कोयले पर आधारित तापीय शक्ति सयंत्र से वायु प्रदूषको का उत्सर्जन तथा उनका फसल उत्पादकता पर प्रभाव

Emission of Air Pollutants from Coal-Based Thermal Power Plant and their Impacts on Crop Productivity

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2018

Emission of Air Pollutants from Coal-Based Thermal Power Plant and their Impacts on Crop Productivity

By

LAL CHAND MALAV

A Thesis

Submitted to the Faculty of Post Graduate School,
ICAR-Indian Agricultural Research Institute, New Delhi,
In partial fulfillment of the requirements
For the award of the degree of

DOCTOR OF PHILOSOPHY
IN
ENVIRONMENTAL SCIENCES
2018

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CERTIFICATE

This is to certify that the thesis entitled "**Emission of Air Pollutants from Coal-Based Thermal Power Plant and their Impacts on Crop Productivity**" submitted to the Post Graduate School, ICAR-Indian Agricultural Research Institute, New Delhi in partial fulfillment of the requirements for the award of the degree of **Doctor of Philosophy in Environmental Sciences** embodies the results of *bona-fide* research work carried out by **Mr. Lal Chand Malav, Roll no. 10444,** under my supervision and guidance, and that no part of the thesis has been submitted by him for any other degree or diploma.

It is further certified that any help or information received during the work on this thesis has been duly acknowledged by him.

Date: 20/12/2018
Place: New Delhi

(Dr. Shakeel A. Khan)
Chairman

Dedicated to My
Beloved Grand
Mother

ACKNOWLEDGEMENT

First and above all, I would like to praise God, the almighty for providing me this opportunity and granting me the capability to proceed successfully. This thesis appears in its current form due to the guidance and assistance of several people. Therefore, I would like to extend my sincere thanks to all of them who helped me a lot during my research.

Fervently and modestly, I admire the genuine cooperation, inspiration and affection offered to me by my Chairman, Dr. Shakeel A. Khan, Senior Scientist, Centre for Environment Science and Climate Resilient Agriculture, for his highly esteemed and enthusiastic guidance, sound counseling, meticulous suggestions, enduring encouragement and peerless criticism during the course of investigation and preparation of the manuscript, which led this work to its successful completion and shall remain a lifelong gifted memory for me. It was indeed a rare privilege for me to work under his supervision. My gratitude is again to my chairman sir.

It is a great privilege for me to express my esteem and profound sense of gratitude to my Co-chairman, Dr. Navindu Gupta, Principal Scientist Center for Environment Science and Climate Resilient Agriculture, for taking keen interest in my research and for his constant encouragement and valuable suggestions during the course of my research work.

I feel immense pleasure to convey my heartfelt thanks to my advisory committee members, Dr. Bhupinder Singh, Principal Scientist, Center for Environment Science and Climate Resilient Agriculture, Dr. Manoj Shrivastava , Senior Scientist, Center for Environment Science and Climate Resilient Agriculture, Dr. V. K. Sehgal, Pricipal Scientist, Division of Agricultural Physics and Dr.

S. L. Meena, Pricipal Scientist, Division of Agronomy and Special thanks to Dr. Shiv Prasad, Principal Scientist, Center for Environment Science and Climate Resilient Agriculture for their encouragement and invaluable suggestions endowed during the course of my research work.

I express my gratitude to Dr. S.D. Singh, Head, Centre for Environment Science and Climate Resilient Agriculture for providing me the necessary facilities, for his valuable cooperation and help during the course of my studies as well as research work.

I take this opportunity to express my thankfulness to Dr. S. Naresh Kumar Professor, Centre for Environment Science and Climate Resilient Agriculture for his useful suggestions and endless help from time to time during the course of this investigation.

I express my special thanks to Mr. Sandeep Kumar (Mere guru), Scientist, Centre for Environment Science and Climate Resilient Agriculture, Mahesh Kumar Malav (Bhai), Sudha Kannojiya, Sushil Kumar Kharia, my batchmates and Priya Choudhary, Senior Research Fellow, Centre for Environment Science and Climate Resilient Agriculture for their help during my research work.

I convey my heartiest thanks to all the staff of Centre for Environment Science and Climate Resilient Agriculture for their support and valuable help during the entire span of study.

It gives me immense pleasure to mention names of my batch mates Amita, Aniket, Varun, whose help and collective efforts have been reflected in the completion of this venture. The unceasing affection and support of seniors, Deepak Sir, Rachana mam, Ram sir, Sheetal mam, Fayaz sir, Gulshan sir, Sweta mam, *Lakra mam would be in my memory for all the time. I extend my heartfelt thanks to my juniors like munmi, Ram Kumar, Ranjeet, Pawan, Soumen, Jayanta, Chandrashekhar, Ravi Yogendra, Alesh, Anjali, Anurag, Debabrata, Prakash, Chandra Prakash, Partho, Jeetu, Meenu and Prakash, Brijesh, Anil, Dinesh for their help and support.*

I shall ever remained indebted and affectionately cherish the blessings and good wishes of my beloved Papa, Mummy, Uncle, Aunty, Tauji, Sunil bhaiya, Bhab, Dheeraj, Lakshita, Chirag, Jaya, Urvashi, Himanshu, Krishana and all my relatives who bestowed on me from miles apart, who were the constant sources of inspiration to me.

I express my special thanks to Surbhi Malav (Wife) for her love and support.

I express my heartiest thanks to my lifelong Seniors and friend Satyavan sir, Rajkumar Sir, Anil Sir, Shivani mam, Jairam Sir, Abhishek Sir, Vishal Sir, Soni Sir, Gopal sir, Pavan, Ravi, and all the members of Dhuliya group for giving me inspiration and kick me for continuous efforts to achieve my goals with their endless support and love.

My sincere thanks to the Dean and Director of Indian Agricultural Research Institute, New Delhi. Finally, the financial assistance provided by the UGC-JRF in the form of Fellowship during the tenure is gratefully acknowledged.

Date: 20/12/2018

(Lal Chand Malav)

Place: New Delhi-110012

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List of Abbreviations

TPP – Thermal Power Plant
NTPC – National Thermal Power Corporation
SPM – Suspended Particulate Matter
GPDM – Gaussian Plume Dispersion Model
CESCRA – Centre for Environment Science and Climate Resilient Agriculture
IARI – Indian Agricultural Research Institute
CPCB – Central Pollution Control Board
$\mu g/m^3$ – Microgram per meter cube
mg/m^2 – Milli gram per meter square
IRGA – Infrared Gas Analyzer
RLWC – Relative Leaf Water Content
APTI – Air Pollution Tolerance Index
FW - Fresh Weight
DW – Dry Weight
PM_{10} – Particulate matter of size 2.5 to 10 μm
ADR – Aerial Deposition Rate
Pn – Photosynthetic Rate
E – Transpiration Rate
gs – Stomatal Conductance
LAI – Leaf Area Index
VP – Vegetative Phase
FS – Flowering Stage

1. INTRODUCTION

Urbanisation, rapid industrialization and population explosion are the root cause for taking a toll on the environmental sustainability. The air pollution is world's deadliest environmental problem. As per World Health Organization (WHO) estimates around 7 million premature deaths resulted from air pollution, more than double previous estimates in 2012. According to WHO, outdoor air pollution caused 3.7 million premature deaths in 2012. Air pollution is responsible for about 4.3 million premature deaths per annum (WHO, 2015). The 2014 UNEP Year Book noted that in 2010 the cost of air pollution to society was estimated at US$1.4 trillion in China and an additional US$0.5 trillion in India (UNEP, 2014). Air pollution is a sum total of pollutants that freely exist in the air, and on coming in contact with the human beings and plants, can cause harmful effects (Sharma et al., 2018). More than 100 pollutants which pollute air have been identified. They may be in the form of solids, liquids or gases. The air pollutants currently considered to be most important in causing direct damage to vegetation are sulphur dioxide (SO_2), oxides of nitrogen (NO_x), ozone (O_3) and suspended particulate matter (SPM). The atmospheric particulate matter is one of the criteria pollutants and the most important regarding phytotoxicity. Urban and peri-urban air pollution is one of the important environmental concerns throughout the world. Atmospheric particulates and gaseous pollutants, pose severe health effects both for humans and plants species (Gupta and Kulshrestha, 2016; Maatoug, 2010).

The major sources of particulate matter (PM) pollution include suspension of soil, agriculture-related activities, road dust, vehicular exhaust, power plants, construction activities, brick kilns and cement factories, etc. (Gupta et al., 2016; Karanasiou et al., 2014; Upadhyay et al., 2015). In addition, transboundary and long-range transport also contributes a significant amount of atmospheric dust in the south Asian region (Begum et al., 2011). Dust particles contribute a major part of air pollutants arising due to industrial processes and pose serious threat to the ecosystem. In India, 30-35% of air pollutants comprises of particulate matter. Coal mining, quarrying, stone crushing, thermal power plants, cement industries, etc. activities add huge quantities of particulate matter to the environment. The current scenario of large-scale deforestation; destruction of biota and other ecosystem components are being attributed to be the effect of particulate matter pollution (Sett et al., 2017). In general, atmospheric aerosols are dominated by crustal components in Indian region mainly because of their origin from re-suspended soil-dust and road dust (Bhaskar and Sharma, 2008; Kulshrestha et al., 1998). Due to this reason, ambient levels of suspended particulate matter have often been reported violating the

National Ambient Air Quality Standards (NAAQS) limits (CPCB, 2012; Kulshrestha and Sharma, 2014; Sharma and Kulshrestha, 2015; Kulshrestha et al., 1995).

Table 1.1: Sources of air pollutants

Air pollutants	Anthropogenic sources	Natural sources
Sulphur dioxide (SO_2)	Fuel combustion in stationary sources industrial process emissions; metal and petroleum refining	Atmospheric oxidation of organic sulphides
Nitrogen dioxide (NO_2)	Combustion	Volcano, ocean and forest
Particulate matter	Transportation, Stationary fuel combustion, Industrial processes, Solid waste disposal	Volcano, ocean, forest and shrub fires, Sea salt aerosol, dust pollen, spores, microorganisms, methane, nitrogen dioxide, hydrogen sulphide, nitrates (Schelle-Kreis et al., 2007)
Ozone (O_3)	No primary source for O_3. It is formed by reactions between hydrocarbons and oxides of nitrogen in the presence of sunlight	Natural tropospheric chemistry and transport from stratosphere to the troposphere

Coal-fired power comes with significant costs to the environment and human beings. The runoff from coal washeries carries pollution loads of heavy metals that contaminate groundwater, rivers, and lakes - thus affecting aquatic flora and fauna. Fly-ash residue and pollutants settle on soil and infect the areas and are especially affects the agricultural activities and production. Most importantly for human and plant health, combustion of coal releases emissions of SO_2, NO_x, PM, CO, volatile organic matter, and various trace metals like mercury, into the air through stacks that can disperse this pollution over large areas.

1.1 Basic Processes of Coal Combustion

Coal is an organic fuel. Organic content of coal is pyrolyzed by the heating process, and due to pyrolysis, volatile matter is then evolved out. The remaining mixture of carbon and mineral matter is known as“char.” The combustion of coal is the combustion of carbon as well as the volatile matter. Basic combustion process of coal involves three basic stages: (1) The release of the volatile matter resulting from pyrolysis (2) The burning of the released volatile matter and (3) The burning of the remaining char. Depending upon specific combustion conditions, the burning process of volatile matter and coal char may take place simultaneously, sequentially, or with some overlapping (Shen and Xianglin, 2009).

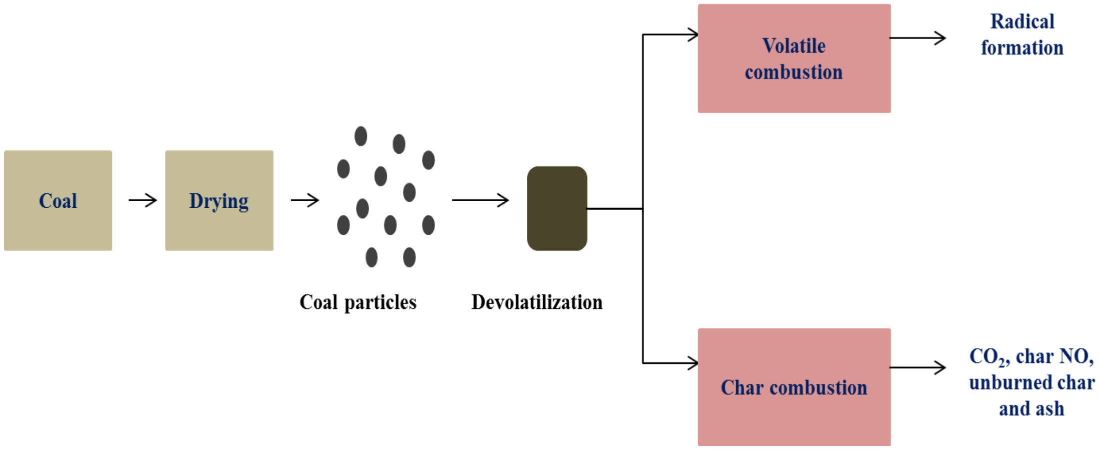

Figure 1.1: Basic Processes of Coal Combustion

1.2 Modes of particulate matter deposition

Deposition of PM is the process by which the aerosol particles are deposited on various surfaces, which results in decreased concentration of particles in the air. According to McDonald et al., (2007), plants play a vital role in filtering ambient air through leaf surfaces. Trees with more leaf area are considered the most efficient type of vegetation for particle collection. Leaves of rough and broad surfaces area are more efficient in capturing PM than those with smooth surfaces (Beckett et al. 2000; Gupta et al., 2015 a,b,c). The rate of particle deposition on the vegetative surfaces depends on dust properties, characteristic of the location of plant and nature of receiving material (Grantz et al., 2003; Chen et al., 2015). It also may be associated with the reduction in sunlight required for the photosynthesis and an increase in the leaf temperature due to changed optical properties of the leaf surface. The exchange of energy through the leaves is highly influenced by particulate matter load, size, and colour as compared to gasses (Rahul and Jain, 2014).

The deposition of atmospheric particulate matter on crop surface has three major routes: (1) Dry deposition, (2) Wet deposition, and (3) Occult deposition (Grant et al., 2003).

1.2.1 Dry deposition

Generally, dry deposition of air pollutants takes place through diffusion, Brownian movement, and impaction processes (Finlayson-Pitts and Pits, 1986; Gupta et al., 2016). It is the Gravitational sedimentation of particles during periods without precipitation. It is a much slower process in comparison to wet or occult deposition, but it continuously affects all exposed leaf surfaces (Hicks, 1986).

1.2.2 Wet deposition

Wet deposition is due to the incorporation of air pollutants into cloud droplets by nucleation process, and their subsequent precipitation. It may be due to below-cloud scavenging of gases and particulates by impaction process as raindrops or snowflakes fall (Lovett, 1994).

1.2.3 Occult deposition

It is a combination of different factors of both dry and wet deposition. Occult deposition occurs by impaction and gravitational settling and impaction processes, governed by instantaneous particle size. This type of deposition may be significant at higher elevation and near the base of orographic clouds.

1.3 Pathways of pollutants uptake by plants

The most susceptible plant part to injury is the leaves due to the abundance of stomata which is the route for pollutants to the leaves (Heath et al., 2009).

The response of stomata to air pollutants is varying and varies with the crop species. Concentration of pollutants, the age of the crop plants and environmental factors are the other factors, which affects the plant response to air pollution (Saxena and Kulshrestha., 2016; Abeyratne and Illeperuma, 2006). The deposition of PM on soils can cause alteration of the nutrient content of the soil in the vicinity of the plant. This changes the soil conditions and hence leads to an indirect effect of PM pollutants on vegetation and plants (Levitt, 1972). Most of the plants use inorganic minerals for nutrition. Nutrient uptake for plants is influenced by soil pH along with other factors. Acidification of soils also results in the loss of essential cations from soils, including calcium, magnesium, and potassium (Ca^{2+}, Mg^{2+}, K^{+}) (Bailey et al., 2005).

In the last three decades, however, changes in the pattern of air pollutant emissions, including increases in those from motor vehicles and Thermal Power Plants (TPP), have led to higher pollutant impacts in more remote rural areas. In developing countries, most of the emphasis has given to air pollution impacts on human health aspects. However, air pollution in urban and peri-urban regions could also have significant implications for agricultural productivity. There are a large number of industries that are polluting the surrounding environment and having potential effects on the health of living beings. Currently, coal-fired TPP contributes a significant portion of electricity generation of the country. At present, the primary source of energy in India is coal and near about 62 % of electric power is generated through this natural resource. This situation will persist for several decades until alternative sources of energy like renewable energy are developed and used on a commercial level (Ram et al., 2007). Several types of research of many authors from different countries from have shown the major environmental and socioeconomic impact of coal-based thermal power plants with its surroundings (Alastuey et al., 1999; Sharma et al., 2005; Xie et al., 2006). The primary emissions from coal based TPPs are particulate matter (fly ash), sulphur oxides, nitrogen oxides, carbon dioxide and other trace gas species.

Air pollution has become severe environmental stress to crops due to increasing industrialization and urbanization during last few decades. Air pollutants have the potential to reduce both nutritional quality and productivity of crop plants (Jager et al., 1993; Ashmore and Marshall, 1999). Air pollutants like sulphur dioxide, nitrogen dioxide, SPM and ozone have significant threat to crop production. These gasious pollutants and particulates could have increasing adverse impacts on the livelihoods of farmers and consumers through affecting the agricultural crop production (Marshall et al., 2001; Te Lintelo et al., 2002). The particulates and gaseous pollutants, alone and in combination, can cause serious setbacks to the overall growth, physiology, and biochemistry of crop plants (Ashenden and Williams, 1980; Mejstrik, 1980; Anda, 1986).

Although industrial agriculture has successfully fed the world and achieved sustained food surpluses, over-dependence on fossil fuels and intensification have also caused extensive environmental damages. One of the most notable environmental issues is the air pollution. Air pollution in turn could damage agricultural production, and shift the equilibrium of food markets. Meanwhile, atmospheric pollution might be adverse to agricultural production in turn. For instance, the toxic air pollutants, such as sulfates, nitrates, particulates, and heavy metals can accumulate and concentrate in the food chain by diffusion, settling, and precipitation, and consequently harm plants and animals. Global warming, caused by the GHG emissions, is changing the distribution and behavior of species, which would influence agricultural productivity in the long-term (Chen et al., 2015). Besides, the health effects caused by air pollution would reduce worker productivity and thereby threaten food supply indirectly (Sun et al. 2017).

A considerable amount of damage caused to vegetation by the air pollutants showing the bodily harm of leaves as a result of dust deposition, inhibition of photosynthetic activities and protein synthesis as well as susceptibility to injuries caused by microorganisms and insects (Saha and Padhy, 2011). Dust deposition effects on crop plants may be related with the decrease in sunlight available for photosynthesis. It may increase the leaf temperature, and also interference with the gaseous diffusion through leaves (Prajapati et al., 2012). Hence, particulate matter deposition on foliar surfaces of the crop plants has significant impacts on the gaseous exchange and growth (Sharifi et al., 1997). The rate of transfer of air pollutants from the air to leaves surfaces varies greatly with its properties, and environmental conditions (Grantz et al., 2003). Of all plant parts, the leaf is the most sensitive part to the PM deposition and several other such external factors (Lalman and Singh, 1990). Plants provide an enormous leaf area for impingement, absorption, and accumulation of air pollutants to reduce their level in the air environment (Shannigrahi et al., 2004).

Plants have different responses like sensitive, tolerant and hardy towards the air pollution. Life cycle and interaction of plants with the environment also depends on this nature (Tripathi and Dwivedi, 2002). Therefore, categorization of the plants by their susceptibility whether sensitive or tolerant, air pollution tolerance index (APTI) established. APTI is calculated using four biochemical parameters like ascorbic acid content, chlorophyll content, leaf extract pH and relative water content of leaves (Singh and Rao, 1983; Liu and Ding, 2008). APTI is an inherent quality of plants to encounter air pollution stress which is present of prime concern (Rai et al., 2013). Air pollution affects not only growth, physiological and biochemical parameters of the crop plants but also it has some drastic impacts on biological and socioeconomic characteristics. That’s why to an overall reduction in effects of air pollutants on crops, anticipated performance index (API) was developed. APTI includes only biochemical parameters, whereas API comprises socioeconomic and biological parameters (Govindaraju et al., 2012). Plants are affected by a lot of stresses during its life cycle. So with the help of single character, we can’t justify that, whether a plant is sensitive or tolerant to that particular stress like air pollution. Therefore four biochemical parameters (ascorbic acid content, chlorophyll content, leaf extract pH and relative water content) are necessary to build up APTI (Raza et al., l985; Dwivedi, 2008). Crops with higher index value are tolerant to air pollution, whereas lower value shows that plants are sensitive. Hence, tolerant crops could be suggested to the farmers to get better yield and production than susceptible crops in the polluted areas. Sensitive plants can be used as indicators of pollution (Krishnaveni et al., 2013). During research on APTI, researchers mainly focus only on trees species, but air pollution severely affects the crops also. It is necessary to focus on the crops about air pollution because crops are the central pillar to maintain the food security and sustainability of the ecosystem.

Air pollutant can cause a series of adverse effects on crops productivity hence it was crucial to assess the impacts of TPP on the surrounding agriculture. Increasing urban and peri-urban air pollution requires a need of comprehensive monitoring of air quality. It is not always feasible to monitor the concentrations of pollutants at various sites of a particular area due to high cost and the experimental difficulties involved, so air pollution dispersion modeling is a better option. An easy and an inexpensive estimation can be performed through dispersion modelling.

Pollutants enter the atmosphere in a number of different ways. For example, the wind blows dust into the air. Automobiles, trucks, and buses emit pollutants from engine exhausts and during refueling. One method of pollution release from stationary point sources has received more attention than any other: stacks of the thermal power plant. As the exhaust gases and pollutants leave a stack, they mix with ambient air describing a plume (Mahanta et al., 2013; Rodriguez et al., 2013). As the plume travels downwind, the plume diameter grows, and it progressively spreads and disperses. After this initial stage, the dispersion of pollutants in the atmosphere is the result of the following three mechanisms: 1) general air motion that transports pollutants downwind, 2) turbulent velocity fluctuations that disperse pollutants in all directions and 3) diffusion due to concentration gradients. The stability of the air (vertical air movement) together with the horizontal air flow influences the behavior of plumes from stacks. Thus, watching smoke plumes provides a clue to the turbulence of the atmosphere, and knowing the stability yields important information about the dispersion of pollutants. Air quality modeling is the necessary substitute for ubiquitous air quality monitoring, which is impossible. It is also necessary for predicting the impacts from potential emitters, simulation of ambient concentrations under different policy options, determining the relative contributions from different sources. Air quality models (AQM) are tools to research the relations between the emission of pollutants and precursors and the ambient air concentration (Stockie, 2011; Behrens, 2007).

The present research focuses on quantification of the air pollutant from TPP and its impacts on crop productivity and information about the safe distance of thermal power plant to the agricultural productivity. Keeping these views in mind, the present research work entitled **"Emission of air pollutants from coal-based thermal power plant and their impacts on crop productivity"** was undertaken with the following objectives:-

1. To quantify and characterize the air pollution load at selected sites on the basis of plume dispersion.
2. To assess the impact of air pollution on crop growth and productivity.
3. To calibrate and validate the air pollution dispersion model for the coal-based thermal power plant.

2.REVIEW OF LITERATURE

With the dawn of industrialization and urbanization air pollution has become an important issue on account of rapid population growth and ever-expanding human activities (Karki et al., 2005; Angel and Rock, 2009). In literature, there is mounting evidence to show that air pollution has a widespread subtle effect on plants and animals including human beings (Jayanthi and Krishnamoorthy, 2006). The World Health Organization (WHO) defines air pollution as "Air is polluted when one or several pollutants are present in the atmosphere at such a concentration and for such long time that they are harmful to man, animals, plants or material property, cause harm or reduce well-being or disturb its application appreciably". Lacks of implementation of environmental rules and regulations are contributing to the poor air quality of the Indian cities (CPCB, 2009). Air pollution generated in any airshed are not entirely confined, it is also spread, hence do not remain only a problem of urban areas but affect the periurban and rural areas supporting vast productive agricultural land. The transboundary nature of pollutants was evident when remote areas also showed a higher level of air pollutants. Growing Industrial and transport sectors has led to the increase in levels of particulates and gaseous pollutants (Rizzo and Scheff, 2007). Urban air pollution has a direct effect on peri-urban agriculture due to the dispersion of air pollutants along the wind direction. Primary pollutants are converted into the secondary pollutants by a variety of reactions, causing a more significant adverse effect in peri-urban areas. Level of phytotoxic air pollutants concentration often exceed the threshold limits in Indian cities (Kulshrestha and Sharma, 2014; Trivedi et al., 2003).

The air pollution level is rapidly increasing in urban and peri-urban areas in many megacities of the developing countries (UNEP, 1999). In India, air pollution has proliferated due to populations, high numbers of vehicles, use of technologies and fuels with poor environmental efficiency, and ineffective environmental regulations. As a result, agricultural land nearby to urban centers is facing air pollution level of urban origin. In India unplanned, unstructured and haphazard growth of industry intermingled with urbanization greatly exacerbating the problem of air pollution. Air pollution monitoring is carried out by Central Pollution Control Board (CPCB) under National Air Quality Monitoring Programme (NAMP) at 503 stations located in 209 cities, 26 states and five Union Territories in India (CPCB, 2011). NAMP carry out regular monitoring of sulphur dioxide (SO_2), oxides of nitrogen (NOx), particulate matter (PM) at different urban sites.

2.1 Types of air pollutants

There are basically two types of air pollutants: primary and secondary pollutants.

2.1.1 Primary pollutants

Pollutants released directly into the atmosphere in a harmful form.

Examples: CO, SO_2, NO), Particulate material (soot, ash), Toxic metals (lead, mercury), Volatile organic compounds (VOCs) etc.

2.1.2 Secondary pollutants

Chemicals released into the air that become hazardous after reacting with substances in the air. Examples: (H_2SO_4, HNO_3), Photochemical oxidants (Ozone, NO_2). (Murphy et al., 2005)

2.2 Sources of air pollutants

2.2.1 Major Sources

2.2.1.1 Transportation-Combustion Sources

There are so many types of transportation sources and motor vehicles are most crucial.. They produce different pollutants including CO, CO_2, hydrocarbons, NOx, lead (Pb) particulates and even small amounts of sulphur oxides. Additionally, the pollutants from transportation sector may react in the atmosphere to form new and even more toxic and reactive pollutants like photochemical smog. Diesel vehicles are more economical but these are also a source of hazardous hydrocarbons and carcinogenic polycyclic aromatic hydrocarbons (PAH's) (Gorham et al., 2002).

2.2.1.2 Solvent Evaporation

Paints, spills, pipelines breakage and leakage between pipes joints are sources of solvent evaporation.

2.2.1.3 Emissions from stacks

The discharge of flue gases and smokes to the atmosphere are usually through smokestack. A backyard incinerator or small industry could also be source of as a stack emission to the atmosphere (Harrison, 2012). There are so many pollutants; those are vented to the atmosphere through stack emission. Plume dispersion is the sign of this type of emission. The plume is a mixture of concentrated emissions that slowly become diluted into the atmosphere.

2.2.1.4 Fugitive Emissions and Other Sources

Fugitive emissions are escape from a process rather than being discharged into the atmosphere. There is no provision of monitoring of this fugitive emission, that's why it may be serious issues. If they entered into the atmosphere, remains untreated. There are many sources of fugitive emissions like fluorides from aluminum smelters, dry cleaning, agriculture and natural sources like volcanoes and forest fires (Chen et al., 2017).

2.2.2 Sulphur dioxide (SO_2)

The main anthropogenic source of SO_2 is from the combustion of sulphur containing fossil fuels. Coal (poor quality, high sulphur content brown coal or lignite) and fuel oil are the measure source for SO_2 pollution as compared to low sulphur containing fuels like natural gas, petrol and diesel (Reddy et al., 2002). In general, combustion of coal in thermal power plants is the most critical source of SO_2 emissions. Concentrations of SO_2 gas tend to be directly related to the extent of local emissions, and the height of emissions because SO_2 is a primary pollutant.

2.2.3 Nitrogen oxides (NO_x)

Nitrogen dioxides is mainly a secondary pollutant formed primarily to the reaction between emissions of the primary pollutant nitric oxide (NO) and secondary pollutant like ozone. Rapid conversion of NO to NO_2 is also another reason behind the atmospheric level of NOx (Clapp and Jenkin, 2001). The primary source of NOx is combustion of atmospheric nitrogen and oxygen at high temperature (>1400°C).

2.2.4 Ozone (O_3)

O_3 is a secondary pollutant. The concentration of ozone depends upon two different processes in the atmosphere; O_3 may transfer from the stratosphere to the troposphere and combination of photochemical reactions. The latter involves O_3 formation from the recombination of atomic and molecular oxygen via the photolysis of nitrogen dioxide, and also destruct the O_3 by reaction with nitric oxide to reform NO_2. In the atmosphere, degradation of hydrocarbon generates the free radical species that converted NO into NO_2. This process directly increases the concentration of ozone. Level of O_3 is higher at rural and suburban places because at the local scale, ozone-depleted by NO (Ashmore, 2005). The primary sources of NOx have already discussed above. Hydrocarbons are released from so many sources like forest trees (natural source), transportation and use of solvents (anthropogenic sources).

2.2.5 Particulate matter (PM)

Atmospheric PM is microscopic, solid or liquid matter suspended in the Earth's atmosphere. In general, PM is a combination of fine solids such as dirt, soil dust, pollens, ashes, and soot and refers to the aerosol form present in the atmosphere (Thonnessen, 2007). The bulk of PM, about 90% by mass have natural origins. About 10% of the total amount of aerosols present in the atmosphere is released from anthropogenic activities. The abundance of PM varies in both way temporally and spatially, and hence, the impact prediction at regional level is tough. The deposition rate of PM to plant surfaces depends on particle size distribution and atmospheric the chemistry both. The deposition rate of PM to plant surfaces depends on particle size distribution and atmospheric the chemistry both. However, chemical characteristics of PM play a significant role in the impact of PM on plants. Particulate matter with aerodynamic diameter < 10 µm diameter (PM10) and < 2.5 µm diameter (PM2.5) are of high significance to public health due to the presence of heavy metals and PAHs (Prajapati and Tripathi, 2008a-c; NEPC, 1998). PM is present everywhere, but high concentrations and specific types of particles present in atmosphere pose a serious threat to ecosystems (Vincent and Clement, 2000; See et al., 2006). Apart from the local effects, these pollutants travel a long distance and cause harmful impacts far from its source (Agarwal, 2005).

2.3 Basic processes about air pollution

There are four types of processes in relation to the air pollution

2.3.1 Emissions

A range of sources emits pollutants into the atmosphere. Anthropogenic sources include human activities, such as burning fossil fuel whereas natural sources like desert dust, volcanoes, functions of biological organisms, such as the microbial breakdown of organic materials.

2.3.2 Chemistry

Chemical reactions play a significant role to create, modify, and destroy chemical pollutants.

2.3.3 Transport

Air pollutants are dispersed on the basis of wind speed and wind direction. So that emission at one place may have several impacts far away from the origin.

Long-range transport creates the so many problems for society and policymakers because it is difficult to determine who should bear the costs of reducing pollution in case of long-range transport.

2.3.4 Deposition

There is a lot of direct and indirect process; those help to settle down of the air pollutants. Pollutants are absorbed directly, or sometimes it is taken up by chemical reactions in the atmosphere. Rain, fog, and snow also remove the pollutants from the environment (Hirota et al., 2017).

2.4 Role of thermal power plants in air pollution

India is the 4th largest consumer of electricity in the world, with coal as the primary fuel of choice for power generation and this will only get larger in the coming years. Most of the existing coal-fired TPPs are based on conventional pulverized coal or fluidized bed combustion technology. Some newer projects plan to use supercritical- and ultra- steam conditions, which offer better performance ratios (Deb et al., 2015).

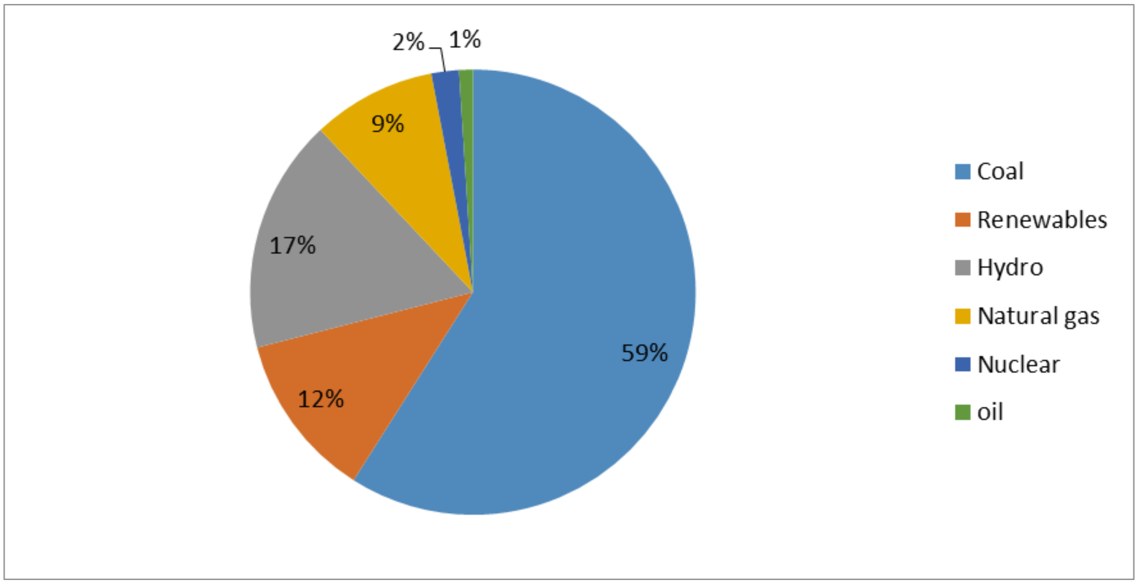

Figure 2.1: Sources of electricity in India based on the installed capacity in 2013 (Source: Central Electrical Authority, 2013)

Coal-fired power comes with significant costs to the environment and human beings. The runoff from coal washeries carries pollution loads of heavy metals that contaminate groundwater, rivers, and lakes - thus affecting aquatic flora and fauna. Fly-ash residue and pollutants settle on soil and infect the areas and are especially affects the agricultural activities and production. Most importantly for human health, combustion of coal releases emissions of SO2, NO_x, PM, CO, volatile organic matter, and various trace metals like mercury, into the air through stacks that can disperse this pollution over large areas.

More than 51% of India's commercial energy demand is met through the country's vast coal reserves. Public sector undertaking National Thermal Power Corporation and several other state-level power generating companies are engaged in operating coal-based thermal power plants.

