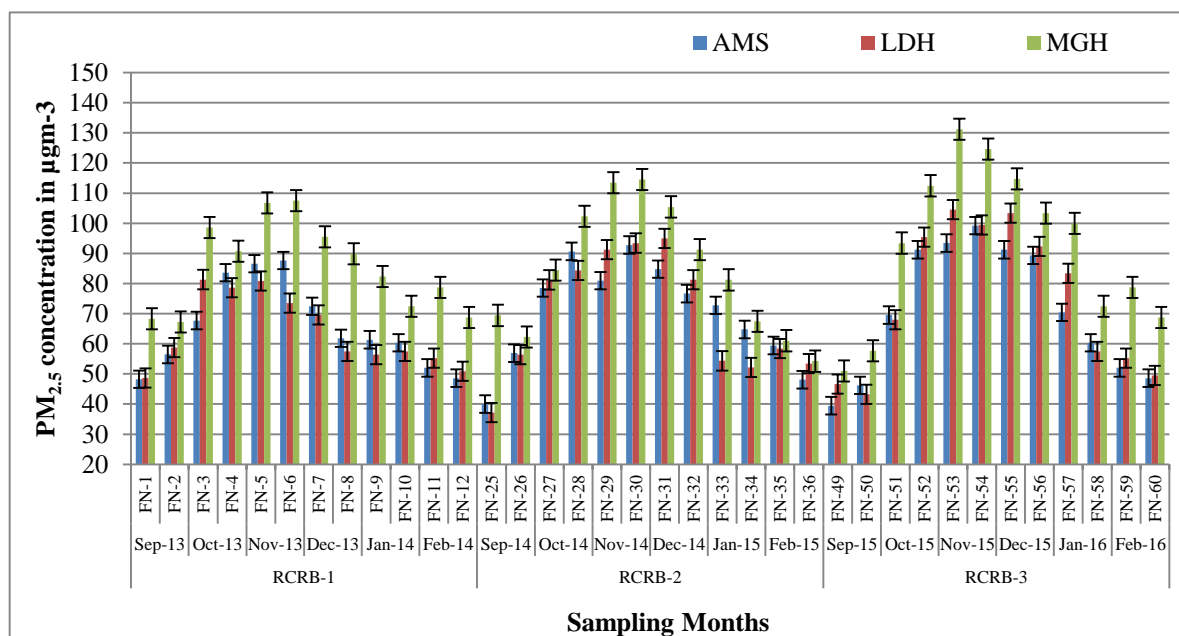
**Figure 4.11: Fortnightly averaged trends of PM<sub>2.5</sub> at all sites during 2015-16 RWRB periods**

Similarly, in 2015-16, 14 to 16 fortnights were observed to have more than national and international standards. The key observations have been estimated from the Figures 4.9 to 4.11 that each year ambient PM<sub>2.5</sub> levels were observed higher in particular months (October-November and March-April) than other months. In each consecutive year, concentration level of PM<sub>2.5</sub> increased by about 16% to 27% than previous years. During 2015-16, the level of PM<sub>2.5</sub> was estimated to be higher than previous years by 45% to 55%. At all sites, the trends were observed more or less the same. The level of PM<sub>2.5</sub> was higher in all rice crop seasons than in wheat crop seasons. Even from the trends, it has been seen that before the beginning of burning episodes the concentration levels of PM<sub>2.5</sub> was almost stable and lesser than the standard limits. A sharp rise in PM<sub>2.5</sub> was observed during the beginning of rice and wheat crop residue burning events. The difference in both seasons is further investigated to find significant observations.

#### 4.2.2 Seasonal trends and comparison

Each year, rice crop is ready for harvesting in the early days of October month and the practice of ACRB is held in the last days of October and continued till the middle of

November. Similarly, wheat crop is ready to harvest in the middle of April and the practice of ACRB is held in the middle of April and continued till the middle of May. The Rice Crop Residue Burning (RCRB) episodes for three consecutive sampling years are shown in Figure 4.12.

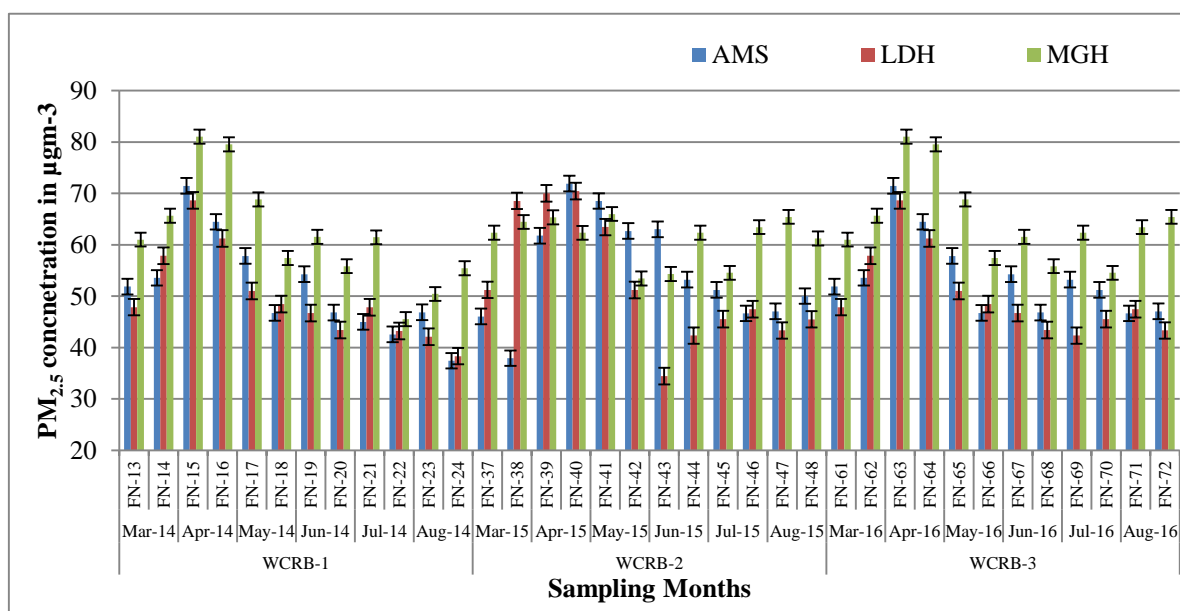


**Figure 4.12: PM<sub>2.5</sub> levels during rice crop residue burning periods during 2013-2016**

During RCRB-1 season (Period: 2013-14, FN-1 to FN-12), the ambient concentration level of PM<sub>2.5</sub> varied from  $47 \pm 11 \mu\text{gm}^{-3}$  to  $108 \pm 31 \mu\text{gm}^{-3}$  (80% more than permitted level). Similarly, in RCRB-2 season (Period: 2014-15, FN-25 to FN-36), the concentration level of PM<sub>2.5</sub> varied from  $35 \pm 19 \mu\text{gm}^{-3}$  to  $116 \pm 25 \mu\text{gm}^{-3}$ . The level of PM<sub>2.5</sub> was observed to be 91% more than the NAAQS ambient air PM<sub>2.5</sub> standard at all sampling sites. In RCRB-3 season (Period: 2015-16, FN-49 to FN-60), the concentration level of PM<sub>2.5</sub> varied from  $39 \pm 23 \mu\text{gm}^{-3}$  to  $134 \pm 29 \mu\text{gm}^{-3}$  (123% more than safety limits). It has been observed from the trends shown in Figure 4.12 that the level of PM<sub>2.5</sub> suddenly exceeds the permitted levels in the month of October and remains till the last weeks of January in all RCRB seasons (approximately 10 fortnights out of 12 fortnights in each RCRB season). In each RCRB season, concentration level of PM<sub>2.5</sub> increased by about 17% to 31% than the previous seasons. During RCRB-3 season, the level of PM<sub>2.5</sub> was estimated to be higher than the previous years by 22% to 27%.

The Wheat Crop Residue Burning (WCRB) episodes for three consecutive sampling years are shown in Figure 4.13. During WCRB-1 season (Period: 2014, FN-13 to FN-24), the ambient concentration level of PM<sub>2.5</sub> varied from  $37 \pm 13 \mu\text{gm}^{-3}$  to  $81 \pm 15 \mu\text{gm}^{-3}$  (38% more than the

permitted level). Similarly in WCRB-2 season (Period: 2015, FN-37 to FN-48), the concentration level of  $PM_{2.5}$  varied from  $35 \pm 16 \mu g m^{-3}$  to  $72 \pm 23 \mu g m^{-3}$ . The level of  $PM_{2.5}$  was observed to be 37% more than the NAAQS ambient air  $PM_{2.5}$  standard. In WCRB-3 season (Period: 2016, FN-61 to FN-72), the concentration level of  $PM_{2.5}$  varied from  $43 \pm 10 \mu g m^{-3}$  to  $83 \pm 22 \mu g m^{-3}$  (41% more than safety limits). It has been observed from the trends shown in Figure 4.13 that the level of  $PM_{2.5}$  suddenly exceeds the permitted levels in the month of April and remains till the last weeks of April in all WCRB seasons (approximately 6 to 7 fortnights out of 14 fortnights in each WCRB season). In each WCRB season, concentration level of  $PM_{2.5}$  increased by about 5% to 7% than the previous seasons. During WCRB-3 season, the level of  $PM_{2.5}$  was estimated to be higher than the previous years by 5% to 8%.



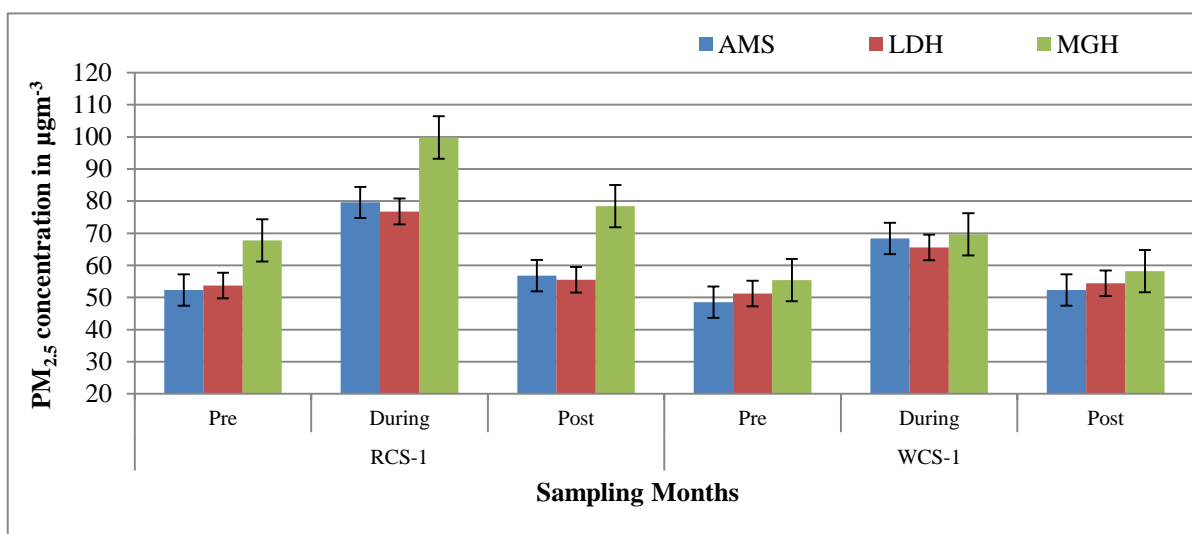
**Figure 4.13:  $PM_{2.5}$  levels during whole crop residue burning periods during 2013-2016**

Overall, it has been observed that the ambient  $PM_{2.5}$  levels remained higher than permitted levels for more fortnights in rice seasons than in wheat seasons. The ambient concentration level of  $PM_{2.5}$  was estimated to be about 75% to 84% more in RCRB seasons than WCRB seasons. In each ACRB period, the concentration level of  $PM_{2.5}$  was higher during and after CRB episodes than non CRB episode. The episodic trends are further investigated to find significant observations.

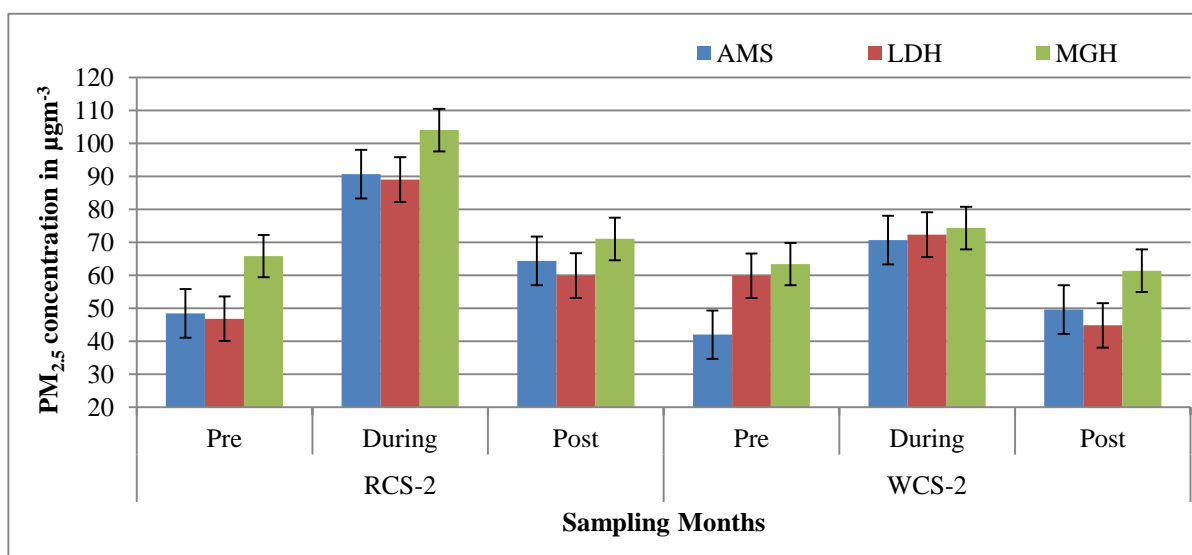
#### 4.2.3 Trends and comparison in non-burning and burning harvesting periods

In each crop season, a sharp rise in  $PM_{2.5}$  concentration level was observed at each sampling site. The levels observed were higher several times more than the permitted levels and stayed in the ambient air during the forthcoming fortnights. To investigate the episodic trends, the

data has been presented in pre, during and post CRB episodes. The episodic trends are shown in Figure 4.14 - 4.16.



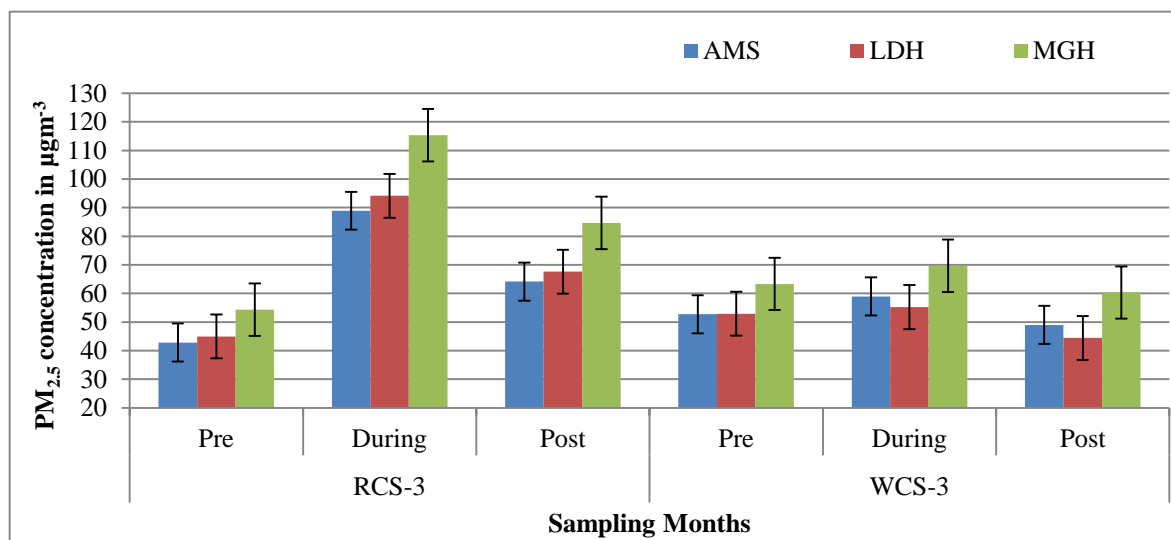
**Figure 4.14: PM<sub>2.5</sub> levels during Rice and Wheat crop seasons during 2013-14**



**Figure 4.15: PM<sub>2.5</sub> levels during Rice and Wheat crop seasons during 2014-15**

During pre-burning periods of 2013-16 rice crop seasons, the PM<sub>2.5</sub> concentration levels varied from 40µgm<sup>-3</sup> to 56µgm<sup>-3</sup> at all sites. During CRB periods, the PM<sub>2.5</sub> levels increased beyond the standard limits (60µgm<sup>-3</sup>, as per NAAQ standards) by about 80%-120% (108µgm<sup>-3</sup> to 134µgm<sup>-3</sup>). A gradual fall in PM<sub>2.5</sub> concentration level (65µgm<sup>-3</sup> to 80µgm<sup>-3</sup>) was observed in post CRB periods which were still higher than the standard levels at all sampling sites. During pre-burning periods of 2013-16 wheat crop seasons, the PM<sub>2.5</sub> levels varied from 40µgm<sup>-3</sup> to 56µgm<sup>-3</sup> at all sites. During CRB periods, again sharp rise in PM<sub>2.5</sub> levels were observed. The PM<sub>2.5</sub> concentration varied from 72µgm<sup>-3</sup> to 83µgm<sup>-3</sup>

(18% to 23% higher than National and International Safety standards) at all sites. A fall in the  $PM_{2.5}$  levels ( $45\mu g m^{-3}$  to  $59\mu g m^{-3}$ ) was observed in post-CRB periods and the levels stayed less than the permitted levels. It has been observed from the trends that the levels of  $PM_{2.5}$  were below permitted limit during pre-CRB periods of both crop seasons but a sharp rise in  $PM_{2.5}$  levels suddenly occurred due to CRB practice by farmers in the state.



