A PROJECT REPORT

ON

SIMULTANEOUS MEASUREMENT AND ANALYSIS OF PM_{10}, $PM_{2.5}$ AND PM_1 EMITTED DURING FIREWORKS IN INDIA

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CANDIDATE'S DECLARATION

I, *DASHMEET SINGH*, Roll No. 2K18/ENE/07, M.Tech. Environmental Engineering, hereby declare that the report entitled "*SIMULATENOUS MEASUREMENT AND ANALYSIS OF PM_{10}, $PM_{2.5}$ AND PM_1 EMITTED DURING FIREWORKS IN INDIA*" submitted by me in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not formed the basis for the award of any Degree, Diploma, Associateship, Fellowship or other similar title or recognition. This work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere to the best of my knowledge.

Place: Delhi **DASHMEET SINGH**

Date: July 2020

CERTIFICATE

I hereby declare that the Project Report titled "Simultaneous Measurement and Analysis of PM_{10}, $PM_{2.5}$ and PM_1 Emitted During Fireworks in India" submitted by Dashmeet Singh, Roll No. 2K18/ENE/07, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision.

Place: Delhi

Date: July 2020

Dr. Rajeev Kumar Mishra

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Dashmeet Singh

Place: Delhi

Date: July 2020

ABSTRACT

Delhi is known to be one of the most polluted cities in the global world peculiarly during the period of October to January. These months fall during the time of main religious festivals of India with the most famous and important festival of Diwali. People argue that during this time the air quality of the city get worse due to the post effects of Diwali festival because of the extensive use of burning of fireworks by the urban and rural people which emits large amount of atmospheric Particulate Matter. Bursting of fireworks during the time of festival can lead to a short- term range air quality problems. This study focused on the variation of the levels of Particulate Matter which includes PM_{1}, $PM_{2.5}$, and PM_{10} during the interval of bursting of fireworks. The concentrations of particulate pollutants were measured for 4 consecutive days during the end of the October'19 at DTU (Delhi Technological University) campus which is institutional cum residential area in Delhi. The study was done so that we can know the harmful impacts of fireworks on the Particulate Matter levels in the atmospheric air of Delhi. On the day of festival i.e. Diwali, PM_{10}, $PM_{2.5}$, PM_{1} average mean concentrations was noticed to be 324.9, 173.45 and 139.03 $\mu g/m^3$ respectively which were quite much higher than the normal day levels. The mean concentrations of $PM_{2.5}$ & PM_{10} of each day were found to be higher than 24 hour standards as prescribed by NAAQS (National Ambient Air Quality Standards). The regression analysis of PM ($PM_{2.5}$ & PM_{10}) was performed with gaseous pollutants (O_3, NO_2 CO and SO_2) and Relative Humidity (RH), Temperature and Wind Speed. Among all the selected pollutants (CO, NO_2, SO_2), the Particulate Matter gave best correlation with CO with values (r=0.66) and (r=0.81) respectively and O_3 showed inverse correlation with PM respectively on Diwali day. Regression analysis of PM_{10} & $PM_{2.5}$ showed negative correlation factor with Temperature and strong positive correlation factor with RH and wind speed during Diwali day. Nevertheless, the increment in the mean concentrations of Diwali day was found to be highest from the ground level concentrations due to accumulation of the particles. The short term range health effects caused by Particulate Matter concentration have been discussed. The above study shows that the regional pollution have a significant role leading to the hazardous effects due to deteriorating urban air quality in megacity like Delhi.

***Keywords*:** Air Quality, Diwali, Fireworks, NAAQS, Particulate Matter

CONTENTS

Abstract v

List of Figures viii

List of Tables ix

List of Symbols, abbreviations xi

CHAPTER 1 INTRODUCTION **1**

1.1 Scenario of Particulate Matter 1

1.2 Diwali Festival 3

1.3 Objectives of the Study 5

CHAPTER 2 LITERATURE REVIEW **7**

CHAPTER 3 METHODOLOGY **11**

3.1 Location and Topography of Study Area 11

3.2 Data Collection 12

3.2.1 Instrumentation 14

CHAPTER 4 RESULTS & DISCUSSION **16**

4.1 Monitoring of Particulate matter (PM) at selected location (DTU campus) 16

4.2 Temporal Variation of PM Concentration 20

4.3 Correlation Between PM and Trace Gases During Diwali Festival 27

4.4 Correlation of PM With Meteorological Parameters During Diwali Festival 33

4.5 Contribution of Fireworks in $PM_{2.5}$ 38

4.6 Short-Term Health Effects Discussion Due to Fireworks 40

CHAPTER 5 CONCLUSION **42**

References **43**

LIST OF FIGURES

Figure 3.1 Location of the site through Google view 13

Figure 3.2 Portable aerosol spectrometer 15

Figure 4.1 Mean temporal variation of PM_{10}, $PM_{2.5}$, PM_1 concentration in Delhi 22

Figure 4.2 Mean temporal variation of PM_{10}, $PM_{2.5}$, PM_1 concentration in Delhi 23

Figure 4.3 Mean temporal variation of PM_{10}, $PM_{2.5}$, PM_1 concentration in Delhi 24

Figure 4.4 Mean temporal variation of PM_{10}, $PM_{2.5}$, PM_1 concentration in Delhi 25

Figure 4.5 Linear correlation analysis of PM_{10} and trace gases during Diwali day (a) to (d) 29

Figure 4.6 Linear correlation analysis of $PM_{2.5}$ and trace gases during Diwali day (a) to (d) 31

Figure 4.7 Correlation between PM_{10} and temperature, wind speed and relative humidity during Diwali day (a) to (c) 35

Figure 4.8 Correlation between $PM_{2.5}$ and temperature, wind speed and Relative humidity during Diwali day (a) to (c) 37

LIST OF TABLES

Table 4.1: Daily means and peaks of PM during the monitoring period **17**

Table 4.2: Daily 2 hour mean and peaks of PM during the monitoring period **18**

Table 4.3: The ratios of PM_1 & $PM_{2.5}$ trends **26**

Table 4.4: Linear regression coefficients of PM and Trace gases **27**

Table 4.5: Mean concentration of $PM_{2.5}$ & CO during each day of study (2018) **39**

Table 4.6: Mean concentration of $PM_{2.5}$ & CO during each day of study (2019) **40**

List of Symbols and abbreviations used

Symbols

- µ - micro
- m3/m^3 – Metre cubed
- g – gram

Abbreviation

- NCR – National Capital Region
- CSIR – Council of Scientific and Industrial Research
- NEERI – National Environmental Engineering Research Institute
- SCI – Supreme Court of India
- WHO – World Health Organization
- NAAQ – National Ambient Air Quality Standard
- CPCB – Central Pollution Control Board
- PM10 - Particulate Matter ≤10µm
- PM2.5 - Particulate Matter ≤ 2.5µm
- PM1 - Particulate Matter ≤1µm

CHAPTER 1

INTRODUCTION

Diwali is one of the most religious festival of Hindus celebrated across India every year with pomp and fervour, coincides in the winter months only. During Diwali large number of fireworks and firecrackers are being used which becomes the short and long term man- made sources of air pollution which lead to the severe impacts on quality of air and also corresponding health concerns (Pathak et al., 2013; Galea and Powles, 2010). The post-effects of burning of fireworks can lead to deterioration of air quality in the atmosphere. Research on "Diwali" effects on air quality has focused on measurement of the concentration of the harmful pollutants which occurs during and about Diwali. Singh et al., (2010); Chatterjee et al., (2013); Devara et al., (2018) have found significant metal concentration in air contributing to pollution on Diwali. A study has reported that there is an increase up to 100% of PM_{10} concentration when fireworks are burned during the celebration of a Vishu festival. In Delhi, there was an increase of 20-30% of total PM10 concentration due to emission of firecrackers and around 21-27% increase in PM10 concentration in Jamshedpur (Ambade, 2018).

1.1 PARTICULATE MATTER POLLUTION

One of the megacities of Indian subcontinent, Delhi comes under second number in the most polluted capital city all over the world in terms of particulate matter pollution (WHO report, 2018). Around 846 million people in India (60% of the population) were exposed to air pollution from household only in 2017 (HEI Report 2019). There were about 3 million deaths due to PM2.5 pollution in the year of 2017 (HEI Report 2019). India one of the most populous countries added the highest burden with 673,000 deaths and 21.3 million DALYs (Disability-adjusted life year) which both contributed to 52% of the total worldwide PM 2.5 caused deaths and 50% of the DALYs. It's a metropolitan city in terms of industrialisation, construction and population density. Delhi ranks seventh in the list of mostly populated city in terms of population density. Universally, more than 90% people live in those areas where they have exceeded the WHO guideline for healthy air. More than of the areas don't even meet WHO's least stringent air quality target. The pollutants are emitted from major sources like emission of solid waste burning, big power plants, transportation sectors and industrial activities (Viana et al., 2008; Thurston et al., 2011; Amato et al., 2016). As far as numbers of vehicles are concerned more than 0.4-0.45 million commercial and private vehicles are being added to Delhi according to the information of Delhi Government during the year of 2011. With the passage of years, the concern related to exposure in terms of short and long range effects of air pollution has risen. Air pollutants stays as suspension in air for maximum duration in winter season because of slow wind, lower degree of temperature and high relative density during OCTOBER -JANUARY. In early days of November, the stubble burning in the states of Haryana and Punjab contributes significantly to the arrival of air carrying smoke in Delhi (Jain *et al*., 2014).

Multifarious events and festivals around the globe involves the use of firecrackers including Festival of Diwali in India, Bastille Day Celebration in France, Australia Day (Australia), Chinese New Year in China, New Years's Eve (globally), Christmas Day and other large events. A study was conducted in Mexico which says that while burning of fireworks there was a slight production of nitrous acid also. With the extreme burning of firecrackers during the festivals and other like events can lead to serious health effects related to human body like lung infections, bronchitis, asthmatic problems, cardiovascular attacks (Hirai et al., 2000; Barman et al., 2008; Beig et al., 2013). Generally, there are four major elements in each type of fireworks which are magnesium, charcoal/sulphur, aluminium and some of the oxidizing components, which are majorly nitrates (strontium/barium nitrates etc.) or chlorates (potassium chlorates etc.), for providing colours certain metals are added like iron, lead, barium etc., that acts as a colouring agent and also a binding agent. Barium related compounds have the essence of green colour (e.g., BaCl2) and copper compounds shows the presence of blue colour like $CuCl_2$ (Copper Chloride). If we talk about aerosol number concentration, whistling sparkles shows highest PM emission rates also get easily deposited in respiratory system more efficiently (Betha and Balasubramanian, 2013). There is multiple times increase in the air pollutants concentration which includes PM2.5, PM10 and Nitrogen like gases during fireworks events which are taking place across the globe (Seidal and Birnbaum., 2015 and Kong et a., 2015). According to the studies, the air pollutant concentrations during fireworks events are usually 2 to 8 times higher than the non-episodic event days. The sharpest skewer concentration can be seen usually during the event and after the event which is back to ground levels after 24- 48 hours. During the festival day of Diwali, highest concentration is seen during after the evening time (20:00-01:00 hours) (Joshi et al., 2016). Across different cities, the concentration during fireworks events is ranging from few µg/m^3 to maximum of 2 mg/m^3 during shorter spans of time.

Usage of fireworks unharness a variety of pollutants as well as particulate matter and gases like sulphur dioxide, CO_2 and they are having a direct influence on respiratory system of human beings (Ravindra et al., 2003; Seidal and Birnbaum, 2015; Hamad et al., 2016). The emitting activities of Particulate matter and vaporous pollutants in occasions will absorb and scatter lightweight waves of radiation and add to lightweight extinction which results in luminousness. The unexpected impale of waste matter concentrations in throughout fireworks and different events may end up in serious health hazards which embrace asthmatic attacks, respiratory organ diseases, fever, lung allergies and upset (Hirai et al., 2000; Becker et al., 2000; Beigal et al., 2013). Shamoun-Baranes et al., (2011) stated that other than human life, it can also affect the wildlife through its high levels of noise. Surface water quality, other water bodies and snow too getting deteriorated and contaminated due to the use of such emitted chemicals (Wilkin et al., 2007; Steinhauser et al., 2008).

Several stations have exceeded the standard of $PM_{2.5}$ (35 µg/m^3) during the events as per the National Ambient Air Quality Standard (NAAQS) (Seidal and Birnbaum, 2015). In USA, on the time of their celebration of Independence Day which falls on July 4th, the fireworks have shown increase in PM (Wang et al., 2012). Similarly in China there was also an increase in the PM concentration during the celebration of Chinese New Year (Li et al., 2013; Li et al., 2017; Song et al., 2017; Lai and Brimblecombe ., 2017).