Table 2.1: Estimated energy consumption and emissions for the coal-fired TPPs operational in 2014

State	GW	Coal (Mt)	SO_2 (kt)	NO_x (kt)	CO (kt)	CO_2 (Mt)
Andhra Pradesh	8.9	35	172	160	129	85
Bihar	6.2	25	120	107	89	59
Chhattisgarh	11.1	46	223	250	166	110
Delhi	0.8	4	17	23	13	9
Gujarat	15.9	63	309	275	231	152
Haryana	6.0	25	124	165	92	61
Jharkhand	6.2	27	129	172	97	64
Karnataka	5.5	23	93	151	85	56
Madhya Pradesh	12.4	51	250	281	186	123
Maharashtra	21.3	87	373	449	316	209
Odisha	11.0	47	229	305	171	113
Punjab	4.7	20	95	117	71	47
Rajasthan	7.4	30	148	167	111	73
Tamilnadu	9.1	39	189	252	141	93
Telangana	5.3	22	110	146	82	54
Uttar Pradesh	15.3	65	317	423	237	156
West Bengal	11.9	51	247	330	185	122
Grad Grand Total	159.1	660	3,147	3,774	2,402	1,584

(CEA, 2014)

Table 2.2: Estimated energy consumption and emissions for the coal-fired TPPs operational in 2030

State	GW	Coal (mt)	$PM_{2.5}$ (kt)	SO_2 (kt)	NO_x (kt)	CO (kt)	CO_2 (mt)
Andhra Pradesh	37.1	141	94	687	514	513	338
Assam	1.3	5	3	25	34	19	12
Bihar	30.2	117	83	572	560	427	282
Chhattisgarh	50.1	200	149	973	1,008	726	479
Delhi	0.8	4	12	17	23	13	9
Gujarat	37.7	143	173	699	557	522	344
Haryana	6.6	28	16	135	170	101	67
Jharkhand	29.4	113	93	553	511	412	272
Karnataka	18.9	73	61	319	317	267	176
Kerala	1.3	5	3	23	11	17	11
Madhya Pradesh	34.6	138	87	673	653	502	331
Maharashtra	42.4	171	144	764	860	622	410
Meghalaya	0.8	3	2	15	20	11	7
Odisha	44.3	173	151	682	810	631	416
Punjab	11.0	44	26	217	228	162	107
Rajasthan	14.9	58	101	282	235	210	139
Tamilnadu	26.9	104	92	453	461	379	250
Telangana	10.0	39	35	192	197	143	95
Uttar Pradesh	36.3	143	110	699	715	522	344
West Bengal	23.2	96	82	467	558	349	230
Grand Total	457.9	1,799	1,514	8,447	8,440	6,547	4,318

(CEA, 2014)

Table 2.3: National ambient air quality standards (2009)

Pollutants	Time Weighted Average	Concentration in Ambient Air	
		Industrial, Residential, Rural and other Areas	Ecologically Sensitive Area (Notified by Central Government)
Sulphur Dioxide (SO_2), µg/m^3	Annual	50	20
	24 Hours	80	80
Nitrogen Dioxide (NO_2), µg/m^3	Annual	40	30
	24 Hours	80	80
Particulate Matter or PM_{10}, µg/m^3	Annual	60	60
	24 Hours	100	100
Particulate Matter or $PM_{2.5}$, µg/m^3	Annual	40	40
	24 Hours	60	60
Ozone (O_3) µg/m^3	8 Hours	100	100
	1 Hour	180	180
Lead (Pb) µg/m^3	Annual	0.50	0.50
	24 Hours	1.0	1.0
Carbon Monoxide(CO), mg/m^3	8 Hours	02	02
	1 Hour	04	04
Ammonia (NH_3), µg/m^3	Annual	100	100
	24 Hours	400	400
Benzene (C_6H_6), µg/m^3	Annual	05	05
Benzo(a)Pyrene (BaP) ng/m^3	Annual	01	01
Arsenic (As), ng/m^3	Annual	06	06
Nickel (Ni), ng/m^3	Annual	20	20

Source-CPCB (2012)

2.5 Action mechanism of different air pollutants

2.5.1 Sulphur dioxide (SO_2)

Leaf age, concentration and combination of pollutants affect the entry of SO_2 through the stomata (Pfanz et al., 1987). According to Black and Unsworth, (1980) stomatal conductance was stimulated at low concentration of SO_2 in *Vicia faba* L. at 15 minutes of exposure level. SO_2 enters in the leaves through stomata. After the absorption of SO_2, it converts into acidic form, which creates detrimental effects at cellular level. The absorption of SO_2 generates reactive oxygen species (ROS) within the cellular space, and chemical reactions (Bartosz, 1997) are:

$HSO_3^- + {}^{\cdot}O_2^- + 2H \Longrightarrow HSO_3^-$ (bisulphate radical) + $2^{\cdot}OH$

$HSO_3^- + {}^{\cdot}OH + H^+ \Longrightarrow HSO_3^- + H_2O$

$HSO_3^{\cdot} + O2 \Longrightarrow SO_3^{2-} + O_2 + H^+$

$HSO_3^{\cdot} + {}^{\cdot}OH \Longrightarrow SO_3^{2-} + H_2O$

$2HSO3^{\cdot} \Longrightarrow SO_3^{2-} + HSO_3^- + H^+$

$SO_3 + H_2O \Longrightarrow SO_4^{2-} + 2H^+$

$O_2^{\,-} + {}^{\cdot}O_2^- + 2H^+ \Longrightarrow O_2 + H_2O_2$

${}^{\cdot}OH + {}^{\cdot}OH \Longrightarrow H_2O_2$

SO_3^{2-} and HSO_3^- ions create phytotoxicity in the crop plants (DeKok, 1990). Higher uptake of SO_2 affects the plant growth, physiological and biochemical parameters, which ultimately affects the crop production (Agrawal and Deepak, 2003; Agrawal et al., 2006).

2.5.2 Nitrogen oxides (NO_x)

NO and NO_2 are toxic air pollutants and NO is rapidly oxidises to NO_2 in the atmosphere. Generally, the uptake of nitrogen di oxide by crop plants occurs by leaves. Stomatal opening is the main entry route for oxides of nitrogen (Darrall, 1989). The entry of nitrogen dioxide into crop leaves is similar to sulphur dioxide. NO_2 entres into the leaves also through cutical, but cuticular admission is more in case of NO_2 as compared to SO_2 due to lesser cuticular resistance against NO_2.

$NO_2 + H_2O \Longrightarrow HNO_3$

$NO + H_2O \Longrightarrow HNO_2$

$HNO_3 + HNO_2 \Longrightarrow NO_3^{2-} + NO_2^{2-} + H^+$

2.5.3 Ozone (O_3)

The harmful effects of O_3 on agricultural crops are now well-known. When the level of ozone is severe, the death of plant parts may occur. Impact on cellular level and plant parts affect plant growth, which ultimately leads to yield. The detrimental effects of O_3 occur due to the production of free radicals and other products of chemical reactions. The mechanism of formation of ROS under O_3 exposure are given below:

$O_3 + OH^{\cdot} \Longrightarrow {}^-O_2^{\cdot}$ (superoxide radical)

$^{\cdot}O_2{}^{-} + H^+ \Longrightarrow HO^{\cdot}{}_2$ (peroxy radical)

$^{\cdot}HO'_2 + {}^{\cdot}HO'_2 \Longrightarrow H_2O_2$ (hydrogen peroxide) + O_2

$^{\cdot}O_2^- + {}^{\cdot}HO'_2 + H_2O \Longrightarrow H_2O_2 + OH^- + O_2$

The injury caused in the plasma membrane is mainly due to O_3 and O_3 generated ROS, which results changes in permeability of cell membrane, fluidity, ion exchange (Heath et al., 2009). A change in plasma membrane function leading to a hike in the level of intercellular Ca^{2+} that would alter the cellular metabolism (Heath, 2008).

2.5.4 Particulate matter (PM)

Particulate matter deposition and effects on crop plants also include NO_3^- and SO_4^{-2} and their acidic deposition may contain trace elements and heavy metals, including lead. PM may affect crop plants directly by foliar deposition or indirectly by changing soil chemistry or chemical reactions or the amount of solar radiation reaching the Earth’s surface. Indirect effects are usually the most significant because they can alter nutrient cycling. Particles transferred from the atmosphere to crop canopy may remain on the leaf surface for longer periods, be taken up through the leaf surface, or be removed from the plant by rainfall, or litter-fall with subsequent transfer to the soil. The majority of studies related with direct effects of PM and trace metals on crop plants has focused on responses of individual plant species and was conducted in the laboratory or in controlled environmental condition (Saunders and Godzik, 1986).

2.6 Plant responses to different air pollutants

In the process of developing standards for the assessment and the regulation of air pollution, the main emphasis has always been on controlling the effects of air pollutants on human health, with all other effects considered as of much lesser importance (Oliva and Mingorance, 2006).

Air pollutants may injure crop plants in different ways. Effects may be subtle, or clearly visible. Visible effects usually involve identifiable changes in the leaf structure such as chlorosis, necrosis and pigment formation. Subtle effects include inhibition of plant growth and reduction in photosynthetic rate. Plant tissue damage may be either acute or chronic. Acute exposures to high levels of pollutants lead to necrosis. Chronic injuries result from intermittent or long-term exposures to lower levels of pollutants, with chlorosis or chlorophyll destruction being the most common symptoms of injury. Different pollutants produce different significant effects on plants, and this can be used as an indicator. These are discussed in the paragraphs below. Air pollution is a widely known problem which can have significant effects on plant health. In this regard, pollutants such as air particulates, ozone, nitrogen oxides, sulphur dioxides have a negative impact on plant physiology and morphology (Saxena and Kulshrestha, 2016). Various studies on exposure assessment of several pollutants were carried out in the developing world (Saxena and Ghosh, 2015; Garg et al., 2015, Saxena and Ghosh, 2013; Agrawal et al., 2003) and it has been recognized that both outdoor and indoor pollutants are associated with acute adverse effects on health of human and plants (Dwivedi et al., 2008; Tripathi et al., 2008).

2.6.1 Sulfur Dioxide and Nitrogen dioxide

Atmospheric sulphur dioxide below 1ppm level is harmful to certain types of plants, causing tissue damage and chlorosis. However, it is due to chemical changes in the atmosphere and cell sap, which produces H_2SO_4, that SO_2 emission has caused their most significant damage. In conjunction with the HNO_3 produced from nitrogen oxide emissions, the phenomenon known as acid rain and destroying agricultural land, forests and increasing acidity levels in lakes by several pH units.

2.6.2 Ozone

Ozone also enters the leaf through the stomata on the lower leaf surface. In dicots, it passes the spongy cells and injures the palisade mesophyll cells preferentially. Due to this, the acute injury symptoms are visible on the upper surface of leaves. Developing leaves ranging from 60-90% of their full size or mature leaves are most sensitive to O_3 injury. The most common O_3-induced symptom observed on dicots is upper surface flecks. These flecks are produced by the killing of palisade tissues, resulting in chlorotic or necrotic lesions.

2.6.3 Particulate Matter

Gupta et al., (2016) reported that particulate matter adversely affects the leaf surface, cuticle and epidermal layers. Dust deposition ruptures stomatal pores. The leaves samples collected from the industrial site showed a more significant impact of particulates on biochemical parameters and surface morphology as compared to the residential site. The average dustfall fluxes on Arjun plant’s leaves were found as 229 ± 12 mg m^{-2} d^{-1} and 95 ± 6 mg m^{-2} d^{-1} at industrial site and resedential site, respectively whereas 271 ± 13 mg m^{-2} d^{-1} and 108 ± 6 mg m^{-2} d^{-1} on Morus foliar at industrial site and resedential site. The concentrations of Chl a, Chl b, total Chl and Carotenoids decreased with an increase in particulate matter deposition.

Mishra et al., (2016) told that at urban background site (JNU), the dust flux was lowest (172 mg/m^2/day) followed by CP, a commercial site, (192 mg/m^2/day) and GB, an industrial/residential area, (302 mg/m^2/day). Deposition of particulate matter on vegetation is affected by the particle size distribution, dimensions, and density of the foliage elements in the dispersion path. PM can cause adverse effects on plants like stomatal clogging, reduced photosynthetic activity, leaf fall and death of tissues (Farooq, et al., 2000; Garg, et al., 2000, Shrivastava and Joshi, 2002). Due to PM deposition many physicalchemical changes take place on aerial parts of plants (Grantz et al., 2003). A major proportion of stomata may cover by PM which reduces the rate of transpiration and rate of evaporative cooling. Leaf chlorosis also caused by dust pollution due to its effect on chlorophyll biosynthesis (Seyyednejad, et al., 2011). Rai et al. (2011) have studied risks on the yield of crops posed by air pollutants their emission patterns, atmospheric transport and leaf uptake including their effects on the plant's biochemical defense capacity. Agrawal et al. (2003) have reported SO_2, NO_2 and ozone and related plant responses measured regarding physiological parameters, chlorophyll, biomass, and yield.

Several authors reported that particulate matter may affect the leaf by destroying its cuticle, hydrolyses the lipid and wax component, and denature protein due to the rising alkalinity on the leaves surface by libration of calcium hydroxide on hydration through cement dust (Guderian, 1986; Darley 1966). Some of the microorganism, fungi, and arthropods residents on the plants play a very important role in decomposition of litterfall (Miller et al., 1982) Apart from direct effects, some of the indirect effects are also responsible for ecosystem response on PM. Indirect plant responses to PM are limited to soil environment (i.e., mineral, organic matter, water, air, verity of bacteria, fungi, protozoan, nematodes, and arthropods), depending on chemical composition of the each element present in PM.

PMs are having a great matter of concern due to its impacts on ecosystem function and great potential significance for human welfare (Prajapati and Tripathi, 2008 a-c; Gupta et al., 2015 a,b,c). Many recent studies observed that the concentrations of PM10 and PM2.5 airborne aerosols show a significant relationship with traffic, coal fired power plants and other combustion-related processes (Prajapati and Tripathi, 2007). Whereas, resuspended road dust, crustal material, and longrange transport events are mainly identified as sources of the coarse particles (Gupta et al., 2015a,b; Vallius et al., 2005). Particle size is one of the factors related to the damaging effect of the PM, Coarse particles settle nearer their site of formation than fine particles. The size of PM correlated significantly with specific leaf area, but Chl a, Chl b, carotenoid and relative water content were inversely related with PM fraction (Chen et al., 2015). PM pollutants may damage the plant's leaves, impair plant growth and limit primary productivity according to the sensitiveness of the plants to pollutants (Ulrich, 1984). Particulate pollutants can cause blockage of stomata on the upper surface of the vegetation and to a smaller extent at the lower surface. According to Krajickova and Mejstrik, (1984), the stomatal diameters of the most plants range from 8 to 12 μm. Therefore, size of PM is an important criterion for a possible penetration of PM to the leaves. Direct effects include visible and invisible injury. The direct effects of PM deposition on vegetation became apparent only at relatively high surface loads, i.e., >7g/ m^2. Invisible injury results from pollutant impacts on plant physiological or biochemical processes and can lead to significant reduction in growth or yield and changes in nutritional quality (Ashenden and Williams, 1980; Mejstrik, 1980). Nanos and Ilias, (2007) report that cement PM deposition decreased leaf total chlorophyll content and chlorophyll a/b ratio. As a result, photosynthetic rate and yield decreased. Particulate deposition reduces growth, yield, flowering, and reproduction of plants (Saunders and Godzik, 1986).

2.6.4 Visible symptoms

Air pollution can produce a wide range of visible symptoms (acute injury) on crops. Injury to plants as a result of pollutants has been classified as either chronic or acute. An acute SO_2 means higher SO_2 concentration for short duration. Acute SO_2 injury symptoms consist of chlorosis and necrosis on leaves at the full maturity stage. Chronic exposure may be reduced the crop growth and yield without showing any visible symptoms (Legge and Krupa, 2002).

Whenever air pollutants concentrations (SO_2 and NO_2) go to higher than the threshold, plants show the visible injury. However, in case of ozone, acute visible symptoms can be showed on sensitive plant species only, when concentration of ozone is increased by twice as compared to the ambient level of ozone. Thus, SO_2 and NO_2 visible injury are mostly confined to the agricultural field, which is severely polluted. Acute injury by the action of air pollutants show several effects like necrotic lesions from small to large patches of dead tissue and white to brown-black in colour (Tayloo et al., 1987).

2.7 Effect of air pollution on crop growth and productivity

Lee, (1999) also reported similar types of results, that the air pollution led losses of $ 4.0 to 5.0 billion due to a reduction in major crop plants. According to Wahid et al., (1995), grain yield reductions of 46 and 38% in winter wheat through open-top chamber (OTC) had recorded in the vicinity of Lahore, Pakistan. Maggs et al., (1995) have further reported that yield of wheat and rice crop was reduced at annual mean nitrogen dioxide concentration of 20-25 ppb.

In an OTC study conducted at the suburban site in Varanasi, Rai et al., (2007) reported that reduction of 20.7% in yield of wheat variety M 234 grown at ambient air pollution level (SO_2- 7.8 ppb, NO_2- 40.6 ppb, O_3- 42.1 ppb). At a rural site in Varanasi, experiencing low concentrations of SO_2 7.3 ppb and NO_2 14.5 ppb and high concentration of O_3 (35 ppb) found 10 and 14% reduction in yield of rice varieties NDR 97 and Saurabh 950 grown at ambient air (Rai and Agrawal, 2008). Chauhan and Joshi (2010) reported the effect of air pollutants on mustard and wheat. The result showed that site 3 received higher load of pollutants (SO2 6.5 ppb and NO2 9 ppb) as compared to other selected sites, showed maximum reductions in growth and yield.

Photosynthesis, a core function in the physiology of plants is most susceptible to O3. Reductions in photosynthesis have been widely reported under ambient field conditions at higher concentrations of O3 (Rai et al., 2007; Tiwari et al., 2006, Calatayud et al., 2002; Agrawal et al., 2003). Meta-analytical analyses on several varieties of wheat (Feng et al., 2008), rice (Ainsworth, 2008) and soybean (Morgan et al., 2003, 2006) also found varying degrees of response of photosynthesis to O_3. O_3 caused a reduction in the level of RNA transcript and also reduced the expression of photosynthetic genes including Rubisco and Rubisco activase. O3 leads to reductions in m RNA levels of both small (RBCs) and large (rbcL) subunits of Rubisco of wheat varieties M 510 and Sonalika (Sarkar et al., 2010) grown in open-top chambers receiving ambient+ 10 ppb and ambient+ 20 ppb O_3. In a proteomic analysis conducted in- vivo condition on rice seedlings exposed to O_3 (40, 80, 120 ppb for six h/d for 9 d), reduction in expression of Rubisco large subunit (LSU) and small subunit was reported (Feng et al., 2008). Reductions in photosynthesis affect carbon assimilation, translocation and accumulation in different plant parts. A study in Europe indicated that over 30 crop species growing in commercial fields in 16 countries showed visible ozone injury symptoms and other negative effects of ozone such as biomass/yield reduction during the period 1990 to 2006 (Hayes et al., 2007, Mills et al., 2011b).

2.8 Air Pollution Modeling

The fast growth of energy sector will result in polluting the environment. Both the major sources of energy, i.e. coal based (or sometimes natural gas based) thermal energy and hydel power have associated environmental problems. Or in other words, all energy producing technologies (except renewable) pollute the environment. In the thermal power plants, the environmental related problems start with the transportation of coal from the mine, feeding it to the boiler, emission from the plants namely particulate matter, gaseous pollutants (SOx, and NOx) and thermal pollution to the cooling water/air. So management of pollutants and control technologies has to be developed side by side to save the environment.

2.8.1 Atmospheric dispersion model

A model is a simplified representation of the real situation. It doesn’t contain all the features of the real system but includes the features of interest for the management issue or scientific problem we wish to solve by its use. Models are widely used in science to make predictions and to solve problems and are often used to identify the best options for the management and regulate the specific environmental issues.

Models may be:

- Physical − a scaled-down representation of reality
- Mathematical – a description of any system using mathematical relationships and equations.

An atmospheric dispersion model is a mathematical simulation of the physical and chemical processes governing the transport, dispersion and transformation of pollutants in the atmosphere. It is also predicted the downwind air pollution concentrations given information about the pollutant emissions and nature of the atmosphere. Most modern air pollution models are computer-based programs that calculate the pollutant concentration downwind of a source using information on the: pollutant emission rate ,characteristics of the emission source, local topography, meteorology of the area and ambient or background concentrations of pollutant.

2.8.2 Gaussian-plume models

Gaussian-plume models are most widely used, easily understood, easy to apply, and until more recently have received international approval. Even today, from a management and regulatory point of view ease of application and consistency between applications, is essential. Also, the assumptions, uncertainties and errors of these models are well understood, although they still suffer from misuse. Gaussian-plume models play a significant role in the regulation field.

The Gaussian-plume formula is derived assuming ‘steady-state’ conditions. The Gaussian-plume dispersion model formulae do not depend on time, although they do represent an ensemble time average. The meteorological conditions for the study area are assumed to remain constant during the dispersion, which is effectively instantaneous. Due to this simple mathematical derivation, it is common to refer to Gaussian-plume models as steady-state dispersion models.

2.8.4 Data requirements

Although plume models do not require large meteorological data, the meteorology is a crucial component, and good-quality data are essential, ideally from a monitoring site within the area of interest. This is not prohibitively expensive and is far preferable to using data from a more distant site.

2.8.5 Case studies of GPDM

Kumat et al., (2014) simulated the dispersion pattern of sulphur dioxide (SO_2) pollution in a city (Dadri) downwind of a large Thermal Power Plant based on data collected from a Power Plant. The pollution rose summarised 8 - hourly SO_2 concentrations at the Dadri Thermal Power Plant. This study concluded that pollution rose based on data collected from Thermal Power Plant can be used to investigate contributions from source to air pollution in the study area. Results showed that the maximum concentration in February is 94 µg/m^3.

According to Naik, (1991), the concentration of SO_2 is computed at a distance of every 500 m in 16 directions up to the city limit. The air quality as moderate to severe is estimated in downwind distances under unfavourable meteorological conditions. The probable zones of high concentrations of SO_2 over the residential, commercial and industrial area are below the ambient air quality standards almost throughout the year. However, in April and October, the zone of high concentration (500 µg/m^3) exceeds the EPA standard. Also, under the most unfavourable meteorological conditions, the estimated high ground-level concentration of sulphur dioxide can reach up to 1000 µg/ m^3 at a distance of 1.25 km from the thermal power plant. This may be due to the effect of fumigation process.

Awasthi et al., (2006) reported that GPDM applicable for both rural and urban roughness conditions, uses meteorological and emission data as its input parameters, and calculates concentrations of pollutant at the center of each cell in a predefined grid area with respect to the given source location. Its performance was tested by comparing with 4-h average field data of continuous releases of SO_2 from Dadri thermal power plant (Uttar Pradesh, India). Results showed that the Turner scheme used with Holland's equation gives the best outcome having a degree of agreement (d) of 0.522.

Yuwono et al., (2014) carried out a study. The aim of this study was to assess the distribution of air pollutants (SO_2 and NO_2) concentration emitted from the biodiesel plant using Gaussian Dispersion Equation. The results showed that the SO_2 and NO_2 pollutants emission from the production of biodiesel was below the threshold limit, which means it did not endanger the surrounding population. Whereas, the concentration of CO pollutant emission in the radius below 450 m from the emission source, give the negative impacts on the environment. It indicated that the safe distance of biodiesel plant site to the settlements area is out of 450 m radius from the source.

A field experiment was set up by Spijkerboer et al., (2002) to test that whether GPM, as applied to the dispersal of spores or not. Spores of the fern *Lycopodium cladatum* were released artificially from a source in a potato crop. Spore catches were made with a network of samplers, placed downwind from the source and at several heights and crosswind distances from the anticipated plume axis. They found a low correlation (R=0.4) between observed spore concentrations and predicted spore concentrations. More precise methods for predicting the width and height of Gaussian plumes require detailed site-specific information (measurements of wind speed and temperature at two heights above the vegetation) and are therefore not readily applicable in risk assessments.

3. MATERIALS AND METHODS

3.1 The experimental area

The study was conducted in the vicinity of NTPC Dadri. It is located in Gautam Budh Nagar district of Uttar Pradesh, India (28°35′54″N & 77°36′34″E). The experiment was carried out during Kharif and Rabi seasons of 2015-16 and 2016-17. The climate of the study area was very dry and hot during summer, humid and hot during monsoon, dry and pleasant during spring and autumn, and cool to cold during winters. The wind direction was predominantly northwesterly during the whole growing period (as shown in wind rose diagram, fig. 4.1 and 4.2). During the experimental period, meteorological parameters like maximum temperature (°C), minimum temperature (°C), rainfall (mm), relative humidity (%), wind speed (km/hr) and wind direction has been recorded.

3.2 Selection of sites

Around the thermal power plant (TPP), ten sites were selected based on dominant wind direction and distance from the power plant. Two sites were identified towards the windward direction to the TPP (Akilpur Jagir, Pyawali Tajpur). Dominant wind direction throughout the year was in the north-west (NW). Near about four sites were selected in a leeward direction (Jarcha, Uncha Amirpur, Khangoda and Nagla Kashi), two were chosen perpendicular to dominant wind direction (Nidhauli and Ranauli Latifpur) and two in extreme north and south directions to the TPP (Tatarpur and Salarpur Kalan) (Fig. 3.1 and Table 3.1).

Table: 3.1 Selected sites along with latitude and longitude

Village	Direction to NTPC	Aerial distance from TPP (km)	Latitude	Longitude
Akilpur Jagir (AJ)	NW	4.5	28.615427 N	77.562230 E
Pyawali Tajpur (PT)	NW	2.5	28.609550 N	77.580426 E
Tatarpur (T)	N	3.0	28.628311 N	77.604716 E
Salarpur Kalan (SK)	S	3.5	28.581064 N	77.598107 E
Ranauli Latifpur (RL)	SW	4.0	28.579108 N	77.583039 E
Jarcha (J)	SE	6.5	28.570963 N	77.651665 E
Khangoda (K)	SE	3.5	28.590027 N	77.627510 E
Uncha Amirpur (UA)	SE	1.0	28.606024 N	77.610476 E
Nagla Kashi (NK)	SE	8.0	28.585104 N	77.674442 E
Nidhauli (N)	NE	3.0	28.618532 N	77.627541 E

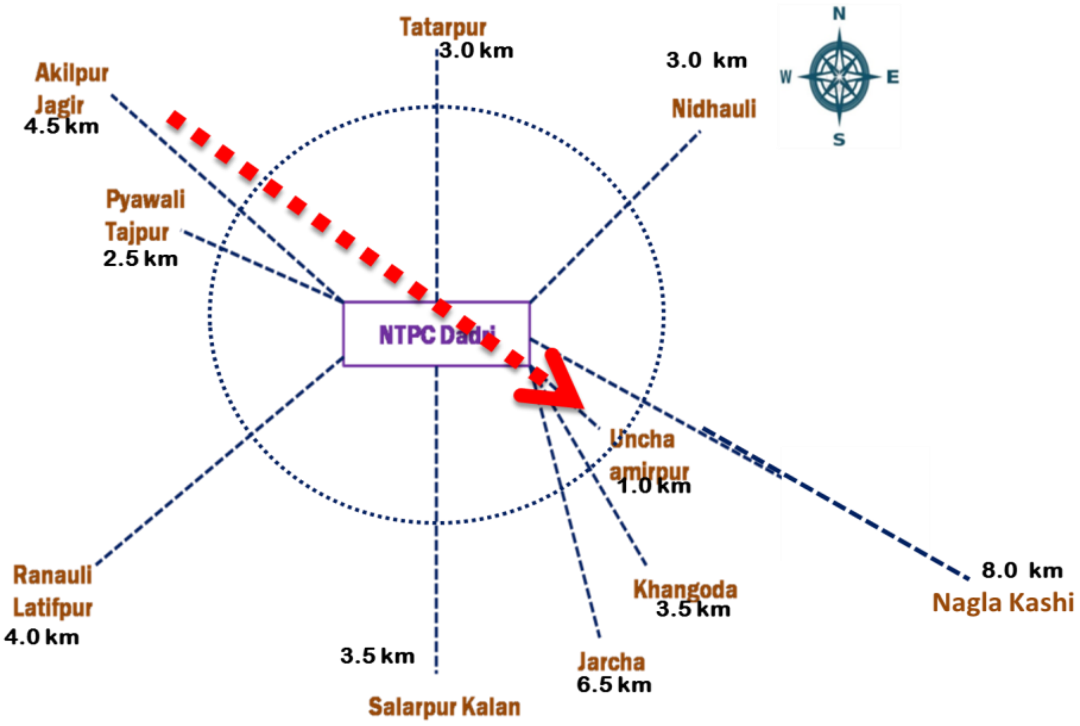

Figure: 3.1 Map of Selected sites around NTPC Dadri

*** Red arrow shows pre dominant wind direction**

3.3 Experimental setup

The soil samples were collected from each site and analyse at the laboratory. Mainly two crops (Rice and Wheat) were grown in the study area. Rice was grown from July to October, and the wheat crop was grown from the month of November to April. Farmers were mainly growing Pusa 1121 variety of rice and PBW 343 variety of wheat crop. Transplanting of rice seedlings was done during the second fortnight of July. Wheat sowing was done in the second week of November. Farmers field was selected which grown same crop variety and following almost similar crop management practices. Field visits were done at the monthly interval for recording growth, and yield parameters of rice and wheat plants during Kharif and Rabi season. The farmer’s fields were also continuously monitored for any other stresses like insect pest infestation and diseases during the growing season.

3.4 Soil parameters analysis

In the intial stage of experiment, we collected soil samples (0-15 cm) from selected sites. After that, samples were analyzed for various physic-chemical properties like organic carbon (Walkley and Black, 1934), pH (pH meter), EC (EC meter), available Nitrogen (Subbaiah and Asija, 1956), Phosphorous (Jackson, 1973) and Pottassium (neutral normal ammonium acetate method using a flame photometer). The analytical data quality was ensured through careful standardization, procedural blank measurements and duplicate sample.

3.5 Quantification of Air Pollutants

3.5.1 Particulate matter (PM)

Quantification of atmospheric load of particulate matter was carried out at different selected sites through gravimetric method during 2015-16 and 2016-17 at the monthly interval for 8-hour duration.

Gravimetric method

Gravimetric estimation of the atmospheric particulate matter was done by collecting samples by Respirable dust sampler (RDS) (model – Envirotech, APM411) on quartz microfiber sheet (QMF sheet; 8 ×10 inch). Air is drawn through a size-selective inlet of RDS and through a 20.3 ×25.4 cm (8 X 10 in) quartz filter at a flow rate, which is typically 1132 L/min or 1.13 m^3/min. The mass of these particles is determined by the difference in sheet weights before and after the completion sampling. The concentration of particulate matter in the designated size range was calculated by using following formulae:

$$\mathbf{PM_{10}\ (\mu g/m^3) = (W_f - W_i) \times 10^6 / V}$$

Where,

PM_{10} = Concentration of Particulate matter (PM_{10}), $\mu g/m^3$

W_f = Weight of filter in g

W_i = Initial weight of filter in g

10^6 = Conversion of g to µg

V = Volume of air passed in m^3

PM_{10} = particulate matter 10 µm or less in diameter (CPCB, 2012; IS: 5182 (Part XV), 1974)

Suspended particulate matter (SPM) in air generally is considered to be all airborne solid and low vapor pressure liquid particles, involving a complex, multi-phase system consisting of a spectrum of aerodynamic particle sizes ranging from below 0.01 µm to 100 µm and larger.

PM10 includes only particles with an aerodynamic diameter from 2.5 µm to 10 µm.

3.5.2 Sulphur dioxide (SO_2)

Improved West and Gaeke Method

Tetrachloromercurate (TCM) was used as absorbing solution for the SO_2 sampling from ambient air. After the absorption of $SO_{2,}$ dichlorosulphitomercurate complex was formed, which resists the oxidation of $SO_{2.}$ This stable complex was less affected by oxidants like ozone and nitrogen oxides. So we may be stored the absorber solution before analysis. After that para-rosaniline and formaldehyde were added to the complex to form intensely coloured pararosaniline methylsulphonic acid. After that, the absorbance of the solution was measured by a spectrophotometer (CPCB, 2012; IS: 5182 (Part II), 1974).

Sampling

Impingers were filled with absorbing solution (30 mL), and sampling was done for four hours at flow rate of 1 L/min. After the completion of sampling, solution was measured and transferred to storage bottle for further analysis.

Analysis

Maintain the solution level-up to 30 mL by adding distilled water, if the absorbing solution might be lost due to evaporation process at the time of sampling. After mixing the collected sample thoroughly, Pipette out 10 or 20 mL sample into 25 mL volumetric flask. Add the 1 mL 0.6% sulphamic acid and keep it for 10 minutes for reacting to destroy nitrites. After that add 2 mL of 0.2% formaldehyde solution and 2 ml pararosaniline solution and volume make up to 25 mL with distilled water.

Blank solution was also prepared in similar way by using fresh absorbing solution, which was not used for sampling. After the colour development (between 30 to 60 minutes), absorbance was recorded at 560 nm.

$$\mathbf{C\ (SO_2\ \mu g/m^3) = (A_s - A_b\ )\ x\ CF\ x\ V_s\ /\ V_a\ x\ V_t}$$

Where,

C (SO_2) = Concentration of Sulphur dioxide, $\mu g/m^3$

A_s = Absorbance of sample

A_b = Absorbance of reagent blank

CF = Calibration factor

V_a = Volume of air sampled, m^3

V_s = Volume of sample, mL

V_t = Volume of aliquot taken for analysis, mL

3.5.3 Nitrogen dioxide (NO_2)

Modified Jacob and Hochheiser Method

Sodium hydroxide and sodium arsenite were used as absorbing solution for the NO_2 sampling from ambient air. Nitrite ions (NO_2^-) were formed after the sampling in solution, then phosphoric acid, sulfanilamide, and N-(1-naphthyl)-ethylenediamine dihydrochloride (NEDA) were added. After that, the absorbance of the solution was measured by a spectrophotometer (CPCB, 2012; IS: 5182 (Part VI), 1974).

Sampling

Impingers were filled with absorbing solution (30 mL), and sampling was done for four hours at flow rate of 0.2 to1 L/min. After the completion of sampling, solution was measured and transferred to storage bottle for further analysis.

Analysis

Maintain the solution level-up to 30 mL by adding distilled water, if the absorbing solution might be lost due to evaporation process at the time of sampling. After mixing the collected sample thoroughly, Pipette out 10 mL sample into 50 mL volumetric flask. Add in 1 mL of hydrogen peroxide solution, 10 mL of sulphanilamide solution, and 1.4 mL of NEDA solution. After thoroughly mixing volume was made up to 50 mL with distilled water.

Blank solution was also prepared in similar way by using fresh absorbing solution, which was not used for sampling. After the colour development (10 minutes interval), absorbance was recorded at 540 nm.