**Figure 4.16:  $PM_{2.5}$  levels during Rice and Wheat crop seasons during 2015-16**

During post-CRB periods,  $PM_{2.5}$  concentration level was still high during rice crop season than the wheat crop season by 5% to 19%. It can be seen from Figures 4.14 to 4.16 that the levels of  $PM_{2.5}$  rose much higher than the beginning of rice and wheat crop residue burning seasons. Again, an abrupt increase by 45% to 125% in  $PM_{2.5}$  was observed during the crop residue burning episodes. It is clear from the trends that an abrupt increase in PM levels was more in rice crop residue burning season than during the wheat crop season at all sites. The increased levels of PM stayed for more number of fortnights (FNs) after the burning episodes in rice crop season as compared to the wheat crop season.

#### 4.2.4 Site wise comparison

It has been observed from Figures 4.9 to 4.16 that the Mandi Gobindgarh site had consistently high  $PM_{2.5}$  level as compared to that of Ludhiana and Amritsar sites during crop residue burning fortnights. Further, among the three sites, the level of  $PM_{2.5}$  was higher in both crop seasons at MGH by 34-53% than LDH and AMS. At LDH and AMS sites the levels of  $PM_{2.5}$  was not much different from those of rice to wheat seasons. Overall trends of both periods indicated that the levels of PM were higher at all sites due to agriculture crop

residue burning practice that may significantly affect the respiratory health of human subjects.

### **4.3 Discussion**

During sampling periods, PM concentration levels of both PM<sub>10</sub> and PM<sub>2.5</sub> were more in rice crop residue burning seasons than in wheat crop residue burning seasons at all sampling sites. The raised levels of PM stayed more number of FNs after the burning episodes in rice crop residue burning periods as compared to the wheat crop residue burning periods. The large variance in the range of PM<sub>10</sub> levels is due to the special events like crop residue burning and festival activities during the study periods leading to exceptional increase in the PM levels. The difference in both seasons were investigated and found significant due to the following reasons:

#### **Economic Benefits**

In Punjab region, 78% of total population is living in villages where cattle's farming is also found as the sub part of their economy and source of dairy products. Local inhabitants used a mixture of the husk of crop residue with other readymade foods for cattles to save their expenses. It has been observed from the evidences that, wheat crop stubble is stored as fodder for cattle than rice crop husk. In investigation it has been observed that the rice husk has high content of silica which is unhealthy for animals. So, local people do not prefer to feed rice husk. As per Badarinath *et al.* (2006) and Awasthi *et al.* (2010) reports, only 29% to 37% of total wheat crop residue waste is stored by local people due to usage and inabilities to store. Hence, remaining waste is burnt in the open fields (Badarinath *et al.* 2006; Badarinath *et al.* 2009).

#### **Environmental constraints**

As per studies, environmental and meteorological parameters have the biggest role in settling any kind of pollutant in ambient air (Bell *et al.* 2007; Kothi *et al.* 2011; Awasthi *et al.* 2011). Geographically, Punjab state is a plain area which is in North-western side of Himalaya hills and north-east to deserts of Rajasthan state. This area has chiefly two weather seasons (October to April: Winter season and May to September: Summer season). In winter seasons, the temperature goes down to 23°C to 5°C and in summer it varies from 28°C to maximum 46°C. As per crops compatibility, rice crop is processed till the end of summer season

whereas wheat crop is processed till the end of winter season. In both seasons, the speed of air is low or moderate. In this area, the level of precipitation is below average and seasonal. Maximum rainy days occur in July and December months. At all sampling sites, environmental and meteorological data was arranged from the state pollution control agencies. The data is reported in Table 4.1 (duration: 2013 to 2016). These crops are cyclic by nature and are very sensitive to any kind of delay in their sowing process.

**Table 4.1: Meteorological parameters variations in rice and wheat crop seasons**

S. No.	Meteorological parameters	Rice season	Wheat season
1	Weather	Cold and Humid	Dry and Hot
2	Temperature ( $^{\circ}$ C)	2 to 32	25 to 46
3	Wind speed (km/hour)	1 to 7	6 to 16
4	Precipitation	Low	Moderate
5	Humidity (%)	63 to 92%	27 to 54%
6	Visibility (Km)	0.5 to 1.5	2 to 4

In rice seasons, crop is ready to harvest in the middle of October. In November, crop remains are disposed by burning in the open fields. This practice increased the PM level in the ambient air 67% to 78% than the National Ambient Air Quality Standards (NAAQS) limits (Gupta *et al.* 2017). Due to Meteorological constraints (low temperature, less precipitation, less wind speed and high humidity), the rate of dispersion of PM concentration got reduced leading to the raised level of PM which continues to stay in the areas for the next one to two months. During and after burning episodes, the visibility was reduced due to thick layers of smoke in the surrounding environment. The satellite studies have also presented the trends in rice seasons (Badarinath *et al.* 2009).

Similarly in the wheat seasons, the crop is ready to harvest in the end of March. In April, the deposition of crop waste is done by burning practice in the fields. Again, concentration level of SPM crossed standard levels by 10% to 40% and violates the pollution control agencies guidelines. During wheat seasons, weather is favorable for dispersion of pollutants. Hence, in the wheat season, PM levels took less time than rice season to settle in the ambient air.

Overall, at all sampling sites, the ambient temperature during and after rice crop residue burning periods (October to February), is low and is in the range 10°C-20°C as compared to 35°C-45°C during wheat crop periods due to which the height of boundary layer also remains lower than in summer (Kothi *et al.* 2011; Awasthi *et al.* 2011). The mixing height remains low and directly affects the ventilation coefficient for PM pollutants in ambient environment for dispersion. But in wheat residue burning seasons, the weather was hot and dry. In wheat season the mixing height and ventilation coefficients are good enough for pollutants to travel longer distances and settle down rapidly. The PM having smaller size is more dangerous to human health because of its deep impact on alveolar sacs of lungs leading to reduced lung capacity (Balakrishnan *et al.* 2002; Cancado *et al.* 2006). Hence, it has been hypothesized that the higher level of PM affects the working capacity of various respiration related physiological parameters of human subjects, especially in the school going children.

## **Part 2: Trends in physiological parameters**

It has been observed from PM bar charts ( Figures 4.1 to 4.16) that the concentration level of both PM<sub>10</sub> and PM<sub>2.5</sub> were higher than the recommended levels at all sites because of ACRB practice at sampling sites. Seasonal and episodic trends reveal that the burden of PM in ambient environment affects working capacity of various respiratory parameters. The physiological parameters such as Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV<sub>1</sub>), Peak Expiratory Flow (PEF) and Forced Expiratory Flow 25-75% (FEF<sub>25-75%</sub>) were continuously measured from selected school going children at all the selected sites. The statistically significant trends in various time slots are presented and discussed in further sections.

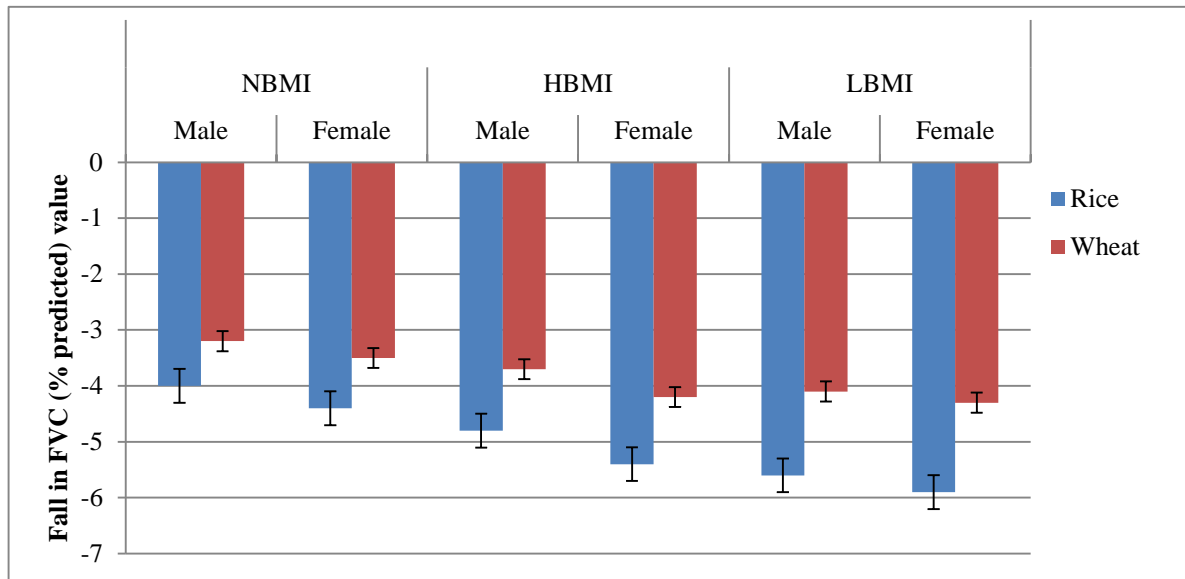
### **4.4 Pulmonary Function Test Parameters**

All the male and female subjects were grouped separately on the basis of their respective BMI values i.e., either as NBMI (18-23 kgm<sup>-2</sup>), LBMI (less than 18 kgm<sup>-2</sup>) or HBMI (>23 kgm<sup>-2</sup>). The physiological parameters of selected subjects were segregated as per their Body Mass Index (BMI) level for exhaustive analysis.

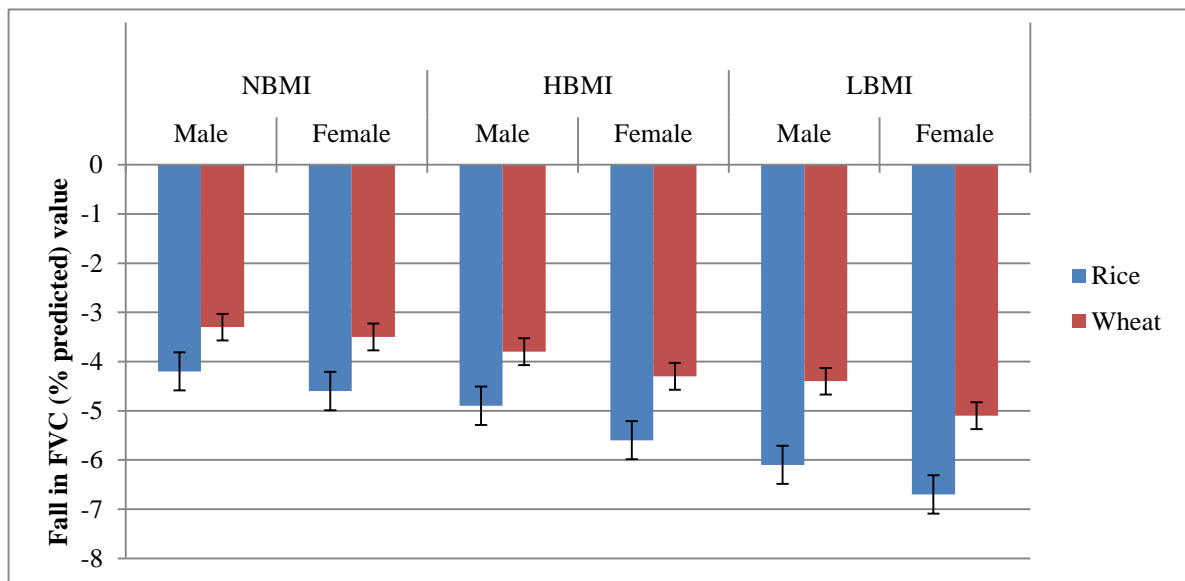
#### **4.4.1 Descriptive analysis of PFT parameters**

Year wise, the bar charts are plotted in three BMI categories such as Low BMI, Normal BMI and High BMI to estimate changes.

**Forced Vital Capacity (FVC):** Figures 4.17 to 4.19 presents percent changes in various physiological parameters during 2013-16 RWCR burning seasons with respect to baseline values. Averaged values are shown separately for male and female children.



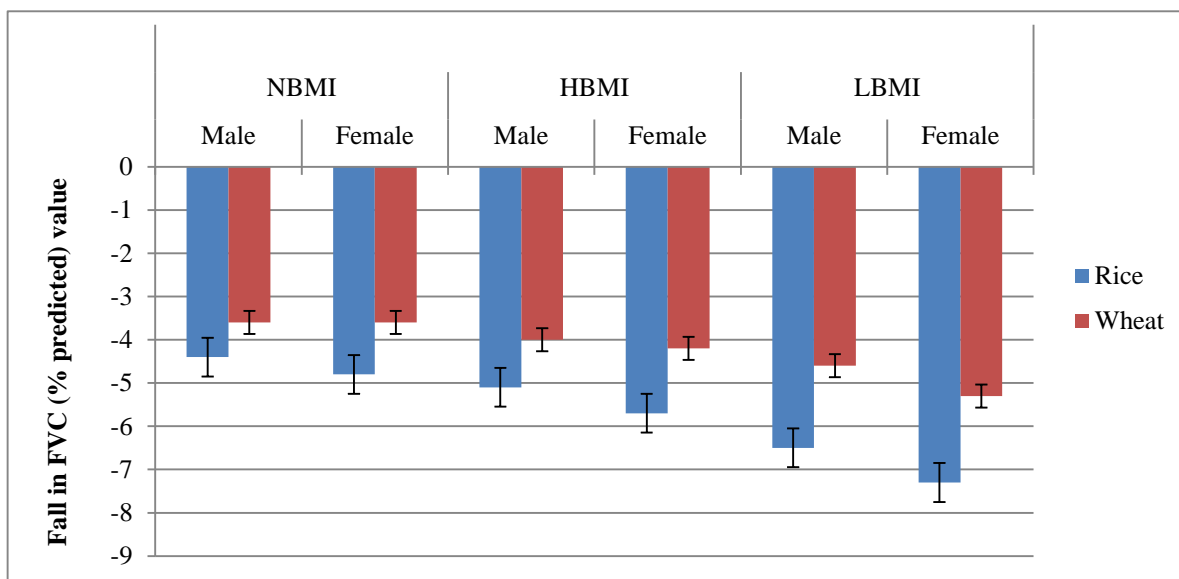
**Figure 4.17: Averaged fall in FVC of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2013-14**



**Figure 4.18: Averaged fall in FVC of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2014-15**

It has been observed from the trends in 2013-14 that FVC of all subjects declined from their baseline values and the fall was greater in LBMI subjects than HBMI and NBMI from 45% to 53%. Similarly for the wheat crop residue burning season, the FVC levels of all categories declined due to burden of PM levels. FVC of NBMI subjects reduced marginally from 3.2%

to 3.4%. The fall in FVC of HBMI subjects were however, greater from 3.6% to 4.2% while for LBMI it varied from 4.1% to 4.3% from their respective baseline values.



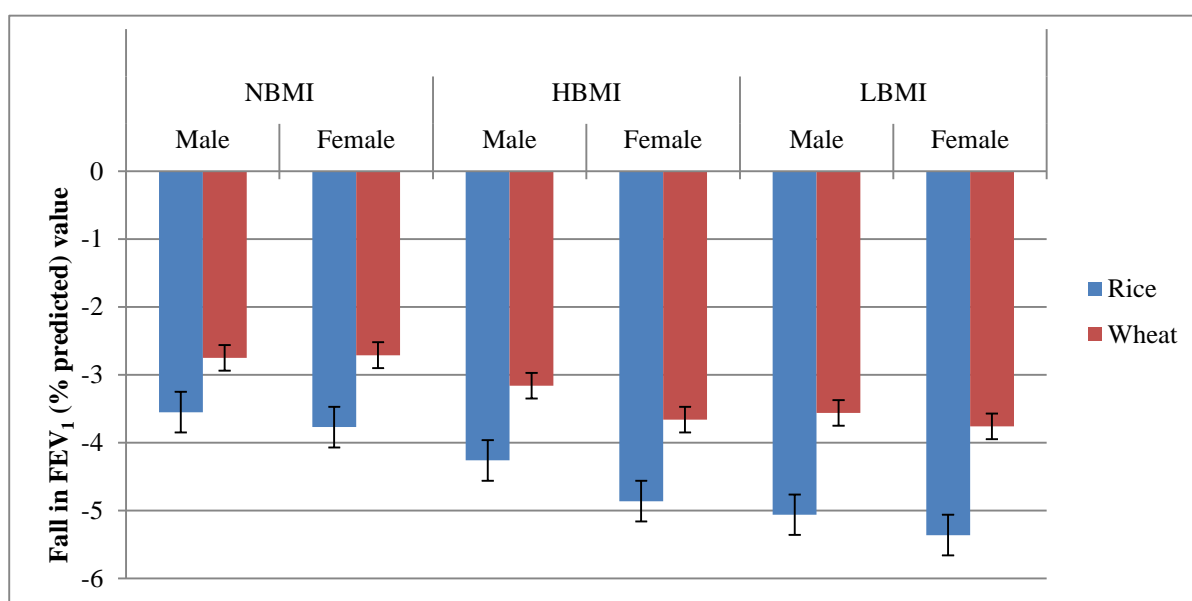
**Figure 4.19: Averaged fall in FVC of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2015-16**

It has been observed from FVC trends in wheat crop residue burning season that FVC of all subjects declined from their baseline values and the fall was the greatest in LBMI subjects. Similarly in 2014-15 rice crop season, the FVC of NBMI subjects varied marginally from 4.1% to 4.6% from their baseline values whereas for HBMI subjects it decreased from 4.9% to 5.7%. The fall in FVC of LBMI subjects increased from 6.1% to 6.8% from the baseline value. The trends in rice crop season indicate that the FVC of all subjects declined from their baseline values and the fall was greater in LBMI subjects as compared to HBMI and NBMI (55% to 65%). In 2014-15 wheat crop residue burning season, the FVC levels of all categories declined due to increased burden of PM in the ambient air. FVC of NBMI subjects reduced from 3.2% to 3.3%. The fall in FVC of HBMI subjects were varied from 3.8% to 4.1%. The decrement in FVC of LBMI subjects was varied by 4.3% to 5.1% from the baseline value. It has been observed from FVC trends in wheat crop residue burning season that the FVC of all subjects declined from their baseline values and the fall was the largest in LBMI subjects (50% to 55%).