1.2 DIWALI FESTIVAL

Diwali is one of the most religious festival of Hindus celebrated across India every year with pomp and fervour, coincides in the winter months only. During Diwali large number of fireworks and firecrackers are being used which becomes the short and long term man- made sources of air pollution which lead to the severe impacts on quality of air and also with corresponding health concerns (Pathak et al., 2013; Galea and Powles, 2010). Fireworks plus the firecrackers that are being enjoyed at the time of festival are having tubes made of paper which are having fillers inside like metallic & non-metallic elements (silicon, sulphur, aluminium etc.), organic elements (carbon and charcoal), colouring agents (lead, strontium etc.) and binders also (Vecchi et al., 2008; Drewnick et al., 2006). These components lead to emission of toxic pollutants which includes particulate matter, charcoal, trace gases and metals (Wang et al., 2007). Potassium (K) is the major component during fireworks emission (Wang et al., 2007). The emitted PM is having a rich source of metals i.e. Pb (Lead), Ba (Barium) and M (Manganese) with some of the organic compounds like PAH (polycyclic aromatic hydrocarbons). Barman et al. (2008) outlined the increase in the concentration of cadmium (Cd), nickel (Ni), zinc (Zn) and Chromium (Cr) in the region of Lucknow (India) during episodic event of Diwali. There was a significant increase in the concentration of Barium with others Cu, K, Mg, Arsenic (As) accompanied by notable increase in barium, strontium, aluminium and potassium (the particles with size 25µm and lower were reporting 58µg/m^3 of Potassium). A limited work concern to Particle mass and particle number concentration has been done till date. PNC have been seen increased during such type of events (Wehner et al., 2000; Drewnick et al., 2006). Betha and Balasubramanian (2013) gave an account of that particles around 60 to 85% from firework emissions were ranging in ultrafine size range (that is below 100µm). In China, during spring festival season the total PNC was 42% and 57% with Aitken and accumulation mode respectively in firework emission (Yang et al., 2014). The average PNC of 24783 cm^3 was reported during Spring festival fireworks. Wehner et al. (2000) detailed about the PNC increase in the accumulation range (less than 100µm) in the events of firework. Pitz etal (2008b) reported that when they matched the results of PNC of during day time and night time, they found that the particle number concentrations (PNC) was far more in number during day time than the PNC during the night time because of the effects of human activities, so if there is no data of the day time then the daily mean PNC will be definitely lower than normal daily mean particle number concentrations. A study conducted in India in which evaluation was done that there was at least 2% health effects which got increased with exposure to certain elements linked with emission of fireworks (Ba, Mn , Al) during festival of Diwali while no such risk difference was noted in Bangkok for metal elements such as Cr, Zn and Pb. It is unclear that whether there are long term effects along with short term effects or not. Ultrafine particles are having the easy access to get into the bronchi and alveoli of the human respiratory system and deposit in the areas of the respiratory tract (Dockery et al., 1994 ICRP, 1994; Oberdörster *et al.*, 2005). The processes through which the inhaled particles get deposited in the human respiratory system are diffusion, gravitational settling, interception and inertial compaction.

In China, due to strict regulations there is a decrease in the overall emissions (Lai and Brimblecombe, 2017). In Shanghai, between 2013 and 2017, PM2.5 level got reduced from 79 to 32 $\mu g/m^3$ at the rate of - 13.8 $\mu g/m^3$ because of the restriction on the fireworks. In India, the sale of the fireworks was restricted in 2018 but no benefits were seen on the air quality (Trivedi et al., 2018). In the year 2016, due to excessive bursting of firecrackers in the national capital and the crop burning in the neighbouring states, the ambient air quality rose to alarmingly grave levels. On 25th November 2016, the Supreme Court of India (SCI) (Times of India, 2016) passed a ruling on banning the sales of firecrackers within Delhi – NCR in order to check the deteriorating air quality. On 1st October 2017, the Delhi High Court passed a ruling to prevent the burning of agricultural wastes. The Ministry of Environmental, Forestry and Climate change was ordered to collect weekly environmental reports from special committees established in each concerned state by respective governments. The ruling passes did not help in achieving the intended results as the ambient air quality data from Diwali 2017 indicated that severe indication still prevailed.

The current literature is clearly showing the data from different countries that how the extreme burning of fireworks is effecting the atmosphere's air quality. Present evidence gives the path that how the usage of firecrackers can increase PNC significantly, and lot of studies is need to be done in future to improve this type of scenario.

1.3 OBJECTIVES OF THE STUDY

The study was undertaken with the aim of assessing the episodic event of Diwali in an air pollution prone metropolitan city of Delhi in the year of 2019. Portable Aerosol Spectrometer (PAS) has been used to monitor the particle mass concentration at selected site. In view of studying the trend for $PM_{10,}$ $PM_{2.5}$ and PM_1 concentrations in DTU campus area in the city, dispositions were put into place for the successful and effective monitoring of the aforementioned parameters. The aim of this study is to understand the hazardous effects of Diwali festival in the Delhi city. It has been attained with the following objectives:-

- To study the temporal variations of the particulate Matter concentration (PM_{10}, $PM_{2.5}$,PM_1) levels during the Diwali festival for 4 days X 14 hours monitoring at DTU campus situated in New Delhi.
- To study the variations of the particulate matter concentration at extreme fireworks bursting during festival day i.e. Diwali day.

- To study the linear regression analysis of PM_{10} and $PM_{2.5}$ with gaseous pollutants CO, NO_2, O_3 and SO_2.
- To study the linear regression analysis of PM_{10} and $PM_{2.5}$ with different meteorological parameters like temperature, Relative Humidity (RH) and wind speed (WS).
- To calculate the contribution of $PM_{2.5}$ in concentration (µg/m^3) due to fireworks emission during the festival duration in year 2018 and 2019.

CHAPTER 2

LITERATURE REVIEW

According to the HEI report of 2019, there were almost 3 million deaths due to the subjection of the $PM_{2.5}$ concentrations globally. Because of the occurrence of some major events in our daily life like fireworks usage (episodic event), big dust storms (periodic event) can lead to the increment of the levels of Particulate matter concentration in the environment further leading to increase in short-term effects on the human health, reducing visibility and further deteriorating the air quality. Some of the major sources of air pollution includes dust and waste burning, industrial plants, transportation and energy usage in residential areas (Amato et al., 2016; Viana et al., 2008). In modern world, people celebrate cultural occasions at national level mainly through burning of firecrackers or by doing bonfires activities in the forests/tourists spots which is having dangerous impacts on the atmospheric air quality (Pathak et al., 2013). Emission from bonfires or fireworks don't emit only particulate matter but also various range of pollutants like CO, SO_2, CO_2 & NO_x which having toxic impacts on the health of human beings (Hamad et al., 2016 & Seidal and Birnbaum, 2015). These trace gases and particulate matter emitted from fireworks events have the ability to absorb the radiation caused by light and also to scatter them which heading towards the complete vanishing of light, further changing visibility (Singh and Dey, 2012). During the burning of firecrackers, the pollutants which were emitted from them were mainly consisted of $PM_{2.5}$, PM_{10} and NO_x because concentration of these pollutants were many times got increased (Kong et al., 2015). The sudden rises in the concentrations of pollutants were noticed immediate after the episodic event though it got decreased down to normal levels after a day or a two day (Drewnick et al., 2006). A study was done where, Masiol et al. (2014) observed high attribution of particulate matter under the range <10 µm with peak of 700 µg/m^3 and gaseous pollutants during the burning of folk fires with the rise of mean concentration of 90-235 and 65-200 µg/m for $PM_{2.5}$ and PM_{10} respectively. High concentrations of particulate matter more than the mean concentration were noticed at the time of firecrackers bursting event in Iran during the festival of Shanbe Suri (Oroji et al., 2019).

Some of the studies were done in India for the calculation of the contribution of parameters of particulate matter in which Sarkar et al. (2010) showed that around 20-30% contribution was there in PM_{10} concentrations in Delhi. In Jamshedpur, Ambade (2018) showed 21-27% role of in overall ambient concentration of PM_{10}. A study was done by the Resmi et al. (2019) in Kannur district, a coastal city in Kerala, where she monitored the air pollutants concentrations in the pre and post-Vishu festival for 4 consecutive years and found a change in the ambient concentrations of the $PM_{10,}$ NO_2, O_3 and NO because of the extreme use of firecrackers. The pollutants like O_3 and NO_2 had concentrations more than 100% during the festival then the normal days. With the help of a photochemical box model, a simulation was done which showed that there was 100% rise in the photolysis production of O_3 due to extensive use of firecrackers which further depleted the air quality index of that city.

Diwali is major festival celebrated in India with lighting diyas and candles with full joyfulness during the month of October- November. Sky receives large amount of pollutants as a result of burning of fireworks. A study was done in a Collectorate campus of Raipur in which continuous measurement of concentration of air pollutants was done in the month of October from 9 to 25th October in the year of 2017. The collection of the data was done for pre-Diwali days, post-Diwali days and during the Diwali day. For pre-Diwali day the concentration was 137.17-564.05 µg/m^3, for Diwali day the concentration was 171.20-517.67 µg/m^3 and for post Diwali day it was 79.46-266.26 µg/m^3. The collected data was also compared with the standards of the CPCB (Central Pollution Control Board). The pollutants concentrations of Diwali day were still present till 2-days and then the concentration got back to its normal levels slowly. These post Diwali concentrations had very toxic impacts on the asthmatic and cardiovascular disease related patients. For the month of October, the average concentration of $PM_{2.5}$ was found to be 227.71µg/m^3. The relative humidity was recorded as 68% and temperature was 29˚C. The clean air can only be breathed by people, if there will be good control on the fireworks regulations (Dammani et al., 2018). In a study conducted by Tiwari et al., (2011) in Delhi, data of PM_{10} was collected over 2-years from January 2007 to December 2008 and it was also compared to the CPCB (Central Pollution Control Board) permissible limits. It was noticed that Particulate matter levels were lower than the NAAQS in summer but they were higher in winters. All the data of PM_{10}, $PM_{2.5}$ & PM_1 was presented on the day of Diwali festival. On the festival days, PM_{10}, $PM_{2.5}$ & PM_1 levels were 501, 389 & 346 µg/m^3 in the year 2008 and 723, 588 & 536 µg/m^3 in 2008. Correlation was also established between PM_{10} and CO, NO_2, O_3, SO_2 and also with meteorological parameters like temperature, RH & wind speed . A good correlation was found with CO. There are various methods to monitor the air pollutants like particulate matter in ambient air. Evaluation was done on the acute short-term effects caused by the exposure of atmospheric particulate matter ($PM_{2.5}$ & PM_{10}) at the time of Diwali festival. Burning fireworks can cause short-term air pollution in the ambient air. Monitoring of these particulate pollutants was done during Diwali festival for 6 consecutive days in an area near Jabalpur which is a densely populated area to check the impacts on the air quality of that area. Study was continued from 2012 to 2013 consecutively. After getting the results it showed that air quality was getting deteriorated during the festival due to the impacts of fireworks (Srivastava et al., 2014). The effects of fireworks on the air quality of Lucknow city, was studied during the day of Diwali by Barman et al., (2007). At four locations in the city, the estimation of pollutants (PM_{10}, NO_x, SO_2) was done during day and night time of the pre-Diwali day and on the Diwali day. The 24-hour concentration of the pollutants (SO_2, PM_{10} and NO_x) during the festival day was observed to be 134.14, 758.8 and 102.3 μg/m^3 respectively. For SO_2, it was 1.95 and 6.59 times higher, for PM_{10} it was 12.47 & 5.67 times higher and last for NO_x it was 1.79 and 2.69 times higher when compared to concentrations of pre and normal Diwali respectively. The data of the Diwali day i.e. 24-hour concentrations was found to be higher than the NAAQS (National Ambient Air Quality Standards). Ghei et al., (2018) studied the estimations of air pollution due to the emission of fireworks. As Delhi comes under the list of most polluted cities in the world mainly during the time of October to January which are called as winter duration in India. Most of the researcher in fact common public also think that the ambient air quality of the capital city get deteriorated because of the after effects of the firecrackers emission. Hourly concentration of $PM_{2.5}$ was monitored from the year 2013-2017 to calculate the effects of fireworks emission on the air quality of the capital city. Different types of study event techniques were done and regression techniques were also used to know and calculate the effects of $PM_{2.5}$ concentration caused by the burning of fireworks in the ambient air of the city. After the whole study, it was got to know that fireworks emission can lead to significant increase of the pollution in the atmosphere. The results of the study may vary according to the different regions of the city. Similarly, a study was also done by Sati et al., (2014) on the severe air pollution caused during the period of smog event in Delhi. It was very severe occurred at during the month of November 2012 under the very bad meteorological conditions leading to very serious respiratory problems and low visibility too. The concentration levels of particulate pollutants were very much higher like $PM_{2.5}$ was 585μg/m^3, PM_{10} was 989 μg/m^3 and NO_x concentration was 540 μg/m^3. These concentrations are the total concentrations measured all over the Delhi. During the study period, different episodes were analysed with the help of remote sensing techniques. It was observed that the pollution levels of PM_{10} and $PM_{2.5}$ was much higher than the levels of pollutants occurred in Diwali festival which is itself a deadly pollution episodic event. After the complete analysis, it was observed that the events causing regional pollution are much concern than the local events of causing pollution and they can be more dangerous under the meteorological conditions. The effect of burning of firecrackers on the ambient air pollution of a city in China was analysed, the city called valley city situated in Northwestern China. The measurement was done from 25th January to 24th February during the year 2013. Generally, the lightning of fireworks has significant impact on the particle mass concentrations and also on the particle number concentrations too. The hourly average concentrations of PM_1 during the peak hours of festival was found to be around 225 $\mu g/m^3$ which was almost 2 times higher than the pre-Festival days. So after analysing the whole study, it was noticed that particulate matter specially in fine range should not be ignored while firework displays as it can have devastating effects on the increase of local area pollution on short-scale period (Zhao et al.,2014).