Calculation

$$\mathbf{C\ (NO_2\ \mu g/m^3) = (A_s - A_b) \times CF \times V_s / V_a \times V_t \times 0.82}$$

Where,

C (NO_2) = Concentration of Nitrogen dioxide, $\mu g/m^3$

A_s = Absorbance of sample

A_b = Absorbance of reagent blank

CF = Calibration factor

V_a = Volume of air sampled, m^3

V_s = Volume of sample, mL

V_t = Volume of aliquot taken for analysis, mL

0.82 = Sampling efficiency

3.5.4 Ozone (O_3)

Chemical Method

Potassium iodine buffered solution at pH 6.8 + 0.2 was used as absorbing solution for the O_3 sampling from ambient air. When O_3 reacts with the potassium iodine solution, iodine was liberated and the iodine was measured by a spectrophotometer at 352 nm (CPCB, 2012; IS: 5182).

The following reaction described the stoichiometry:

$$\mathbf{O_3 + 3KI + H_2O \rightarrow KI_3 + 2KOH + O_2}$$

Sampling

Impingers were filled with absorbing solution (10 mL), and sampling was done for one hour at flow rate of 1 L/min. After the completion of sampling, solution was measured and transferred to storage bottle for further analysis. Direct sunlight exposure to the absorbing solution was extremely prohibited here.

Analysis

Maintain the solution level-up to 10 mL by adding distilled water, if the absorbing solution might be lost due to evaporation process at the time of sampling. After mixing the collected sample thoroughly, absorbance was directly recorded at 352 nm against a reference cuvette containing distilled water.

Calculation

$$\mathbf{C\ (Ozone\ \mu g/m^3) = (A_s - A_b)\ x\ CF\ x\ 1.962/\ V_a}$$

Where,

$C(O_3)$ = Concentration of Ozone in $\mu g/m^3$

A_s = Absorbance of sample

A_b = Absorbance of reagent blank

CF = Calibration factor

V_a = Volume of air sampled in m^3

1.962 = Conversion factor, μL to μg

3.5.5 Heavy Metals (Lead, Nickel and Arsenic)

Atomic Absorption Spectrophotometer Method

Heavy metal concentration in ambient air was estimated by Atomic Absorption Spectroscopy (AAS) technique. In this method, we collected samples by Respirable dust sampler on quartz microfiber sheet and analysis was carried out by AAS on a different wavelength (USEPA—Method IO-3.1 1999; USEPA—Method IO-3.2 1999).

Analysis

Hotplate procedure was used for extraction of the sample, those were collected on quartz microfiber sheet. At first, we cut the filter paper in two strips and placed it to the beaker, which was filled with the extraction solution (3% HNO_3 & 8% HCl) and placed that beaker on hot-plate (Temperature below 80°C). After the completion of digestion, we removed beaker outside and allow to cool. Then add 10 mL distilled water and allow to stand for at least 30 minutes. Then we transferred the extraction solution to a100 mL volumetric flask and diluted to volume makeup. After filtration, samples were analysed by AAS.

Calculations

Sample Air Volume

Sample air volume can be calculated by using the following equation:

$$\mathbf{V = (Q)/\ (t)}$$

Where,

V = volume of air, m^3

Q = average sampling rate, m^3/min.

t = time in minutes.

Concentration of metal

$$\mathbf{C\ (\mu g/m^3) = (M_s - M_b) \times V_s \times F_a/V \times Ft}$$

Where,

C = concentration, µg metal/m^3.

M_s = metal concentration µg/mL

M_b = blank concentration µg/mL

V_s = total volume of extraction in mL

F_a = total area of exposed filter in cm^2

V = Volume of air sampled in m^3

F_t = Area of filter taken for digestion in cm^2

3.5.6 Measurement of air quality index (AQI)

Air quality index (AQI) was calculated by using the formula given by (Rao and Rao, 1998).

$$\mathbf{AQI = 1/3\,(SO_2/S_{SO_2} + NO_X/S_{NO_x} + SPM/S_{SPM}) \times 100}$$

Where (SO_2), (NOx) and (SPM) represent the individual concentration and S_{SO_2}, S_{NOX}, S_{SPM} represents the ambient air quality standards for SO_2, NOx and Suspended Particulate Matter (SPM), respectively. Ambient air quality standards are shown in table 2.4.

Table: 3.2 AQI value and level of air pollution

AQI value	Air pollution level
0–25	Clean air (CA)
26–50	Light air pollution (LAP)
51–75	Moderate air pollution (MAP)
76–100	Heavy air pollution (HAP)
>100	Severe air pollution (SAP)

3.5.7 Dust deposition on crop canopy

Deposition of particulate matter on crop canopy was also measured as per the methodology of Prusty et al., (2005). Leaf samples were randomly collected in a beaker and washed thoroughly by a hairbrush with distilled water. The water in the beaker was completely evaporated in an oven at 100°C and weighed.

The following equation quantified dust load:

$$\mathbf{W = (w_2 - w_1)/A}$$

Where, W is the amount of dust load (mg/cm^2)’ w_1 is initial weight of beaker without dust; w_2 is final weight of the beaker with dust; A is total area of the leaf (cm^2).

3.6. Morphological, physiological and biochemical Parameters of the crops

3.6.1 Leaf Area Index

Leaf area was recorded by placing the fresh leaves of one hill flat in a digital leaf area meter (LI-3100, LiCor Inc., Lincoln, Nebraska). The area obtained was then divided by the area of ground to get LAI (Pask et al., 2012).

3.6.2 Physiological Parameters

Photosynthetic rate, stomatal conductance and transpiration rate were measured by portable photosynthesis system (LI-6400-40 Portable Photosynthesis system Infrared gas analyser (IRGA). Hetero-atomic gas molecules absorb radiation at specific infrared wavelengths, each gas having a characteristic absorption band spectrum. Infrared gas analysers measure the reduction in transmission of IR wavebands caused by the presence of CO_2 between the radiation source and a detector. The reduction in transmission is a function of the concentration of CO_2. Photosynthetic rate, stomatal conductance and transpiration were expressed in the units of μmol $CO_2/m^2/s$, $mol/m^2/s$ and mmol $H_2O/m^2/s$ respectively.

3.6.3 Biochemical parameters

For the analysis of biochemical parameters, seven crops such as *Oryza sativa, Triticum aestivum, Pennisetum glaucum, sorghum bicolor, Hordeum vulgare, Brassica juncea and Trifolium alexandrinum* were selected which were common in all selected sites in the study area during kharif and Rabi seasons in 2015-16 and 2016-17. Only four sites were selected for the analysis of biochemical parameters because only these sites had all selected crops. Farmers field was selected which grown same crop variety and following almost similar crop management practices. Fully matures leaves of each crop plants were randomly collected in triplicate. After that leaves samples were immediately brought to the laboratory in polythene bags in ice box for further biochemical and dust deposition analysis.

3.6.3.1 Relative Leaf Water Content (RLWC)

Relative Leaf Water Content was determined according to the method of Liu and Ding, (2008) and calculated by the formula:

$$\mathbf{RLWC\ (\%) = [(FW-DW) / (TW-DW)] \times 100}$$

FW = Fresh weight, TW = turgid weight and DW = dry weight

Fresh weight was measured by weighing 30 discs of 5 mm diameter cut from the fresh leaves for every sample. The discs were then immersed in distilled water overnight till they got saturated, blotted dry and then weighed to get the turgid weight. The same leaf discs were oven dried at 70°C for 4-5 hrs and reweighed to obtain the dry weight.

3.6.3.2 Chlorophyll

Total chlorophyll estimation was done according to the method described by Arnon (1949). 2 g of fresh leaf sample from each selected site was blended and then extracted with 15 ml of 80% acetone and left for 15 minutes. The liquid portion was decanted into another test tube, after that, it was centrifuged at 2,500 rpm for 3 minutes. Then, the supernatant was collected, and the absorbance was taken at 645 nm and 663 nm using a spectrophotometer.

Calculations were done using the formula below:

Chlorophyll a = 12.7 DX663 – 2.69DX645 x V/1000W mg/g

Chlorophyll b = 22.9 DX645 – 4.68DX663 x V/1000W mg/g

Total Chlorophyll content = (Chlorophyll a + Chlorophyll b) mg/g
Dx = Absorbance of the extract at the wavelength X nm
V = Total volume of the chlorophyll solution (ml) and
W = weight of the tissue extract (g)

3.6.3.3 Leaf Extract pH

5 g of the fresh leaves was homogenised in 50 ml distilled water. After that, this was then filtered and the pH of leaf extracted determined pH meter after calibrating it with a buffer solution of pH 4 and pH 9.

3.6.3.4 Ascorbic Acid

Ascorbic acid content was determined by the method as described by Sadasivam and Manikam (1991). Stock standard was made by dissolving 100 mg ascorbic acid in 100 ml of 4% oxalic acid solution in standard flask (1mg/ml). Working standard was made by diluting 10 ml of the stock solution to 100 ml with 4% oxalic acid. The concentration of working standard was 100 µg/ml. Dye solution used for the titration was made by weighing 42 mg sodium bicarbonate into small volume of distilled water. Then, 52 mg, 2-6 dichlorophenol indophenol was dissolved to make volume up to 200 ml with distilled water.1 g leaf sample was extracted in 4% oxalic acid (10 ml) and volume was made up to 50 ml with 4% oxalic acid. It was centrifuged at 5000 rpm for 20 minutes at 4 °C. 5 ml of the supernatant was collected through a pipette, 10 ml of 4% oxalic acid was added to it and titrated against the dye.

Amount of Ascorbic acid in the sample was calculated in mg/g sample as per the following formula:

Ascorbic acid (mg/g) = (0.5 mg/V1 ml) X (V2/15 ml) X (100 ml/wt of sample in g) X 100

3.6.3.5 Air Pollution Tolerance Index (APTI)

The air pollution tolerance index [APTI] was calculated by the given formula (Singh and Rao (1983) as follows:

$$\mathbf{APTI = A (T + P) + R/10}$$

Where:

A   Ascorbic acid (in mg/g)

T   Total chlorophyll (in mg/g)

P   pH of the leaf extract

R   Relative water content of leaf (%)

Table: 3.3 APTI values and their responses

APTI value	Response
≤ 12	Sensitive
13-16	Intermediate
17	Moderately tolerant
≥ 20	Tolerant

(Singh and Rao, 1983)

3.6.3.5 Anticipated Performance Index (API)

After the computation of APTI for all the crop species, we calculated API on the basis of final APTI values with some socioeconomic and biological characters (Govindaraju et al., 2012). Different grades like (+, -) were given to all crop species on the basis of these parameters (Thambavani and Sabitha, 2011).

Table 3.4 Gradation of crop species for API calculation on the basis of APTI and other biological and socioeconomic characters

S. No.	Grading character		Pattern Assessment	Grade allotted
1	Tolerance	APTI	6.0 - 6.5	+
			6.5 - 7.0	++
			7.0 - 7.5	+++
			7.5 - 8.0	++++
			8.0 - 8.5	+++++
2	Biological, socioeconomic	Plant habitat	Small	+
			Medium	++
			Large	+++
		Size	Small	-
			Medium	+
			Large	++
		Texture	Smooth	-
			Coriaceous	+
		Economic value	Less	-
			Medium	+
			More	++

Table 3.5 Anticipated performance index (API) of crop species

Grade	Score (%)	Category
0	Up to 30	Not recommended
1	31–40	Very poor
2	41–50	Poor
3	51–60	Moderate
4	61–70	Good
5	71–80	Very good
6	81–90	Excellent
7	91–100	Best

3.7 Yield parameters

3.7.1 Number of plants/m^2

Numbers of plants/m^2 were counted manually from 1 m^2 area in the study field.

3.7.2 Biological Yield

The crop was harvested from 1m^2 area at maturity stage, dried for three days, weighed and after threshing grain yield was adjusted to a moisture content of 14%. The straw yield was measured, and biological yield was calculated as the total of grain and straw yield. The yield was expressed in t/ha.

3.7.3 Grain Yield

The crop was harvested at maturity, dried for three days, weighed and after threshing grain yield was adjusted to a moisture content of 14%.Grain yield was expressed in t/ha.

3.7.4 1,000-Grain Weight

The 1,000 filled grains taken from sampled panicles were first counted by a seed counter and then weighed to compute the 1,000-grain weight.

3.8 Calibration and validation of the point source Gaussian Plume Dispersion Model (GPDM)-

A model is a simplified representation of the real situation. It doesn't contain all the features of the real system but includes the features of interest for the management issue or scientific problem we wish to solve by its use. Models are widely used in science to make predictions and to solve problems and are often used to identify the best options for the management and regulate the specific environmental issues.

An atmospheric dispersion model is a:

- Mathematical simulation of the physical and chemical processes governing the transport, dispersion and transformation of pollutants in the atmosphere.
- Means of predicting the downwind air pollutants concentrations on the basis of given information about the pollutant emissions and nature of the atmosphere.

The Gaussian model is perhaps the oldest (1936) and most commonly used model type. Gaussian models are most often used for predicting the dispersion of continuous, buoyant air pollution plumes originating from ground-level or elevated sources.

3.8.1 Overview of the air pollution modelling procedure

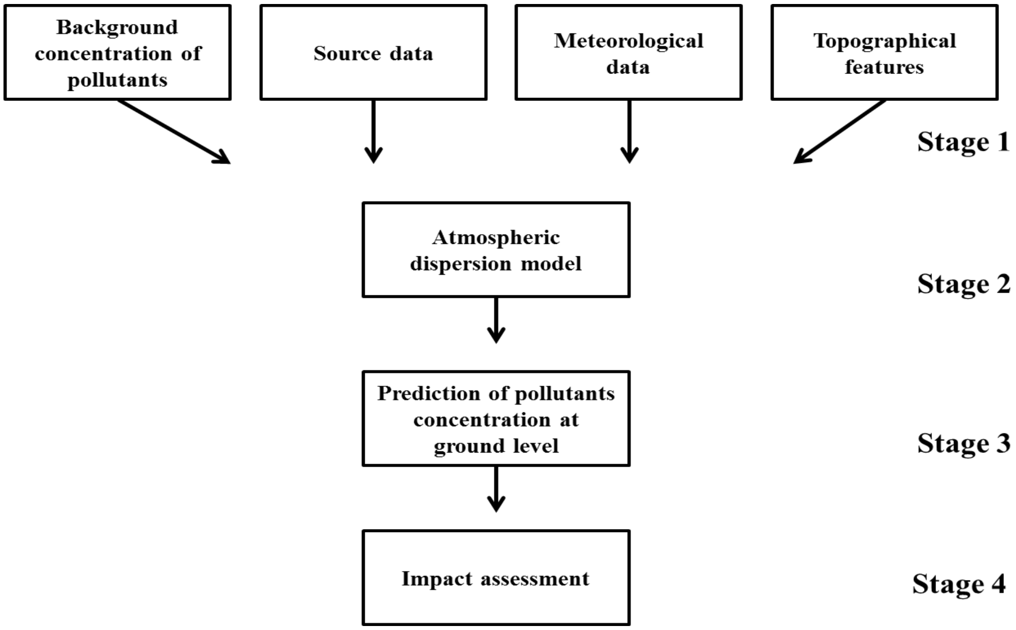

Figure: 3.2 Schematic diagram of air pollution modelling

3.8.2 Input data requirement

Table 3.6 Input data requirement for model

Source characteristics	Meteorological conditions	Downwind dispersion
Location of the sources (x, y, z),m	Wind direction (degrees)	Distance from source (km)
Stack physical height (m)	Wind speed (m/s)	Direction
Stack inner diameter (m)	Ambient air temperature (K)	
Stack exit velocity (m/s)	Stability class	
Temperature of stack gas (K)		
Pollutant emission rate (g/s)		

3.8.3 The Point Source Gaussian Plume Dispersion Model Equation-

Following equation was used to predict the air pollutants concentration at selected sites in the study area (Briggs et al., 1975; Turner, 1994; Matthias et al., 2006).

$$C_{(x,y,z,H)} = \frac{Q}{2\pi\sigma_y\sigma_z\bar{\mu}} \times exp\left(-\frac{y^2}{2{\sigma_y}^2}\right) \times \left[exp\left(-\frac{(Z-H)^2}{2{\sigma_z}^2}\right) + exp\left(-\frac{(Z+H)^2}{2{\sigma_z}^2}\right)\right]$$

Where:

C ($\mu g/m^3$) = pollutant concentration at receptor;

(x, y, z) = ground level coordinates of the receptor, in meters;

H (m) = effective stack height;

Q ($\mu g/s$) = emiission rate of pollutant from a source;

$\bar{u}$ = wind speed, in m/s;

σy and σz = standard deviation of plume concentration distribution in y and z plane, in m.

For measurement of pollutants concentration at ground level (y=z=0) following equation was used.

$$C_{(x)} = \frac{Q}{2\pi\sigma_y\sigma_z\bar{\mu}} \times exp\left(-\frac{H^2}{2\sigma_z{}^2}\right)$$

3.8.4 Wind speed at stack height

Wind speed changes with elevation were measured by following formula. (Davenport et al., 1961)

$$\frac{U_H}{U_a} = \left(\frac{H}{z_a}\right)^p$$

Where:

U_H = wind speed at elevation H (m/s)

U_a = wind speed at anemometer height (m/s)

H = effective stack height (m)

z_a = Anemometer height (10 m)

p = a dimensionless parameter that depends on surface roughness and atmospheric stability

Table 3.7 Value of p for different types of terrain

Stability class	Description	P value for rough terrain	P value for smooth terrain
A	Very unstable	0.15	0.15×0.6= 0.09
B	Mod. Unstable	0.15	0.15×0.6= 0.09
C	Slightly unstable	0.20	0.20×0.6= 0.12
D	Neutral	0.25	0.25×0.6= 0.15
E	Slightly stable	0.40	0.40×0.6= 0.24
F	Stable	0.60	0.60×0.6= 0.36

Table 3.8 Pasquill turbulence types based on stability classification

Surface wind speed (m/s)	**Daytime insolation**			**Night-time conditions**	
	Strong	Moderate	Slight	Thin overcast or >4/8 low cloud	≤3/8 cloudiness
<2	A	A-B	B		
2-3	A-B	B	C	E	F
3-4	B	B-C	C	D	E
4-5	C	C-D	D	D	D
>6	C	D	D	D	D

3.8.5 Plume Rise

Plume rise was calculated by Holland formula.

$$\Delta h = \frac{V_s D}{u}(1.5 + 0.00268\, PD)\frac{(T_s - T_a)}{T_s})$$

Where: Δh = Plume rise (m), V_s = Exit velocity of pollutant from stack (m/s), u = Wind speed (m/s), P = Pressure (mb), D = Stack diameter (m), T_s = Stack gas temperature (K) and T_a = Ambient temperature (K).

3.8.6 Gaussian dispersion coefficients (σ_y & σ_z)

These coefficient were calculated by following formula

$$\sigma_y = ax^{0.894} \qquad \sigma_z = cx^d + f$$

Where,

σ_y = lateral/horizontal dispersion coefficient function (m)

σ_z = vertical dispersion coefficient function (m)

x = Horizontal distance from source

a, c, d and f are constants (Table 3.9)

Table 3.9 Values of a, c, d & f constants

Stability	$x \leq 1$ km				$x \geq 1$ km		
	a	c	d	f	c	d	F
A	213	440.8	1.941	9.27	459.7	2.094	-9.6
B	156	106.6	1.149	3.3	108.2	1.098	2.0
C	104	61.0	0.911	0	61.0	0.911	0
D	68	33.2	0.725	-1.7	44.5	0.516	-13.0
E	50.5	22.8	0.678	-1.3	55.4	0.305	-34.0
F	34	14.35	0.740	-0.35	62.6	0.180	-48.6

(Martin et al., 1976)

3.8.7 Performance evaluation of Gaussian plume model

Model performance will be validated by comparing observed and predicted concentrations. Index of agreement d was used to evaluate the predictive performance of the Gaussian Plume Dispersion Model (Willmott et al., 1981). Index d allows for sensitivity towards differences in predicted and observed values (d = 0 indicates no agreement; d = 1 indicates perfect agreement).

$$\mathbf{d} = \mathbf{1} - \frac{\sum\left(C_{pi} - C_{oi}\right)^2}{\sum\left\{abs\left(C_{pi} - C_{om}\right) + abs\left(C_{oi} - C_{om}\right)\right\}^2}$$

Where, Coi = Observed concentration,

Cpi = Predicted concentration, and

Com = Averages of the observed concentrations.

3.9 Errors and uncertainties

It might be due to electricity unavailability, samples storage and analysis, results of analysis evaluation, inspection and storage. Evaluation of conditions and rules during: – sampling (temperature, air volume and flow continuity) – storage and transportation of samples (temperature) – laboratory analysis.

3.10 QA/QC

Quality assurance refers to the overall management of the process involved in obtaining the data, i.e. relates to the measurement process. Quality control refers to the activities undertaken to check and optimise data accuracy and precision after collection, i.e. concerned primarily with outputs. The equipments are maintained and operated according to the standard specifications of supplier. We have adopted US EPA's Standard Operating Procedures for instrument calibration and maintenance. We visited the sites regular basis. On monthly basis review meeting was conducted. The quality of sampling and analysis was ascertained by analyzing blank. Whereas in case of plant sample collection, freshly plucked foliar samples were firstly kept in sealed polythene and in an ice box and then brought to the laboratory for the further investigation. For analysis of different biochemical parameter, the foliar samples were taken as triplicate. During biochemical analysis, the margin and mid rib portions were avoided in all the triplicates to ensure the authenticity of the results. The QC procedures for the air sampling and monitoring sections include preventative maintenance of equipment, calibration of equipment, analysis of field blanks and lab blanks.

3.11 Statistical analysis

Significant differences of the mean between selected sites were statistically analyzed by one way ANOVA (at $p \leq 0.05$) using SAS software package 9.2.

4. RESULTS

In the present study, experiments were carried out – (i) To quantify and characterize the air pollution load at selected sites on the basis of plume dispersion (ii) To assess the impact of air pollution on crop growth and productivity (iii) To calibrate and validate the air pollution dispersion model for coal-based thermal power plant.

4.1 Meteorological conditions during the experimental period

The meteorological parameters were recorded during the monitoring period. During 2015-16, the maximum mean monthly temperature ranged from 36 to 46 °C with minima from 28 to 34 °C in summer season, and during the winter months, the maximum temperature ranged from 27 to 33 °C and minima from 13 to 22 °C. It received an annual rainfall of 530.32 mm. The wind speed varied from 13.0 to 15.4 km/h during the summer and 9.0 to 11.1 km/h during the winter (Table 4.1). The wind direction was predominantly northwesterly during the study period (as shown in wind rose diagram, fig. 4.1). Whereas during 2016-17, the summer months maximum mean monthly temperature ranged from 37 to 44 °C with minima from 27 to 33 °C and during the winter months maximum temperature ranged from 24 to 34 °C and minima from 12 to 20 °C. It received an annual rainfall of 621.6 mm, out of which 80 to 90 % occurs during the months of June-August. The wind speed varied from 8.7 to 13 km/h during the summer and 9.3 to 11.9 km/h during the winter (Table 4.2). The wind direction was predominantly northwesterly during the study period (as shown in wind rose diagram, fig. 4.2).

4.2 Soil physico-chemical properties

The soil samples were collected from each site and analyse at the laboratory. Soil samples were analyzed for pH, EC, Nitrogen, Phosphorous, potassium, and soil organic carbon content. Soils were found to be alkaline with pH ranging from 7.57 - 8.81 and electrical conductivity (EC) ranging from 0.24 - 0.47 mmhos/cm. Total nitrogen content of soils varied from 0.06 to 0.08 %, available phosphorus (P_2O_5) was 19.4 to 23.8 kg/ha and available potassium (K_2O) ranged from 137.5 to 162.7 kg/ha. Soil organic carbon content was 0.39 to 0.44 % (Table 4.3).

Table 4.1: Meteorological information of study area (2015-16)

Month	Temp (°C)		RH (%)		Rainfall (mm)	Wind velocity (km/h)
	Min.	Max.	Min.	Max.		
Jan 2016	13	27	40	86	1.60	9.0
Feb 2016	15	30	34	89	2.80	11.1
March 2016	20	36	29	76	20.30	13.0
April 2016	28	42	21	72	0.20	15.4
May 2016	32	46	20	58	19.52	13.4
June 2015	34	43	48	91	18.11	14.8
July 2015	30	39	54	88	267.77	14.0
Aug 2015	29	39	55	84	178.01	11.6
Sept 2015	28	39	42	82	20.70	13.0
Oct 2015	26	37	29	69	1.31	9.3
Nov 2015	22	33	27	85	0.30	9.7
Dec 2015	16	27	28	81	0.00	9.8

Table 4.2: Meteorological information of study area during (2016-17)

Month	Temp (°C)		RH (%)		Rainfall (mm)	Wind velocity (km/h)
	Min.	Max.	Min.	Max.		
Jan 2017	12	24	45	90	42.70	9.7
Feb 2017	14	29	38	87	2.00	11.9
March 2017	19	35	34	81	17.40	13.0
April 2017	28	42	24	64	8.60	13.7
May 2017	27	39	26	57	15.90	8.7
June 2016	33	44	52	89	79.96	11.9
July 2016	30	39	53	91	264.05	11.1
Aug 2016	28	37	48	84	177.89	11.1
Sept 2016	27	39	49	86	13.60	10.1
Oct 2016	26	39	32	75	0.00	9.0
Nov 2016	20	34	29	82	0.00	9.7
Dec 2016	16	29	41	87	0.00	9.3

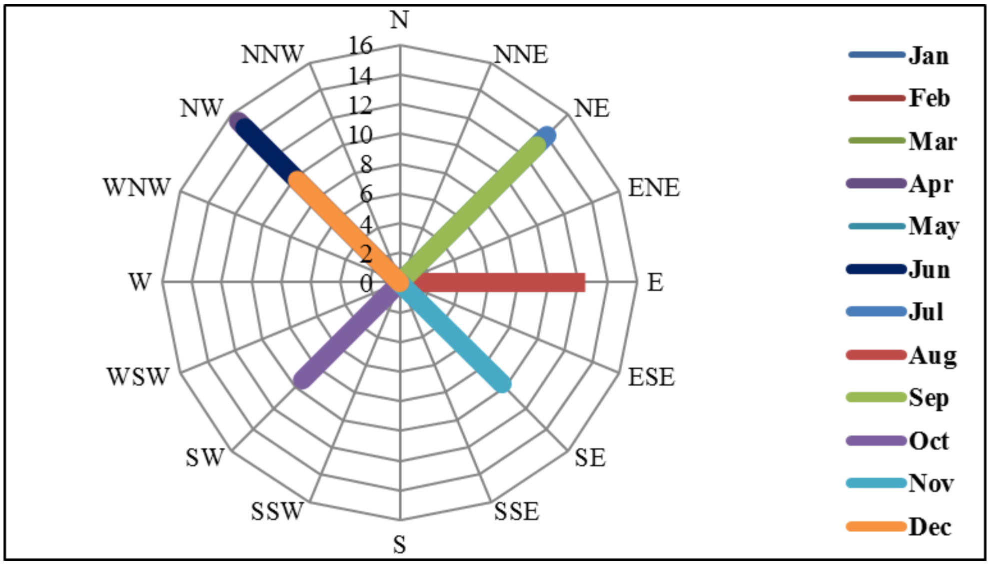

Figure 4.1: Wind diagram during 2015-16

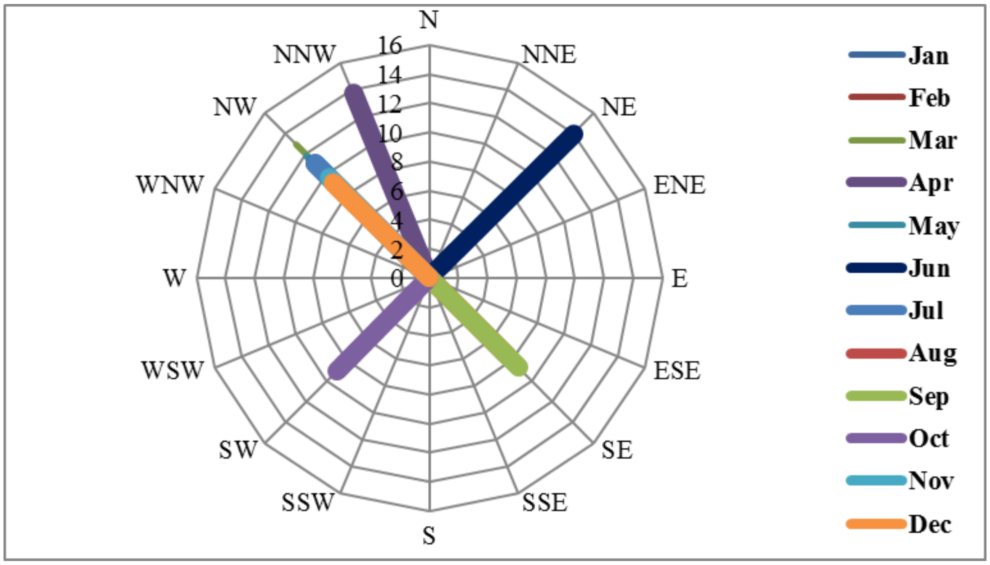

Figure 4.2: Wind diagram during 2016-17

Table 4.3: Soil physico-chemical properties range at selected sites

Parameters	Range
pH	7.57 - 8.81
EC (mmhos/cm)	0.24 - 0.47
Organic carbon (%)	0.39 to 0.44
Total N (%)	0.06 to 0.08
Available P (kg/ha)	19.40 to 23.80
Available K (kg/ha)	137.50 to 162.70

4.3 Level of air pollutants at different selected sites

Air quality monitoring was carried out at monthly interval basis, and the following air pollutant measured; TSP, SO_2, NO_2, O_3 and heavy metals (As, Ni and Pb).

4.3.1 Particulate matter

Air quality monitoring showed that concentration of PM_{10} found minimum at Akilpur Jagir followed by Pyawali Tajpur (control sites), whereas maximum level was found at Khangoda, Jarcha and Uncha Amirpur villages as these villages are located on the leeward side of the TPP. PM_{10} concentration gradually decreased as we move away from TPP. All these particulates concentration were maximum in Rabi season and minimum in the Kharif season. Almost the same results have been found in the consecutive year. The concentration of particulates matters at selected experimental sites are shown in table 4.4 and 4.5.

During 2015-16, seasonal mean concentration of PM_{10} ranged from 219 to 318 $\mu g/m^3$ and 149 to 296 $\mu g/m^3$ in Rabi and Kharif season respectively, whereas During 2016-17, PM_{10} ranged from 156 to 314 $\mu g/m^3$ and 104 to 242 $\mu g/m^3$ in Rabi and Kharif season respectively (Fig. 4.3 and 4.4).

Table 4.4: Seasonal particulate matter concentration 2015-16

Sites	PM10 (µg/m^3)			
	Kharif		Rabi	
	Mini.	Max.	Mini.	Max.
Akilpur Jagir	110	187	170	242
Pyawali Tajpur	126	195	182	250
Tatarpur	147	212	196	269
Salarpur Kalan	150	202	192	262
Ranauli Latifpur	165	232	213	258
Jarcha	234	295	250	320
Khangoda	250	288	242	335
Uncha Amirpur	256	326	260	339
Nagla Kashi	222	272	198	254
Nidhauli	232	277	202	240

Table 4.5: Seasonal particulate matter concentration 2016-17

Sites	PM10 (µg/m^3)			
	Kharif		Rabi	
	Mini.	Max.	Mini.	Max.
Akilpur Jagir	119	192	182	256
Pyawali Tajpur	121	205	189	262
Tatarpur	154	198	202	277
Salarpur Kalan	144	214	211	289
Ranauli Latifpur	177	221	236	265
Jarcha	222	290	260	335
Khangoda	251	302	283	346
Uncha Amirpur	267	335	287	352
Nagla Kashi	211	270	215	249
Nidhauli	204	264	222	232

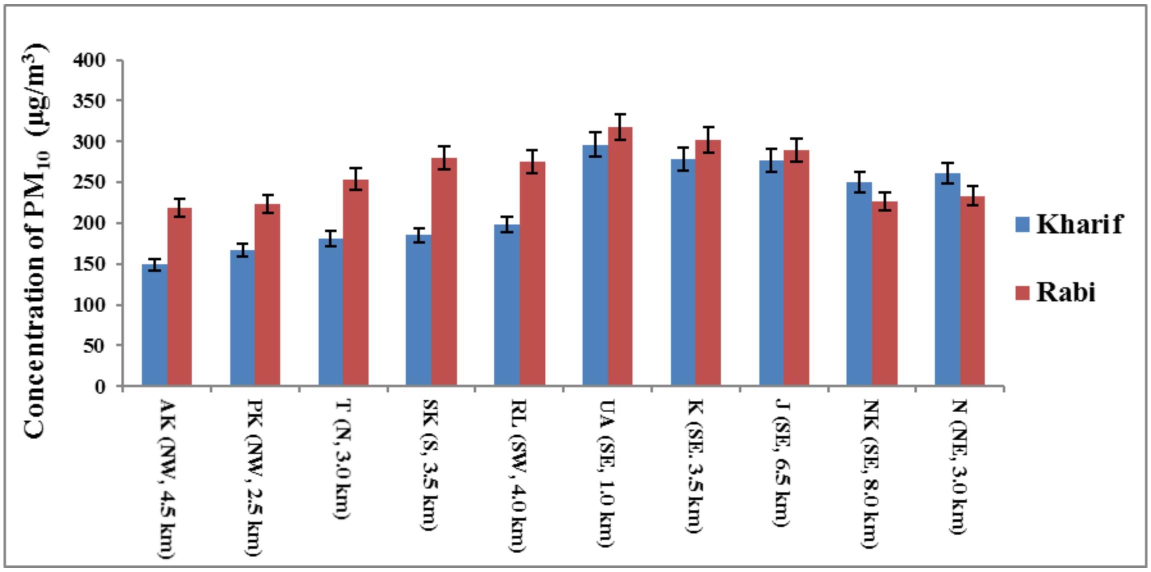

Figure 4.3: Seasonal average PM$_{10}$ concentration (µg/m^3) at selected sites (2015-16)

* Akilpur Jagir (AJ) (Village Name)	NW (Direction from the TPP)
Pyawali Tajpur (PT)	W (Direction from the TPP)
Tatarpur (T)	N (Direction from the TPP)
Salarpur Kalan (SK)	S (Direction from the TPP)
Ranauli Latifpur (RL)	SW (Direction from the TPP)
Jarcha (J)	SE (Direction from the TPP)
Khangoda (K)	SE (Direction from the TPP)
Uncha Amirpur (UA)	SE (Direction from the TPP)
Nagla Kashi (NK)	SE (Direction from the TPP)
Nidhauli (N)	NE (Direction from the TPP)

**Km is represented as distance from the TPP

*** The same classification followed in each graphical representation

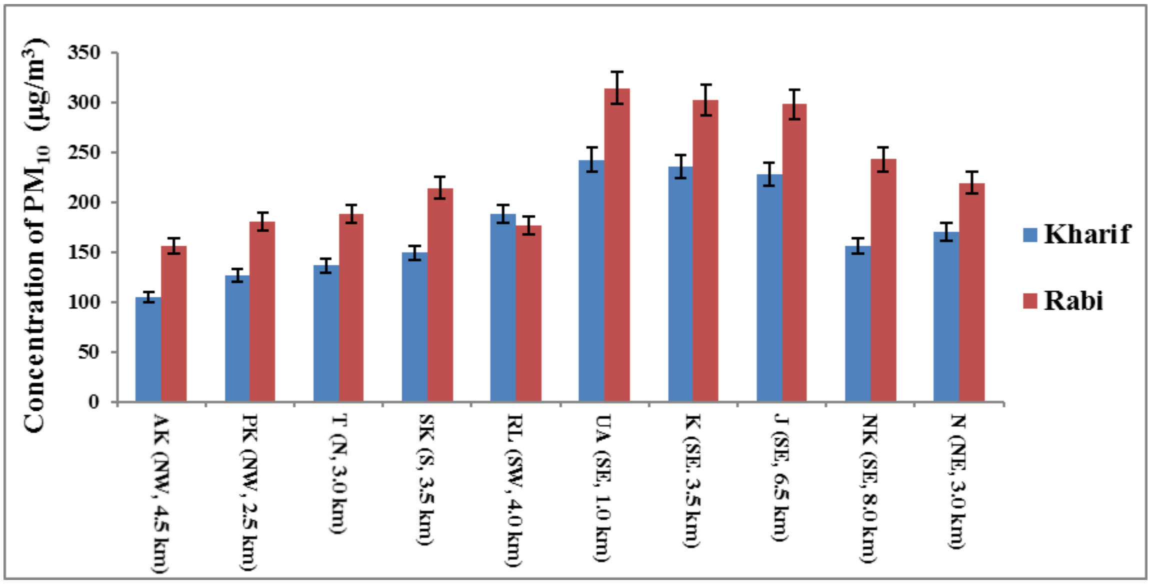

Figure 4.4: Seasonal average PM$_{10}$ concentration (µg/m^3) at selected sites (2016-17)

4.3.2 Gaseous pollutants concentration

The concentration of SO_2, NO_2 and O_3 were minimum at Akilpur Jagir followed by Pyawali Tajpur (control sites), whereas maximum concentraion was found at Khangoda, Jarcha, Uncha Amirpur village, because their location in the leeward side of the TPP. SO_2 and NO_2 concentration were maximum in Rabi and minimum in the Kharif season, but O_3 concentration was maximum in Kharif and minimum in Rabi season. It was due to the role of higher temperature and sunlight in the formation of O_3. The concentration of gaseous pollutants at selected experimental sites are shown in table 4.6 and 4.7.