In 2015-16 rice crop season, the FVC of NBMI subjects reduced from 4.3% to 4.9% from their baseline values. The fall in FVC of HBMI subjects was declined from 5.1% to 5.7%. The fall in FVC of LBMI subjects varied from 6.3% to 7.2% from the baseline value. It has

been observed from the trends in rice season that the FVC of all subjects declined from their baseline values and the fall was greatest in LBMI subjects as compared to HBMI and NBMI (65% to 70%). Similarly in 2015-16 wheat crop residue burning season, the FVC levels of all categories declined due to burden of PM levels. FVC of NBMI subjects reduced marginally from 3.4% to 3.6% while the subjects of HBMI experienced a fall estimated by 3.9% to 4.1%. The fall in FVC of LBMI subjects from the baseline value varied from 4.6% to 5.1%. It has been observed from the FVC trends in wheat crop residue burning season that the FVC of all subjects declined from their baseline values and the fall was greater in LBMI subjects than HBMI and NBMI subjects.

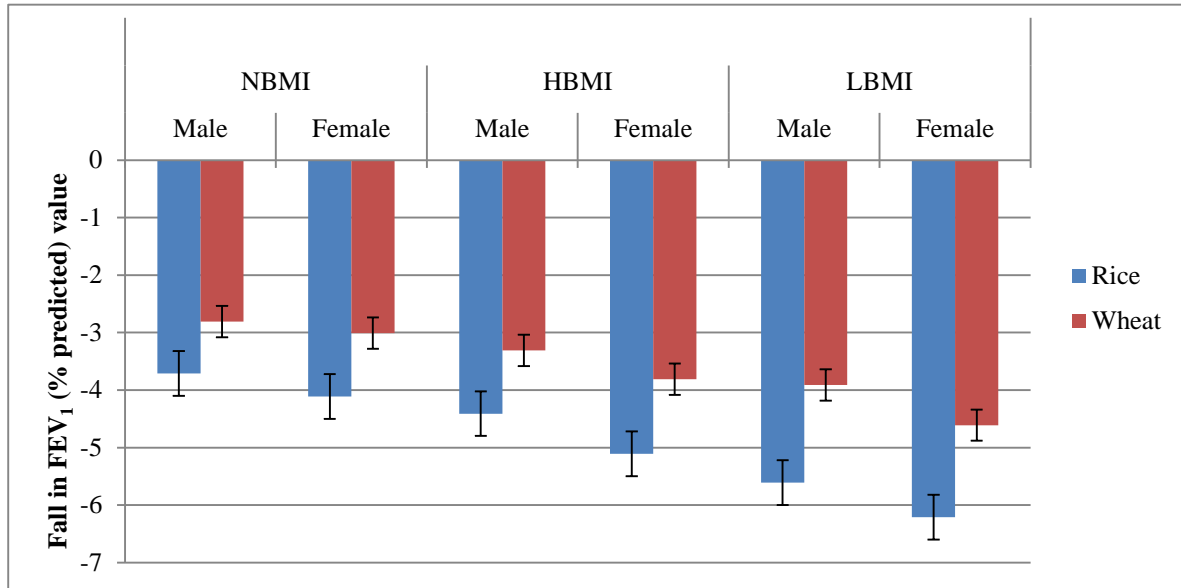
**Forced Expiratory Volume in first second (FEV<sub>1</sub>):** Figures 4.20 to 4.22 present the percent changes in FEV<sub>1</sub> parameter during 2013-16 RWCR burning seasons from their baseline values. Trends of fall in FEV<sub>1</sub> are shown separately for male and female subjects of each BMI category.



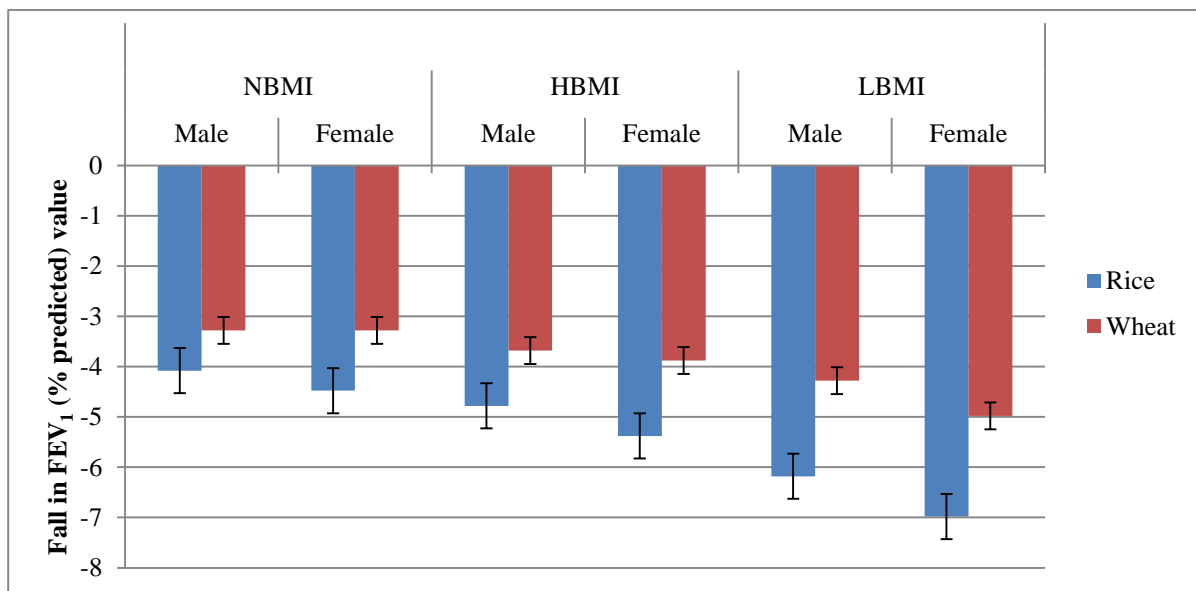
**Figure 4.20: Averaged fall in FEV<sub>1</sub> of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2013-14**

In 2013-14 rice crop residue burning periods, the FEV<sub>1</sub> of NBMI subjects decreased by 3.5% to 3.8% from their baseline values. The fall in FEV<sub>1</sub> of HBMI subjects varied by 4.1% to 4.9% while that of LBMI it varied from 5.0% to 5.4% from the baseline value. It has been observed from the trends that the FEV<sub>1</sub> of all subjects decreased from their baseline values and the fall was greatest in LBMI subjects in comparison to HBMI and NBMI subjects by 50 to 55%. Similarly in 2013-14 wheat crop residue burning periods, the FEV<sub>1</sub> levels of all

categories declined due to burden of PM levels. FEV<sub>1</sub> of NBMI subjects reduced marginally from 2.7% to 2.8%, while the fall in FEV<sub>1</sub> of HBMI subjects varied by 3.1% to 3.8%.



**Figure 4.21: Averaged fall in FEV<sub>1</sub> of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2014-15**



**Figure 4.22: Averaged fall in FEV<sub>1</sub> of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2015-16**

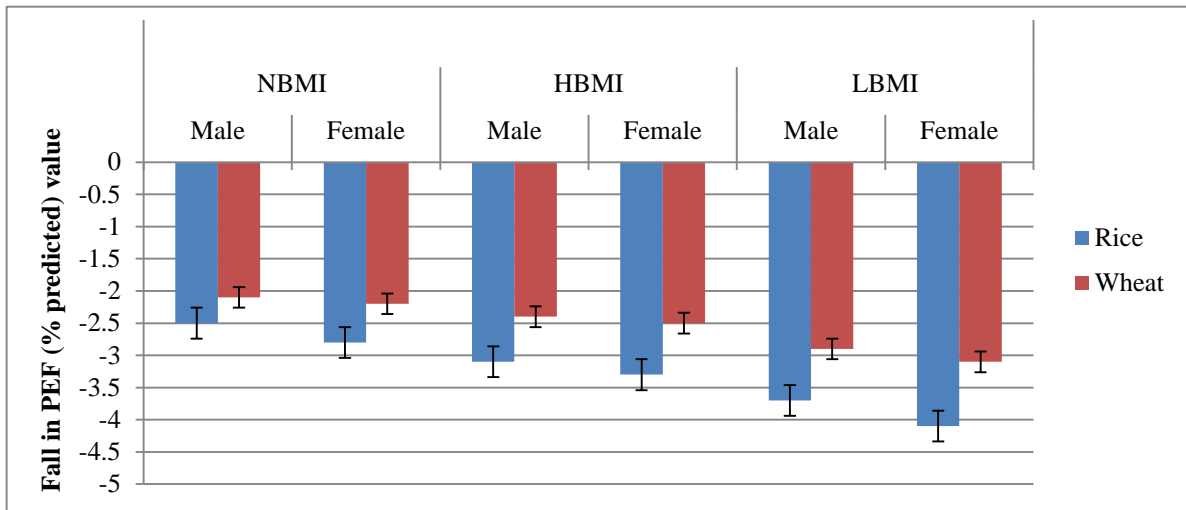
The fall in FEV<sub>1</sub> of LBMI from 3.8% to 3.9% from the baseline value indicates that the subjects with HBMI suffer in their respiratory health more than the children with NBMI and even LBMI. It has been observed from the FEV<sub>1</sub> trends in wheat crop residue burning period

that the FEV<sub>1</sub> of all subjects declined from their baseline values and the fall was greatest in LBMI subjects as compared to HBMI and NBMI subjects (40% to 45%).

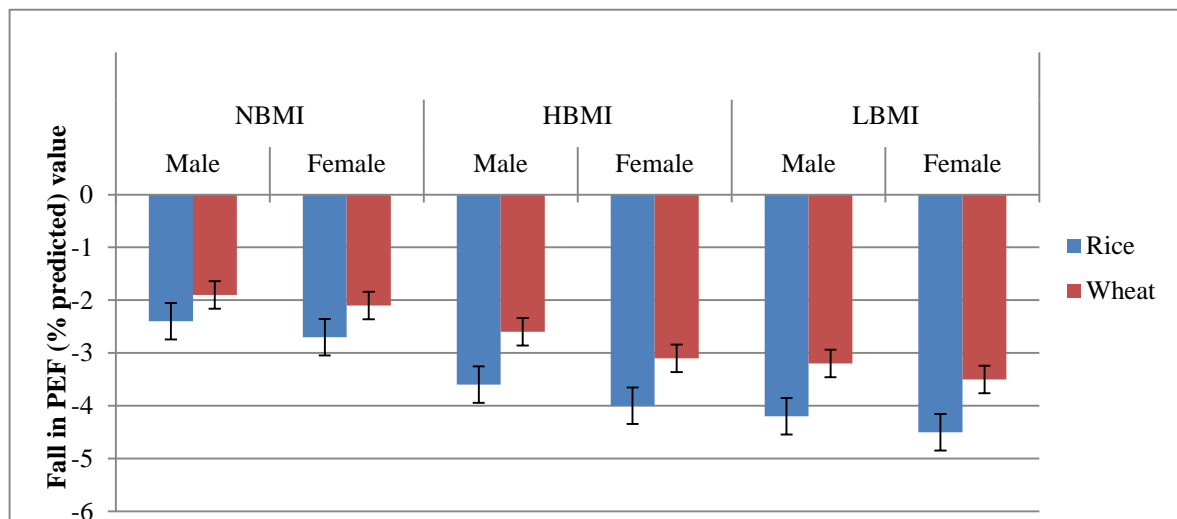
Similarly in 2014-15 rice crop sampling periods, the FEV<sub>1</sub> of NBMI subjects were reduced by 3.8% to 4.1% from their baseline values, while for HBMI subjects it varied by 4.2% to 5.1%. The decrement in FEV<sub>1</sub> of LBMI subjects varied by 5.5% to 6.2% from the baseline value. It has been observed from the trends in rice season that the FEV<sub>1</sub> of all subjects declined from their baseline values and the fall was the greatest in LBMI subjects as compared to HBMI and NBMI subjects by 85% to 90%. Similarly in the wheat crop residue burning period, the FEV<sub>1</sub> levels of all categories declined due to increased levels of fine PM. FEV<sub>1</sub> of NBMI subjects reduced marginally from 2.8% to 3.0%, while the fall in HBMI subjects varied by 3.1% to 4.9%. The fall in FEV<sub>1</sub> of LBMI subjects decreased by 3.9% to 4.7% from the baseline value. It has been observed from the FEV<sub>1</sub> trends in wheat crop residue burning period that the FEV<sub>1</sub> of all subjects declined from their baseline values and the fall was the greatest in LBMI subjects as compared to HBMI and NBMI by 65% to 67%. Again in 2015-16 rice crop sampling periods, the FEV<sub>1</sub> of NBMI subjects reduced from 4.1% to 4.4% from their baseline values. The fall in FEV<sub>1</sub> of HBMI subjects varied from 4.8% to 5.2%, while that of LBMI subjects it varied by 6.1% to 7.0% from the baseline value. It has been observed from the trends of FEV<sub>1</sub> in rice season that the fall was more in LBMI subjects than HBMI and NBMI by 70% to 73%. Similarly in 2015-16 wheat crop residue burning season, the FEV<sub>1</sub> of NBMI subjects reduced marginally from 3.1% to 3.2%, while for HBMI subjects it was from 3.7% to 3.9%. The decrease in FEV<sub>1</sub> of LBMI was relatively greater and it varied from 4.1% to 5.0% from the baseline value. It can be concluded from the FEV<sub>1</sub> trends in wheat crop residue burning season that the fall was greatest in LBMI subjects than for HBMI and NBMI subjects by 60% to 63%.

**Peak Expiratory Flow (PEF):** PEF parameter is a very important parameter to measure the strength of lung muscles when air is forcefully exhaled in spirometer. Figures 4.23 to 4.25 present the variation in peak expiratory flow of the selected subjects during 2013-16 RWCR burning periods from their baseline values. Trends of fall in FEV<sub>1</sub> are shown separately for male and female subjects of each BMI category. In 2013-14 rice crop residue burning periods, the PEF of NBMI subjects decreased by 3.5% to 3.8% from their baseline values. The fall in PEF of HBMI subjects varied by 4.1% to 4.9% while that of LBMI it varied from 5.0% to 5.4% from the baseline value. It has been observed from the trends that the PEF of all subjects decreased from their baseline values and the fall was greatest in LBMI subjects in

comparison to HBMI and NBMI subjects by 50 to 55%. Similarly in 2013-14 wheat crop residue burning periods, the PEF levels of all categories declined due to burden of PM levels. PEF of NBMI subjects reduced marginally from 2.7% to 2.8%, while the fall in PEF of HBMI subjects varied by 3.1% to 3.8%.



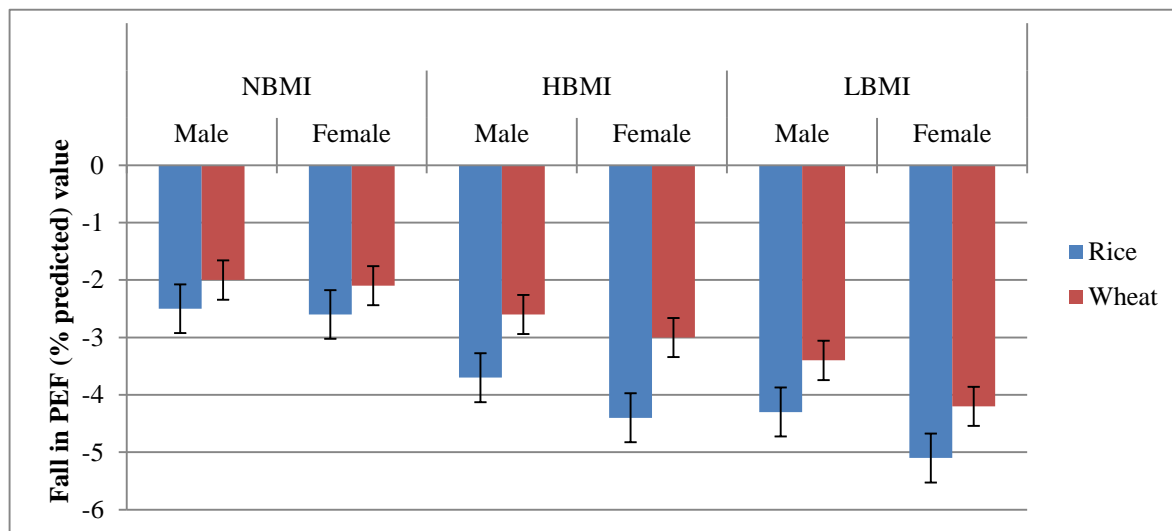
**Figure 4.23: Averaged fall in PEF of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2013-14**



**Figure 4.24: BMI Averaged fall in PEF of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2014-15**

The fall in PEF of LBMI from 3.8% to 3.9% from the baseline value indicates that the subjects with HBMI suffer in their respiratory health more than the children with NBMI and even LBMI. It has been observed from the PEF trends in wheat crop residue burning period

that the PEF of all subjects declined from their baseline values and the fall was greatest in LBMI subjects as compared to HBMI and NBMI subjects (40% to 45%).