Very less information or study is there on the effects of the fireworks bursting during Diwali pre, during and post days. Maximum of the research work is done related to fireworks emission is done on annually basis and very less is there during the Diwali days. The particulate matter pollution is very much high during the Diwali week crossing the National ambient air quality standards which people have very less shown in their studies Tiwari et al., 2011 have shown the crossing the air quality standards of particulate matter pollution. Sometimes we heard news that due to mishandling of firecrackers the shop has caught fire or the people who were transporting them got injury like body burning and hearing loss. If we talk about the festivals in which fireworks burning takes place, then the people who are more in danger are young age people and children. These people are more prone to affects caused by fireworks burning (Billock et al., 2017). At the time of firecrackers burning, old people can catch the problems like loss of hearing, mental stress due to so much of noise, hearing dysfunction etc. Poor visibility can also be the cause of this fireworks bursting. Mainly, the Particulate Matter concentration which is emitted by the fireworks emission have some unique health effects like lung related problems which includes cardiovascular and respiratory problems as one of the dangerous diseases (Franklin et al., 2015).

CHAPTER 3

METHODOLOGY OF THE STUDY

3.1 LOCATION AND TOPOGRAPHY OF STUDY AREA

New Delhi is the national capital of Republic of India officially called 'National Capital Territory of Delhi'. It is surrounded by western parts of state Uttar Pradesh, north-east-south of state Haryana, western and southern parts of Rajasthan. Delhi is situated in northern plains of India, Himalayas in the north and Thar Desert towards west. The Holy river Yamuna (tributary of Holy river Ganga) pass through Delhi with a stretch of 162 km^2. The city covers up an area of 1484 km^2 and situated at a height of 317 m above the sea level. The climate of Delhi is semi-arid in mature. The maximum and minimum temperature occurs generally here is 46˚C and 2˚C respectively. There are total four seasons that occurs in the state given by IMD (India Meteorological Department) namely summer season (March to May), rainy season (June to September), winter season or post monsoon (October to November) and last winter season (December to March). The average rainfall occurs in the state is about 680 mm which is 31.5 inches at a particular year. The sun normally shines in the summer days but a monsoon reaches city, the shining hours of the sun get reduce.

During the month of October in the capital city, the temperature decreases down rapidly because of the arrival of North-western or westerly winds coming from the Rajasthan side during winters. The whole part of India which comes under Northern Plains have to face thick foggy conditions at the time of winter parallel with lower mixing heights. This leads to slow down the movement of aerosols having pollutants in them called as air masses and not able to mix up with the upper layers thus leading to the poor visibility. Different industrial units are also situated in Delhi like power plants plus with significant sources of air pollution like vehicular pollution and coal burning plants making the condition of air quality worse in nature.

Delhi comes out as the 13th largest economy in the country with other states and union territories. The growth rate of the city annually is at 8.1% with the GSDP (Gross State Domestic Product) was calculated at US$96 billion which is ₹ 6.86 lakh crore rupees during the year of 2017-18. The state is ranking at 1st number in the GDP per capita rank all over the country. Delhi also comes under the second number in the list of most productive metropolitan area in the country.

3.2 DATA COLLECTION

This study was conducted at DTU (Delhi Technological University) campus situated in the North-West part of the Delhi. The campus is basically in at Bawana road, shahbad Daulatpur, Rohini area. Rohini is one of the 70 vidhan sabha constituencies in Delhi. It is part of the North-West Lok sabha constituency of National Capital Territory of Delhi. It comes under as both residential cum market area. It has the status of second largest sub-city in Asia after the Dwarka sub-city which is located in South-West part of New Delhi. In the residential area, mostly there are apartments. Most of the residential areas are well maintained with proper parks and gardens making a good green cover. Each sector is having proper bus stops for the easy movement of people. Variety of malls are located in the area and also some amusement park like Adventure Island. The most developing colony in that area is Rajeev Nagar which has good values of houses and having an amazing metro link. The nearest metro line which passes through this area is Red line and Yellow line. Red line starting station is Rithala which is also near to Rohini and end station is Shaheed Sthal in Ghaziabad plus it's two stations are located in Rohini only which are Rohini West & Rohini East and yellow line's starting station is Samaypur Badli which is also near to Rohini sector-18 & 19 and end station is Huda city centre connecting it to well established places like Connaught Place, Saket and Cyber Hub in Gurgaon. Through Yellow Line of Metro, major bus stand ISBT Kashmiri Gate and New Delhi railway station is easily accessible. The outer ring road is also nearby to the campus which directly connects to West District of Delhi areas like Janakuri, Hari Nagar, Tilak Nagar, Dwarka also with IGI Airport at one end and the other end with NH1, Wazirpur area.

To carry out the analysis work, the study was conducted in three divided periods:-

- Before Diwali i.e. Pre-Diwali period consisting of two days (25th to 26th October, 2019.
- Occasional Day i.e. Diwali Day consisting of one day (27th October, 2019).
- After Diwali i.e. Post-Diwali period consisting of one day only (28th October, 2019).

This location was selected because it covers up the both residential cum institutional plus commercial area. The important feature of this area is that it is having a homogenous type of area far away from major road network area so that during our study period we can entirely focus on the emission coming out of the Fireworks bursting having larger amount of aerosol masses in the atmosphere. The instrument was placed at height of 10 metres at the outer area in the campus mainly boundary area. The measurement of Particulate Matter (PM) was done for 4 consecutive days i.e. from 25th October to 28th October, 2019. The main activity for which the measurement was done occurred on 27th October'19. The major spike due to firecrackers bursting was noticed from 18:00-22:00 hours on festival day. The figure 3.1 shows the location of our site at DTU campus.

Figure 3.1: Location of the site through Google view

Particulate Matter also called as Particulates, SPM (Suspended Particulate Matter) or Atmospheric Particulate Matter, Aerosols made up of solid or liquid matter which present in air through suspension. They have direct impacts on air quality and climate. There source can be both Natural or anthropogenic.

We can assign them in three different groups based on their size:-

- Coarse particles called PM_{10} & $PM_{2.5}$ which are basically the particles come under the range of diameter from 10 micro meters (µm) to 2.5 micro metres (µm).
- Fine particles which are basically below 2.5 micro meters (µm) mainly called $PM_{2.5}$ and below 1 µm called ultrafine particles.

3.2.1 Instrumentation

GRIMM Portable Aerosol Spectrometer (PAS) is used to monitor $PM_{1,}$ $PM_{2.5}$ and PM_{10} particles at the above mentioned selected location in Delhi. The PAS model 1.109 is a compact portable device which has been manufactured for continuous measurement of masses of atmospheric aerosols or air borne particles and also with measurement of aerosol number count. This instrument also having a gravimetric filter paper called PTFE (Poly tetra fluoro ethylene) filter paper for the collection of the air particulates on it so that further analysis can be done. The data representation in the instrument can be as mass concentration (µg/m^3) and also as particle number concentration in per particle/litre. This instrument is of Dual-Technology by Grimm Aerosol Technik as a registered patent. It also includes Grimm windows software which displays variation of dust mass fractions also with calculated surface area of an aerosol or particle. The proper category wise dust mass fractions are shown like thoracic, respirable and alveolic.

This instrument works on the principle of light scattering of the particles. Inside it, there is a measuring cell which includes a light source called semiconductor which provides laser as a light source. When the particle passes through the laser, the scattered light is put onto the detector with the help of mirror having a wide opening angle. The detector is placed at an angle of 90˚ so that incident light can directly fall on it. All this alignment is made for only one purpose just to increase the scattering of the incident light on the detector which converts it into signal to noise ratio. One advantage of this setup is that it wears away the unwanted undulations caused due to monochromatic light as it generally occurs in the spectrometers (scattering) and leads to single definite particle sizing. Whenever a particle passes through the laser beam, it generates a light pulse. Each type of amplification in this model is divided into different size bins or channels. This model is having 31 size channels. Through this whole procedure the measurement and calculation of dust mass in different particulate size distribution can be possible. These devices are best used for dust analysis, occupational health data, inhalation technology, atmospheric or aerosol research.

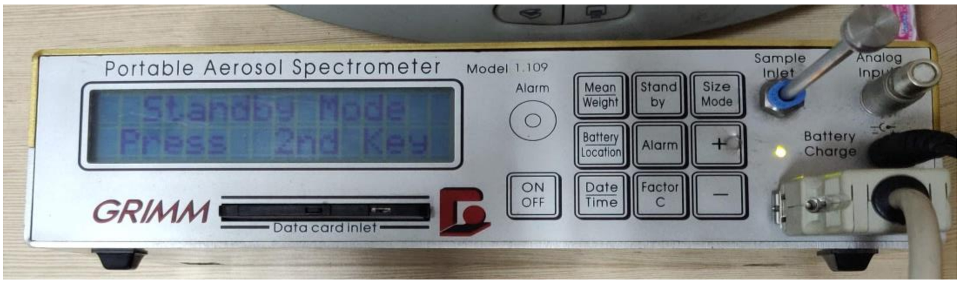


Figure 3.2: Portable Aerosol Spectrometer (PAS)

CHAPTER 4

RESULTS AND DISCUSSION

The study was conducted during 8:00 AM to 10:00 PM on all four defined days. The period was selected due to prior ruling of SCI of burning only two types of crackers Anar (flower pot) and Phuljari (sparkles) which are called Green crackers during the festive season so that the effectiveness and implementation can be known and observed.

4.1 MONITORING OF PARTICULATE MATTER (PM) AT SELECTED LOCATION (DTU CAMPUS)

The monitoring of PM_{10}, $PM_{2.5}$ and PM_1 was carried out with the help of Portable Aerosol Spectrometer (PAS) at residential cum institutional area of DTU campus and carried out as per following schedule:-

- 25th October'19 to 26th October'19 (Pre-Diwali period)
- 27th October'19 (Diwali Day)
- 28th October'19 (Post-Diwali period)

Table 4.1: Daily mean and peak concentration of PM concentration during the monitoring period

Dates	Mean conc. PM_{10} (μg/m^3)	Mean Conc. $PM_{2.5}$ (μg/m^3)	Mean Conc. PM_1 (μg/m^3)	Peak Conc. PM_{10} (μg/m^3)	Peak Conc. $PM_{2.5}$ (μg/m^3)	Peak Conc. PM_1 (μg/m^3)	Minima Conc. PM_{10} (μg/m^3)	Minima Conc. $PM_{2.5}$ (μg/m^3)	Minima Conc. PM_1 (μg/m^3)
Oct 25	314.91	129.62	89.95	420.72	187.6	141.47	163.32	76.25	61.03
Oct 26	264.91	139.35	109.67	385.91	223.03	172.27	206.08	90.53	64.20
Oct 27	324.9	173.45	139.03	786.9	300.8	199.6	115.77	48.35	36.97
Oct 28	295.5	148.15	111.38	365.64	231.15	181.65	173.93	91.79	83.97

Table 4.2: Daily 2 hourly mean and peak concentration of PM concentration during the Monitoring period

Time (Hours)	Mean 2 hourly concentration (μg/m^3)			Peak 2 hourly concentration (μg/m^3)		
	PM_{10}	**$PM_{2.5}$**	**PM_1**	**PM_{10}**	**$PM_{2.5}$**	**PM_1**
08:00-10:00	385.21	204.31	165.95	575.2	243.1	185.3
10:00-12:00	212.79	113.18	93.79	337.7	173.7	146
12:00-14:00	124.91	52.41	40.27	139.6	64.5	51.1
14:00-16:00	148.84	55.87	40.675	440.1	88.4	48.7
16:00-18:00	421.5	137.51	97.76	421.5	216.1	130.4
18:00-20:00	282.75	188.25	153.67	713.6	251.4	181.7
20:00-22:00	380.52	223.90	175.59	786.9	300.8	199.6

The above mentioned table no. 4.1 shows the overall PM concentration of mean and peak of the monitoring days during the occasional event of Diwali. The maximum peak shows of up to 199.6 μg/m^3 on the day of Diwali that how firecrackers are having big role in contribution of PM_1 due the usage of organic and non-organic concentrations in it. The overall mean averages of the same varying from 89.95 μg/m^3 to 139.03 μg/m^3, as we can see from the table that the mean 24 hours PM_1 concentration is quite less before Diwali phase because we know that before the days of Diwali, some of the industrial activities are halted as workers of the industrial units have gone to their hometowns to celebrate Diwali with their families and from this we may say that pollution from industries got a small break from emitting the pollution into the air and hence the effects are getting lowered in this case. It is also true that the mean values are on the vague on increasing up to Diwali, leading to a maxima on the day of the festival and continues to hold high values after the festival and then slowly getting back to normal ground level conditions probably due to factors like as winter season has started approaching to Delhi which lead to low wind velocities in the region, enhanced mixing layer heights and wind observations showing calm conditions which leads to trapping of increased emissions during Diwali and also the land locked geography of Delhi contributing to the same. It can be observed that it may be due to less number of vehicles or traffic volume on the roads of Delhi on pre- Diwali and post- Diwali days. The entire contribution of increase in the levels of particulate matter can be given to the burning of fireworks. A large increment has been noticed between 20:00- 22:00 hours in mean 2 hourly concentration of PM1 concentration. The mean of 2 hourly PM_1 concentrations had risen from 153.67 µg/m^3 to 175.59 µg/m^3. The 2 hourly mean rose during 20:00-22:00 hours (153.67µg/m^3) and found to be greater than concentration observed during 18:00-20:00 hours (175.59µg/m^3) which shows poor implementation of green crackers policy.