Table 4.6: Seasonal SO_2, NO_2 and O_3 concentration in 2015-16

Sites	NO_2 (µg/m^3)		SO_2 (µg/m^3)		O_3 (µg/m^3)	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Akilpur Jagir	18.51 ± 0.96	19. 4 ± 1.34	8.98 ± 0.64	10.58 ± 0.93	22.37 ± 4.88	16.98 ± 1.87
Pyawali Tajpur	20.24 ± 2.08	20.28 ± 0.74	10.81 ± 0.88	11.95 ± 1.14	24.08 ± 5.21	18.62 ± 2.21
Tatarpur	24.11 ± 2.98	26.31 ± 3.7	11.44 ± 0.89	13.52 ± 0.9	25.62 ± 4.17	22.64 ± 2.24
Salarpur Kalan	22.63 ± 3.09	25.40 ± 2.1	11.83 ± 0.79	13.76 ± 1.37	25.97 ± 3.46	22.91 ± 1.35
Ranauli Latifpur	24.50 ± 3.6	27.57 ± 2	12.89 ± 0.3	14.58 ± 1.12	26.84 ± 3.73	22.63 ± 1.49
Jarcha	38.53 ± 2.92	40.70 ± 3.31	16.36 ± 1.19	19.95 ± 2.4	32.57 ± 5.37	27.24 ± 2.9
Khangoda	37.35 ± 2.3	39.32 ± 1.99	16.04 ± 2.01	18.58 ± 1.37	31.97 ± 3.95	26.87 ± 2.25
Uncha Amirpur	32.09±3.54	32.54 ± 1.2	14.56 ± 1.07	16.47 ± 0.64	29.73 ± 3.54	25.69 ± 2.39
Nagla Kashi	20.86 ± 4.24	25.79 ± 1.5	11.97 ± 0.59	13.10 ± 0.6	34.13 ± 6.22	27.05 ± 3.64
Nidhauli	23.56 ± 2.75	27.71 ± 2.71	12.71 ± 1.23	14.37 ± 0.09	26.91 ± 3.98	24.64 ± 3.93
LSD (P=0.05)	2.76	2.82	1.05	1.41	1.29	1.66

Table 4.7: Seasonal SO_2, NO_2 and O_3 concentration in 2016-17

Sites	NO_2 (µg/m^3)		SO_2 (µg/m^3)		O_3 (µg/m^3)	
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
Akilpur Jagir	21.44 ± 1.66	23.44 ± 2.22	10.84 ± 0.77	12.32 ± 0.83	21.08 ± 4.25	17.98 ± 1.50
Pyawali Tajpur	23.20 ± 2.16	26.04 ± 1.63	12.88 ± 0.62	14.07 ± 1.54	25.12 ± 3.24	19.57 ± 2.42
Tatarpur	26.48 ± 2.54	29.97 ± 3.41	17.82 ± 1.30	14.62 ± 0.96	27.22 ± 5.74	23.51 ± 1.65
Salarpur Kalan	28.87 ± 3.17	30.42 ± 2.36	15.81 ± 0.37	18.58 ± 1.74	26.52 ± 3.55	24.79 ± 2.04
Ranauli Latifpur	26.88 ± 3.22	25.12 ± 1.87	13.42 ± 0.32	15.80 ± 1.15	28.87 ± 3.30	26.22 ± 1.66
Jarcha	36.09 ± 2.70	42.66 ± 2.40	17.20 ± 1.27	22.07 ± 1.51	35.04 ± 4.51	32.36 ± 2.75
Khangoda	40.58 ± 2.43	46.08 ± 1.98	19.08 ± 1.85	23.04 ± 2.08	32.33 ± 3.55	29.57 ± 2.36
Uncha Amirpur	38.57 ± 2.41	34.82 ± 2.74	16.97 ± 1.24	19.89 ± 0.74	30.42 ± 3.05	28.42 ± 2.39
Nagla Kashi	27.05 ± 3.37	30.43 ± 1.52	12.98 ± 0.88	14.98 ± 0.65	24.17 ± 4.82	20.82 ± 3.52
Nidhauli	22.86 ± 2.47	25.80 ± 2.32	16.67 ± 1.17	13.08 ± 1.55	28.24 ± 3.27	25.08 ± 2.27
LSD (P=0.05)	2.60	2.78	1.23	1.57	1.24	1.54

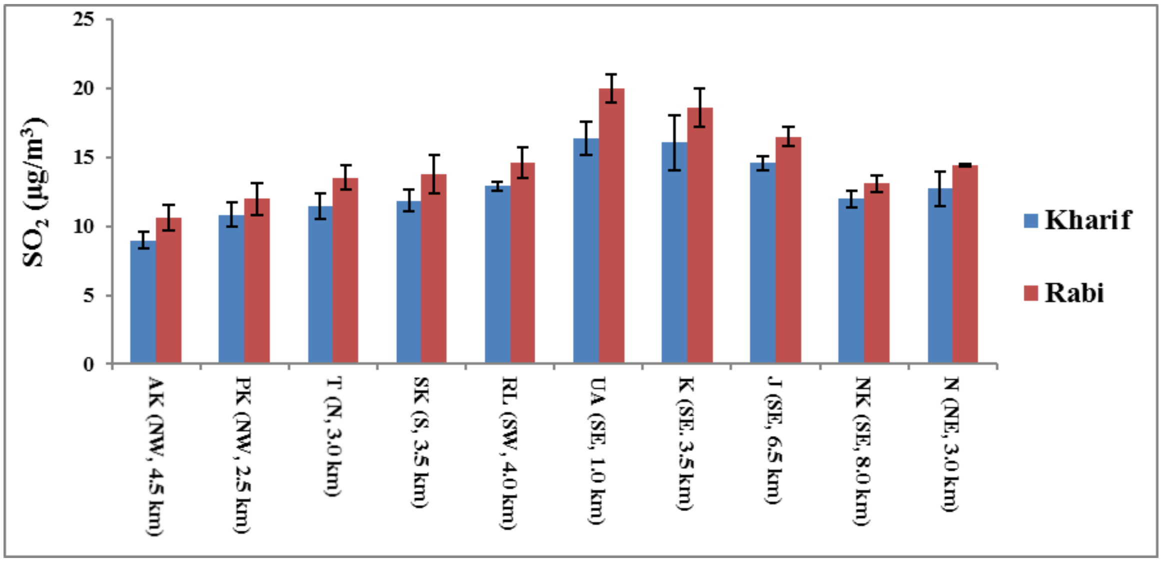

Figure 4.5: Seasonal SO₂ (µg/m³) at selected sites (2015-16)

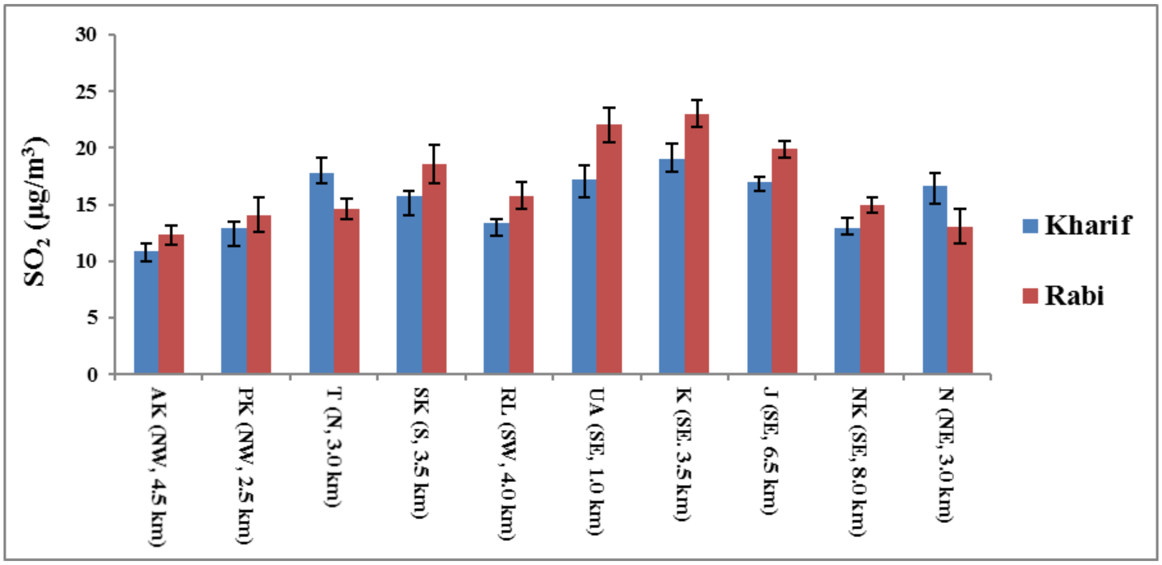

Figure 4.6: Seasonal SO₂ (µg/m³) at selected sites (2016-17)

4.3.2.2 NO_2 concentration

NO_2 concentration at different selected sites ranged from 18.51 to 38.53 µg/m^3 and 19.40 to 40.70 µg/m^3 in Kharif and Rabi season respectively in 2015-16, whereas during 2016-17, NO_2 ranged from 21.44 to 40.58 µg/m^3 and 23.44 to 46.08 µg/m^3 in Kharif and Rabi season respectively. Results showed that concentration of NO_2 reported minimum at Akilpur Jagir followed by Pyawali Tajpur (control sites), whereas maximum concentraion was found at Jarcha followed by Khangoda and Uncha Amirpur villages in both the seasons and year (Fig. 4.7 and 4.8).

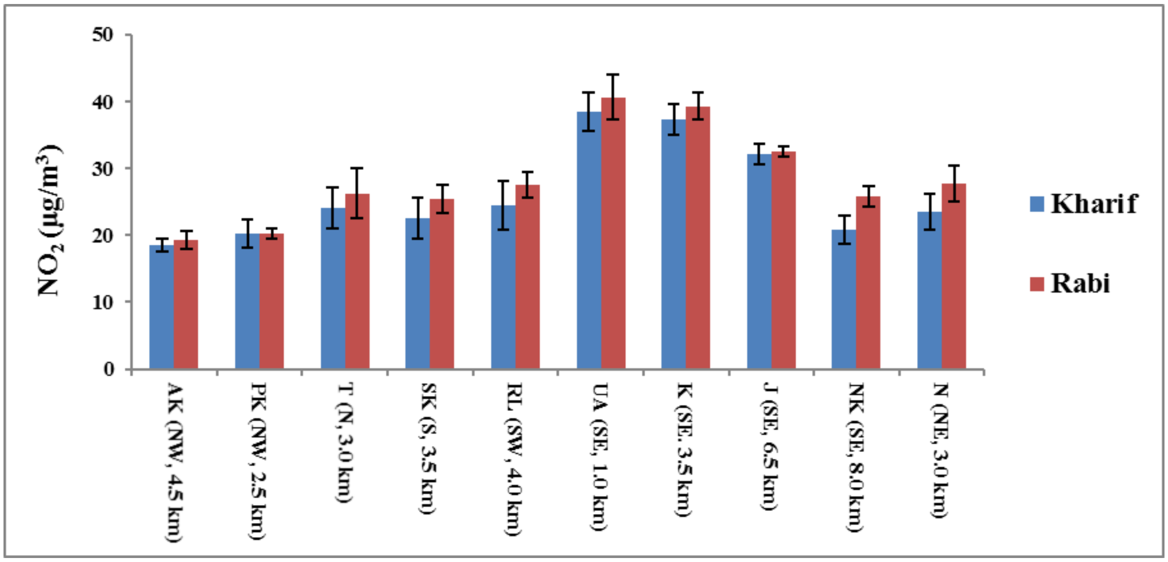

Figure 4.7: Seasonal NO_2 (µg/m^3) at selected sites (2015-16)

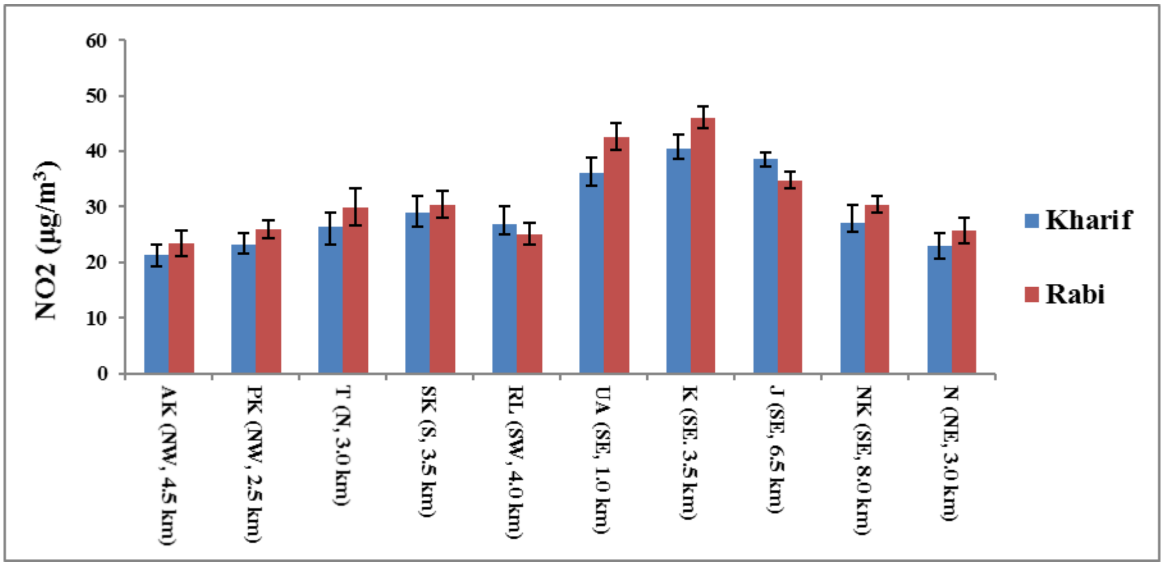

Figure 4.8: Seasonal NO_2 (µg/m^3) at selected sites (2016-17)

4.3.2.3 O_3 concentration

Ozone concentration at different selected sites ranged from 22.37 to 32.57 µg/m^3 and 16.98 to 27.24 µg/m^3 in Kharif and Rabi season respectively in 2015-16, whereas during 2016-17, O_3 ranged from 21.08 to 35.04 µg/m^3 and 17.98 to 32.38 µg/m^3 in Kharif and Rabi season respectively. Results showed that concentration of O_3 found minimum at Akilpur Jagir followed by Pyawali Tajpur (control sites), whereas maximum level was found at Jarcha followed by Khangoda and Uncha Amirpur villages in both the seasons and year (Fig. 4.9 and 4.10).

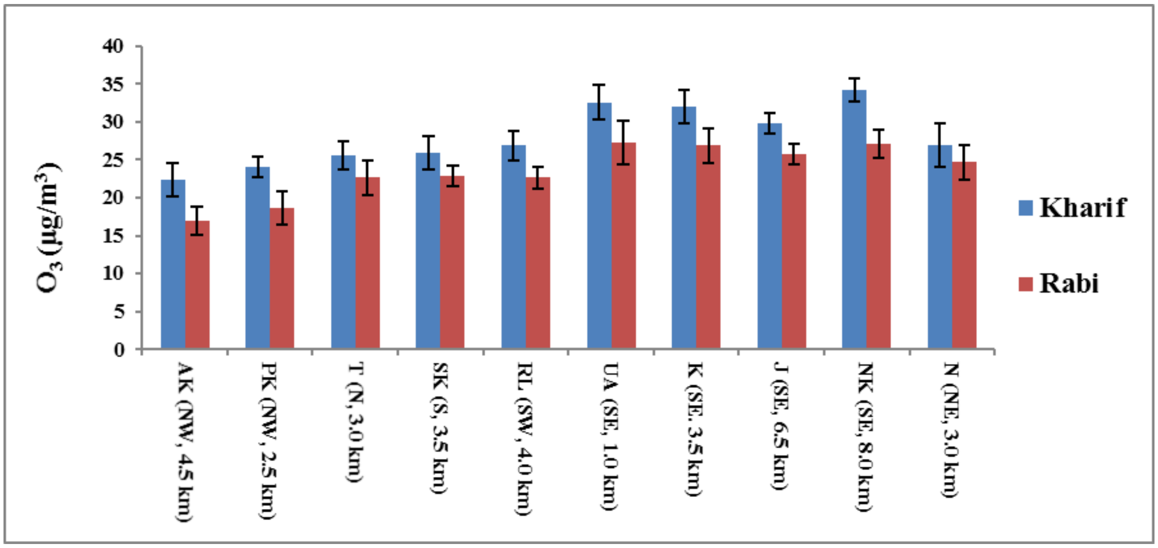

Figure 4.9: Seasonal O_3 (µg/m^3) at selected sites (2015-16)

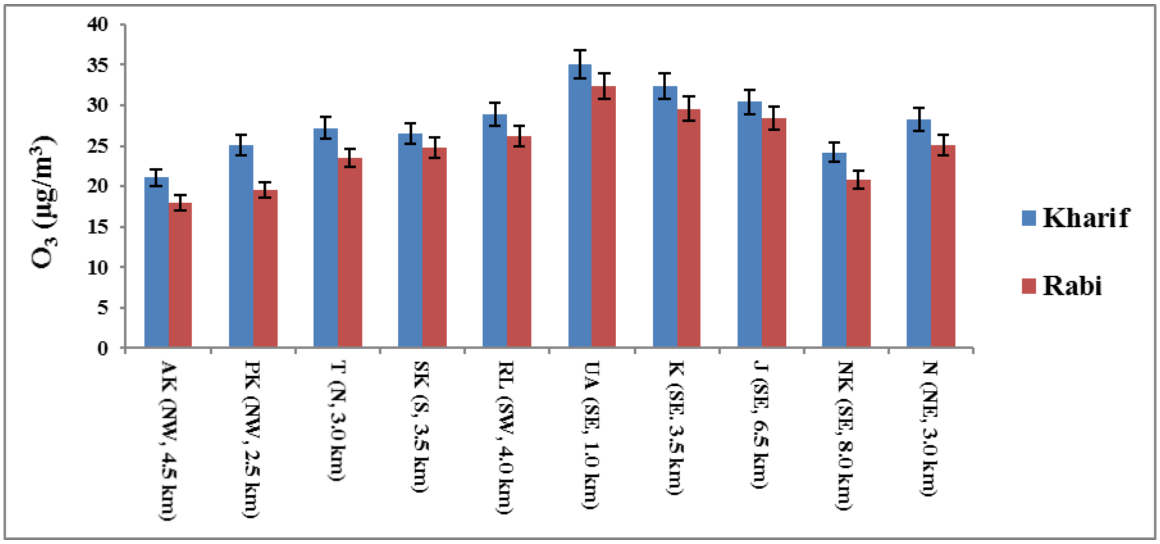

Figure 4.10: Seasonal O_3 (µg/m^3) at selected sites (2016-17)

4.3.3 Heavy metals

The concentration of heavy metals like As, Ni and Pb ranged from 0.28 to 0.44 ng/m^3, 1.24 to 1.74 ng/m^3 and 7.68 to12.54 ng/m^3 during Kharif season respectively, whereas, in Rabi season concentration of As, Ni and Pb ranged from 0.35 to 0.45 ng/m^3, 2.34 to 4.74 ng/m^3 and 10.24 to 16.89 ng/m^3, respectivley. There was no significant diffrence among heavy metals concentration at selected sites (Fig. 4.11 and 4.12).

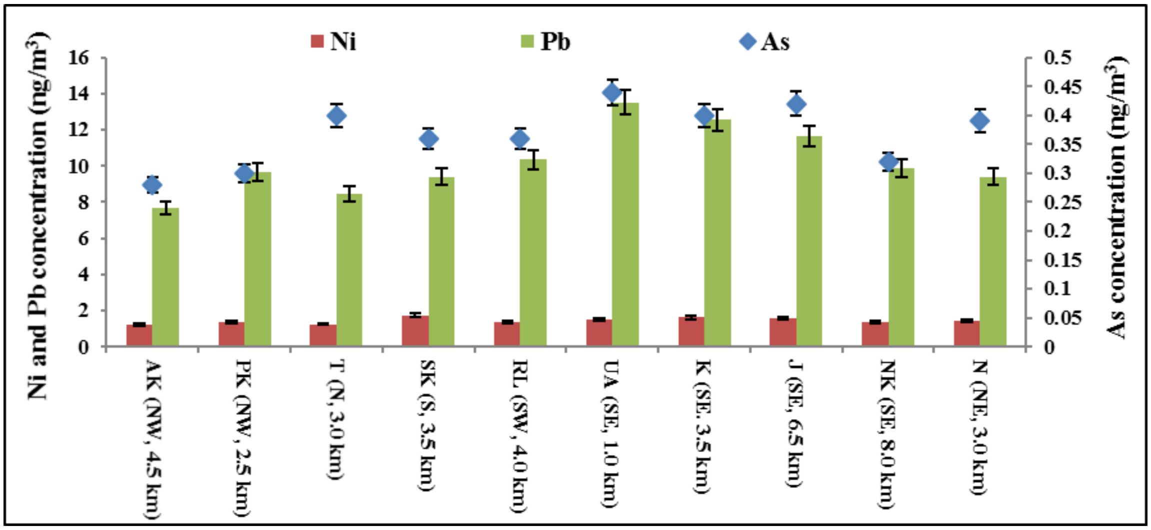

Figure 4.11: Heavy metals (As, Ni and Pb) concentration in Kharif season during 2015-16

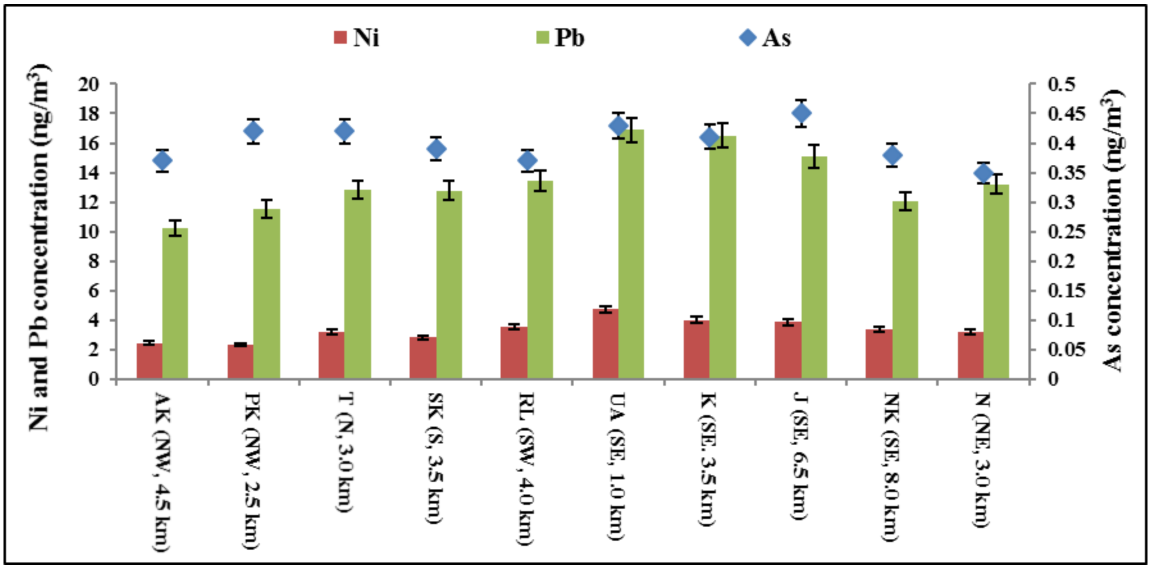

Figure 4.12: Heavy metals (As, Ni and Pb) concentration in Rabi season during 2015-16

4.3.4 Air qulaity index (AQI)

AQI values were varied from 67.79 to 136.64 and 72.49 to 138.76 in Kharif and Rabi season respectively in 2015-16. Whereas during 2016-17, AQI ranged from 43.45 to 133.26 and 51.57 to 142.29 in Kharif and Rabi season respectively. AQI values showed that air pollution level was light to moderate at control sites (Akilpur jagir, Pyawali tajpur), whereas heavy pollution level at other selected sites (Jarcha Khangoda Uncha Amirpur Nagla Kashi Ranauli Latifpur) (Table 4.8). This is due to SPM, which play most significant role in calculation of AQI.

Table 4.8: Seasonal AQI at selected sites

AQI	2015-16		2016-17	
	Kharif	Rabi	Kharif	Rabi
Akilpur Jagir	68	72	43	52
Pyawali Tajpur	76	78	50	57
Tatarpur	88	93	89	113
Salarpur Kalan	91	105	117	139
Ranauli Latifpur	90	105	93	108
Jarcha	131	139	133	142
Khangoda	137	126	124	141
Uncha Amirpur	123	134	125	138
Nagla Kashi	101	121	108	122
Nidhauli	88	99		103

4.4 Aerial deposition rate (ADR) of particulate matter on crop canopy at selected sites

The maximum deposition on wheat crop was found in Jarcha (1.88 mg/cm^2) followed by Khangoda (1.75 mg/cm^2) and Uncha Amirpur villages (1.67 mg/cm^2) and the minimum deposition was found in Akilpur Jagir (0.85 mg/cm^2) followed by Pyawali Tajpur villages (0.98 mg/cm^2) at vegetative phase. The almost similar trend was also observed at flowering stage. In rice crop maximum deposition was found at Jarcha (1.44 mg/cm^2) followed by Khangoda (1.42 mg/cm^2) and Uncha Amirpur villages (1.33 mg/cm^2) whereas minimum deposition was found in Akilpur Jagir (0.54 mg/cm^2) followed by Pyawali Tajpur villages (0.67 mg/cm^2) at vegetative phase. Again almost similar trend was also observed at flowering stage.

During 2016-17, maximum deposition on wheat crop was found in Khangoda (2.19 mg/cm^2) followed by Jarcha (2.03 mg/cm^2) and Uncha Amirpur villages (1.62 mg/cm^2) and the minimum deposition was found in Akilpur Jagir (1.15 mg/cm^2) followed by Pyawali Tajpur villages (1.24 mg/cm^2) at vegetative phase. The almost similar trend was also observed at flowering stage. In rice crop maximum deposition was found in Jarcha (1.67 mg/cm^2) followed by Khangoda (1.56 mg/cm^2) and Uncha Amirpur villages (1.28 mg/cm^2) whereas minimum deposition was found in Akilpur Jagir (0.69 mg/cm^2) followed by Pyawali Tajpur villages (0.82 mg/cm^2) at flowering stage. Again almost similar trend was also observed at vegetative phase. Deposition was more at flowering stage as compared to vegetative stage in both the crops. In wheat crop atmospheric deposition load on leaves was found to be more than rice at both the stages. This is primarily due to that wheat is grown in the Rabi season when rainfall is much less than the Kharif season when rice grown. Higher rainfall in Kharif might have washed out some of the deposited particulate matter from rice leaves (Table 4.9 and 4.10).

Table 4.9: Aerial deposition on rice and wheat crop (mg/cm^2) (2015-16)

Sites	Wheat		Rice	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	0.85 ± 0.07	1.08 ± 0.08	0.54 ± 0.07	0.64 ± 0.04
Pyawali Tajpur	0.98 ± 0.06	1.17 ± 0.11	0.67 ± 0.60	0.88 ± 0.06
Tatarpur	1.21 ± 0.07	1.41 ± 0.09	0.77 ± 0.13	0.96 ± 0.05
Salarpur Kalan	1.08 ± 0.11	1.36 ± 0.05	0.98 ± 0.11	1.08 ± 0.08
Ranauli Latifpur	1.24 ± 0.10	1.39 ± 0.07	1.12 ± 0.1	1.20 ± 0.07
Jarcha	1.88 ± 0.09	2.20 ± 0.10	1.44 ± 0.09	1.89 ± 0.08
Khangoda	1.75 ± 0.07	1.98 ± 0.11	1.42 ± 0.08	2.07 ± 0.09
Uncha Amirpur	1.67 ± 0.05	1.87 ± 0.012	1.33 ± 0.08	1.77 ± 0.05
Nagla Kashi	1.45 ± 0.06	1.65 ± 0.07	1.02 ± 0.09	1.19 ± 0.06
Nidhauli	1.30 ± 0.09	1.44 ± 0.06	1.21 ± 0.12	1.34 ± 0.07
LSD (P=0.05)	0.14	0.16	0.12	0.16

Table 4.10: Aerial deposition on rice and wheat crop (mg/cm^2) (2016-17)

Sites	Wheat		Rice	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	1.15 ± 0.11	1.31 ± 0.13	0.63 ± 0.07	0.69 ± 0.10
Pyawali Tajpur	1.24 ± 0.10	1.30 ± 0.10	0.77 ± 0.06	0.82 ± 0.08
Tatarpur	1.33 ± 0.08	1.47 ± 0.09	0.83 ± 0.09	0.97 ± 0.07
Salarpur Kalan	1.43 ± 0.07	1.45 ± 0.07	0.97 ± 0.12	1.05 ± 0.09
Ranauli Latifpur	1.53 ± 0.07	1.66 ± 0.06	1.04 ± 0.13	1.11 ± 0.06
Jarcha	2.03 ± 0.08	2.18 ± 0.05	1.56 ± 0.10	1.67 ± 0.12
Khangoda	2.19 ± 0.12	2.21 ± 0.08	1.43 ± 0.08	1.56 ± 0.14
Uncha Amirpur	1.62 ± 0.09	1.77 ± 0.11	1.22 ± 0.08	1.28 ± 0.11
Nagla Kashi	1.31 ± 0.05	1.39 ± 0.09	0.98 ± 0.07	1.06 ± 0.08
Nidhauli	1.76 ± 0.06	1.87 ± 0.11	1.07 ± 0.09	1.21 ± 0.11
LSD (P=0.05)	0.13	0.14	0.16	0.12

4.5 Effect of air pollutants on growth and physiological parameters of the crops

4.5.1 Effect of air pollution on Leaf Area Index (LAI)

Air pollution significantly hampered the growth and physiological parameters of the both rice and wheat crops. Leaf area index (LAI) is directly correlated with photosynthesis rate, so a reduction in photosynthetic rate directly affects the LAI of the crops. The LAI was maximum at Akilpur Jagir (3.61) followed by Pyawali Tajpur (3.57) and the LAI was minimum at Jharcha (3.37) followed by Khangoda (3.41) in rice crop at flowering stage (FS). In wheat crop maximum LAI was found at Akilpur Jagir (3.91) followed by Piyawali Tajpur (3.88), whereas minimum at Jharcha (3.34) followed by Khangoda (3.37) at flowering stage. Near about Similar trend of LAI was observed in both crops at vegetative phase (VS) during 2015-16 (Fig. 4.13 and 4.15).

During second year, maximum LAI was found at Akilpur Jagir (3.70) followed by Pyawali Tajpur (3.56) and the LAI was minimum at Jharcha (3.08) followed by Uncha Amirpur (3.15) in rice crop. In wheat crop maximum LAI was found at Akilpur Jagir (4.02) followed by Piyawali Tajpur (3.91), whereas minimum at Jharcha (2.89) followed by Khangoda (3.30) at flowering stage (FS) (Fig. 4.14 and 4.16). Near about Similar trend of LAI was observed in both crops at vegetative phase (VS) (Table 4.11 and 4.12).