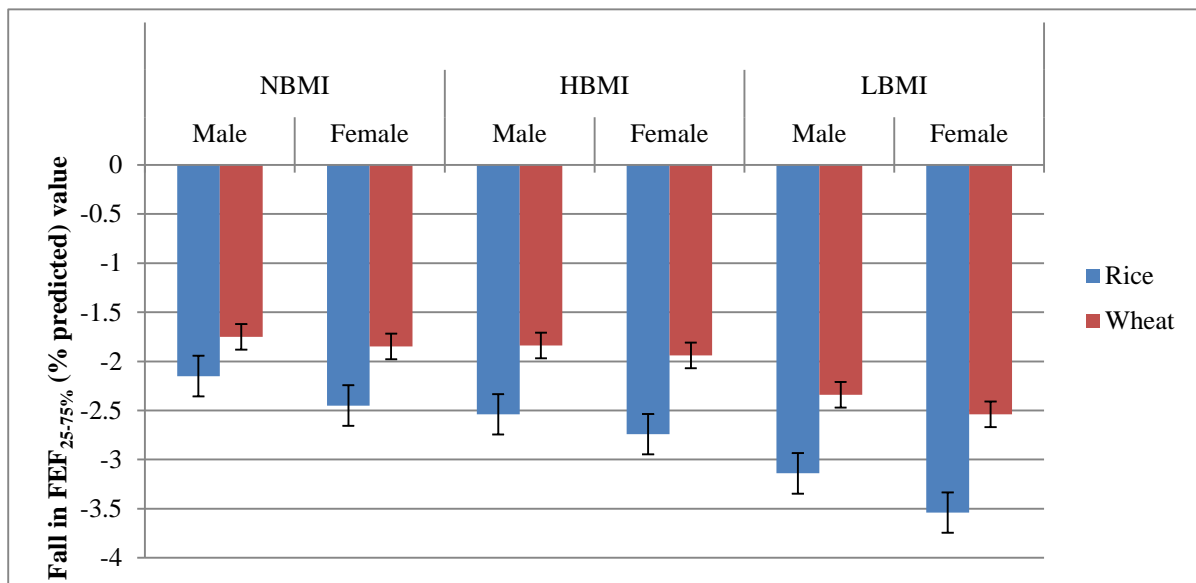


**Figure 4.25: Averaged fall in PEF of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2015-16**

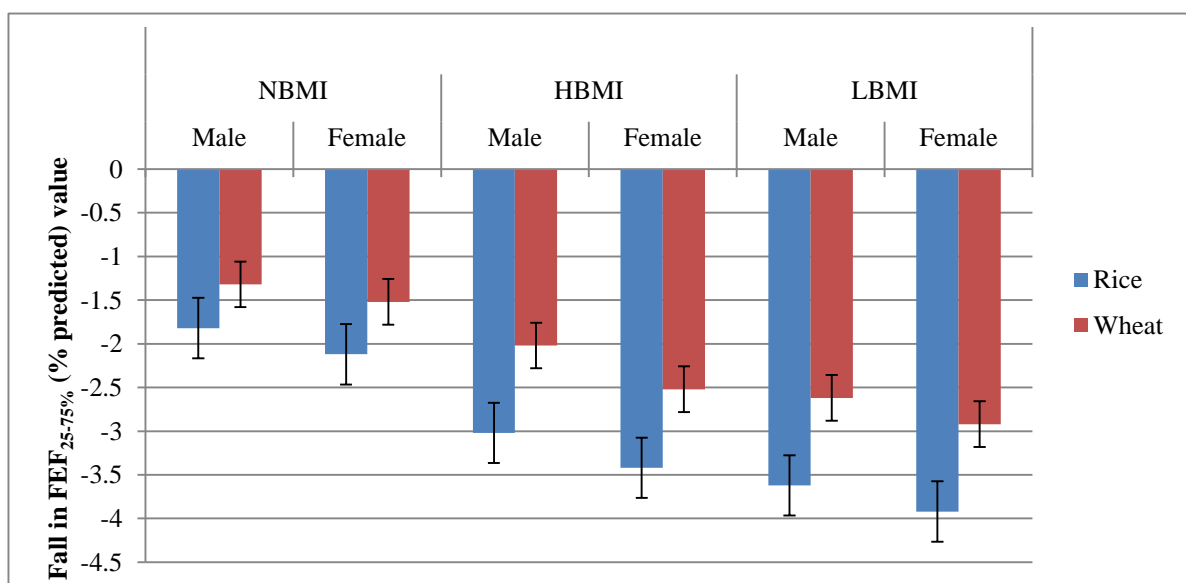
Similarly in 2014-15 rice crop sampling periods, the PEF of NBMI subjects were reduced by 3.8% to 4.1% from their baseline values, while for HBMI subjects it varied by 4.2% to 5.1%. The decrement in PEF of LBMI subjects varied by 5.5% to 6.2% from the baseline value. It has been observed from the trends in rice season that the PEF of all subjects declined from their baseline values and the fall was the greatest in LBMI subjects as compared to HBMI and NBMI subjects by 85% to 90%. Similarly in the wheat crop residue burning period, the PEF levels of all categories declined due to increased levels of fine PM. PEF of NBMI subjects reduced marginally from 2.8% to 3.0%, while the fall in HBMI subjects varied by 3.1% to 4.9%. The fall in PEF of LBMI subjects decreased by 3.9% to 4.7% from the baseline value. It has been observed from the PEF trends in wheat crop residue burning period that the PEF of all subjects declined from their baseline values and the fall was the greatest in LBMI subjects as compared to HBMI and NBMI by 65% to 67%. Again in 2015-16 rice crop sampling periods, the PEF of NBMI subjects reduced from 4.1% to 4.4% from their baseline values. The fall in PEF of HBMI subjects varied from 4.8% to 5.2%, while that of LBMI subjects it varied by 6.1% to 7.0% from the baseline value. It has been observed from the trends of PEF in rice season that the fall was more in LBMI subjects than HBMI and NBMI by 70% to 73%. Similarly in 2015-16 wheat crop residue burning season, the PEF of NBMI subjects reduced marginally from 3.1% to 3.2%, while for HBMI subjects it was from 3.7% to 3.9%. The decrease in PEF of LBMI was relatively greater and it varied from 4.1%

to 5.0% from the baseline value. It can be concluded from the PEF trends in wheat crop residue burning season that the fall was greatest in LBMI subjects than for HBMI and NBMI subjects by 60% to 63%.

**Forced Expiratory Flow 25-75% (FEF<sub>25-75%</sub>):** Figures 4.26 to 4.28 present the percent changes in FEF<sub>25-75%</sub> parameters during 2013-16 RWCR burning seasons from their baseline values. Trends of fall in FEF<sub>25-75%</sub> are shown separately for male and female subjects of each BMI category.

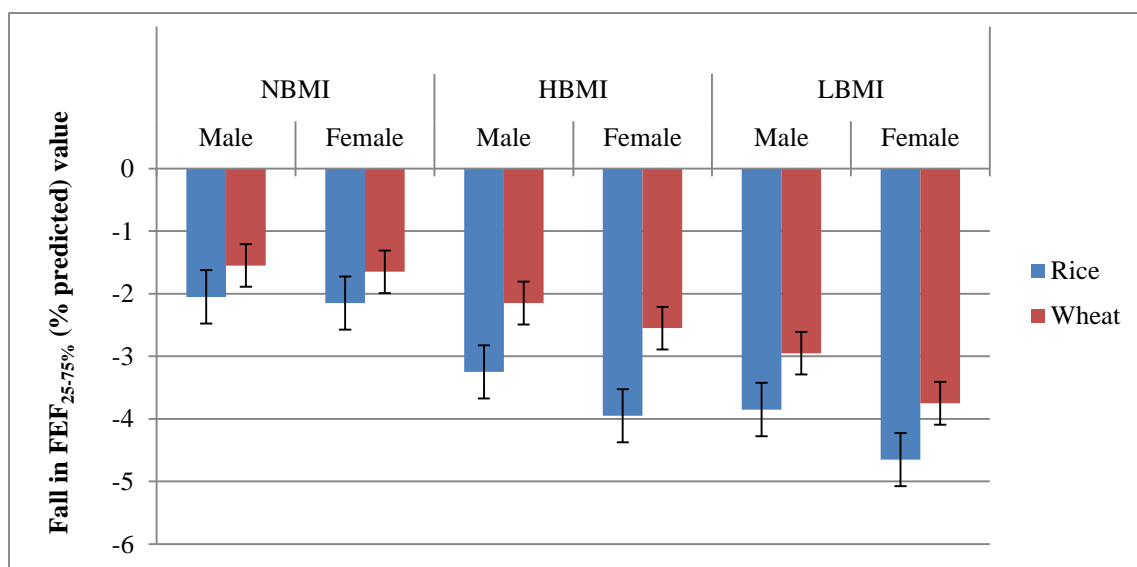


**Figure 4.26: Averaged fall in FEF<sub>25-75%</sub> of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2013-14**



**Figure 4.27: Averaged fall in FEF<sub>25-75%</sub> of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2014-15**

In 2013-14 rice crop residue burning periods, the  $FEF_{25-75\%}$  of NBMI subjects decreased by 2.3% to 2.5% from their baseline values. The fall in  $FEF_{25-75\%}$  of HBMI subjects varied by 2.6% to 2.7% while that of LBMI subjects it varied by 3.1% to 3.6% from the baseline value. It has been observed from the trends that the  $FEF_{25-75\%}$  of all subjects decreased from their baseline values and the fall was greatest in LBMI subjects in comparison to HBMI and NBMI subjects by 53% to 57%. Similarly in 2013-14 wheat crop residue burning period, the  $FEF_{25-75\%}$  levels of all categories declined due to burden of PM levels.  $FEF_{25-75\%}$  of NBMI subjects reduced marginally from 1.7% to 1.9%, while the fall in  $FEF_{25-75\%}$  of HBMI subjects varied by 1.6% to 1.9%. The fall in  $FEF_{25-75\%}$  of LBMI subjects varied by 2.3% to 2.6% from the baseline value indicates that the subjects with HBMI suffer in their respiratory health more than the children with NBMI and even LBMI. It has been observed from the  $FEF_{25-75\%}$  trends in wheat crop residue burning period that the  $FEF_{25-75\%}$  of all subjects declined from their baseline values and the fall was greatest in LBMI subjects as compared to HBMI and NBMI subjects by 51% to 53%.



**Figure 4.28: Averaged fall in  $FEF_{25-75\%}$  of human subjects separately for NBMI, HBMI and LBMI from baseline values during 2015-16**

Similarly in 2014-15 rice crop sampling periods, the  $FEF_{25-75\%}$  of NBMI subjects was reduced by 1.7% to 2.3% from their baseline values, while for HBMI subjects it varied by 3.1% to 3.4%. The decrement in  $FEF_{25-75\%}$  of LBMI subjects varied by 3.6% to 3.9% from the baseline value. It has been observed from the trends in rice season that the  $FEF_{25-75\%}$  of all subjects declined from their baseline values and the fall was greatest in LBMI subjects as compared to HBMI and NBMI subjects by 80% to 84%. Similarly in the wheat crop residue

burning period, the  $FEF_{25-75\%}$  levels of all categories declined due to increased levels of fine PM.  $FEF_{25-75\%}$  of NBMI subjects reduced marginally from 1.3% to 1.6% while the fall in HBMI subjects varied by 2.0% to 2.5%. The fall in  $FEF_{25-75\%}$  of LBMI subjects varied from 2.6% to 2.9% from the baseline value. It has been observed from the  $FEF_{25-75\%}$  trends in wheat crop residue burning period that the  $FEF_{25-75\%}$  of all subjects declined from their baseline values and the fall was greatest in LBMI subjects as compared to HBMI and NBMI subjects by 72% to 75%. Again in 2015-16 rice crop sampling periods, the  $FEF_{25-75\%}$  of NBMI subjects reduced by 2.1% to 2.3% from their baseline values. The fall in  $FEF_{25-75\%}$  of HBMI subjects varied from 3.3% to 3.9%, while that of LBMI subjects it varied by 3.6% to 4.6% from the baseline value. It has been observed from the trends of  $FEF_{25-75\%}$  in rice season that the fall was more in LBMI subjects than HBMI and NBMI by 57% to 62%. Similarly in 2015-16 wheat crop residue burning season, the  $FEF_{25-75\%}$  of NBMI subjects reduced marginally from 1.5% to 1.7% while for HBMI subjects it was from 2.2% to 2.5%. The decrease in  $FEF_{25-75\%}$  of LBMI subjects was relatively greater and it varied by 2.9% to 3.7% from the baseline value. It can be concluded from the  $FEF_{25-75\%}$  trends in wheat crop residue burning season that the fall was greatest in LBMI subjects than for HBMI and NBMI subjects by 46% to 53%.

From Figures 4.17 to 4.26, it has been observed that the decline in FVC and PEF of LBMI subjects were more than HBMI and NBMI subjects in relation to higher level of ambient PM level. The intensity of decrement in physiological parameters of subjects was lower in NBMI candidates. Other parameters such as  $FEV_1$  and  $FEF_{25-75\%}$  were also declined. The decline in various physiological parameters of selected subjects in both seasons was found significant. Further, site wise episodic trends in measured physiological parameters were calculated to observe percent fall in different BMI categories of selected school going children.

#### **4.4.2 Episodic changes in PFT parameters of school going children in relation to the effect of increased level of ambient PM**

Due to cause of ACRB practice in the area, the concentration level of both  $PM_{10}$  and  $PM_{2.5}$  were observed significantly higher than permitted limits during CRB episodes at all selected sites. Even after CRB episodes the level of PM was still higher than the standard values due to meteorological constraints at all sites during RWCR burning episodes. Site wise, trends and percent changes in physiological parameters of selected subjects during both rice and wheat seasons were estimated and are reported.

## Amritsar (AMS)

The episodic changes in spirometric parameters of selected subjects during rice crop seasons at Amritsar site are presented in Table 4.2.

**Table 4.2: Episodic changes in physiological parameters during rice crop residue burning episodes (p-value <0.05)**

Sampling site	Physiological parameters	Categories of BMI	Baseline value (% predicted)	Change in values (% predicted $\pm$ SD)			F-test
				Pre	During	Post	
AMS	FVC	Overall	89.43	-2.28 $\pm$ 0.7	-4.56 $\pm$ 0.7	-1.76 $\pm$ 0.6	134.92
		NBMI	89.49	-1.56 $\pm$ 0.6	-3.41 $\pm$ 0.5	-0.76 $\pm$ 0.4	113.32
		HBMI	88.61	-2.23 $\pm$ 0.6	-4.24 $\pm$ 0.6	-1.37 $\pm$ 0.5	134.32
		LBMI	88.30	-2.41 $\pm$ 0.7	-4.72 $\pm$ 0.6	-1.91 $\pm$ 0.6	138.76
	FEV <sub>1</sub>	Overall	83.54	-1.10 $\pm$ 0.6	-3.21 $\pm$ 0.6	-2.16 $\pm$ 0.7	120.64
		NBMI	83.89	-0.87 $\pm$ 0.2	-1.24 $\pm$ 0.5	-1.03 $\pm$ 0.4	110.41
		HBMI	83.31	-0.97 $\pm$ 0.3	-2.87 $\pm$ 0.5	-1.87 $\pm$ 0.6	116.22
		LBMI	82.92	-1.26 $\pm$ 0.6	-3.46 $\pm$ 0.7	-2.36 $\pm$ 0.6	131.10
	PEF	Overall	78.64	-1.37 $\pm$ 0.8	-4.51 $\pm$ 0.9	-1.49 $\pm$ 0.5	131.76
		NBMI	78.87	-1.07 $\pm$ 0.4	-3.12 $\pm$ 0.6	-0.87 $\pm$ 0.3	115.54
		HBMI	78.52	-1.14 $\pm$ 0.3	-4.29 $\pm$ 0.7	-1.85 $\pm$ 0.6	128.67
		LBMI	77.89	-1.56 $\pm$ 0.5	-4.87 $\pm$ 0.6	-1.86 $\pm$ 0.5	126.54
	FEF <sub>25-75%</sub>	Overall	66.72	-1.61 $\pm$ 0.7	-2.09 $\pm$ 0.8	-1.71 $\pm$ 0.5	121.76
		NBMI	67.62	-1.03 $\pm$ 0.5	-1.78 $\pm$ 0.6	-0.87 $\pm$ 0.3	103.57
		HBMI	66.68	-1.24 $\pm$ 0.5	-2.11 $\pm$ 0.6	-1.67 $\pm$ 0.6	126.26
		LBMI	66.13	-1.87 $\pm$ 0.5	-2.38 $\pm$ 0.6	-1.84 $\pm$ 0.6	139.62

In Amritsar, during pre burning episodes of rice crop residue, a fall in FVC (-2.28%, F-test: 134.92) of all selected subjects were observed from the baseline value. The fall in FVC was more in LBMI subjects than in HBMI and NBMI subjects. During residue burning episodes, the fall in FVC of LBMI subjects was observed as -4.72% (F-test value: 138.76) which were more than those for subjects of other BMI categories. After burning episodes, a recovery in FVC was recorded for subjects of all BMI categories. But, still the FVC parameters of the selected subjects were unable to cover up to the baseline values. Similarly, the fall in FEV<sub>1</sub> of the selected subjects was more during CRB episodes (-3.21%, F-test: 120.64) with a greater fall in LBMI and HBMI categories as compared to NBMI category students due to higher levels of PM<sub>10</sub> and PM<sub>2.5</sub> at the sampling sites. The PEF of LBMI subjects was estimated to be less by -4.87% (F test- value 126.54) from the baseline value during CRB episodes and was unable to recover even after the rice crop residue burning episodes. The fall in FEF<sub>25-75%</sub>

parameter was recorded as -2.37% from the baseline value which was higher in LBMI candidates.