During PM concentration analysis of monitoring days, the mean value of monitoring days (25th Oct'19 to 28th Oct'19) was found within a range of 89.95 to 139.03 µg/m^3, 129.62 to 173.45 µg/m^3 and 264.91 to 324.9 µg/m^3 for PM_1, $PM_{2.5}$ and PM_{10} respectively. The table no.4.1 is representing the mean average values of each day during 25th-28th October 2019 which are 89.95, 109.67, 139.03 & 111.38 µg/m^3, 129.62, 139.35, 173.45 & 148.15 µg/m^3 and 324.9, 264.91, 314.95 & 295.5µg/m^3 for PM_1, $PM_{2.5}$ and PM_{10} concentration respectively. From the table 1, it can be seen that there was a slight increase in the mean values of PM_1 and $PM_{2.5}$ concentration between 25th October'19 and 27th October'19. The percentage increase was around 55% and 34% for PM_1 and $PM_{2.5}$ respectively. The mean concentration of PM_1 and $PM_{2.5}$ on Diwali (27th October'19) was found to be slightly greater than pre Diwali days (25th & 26th Oct'19) which was pointing towards the role of burning of fireworks on the Diwali day. On Diwali day, the mean average value 314.95 &173.45 µg/m^3 was found to be 3.1 and 2.89 times higher than the National Ambient Air Quality Standards of CPCB. The peak 2 hourly aerosol concentration of PM was found very much high from 18:00-20:00 hours to 20:00-22:00 hours i.e. 713.6 µg/m^3 to 786.95µg/m^3 which is definitely due to the extreme burning of fireworks on 27th October'19. Similarly, the aerosol levels of peak 2 hourly concentrations of PM2.5 and PM1 had also increased from 251.4-300.9 μg/m^3 and 181.7-199.6 μg/m^3 from 18:00-20:00 hours and 20:00-22:00 hours respectively.

4.2 TEMPORAL VARIATION OF PM CONCENTRATIONS

During the celebration of Diwali festival, usually people like to show their happiness of festival by lighting the fireworks on a vast scale which results in discharge of harmful gases, dust, solid waste and also increases further the noise levels, which disturbs and affects the local public living there and also the asthmatic patients specially. The measurements of concentration of PM concentration which includes PM10, PM2.5 and PM1 all were carried out in the campus of DTU, Delhi at the outer boundary parts of the campus. The temporal concentration of PM was measured for four consecutive days from 25th to 28th October 2019 in which Diwali day was falling on 27th of October. The observations of PM10, PM2.5 & PM1 was measured for round 14 hours on 2 days before Diwali, on Diwali day and one day after Diwali festival as shown in Figures (4.1 to 4.4). The mean concentration of PM10, PM2.5 and PM1 on the festival day was 314.95, 173.45 and 139.03 u g/m^3 respectively. If we see the Figure (4.1 to 4.4)) properly, then will find that PM2.5 and PM1 concentration was rising after 20:00 hours of every day i.e. pre- Diwali days, Diwali day and post-Diwali day. In early morning hours of the monitoring period, the aerosol concentration of PM10, PM2.5 and PM1 was already significantly high at the early 08:00 hours but after 08:00-11:00 hours, the aerosol levels of particulate concentration was decreasing on every day. The high aerosol levels of particulate matter in the early morning may be due to the traffic flow of heavy duty vehicles or trucks in late night hours which enters the city from national highways for the transportation of essential or non-essential heavy goods. In figures 4.2 & 4.5 , the PM10 levels were on the verge of increasing from 11:00-12:00 hours that may be due to the people were on roads travelling on their vehicles to reach offices/ places etc. Usually two or three days before the Diwali festival people like to go to meet their friends and relatives to distribute sweets and gifts on this special occasion which may lead to increase in vehicles leading to increment of PM10 levels on the roads. From the figures 4.1 to 4.4, it can be observed that the average PM2.5 aerosols concentration during pre -Diwali days were similar to average of 300 μg/m^3. The rise in average concentration of particulate matter during pre-Diwali period may be due to the commercial sources of emission, vehicular emission and may be due to the meteorological parameters. The average aerosol concentration rose to

325µg/m^3 on the next consecutive day i.e. Diwali day. Similar results were shown by PM2.5 and PM1 concentration in which their average mean aerosol concentration during pre-Diwali period was lower but higher on Diwali day. From this, it can be concluded that comparatively lesser lighting of fireworks was done on these days. The increase of aerosol concentrations on Diwali day can be attributed to the extreme usage of firecrackers. In figure 6, the trend line of all the PM concentrations was lesser than the Diwali day, though all the parameters are following the same pattern with low peaks than the Diwali days. During 13:00-15:00 hours in figure 4.1 to 4.4 , the aerosol concentration of PM_1 levels was found below 50 µg/m^3 because majority of the people were at their homes due to public holiday and celebrating the festival at their home by enjoying the festival through busy in making rangoli, cleaning their houses, worshipping Goddess Lakshmi and factories as well as industries were closed, so no source of pollution was there. But on post- Diwali day (28th October'19) in same figure the curve PM1 concentration was increased and around 75 µg/m^3 and further increasing before 15:00 hours only. On Diwali day in figure 5, the $PM_{2.5}$ and PM1 were on the verge of increasing from 16:00 hours in the evening and getting increased till 20:00 hours and also further leading to more hike at 21:00 hours indicating towards the rigorous burning of green crackers and may be other crackers also.

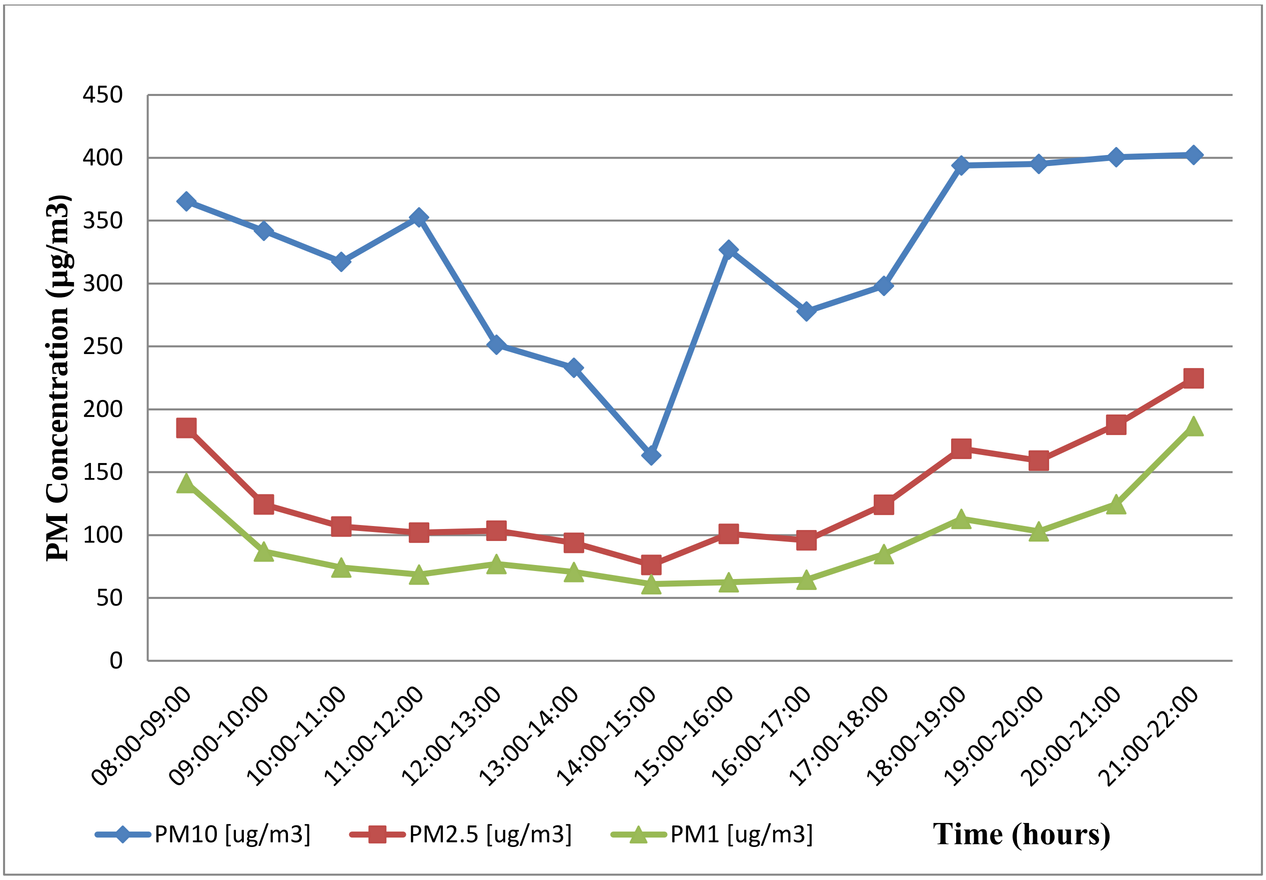


Figure 4.1: Mean temporal variation of PM_{10}, $PM_{2.5}$ & PM_1 concentration in Delhi

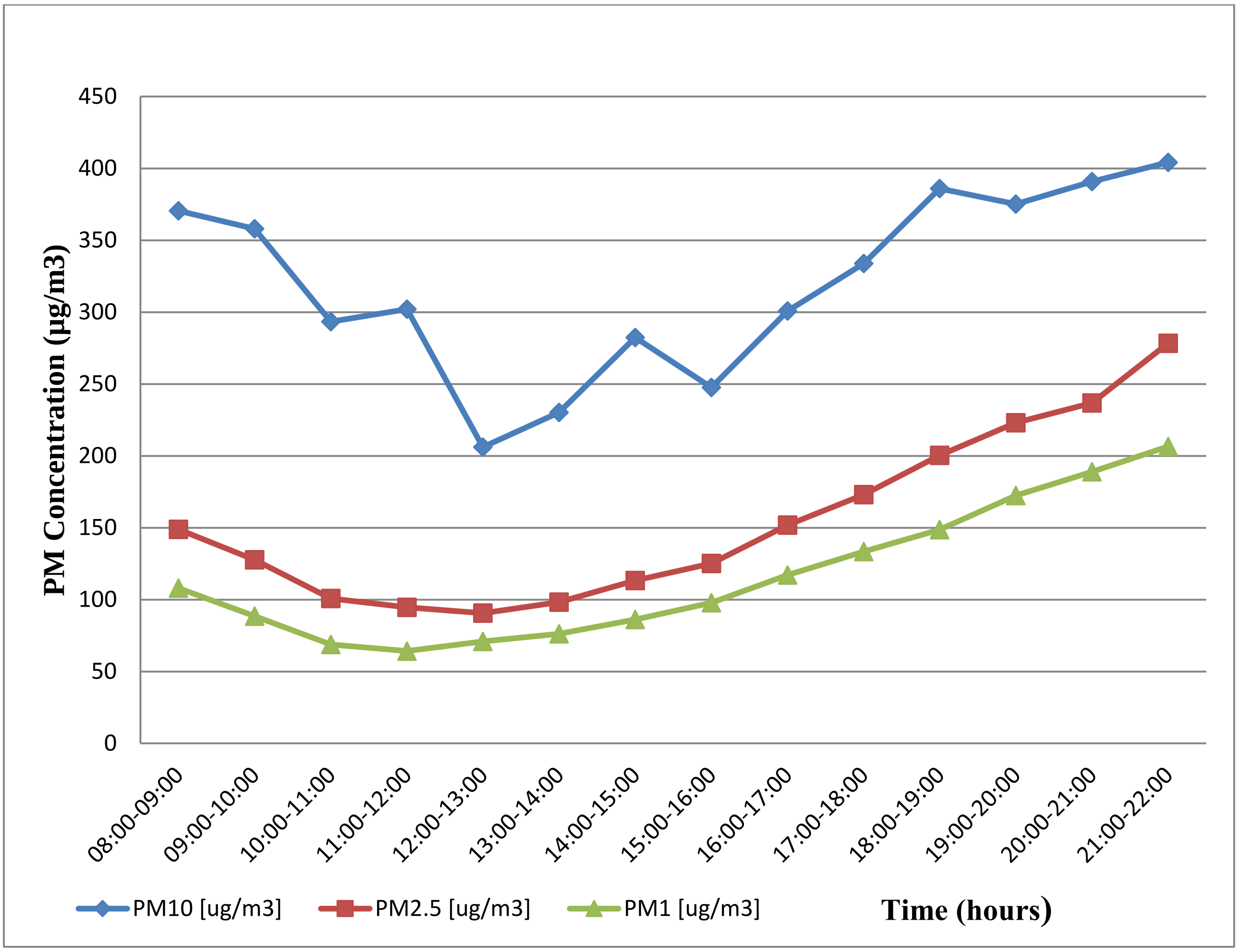


Figure 4.2: Mean temporal variation of PM_{10}, $PM_{2.5}$ & PM_1 concentration in Delhi city