Table 4.11: Leaf area index in rice and wheat crop (2015-16)

Sites	Rice		Wheat	
	Vegetative phase	Flowering Stage	Vegetative phase	Flowering stage
Akilpur Jagir	2.24 ± 0.15	3.61 ± 0.35	2.34 ± 0.03	3.91 ± 0.03
Pyawali Tajpur	2.22 ± 0.22	3.57 ± 0.14	2.37 ± 0.02	3.88 ± 0.03
Tatarpur	2.19 ± 0.27	3.59 ± 0.29	2.28 ± 0.02	3.72 ± 0.05
Salarpur Kalan	2.2 ± 0.2	3.58 ± 0.12	2.29 ± 0.05	3.64 ± 0.02
Ranauli Latifpur	2.16 ± 0.22	3.52 ± 0.17	2.26 ± 0.02	3.47 ± 0.02
Jarcha	2.13 ± 0.15	3.37 ± 0.01	2.09 ± 0.04	3.34 ± 0.02
Khangoda	2.14 ± 0.08	3.41 ± 0.02	2.11 ± 0.02	3.37 ± 0.02
Uncha Amirpur	2.16 ± 0.18	3.43 ± 0.13	2.08 ± 0.02	3.4 ± 0.03
Nagla Kashi	2.18 ± 0.1	3.48 ± 0.06	2.19 ± 0.02	3.49 ± 0.02
Nidhauli	2.17 ± 0.07	3.5 ± 0.03	2.22 ± 0.03	3.44 ± 0.02
LSD (P=0.05)	0.03	0.04	0.05	0.04

Table 4.12: Leaf area index in rice and wheat crop (2016-17)

Sites	Rice		Wheat	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	2.56 ± 0.03	3.7 ± 0.12	2.49 ± 0.04	4.02 ± 0.05
Pyawali Tajpur	2.47 ± 0.03	3.56 ± 0.07	2.58 ± 0.03	3.94 ± 0.02
Tatarpur	2.25 ± 0.02	3.24 ± 0.02	2.4 ± 0.02	3.66 ± 0.08
Salarpur Kalan	2.38 ± 0.02	3.1 ± 0.02	2.24 ± 0.06	3.68 ± 0.01
Ranauli Latifpur	2.33 ± 0.02	3.33 ± 0.03	2.26 ± 0.17	3.55 ± 0.03
Jarcha	2.22 ± 0.02	3.08 ± 0.04	1.98 ± 0.02	2.89 ± 0.02
Khangoda	2.17 ± 0.01	3.21 ± 0.02	2.16 ± 0.02	3.3 ± 0.02
Uncha Amirpur	2.27 ± 0.03	3.15 ± 0.02	2.02 ± 0.06	3.42 ± 0.04
Nagla Kashi	2.38 ± 0.02	3.4 ± 0.02	2.19 ± 0.02	3.84 ± 0.02
Nidhauli	2.21 ± 0.02	3.32 ± 0.02	2.32 ± 0.03	3.49 ± 0.01
LSD (P=0.05)	0.03	0.08	0.11	0.06

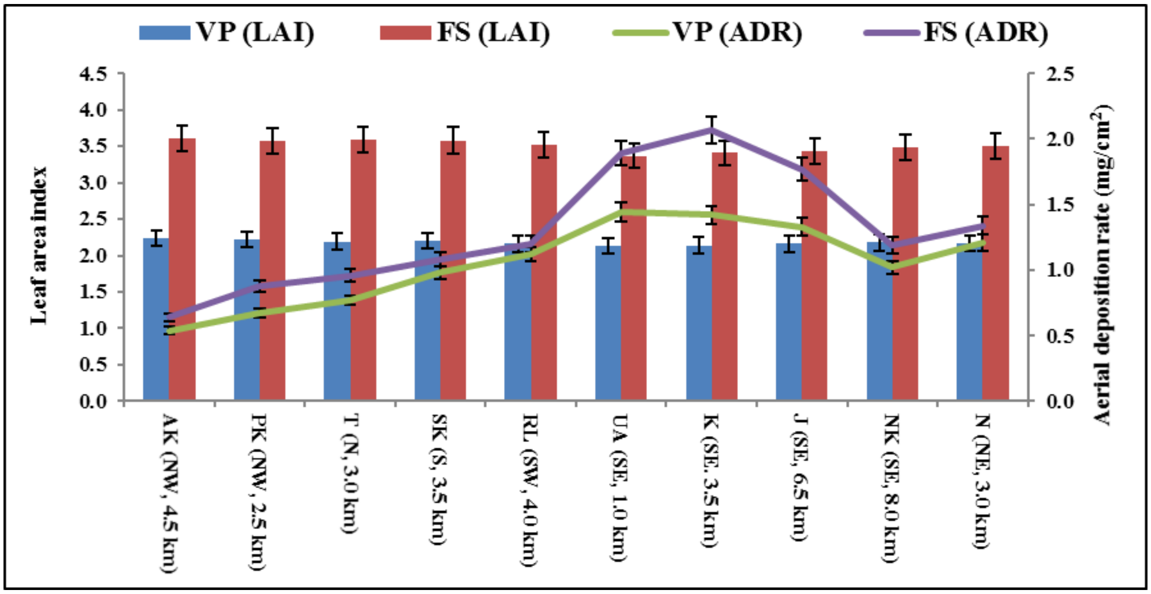

Figure 4.13: Aerial deposition rate (ADR) (mg/cm^2) on crop canopy and leaf area index (LAI) of rice crop at vegetative phase (VP) and flowering stage (FS) (2015-16)

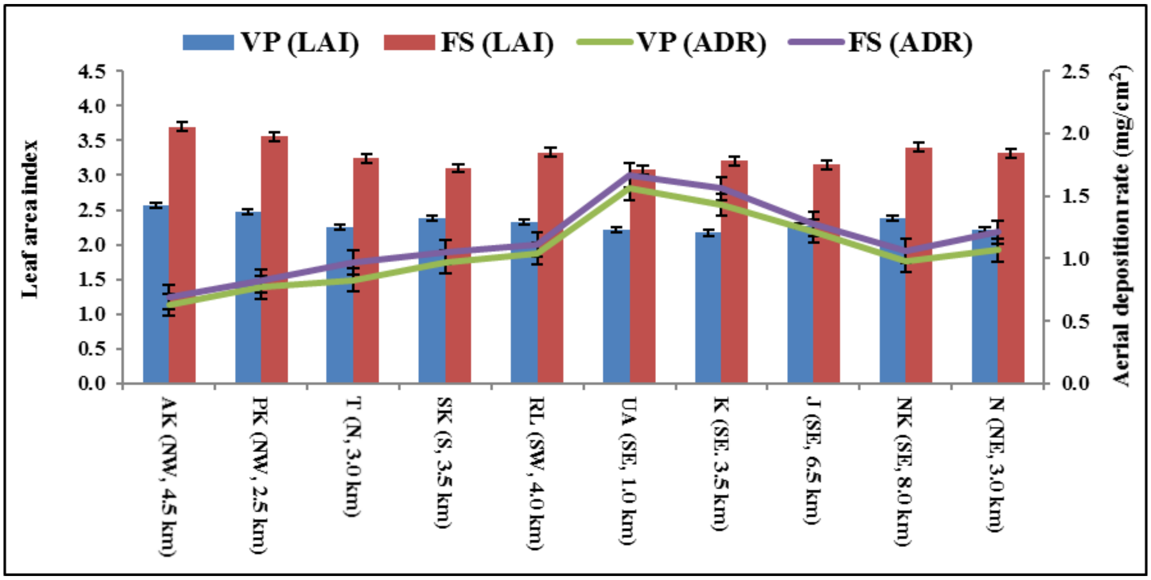

Figure 4.14: Aerial deposition rate (mg/cm^2) on crop canopy and leaf area index (LAI) of rice crop at vegetative and flowering stages (2016-17)

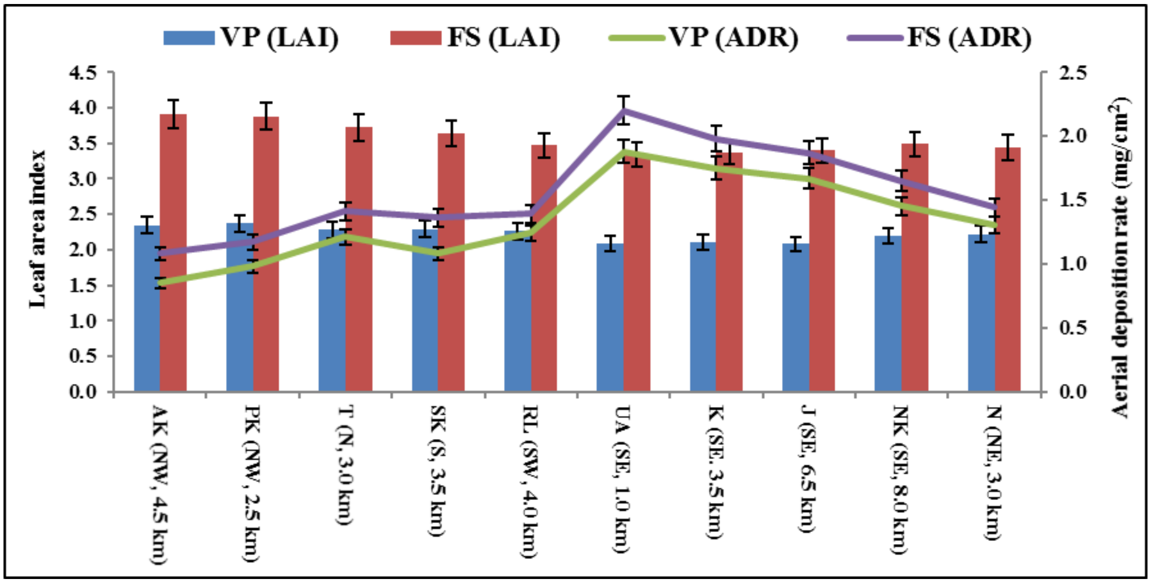

Figure 4.15: Aerial deposition rate (mg/cm^2) on crop canopy and leaf area index (LAI) of wheat crop at vegetative and flowering stages (2015-16)

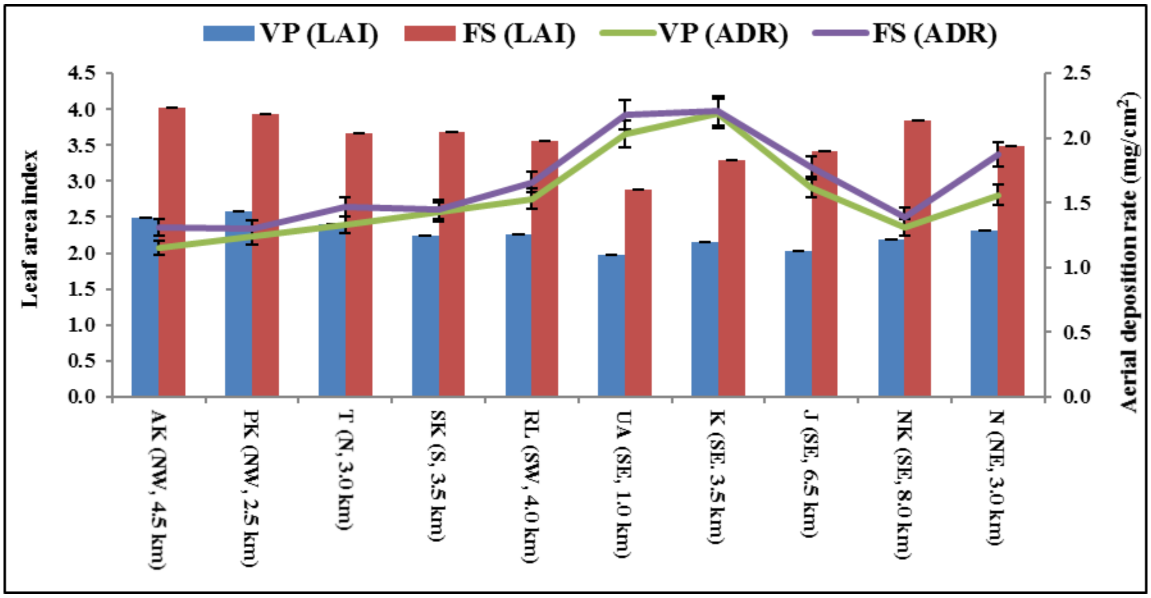

Figure 4.16: Aerial deposition rate (mg/cm^2) on crop canopy and leaf area index (LAI) of wheat crop at vegetative and flowering stages (2016-17)

4.5.2 Effect of air pollution on photosynthetic rate (Pn)

Air pollutants significantly affect the physiological parameters of the crpos. Crops grown at leeward side were more affected than windward side. Photosynthetic rate, transpiration rate and stomatal conductance were reduced with an increase in level of air pollutants. In rice crop maximum photosynthetic rate was found at Akilpur Jagir (12.57µmol/m^2/s) followed by Pyawali Tajpur (11.24 µmol/m^2/s), and the minimum was found at Khangoda (7.84µmol/m^2/s) followed by Jarcha (8.84µmol/m^2/s) at vegetative phase. Near about similar trend in photosynthesis rate in rice crop was also observed at flowering stage. The maximum photosynthetic rate was found at Akilpur Jagir (17.98 µmol/m^2/s) followed by Pyawali Tajpur (17.15µmol/m^2/s) whereas minimum at Uncha Amirpur (8.17µmol/m^2/s) followed by Jarcha (8.67µmol/m^2/s) in wheat crop at vegetative phase. The almost similar trend in photosynthesis rate was observed in the wheat crop at flowering stage during first year study (Fig. 4.17 and 4.19).

In the second consecutive year of study (2016-17), the maximum photosynthetic rate was found at Akilpur Jagir (20.15 µmol/m^2/s) followed by Tatarpur (19.77 µmol/m^2/s), whereas minimum was found at Khangoda (12.05 µmol/m^2/s) followed by Uncha Amirpur (12.84 µmol/m^2/s) at flowering stage in rice crop. In wheat crop maximum photosynthetic rate was found at Akilpur Jagir (22.05 µmol/m^2/s) followed by Pyawali Tajpur (21.40 µmol/m^2/s) whereas minimum at Khangoda (14.98 µmol/m^2/s) followed by Jarcha (15.15 µmol/m^2/s) at flowering stage (Fig. 4.18 and 4.20). The almost similar trend in photosynthetic rate was also observed at vegetative phase in both crops (Table 4.13 and 4.14).

Table 4.13: Photosynthetic rate (µmol/m^2/s) in rice and wheat crop (2015-16)

Sites	Rice		Wheat	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	12.57 ± 0.59	21.84 ± 1.11	17.98 ± 1.15	23.15 ± 0.56
Pyawali Tajpur	11.24 ± 0.12	19.15 ± 0.47	17.15 ± 0.45	21.8 ± 0.49
Tatarpur	11.54 ± 0.81	18.62 ± 1.12	15.01 ± 0.49	18.66 ± 1.14
Salarpur Kalan	11.6 ± 0.70	18.18 ± 1.43	16.15 ± 0.48	20.87 ± 0.52
Ranauli Latifpur	9.15 ± 0.97	16.77 ± 1.16	14.87 ± 0.99	17.54 ± 0.46
Jarcha	7.84 ± 0.35	13.45 ± 0.75	8.67 ± 0.35	16.57 ± 0.46
Khangoda	8.84 ± 0.86	12.48 ± 1.03	9.15 ± 0.66	15.36 ± 0.91
Uncha Amirpur	9.48 ± 1.07	12.64 ± 0.64	8.17 ± 0.27	14.05 ± 0.07
Nagla Kashi	10.56 ± 0.64	15.87 ± 0.87	14.15 ± 0.57	18.75 ± 0.27
Nidhauli	10.05 ± 0.52	16.15 ± 0.95	15.15 ± 0.57	18.66 ± 0.23
LSD (P=0.05)	1.28	1.77	1.14	1.05

Table 4.14: Photosynthetic rate (µmol/m^2/s) in rice and wheat crop (2016-17)

Sites	Rice			
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	12.77 ± 0.41	20.15 ± 0.31	18.14 ± 0.71	22.05 ± 0.32
Pyawali Tajpur	11.08 ± 0.53	19.2 ± 0.42	17.24 ± 0.34	21.4 ± 0.49
Tatarpur	11.34 ± 0.51	19.77 ± 1.02	14.05 ± 0.21	17.15 ± 0.41
Salarpur Kalan	10.87 ± 0.13	18.24 ± 0.75	15.8 ± 0.36	19.66 ± 0.36
Ranauli Latifpur	10.87 ± 0.22	15.15 ± 0.65	15.14 ± 0.51	17.63 ± 0.53
Jarcha	9.15 ± 0.43	14.84 ± 0.26	9.18 ± 0.3	15.15 ± 0.36
Khangoda	7.18 ± 0.05	12.05 ± 0.15	8.17 ± 0.54	14.98 ± 0.43
Uncha Amirpur	7.68 ± 0.56	12.84 ± 0.29	8.64 ± 0.42	15.28 ± 0.28
Nagla Kashi	11.8 ± 0.25	14.64 ± 0.52	12.15 ± 0.28	19.16 ± 0.27
Nidhauli	10.88 ± 0.43	16.87 ± 0.31	14.87 ± 0.51	18.7 ± 0.89
LSD (P=0.05)	0.68	0.90	0.77	0.78

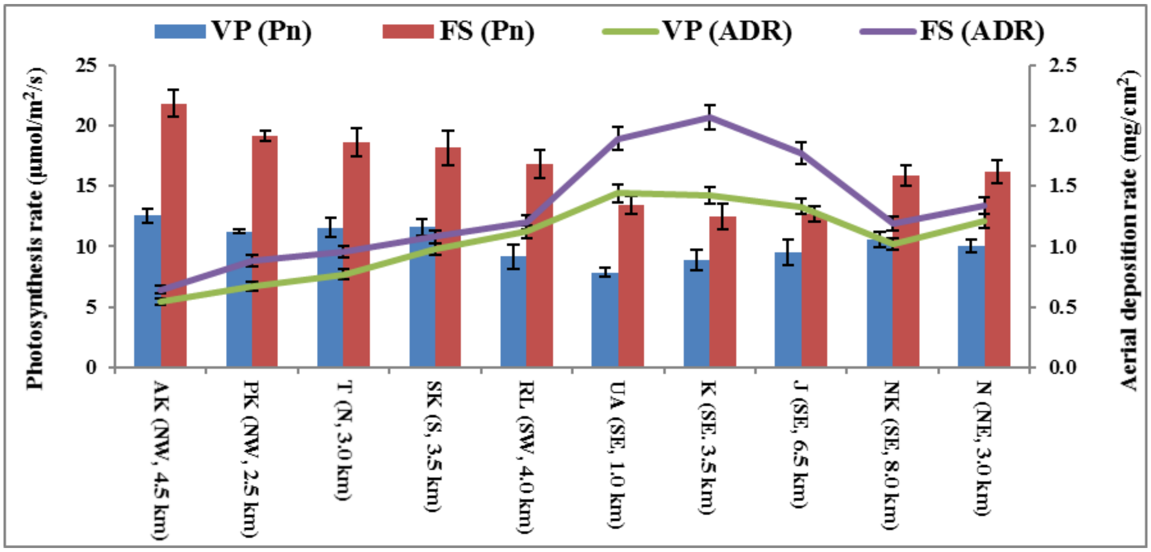

Figure 4.17: Aerial deposition rate (ADR) (mg/cm^2) on crop canopy and photosynthetic rate (Pn) (µmol/m^2/s) of rice crop at vegetative phase (VP) and flowering stages (FS) (2015-16)

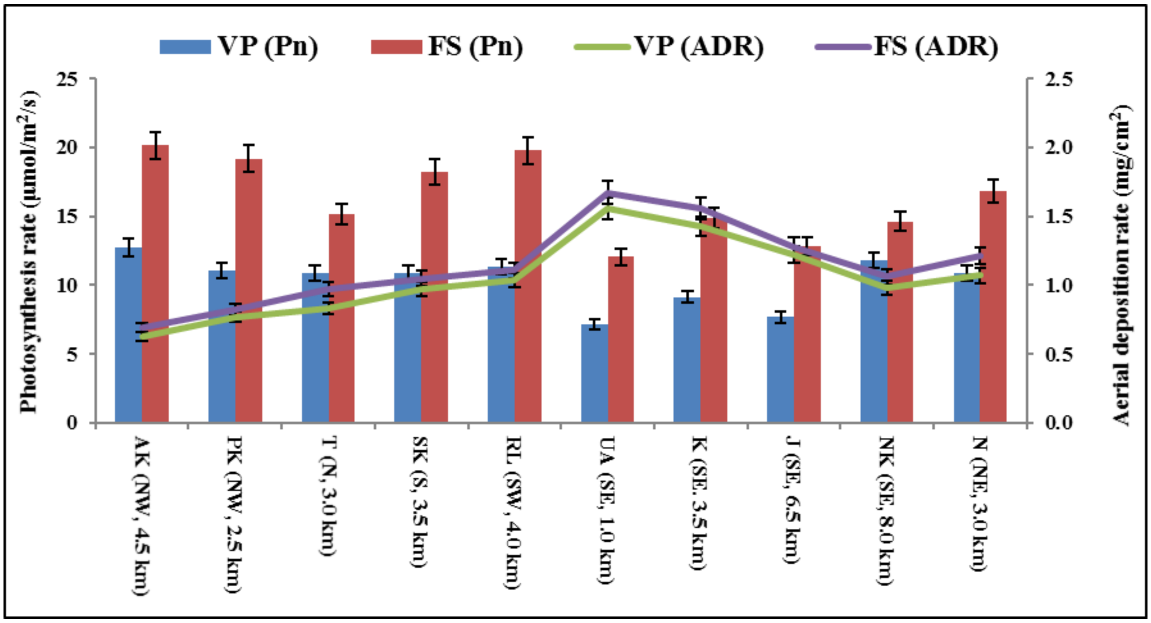

Figure 4.18: Aerial deposition rate (mg/cm^2) on crop canopy and photosynthetic rate (µmol/m^2/s) of rice crop at vegetative and flowering stages (2016-17)

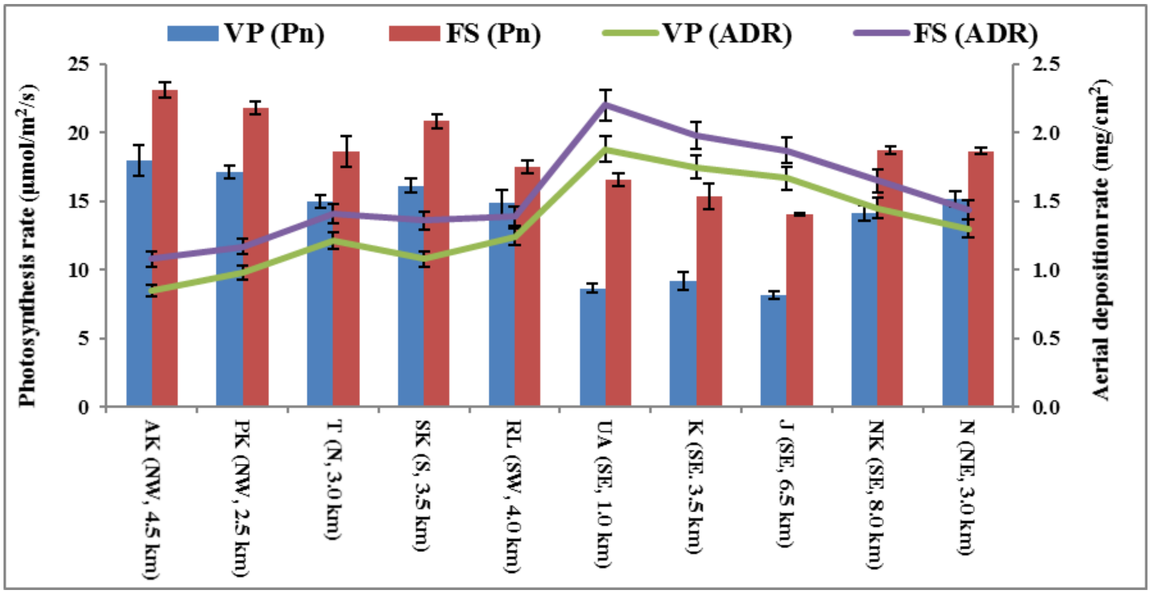

Figure 4.19: Aerial deposition rate (mg/cm^2) on crop canopy and photosynthetic rate (µmol/m^2/s) of the wheat crop at vegetative and flowering stages (2015-16)

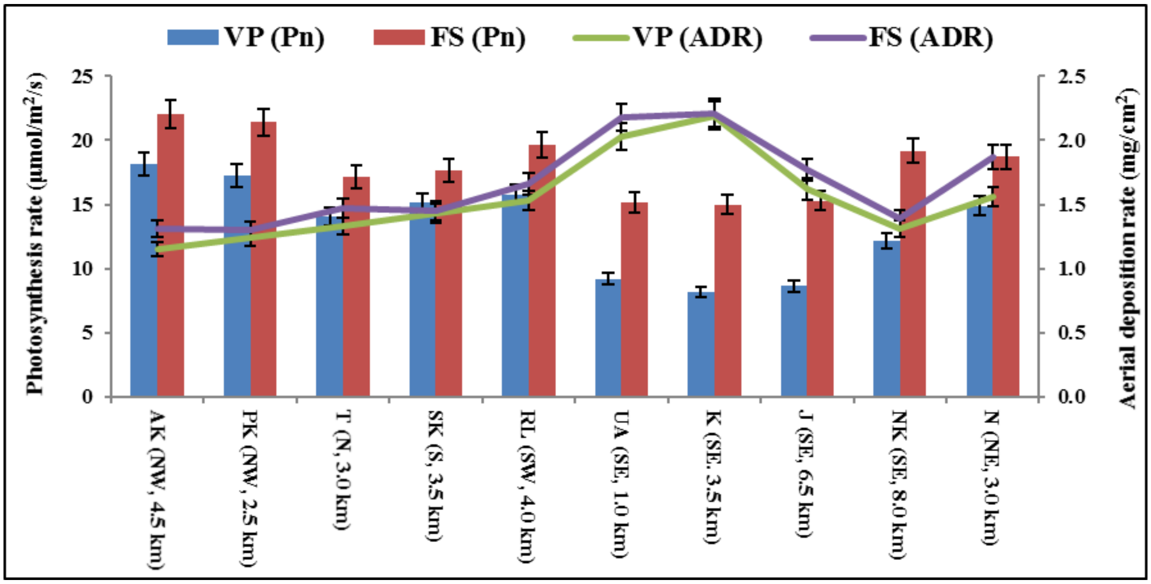

Figure 4.20: Aerial deposition rate (mg/cm^2) on crop canopy and photosynthetic rate (µmol/m^2/s) of the wheat crop at vegetative and flowering stages (2016-17)

4.5.3 Effect of air pollution on transpiration rate (E)

During first year study, at vegetative phase, the maximum transpiration rate in rice was found at Akilpur Jagir (12.55 mmol $H_2O/m^2/s$) followed by Pyawali Tajpur (11.87 mmol $H_2O/m^2/s$), whereas minimum was found at Uncha Amirpur (6.54 mmol $H_2O/m^2/s$) followed by Jarcha (7.32 mmol $H_2O/m^2/s$). Near about similar trend in transpiration rate in rice crop was also observed at flowering stage. The maximum transpiration rate in wheat was found at Akilpur Jagir (11.98 mmol $H_2O/m^2/s$) followed by Pyawali Tajpur (11.35 mmol $H_2O/m^2/s$) whereas minimum at Uncha Amirpur (5.88 mmol $H_2O/m^2/s$) followed by Khangoda (6.31 mmol $H_2O/m^2/s$) at vegetative phase. Almost similar results in wheat crop were also observed at flowering stage (Fig. 4.21 and 4.23).

In 2016-17, results showed that maximum transpiration rate in rice was found at Akilpur Jagir (10.54 mmol $H_2O/m^2/s$) followed by Pyawali Tajpur (9.84 mmol $H_2O/m^2/s$), whereas minimum was found at Uncha Amirpur (6.66 mmol $H_2O/m^2/s$) followed by Khangoda (7.27 mmol $H_2O/m^2/s$) at flowering stage. The maximum transpiration rate in wheat was found at Akilpur Jagir (8.65 mmol $H_2O/m^2/s$) followed by Pyawali Tajpur (7.68 mmol $H_2O/m^2/s$) whereas minimum at Jarcha (5.08 mmol $H_2O/m^2/s$) followed by Khangoda (5.47 mmol $H_2O/m^2/s$) at flowering stage (Fig. 4.22 and 4.24). Almost similar results were also observed at vegetative phase in both the crops (Table 4.15 and 4.16).

Table 4.15: Transpiration rate (mmol $H_2O/m^2/s$) in rice and wheat crop (2015-16)

Sites	Rice		Wheat	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	12.55 ± 0.42	11.65 ± 1.06	11.98 ± 0.78	10.88 ± 0.25
Pyawali Tajpur	11.87 ± 0.55	10.64 ± 0.35	11.35 ± 0.61	10.21 ± 0.38
Tatarpur	9.64 ± 0.43	10.21 ± 0.61	9.74 ± 0.19	9.55 ± 0.51
Salarpur Kalan	9.66 ± 0.68	9.84 ± 0.36	9.15 ± 0.24	8.15 ± 0.03
Ranauli Latifpur	10.54 ± 0.21	8.64 ± 0.52	8.21 ± 0.11	8.87 ± 0.32
Jarcha	7.32 ± 0.17	7.35 ± 0.14	6.86 ± 0.32	7.21 ± 0.28
Khangoda	7.54 ± 0.5	8.08 ± 0.37	6.31 ± 0.24	6.47 ± 0.36
Uncha Amirpur	6.54 ± 0.07	6.44 ± 0.19	5.88 ± 0.43	6.55 ± 0.21
Nagla Kashi	9.84 ± 0.51	10.15 ± 0.28	8.01 ± 0.33	8.14 ± 0.9
Nidhauli	9.88 ± 0.21	10.77 ± 0.44	7.33 ± 0.21	7.63 ± 0.23
LSD (P=0.05)	0.76	0.89	0.70	0.69

Table 4.16: Transpiration rate (mmol $H_2O/m^2/s$) in rice and wheat crop (2016-17)

Sites	Rice		Wheat	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	12.54 ± 0.29	10.54 ± 0.11	10.58 ± 0.13	8.65 ± 0.13
Pyawali Tajpur	11.08 ± 0.11	9.84 ± 0.29	9.78 ± 0.38	7.68 ± 0.12
Tatarpur	9.84 ± 0.35	9.22 ± 0.33	8.65 ± 0.22	7.14 ± 0.11
Salarpur Kalan	10.15 ± 0.25	9.44 ± 0.1	7.18 ± 0.16	7.02 ± 0.12
Ranauli Latifpur	10.85 ± 0.25	8.15 ± 0.12	8.33 ± 0.34	6.54 ± 0.3
Jarcha	6.88 ± 0.2	7.68 ± 0.22	6.15 ± 0.1	5.08 ± 0.07
Khangoda	6.51 ± 0.11	7.27 ± 0.24	5.28 ± 0.17	5.47 ± 0.35
Uncha Amirpur	6.03 ± 0.02	6.66 ± 0.22	5.64 ± 0.48	5.66 ± 0.34
Nagla Kashi	8.36 ± 0.45	8.98 ± 0.36	7.98 ± 0.14	7.1 ± 0.21
Nidhauli	9.21 ± 0.15	8.68 ± 0.28	8.47 ± 0.26	6.89 ± 0.33
LSD (P=0.05)	0.43	0.39	0.44	0.37

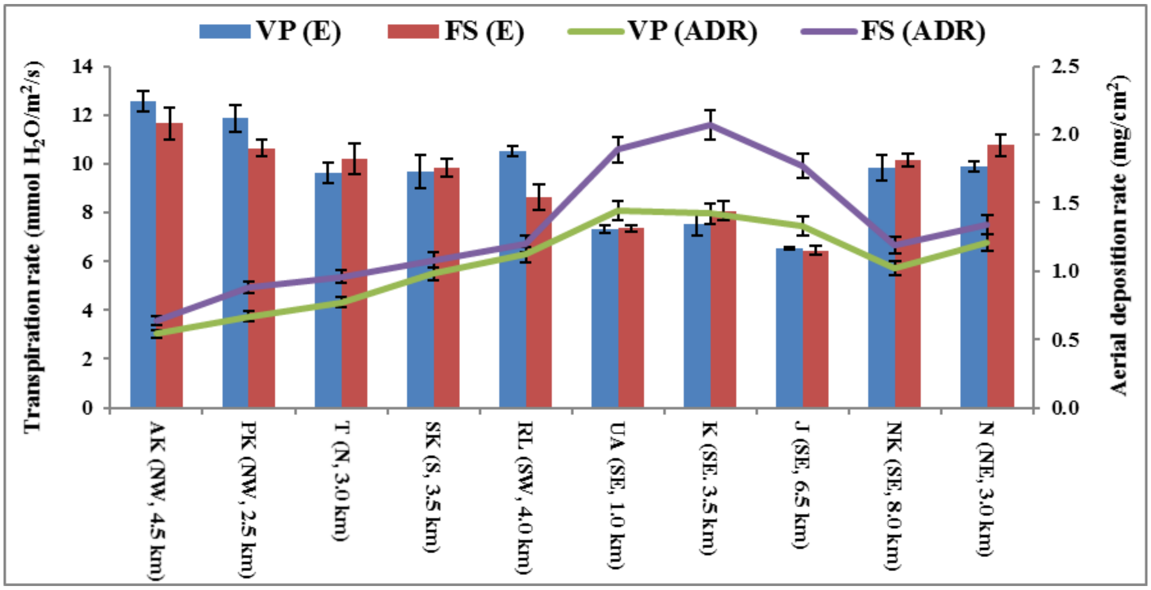

Figure 4.21: Aerial deposition rate (ADR) (mg/cm^2) on crop canopy and transpiration rate (E) (mmol $H_2O/m^2/s$) of rice crop at vegetative phase (VP) and flowering stage (FS) (2015-16)

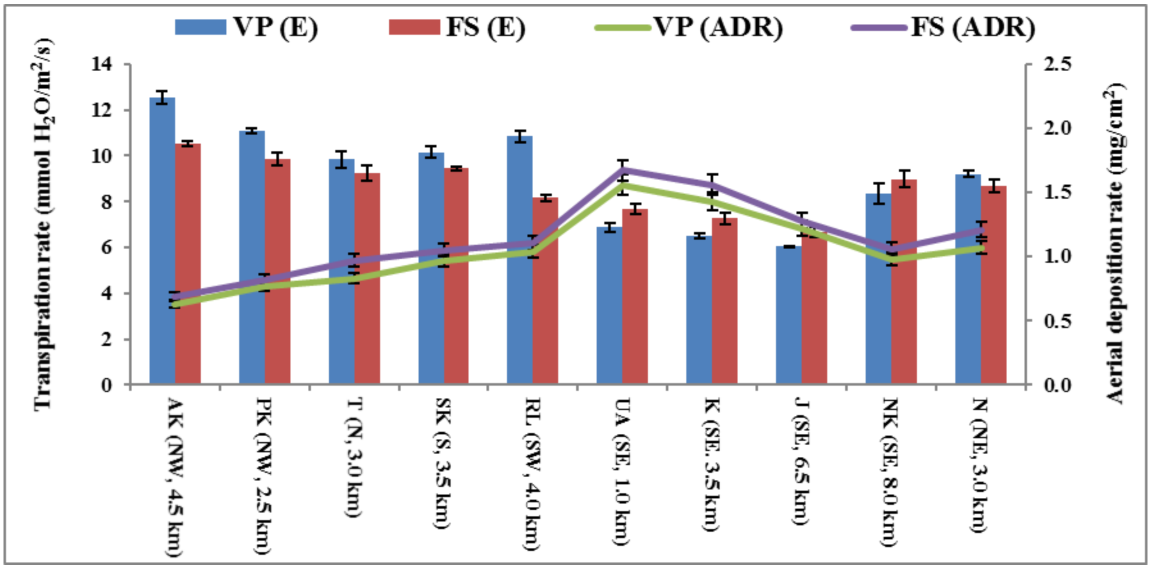

Figure 4.22: Aerial deposition rate (mg/cm^2) on crop canopy and transpiration rate (mmol $H_2O/m^2/s$) of rice crop at vegetative and flowering stages (2016-17)

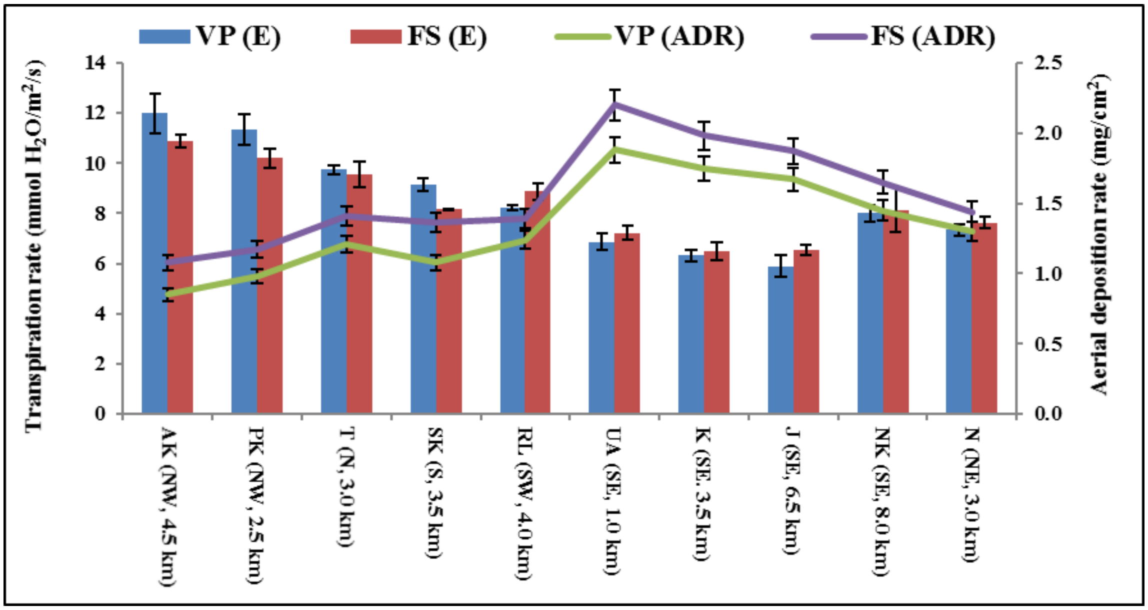

Figure 4.23: Aerial deposition rate (mg/cm^2) on crop canopy and transpiration rate (mmol $H_2O/m^2/s$) of the wheat crop at vegetative and flowering stages (2015-16)

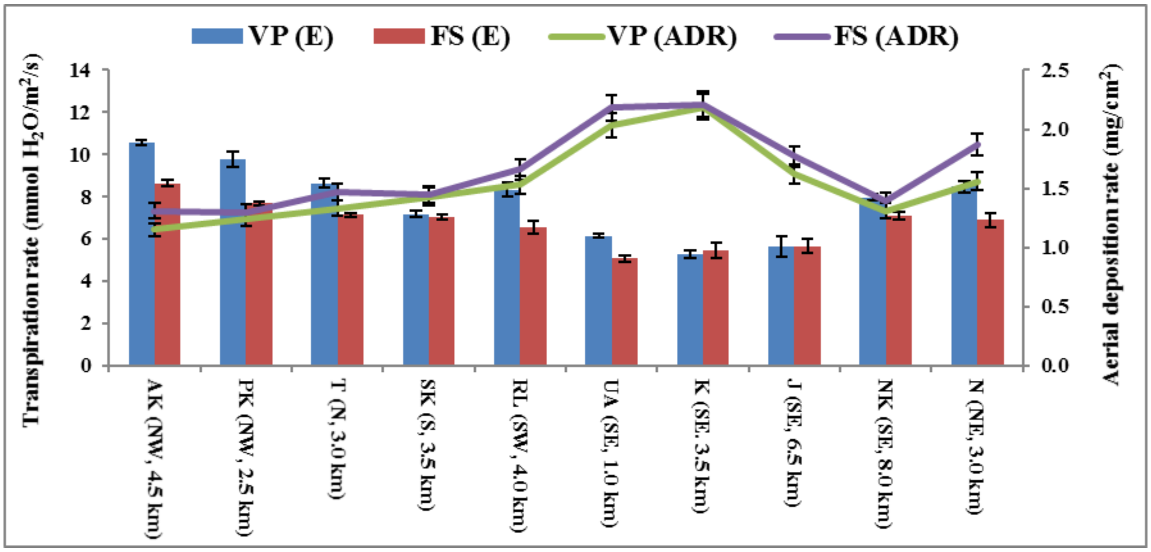

Figure 4.24: Aerial deposition rate (mg/cm^2) on crop canopy and transpiration rate (mmol $H_2O/m^2/s$) of the wheat crop at vegetative and flowering stages (2016-17)

4.5.4 Effect of air pollution on stomatal conductance (gs)

During first year study, the maximum stomatal conductance in rice was found at Akilpur Jagir (0.68 mol/m^2/s) followed by Pyawali Tajpur (0.62 mol/m^2/s), whereas minimum was found at Jarcha (0.44 mol/m^2/s) followed by Khangoda (0.46 mol/m^2/s) at vegetative phase. Near about similar trend in stomatal conductance in rice crop was also observed at flowering stage. The maximum stomatal conductance in wheat was found at Pyawali Tajpur (0.60 mol/m^2/s) followed by Akilpur Jagir (0.55 mol/m^2/s) whereas minimum at Jarcha (0.40 mol/m^2/s) followed by Uncha Amirpur (0.43 mol/m^2/s) at vegetative phase. Almost similar results in wheat crop were also observed at flowering stage (Fig. 4.25 and 4.27).