Episodic changes in physiological parameters of the selected subjects during wheat crop residue burning episodes at Amritsar location are reported in Table 4.3.

**Table 4.3: Episodic changes in physiological parameters during wheat crop residue burning episodes (p-value <0.05)**

Sampling site	Physiological parameters	Categories of BMI	Baseline value (% predicted)	Change in values (% predicted $\pm$ SD)			F-test
				Pre	During	Post	
AMS	FVC	Overall	88.01	+1.15 $\pm$ 0.5	-3.17 $\pm$ 0.7	-1.67 $\pm$ 0.4	101.47
		NBMI	88.46	+1.19 $\pm$ 0.6	-2.11 $\pm$ 0.6	-1.02 $\pm$ 0.3	108.49
		HBMI	87.89	+1.03 $\pm$ 0.5	-2.67 $\pm$ 0.5	-1.56 $\pm$ 0.6	113.45
		LBMI	87.58	+0.78 $\pm$ 0.3	-3.23 $\pm$ 0.4	-1.72 $\pm$ 0.5	125.39
	FEV <sub>1</sub>	Overall	81.32	+0.53 $\pm$ 0.1	-2.22 $\pm$ 0.7	-0.27 $\pm$ 0.1	96.98
		NBMI	81.65	+0.61 $\pm$ 0.1	-1.45 $\pm$ 0.4	-0.12 $\pm$ 0.1	107.59
		HBMI	80.86	+0.47 $\pm$ 0.1	-2.11 $\pm$ 0.5	-0.14 $\pm$ 0.1	107.84
		LBMI	80.71	+0.45 $\pm$ 0.1	-2.36 $\pm$ 0.6	-0.16 $\pm$ 0.1	114.43
	PEF	Overall	77.64	+0.41 $\pm$ 0.1	-2.3 $\pm$ 0.6	-1.01 $\pm$ 0.5	99.43
		NBMI	78.12	+0.54 $\pm$ 0.1	-1.17 $\pm$ 0.3	-0.68 $\pm$ 0.4	104.99
		HBMI	77.56	+0.41 $\pm$ 0.1	-2.11 $\pm$ 0.5	-0.74 $\pm$ 0.4	119.33
		LBMI	77.47	+0.38 $\pm$ 0.1	-2.41 $\pm$ 0.5	-1.12 $\pm$ 0.5	117.93
	FEF <sub>25-75%</sub>	Overall	65.64	+1.75 $\pm$ 0.6	-1.24 $\pm$ 0.6	+1.41 $\pm$ 0.4	83.21
		NBMI	66.05	+1.94 $\pm$ 0.5	-1.12 $\pm$ 0.4	+1.27 $\pm$ 0.2	67.56
		HBMI	65.76	+1.63 $\pm$ 0.4	-1.26 $\pm$ 0.5	+1.12 $\pm$ 0.3	69.18
		LBMI	64.69	+1.23 $\pm$ 0.3	-1.39 $\pm$ 0.5	+0.89 $\pm$ 0.5	74.09

During the burning episodes, a fall was observed in FVC parameter (-3.17, F-test value: 101.47) from their baselines value due to increased levels of PM concentration in the ambient environment of the Amritsar site. The fall in lung function test parameters was more in LBMI subjects than for HBMI and NBMI subjects. During CRB episodes, the fall in FEV<sub>1</sub> was recorded as -2.36% (F-test value: 114.36) from baseline value in all subjects with minimum decline of -1.45% (F-test value: 107.59) in normal BMI subjects. During CRB episodes, the fall in PEF of LBMI subjects was -2.41% (F-test value: 117.93) that were more than other category students. Similarly, the FEF<sub>25-75%</sub> parameter of selected subjects was less by -1.39% (F-test value: 74.09) during the CRB episodes. After CRB episodes, the physiological parameters recovered up to some extent. The recovery effects were better in NBMI candidates than in HBMI and NBMI subjects.

### Ludhiana (LDH)

BMI wise, episodic changes in spirometric parameters of selected subjects during rice crop seasons are reported in Table 4.4.

**Table 4.4: Episodic changes in physiological parameters during rice crop residue burning episodes (p-value <0.05)**

Sampling site	Physiological parameters	Categories of BMI	Baseline value (% predicted)	Change in values (% predicted $\pm$ SD)			F-test
				Pre	During	Post	
LDH	FVC	Overall	87.33	-1.01 $\pm$ 0.4	-3.63 $\pm$ 0.7	-1.70 $\pm$ 0.6	125.87
		NBMI	88.12	-0.56 $\pm$ 0.4	-2.45 $\pm$ 0.6	-1.45 $\pm$ 0.5	134.45
		HBMI	87.67	-0.87 $\pm$ 0.3	-3.18 $\pm$ 0.6	-1.85 $\pm$ 0.5	139.76
		LBMI	87.02	-1.13 $\pm$ 0.5	-3.87 $\pm$ 0.6	-1.87 $\pm$ 0.6	141.21
	FEV <sub>1</sub>	Overall	81.54	-0.91 $\pm$ 0.4	-2.11 $\pm$ 0.6	+0.62 $\pm$ 0.4	114.76
		NBMI	81.97	-0.43 $\pm$ 0.4	-1.15 $\pm$ 0.5	+0.54 $\pm$ 0.2	107.42
		HBMI	81.45	-0.67 $\pm$ 0.3	-2.12 $\pm$ 0.5	+0.58 $\pm$ 0.4	111.65
		LBMI	80.89	-0.87 $\pm$ 0.4	-2.54 $\pm$ 0.5	+0.35 $\pm$ 0.4	117.23
	PEF	Overall	77.85	-1.41 $\pm$ 0.7	-2.72 $\pm$ 0.6	+1.02 $\pm$ 0.3	109.32
		NBMI	78.24	-1.01 $\pm$ 0.6	-1.78 $\pm$ 0.5	+1.06 $\pm$ 0.4	111.76
		HBMI	77.68	-1.25 $\pm$ 0.5	-2.17 $\pm$ 0.6	+0.91 $\pm$ 0.5	115.76
		LBMI	77.65	-1.54 $\pm$ 0.6	-2.96 $\pm$ 0.7	+0.54 $\pm$ 0.5	127.94
	FEF <sub>25-75%</sub>	Overall	66.25	-1.13 $\pm$ 0.5	-1.56 $\pm$ 0.5	+0.41 $\pm$ 0.4	96.43
		NBMI	66.76	-0.34 $\pm$ 0.2	-1.32 $\pm$ 0.4	+0.43 $\pm$ 0.3	99.47
		HBMI	66.12	-0.85 $\pm$ 0.3	-1.33 $\pm$ 0.5	+0.37 $\pm$ 0.1	104.38
		LBMI	65.87	-1.32 $\pm$ 0.4	-1.68 $\pm$ 0.4	+0.54 $\pm$ 0.3	113.48

In Ludhiana, during CRB burning episodes of rice crop residue, a fall in FVC (-3.63%, F-test value: 125.87) of all selected subjects were observed from the baseline value. The fall in FVC of LBMI subjects (-3.87%, F-test value: 141.21) was more than HBMI and NBMI category subjects. After CRB episodes, a recovery in FVC was recorded for subjects of all BMI categories. But, the FVC parameters of the selected subjects were unable to cover up to the baseline values. BMI wise recovery was appreciable in NBMI subjects. The fall in FEV<sub>1</sub> of selected subjects was more during CRB episodes (-2.11%, F-test: 114.76) with a greater fall in LBMI and HBMI categories as compared to NBMI category students due to higher levels of PM<sub>10</sub> and PM<sub>2.5</sub> at the sampling sites. The PEF of LBMI subjects was estimated to be less

by -2.56% (F test- value 127.94) from the baseline value during CRB episodes and was unable to recover even after the rice crop residue burning episodes. The fall in  $FEF_{25-75\%}$  parameter was recorded as -1.68% (F-test value: 113.48) from the baseline value which was estimated to be higher in LBMI candidates.

Episodic changes in physiological parameters of the selected subjects during wheat crop residue burning episodes at Ludhiana location are reported in Table 4.5.

**Table 4.5: Episodic changes in physiological parameters during wheat crop residue burning episodes (p-value <0.05)**

Sampling site	Physiological parameters	Categories of BMI	Baseline value (% predicted)	Change in values (% predicted $\pm$ SD)			F-test
				Pre	During	Post	
LDH	FVC	Overall	88.54	+1.80 $\pm$ 0.4	-2.76 $\pm$ 0.3	+1.07 $\pm$ 0.4	56.43
		NBMI	89.02	+1.92 $\pm$ 0.5	-1.32 $\pm$ 0.2	+1.20 $\pm$ 0.3	60.76
		HBMI	88.48	+1.47 $\pm$ 0.5	-2.16 $\pm$ 0.3	+1.31 $\pm$ 0.3	62.12
		LBMI	88.12	1.36 $\pm$ 0.4	-2.93 $\pm$ 0.3	+1.35 $\pm$ 0.4	67.38
	FEV <sub>1</sub>	Overall	83.78	+1.27 $\pm$ 0.4	-2.12 $\pm$ 0.7	+1.25 $\pm$ 0.5	67.43
		NBMI	84.65	+1.32 $\pm$ 0.4	-1.31 $\pm$ 0.4	+1.42 $\pm$ 0.4	84.34
		HBMI	83.65	+1.25 $\pm$ 0.5	-1.79 $\pm$ 0.78	+1.25 $\pm$ 0.5	85.15
		LBMI	83.34	+1.23 $\pm$ 0.4	-2.27 $\pm$ 0.4	+1.10 $\pm$ 0.5	91.45
	PEF	Overall	78.87	+1.02 $\pm$ 0.5	-1.91 $\pm$ 0.5	-0.44 $\pm$ 0.1	60.54
		NBMI	79.46	+1.25 $\pm$ 0.3	-1.43 $\pm$ 0.6	-0.30 $\pm$ 0.1	65.67
		HBMI	78.68	+0.78 $\pm$ 0.4	-2.11 $\pm$ 0.5	-0.23 $\pm$ 0.1	69.65
		LBMI	78.21	+0.65 $\pm$ 0.4	-2.61 $\pm$ 0.54	-0.23 $\pm$ 0.1	72.21
	FEF <sub>25-75%</sub>	Overall	68.43	+1.62 $\pm$ 0.4	-1.35 $\pm$ 0.4	-0.41 $\pm$ 0.1	31.34
		NBMI	69.56	+1.68 $\pm$ 0.5	-1.11 $\pm$ 0.4	-0.21 $\pm$ 0.2	36.56
		HBMI	68.35	+1.41 $\pm$ 0.3	-1.29 $\pm$ 0.6	-0.33 $\pm$ 0.2	41.54
		LBMI	68.10	+1.05 $\pm$ 0.4	-1.46 $\pm$ 0.5	-0.56 $\pm$ 0.2	47.51

During burning episodes, a fall was observed in FVC parameter (-2.76%, F-test value: 56.43) from their baseline values due to increased levels of PM concentration in the ambient environment of the Ludhiana site. During CRB episodes, the fall was recorded to be more in LBMI subjects than HBMI and NBMI subjects. The fall in FEV<sub>1</sub> was estimated to be -2.12% (F-test value: 67.43) from baseline value in all subjects with minimum decline of -1.31% (F-test value: 84.34) in normal BMI subjects. During CRB episodes, the fall in PEF of LBMI

subjects was -2.61 (F-test value: 72.21) that were more than other category students. Similarly, the FEF<sub>25-75%</sub> parameter of selected subjects was less by -1.46 (F-test value: 47.51) during the CRB episodes. During post CRB episodes, a positive recovery has been observed in physiological parameters of selected subjects. Recovery in FVC and FEV<sub>1</sub> is appreciable in all BMI categories candidates than other parameters.

### Mandi GobindGarh (MGH)

The episodic changes in various physiological parameters of selected subjects during rice crop seasons are reported in Table 4.6.

**Table 4.6: Episodic changes in physiological parameters during rice crop residue burning episodes (p-value <0.05)**

Sampling site	Physiological parameters	Categories of BMI	Baseline value (%) predicted	Change in values (% predicted ± SD)			F-test
				Pre	During	Post	
MGH	FVC	Overall	86.93	-2.78±0.5	-7.61±0.6	-2.74±0.5	167.87
		NBMI	88.54	-1.54±0.5	-5.12±0.7	-2.11±0.4	113.32
		HBMI	87.34	-2.10±0.5	-6.23±0.6	-3.21±0.4	124.32
		LBMI	86.23	-2.91±0.5	-8.12±0.5	-3.58±0.5	135.76
	FEV <sub>1</sub>	Overall	81.63	-3.26±0.6	-4.51±0.5	-3.47±0.6	109.63
		NBMI	82.29	-2.78±0.4	-3.87±0.5	-2.66±0.5	106.45
		HBMI	81.54	-3.44±0.4	-4.21±0.4	-3.22±0.6	110.22
		LBMI	80.31	-3.98±0.6	-4.87±0.7	-3.78±0.5	111.10
	PEF	Overall	76.67	-4.01±0.6	-6.71±0.6	-0.92±0.3	147.65
		NBMI	78.11	-3.10±0.5	-4.33±0.6	-1.43±0.4	135.54
		HBMI	76.65	-4.32±0.5	-5.43±0.6	-2.11±0.7	121.67
		LBMI	76.34	-4.76±0.5	-5.95±0.7	-2.47±0.6	116.54
	FEF <sub>25-75%</sub>	Overall	67.12	-2.68±0.4	-3.82±0.5	+0.70±0.1	123.76
		NBMI	69.65	-1.34±0.5	-2.13±0.5	+0.93±0.2	123.54
		HBMI	67.65	-2.45±0.6	-3.56±0.6	-0.83±0.2	116.26
		LBMI	66.34	-3.41±0.7	-4.01±0.5	-1.07±0.4	129.62

In Mandi Gobindgarh, during CRB burning episodes of rice crop residue, a fall in FVC (-7.61%, F-test value: 167.87) of all selected subjects were observed from the baseline value. The fall in FVC of LBMI subjects (-8.12%, F-test value: 135.76) was more than in HBMI

and NBMI category subjects. After CRB episodes, a recovery was recorded in FVC parameter of all BMI categories. But, the FVC parameters of the selected subjects were unable to cover upto the baseline values. BMI wise, recovery was appreciable in NBMI subjects. The fall in FEV<sub>1</sub> parameter of the selected subjects was more during CRB episodes than other episodes (-4.21%, F-test: 110.22) with a greater fall in LBMI and HBMI categories as compared to NBMI category students due to higher levels of PM<sub>10</sub> and PM<sub>2.5</sub> at the sampling site. The PEF of LBMI subjects was estimated to be less by -5.95% (F test- value :116.94) from the baseline value during CRB episodes and was unable to recover even after the rice crop residue burning episodes. The fall in FEF<sub>25-75%</sub> parameter was recorded as -3.82% (F-test value: 123.76) from baseline value which was higher in LBMI candidates.

Episodic changes in physiological parameters of the selected subjects during wheat crop residue burning episodes at Ludhiana location are reported in Table 4.7.

**Table 4.7: Episodic changes in physiological parameters during wheat crop residue burning episodes (p-value <0.05)**

Sampling site	Physiological parameters	Categories of BMI	Baseline value (% predicted)	Change in values (% predicted $\pm$ SD)			F-test
				Pre	During	Post	
MGH	FVC	Overall	84.67	+0.37 $\pm$ 0.2	-4.46 $\pm$ 0.5	-1.41 $\pm$ 0.4	122.14
		NBMI	85.27	+0.65 $\pm$ 0.1	-2.45 $\pm$ 0.6	-0.95 $\pm$ 0.5	118.45
		HBMI	84.78	+0.17 $\pm$ 0.1	-4.11 $\pm$ 0.4	-1.24 $\pm$ 0.3	123.45
		LBMI	84.12	+0.13 $\pm$ 0.3	-5.21 $\pm$ 0.5	-1.71 $\pm$ 0.4	135.32
	FEV <sub>1</sub>	Overall	77.96	+0.17 $\pm$ 0.1	-2.86 $\pm$ 0.6	-1.03 $\pm$ 0.5	87.31
		NBMI	80.43	+0.26 $\pm$ 0.1	-1.65 $\pm$ 0.4	-0.67 $\pm$ 0.1	109.54
		HBMI	78.87	+0.21 $\pm$ 0.1	-1.89 $\pm$ 0.3	-0.89 $\pm$ 0.2	117.44
		LBMI	77.23	+0.15 $\pm$ 0.1	-3.11 $\pm$ 0.4	-1.32 $\pm$ 0.4	118.65
	PEF	Overall	75.96	+0.50 $\pm$ 0.1	-3.85 $\pm$ 0.3	+0.71 $\pm$ 0.1	115.44
		NBMI	76.47	+0.68 $\pm$ 0.1	-2.13 $\pm$ 0.6	+1.02 $\pm$ 0.3	109.49
		HBMI	77.73	+0.29 $\pm$ 0.1	-3.45 $\pm$ 0.5	+0.21 $\pm$ 0.1	112.33
		LBMI	77.78	+0.16 $\pm$ 0.1	-3.98 $\pm$ 0.7	+0.01 $\pm$ 0.5	115.43
	FEF <sub>25-75%</sub>	Overall	63.06	+2.81 $\pm$ 0.4	-0.91 $\pm$ 0.1	-1.02 $\pm$ 0.4	58.91
		NBMI	67.54	+3.03 $\pm$ 0.5	-0.56 $\pm$ 0.1	-0.22 $\pm$ 0.1	64.56
		HBMI	64.33	+2.38 $\pm$ 0.4	-0.92 $\pm$ 0.3	-1.47 $\pm$ 0.6	60.18
		LBMI	62.11	+2.14 $\pm$ 0.6	-1.31 $\pm$ 0.4	-1.55 $\pm$ 0.5	65.39

During the burning episodes, a fall was observed in FVC parameter (-4.46%, F-test value: 122.14) from their baseline values due to raised level of PM concentration in the ambient environment of the Mandi Gobindgarh site. The fall in LFT parameters was more in LBMI subjects than in HBMI and NBMI subjects. During CRB episodes, the decrement in FEV<sub>1</sub> was recorded as -2.86% (F-test value: 87.31) from baseline value in all subjects with minimum fall of -3.11% (F-test value: 118.65) in normal BMI subjects. During CRB episodes, the fall in PEF of LBMI subjects was -3.85% (F-test value: 115.44) that were more than other category students. Similarly, the FEF<sub>25-75%</sub> parameter of selected subjects was declined by -0.91% (F-test value: 60.18) during the CRB episodes. After CRB episodes, the recovery in physiological parameters was negligible in HBMI and LBMI candidates than in NBMI subjects.