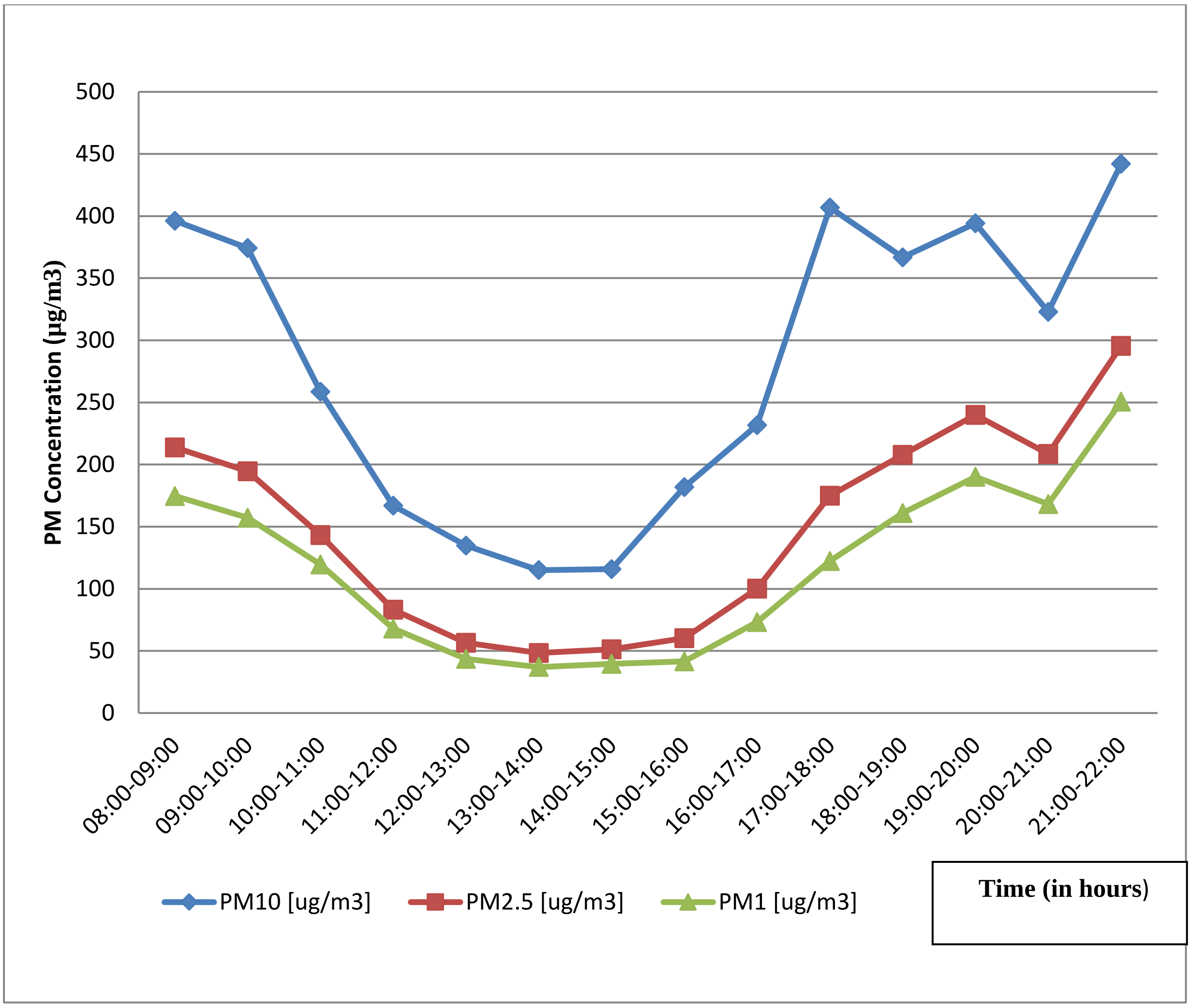


Figure 4.3: Mean temporal variation of PM_{10}, $PM_{2.5}$ & PM_1 concentration in Delhi city

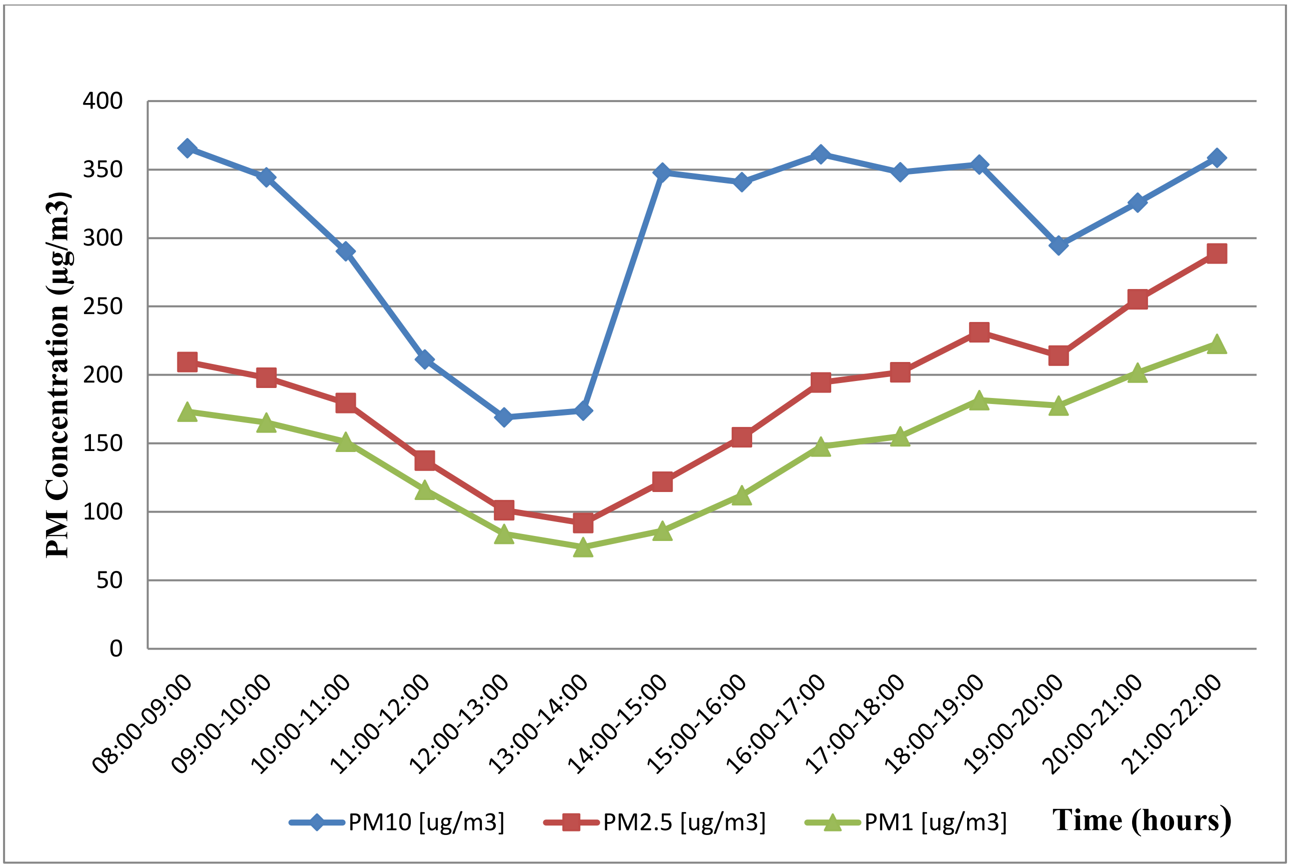


Figure 4.4: Mean temporal variation of PM_{10}, $PM_{2.5}$ & PM_1 concentration in Delhi city

Table 4.3: The ratio of PM_1 &$PM_{2.5}$

Date	$PM_1 : PM_{2.5}$
Oct 25th	0.69
Oct 26th	0.78
Oct 27th	0.80
Oct 28th	0.75

The observations that can be made from the above results are first, the aerosol concentration levels of PM_{10} and $PM_{2.5}$ are very much high than the prescribed NAAQS. Second, PM_1 which doesn't have any standard yet, is also savagely high. Third, the levels of Particulate Matter (PM_{10}, $PM_{2.5}$ & PM_1) starts incrementing post 20:00 hours daily. Fourth, the aerosol concentrations of PM_1 are almost approximately 80% of the $PM_{2.5}$ emitted. For the first and second observations, the reason can be assigned to the rigorous burning of fireworks. The third observation can be discussed by that due to sudden increase in the burning of firecrackers from 8 p.m. onwards was the official timings for the firecrackers bursting ruled by the many states and also with the SCI orders for bursting the green fireworks (anar and phuljari) only stamped and manufactured by CSIR- NEERI (National Environmental Engineering Research Institute). However, the increasing aerosol concentration of Particulate Matter levels post 9 p.m. indicates that the extreme bursting of fireworks was done post 9 p.m. which was may be violated the SCI (Supreme Court Of India) orders of bursting green crackers because green crackers were not emitting less amount of particulate matter concentration. It shows that green crackers are also dangerous and produce somewhat amount of particulate matter pollution and deteriorating the air quality.

On coming at fourth observation which is very important in terms of pollution. Almost ~80% of the aerosol concentration of $PM_{2.5}$ is below 1 µm. This point can help in concluding that $PM_{2.5}$ were not only due to burning of Agricultural waste but was due to extreme usage of fireworks mainly on the pre- Diwali and on Diwali day. Mostly in cities the PM_1:$PM_{2.5}$ remains in the range of 0.5-0.7 but here it is clearly violating it. Such large ratios are very dangerous for us because the human's nasal cavity is not equipped with to remove such fine range of particles from entering our human body neither there is any other part like mucus glands or any other. The masks which are manufactured these days are only equipped with to remove only till $PM_{2.5}$ concentration only. As on Diwali day we are inhaling almost 80% of the PM_1 range particles which is a serious concern for everyone. Already in our country hundreds and thousands of deaths are due to respiratory problems only, but not any of them are recognized as death due to air pollution because air pollution is not the reason for deaths in our country. Because of this not even a single medical reports are taking air pollution as a reason for their consideration in their reports.

4.3 CORRELATION BETWEEN PARTICULATE MATTER AND TRACE GASES DURING DIWALI FESTIVAL

In this data representation of Pearson correlation coefficients of different trace gases CO, O_3, NO_2 and SO_2 with respect to PM_{10} and $PM_{2.5}$ during the day of Diwali is presented in table 4.4 and their scattered plots with linear regression equation is depicted in in figures 4.5 & 4.6.

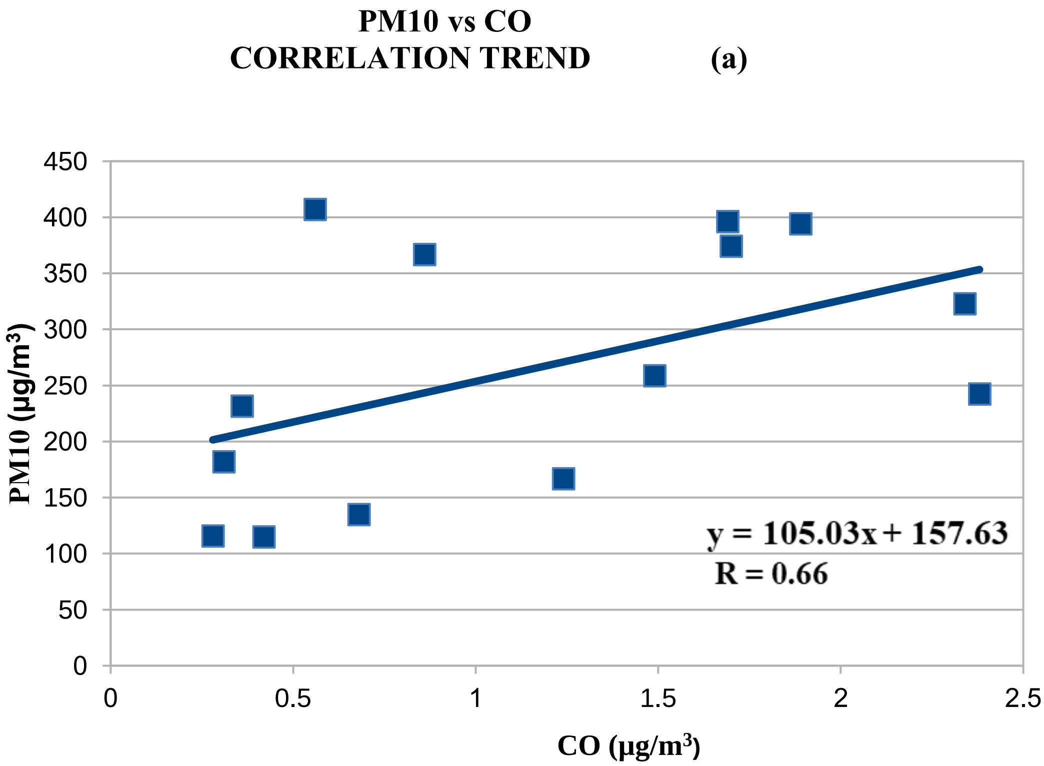
Table 4.4: Linear regression coefficients of PM and Trace gases.