In 2016-17, the maximum stomatal conductance in rice was found at Akilpur Jagir (0.62 mol/m^2/s) followed by Pyawali Tajpur (0.53 mol/m^2/s), whereas minimum was found at Uncha Amirpur (0.36 mol H_2O/m^2/s) followed by Jarcha (0.38 mol/m^2/s) at flowering stage. The maximum stomatal conductance in wheat was found at Akilpur Jagir (0.57 mol/m^2/s) followed by Pyawali Tajpur (0.56 mol/m^2/s) whereas minimum at Jarcha (0.36 mol/m^2/s) followed by Khangoda (0.38 mol/m^2/s) at flowering stage (Fig. 4.26 and 4.28). Almost similar results were also observed at vegetative phase in both the crops (Table 4.17 and 4.18).

Table 4.17: Stomatal conductance (mol/m^2/s) in rice and wheat crop (2015-16)

Sites	Rice		Wheat	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	0.68 ± 0.12	0.54 ± 0.05	0.55 ± 0.03	0.52 ± 0.11
Pyawali Tajpur	0.62 ± 0.04	0.58 ± 0.02	0.6 ± 0.03	0.49 ± 0.07
Tatarpur	0.6 ± 0.02	0.51 ± 0.04	0.5 ± 0.09	0.47 ± 0.04
Salarpur Kalan	0.59 ± 0.06	0.51 ± 0.11	0.54 ± 0.02	0.48 ± 0.06
Ranauli Latifpur	0.56 ± 0.08	0.48 ± 0.04	0.48 ± 0.04	0.46 ± 0.02
Jarcha	0.44 ± 0.07	0.3 ± 0.03	0.4 ± 0.06	0.38 ± 0.05
Khangoda	0.46 ± 0.1	0.32 ± 0.04	0.43 ± 0.03	0.41 ± 0.03
Uncha Amirpur	0.5 ± 0.02	0.35 ± 0.04	0.43 ± 0.01	0.42 ± 0.02
Nagla Kashi	0.54 ± 0.07	0.46 ± 0.02	0.49 ± 0.04	0.51 ± 0.04
Nidhauli	0.56 ± 0.02	0.49 ± 0.1	0.51 ± 0.05	0.46 ± 0.03
LSD (P=0.05)	0.09	0.07	0.08	0.08

Table 4.18: Stomatal conductance (mol/m^2/s) in rice and wheat crop (2016-17)

Sites	Rice		Wheat	
	Vegetative phase	Flowering stage	Vegetative phase	Flowering stage
Akilpur Jagir	0.7 ± 0.03	0.62 ± 0.05	0.64 ± 0.05	0.57 ± 0.08
Pyawali Tajpur	0.63 ± 0.05	0.53 ± 0.05	0.55 ± 0.1	0.56 ± 0.07
Tatarpur	0.54 ± 0.03	0.49 ± 0.13	0.54 ± 0.11	0.5 ± 0.07
Salarpur Kalan	0.59 ± 0.04	0.47 ± 0.08	0.52 ± 0.06	0.48 ± 0.04
Ranauli Latifpur	0.58 ± 0.11	0.42 ± 0.02	0.5 ± 0.07	0.47 ± 0.04
Jarcha	0.52 ± 0.04	0.38 ± 0.06	0.42 ± 0.05	0.36 ± 0.03
Khangoda	0.45 ± 0.04	0.39 ± 0.05	0.38 ± 0.04	0.38 ± 0.07
Uncha Amirpur	0.49 ± 0.01	0.36 ± 0.09	0.37 ± 0.05	0.38 ± 0.08
Nagla Kashi	0.57 ± 0.02	0.44 ± 0.03	0.49 ± 0.01	0.44 ± 0.04
Nidhauli	0.56 ± 0.03	0.4 ± 0.06	0.42 ± 0.02	0.46 ± 0.02
LSD (P=0.05)	0.07	0.11	0.11	0.09

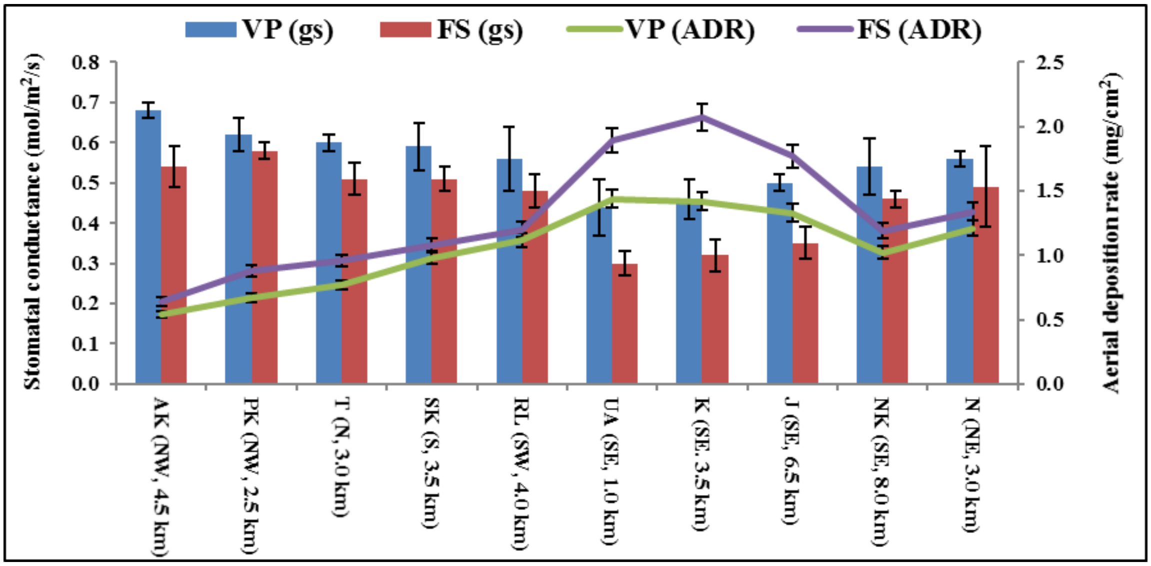

Figure 4.25: Aerial deposition rate (ADR) (mg/cm^2) on crop canopy and stomatal conductance (gs) (mol/m^2/s) of rice crop at vegetative phase (VP) and flowering stage (FS) (2015-16)

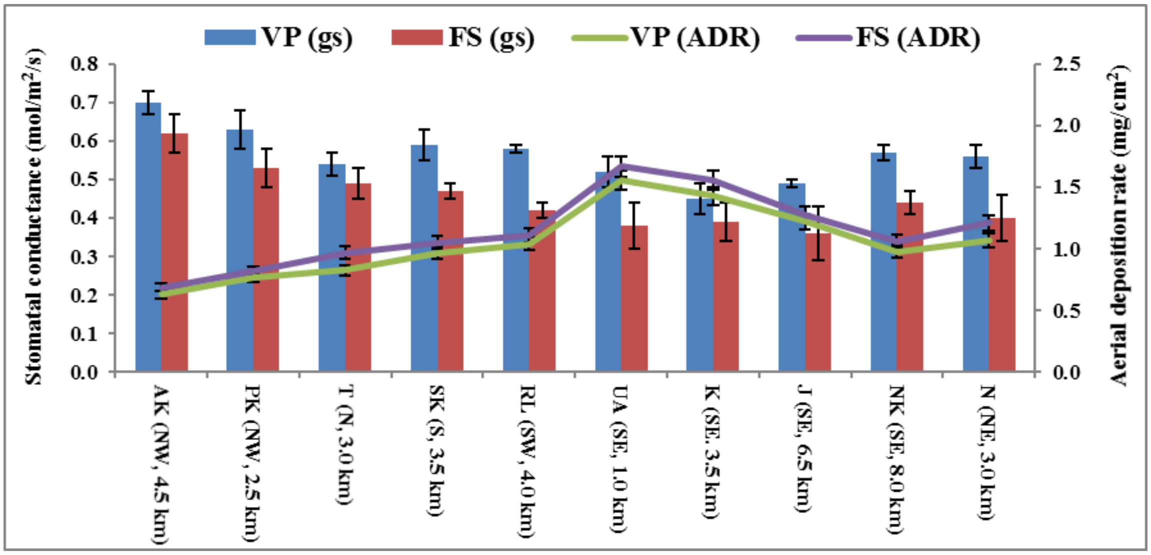

Figure 4.26: Aerial deposition rate (mg/cm^2) on crop canopy and stomatal conductance (mol/m^2/s) of rice crop at vegetative and flowering stages (2016-17)

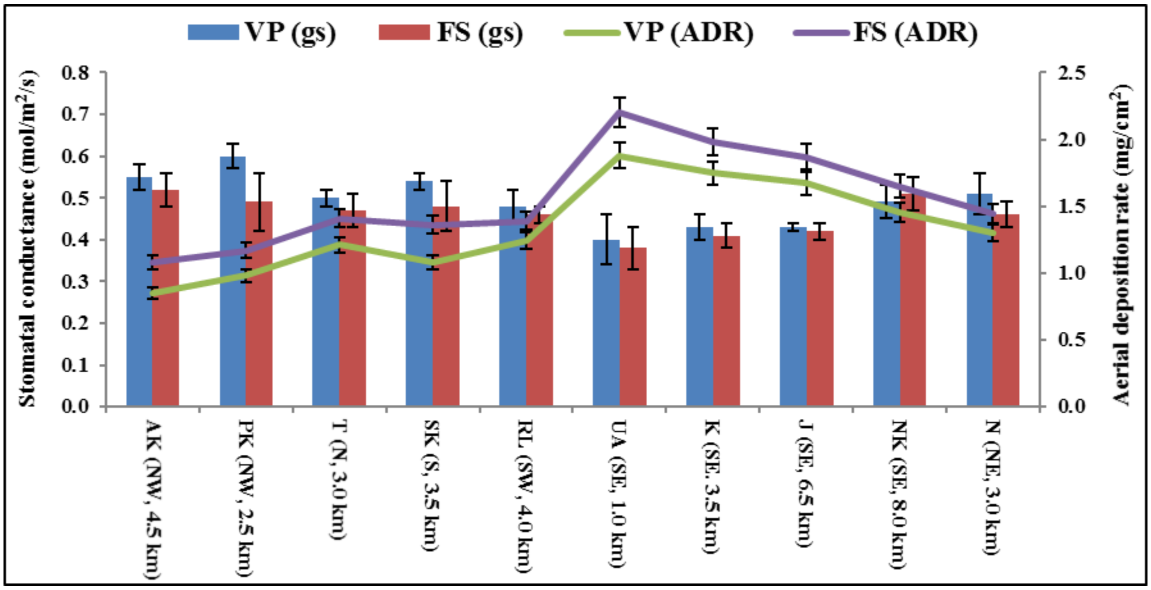

Figure 4.27: Aerial deposition rate (mg/cm^2) on crop canopy and stomatal conductance (mol/m^2/s) of the wheat crop at vegetative and flowering stages (2015-16)

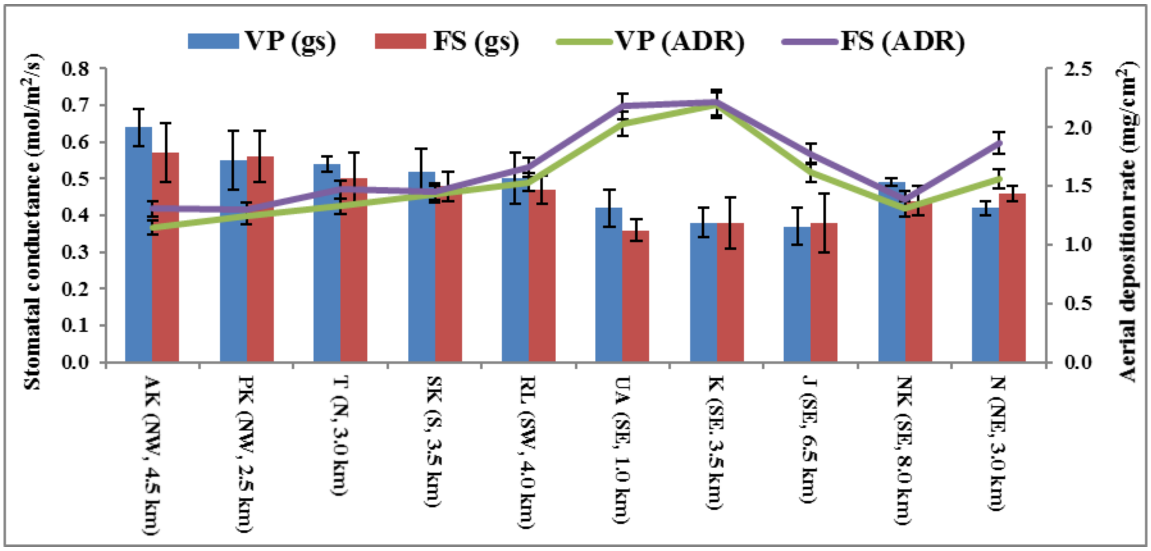

Figure 4.28: Aerial deposition rate (mg/cm^2) on crop canopy and stomatal conductance (mol/m^2/s) of the wheat crop at vegetative and flowering stages (2016-17)

4.6 Effect of air pollutants on biochemical parameters of the crops

For the analysis of biochemical parameters seven crops such as *Oryza sativa, Triticum aestivum, Pennisetum glaucum, sorghum bicolor, Hordeum vulgare, Brassica juncea and Trifolium alexandrinum* were selected which were common in all selected sites in the study area during Kharif and Rabi seasons in 2015-16 and 2016-17. These seven crops were grown at only four villages hence the analysis of biochemical parameters discussed for these selected sites. To calculate the APTI, the leaves samples were collected from these sites and analyzed for biochemical parameters such as pH, total chlorophyll, ascorbic acid and relative water content.

4.6.1 Aerial deposition of particulate matter on crop canopy at selected sites

The maximum deposition was reported at Khangoda (most polluted site) and minimum at Akilpur Jagir (control site) and it was ranged from 0.56 to 2.15 mg/cm^2 for various crop species at selected sites. Dust accumulation capacity was maximum in *Hordeum vulgare* (2.15 mg/cm^2) and minimum in *Brassica juncea* (1.06 mg/cm^2) at most polluted site (Khangoda) during 2015-16. Whereas dust accumulation capacity was maximum in *Triticum aestivum* (2.21 mg/cm^2) and minimum in *Trifolium alexandrinum* (1.06 mg/cm^2) at most polluted site during 2016-17 (Fig. 4.29 and 4.30). In Rabi crops, atmospheric deposition load on leaves was found to be more than Kharif crops. This is primarily due to less rainfall in Rabi season than the Kharif season. Higher rainfall in Kharif might have washed out most of the deposited particulate matter (Table 4.19 and 4.20).

Table 4.19: Aerial deposition on crop canopy (mg/cm^2) (2015-16)

Sites	*Oryza sativa*	*Triticum aestivum*	*Pennisetum glaucum*	*Sorghum bicolor*	*Hordeum vulgare*	*Brassica juncea*	*Trifolium alexandrinum*
Akilpur Jagir	0.88 ± 0.12	1.17 ± 0.12	1.05 ± 0.11	0.97 ± 0.16	1.05 ± 0.08	0.56 ± 0.14	0.72 ± 0.13
Khangoda	2.07 ± 0.16	1.98 ± 0.09	2.11 ± 0.13	1.93 ± 0.14	2.15 ± 0.14	1.06 ± 0.18	1.11 ± 0.13
Ranauli Latifpur	1.2 ± 0.11	1.39 ± 0.12	1.89 ± 0.1	1.67 ± 0.12	1.68 ± 0.1	0.77 ± 0.15	1.02 ± 0.07
Nidhauli	1.34 ± 0.08	1.44 ± 0.1	1.72 ± 0.09	1.52 ± 0.08	1.44 ± 0.1	0.89 ± 0.11	0.82 ± 0.09

Table 4.20: Aerial deposition on crop canopy (mg/cm^2) (2016-17)

Sites	*Oryza sativa*	*Triticum aestivum*	*Pennisetum glaucum*	*Sorghum bicolor*	*Hordeum vulgare*	*Brassica juncea*	*Trifolium alexandrinum*
Akilpur Jagir	0.69 ± 0.07	1.31 ± 0.06	0.98 ± 0.08	1.05 ± 0.14	1.1 ± 0.14	0.68 ± 0.4	0.65 ± 0.1
Khangoda	1.56 ± 0.09	2.21 ± 0.1	1.7 ± 0.12	1.98 ± 0.07	2.01 ± 0.17	1.34 ± 0.17	1.06 ± 0.09
Ranauli Latifpur	1.11 ± 0.08	1.66 ± 0.09	1.56 ± 0.09	1.75 ± 0.11	1.78 ± 0.11	0.98 ± 0.14	0.97 ± 0.12
Nidhauli	1.21 ± 0.06	1.87 ± 0.11	1.69 ± 0.15	1.44 ± 0.13	1.56 ± 0.12	1.06 ± 0.11	0.82 ± 0.12

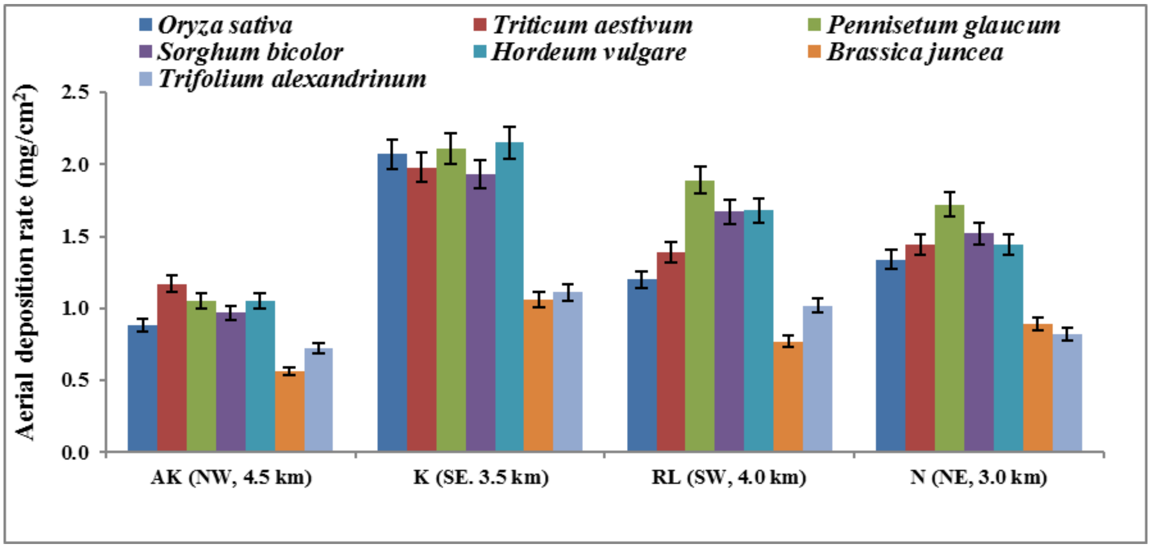

Figure 4.29: Aerial deposition rate (mg/cm^2) on selected crop species at different sites during 2015-16

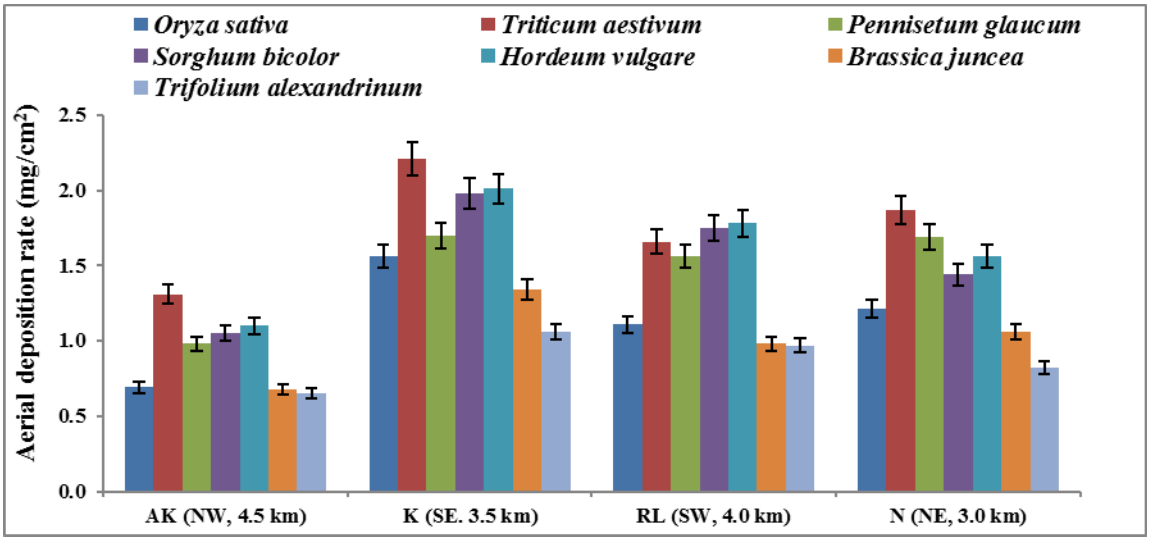

Figure 4.30: Aerial deposition rate (mg/cm^2) on selected crop species at different sites during 2016-17

4.6.2 Effect of air pollutants on pH of leaf extract

The leaf extract pH was ranged from 5.89 to 7.87, 5.4 to 6.12, 5.8 to 6.68 and 5.79 to 6.48 at Akilpur Jagir, Khangoda, Ranauli Latifpur and Nidhauli villages respectively in different crop species and maximum pH was found in *Sorghum bicolor* whereas minimum in *Oryza sativa* crop at Khangoda (most polluted site) during 2015-16. During 2016-17, we found maximum pH value in *Trifolium alexandrinum* amd minimum in *Oryza sativa* crop. Range of pH value at different sites was almost similar to previous year (Table 4.21 and 4.22).

4.6.3 Effect of air pollutants on relative water content (RWC)

It has been found that all crops grown at polluted sites had less RWC than control site. During 2015-16, we recorded maximum RWC in *Trifolium alexandrinum* (92.26%), whereas minimum in *Brassica juncea* (83.41%) at control site and at Khangoda (most polluted site), maximum RWC was found in *Triticum aestivum* (82.17%), whereas minimum in *Sorghum bicolor* (62.79%). During second year study, we observed that highest RWC in Sorghum bicolor (90.70%) and minimum in *Brassica juncea* (85.42%) at control site, whereas at most polluted site, maximum in *Pennisetum glaucum* (79.76%) and minimum in *Sorghum bicolor* (66.18%) (Table 4.21 and 4.22).

4.6.4 Effect of air pollutants on total chlorophyll content

Total chlorophyll content in different crop species was analyzed at selected sites and results showed that maximum total chlorophyll was in *Trifolium alexandrinum* (3.42 mg/g), whereas minimum in Oryza sativa (2.92 mg/g) at control site and at Khangoda (most polluted site), maximum total chlorophyll was found in *Triticum aestivum* (2.71 mg/g), whereas minimum in *Sorghum bicolor* (2.14 mg/g) in 2015-16. During second year study, we observed that highest total chlorophyll content in *Triticum aestivum* (3.45 mg/g) and minimum in *Hordeum vulgare* (2.87 mg/g) at control site, whereas at most polluted site, maximum in *Triticum aestivum* (2.70 mg/g) and minimum in *Sorghum bicolor* (2.08 mg/g) (Table 4.21 and 4.22).

4.6.5 Effect of air pollutants on ascorbic acid

Ascorbic acid level was reduced at all pollutes sites in compared to control site. Ascorbic acid was maximum in *Brassica juncea* (0.017) and minimum in *Hordeum vulgare* (0.025) at control site whereas maximum in *Oryza sativa* (0.012) and minimum in *Hordeum vulgare* (0.016) at most polluted site (Khangoda) during 2015-16. Second year study, results showed that maximum ascorbic acid found in *Brassica juncea* (0.018) and minimum in *Triticum aestivum* (0.026) at control site whereas maximum in *Oryza sativa* (0.011) and minimum in *Hordeum vulgare* (0.015) at most polluted site (Table 4.21 and 4.22).

4.6.6 Air pollution tolerance index (APTI)

On the basis of above these biochemical parameters, APTI was calculated and results showed that crop grown at polluted sites had less APTI value than control site. Maximum APTI value was found in *Triticum aestivum* (8.23) and minimum in *Brassica juncea* (7.63) at most polluted site, whereas at control site maximum APTI value was found in *Trifolium alexandrinum* (9.25) and minimum in *Brassica juncea* (8.36) in 2015-16. During 2016-17 maximum APTI value was found in *Trifolium alexandrinum* (7.97) and minimum in *Brassica juncea* (7.46) at most polluted site. It has been found that the APTI values are less than 12 which means all crops were sensitive to air pollution in selected area but *Triticum aestivum* and *Trifolium alexandrinum* were less sensitive in compared to other crops during first and second year study respectively. Crop plants having more APTI value are tolerant, whereas those having less value are sensitive to air pollution (Table 4.21 and 4.22).

Table 4.21: Biochemical parametrs and APTI values for different crop species at selected sites during 2015-16

Crops	Sites	RWC (%)	pH	Total chlorophyll (mg/g)	Ascorbic acid (mg/g)	APTI
Oryza sativa	Akilpur Jagir	87.54 ± 2.62	6.57 ± 0.03	2.92 ± 0.06	0.022 ± 0.07	8.77
	Khangoda	78.54 ± 3.39	5.4 ± 0.03	2.54 ± 0.06	0.012 ± 0.03	7.86
	Ranauli Latifpur	82.04 ± 4.32	5.94 ± 0.02	2.6 ± 0.07	0.014 ± 0.06	8.22
	Nidhauli	82.15 ± 3.27	6.21 ± 0.02	2.67 ± 0.09	0.014 ± 0.03	8.23
Triticum aestivum	Akilpur Jagir	91.21 ± 1.69	6.11 ± 0.05	3.31 ± 0.07	0.023 ± 0.05	9.14
	Khangoda	82.17 ± 3.23	5.77 ± 0.03	2.71 ± 0.06	0.012 ± 0.07	8.23
	Ranauli Latifpur	86.82 ± 2.43	5.8 ± 0.02	2.8 ± 0.04	0.014 ± 0.07	8.69
	Nidhauli	89.74 ± 2.74	5.79 ± 0.05	2.75 ± 0.07	0.016 ± 0.04	8.99
Pennisetum glaucum	Akilpur Jagir	91.3 ± 1.92	7.26 ± 0.06	3.25 ± 0.08	0.021 ± 0.07	9.15
	Khangoda	82.11 ± 4.09	5.89 ± 0.03	2.23 ± 0.04	0.014 ± 0.06	8.22
	Ranauli Latifpur	88.51 ± 1.63	6.12 ± 0.06	2.56 ± 0.05	0.016 ± 0.04	8.87
	Nidhauli	86.7 ± 2.86	6.48 ± 0.05	2.66 ± 0.02	0.016 ± 0.05	8.68
Sorghum bicolor	Akilpur Jagir	87.94 ± 2.07	7.87 ± 0.05	2.97 ± 0.12	0.022 ± 0.03	8.82
	Khangoda	78.54 ± 2.52	6.12 ± 0.04	2.14 ± 0.03	0.013 ± 0.07	7.86
	Ranauli Latifpur	75.39 ± 3.16	6.3 ± 0.04	2.43 ± 0.04	0.016 ± 0.04	7.55
	Nidhauli	85.85 ± 3.01	6.48 ± 0.05	2.39 ± 0.08	0.013 ± 0.06	8.60
Hordeum vulgare	Akilpur Jagir	92.11 ± 2.42	6.76 ± 0.05	3.12 ± 0.07	0.025 ± 0.04	9.24
	Khangoda	78.71 ± 3.52	5.7 ± 0.04	2.57 ± 0.05	0.016 ± 0.04	7.88
	Ranauli Latifpur	82.44 ± 3.81	6.05 ± 0.08	2.67 ± 0.08	0.017 ± 0.06	8.26
	Nidhauli	90.19 ± 1.96	6.22 ± 0.03	2.8 ± 0.1	0.017 ± 0.03	9.03
Brassica juncea	Akilpur Jagir	83.41 ± 2.89	6.8 ± 0.05	2.92 ± 0.03	0.017 ± 0.04	8.36

Continue…

	Khangoda	76.19 ± 3.03	5.52 ± 0.05	2.57 ± 0.05	0.014 ± 0.06	7.63
	Ranauli Latifpur	79.82 ± 4.16	5.8 ± 0.05	2.6 ± 0.04	0.013 ± 0.05	7.99
	Nidhauli	80.19 ± 4.09	5.97 ± 0.07	2.72 ± 0.09	0.015 ± 0.03	8.03
Trifolium alexandrinum	Akilpur Jagir	92.26 ± 1.03	7.54 ± 0.06	3.42 ± 0.04	0.023 ± 0.07	9.25
	Khangoda	81.5 ± 3.52	6.1 ± 0.05	2.37 ± 0.04	0.015 ± 0.05	8.16
	Ranauli Latifpur	85.38 ± 2.74	6.68 ± 0.06	2.56 ± 0.03	0.016 ± 0.04	8.55
	Nidhauli	85.85 ± 3.41	6.09 ± 0.05	2.4 ± 0.04	0.017 ± 0.09	8.60

Table 4.22: Biochemical parametrs and APTI values for different crop species at selected sites during 2016-17

Crops	Sites	RWC (%)	pH	Total chlorophyll (mg/g)	Ascorbic acid (mg/g)	APTI
Oryza sativa	Akilpur Jagir	87.54 ± 2.62	6.57 ± 0.03	2.92 ± 0.06	0.022 ± 0.07	8.77
	Khangoda	78.54 ± 3.39	5.4 ± 0.03	2.54 ± 0.06	0.012 ± 0.03	7.86
	Ranauli Latifpur	82.04 ± 4.32	5.94 ± 0.02	2.6 ± 0.07	0.014 ± 0.06	8.22
	Nidhauli	82.15 ± 3.27	6.21 ± 0.02	2.67 ± 0.09	0.014 ± 0.03	8.23
Triticum aestivum	Akilpur Jagir	91.21 ± 1.69	6.11 ± 0.05	3.31 ± 0.07	0.023 ± 0.05	9.14
	Khangoda	82.17 ± 3.23	5.77 ± 0.03	2.71 ± 0.06	0.012 ± 0.07	8.23
	Ranauli Latifpur	86.82 ± 2.43	5.8 ± 0.02	2.8 ± 0.04	0.014 ± 0.07	8.69
	Nidhauli	89.74 ± 2.74	5.79 ± 0.05	2.75 ± 0.07	0.016 ± 0.04	8.99
Pennisetum glaucum	Akilpur Jagir	91.3 ± 1.92	7.26 ± 0.06	3.25 ± 0.08	0.021 ± 0.07	9.15
	Khangoda	82.11 ± 4.09	5.89 ± 0.03	2.23 ± 0.04	0.014 ± 0.06	8.22
	Ranauli Latifpur	88.51 ± 1.63	6.12 ± 0.06	2.56 ± 0.05	0.016 ± 0.04	8.87
	Nidhauli	86.7 ± 2.86	6.48 ± 0.05	2.66 ± 0.02	0.016 ± 0.05	8.68

Continue…

Sorghum bicolor	Akilpur Jagir	87.94 ± 2.07	7.87 ± 0.05	2.97 ± 0.12	0.022 ± 0.03	8.82
	Khangoda	78.54 ± 2.52	6.12 ± 0.04	2.14 ± 0.03	0.013 ± 0.07	7.86
	Ranauli Latifpur	75.39 ± 3.16	6.3 ± 0.04	2.43 ± 0.04	0.016 ± 0.04	7.55
	Nidhauli	85.85 ± 3.01	6.48 ± 0.05	2.39 ± 0.08	0.013 ± 0.06	8.60
Hordeum vulgare	Akilpur Jagir	92.11 ± 2.42	6.76 ± 0.05	3.12 ± 0.07	0.025 ± 0.04	9.24
	Khangoda	78.71 ± 3.52	5.7 ± 0.04	2.57 ± 0.05	0.016 ± 0.04	7.88
	Ranauli Latifpur	82.44 ± 3.81	6.05 ± 0.08	2.67 ± 0.08	0.017 ± 0.06	8.26
	Nidhauli	90.19 ± 1.96	6.22 ± 0.03	2.8 ± 0.1	0.017 ± 0.03	9.03
Brassica juncea	Akilpur Jagir	83.41 ± 2.89	6.8 ± 0.05	2.92 ± 0.03	0.017 ± 0.04	8.36
	Khangoda	76.19 ± 3.03	5.52 ± 0.05	2.57 ± 0.05	0.014 ± 0.06	7.63
	Ranauli Latifpur	79.82 ± 4.16	5.8 ± 0.05	2.6 ± 0.04	0.013 ± 0.05	7.99
	Nidhauli	80.19 ± 4.09	5.97 ± 0.07	2.72 ± 0.09	0.015 ± 0.03	8.03
Trifolium alexandrinum	Akilpur Jagir	92.26 ± 1.03	7.54 ± 0.06	3.42 ± 0.04	0.023 ± 0.07	9.25
	Khangoda	81.5 ± 3.52	6.1 ± 0.05	2.37 ± 0.04	0.015 ± 0.05	8.16
	Ranauli Latifpur	85.38 ± 2.74	6.68 ± 0.06	2.56 ± 0.03	0.016 ± 0.04	8.55
	Nidhauli	85.85 ± 3.41	6.09 ± 0.05	2.4 ± 0.04	0.017 ± 0.09	8.60

4.7 Anticipated performance index (API)

After the computation of APTI for all the crop species, we calculated API on the basis of final APTI values with some socioeconomic and biological characters and different grades like (+, -) were given to the all crop species on the basis of these parameters (Table 3.4 and 3.5).