Overall, it has been estimated from the episodes from the episodic trends that during peak time of rice crop residue burning (beginning of ACRB activity), a sharp fall was observed in spirometric parameters. During this period, the levels of PM increased substantially and crossed the NAAQS (India) level of PM<sub>10</sub> and PM<sub>2.5</sub> accompanied with fall in physiological parameters with greater magnitudes. The fall in parameters revealed that the human physiological parameters are highly sensitive to the increased levels of particulate pollutants. The physiological parameters like FVC, FEV<sub>1</sub>, PEF and FEF<sub>25-75%</sub> further decreased by about 4.0%, 2.4%, 4% and 2.3%, respectively, during the peak events as compared to the baseline levels of pollution. In rice crop residue burning seasons, highest levels of PM concentrations were observed. In post crop burning episodes, levels of PM decreased than standard levels but still a negative percentage change was observed in spirometer parameters. In wheat crop residue burning periods, the levels of PM were measured and found higher than permitted levels. Corresponding to each PM level, FVC decreased from -0.76% to -4.46%, FEV<sub>1</sub> decreased from -2.12% to -2.86%, PEF decreased from -1.91% to -2.86% and FEF<sub>25-75%</sub> decreased from -0.91% to -1.35%.

The maximum increase in level of PM were observed in rice crop periods than in wheat crop periods and correspondingly, maximum negative change was observed in FVC and PEF parameters of LBMI subjects which indicated the relation between raised levels of PM concentrations and their consequences on working capacity of lungs of children. Generally, the levels of PM were higher at MGH than in LDH and AMS (Figure 4.1 to 4.16).

## 4.5 Development of Statistical Model for Prediction of Changes in PFT Parameters

### 4.5.1 Pearson Correlation Coefficients

Pearson coefficients were estimated for statistically significant correlations between the raised levels of respirable particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) and different physiological parameters of the selected subjects at all sites. The intensity of correlation coefficients were found negative between measured parameters and shown in Table 4.8.

**Table 4.8: Correlation coefficients between ambient PM and physiological parameters (p-value < 0.05) during rice and wheat crop residue burning seasons**

Physiological Parameters		Correlation Coefficient Values											
		AMS				LDH				MGH			
Human Subject category		PM <sub>10</sub>		PM <sub>2.5</sub>		PM <sub>10</sub>		PM <sub>2.5</sub>		PM <sub>10</sub>		PM <sub>2.5</sub>	
		Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat	Rice	Wheat
FVC	Overall	-0.56	-0.41	-0.73	-0.70	-0.53	-0.45	-0.68	-0.66	-0.61	-0.58	-0.79	-0.71
	NBMI	-0.48	-0.34	-0.57	-0.54	-0.45	-0.35	-0.56	-0.41	-0.48	-0.41	-0.69	-0.62
	HBMI	-0.54	-0.39	-0.68	-0.64	-0.52	-0.41	-0.63	-0.57	-0.58	-0.53	-0.78	-0.69
	LBMI	-0.67	-0.53	-0.79	-0.75	-0.65	-0.48	-0.72	-0.70	-0.69	-0.59	-0.86	-0.75
FEV <sub>1</sub>	Overall	-0.41	-0.38	-0.7	-0.59	-0.45	-0.33	-0.63	-0.6	-0.51	-0.49	-0.71	-0.67
	NBMI	-0.34	-0.31	-0.58	-0.47	-0.31	-0.29	-0.53	-0.48	-0.41	-0.38	-0.61	-0.57
	HBMI	-0.39	-0.36	-0.63	-0.56	-0.43	-0.31	-0.61	-0.57	-0.48	-0.46	-0.69	-0.65
	LBMI	-0.46	-0.42	-0.72	-0.62	-0.47	-0.35	-0.67	-0.63	-0.54	-0.51	-0.74	-0.73
PEF	Overall	-0.61	-0.36	-0.68	-0.61	-0.38	-0.41	-0.67	-0.63	-0.58	-0.53	-0.76	-0.69
	NBMI	-0.51	-0.21	-0.53	-0.52	-0.24	-0.32	-0.57	-0.58	-0.47	-0.41	-0.59	-0.51
	HBMI	-0.58	-0.32	-0.65	-0.59	-0.34	-0.37	-0.61	-0.61	-0.54	-0.45	-0.69	-0.58
	LBMI	-0.64	-0.38	-0.71	-0.64	-0.41	-0.45	-0.72	-0.64	-0.61	-0.55	-0.83	-0.71
FEF <sub>25-75%</sub>	Overall	-0.38	-0.31	-0.55	-0.42	-0.41	-0.37	-0.58	-0.62	-0.57	-0.51	-0.62	-0.72
	NBMI	-0.21	-0.22	-0.42	-0.31	-0.32	-0.29	-0.43	-0.52	-0.45	-0.42	-0.52	-0.62
	HBMI	-0.34	-0.27	-0.51	-0.37	-0.38	-0.37	-0.52	-0.61	-0.56	-0.49	-0.57	-0.69
	LBMI	-0.42	-0.32	-0.59	-0.43	-0.46	-0.40	-0.59	-0.64	-0.62	-0.52	-0.63	-0.74

During rice crop residue burning periods, the correlation coefficients between FVC parameters and PM<sub>10</sub> of all subjects varied from -0.53 to -0.61, whereas the coefficient intensity between FVC and PM<sub>2.5</sub> level varied from -0.56 to -0.79. The intensity of coefficient was more in LBMI subjects (-0.72 to -0.86) than NBMI (-0.56 to -0.69) and HBMI (-0.63 to -0.78) subjects due to the burden of ambient PM<sub>2.5</sub> levels. The intensity of correlation between FEV<sub>1</sub> and PM<sub>10</sub> varied from -0.41 to -0.51 whereas the coefficient of correlation between FEV<sub>1</sub> and PM<sub>2.5</sub> varied from -0.63 to -0.71. The strength of coefficient was more in LBMI (-

0.67 to -0.74) subjects than HBMI and LBMI subjects due to fine particulate matter (PM<sub>2.5</sub>). The correlation coefficients between PEF and ambient PM<sub>2.5</sub> was more intense in LBMI subjects (-0.71 to -0.83) than HBMI (-0.59 to -0.69) and NBMI (-0.53 to -0.59) subjects at all sites. The correlation coefficients between PM<sub>2.5</sub> and FEF<sub>25-75%</sub> of all subjects of different categories were found significant while the LBMI subjects possessed negative intensity (-0.42 to -0.63).

Similarly, in wheat crop residue burning periods, the correlation coefficients between FVC parameter and PM<sub>10</sub> of all subjects varied from -0.41 to -0.58, whereas the coefficient intensity between FVC and PM<sub>2.5</sub> level varied from -0.53 to -0.75. The strength of coefficient was more in LBMI subjects (-0.53 to -0.75) than NBMI (-0.34 to -0.62) and HBMI (-0.64 to -0.69) subjects due to the greater burden of ambient PM<sub>2.5</sub> levels. The intensity of correlation between FEV<sub>1</sub> and PM<sub>10</sub> varied from -0.38 to -0.49 whereas the coefficient of correlation between FEV<sub>1</sub> and PM<sub>2.5</sub> varied from -0.38 to -0.51. The strength coefficient was more in LBMI (-0.42 to -0.54) subjects than HBMI and LBMI subjects due to fine particulate matter (PM<sub>2.5</sub>). The correlation coefficients between PEF and ambient PM<sub>2.5</sub> was more intense in LBMI subjects (-0.64 to -0.71) than HBMI (-0.58 to -0.61) and NBMI (-0.52 to -0.58) subjects at all sites. The correlation coefficients between PM<sub>2.5</sub> and FEF<sub>25-75%</sub> of all BMI categories were found significant and more negative intensity was found in LBMI subjects (-0.43 to -0.74).

It has been observed from the results that in rice crop seasons, the negative correlation was more with respect to FVC for PM<sub>2.5</sub> (-0.79, p-value <0.05) than PEF (-0.76, p-value <0.05) in LBMI subjects. The correlation coefficients of FVC with PM<sub>2.5</sub> for human subjects at MGH were more negative (-0.79, p-value <0.05) than those of LDH (-0.68, p-value <0.05) and AMS (-0.61, p-value <0.05 sites). Similarly, in wheat crop seasons, maximum negative correlation was observed for FVC (-0.71, p-value < 0.05) and PEF (-0.7, p-value <0.05) for PM<sub>2.5</sub> and PM<sub>10</sub> levels. It has been observed that both periods of stubble burning do affect the physiological parameters of all subjects at all the three sites but rice crop periods had more negative impact. This relation reveals that PM with lesser size had more impact on the working capacity of organs as they enter deep into the respiratory system. FVC and PEF are more sensitive to changes in PM<sub>2.5</sub> indicating that flow of air in the lungs is hindered due to restrictions in respiration mechanisms. MGH had more significant negative correlation (-0.79, p-value <0.05) than LDH (-0.68, p-value <0.05) and AMS (-0.61, p-value <0.05) due to higher concentration of PM, supporting the hypothesis that the decrease in physiological

parameters in different FNs were mostly due to raised levels of PM in both crop periods at all the selected sites.

#### 4.5.2 Mixed effect modeling based estimations

In order to quantify the response in physiological parameters of subjects in a rational way, the changes in these parameters were calculated resulting from the period increase in PM load of  $10\mu\text{gm}^{-3}$  in the ambient air resulting from an incremental dose of  $10\mu\text{gm}^{-3}$  in  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  levels, studies were carried out by mixed effect model with adjustment of potential covariates such as BMI. Significant changes in physiological parameters were observed during both crop seasons. The results in Table 4.9 indicate that the capacity and peak flow (FVC and PEF) parameters are more sensitive to  $\text{PM}_{2.5}$  levels than other spirometric parameters with a quantum increase of  $10\mu\text{gm}^{-3}$  in the PM levels.

**Table 4.9: Relative changes in physiological parameters under the effect of increased levels of PM by  $10\mu\text{gm}^{-3}$  at three different sampling sites of Amritsar (AMS), Ludhiana (LDH) and Mandi Gobindgarh (MGH) (p-value <0.05)**

Physiological Parameters	Relative change in physiological parameters (%) with increase of PM by $10\mu\text{gm}^{-3}$					
	Rice crop period					
	AMS		LDH		MGH	
	$\text{PM}_{10}$	$\text{PM}_{2.5}$	$\text{PM}_{10}$	$\text{PM}_{2.5}$	$\text{PM}_{10}$	$\text{PM}_{2.5}$
FVC	-3.38	-5.27	-2.84	-6.01	-3.91	-7.53
FEV <sub>1</sub>	-2.43	-4.27	-1.42	-5.07	-2.36	-5.11
PEF	-3.28	-4.89	-3.69	-5.21	-4.69	-7.12
FEF <sub>25-75%</sub>	-1.64	-2.04	-0.89	-3.73	-3.98	-4.63
	Wheat crop period					
FVC	-2.24	-3.03	-2.12	-3.11	-2.57	-5.02
FEV <sub>1</sub>	-1.36	-2.54	-2.47	-3.58	-1.38	-3.43
PEF	-2.26	-3.47	-1.92	-4.41	-2.21	-4.22
FEF <sub>25-75%</sub>	-1.75	-2.29	-1.36	-3.12	-1.55	-3.78

In rice crop periods, greater negative changes were observed in FVC and PEF for  $\text{PM}_{2.5}$  concentration than for  $\text{PM}_{10}$  at all sites. The decrease in FVC as a function of PM levels varied from -5.27% to -7.53% whereas for PEF, changes were from -4.89% to -7.12%. In wheat crop periods, similar trends were recorded in FVC (-3.03% to -5.02%) and PEF (-3.47% to -4.22%) for  $\text{PM}_{2.5}$  concentration. The maximum effect was observed in the subjects at MGH site as compared to those in LDH and AMS sites. These results also indicated some permanent changes in spirometric parameters of the subjects.

#### 4.6 Apparent resistance to fall in Forced Vital Capacity in children with increasing mass level of fine particulate

The most important parameter of respiratory health measurement is Forced Vital Capacity (FVC). The FVC values of all subjects in the age group 10 to 14 years were monitored over a period of three years covering at least three wheat crop seasons and three rice crop seasons. With the ongoing practice of crop residue burning after each harvesting season, there has not been any improvement in the respiratory health of subjects from 2014-2016.

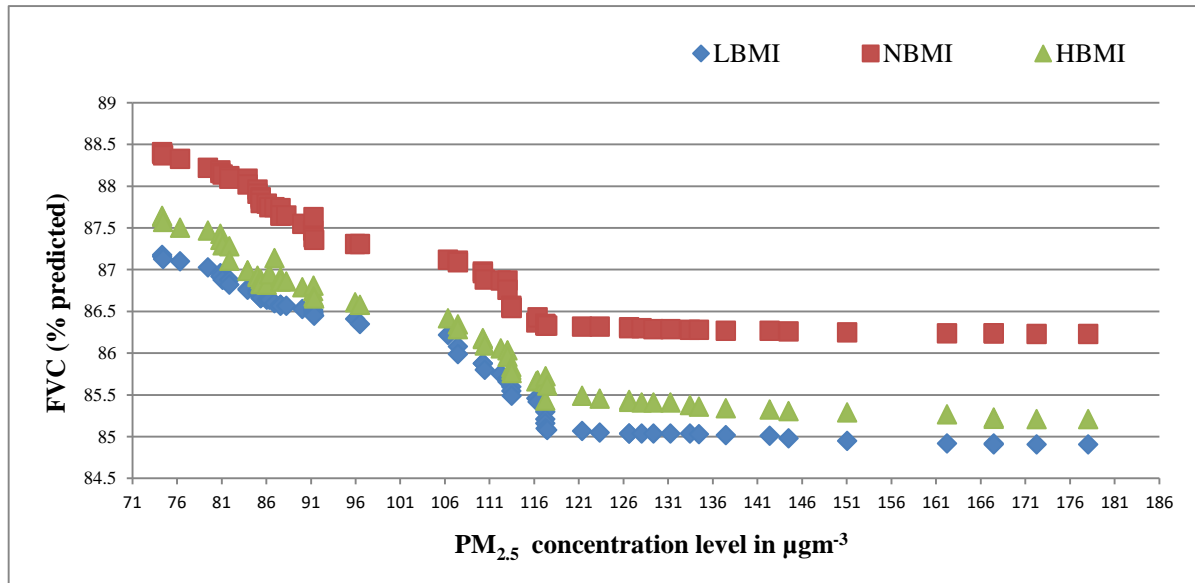


Figure 4.29: Trends in FVC of children with quantized increase in levels of PM<sub>2.5</sub> by 10µgm<sup>-3</sup> in the ambient air of Amritsar site