Parameters	**CO**	**O_3**	**NO_2**	**SO_2**
PM_{10}	0.66	-0.88	0.64	-0.08
$PM_{2.5}$	0.81	-0.94	0.79	-0.03

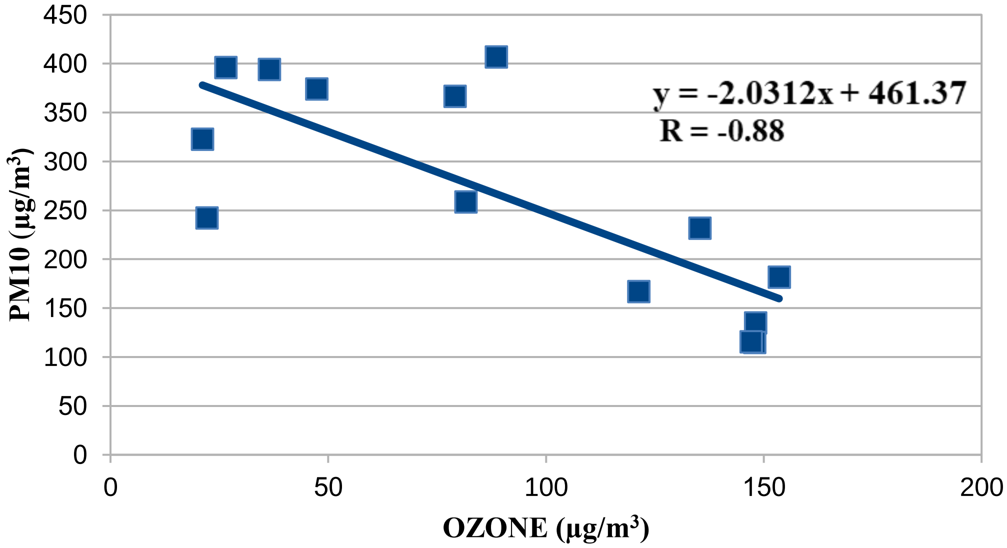
PM_{10} has the ability to change the level of energy consumption of the urban atmosphere through power of absorption and scattering. As PM_{10} is having the larger surface area, it can change the various properties like tropospheric gas chemistry of gaseous pollutants with the help of its reactions on the surface areas leading to the reduction in the kinetic rate of photolysis which results in resisting the production of ozone. Reduction of ozone can be due to heterogeneous actions on the Particulate Matter. Bonasoni et al., (2000) observed that there was reduction in ozone concentration in the atmosphere due to the settlement of coarse particles with air. As $PM_{2.5}$ reaches in more fine range particles, it start to show much better results with ozone.

During the study period of Diwali day, it was observed that PM_{10} and O_3 had given a strong negative correlation coefficient of - 0.88 through a linear relation shown in figure 4.5(b) and 4.6 (b). Because of the high PM_{10} levels, it has downgraded the solar radiation of the sun which was indenting on the earth's surface, which could weaken the production of ozone leading to the negative correlation of PM_{10} and ozone. Similarly, with $PM_{2.5}$ also which is also showing a strong negative correlation coefficient -0.94 more effective in reduction of ozone.

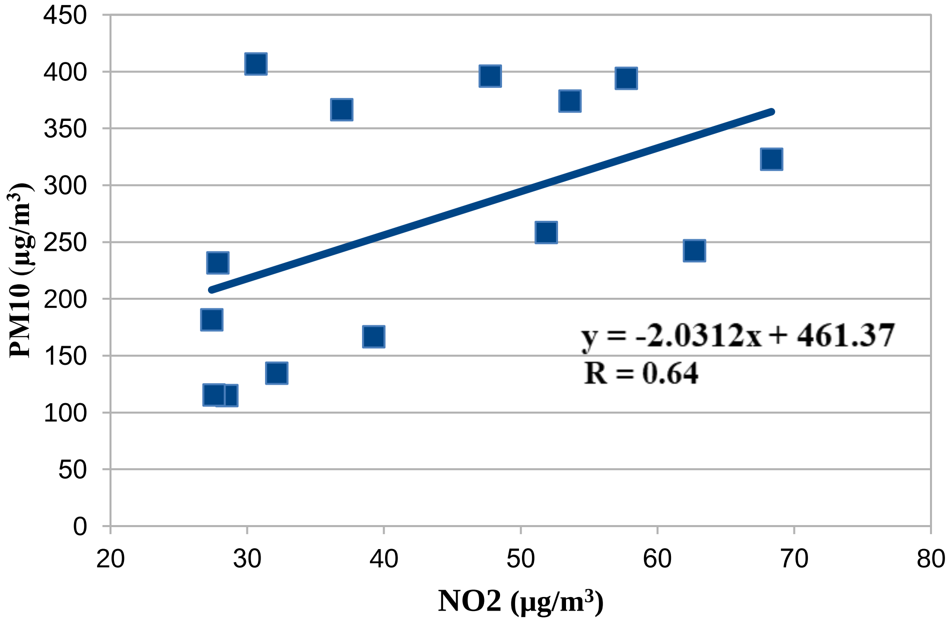
On the other hand, NO_2 gas accelerates in the lower layers of the earth's atmosphere because it is denser than air. NO_2 has significant impacts on Particulate matter as its having a tendency to change its atmospheric oxidation state to nitrates and also there is a production of CO from the decomposition of the Volatile organic compounds (VOCs). The correlation analysis was done for PM_{10} and $PM_{2.5}$ with O_3, NO_2, CO and SO_2 as shown in figures 4.5 and 4.6 respectively. Linear correlation of PM_{10} & NO_2 and $PM_{2.5}$ & NO_2 is shown in figures 4.5(c) and 4.6(c). Both parameters of particulate matter (PM_{10} & $PM_{2.5}$) showing a positive correlation coefficients with respect to NO_2 which are 0.64 and 0.79. Regression analysis in figures 4.5(a) and 4.6(a) show a good relationship with CO than NO_2. The regression plots on the graph shows increasing trend of Particulate matter with CO better than the increasing trend of NO_2. Though NO_2 is also having a somewhat good relation with particulate matter concentration. Both have a good linear relation with Particulate matter concentration. It's very interesting to know that the best correlation analysis of $PM_{2.5}$ mean concentrations with CO (r=0.81) and NO_2 (r=0.79) is somewhat higher than the correlation of PM_{10} with CO (r=0.66) and NO_2 (r=0.64). It shows that emission from the CO is accompanied by the emission of fine range of particulates. These results help us to know that these gaseous pollutants emitted highly from anthropogenic sources like fireworks bursting. Ozone is negatively more correlated with $PM_{2.5}$ (r= -0.94) than PM_{10} (r= -0.88).. SO_2 is showing a weak negative correlation coefficient factor with both the parameters of Particulate matter i.e. PM_{10} (r = -0.08) and $PM_{2.5}$ (r = -0.03) respectively. It shows that the production of mean concentration of SO_2 with particulate matter was almost negligible on that day. The mean concentration of NO_2 was 42.29µg/m^3 at DTU campus in Delhi. Gaseous pollutant NO_2 slightly exceeded the NAAQs standards given by CPCB (NO_2 = 40 µg/m^3) and also exceeded the WHO standard of NO_2 (40µg/m^3) leading to deterioration of urban air quality during Diwali festival.



PM10 vs OZONE
CORRELATION TREND
(b)



PM10 vs NO2
CORRELATION TREND (c)



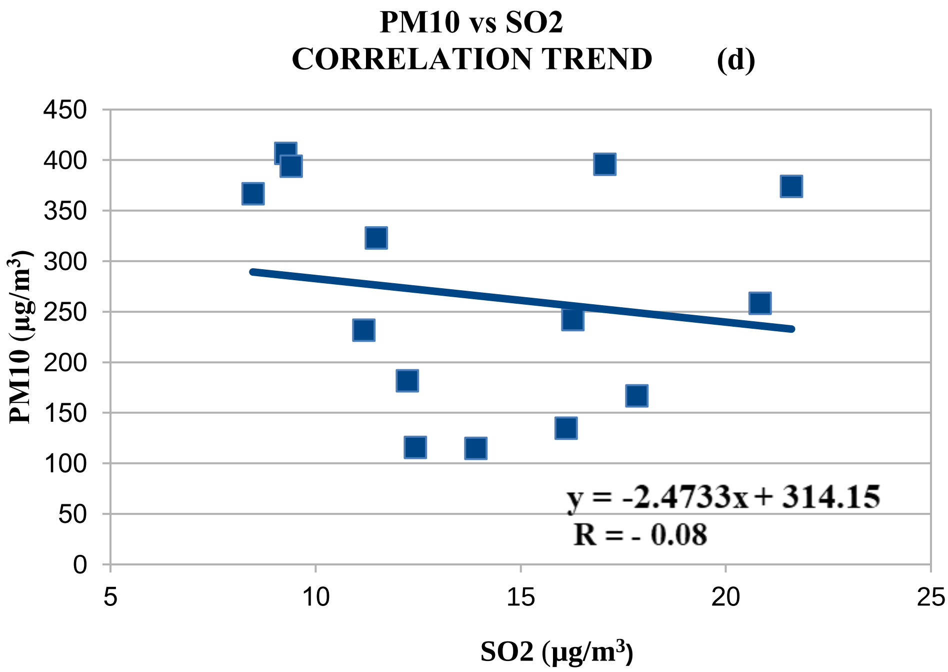
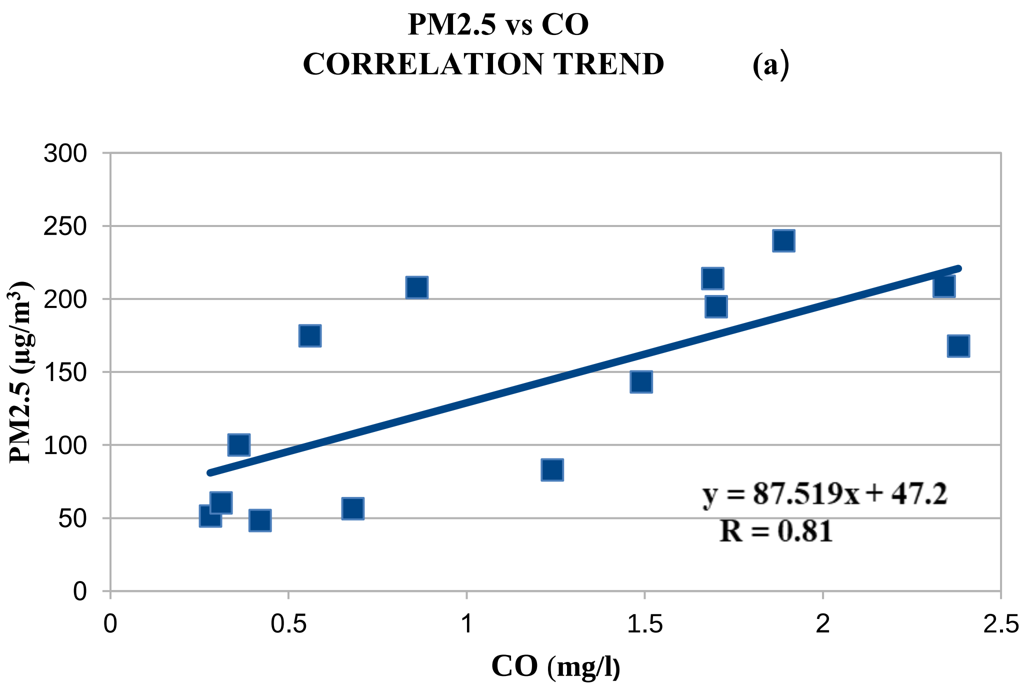
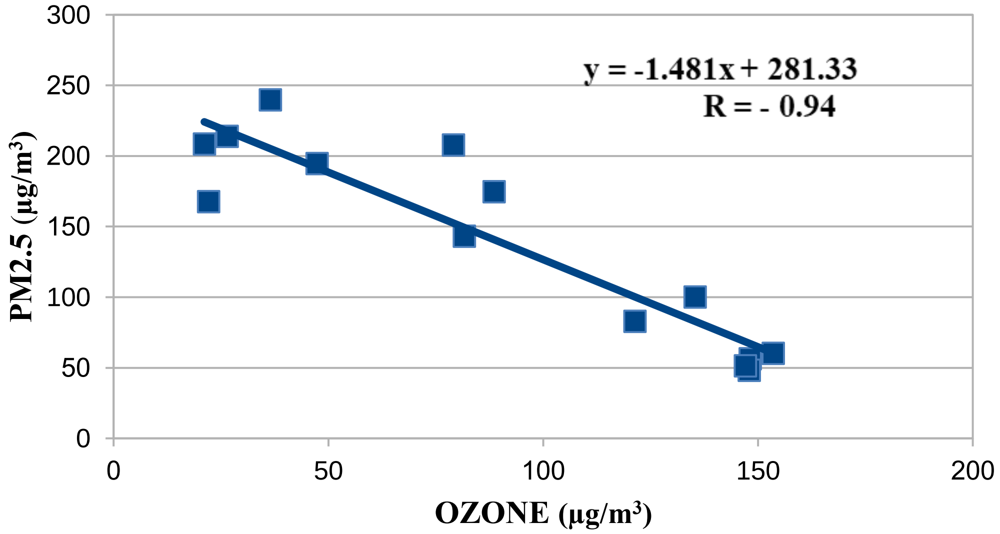