After the computation of APTI and API, we evaluated the different crop species with respect to the air pollution load. The maximum API value has been found in *Triticum aestivum* (7) followed by *Oryza sativa* (6), *Pennisetum glaucum* (5) during 2015-16. *Triticum aestivum* was assessed as best and *Oryza sativa* as excellent, while the other crops was assessed as good. Wheras during 2016-17, results showed that maximum API value was seen in *Triticum aestivum* (6) followed by *Oryza sativa* (5) and other crops had API value 4 or less. *Triticum aestivum* was assessed as excellent and *Oryza sativa* as very good, while other crops was assessed as good (Table 4.23, 4.24). It means *Triticum aestivum* and *Oryza sativa* were best suited crops in the slected study area as compared to other crops. So API and APTI paly a very significant role in the selection of crop species in polluted area.

Table 4.23: Evaluation of crop species on the basis of API during 2015-16

Crop species	APTI value	Crop habitat	Laminar size	Laminar texture	Economic value	Grade		API grades	Category
						Total	% score		
Oryza sativa	++++	+++	+	+	++	11	84.62	6	Excellent
Triticum aestivum	+++++	+++	+	+	++	12	92.31	7	Best
Pennisetum glaucum	+++++	++	++	+	-	10	76.92	5	Very good
Sorghum bicolor	++++	++	++	+	-	9	69.23	4	Good
Hordeum vulgare	++++	+	+	+	+	8	61.54	4	Good
Brassica juncea	++++	+	++	+	+	9	69.23	4	Good
Trifolium alexandrinum	+++++	++	-	-	-	8	61.54	4	Good

Table 4.24: Evaluation of crop species on the basis of API during 2016-17

Crop species	APTI value	Crop habitat	Laminar size	Laminar texture	Economic value	Grade		API grades	Category
						Total	% score		
Oryza sativa	+++	+++	+	+	++	10	76.92	5	Very good
Triticum aestivum	++++	+++	+	+	++	11	84.62	6	Excellent
Pennisetum glaucum	++++	++	++	+	-	9	69.23	4	Good
Sorghum bicolor	++++	++	++	+	-	9	69.23	4	Good
Hordeum vulgare	++++	+	+	+	+	8	61.54	4	Good
Brassica juncea	+++	+	++	+	+	8	61.54	4	Good
Trifolium alexandrinum	++++	++	-	-	-	5	38.46	2	Poor

4.8 Effect of air pollutants on yield parameters

The crop productivity would be affected if growth, physiological and biochemical parameters of crop were influenced with the external factors. In this study, we found that air pollutants have significantly affected the grain and straw yield of the crops.

4.8.1 Grain yield (t/ha)

The study showed that grain yield of rice was reduced from 3.56% to 8.46% and in wheat from 2.84% to 9.52%. In rice maximum grain yield was found at Akilpur Jagir (3.37 t/ha) followed by Pyawali Tajpur (3.32 t/ha) and the minimum was at Jarcha (3.05 t/ha) followed by Khangoda (3.08 t/ha). Whereas in wheat maximum grain yield was at Akilpur Jagir (4.57 t/ha) followed by Pyawali Tajpur (4.51 t/ha) villages and the minimum was at Uncha Amirpur (4.14 t/ha) followed by Khangoda (4.17 t/ ha) in 2015-16. In second year study, we found that reduction in rice grain yield was up to 9.83% and 10.62% in wheat crop. In rice maximum grain yield was at Akilpur Jagir (3.56 t/ha) followed by Pyawali Tajpur (3.47 t/ha) and the minimum was at Jarcha (3.21 t/ha) followed by Khangoda (3.24 t/ ha). Whereas in wheat maximum grain yield was at Akilpur Jagir (4.77 t/ha) followed by Pyawali Tajpur (4.63 t/ha) villages and the minimum was at Jarcha (4.27 t/ha) followed by Khangoda (4.33 t/ha) (Table 4.25 and Fig. 4.31 and 4.32).

Table 4.25: Grain yield (t/ha) of rice and wheat crops grown at selected sites

Sites	2015-16		2016-17	
	Rice	Wheat	Rice	Wheat
Akilpur Jagir	3.37 ± 0.03	4.57 ± 0.03	3.56 ± 0.02	4.77 ± 0.05
Pyawali Tajpur	3.32 ± 0.05	4.51 ± 0.04	3.47 ± 0.03	4.63 ± 0.04
Tatarpur	3.24 ± 0.09	4.44 ± 0.04	3.41 ± 0.04	4.5 ± 0.05
Salarpur Kalan	3.17 ± 0.04	4.37 ± 0.05	3.37 ± 0.07	4.59 ± 0.03
Ranauli Latifpur	3.22 ± 0.06	4.35 ± 0.09	3.35 ± 0.05	4.47 ± 0.05
Jarcha	3.05 ± 0.07	4.19 ± 0.08	3.21 ± 0.05	4.27 ± 0.05
Khangoda	3.08 ± 0.04	4.17 ± 0.06	3.24 ± 0.03	4.33 ± 0.03
Uncha Amirpur	3.12 ± 0.07	4.14 ± 0.08	3.3 ± 0.05	4.38 ± 0.04
Nagla Kashi	3.17 ± 0.04	4.32 ± 0.04	3.39 ± 0.05	4.48 ± 0.06
Nidhauli	3.25 ± 0.07	4.28 ± 0.04	3.36 ± 0.02	4.54 ± 0.03
LSD (P=0.05)	0.09	0.06	0.10	0.09

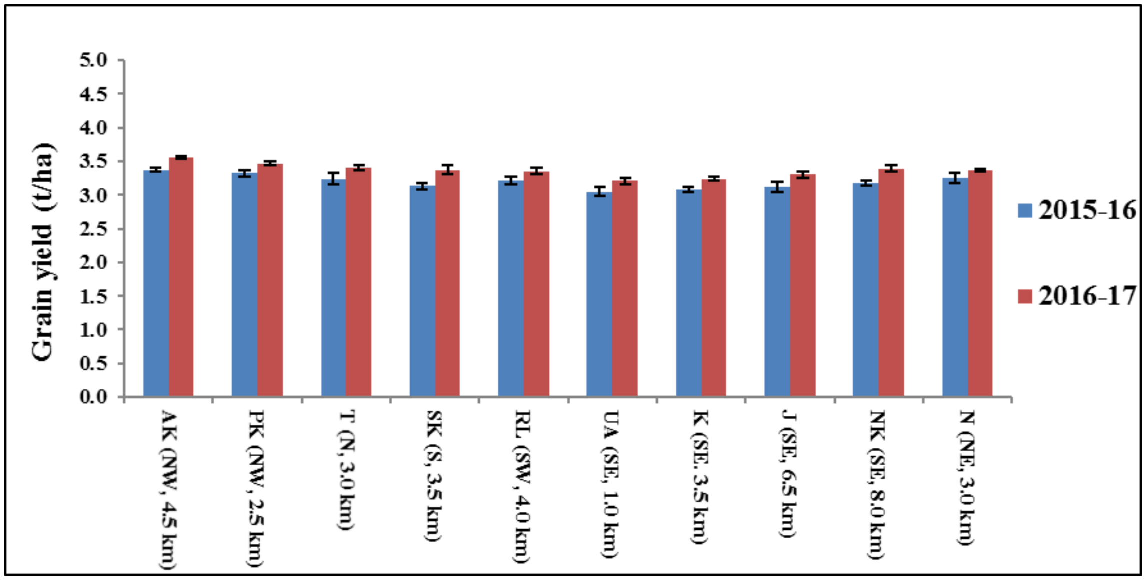

Figure 4.31: Grain yield (t/ha) in rice crop

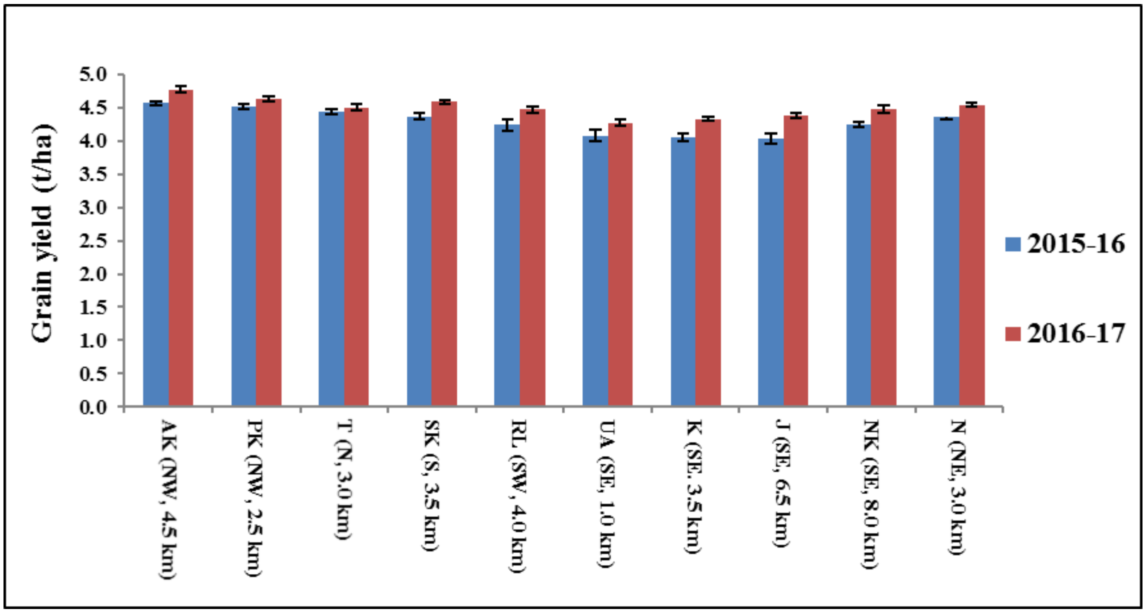

Figure 4.32: Grain yield (t/ha) in wheat crop

4.8.2 Straw yield (t/ha)

In case of rice, straw yield reduction was from 5.61% to 11.08% and in wheat from 3.11% to 12.24%. In rice, the maximum straw yield was at Akilpur Jagir (6.77 t/ha) followed by Pyawali Tajpur (6.42 t/ha) villages and the minimum was at Uncha Amirpur (6.02 t/ha) followed by Jharcha (6.07 t/ha). Whereas in wheat maximum straw yield was at Akilpur Jagir (8.67 t/ha) followed by Pyawali Tajpur (8.56 t/ha) villages and minimum was at Uncha Amirpur (7.48 t/ha) followed by Khangoda (7.61 t/ha) in 2015-16.

During 2016-17, in rice, straw yield reduction was from up to 12.44% and in wheat 11.77%. In rice, the maximum straw yield was at Akilpur Jagir (7.24 t/ha) followed by Pyawali Tajpur (7.05 t/ha) villages and the minimum was at Uncha Amirpur (6.34 t/ha) followed by Khangoda (6.39 t/ha). Whereas in wheat maximum straw yield was at Akilpur Jagir (9.33 t/ha) followed by Pyawali Tajpur (9.17 t/ha) villages and minimum was at Jarcha (8.24 t/ha) followed by Uncha Amirpur (8.40 t/ha) (Table 4.26 and Fig. 4.33 and 4.34).

Table 4.26: Straw yield (t/ha) of rice and wheat crops grown at selected sites

	2015-16		2016-17	
Villages	Rice	Wheat	Rice	Wheat
Akilpur Jagir	6.77 ± 0.04	8.67 ± 0.08	7.24 ± 0.05	9.33 ± 0.07
Pyawali Tajpur	6.42 ± 0.03	8.56 ± 0.06	7.05 ± 0.13	9.17 ± 0.09
Tatarpur	6.39 ± 0.06	8.32 ± 0.03	6.82 ± 0.05	8.47 ± 0.06
Salarpur Kalan	6.32 ± 0.06	8.40 ± 0.1	6.78 ± 0.06	8.23 ± 0.09
Ranauli Latifpur	6.22 ± 0.09	8.21 ± 0.06	6.6 ± 0.08	8.88 ± 0.04
Jarcha	6.07 ± 0.08	7.84 ± 0.05	6.5 ± 0.06	8.24 ± 0.1
Khangoda	6.21 ± 0.04	7.61 ± 0.05	6.39 ± 0.07	8.46 ± 0.05
Uncha Amirpur	6.02 ± 0.08	7.48 ± 0.05	6.34 ± 0.09	8.4 ± 0.07
Nagla Kashi	6.34 ± 0.06	8.08 ± 0.05	6.77 ± 0.06	8.8 ± 0.07
Nidhauli	6.10 ± 0.06	8.16 ± 0.07	6.65 ± 0.04	8.89 ± 0.08
LSD (P=0.05)	0.10	0.07	0.10	0.13

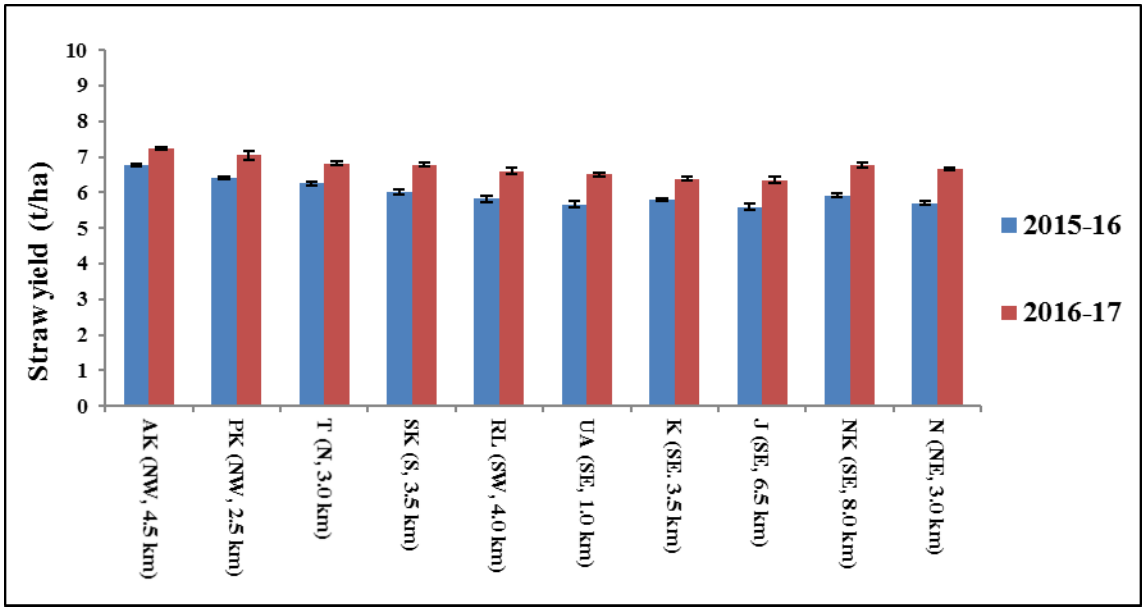

Figure 4.33: Straw yield (t/ha) in rice crop

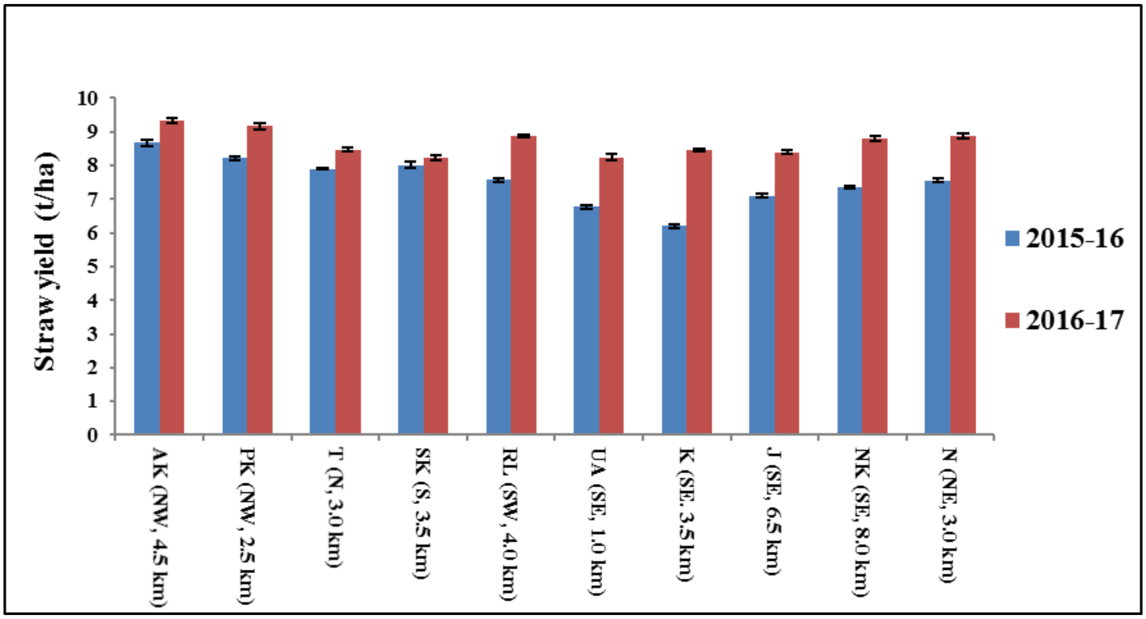

Figure 4.34: Straw yield (t/ha) in wheat crop

4.8.3 Number of plants/m^2

In rice, the maximum number of plants/m^2 was at Akilpur Jagir (83) and the minimum was at Khangoda (72). Whereas in wheat maximum Number of plants/m^2 was at Akilpur Jagir (74) and minimum was at Jarcha (64) 2015-16. Similar types of results were found in second year also (Table 4.27). There was no significant difference among the different selected sites in respective of Number of plants/m^2.

Table 4.27: Number of plants/m^2 in rice and wheat crops grown at selected sites

Sites	2015-16		2016-17	
	Rice	Wheat	Rice	Wheat
Akilpur Jagir	83 ± 3.61	74 ± 3.00	79 ± 4.00	68 ± 7.00
Pyawali Tajpur	80 ± 6.24	73 ± 3.61	84 ± 5.29	74 ± 5.29
Tatarpur	82 ± 2.65	74 ± 6.08	80 ± 3.61	71 ± 8.54
Salarpur Kalan	81 ± 3.61	68 ± 4.58	83 ± 4.00	74 ± 5.29
Ranauli Latifpur	75 ± 5.57	72 ± 3.61	78 ± 3.00	73 ± 5.57
Jarcha	73 ± 4.58	64 ± 4.00	75 ± 6.08	65 ± 4.36
Khangoda	72 ± 2.65	69 ± 1.00	76 ± 7.21	71 ± 6.56
Uncha Amirpur	76 ± 4.58	71 ± 5.57	72 ± 2.00	72 ± 2.00
Nagla Kashi	79 ± 2.65	72 ± 4.00	74 ± 5.00	69 ± 2.65
Nidhauli	80 ± 3.61	68 ± 2.00	78 ± 5.57	68 ± 6.00

4.8.4 1000 grain weight (g)

In rice, the maximum test weight was at Pyawali Tajpur (22.75 g) followed by Akilpur Jagir (22.60 g) villages and the minimum was at Jarcha (21.26 g) followed by Nagla kashi (21.46 g). Whereas in wheat maximum test weight was at Akilpur Jagir (38.03 g) followed by Pyawali Tajpur (37.50 g) villages and minimum was at Uncha Amirpur (31.57 g) in 2015-16 (Table 4.28). Similar types of results were found in second year also in both the crops.

Table 4.28: Thousand grain weight (g) in rice and wheat crops grown at selected sites

Sites	2015-16		2016-17	
	Rice	Wheat	Rice	Wheat
Akilpur Jagir	22.6 ± 0.29	38.03 ± 0.14	22.47 ± 0.1	35.68 ± 0.19
Pyawali Tajpur	22.75 ± 0.15	37.5 ± 0.24	23.01 ± 0.15	39.45 ± 0.15
Tatarpur	23.24 ± 0.54	35.1 ± 0.18	22.29 ± 0.36	35.28 ± 0.44
Salarpur Kalan	23.5 ± 0.3	33.94 ± 0.21	20.92 ± 0.36	36.73 ± 0.35
Ranauli Latifpur	22.65 ± 0.18	32.29 ± 0.08	22.04 ± 0.26	32.38 ± 0.19
Jarcha	21.26 ± 0.34	32.52 ± 0.17	21.45 ± 0.24	31.75 ± 0.27
Khangoda	21.5 ± 0.3	32.58 ± 0.12	21.77 ± 0.1	30.99 ± 0.33
Uncha Amirpur	21.66 ± 0.2	31.57 ± 0.15	21.26 ± [illegible]	33.58 ± 0.27
Nagla Kashi	21.46 ± 0.1	35.1 ± 0.2	21.66 ± 0.09	34.41 ± 0.22
Nidhauli	21.6 ± 0.38	33.77 ± 0.19	21.82 ± 0.19	32.76 ± 0.10

4.9 Correlation between air pollution level and different parameters of the crops

Plant characteristics like photosynthesis rate, transpiration rate, stomatal conductance, LAI, grain yield and straw yield were found to be negatively correlated with atmospheric deposition on plant leaves (Table 4.29, 4.30, 4.31 and 4.32).

Table 4.29: Correlation between different parameters in rice (2015-16)

	Aerial deposition	Photosynthetic rate	Transpiration rate	Stomatal conductance	LAI	Grain yield	Straw yield
Aerial deposition (mg/cm^2)	1.00						
Photosynthetic rate (µmol/m^2/s)	-0.97	1.00					
Transpiration rate (mmol/m^2/s)	-0.85	0.86	1.00				
Stomatal conductance (mol/m^2/s)	-0.95	0.91	0.86	1.00			
LAI	-0.94	0.94	0.81	0.94	1.00		
Grain yield (t/ha)	-0.86	0.86	0.81	0.86	0.81	1.00	
Straw yield (t/ha)	-0.82	0.90	0.75	0.73	0.81	0.80	1.00

Number of smaples = n

Table 4.30: Correlation between different parameters in rice (2016-17)

	Aerial deposition	Photosynthetic rate	Transpiration rate	Stomatal conductance	LAI	Grain yield	Straw yield
Aerial deposition (mg/cm^2)	1.00						
Photosynthetic rate (µmol/m^2/s)	-0.79	1.00					
Transpiration rate (mmol/m^2/s)	-0.84	0.90	1.00				
Stomatal conductance (mol/m^2/s)	-0.86	0.84	0.92	1.00			
LAI	-0.76	0.52	0.70	0.79	1.00		
Grain yield (t/ha)	-0.97	0.81	0.88	0.92	0.85	1.00	
Straw yield (t/ha)	-0.88	0.88	0.97	0.97	0.81	0.93	1.00

Table 4.31: Correlation between different parameters in wheat (2015-16)

	Aerial deposition	Photosynthetic rate	Transpiration rate	Stomatal conductance	LAI	Grain yield	Straw yield
Aerial deposition (mg/cm^2)	1.00						
Photosynthetic rate (µmol/m^2/s)	-0.84	1.00					
Transpiration rate (mmol/m^2/s)	-0.86	0.86	1.00				
Stomatal conductance (mol/m^2/s)	-0.87	0.81	0.77	1.00			
LAI	-0.85	0.88	0.92	0.76	1.00		
Grain yield (t/ha)	-0.92	0.93	0.91	0.81	0.91	1.00	
Straw yield (t/ha)	-0.92	0.88	0.89	0.82	0.89	0.92	1.00

Table 4.32: Correlation between different parameters in wheat (2016-17)

	Aerial deposition	Photosynthetic rate	Transpiration rate	Stomatal conductance	LAI	Grain yield	Straw yield
Aerial deposition (mg/cm^2)	1.00						
Photosynthetic rate (µmol/m^2/s)	-0.83	1.00					
Transpiration rate (mmol/m^2/s)	-0.88	0.94	1.00				
Stomatal conductance (mol/m^2/s)	-0.84	0.91	0.95	1.00			
LAI	-0.93	0.87	0.93	0.87	1.00		
Grain yield (t/ha)	-0.83	0.95	0.97	0.94	0.89	1.00	
Straw yield (t/ha)	-0.54	0.75	0.76	0.74	0.71	0.73	1.00

4.10 Calibration and validation of Gaussian plume model (GPM) for coal-based thermal power plant

In our study, GPM was simulated for SO_2 and NO_2 emission from coal based thermal power plant (TPP). The GPM model was validated with real time monitoring data of the field area. We measured the wind speed at stack height, plume rise and dispersion coefficients at various distance and did estimation of stability classes (Table 4.33, 4.35). The stack characteristics and emission rate for SO_2 and NO_2 were taken at NTPC, Dadri (Table 4.34).

The GPM was calibrated using observed concentration of the pollutants. We calibrated the model for σy and σ_z. we did not calculate σ_y and σ_z directly but indirectly with help of stability class. Results showed that SO_2 and NO_2 concentration was highest near to TPP. Concentration showed a normal probability distribution curve. Variation in concentration was higher near to source with a peak, then curve became less steep with downwind distance. Maximum SO_2 and NO_2 concentration was found between 1 to 6 km distance, thereafter a continuous decrease was observed. Peaks were varying with wind speed and stability class during whole year (Fig. 4.35 and 4.37).

Table 4.33: Meteorological parameters and plume rise data

Wind Speed (m/s)	Wind speed at Stack height (m/s)	Stability class	Plume rise (m)
2.7	4.2	C	370.96
3.3	5.0	C	341.70
3.6	4.9	B	330.72
3.8	5.2	B	324.37
2.4	3.3	A-B	391.08
2.7	3.7	A-B	370.96
3.1	5.0	B-C	350.19
3.1	5.0	B-C	350.19
2.8	3.9	B	365.22
2.5	3.5	B	383.84
2.7	3.7	B	370.96
2.6	4.0	C	377.15

Table 4.34: Stack characteristics and emission rate for SO_2 and NO_2 at NTPC, Dadri

Source characteristics	**SO_2**	**NO_2**
Location of the sources (x) m	At various distances (km)	At various distances (km)
Stack physical height (m)	210	210
Stack inner diameter (m)	4.5	4.5
Stack exit velocity (m/s)	20	7.5
Temperature of stack gas (K)	403	403
Pollutant emission rate (g/s)	108	90

Table 4.35: Gaussian dispersion coefficients (σ_y & σ_z) for different stability class at various distances

Distance from Source (km)	Gaussian dispersion coefficients (m)	Stability class					
		A	B	C	D	B-C	C-D
1	σy	213.00	156.00	104.00	68.00	130.00	86.00
	σz	450.07	109.90	61.00	31.50	85.45	46.25
2	σy	395.82	289.90	193.27	126.37	241.58	159.82
	σz	1953.00	233.61	114.70	50.63	174.16	82.67
3	σy	568.76	416.55	277.70	181.57	347.13	229.64
	σz	4577.80	363.50	165.95	65.44	264.73	115.70
4	σy	735.57	538.72	359.15	234.83	448.94	296.99
	σz	8369.32	497.78	215.68	78.00	356.73	146.84
5	σy	897.96	657.66	438.44	286.67	548.05	362.56
	σz	13359.98	635.43	264.30	89.10	449.86	176.70
6	σy	1056.93	774.09	516.06	337.42	645.08	426.74
	σz	19575.38	775.82	312.05	99.17	543.93	205.61
7	σy	1213.10	888.47	592.31	387.28	740.39	489.80
	σz	27036.82	918.53	359.10	108.46	638.81	233.78
8	σy	1366.92	1001.12	667.41	436.39	834.27	551.90
	σz	35762.54	1063.26	405.55	117.12	734.40	261.34

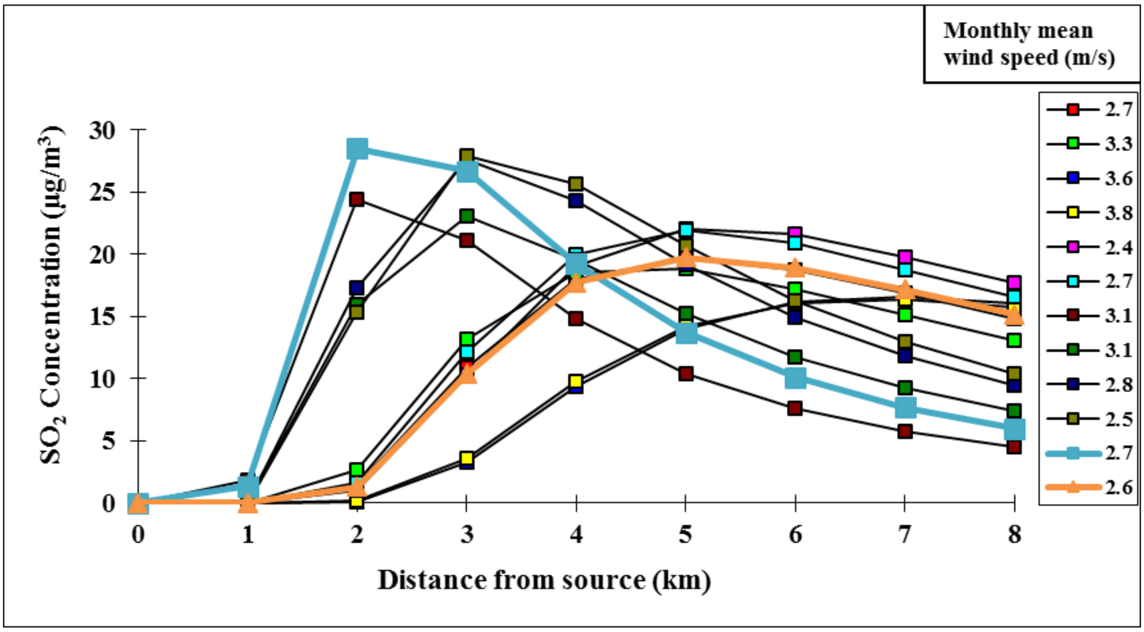

Figure 4.35: Gaussian Dispersion Pattern of SO_2 at different wind speed (m/s) downwind to thermal power plant

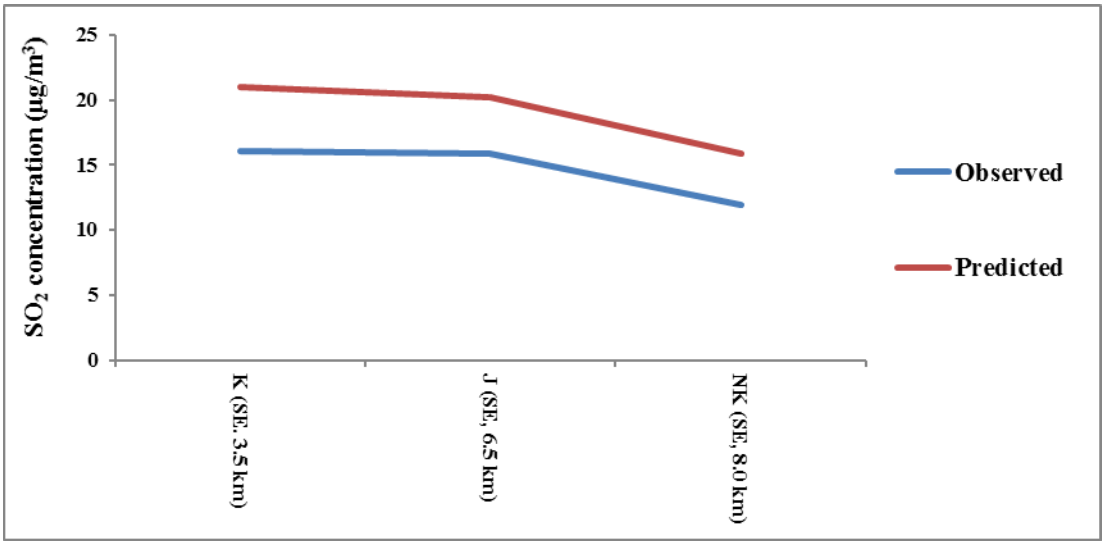

Figure 4.36: Comparison between observed and predicted concentration at selected sites for SO_2

Table 4.36: Performance evaluation index (d) at selected sites for SO_2

Sites	d
Khangoda	0.66
Jarcha	0.52
Nagla kashi	0.57

GPM performance evaluation index was evaluated by comparing the observed SO_2 concentration with predicted or simulated values by the model at same points. Performance evaluation index (d) ranged from 0.57 to 0.66. This d values showed that agreement between predicted and observed data was good to average. d value may be varied due to stochastic nature of atmospheric turbulence. Maximum d value was found at Khangoda (3.5 km) (0.66) followed by Nagla Kashi (8.0 km) (0.57) and Jarcha (6.5 km) (0.52) at leeward side from power plant. So finally, we found that maximum SO_2 impact was 1 to 6 km range from TPP at downwind distance (Table 4.36).