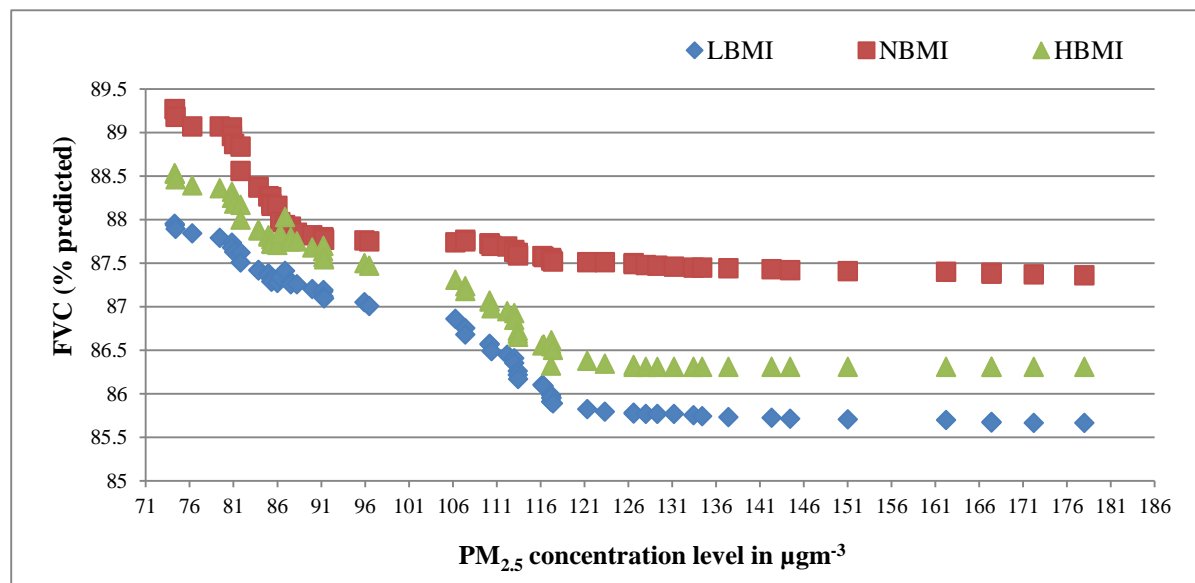
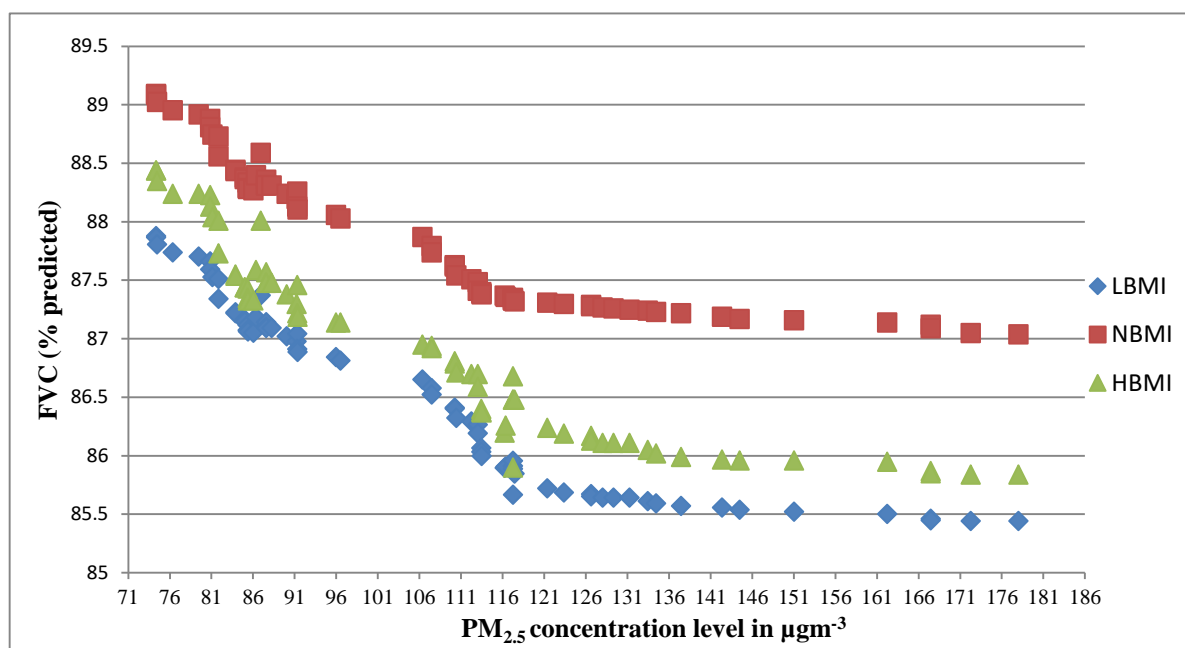


Figure 4.30: Trends in FVC of children with quantized increase in levels of PM<sub>2.5</sub> by 10µgm<sup>-3</sup> in the ambient air of Ludhiana site

As discussed in previous paras, a sharp rise in levels of fine particulate matter was observed with significant impacts on the respiratory health indicated by a significant fall in FVC values by 3% - 7%. For the first time, an exhaustive study on the damage in the respiratory health of children is being correlated with the Body Mass Index (BMI) of children and reported here. Very interesting observations have been noticed and are quantized (Figure 4.29 to 4.31).



**Figure 4.31: Trends in FVC of children with quantized increase in levels of PM<sub>2.5</sub> by 10µgm<sup>-3</sup> in the ambient air of Mandi Gobindgarh site**

- Subjects with BMI in the normal range category (18 Kgm<sup>-2</sup> to 23 Kgm<sup>-2</sup>) have shown better resistance to the degrading air quality as compared to those with BMI greater than 23 Kgm<sup>-2</sup> (HBMI) and less than 18 Kgm<sup>-2</sup> (LBMI). The plots of FVC as a function of PM<sub>2.5</sub> for NBMI subjects lie higher than HBMI and LBMI (Figure 4.29-4.31).
- The extent of resistance by NBMI subjects over HBMI and LBMI subjects at a given site can be calculated in terms of relative lesser fall in FVC during CRB period of the baseline FVC value. The relative fall in FVC of NBMI is less by 17% and 24% from that of HBMI and LBMI subjects, respectively, at AMS site. Similarly, at LDH and MGH sites, the FVC of NBMI is correspondingly less by 12.5% and 22%; 10% and 17%, respectively. The above data strongly support the hypothesis that BMI is a fitting tool for analyzing respiratory health of school children.

- FVC of human subjects of all BMI categories do not respond linearly with increasing  $PM_{2.5}$  levels rather remain stable in certain ranges of  $PM_{2.5}$  levels. FVC responses have been recorded as a function of  $PM_{2.5}$  levels and can be grouped in four different steps, i.e.,  $74\mu g m^{-3}$  till  $81\mu g m^{-3}$ ,  $82\mu g m^{-3}$  till  $106\mu g m^{-3}$ ,  $107\mu g m^{-3}$  till  $117\mu g m^{-3}$  and more than  $117\mu g m^{-3}$ .
- The major effect of a quantum increase of  $10\mu g m^{-3}$   $PM_{2.5}$  on FVC is seen when the level increases from  $81\mu g m^{-3}$  to  $86\mu g m^{-3}$  where a fall of about 2.8 % is observed for children of NBMI at Ludhiana station. Interestingly, the fall in FVC for the children of NBMI is much less at Amritsar and Mandi Gobindgarh (being 0.4% at Amritsar and 0.3 % at Mandi Gobindgarh). It is difficult to comment on the greater effect of  $PM_{2.5}$  levels on subjects with NBMI at Ludhiana as compared to those at Amritsar and Mandi Gobindgarh for the same increase in  $PM_{2.5}$ .
- The FVC of subjects with HBMI and LBMI follow the similar trend as that of NBMI but with a greater change in magnitude.
- The FVC of all the three categories of subjects i.e., NBMI, HBMI and LBMI remain stable during increase in  $PM_{2.5}$  level from  $86\mu g m^{-3}$  till  $106\mu g m^{-3}$  without any further fall. On further increase in fine particulate concentration from  $107\mu g m^{-3}$  till  $117\mu g m^{-3}$ , a sharp fall in FVC is noticed for all categories of children (0.8% for NBMI, 2.12% for HBMI and 2.34% for LBMI).
- With further increase in  $PM_{2.5}$  levels from  $117\mu g m^{-3}$  onwards, the FVC of all the three categories remain stable or follow a negligible decrease (0.2%) till  $175\mu g m^{-3}$ . As per ANOVA and t-test, the changes in FVC values became insignificant for higher concentration levels of  $PM_{2.5}$  (beyond  $117\mu g m^{-3}$ ). This can be seen as a long plateau for all the categories of subjects.
- The epidemiological observations as discussed in points 6 and 7 and also reported by us earlier (Gupta *et al.* 2016) indicate an inherent resistance of respiratory system of all human beings after certain degree of damage. Pelsoi *et al.* (1998) and Jones *et al.* (2006) have correlated BMI with FVC but did not report the effect of different levels of  $PM_{2.5}$  on FVC.

### **SAC Theory to explain Plateau in FVC levels**

Since basic physiology of all human beings is the same, the phenomenon of FVC over a range of increasing  $PM_{2.5}$  levels (plateaus) is shown by subjects of all categories and age

groups. The  $PM_{2.5}$  levels in ambient air of North –Western India is affected seriously due to release of particulates of different shapes and sizes which in turn get through the respiratory tracts of human subjects and accumulate in the pulmonary sacs. Since health of pulmonary organs and BMI are related to each other (Pelsoi *et al.* 1998; King *et al.* 2005), the children with NBMI categories are found to suffer to lesser extent than those with HBMI and LBMI categories for the same increase in  $PM_{2.5}$  levels. It is interesting to notice that the Forced vital capacity (FVC) of subjects of all categories do not fall further during the  $PM_{2.5}$  ranges 81-86  $\mu\text{gm}^{-3}$  and 107 till 117  $\mu\text{gm}^{-3}$ , thereby showing apparent resistance to the fall in FVC. Although, it cannot be supported with experimental observations immediately, yet it is hypothesized that during increase in  $PM_{2.5}$  levels from 74 $\mu\text{gm}^{-3}$  till 81 $\mu\text{gm}^{-3}$ , 82 $\mu\text{gm}^{-3}$  to 106  $\mu\text{gm}^{-3}$ , 107 $\mu\text{gm}^{-3}$  to 117 $\mu\text{gm}^{-3}$  and more than 117 $\mu\text{gm}^{-3}$  (Figure 4.29-4.31), the  $PM_{2.5}$  keeps on depositing in the successive pulmonary sacs in the lungs and the FVC observed does not show any fall in its values corresponding to these periods. Further investigations are required to prove this hypothesis. Hence, the sac theory proposed here is supported amply from the plateau getting noticed for children of all age groups and BMI categories.

#### 4.7 Discussion

According to per WHO reports, health levels of human subjects in developing countries are more vulnerable to diseases or disorders due to multi-dimensional factors like under nutrition and uncontrolled releasing of pollutants in the ambient environment (Khan *et al.* 2001; King *et al.* 2005). In this study, more than 70% of selected subjects were found under BMI levels ( $< 18 \text{ kgm}^{-2}$ ) due to their socioeconomic reasons that are already recognized by potential reports (Chekmek *et al.* 2016; Goodman *et al.* 2017). On global scale, various legal policies have been implemented by legislation system to control the release of PM from industries, vehicles and cement and construction plants in ambient air for safety of inhabitants. Agriculture crop residue burning is an uncontrolled source of PM that has no strong policies worldwide to control. This practice produces enormous amount of pollutants in the ambient environment in a short span of time. Our results appreciate the previous reports which reported the decline in physiological parameters of subjects due to short term rise in PM levels in ambient environment (Janssen *et al.* 2013; Ostro *et al.* 2016; Kim *et al.* 2017). But in these reports, the subjects were considered healthy just based on their Tiffenue index only. Tables 4.8 and 4.9 reported that the maximum fall in physiological parameters was observed in rice season due to higher quantum of PM entering the ambient air than in wheat crop

residue burning seasons. The  $PM_{2.5}$  had more burden on the respiratory health than  $PM_{10}$  due to fine size.

In rice and wheat seasons, meteorological parameters had very important role in dispersion coefficient of pollutants in the sampled areas (Kothi *et al.* 2011). FVC and PEF are the key biomarkers of respiration related parameters (Miller *et al.* 2005). They had been identified as the prime indicators for chronic pulmonary implications.

### **Respiratory health of children with regards to their Body Mass Index (BMI) values**

The results of this study indicate a significant role of BMI in the respiration and pulmonary trails of the selected subjects. As per our studies on the respiratory system of children, the lung mechanism tries to recover their working capacity. But due to under nutrition, physiological parameters were unable to retrieve their baseline values due to their weak endothelial mechanism (Roy *et al.* 2012; Hwang *et al.* 2015). The subjects with lower BMI were unable to recover the effect in comparison to other categories. The present studies reporting the vulnerability of volume and exchange rate of lungs for short term rise in PM in ambient air by different sources are supported by the work of Mittal *et al.* (2009); and Roy *et al.* (2012); Agarwal *et al.* (2013); Gupta *et al.* (2016); Raanan *et al.* (2016). Due to personal interest and fitness scale, only 150 subjects were selected for the study. As per literature, small number of sample size may cause biases in the results, but this study had more candidates than previous studies in which the number of subjects varied from 50 to 100, hence, results are statistically significant.

*From results it has been observed that the ambient concentration level of  $PM_{10}$  and  $PM_{2.5}$  was higher in during and post CRB seasons of rice crop than wheat crop by 37% to 55% with annual growth of 17% to 23%. Simultaneously, the intensity of impact was significantly higher for  $PM_{2.5}$  at all sites. Maximum degradation was observed in FVC and PEF parameters of selected subjects during each crop seasons. An unrecoverable effect was observed in physiological parameters compared to their base line values. BMI wise, maximum effect in physiological parameters was observed in LBMI subjects than NBMI and HBMI subjects. Site wise, the burden of PM pollution was higher in MGH due to furnaces in the area and 70% of subjects were found under or low BMI. When FVC and  $PM_{2.5}$  data was stratified, unusual behavior was observed rather than linear. After an increment in  $PM_{2.5}$  range, a stable plateau was observed in FVC of all BMI categories at all sites. It has been observed from the results that the normal BMI subjects have more resistant to raised level of PM pollutant than abnormal BMI subjects.*

# Chapter-5

## Conclusion and Future Recommendation

### 5.1 Conclusion

Agriculture crop residue burning episodes affect physiological parameters of school going children, especially those having BMI levels lower and higher than the recommended standard values of 18-23 kgm<sup>-2</sup>. The crop residue burning practice releases a huge amount of PM<sub>10</sub> and PM<sub>2.5</sub> (50% to 147% more than permitted levels) in ambient environment that impacts respiration related parameters such as FVC and PEF. In the post harvesting periods, physiological parameters of subjects tend to recover the declined levels but not up to baseline values. This trend is more valid for subjects with BMI in the range other than the normal range of 18-23 kgm<sup>-2</sup>. Rice crop residue burning season had more impact on subjects than wheat crop residue burning season due to the release of higher amount of fine PM i.e., PM<sub>2.5</sub> in the ambient environment.

This study revealed for the first time the role of BMI in the respiratory related sickness of human subjects during exposure to ambient air particulate matter. In future, if necessary, steps are not taken to stop these burning activities, it may cause chronic and unrecoverable disorders to human subjects in initial age of their growth. Correlation coefficients were drawn between PM levels and some important physiological parameters. It indicates that for all subjects PM<sub>2.5</sub> is more negatively correlated than PM<sub>10</sub>. Since rice crop residue burning leads to more generation of PM<sub>2.5</sub> than PM<sub>10</sub>, the particulate pollution in the months of October to December are more dangerous for the children than other seasons of the year.

Body Mass Index is a very important metric of respiratory health of children. Children with BMI in the normal range have much better pulmonary health than the HBMI or LBMI subjects. The plateaus in FVC plots observed in the PM<sub>2.5</sub> ranges 86 to 106 µgm<sup>-3</sup> and 117 to 175µgm<sup>-3</sup> indicate as if the pulmonary sacs of lungs are getting filled with PM corresponding to each plateau range, apparently showing no loss of FVC.

### 5.2 Limitations and future recommendation

This study generalized the results to whole population but there is a need to discriminate the results on gender basis for community wise estimation. In the study, only those subjects who were medically fit, non-smokers and have no symptoms of any diseases were recruited and

observed but there is need to include the subjects those were already suffered from pulmonary diseases like asthmatic or COPD patient to observe the consequences due to crop residue burning. No other pollutants were included in the analysis procedure due to focus of the study on fine particulates, because the previous studies estimated the more significant role of PM than other pollutants on physiological parameters when adjusted in statistical models. The proposed estimations in physiological parameters are well supported to analyze the episodic trends due to ACRB practice and may contribute a significant role in designing control policies by National and International communities.

## Summary

Human body is made up of different systems like skeletal system, muscular system, circulatory system, nervous system, respiratory system, digestive system, excretory system *etc.* 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. The main organs affecting pulmonary functions are the lungs and these are surprisingly delicate as they interact with the external as well as the internal environment. Respiratory system made up of organs in body that helps to breathe. The primary function of the respiratory system is to supply the blood with oxygen, in order for the blood to deliver oxygen to all parts of the body.

Ambient air pollution is a serious concern for global communities due to their burden on physiological parameters of human subjects. Burning of fuels, biomass waste, dust from construction plants *etc.* are identified as primary sources who are responsible for emission of poisonous gases and inhalable particulate matters in the ambient environment. Respiration system of human subjects has direct interaction with these pollutants. Hence, primary mode of entry of pollutants into the human body is through the respiratory system by the process of breathing. As per literature survey, the exposure to particulate matter having size PM<sub>10</sub> or lesser caused various types of ailments in human body organs such as asthma or abnormal cardiopulmonary disorders than gaseous pollutants. Particulate matter which remain suspended in the atmosphere for long time have dangerous effects on human health as these particulate matters enter inside the human system through breathing and reached at pulmonary region affect the pulmonary function of lungs. According to World Health Organization (WHO) report, it is a cause of cardiopulmonary morbidity and mortality of 6.4 million people and 3.7 million premature deaths worldwide. Children are more susceptible to higher PM levels. As compared to adults and elder age groups, they have higher respiration rate and narrower airways. Children have less body immunity. They are mentally not aware about their surrounding environmental conditions. Having higher respiration rate, the dose inhalation rate is more than other age groups.

Among the sources, automobiles and industries are considered as the main source of PM generation in the urban areas. From several decades, studies are revolving around the effect

of PM on pulmonary functions of human health which are generated due to combustion of fuels in vehicles, factories or production units but crop residue burning also plays an important role in producing pollution. Burning crop residue is a part of agriculture for many years due to different reasons as it is the cheapest, less time consuming and less laborious method to use the land for further farming but it creates a hazardous effect on health.

Open burning of crop residue remains a widely-adopted method to clear the fields. Globally, it is the second largest source of air contamination after industrial pollution. In Northern India, Punjab is the second largest grain producing state. Rice and wheat are the main cereal crops of this region. Rice is sown in the month of June and is ready to harvest by the month of October. Wheat is sown in the month of December and is ready to harvest by the month of April. During harvesting, the machines produce a huge amount of agricultural waste in the fields. Less time and lack of sources insist the farmers to burn this waste in the fields. This practice releases gaseous pollutants and respirable particulate matter (PM<sub>10</sub> and PM<sub>2.5</sub>) in the ambient environment. Recent satellite-based studies reported the formation of dense clouds of smoke during crop residue burning practice in the region. Due to this activity, concentration of Particulate Matters (PM) increases alarmingly in the nearby areas in comparison to baseline level of pollutants. Toxicologically, composition of PM has oxidative significance which can damage the working capacity of lungs. Respiratory system is the prime target of PM. They enter through the nasal cavity deep into the lungs and stick into the walls of the alveolar sacs. Many researchers found that the abruptly increased concentration of particulate air pollutants, substantially affect working capacity of different body organs. It may lead to disorders like Asthma.