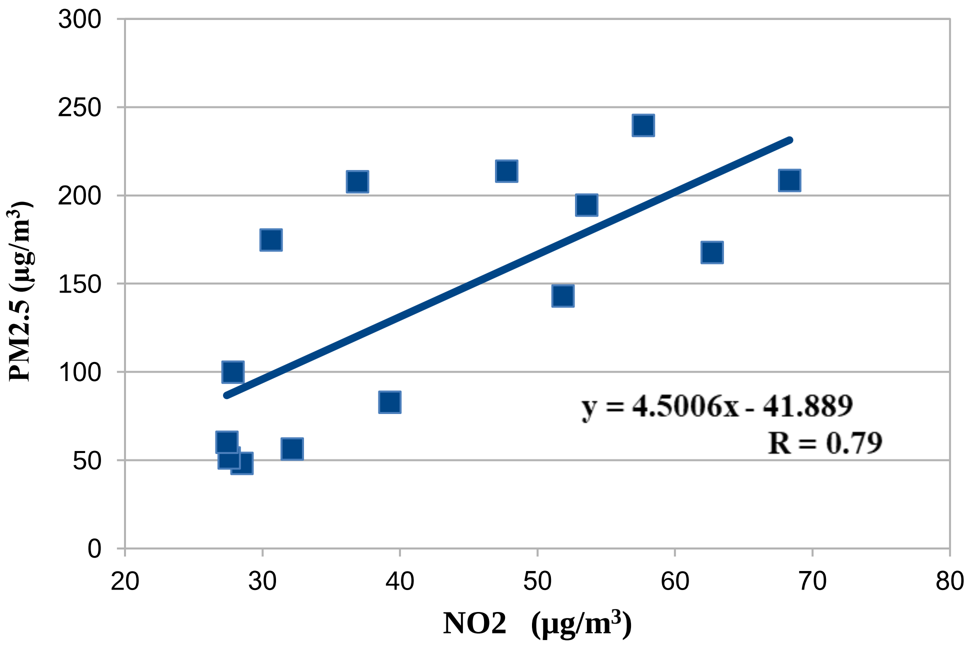
Figure 4.5 (a-d): Linear correlation analysis of PM_{10} and trace gases during Diwali day



PM2.5 vs OZONE
CORRELATION TREND (b)



PM2.5 vs NO2
CORRELATION TREND (c)



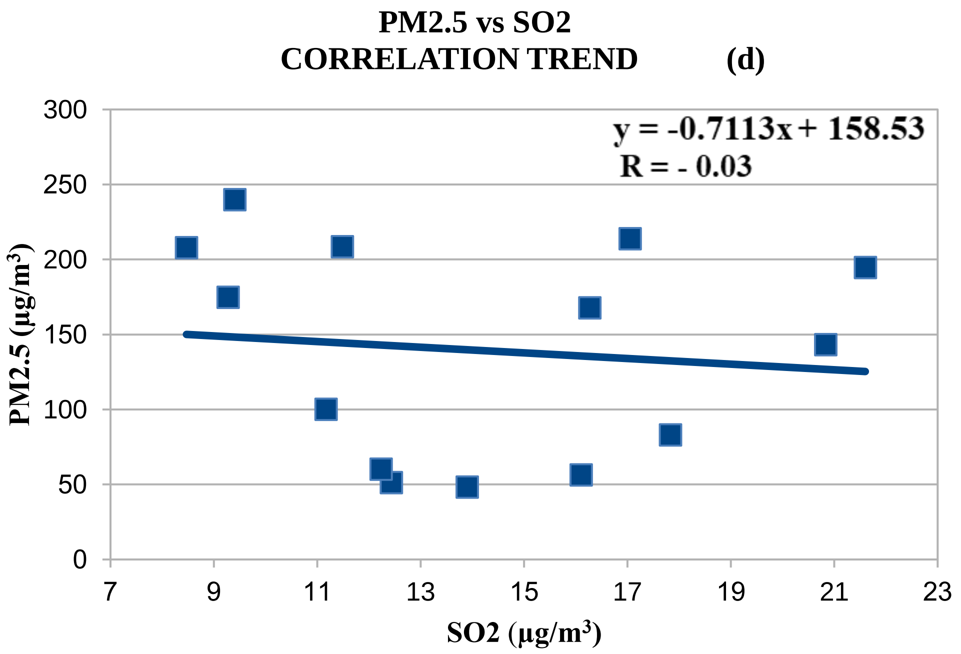
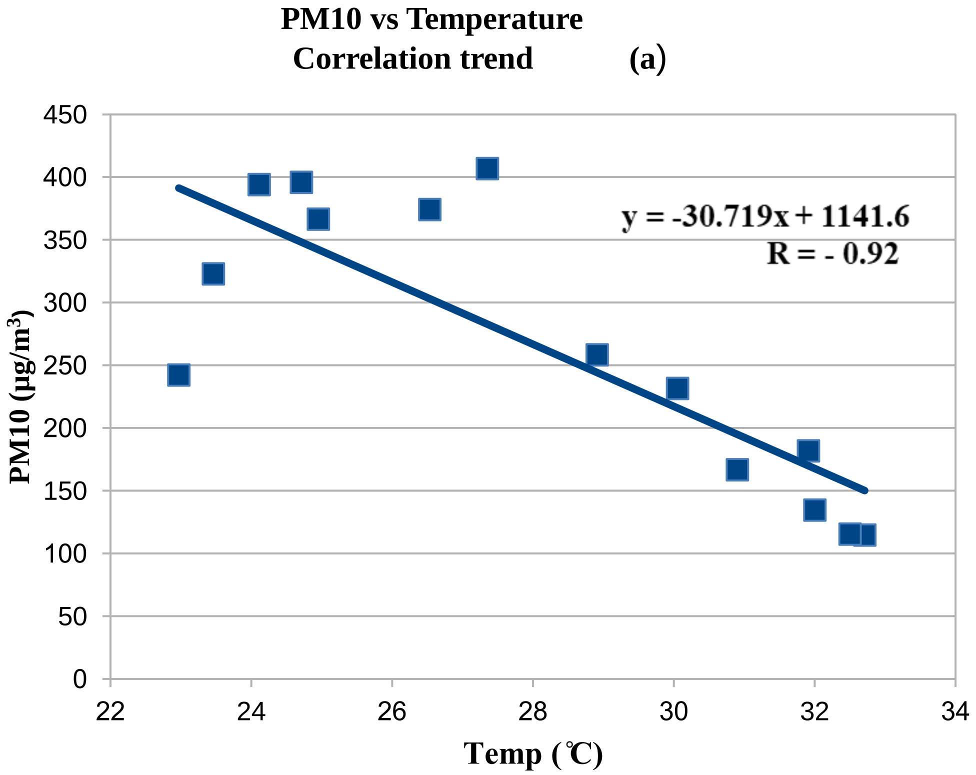
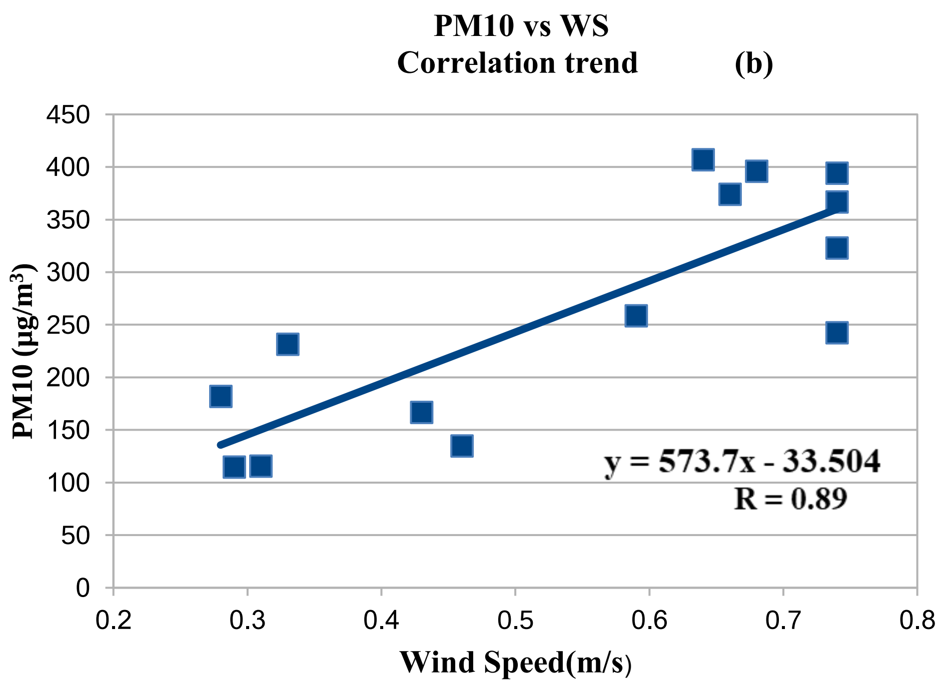


Figure 4.6 (a-d): Linear correlation analysis of $PM_{2.5}$ and trace gases during Diwali day

4.4 CORRELATION OF PM WITH METEOROLOGICAL PARAMETERES DURING DIWALI FESTIVAL

There is a major role of meteorological factors in pollutant dispersion. The factors are humidity, wind speed, temperature which plays a unique role in the pollutants concentration and their transportation in the urban atmosphere. If we talk about wind speed, it is having a control on air pollutants in the atmosphere. If the wind speed is low the pollutants will not move from its source place but at the same time high winds have the ability to transport different air pollutants from one place to other and mixing rapidly with the other gaseous pollutants with the air which may create a harmful and hectic environment. Humidity is basically the presence of moisture in the air. It binds the pollutants to the air. Each aerosol can get attracted to the pollutants with help of water in it. It becomes very difficult to remove the pollutants from the air and plus it comes down on the surface with the help of rain called Acid Rain. Coming on temperature, it is also having a major role in the formations and mixing of air pollutants. As in low temperature conditions, a lower layer is formed near to the earth's surface in which most of the pollutants gets trapped and not able to find the way to escape out. That layer is called Lateral Inversion. All secondary reactions are taking in that place like smog, fog, visibility etc. The ability of the meteorological parameters in hampering the different processes of atmosphere like dilution, transformation of the characteristics of the pollutants, their transportation and mixing have reported by various authors (Munir et al., 2017; Pearce et al., 2011; Dayan et al., 2002). We have performed linear regression analysis of Particulate Matter (PM_{10} & $PM_{2.5}$) with temperature, wind speed and Relative humidity (RH) on the festival day. While studying the observation, the sky was clear with some scattered clouds. The PM levels not only depend on their sources of emission but also on the meteorological parameters like boundary layer height, wind speed, temperature, relative humidity (Munir et al., 2017). In figure 4.7(a) & 4.8 (a), the observations shows that mean concentrations of PM_{10} and $PM_{2.5}$ both are strongly negative correlated with temperature (r= -0.92 & r= -0.97) respectively during the day of Diwali. As the temperature increases the PM concentration decreases. It gives us the relation that temperature and Particulate matter are inversely related to each other on this day. After completing an analysis Bathmanaban et al., (2010) states that the concentration of particulate matter increases during post-monsoon and winter season because of the more accumulation in the range of coarse and fine particulates. Here, $PM_{2.5}$ (Figure 4.8a) was showing better negative regression analysis than PM_{10}. If we talk of wind speed, it is showing strong positive correlation factor with both average concentration of PM_{10} and $PM_{2.5}$ on Diwali day with correlation factors of 0.89 & 0.92 respectively (Figure 4.7b and 4.8b). Comparatively with $PM_{2.5}$, it is showing better regression analysis High wind speeds leads to transfer and travelling of more particulate pollutants from one place to other from local regions to global regions scale and mixes them with particulate concentration already existing there through vertical and horizontal movement of the aerosols (Munir et al., 2017). Now, to study the effect of Relative humidity on PM_{10} and $PM_{2.5}$, we have made linear regression graphs between PM (μg/m^3) and RH (%) for the Diwali day (Figures 4.7c & 4.8c). RH is strongly positive correlated with PM_{10} and $PM_{2.5}$ with r = 0.88 and r = 0.96 respectively in figures 4.7(c) & 4.8 (c). The regression plots graph shows that higher the average RH, higher is the average Particulate matter concentrations (PM_{10} and $PM_{2.5}$) on that particular day. The effect of RH on PM also depends upon the types of particular aerosol sources like here main source was fireworks emission. Generally, during winter season in northern plains October-February, RH is mostly found in show higher percentage. Normally, RH depends upon atmospheric pressure and temperature. With the increase of RH, the particles with the water inside them changes their properties like water intake capacity, weight and volume intake of water. Due to more addition of the water content, it changes the physical structure of the particle by activating the particle chemistry to start. So high loading of PM levels with high RH levels will lead to formation of fog thus reducing the visibility. The regression analysis of $PM_{2.5}$ and RH was better positively correlated than PM_{10} shown as in figures (add any literature support). It also shows that how the effect of RH is varying from coarse to fine particles.