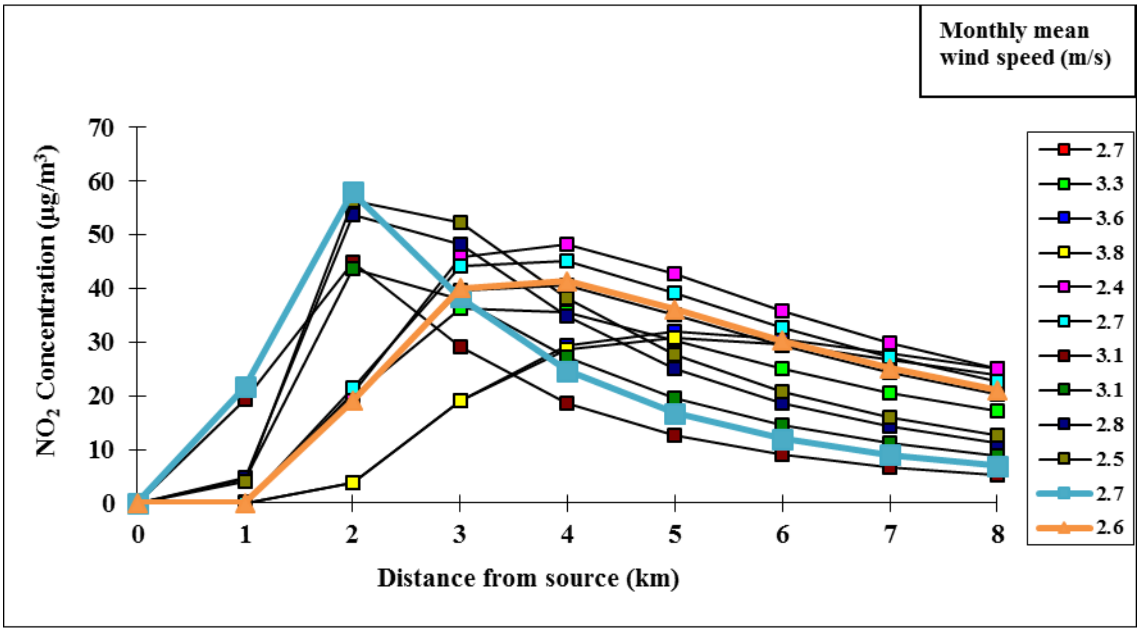

Figure 4.37: Gaussian Dispersion Pattern of NO_2 at different wind speed (m/s) downwind to thermal power plant

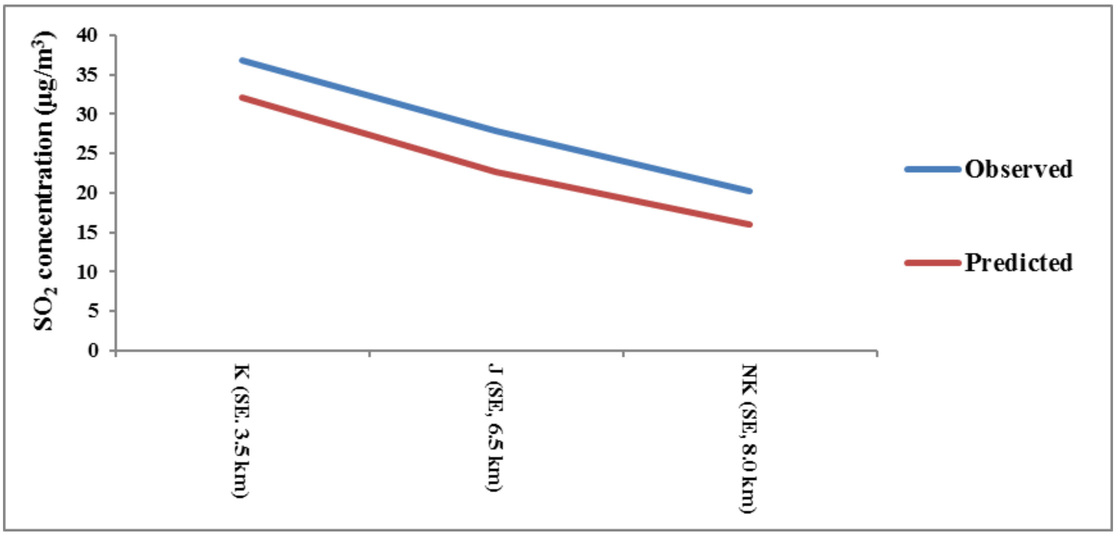

Figure 4.38: Comparison between observed and predicted concentration at selected sites for NO_2

Table 4.37: Performance evaluation index (d) at selected sites for NO_2

Sites	D
Khangoda	0.32
Jarcha	0.54
Nagla kashi	0.48

GPM performance evaluation index was evaluated by comparing the observed NO_2 concentration with predicted or simulated values by the model at similar sites. Performance evaluation index (d) ranged from 0.32 to 0.54. This d values showed that agreement between predicted and observed data was good to average. d value may be varied due to stochastic nature of atmospheric turbulence. Maximum d value was found at Jarcha (6.5 km) (0.54) followed by Nagla Kashi (8.0 km) (0.48) and Khangoda (3.5 km) (0.32) at leeward side from the power plant (Table 4.37).

5. DISCUSSION

The experimental findings of the studies on the emission of air pollutants from the coal-based thermal power plant and their impacts on crop growth and productivity and calibration and dispersion of air pollution dispersion model are discussed under the following heads.

5.1 Concentration of air pollutants at different selected sites

Air quality monitoring observed that concentration of PM10, SO_2, NO_2 and O_3 were minimum at Akilpur Jagir and Pyawali Tajpur (control sites), whereas maximum level was observed at Khangoda, Jarcha and Uncha Amirpur villages. PM10, SO_2 and NO_2 concentration were maximum in Rabi season and minimum in the Kharif season, but O_3 concentration was maximum in Kharif season and minimum in Rabi season because of more sunlight intensity during Kharif season. Agrawal et al., (2003) also observed the higher PM10, SPM, SO_2 and NO_2 concentration in winter while O_3 concentration was higher in summer. Joshi et al., (2008) also reported similar types of results during summer and winter seasons. Air Quality Index (AQI) values showed that air pollution level was light to moderate at control sites (Akilpur jagir, Pyawali tajpur), whereas heavy pollution level at other selected sites (Jarcha Khangoda Uncha Amirpur Nagla Kashi Ranauli Latifpur). Rai et al., (2013) also observed similar types of results in respective to AQI. Chauhan et al., (2010) reported that air pollutants viz. SO_2, NOx, SPM were lowest at windward side therefore he cosidered these sites as control sites for comparing the response to air pollutants.

5.2 Aerial deposition of particulate matter on crop canopy at selected sites

The aerial deposition was more at Khangoda, Jarcha and Uncha Amirpur village (polluted sites) and the minimum at Akilpur Jagir and Pyawali Tajpur (control sites). In Rabi crops, atmospheric deposition load on leaves was found to be more than Kharif crops at vegetative and flowering stages. Higher rainfall in Kharif might have washed out some of the deposited particulate matter from crop leaves. Earlier co-workers reported similar types of results. Chakrabarti et al., (2014) reported that in wheat crop, the atmospheric deposition load on leaves was found to be more than rice at all stages and deposition was gradually decreased with increasing distance from TPP. Gupta et al., 2016 reported that particulate matter deposition adversely affects the plant leaves surface, cuticle and epidermal layers. Dust particle deposition ruptures stomata of the leaves. As compared to the residential site, the foliar samples collected from the industrial site (SB) showed a more significant deposition. Mishra et al. (2016) told that at urban background site, the dust flux was lowest (172 $mg/m^2/day$) as compared to commercial site, (192 $mg/m^2/day$) and industrial/residential area, (302 $mg/m^2/day$). Rai et al. 2011 also reported similar types of results.

5.3 Growth and physiological parameters of the crops

Air pollutants, mostly particulate matter significantly hampered the growth and physiological parameters of rice and wheat crops. Leaf area index (LAI) is directly correlated with photosynthesis rate, so a reduction in photosynthetic rate directly affects the LAI of the crops. LAI was maximum at Akilpur Jagir and Pyawali Tajpur; those were control sites. Whereas minimum at Jharcha, Khangoda and Uncha Amirpur (pollutes sites). Chakrabarti et al., (2014) and Raja et al., (2014) reported similar types of results that LAI significantly decreased with higher level of air pollution.

Air pollution significantly affects the physiological parameters of crops. Crops which were grown leeward side have more severely affected in comparison to windward side. Photosynthetic rate, transpiration rate and stomatal conductance were found maximum at Akilpur Jagir and Pyawali Tajpur. Whereas minimum at Jharcha, Khangoda and Uncha Amirpur (pollutes sites). Raja et al., (2014) reported that how different level of fly ash deposition affected the photosynthesis, transpiration rate and productivity of rice. He reported that photosynthetic and transpiration rate of rice reduced with increasing rate of fly ash deposition. The highest dose of fly ash deposition reduced the photosynthetic rate up to 15.1 to 44.6 % over control at different growth stages. The transpiration rate was decreased up to 11.3 to 44.4 % over control at various growth stages. Lehnherr et al., (1988) and Darrall, (1989) also reported similar types of results. According to Lerman, (1972), regular application of cement dust reduced the stomatal activity and directly affects the gaseous exchange. Pigment content is a good indicator of the physiological condition of the crop plants (Petkovšek et al., 2008).

Air pollution-induced degradation in photosynthetic pigments was also observed by a number of workers (Bansal, 1998; Singh et al., 1990). Rao and LeBlanc, (1966) reported that at cell sap pH between 2 and 3.5, displacement of Mg^{2+} takes place from the chlorophyll molecule by H^+, which is generated due to the splitting of H_2SO_3 into SO_3^{-2} and H^+. This leads to the formation of a chlorophyll degradation product, phaeophytin, which, no longer, serves to trap the solar energy for photosynthesis. According to Rani et al. (2011) at pH above 3.5, HSO_3^- , which is formed during SO_2 metabolization, generates superoxide radical (O^{-2}) which causes the oxidation of carotenoids and in the absence of carotenoid protection, oxidation of chlorophyll molecule occurs, resulting in the reduction of photosynthetic ability of the plant. According to Roth-Nebelsick et al., 2009, higher plant species synthesize more of the chl a than chl b and a ratio of chl a to chl b provides a measure of tolerance index of a tree. High value of this ratio indicates better tolerance to air pollution and vice versa. Krajicova and Mejstrik, (1984) also observed a reduction in photosynthetic rate due to particulate matter deposition. Dust deposition on crop canopy may hamper the reflection and transmission of sunlight, which is the basic requirement for this process. Smaller particles affect more as compared to coarse particles. A similar study was undertaken by Agrawal and Agrawal, (1989) to assess the impact of air pollutants on plants around Obra thermal power plant in the Mirzapur district of Uttar Pradesh. He reported a direct relationship between the concentration of SPM in air and amount of dust deposited on leaf surfaces and leads to deterioration of physiological parmeters. Carotenoids act as antioxidant and also protect chlorophyll from photo-oxidation. It was observed that carotenoid content, like other photosynthetic pigments, decreased with an increase in the pollution load in the environment (Roy et al., 2009).

5.4 Yield parameters

The crop productivity affected if the atmospheric pollutant impair the growth, physiological and biochemical parameters of crop plants. The results of this study has found that the air pollutants significantly affect the grain and straw yield of the crops. The study showed that grain yield reduction was in the range of 3.56 to 8.46 % in rice and from 2.84 to 9.52 % in wheat. The straw yield reduced from 5.61 to 11.08 % in rice and 3.11 to 12.24 % in wheat. Chakrabarti et al., (2014) reported that straw yield was reduced up to 17.6 % and 24.5 % in rice and wheat crop respectively due to air pollution. Raja et al., (2014) also reported the similar types of results, he observed that the yield reduced as fly deposition rate incresed. Chauhan et al., (2010) reported the significant yield reduction in wheat and mustard crops due to air pollutants.

In an open-top chamber study conducted at the suburban site in Varanasi, Rai et al., (2007) reported that reduction of 20.7% in yield of wheat variety M 234 grown at ambient air pollution level (SO_2- 7.8 ppb, NO_2- 40.6 ppb, O_3- 42.1 ppb). At a rural site in Varanasi, experiencing low concentrations of SO_2 7.3 ppb and NO_2 14.5 ppb and high concentration of O_3 (35 ppb) found 10 and 14% reduction in yield of rice varieties NDR 97 and Saurabh 950 grown at ambient air (Rai and Agrawal, 2008). Agrawal et al., (2003) have reported that SO_2, NO_2 and O_3 and related plant responses measured regarding physiological characteristics, pigment, biomass, and yield. Yield reduction in rice and wheat at different selected sites was due to the disturbance in photosynthate translocation and formation of ascorbic acid antioxidants. It has been reported by many researcher that PM deposition hamper the photosynthate translocation within the plants and affects the plants vitality. It will further leads to have the detrimental effects on the grain filling stage leads to higher reductions in yield.

5.5 Biochemical parameters of the crops

Air pollutants significantly affect the pH of cell sap. The SO_2, NO_2 are absorbed to leaves of the crop plants and converted into acid like H_2SO_4, HNO_3, which cause a reduction in pH of the cell sap. Lower pH value indicates more sensitiveness towards the air pollution, whereas higher pH value shows more tolerance (Escobedo et al., 2008; Joshi and Bora, 2011). Scholz and Reck, (1977) and

(Agrawal, 1988) also reported similar types of results. Joshi et al., (2008) reported a decrease in pH value at polluted sites as compared to less or non-polluted sites.

In the present study, it has been observed that PM deposition reduced the relative leaf water content (RWC). According to Rai et al., (2013), maximum RWC was found at control site (87.23%) and lowest at the polluted site (63.08%). It means higher air pollution level reduced the RWC in plant leaves. Chouhan et al., (2012) also reported almost similar types of changes in RWC content in different tree species. Air pollutants, mostly particulate matter deposition on crop canopy affect the transpiration rate, which directly relates to water content of the plant leaves. Higher pollution reduced the RWC so that it affects the cell permeability, which results in more water loss. Plants with higher RWC in their leaves are more tolerant to the air pollution compared to less RWC level.

Particulate matter with gaseous pollutants reduced the chlorophyll content of the crops. At Akilpur Jagir and Pyawali Tajpur, crops showed maximum chlorophyll content, and the minimum was found at Jarcha, Khangoda and Uncha Amirpur. Chlorophyll content of crop plants depends upon so many factors like type of crop species, different environmental factors, morphological characters and stress like, air pollution (Katiyar and Dubey, 2001). Air pollutants like SO_2 reduces the chlorophyll content due to the formation of H_2SO_4, which converts chlorophyll to phaeophytin (Mandloi and Dubey, 1988; Rao and Dubey ,1985; Rao and Leblance, 1966). A Higher level of chlorophyll content shows tolerance of crops to air pollution, whereas lower level indicates its sensitivity. Jyothi et al., (2010) reported that in *Mangifera indica,* a tree species, total chlorophyll content was highest (7.54 mg/g) at control site and lowest at the most polluted site (5.04 mg/g). Joshi et al., (2008) reported similar type of results in case of the rice crop.

The ascorbic acid level reduced at all polluted sites as compared to the control site. When oxidative air pollutants enter into the leaves of the plants, it disturbs the chain reactions due to the generation of free radicals. So ascorbic acid content is decreased to remove these free radicals. Plants with high ascorbic acid content are tolerant to any stress as compared to low level (Pandey and Agarwal, 1994). According to Rai et al., (2013), highest ascorbic acid was found at control site and lowest at polluted site in different tree species. Similar, changes in biochemical parameters in plants due to PM deposition were reported by several researchers (Mandal and Mukherji, 2000; Samal and Santra, 2002). Chauhan et al., (2010) reported a significant reduction in total chlorophyll and ascorbic acid by the effect of air pollutants. Agrawal et al., (2003) also reported that NO_2, SO_2 and O_3 exposure have significant reduction in chlorophyll content of a variety of crop plants.

The air pollution tolerance Index (APTI) was high in plants at polluted sites as compared to control sites. It indicates that tolerance of plant was negatively affected by air pollution. In the recent studies, it has been reported that air pollution has adversely affect and reduce the plants chlorophyll, ascorbic acid, pH, relative moisture content and APTI. The present study observed the reduction in chlorophyll content, indicating that the PM accumulation affects the dynamics of all the pigments in leaf systems (Teresa and Anitha, 2000). Joshi et al., (2008) also reported similar types of results for APTI in rice crop. Rice and Wheat were more appropriate crops in the selected study area as compared to other crops. Therefore, API and APTI must be very helpful in the selection of crop species in the polluted area. The anticipated performance index was calculated for different species and results showed that *F. bengalensis* , *Mangifera indica, Psidium guajava, Ficus religiosa, Artocarpus heterophyllus* and *Lagerstroemia speciosa* were best-suited variety for plantation along the roadside of the polluted area (Rai et al., 2013).

5.6 Calibration and validation of Gaussian plume Dispersion model (GPDM) for coal-based thermal power plant

It has been observed that the SO_2 and NO_2 concentration was highest near the TPP. Concentration showed a normal probability distribution curve. Variation in concentration was higher near to source with a peak; then curve became less steep with downwind distance. The wind speed is one of the parameters that influence the transport and dispersion of air pollutants.

Maximum performance evaluation index (d) was observed higher for SO_2 as compared to NO_2 at Khangoda and Nagla Kashi villages. Therefore, dispersion model was well suited for SO_2 dispersion. d value may be varied due to stochastic nature of atmospheric turbulence. It concluded that maximum SO_2 and NO_2 impact ranged from 2 to 6 km from TPP at downwind distance. Kumar et al., 2014 also carried out similar types of study and reported that the dispersion pattern of SO_2 pollution validated the observed results.

Yuwono et al., (2014) reported that the increase in wind speed could cause the decrease of pollutant concentration, whereas the decrease of wind speed leads to the increase of pollutant concentration. However, such a large scatter is not uncommon between field data with simulated dada from model predictions. One prime reason for this is the stochastic nature of atmospheric turbulence. A model prediction represents an average ensemble value; whereas any measured short-time averaged concentration value reflects a specific realisation of the ensemble.

Awasthi et al., (2006) reported that GPDM applicable for both rural and urban conditions. It uses meteorological and emission data as its input parameters and calculates concentrations of pollutant at predefined area concerning the given source. Its performance was evaluated by comparing with four hours average observed data of SO_2 from TPP. Results showed that the Turner scheme of stability class used with Holland's equation gives the best outcome having a performance evaluation index (d) of 0.52.

According to Naik, (1991), the concentration of SO_2 was computed at a distance of every 0.5 km in 16 directions up to the city limit. The air quality as moderate to severe is estimated in downwind distances under unstable meteorological conditions. Under the most unstable meteorological conditions, the estimated high ground-level concentration of SO_2 can reach up to 1000 $\mu g\ m^{-3}$ at a distance of 1.25 km from the thermal power plant. This may be due to the effect of fumigation process. Spijkerboer et al., (2002) also reported similar types of results in spores dispersion over potato crop, he found a low correlation (*R*=0.4) between observed spore concentrations and predicted spore concentrations.

6. SUMMARY AND CONCLUSION

Experiment to quantify the air pollution load and their impacts on the crop growth and productivity were carried out at in the vicinity of NTPC Dadri. It is located in Gautam Budh Nagar district of Uttar Pradesh, India (28°35′54″N & 77°36′34″E). The experiment was conducted during Kharif and Rabi seasons of 2015-16 and 2016-17. Around the thermal power plant (TPP), ten sites were selected according to dominant wind direction and distance from the power plant. Two control sites were identified towards the windward direction to the TPP (Akilpur Jagir, Pyawali Tajpur). Dominant wind direction throughout the year was in the north-west (NW). Four sites were selected in a leeward direction (Jarcha, Uncha Amirpur, Khangoda and Nagla Kashi), two were chosen perpendicular to dominant wind direction (Nidhauli and Ranauli Latifpur) and two in extreme north and south directions of the TPP (Tatarpur and Salarpur Kalan). Mainly two predominant crops (Rice and Wheat) are grown in the study area. Farmers are mainly growing Pusa 1121 variety of rice and PBW 343 variety of wheat crop. Farmers field was selected which cultivate same crop variety and following almost similar crop management practices. Field visits were done at the monthly interval for recording growth, and yield parameters of rice and wheat plants during Kharif and Rabi seasons. Air pollutants level such as PM_{10}, SO_2, NO_2 and O_3 and aerial dust deposition on crop canopy was quantified at the selected experimental sites. Growth and yield response of selected crops varieties at two growth stages, i.e. vegetative and flowering were monitored at all selected sites. Biochemical parameters were also analysed for the APTI. For the analysis of biochemical parameters, seven crops such as *Oryza sativa, Triticum aestivum, Pennisetum glaucum, sorghum bicolor, Hordeum vulgare, Brassica juncea and Trifolium alexandrinum* were selected which were common in all selected sites in the study area during Kharif and Rabi seasons in 2015-16 and 2016-17. Only four sites were selected for the analysis of biochemical parameters because these sites had all selected crops. To evaluate the effect of different air pollutants on crop growth and production, selected crops were monitored for the changes in morphological, anatomical, physiological, biochemical, and yield characteristics. The salient findings of the study are presented below:

1. During experimental crop growth period, meteorological data has been recorded. During 2015-16, the maximum mean monthly temperature ranged from 36 to 46 °C with minima from 28 to 34 °C, and during the winter months, the maximum temperature ranged from 27 to 33°C and minima from 13 to 22°C. It received an annual rainfall of 530.32 mm. The wind speed varied from 13.0 to 15.4 km h^{-1} during the summer and 9.0 to 11.1 km h^{-1} during the winter. The wind direction was predominantly northwesterly during the whole growing period.
2. Whereas during 2016-17, the summer months maximum mean monthly temperature ranged from 37 to 44 °C with minima from 27 to 33 °C and during the winter months maximum temperature ranged from 24 to 34°C and minima from 12 to 20°C. It received an annual rainfall of 621.6 mm, out

of which 80 to 90% occurs during June-August. The wind speed varied from 8.7 to 13 km h^{-1} during the summer and 9.3 to 11.9 km h^{-1} during the winter. The wind direction was predominantly northwesterly during the whole growing period

3. Air quality monitoring showed that concentration of PM_{10} found minimum at Akilpur Jagir followed by Pyawali Tajpur (control sites), whereas maximum level was found at Khangoda, Jarcha and Uncha Amirpur villages, due to their location on the leeward side to the TPP.

4. Gaseous pollutants monitoring showed that concentration of SO_2, NO_2 and O_3 found minimum at Akilpur Jagir followed by Pyawali Tajpur (control sites), whereas maximum level was found at Khangoda, Jarcha, Uncha Amirpur village, due to their location on the leeward side to the TPP.

5. After the analysis of heavy metals in the ambient air, we found that concentration of heavy metals like As, Ni and Pb ranged from 0.28 to 0.44 ng/m^3, 1.24 to 1.74 ng/m_3 and 7.68 to12.54 ng/m^3 during Kharif season respectively, whereas, in Rabi season, concentration of As, Ni and Pb ranged from 0.35 to 0.45 ng/m^3, 2.34 to 4.74 ng/m^3 and 10.24 to 16.89 ng/m^3, respectively. There was no significant difference among heavy metals concentration at selected sites.

6. AQI values showed that air pollution level was light to moderate at control sites (Akilpur jagir, Pyawali tajpur), whereas heavy pollution level at other selected sites (Jarcha Khangoda Uncha Amirpur Nagla Kashi Ranauli Latifpur).

7. The aerial deposition was significantly varied at different sites. The maximum deposition was found in Jarcha, Khangoda and Uncha Amirpur villages due to their location on the leeward side to the TPP. The minimum deposition was found in Akilpur Jagir and Pyawali Tajpur villages at both growth stages in the consecutive year. But aerial deposition rate was found more in wheat crop than rice.

8. Air pollution significantly hampered the growth and physiological parameters of both rice and wheat crops. After the measurement of LAI in both crops, we found that LAI was maximum at Akilpur Jagir followed by Pyawali Tajpur those were assumed as control sites. Whereas minimum at Jharcha followed by Khangoda, Uncha Amirpur.

8. Dust accumulation capacity was maximum in *Hordeum vulgare* (2.15 mg/cm^2) and minimum in *Brassica juncea* (1.06 mg/cm^2) at polluted site during 2015-16. Whereas dust accumulation capacity was maximum in *Triticum aestivum* (2.21 mg/cm^2) and minimum in *Trifolium alexandrinum* (1.06 mg/cm^2) at polluted site during 2016-17.

9. Response of biochemical parameters to PM deposition and other gaseous pollutants was significant ($P<0.05$). Significant reduction was found in all parameters like chlorophyll content, RWC, ascorbic acid and pH.

10. Maximum pH was found in *Sorghum bicolor* whereas minimum in *Oryza sativa* crop at Khangoda (most polluted site) during 2015-16. During 2016-17, we found maximum pH value in *Trifolium alexandrinum* and minimum in *Oryza sativa* crop.

11. During 2015-16, we recorded that, at Khangoda (most polluted site), maximum RWC was found in *Triticum aestivum* (82.17), whereas minimum in *Sorghum bicolor* (62.79). During second year study, we observed, maximum in *Pennisetum glaucum* (79.76) and minimum in *Sorghum bicolor* (66.18) at most polluted site.

12. Maximum total chlorophyll was found in *Triticum aestivum* (2.71), whereas minimum in *Sorghum bicolor* (2.14) at Khangoda (most polluted site) in 2015-16.

13. Ascorbic acid was found maximum in *Oryza sativa* (0.012) and minimum in *Hordeum vulgare* (0.016) at polluted site during 2015-16. whereas maximum in *Oryza sativa* (0.011) and minimum in *Hordeum vulgare* (0.015) at polluted site during 2016-17.

14. All APTI values are less than 12 which means all crops were sensitive to air pollution in selected area but *Triticum aestivum* and *Trifolium alexandrinum* were less sensitive in compared to other crops during first and second year study respectively.

15. API value showed that Triticum aestivum and Oryza sativa were best-suited crops in the selected study area as compared to other crops. So API and APTI might be very helpful in the selection of crop species in the polluted area.

16. The study showed that grain yield of rice was reduced from 3.56% to 8.46% and in wheat from 2.84% to 9.52% in 2015-16. In second year study, we found that reduction in rice grain yield was up to 9.83% and 10.62% in wheat crop.

17. In case of rice, straw yield reduction was from 5.61% to 11.08% and in wheat from 3.11% to 12.24% in first year of study. During 2016-17, in rice, straw yield reduction was from up to 12.44% and in wheat 11.77%.

18. The Gaussian Plume Dispersion Model (GPDM) was validated for the study area. Maximum performance evaluation index (d) was observed higher for SO_2 as compared to NO_2 at Khangoda and Nagla Kashi villages. Therefore, dispersion model was well suited for SO_2 dispersion. The study revealed that the impact of air pollutant was more severe at a downwind distance from TPP to the range of 2 to 6 km.

CONCLUSION

The study results that air pollutants from coal-based TPP severely affect the growth and productivity at varying degree in rice and wheat crops. Air pollutants level was maximum at leeward side and minimum at the windward side of the TPP. Ozone plays a significant role in Kharif whereas SO_2 and NO_2 in Rabi, but particulate matter as aerial deposition on crop canopy was the main culprit. An area of 2 to 6 km on the leeward side from the TPP is most sensitive to air pollution effects.

This study can be expanded for other agricultural crops in different polluted sites so that we can justify the suitability of crops according to their sensitivity to the air pollution. So that diversified agriculture can be a sustainable option for the farmers to maintain their productivity and income.

Emission of air pollutants from coal-based thermal power plant and their impacts on crop productivity

ABSTRACT

The air pollution is world's deadliest environmental problem, and it also has detrimental effects on crops. This study focuses on quantification of the air pollutants from Thermal Power Plant (TPP) and its impacts on crop productivity. Ten different sites were selected in the vicinity of the TPP on the basis of windrose map. The concentration of Particulate matter (PM_{10}), SO_2, NO_2 and O_3 were minimum at Akilpur Jagir (control site) and maximum at Khangoda, Jarcha and Uncha Amirpur (most polluted sites). It has been observed that the aerial deposition on crop canopy ranged from 0.85 to 2.19 mg/cm^2 and 1.08 to 2.21 mg/cm^2 in wheat and 0.54 to 1.56 mg/cm^2 and 0.64 to 2.07 mg/cm^2 in rice crop at vegetative and flowering stages respectively. The air pollution from the TPP reduced the photosynthetic rate which leads to decrease in leaf area, transpiration rate in rice and wheat crops and finally had an adverse impact on crop yield. The study conducted for the two consecutive years 2015-16 and 2016-17 and the significant reduction in crop yield was observed. The grain yield reduction was observed 8.46 and 9.83 % in case of rice and 9.52 and 10.62 % in wheat for the year 2015-16 and 2016-17 respectively. The maximum yield reduction was observed at Jharcha and Khangoda (most polluted sites) over Akilpur Jagir and Pyawali Tajpur (least polluted sites). The study also evaluated the Air Pollution Tolerance Index (APTI) to analyse the sensitivity or tolerance level of the crops in the selected area. Although all the crops were sensitive to air pollution in the selected area, *Triticum aestivum* and *Trifolium alexandrinum* were found to be less vulnerable in comparison to other crops. On the basis of Anticipated performance Index (API), it has been observed that the wheat and rice were more appropriate crops in the study area. The Gaussian Plume Dispersion Model (GPDM) was validated for the study area. The performance evaluation index (d) value for SO_2 was maximum at Khangoda (0.66) followed by Nagla Kashi (0.57) and Jarcha (0.52) whereas, for NO_2, it was maximum at Jarcha (0.54) followed by Nagla Kashi (0.48) and Khangoda (0.32). Hence, the study revealed that the impact of air pollutant was more severe at a downwind distance from TPP to the range of 2 to 6 km.

कोयले पर आधारित तापीय शक्ति सयंत्र से वायु प्रदूषको का उत्सर्जन तथा उनका फसल उत्पादकता पर प्रभाव

सांराश

वायु प्रदूषण विश्व की सबसे घातक समस्या है और इसका फसलो पर हानिकारक प्रभाव होता है। यह अध्ययन तापीय शक्ति सयंत्र के वायु प्रदुषको की मात्रा के मापन व उनके फसल उत्पादकता पर प्रभाव पर केन्द्रित है। हवा की बहने की दिशा के नक्शे के आधार पर तापीय शक्ति सयंत्र के समीप दस विभिन्न स्थानो का चुनाव किया गया। अकिलपुर जागिर, (नियंत्रित स्थान) पर निलंबित कणों (पीएम$_{10}$),सल्फर डाइऑक्साइड, नाइट्रस ऑक्साइड व ओजोन की मात्रा सबसे कम पाई गई तथा खंगोडा, जारचा व उन्चा अमीरपुर मे सबसे अधिक पाई गई। इस प्रयोग मे यह पाया गया कि गेहूँ की फसल मे वनस्पतिक व विकाश अवस्था मे पादपीय सतह पर इन प्रदूषको का वायुवीय जमाव क्रमशः 0.85 से 2.16 मि.ग्रा. / से.मी.^{2} व 1.08 से 2.21 मि.ग्रा. / से.मी.^{2} तथा धान की फसल मे 0.54 से 1.56 मि.ग्रा. / से.मी.^{2} व 0.64 से 2.07 मि.ग्रा. / से.मी.^{2} पाया गया। थर्मल पावर प्लांट के वायुवीय प्रदूषण से गेहूँ व धान मे प्रकाशसंश्लेषण की दर कम हुई जिसके परिणाम स्वरूप पत्तियो के क्षेत्रफल व वाष्पोत्र्जन की दर मे कमी हुई जिसका बुरा असर इन फसलो की उपज पर हुआ। यह प्रयोग दो वर्षो 2015–16 व 2016–17 के दौरान किया गया और इस दौरान उपज मे महत्वपूर्ण कमी पाई गई। दानो की उपज मे वर्ष 2015–16 व 2016–17 के दौरान गेहूँ में क्रमशः 8.46 से 9.83 % व धान मे 9.52 से 10.62 % तक कमी पाई गई। फसलो की उपज मे यह कमी सबसे अधिक जारजा व खनगोडा, सबसे अधिक प्रदूषित स्थानो मे तथा अकिलपुर जागिर व प्यावली ताजपुर मे सबसे कम पाई गई। इस अध्ययन मे चुने गए स्थानो की फसलो की सहनशीलता व संवेदनशीलता का विशलेषण करने के लिए वायुवीय प्रदूषण सूचकांक, (एपीटीआई) का मूल्याकन कियाा गयाा। यद्यपि सभी फसलें वायु प्रदूषण के प्रति सवेंदनशील होती है लेकिन गेहूँ व बरसीम की फसले अन्य फसलो की तुलना मे सबसे कम संवेदनशील होती है। प्रत्याशित प्रर्दान सूचकांक, (एपीआई) के आधार पर यह पाया गया कि गेहूँ व धान अध्ययन किए गए स्थानो के लिए सबसे उपयुक्त फसलें है। अध्ययन क्षेत्रो के लिए गोसियन प्लूम डिस्प्रसन मॉडल, (जीपीडीएम) को विधिमान्य किया गया। सल्फर डाइऑक्साइड के लिए प्रत्याशित प्रर्दान सूचकांक (डी) का मान सबसे अधिक खंगोडा, (0.66) इसके बाद नागला काशी (0.57) व जारचा (0.52) मे जबकि नाइट्रस ऑक्साइड के लिए यह जारचा (0.54) मे सबसे अधिक इसके बाद नागला काशी मे (0.48) व खंगोडा मे (0.38) पाया गया। इस प्रकार इस अध्ययन मे प्रदूषण का प्रभाव वायु की दिशा मे तापीय शक्ति सयंत्र से 2 से 6 कि.मी. की दूरी तक अधिक पाया गया।

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