Health effect data comes from three types of studies: clinical, epidemiological and toxicological. Clinical and epidemiological studies mainly focus on human subjects, whereas toxicological studies are conducted on animals or simpler cellular systems. Present study mainly includes epidemiological study. In epidemiological studies, natural exposure to communities and diseased groups has been done. Whereas clinical studies mainly revolve around the controlled exposure to experimental and diseased subjects. In general, clinical studies provide evidence on the effects of air pollutants under reproducible laboratory conditions *i.e.* exposure level may be quantified and the health status of the subject is well known. This type of study can determine the presence or absence of various endpoints for a given sample group exposed to short term, low-level concentrations of various air pollutants. Weaknesses of clinical studies are artificial exposure and acute effect measurements.

Whereas in epidemiological studies, subjects are exposed to actual pollutants existing in their community. The strength is the real-world condition of the exposure and the subjects, the weakness is the difficulty in quantifying the relationship between exposure and subsequent effects.

In epidemiological studies, there are some independent factors related to human physiology that are identified as independent effect modifiers. As per UNICEF's malnutrition report on children; compared to other age groups, nutritional status is abnormal in children. According to reports, Body Mass Index has a significant association to recoil the composition of different working order of body organs such as respiration mechanism. Various studies have been done to quantify the effect of PM pollution from different sources like motor vehicles, industries or mines etc. on children. There is hardly any ground based recent report on the cause-effect analysis of PM levels in ambient air and physiological parameters of children due to agriculture crop residue burning practice with adjustment of covariate such as BMI. This study aims to present the episodic trends in PM for six consecutive crop residue burning periods at three agriculturally active sites and their effect on the working of different physiological parameters of children.

With the approval of Indian Council of Medical Research (ICMR) ethical committee, the study was carried out from August 2013 to July 2016 to cover at least three seasons of rice and three seasons of wheat crop. Ground aspects like selection of study area, subjects, instruments and sampling frequency were studied before actual collection of data. Three agriculturally active sites such as Amritsar, Ludhiana and Mandi Gobindgarh were selected in Punjab region of India. The distance between any two sites was approximately 50 to 150 Km and each sampling site located at about 0-2 Km from the nearest point of crop residue burning activity. Seasonal and temporal trends of meteorological parameters at all the sites were found same. The schools and human subjects were selected on the following bases:

- (a) Schools having no other source of area specific pollution within a range of 10 km of the school and have adequate number of subjects (living within 1 km of the school for the last 10 or more years).
- (b) Subjects having no smoking habits and good medical records were selected.

American Thoracic Society (ATS) questionnaires were used during selection of subjects. From schools, 150 healthy children of age group 10 to 14 years were selected for the study. It has been observed that more than 70% of subjects were under nutrition due to low BMI levels

at all sites. Before selection, spirometric test was conducted on each subject. Primarily candidates having more than 80% Tiffenue Index were observed as healthy and selected. Written consent forms (duly signed by the school authorities and guardians) were obtained from the children for sampling exercise. Based on availability of the subjects, sampling frequency was set as four recordings per fortnight at all the sites. The days of sampling were selected so as to stagger on different days of different weeks. For measurement and sampling of data standard instruments were used for data collection. The PM concentration levels were measured using Real Time Optical Light Scattering Aerosol Monitor (RTOLSAM, Grimm Technology, Model 1.108, Germany) and physiological parameters such as Forced Vital Capacity (FVC), Forced Expiratory Volume in 1 second ( $FEV_1$ ), Peak Expiratory Flow (PEF), Forced Expiratory Flow 25-75% ( $FEF_{25-75\%}$ ) of all the selected subjects, were repeatedly measured using SPIRODOC (Medical International Research, Italy). The device consists of spirometer as well as pulse oximetry modes of function. The device is compliant with ATS/ERS (European Respiratory Society) protocols. Season wise, descriptive analyses were done to observe the episodic trends in physiological parameters. The differences between the sites and within the sites were observed by ANOVA and student's t test. Pearson correlation coefficients were measured to observe the relationship between measured PM pollutants and physiological parameters. Mixed effect model was adopted to estimate the changes in physiological parameters due to agriculture crop residue burning episodes. In repeated measurements, it is necessary to account correlations within and between the parameters in the estimation models for accurate outcome. This model has flexibility to adjust both fixed and random variables with their normal and non-normal distribution over time. The statistical analyses were done using Statistical Package for the Social Sciences (SPSS) version 22.0, 2013 and considered significant if  $p\text{-value} < 0.05$ .

The collected data of PM and physiological parameters of school going children has been sorted in multi dimensions (year wise, season wise, episode wise, BMI wise) for exhaust analysis. Statistical models have been developed for cause-effect estimations and trends. During modelling, various factors have been considered for comparisons. During the whole study period from 2013 to 2016, the fortnightly averaged levels of  $PM_{10}$  varied from  $64 \pm 19 \mu\text{gm}^{-3}$  to  $180 \pm 37 \mu\text{gm}^{-3}$ . The levels of  $PM_{10}$  varied from  $64 \pm 21 \mu\text{gm}^{-3}$  to  $167 \pm 34 \mu\text{gm}^{-3}$ ,  $69 \pm 23 \mu\text{gm}^{-3}$  to  $180 \pm 31 \mu\text{gm}^{-3}$  and  $65 \pm 16 \mu\text{gm}^{-3}$  to  $180 \pm 24 \mu\text{gm}^{-3}$ , respectively during crop seasons in 2013-14, 2014-15, 2015-16. Due to ACRB activity in the state, the concentration of  $PM_{10}$  rapidly increased at all sites. It has been estimated that the concentration level of

PM<sub>10</sub> was more than the NAAQS standards by 50% to 80% whereas it was more than permitted levels by 50%, 67% to 80% in consecutive years at all sampling sites. It has been observed from the trends that the ambient PM<sub>10</sub> levels were remained higher than permitted levels for more fortnights in rice seasons than wheat seasons. The ambient concentration level of PM<sub>10</sub> was estimated to be about 57% to 67% more in RCRB seasons than WCRB seasons. In each ACRB period, the concentration level of PM<sub>10</sub> was higher during and after CRB periods than non CRB periods. During the whole study period from 2013 to 2016, the fortnightly averaged levels of PM<sub>2.5</sub> varied from 33±14µgm<sup>-3</sup> to 134±32µgm<sup>-3</sup>. The levels of PM<sub>2.5</sub> varied from 38±15µgm<sup>-3</sup> to 108±26µgm<sup>-3</sup>, 33±11µgm<sup>-3</sup> to 116±25µgm<sup>-3</sup> and 39±11µgm<sup>-3</sup> to 134±29µgm<sup>-3</sup>, respectively during crop seasons in 2013-14, 2014-15, 2015-16. Due to ACRB activity in the state, the concentration of PM<sub>2.5</sub> rapidly increased at all sampling sites. It has been estimated that the concentration level of PM<sub>2.5</sub> was 120% to 127% more than the NAAQS standards where as 80%, 93% and 123% more than permitted levels in consecutive years at all sampling sites. The ambient concentration level of PM<sub>2.5</sub> was estimated to be about 75% to 84% more in RCRB seasons than WCRB seasons. In each ACRB period, the concentration level of PM<sub>2.5</sub> was higher during and after CRB episodes than non CRB episode. The episodic trends are further investigated to find significant observations. Due to economic and meteorological factors, the difference in both seasons were investigated and found significant. Seasonal and episodic trends reveal that the burden of PM in ambient environment affects working capacity of various respiratory parameters.

The physiological parameters such as Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV<sub>1</sub>), Peak Expiratory Flow (PEF) and Forced Expiratory Flow 25-75% (FEF<sub>25-75%</sub>) were continuously measured from selected school going children at all the selected sites. FVC of all subjects declined from their baseline values and the fall was greater in LBMI subjects than HBMI and NBMI from 45% to 53%. Similarly for the wheat crop residue burning season, the FVC levels of all categories declined due to burden of PM levels. FVC of NBMI subjects reduced marginally from 3.2% to 3.4%. The fall in FVC of HBMI subjects were however, greater from 3.6% to 4.2% while for LBMI it varied from 4.1% to 4.3% from their respective baseline values. The FEV<sub>1</sub> of NBMI subjects decreased by 3.5% to 3.8% from their baseline values. The fall in FEV<sub>1</sub> of HBMI subjects varied by 4.1% to 4.9% while that of LBMI it varied from 5.0% to 5.4% from the baseline value. It has been observed from the trends that the FEV<sub>1</sub> of all subjects decreased from their baseline values and the fall was greatest in LBMI subjects in comparison to HBMI and NBMI subjects by 50

to 55%. The PEF of NBMI subjects decreased by 3.5% to 3.8% from their baseline values. The fall in PEF of HBMI subjects varied by 4.1% to 4.9% while that of LBMI it varied from 5.0% to 5.4% from the baseline value. It has been observed from the trends that the PEF of all subjects decreased from their baseline values and the fall was greatest in LBMI subjects in comparison to HBMI and NBMI subjects by 50 to 55%. The FEF<sub>25-75%</sub> of NBMI subjects decreased by 2.3% to 2.5% from their baseline values. The fall in FEF<sub>25-75%</sub> of HBMI subjects varied by 2.6% to 2.7% while that of LBMI subjects, it varied by 3.1% to 3.6% from the baseline value. It has been observed from the trends that the FEF<sub>25-75%</sub> of all subjects decreased from their baseline values and the fall was greatest in LBMI subjects in comparison to HBMI and NBMI subjects by 53% to 57%. It has been observed that the decline in FVC and PEF of LBMI subjects were more than HBMI and NBMI subjects in relation to higher level of ambient PM level. The intensity of decrement in physiological parameters of subjects was lower in NBMI candidates. Other parameters such as FEV<sub>1</sub> and FEF<sub>25-75%</sub> were also declined. The decline in various physiological parameters of selected subjects in both seasons was found significant. During the burning episodes, a fall was observed in FVC parameter (-3.17, F-test value: 101.47) from their baselines value due to increased levels of PM concentration in the ambient environment of the Amritsar site. The fall in lung function test parameters was more in LBMI subjects than for HBMI and NBMI subjects. During CRB episodes, the fall in FEV<sub>1</sub> was recorded as -2.36% (F-test value: 114.36) from baseline value in all subjects with minimum decline of -1.45% (F-test value: 107.59) in normal BMI subjects. During CRB episodes, the fall in PEF of LBMI subjects was -2.41% (F-test value: 117.93) that were more than other category students. Similarly, the FEF<sub>25-75%</sub> parameter of selected subjects was less by -1.39% (F-test value: 74.09) during the CRB episodes. After CRB episodes, the physiological parameters recovered up to some extent. The recovery effects were better in NBMI candidates than in HBMI and NBMI subjects. The fall in parameters revealed that the human physiological parameters are highly sensitive to the increased levels of particulate pollutants. The physiological parameters like FVC, FEV<sub>1</sub>, PEF and FEF<sub>25-75%</sub> further decreased by about 4.0%, 2.4%, 4% and 2.3%, respectively, during the peak events as compared to the baseline levels of pollution. In rice crop residue burning seasons, highest levels of PM concentrations were observed. In post crop burning episodes, levels of PM decreased than standard levels but still a negative percentage change was observed in spirometer parameters. In wheat crop residue burning periods, the levels of PM were measured and found higher than permitted levels. Corresponding to each PM level, FVC decreased from -0.76% to -4.46%, FEV<sub>1</sub> decreased

from -2.12% to -2.86%, PEF decreased from -1.91% to -2.86% and FEF<sub>25-75%</sub> decreased from -0.91% to -1.35%. The strength of coefficient was more in LBMI (-0.67 to -0.74) subjects than HBMI and LBMI subjects due to fine particulate matter (PM<sub>2.5</sub>). The correlation coefficients between PEF and ambient PM<sub>2.5</sub> was more intense in LBMI subjects (-0.71 to -0.83) than HBMI (-0.59 to -0.69) and NBMI (-0.53 to -0.59) subjects at all sites. The correlation coefficients between PM<sub>2.5</sub> and FEF<sub>25-75%</sub> of all subjects of different categories were found significant while the LBMI subjects possessed negative intensity (-0.42 to -0.63). In rice crop periods, greater negative changes were observed in FVC and PEF for PM<sub>2.5</sub> concentration than for PM<sub>10</sub> at all sites. The decline in FVC was observed as a function of PM levels varied from -5.27% to -7.53% whereas for PEF, changes were from -4.89% to -7.12%. In wheat crop periods, similar trends were recorded in FVC (-3.03% to -5.02%) and PEF (-3.47% to -4.22%) for PM<sub>2.5</sub> concentration. The maximum effect was observed in the subjects at MGH site as compared to those in LDH and AMS sites. These results also indicated some permanent changes in spirometric parameters of the subjects.

For the first time, an exhaustive study on the damage in the respiratory health of children is being correlated with the Body Mass Index (BMI) of children and reported here. Very interesting observations have been noticed and are quantized. FVC of human subjects of all BMI categories do not respond linearly with increasing PM<sub>2.5</sub> levels rather remain stable in certain ranges of PM<sub>2.5</sub> levels. FVC responses have been recorded as a function of PM<sub>2.5</sub> levels and are grouped in four different steps viz. 74  $\mu\text{gm}^{-3}$  till 81 $\mu\text{gm}^{-3}$ , 82  $\mu\text{gm}^{-3}$  till 106  $\mu\text{gm}^{-3}$ , 107  $\mu\text{gm}^{-3}$  till 117  $\mu\text{gm}^{-3}$  and more than 117  $\mu\text{gm}^{-3}$ .

From results, it has been observed that the ambient concentration level of PM<sub>10</sub> and PM<sub>2.5</sub> was higher in during and post CRB seasons of rice crop than wheat crop by 37% to 55% with annual growth of 17% to 23%. Simultaneously, the intensity of impact was significantly higher for PM<sub>2.5</sub> at all sites. Maximum degradation was observed in FVC and PEF parameters of selected subjects during each crop seasons. An unrecoverable effect was observed in physiological parameters compared to their base line values. BMI wise, maximum effect in physiological parameters was observed in LBMI subjects than NBMI and HBMI subjects. Site wise, the burden of PM pollution was higher in MGH due to furnaces in the area and 70% of subjects were found under or low BMI. When FVC and PM<sub>2.5</sub> data was stratified, unusual behavior was observed rather than linear. After an increment in PM<sub>2.5</sub> range, a stable plateau was observed in FVC of all BMI categories at all sites. It has been observed from the results that the normal BMI subjects have more resistant to raised level of PM pollutant than

abnormal BMI subjects. The proposed estimations in physiological parameters are well supported to analyze the episodic trends due to ACRB practice and may contribute a significant role in designing control policies by National and International communities.

**List of Publications**  
(In SCI Indexed Journals)

1. Sachin Gupta, Ravinder Agarwal and Susheel K. Mittal (2016) Respiratory health concerns in children at some Strategic locations from high PM levels during crop residue burning episodes. 2016. **Atmospheric Environment (Elsevier), 137:127-134.**
2. Sachin Gupta, Susheel K. Mittal and Ravinder Agarwal (2018) Respiratory health of school children in relation to their Body Mass Index (BMI) during crop residue burning events in North Western India. **MAPAN (SPRINGER), 33 (2):113-122.**
3. Susheel Mittal, Sachin Gupta, Ravinder Agarwal, Apparent resistance to fall in Forced Vital Capacity in children with increasing mass level of fine particulate: A physiological phenomenon. Environmental Science and Pollution Research (SPRINGER), Manuscript ID: ESPR-S-17-03192, (Under Review).
4. Susheel Mittal, Ravinder Agarwal, Sachin Gupta, Body Mass Index as respiratory health indicator of school children during post-harvest crop residue burning in Punjab (India). Environmental Communication (Taylor and Francis) Manuscript ID: RENC-2018-0054, (Under Review).

## List of Publication

(In National and International conferences)

1. Effect of particulate matters in ambient air on the respiration system of children in Amritsar. Sachin Gupta, Gurpreet Saggu, Susheel Mittal, Ravinder Agarwal, Avnish Kumar. Proceeding in National Symposium on Contribution of Metrology & Measurement Standards in Social and Industrial Development (MAPIKI 2014). December 8-9, 2014. NPL, New Delhi.
2. Effect of particulate matters in ambient air on the health of children Worldwide. Ravinder Agarwal, Susheel Mittal. Proceeding in National Symposium on Contribution of Metrology & Measurement Standards in Social and Industrial Development (MAPIKI 2014). December 8-9, 2014. NPL, New Delhi.
3. Effect of burning crop residue around Patiala on lung functioning of school children. Gurpreet Saggu, Sachin Gupta, Susheel Mittal, Ravinder Agarwal. Proceeding in National Symposium on Contribution of Metrology & Measurement Standards in Social and Industrial Development (MAPIKI 2014). December 8-9, 2014. NPL, New Delhi.
4. Burden of particulate matters in Punjab due to agriculture crop residue burning seasons affecting health of school children. Sachin Gupta, Ravinder Agarwal, Susheel Mittal. Proceeding in 4th national conference on Advances in Metrology (ADMET 2015). February 25-27, 2015. CSIR-CMERI, Durgapur.
5. Evaluation of trends in physiological parameters variation of children during rice crop residue burning seasons. Sachin Gupta, Ravinder Agarwal, Susheel Mittal. Proceeding in 9<sup>th</sup> International conference on Advances in Metrology (ADMET 2016). February 24-26, 2016. National Physical Laboratory, New Delhi.

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