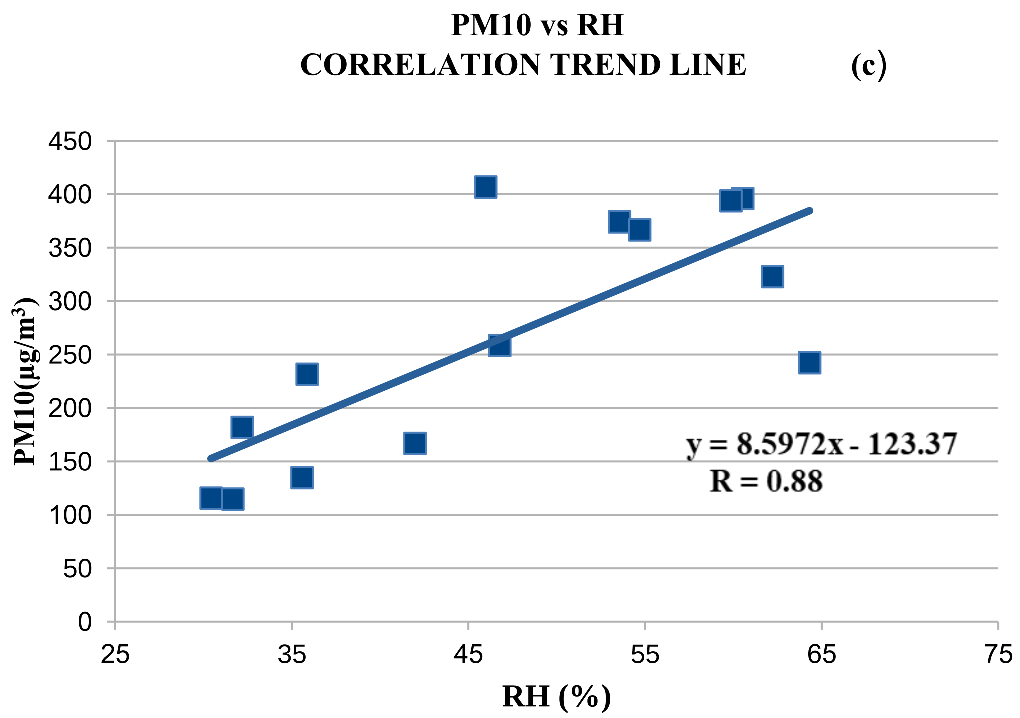
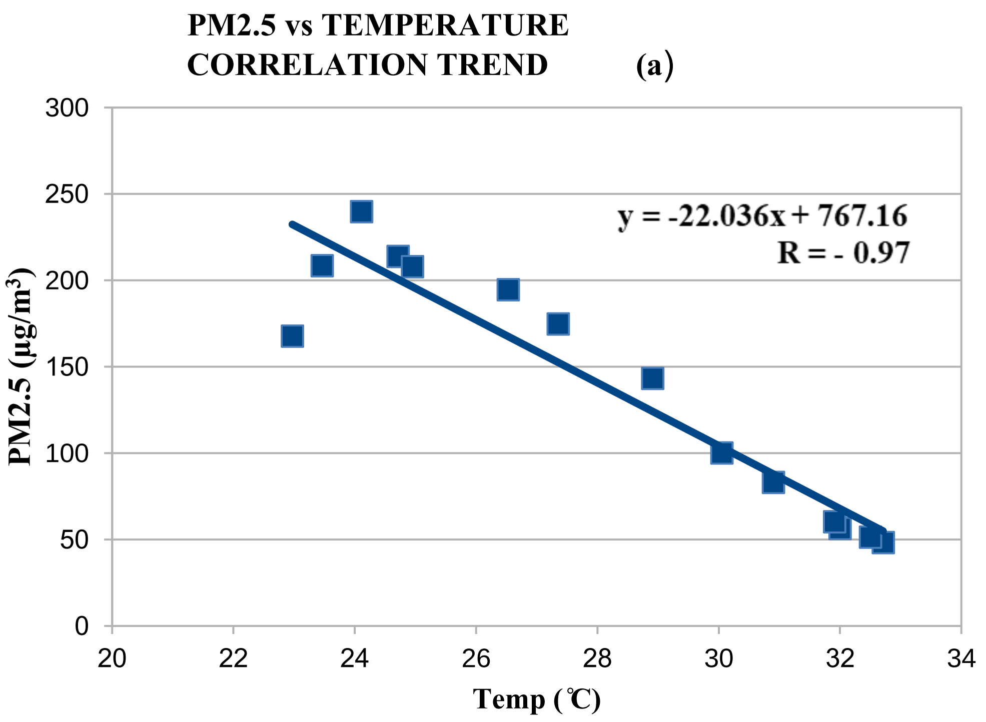
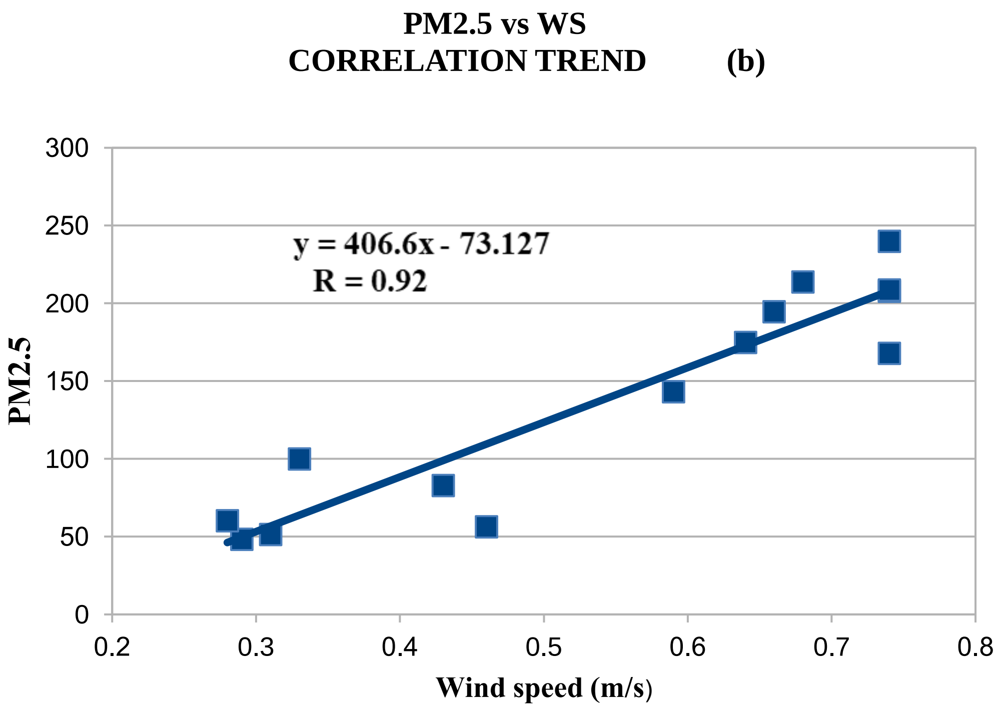


Figure 4.7 (a-c): Correlation between PM_{10} and temperature, wind speed and relative during Diwali day


PM2.5 vs TEMPERATURE
CORRELATION TREND (a)
y = -22.036x + 767.16
R = - 0.97
PM2.5 (µg/m3)
Temp (℃)
300
250
200
150
100
50
0
20
22
24
26
28
30
32
34


PM2.5 vs WS
CORRELATION TREND (b)
y = 406.6x - 73.127
R = 0.92
PM2.5
Wind speed (m/s)
300
250
200
150
100
50
0
0.2
0.3
0.4
0.5
0.6
0.7
0.8

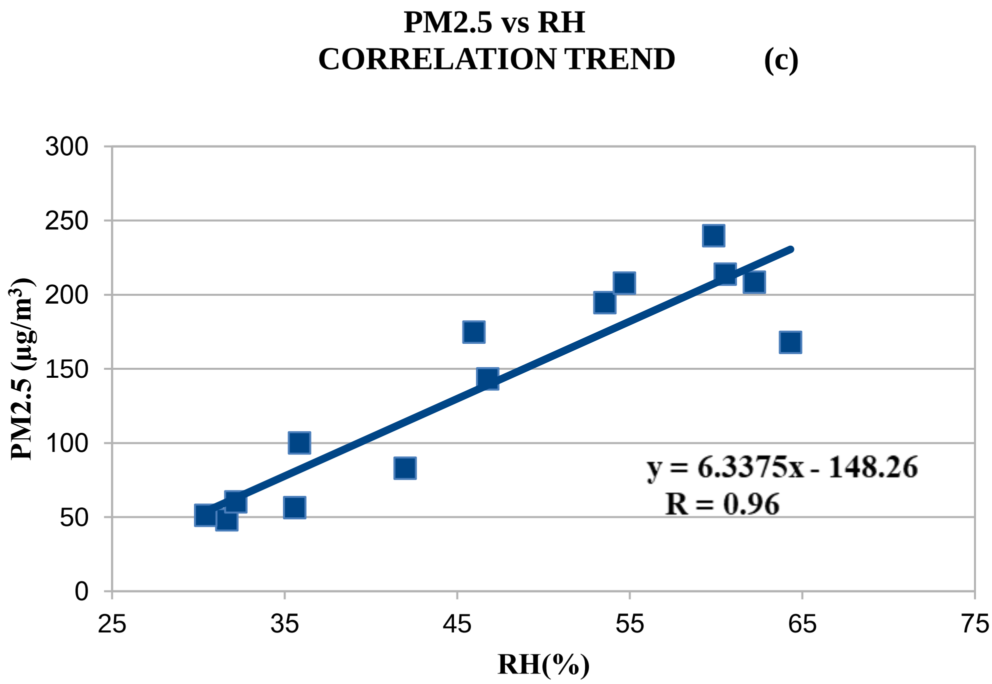


Figure 4.8 (a-c): Correlation between $PM_{2.5}$ and temperature, wind speed and Relative Humidity during Diwali day

4.5 CONTRIBUTION OF FIREWORKS IN $PM_{2.5}$

To estimate the contribution of fireworks bursting to $PM_{2.5}$ is very much helpful to understand the overall impact of the fireworks bursting during the festival duration. Wang et al. have made an appropriate method to estimate the contribution of $PM_{2.5}$ emissions due to fireworks bursting based on the mass ratio relation of $PM_{2.5}$ to CO (Wang et al., 2014). In our study, the following equation has been used to estimate the $PM_{2.5}$ contribution during the duration of Diwali festival in Delhi during the year of 2018 and 2019 of the 4 days monitoring.

$$PM^{f}_{2.5} = PM_{2.5} - PM^{nf}_{2.5} = PM_{2.5} - CO \times (PM_{2.5}/CO)_{nf} \tag{4.1}$$

Where $PM^{f}_{2.5}$ and $PM^{nf}_{2.5}$ are the concentrations of $PM_{2.5}$ related to emission of fireworks during the day of festival and non-fireworks activities during the festival respectively in (µg/m^3)

$PM_{2.5}$ and CO are the concentrations measured on the day of Diwali (µg/m^3).

$(PM_{2.5}/CO)_{nf}$ attributes to the ratio of the average concentrations of $PM_{2.5}$ and CO during the non-firework days (the average value of pre and post Diwali days)

Table 4.5: Mean concentration of $PM_{2.5}$ and CO during each day of study (2018)

Days	**During year 2018**	
	$PM_{2.5}$ (µg/m^3)	**CO (mg/m^3)**
5th November'18	376	2
6th November'18	196	1
7th November'18 (Diwali Day)	222	1
8th November'18	395	2

Source: *$PM_{2.5}$ and CO data taken from CPCB 2018*

Table 4.6: Mean concentration of $PM_{2.5}$ & CO during each day of study (2019)

Days	During year 2019	
	$PM_{2.5}$ (µg/m^3)	**CO (mg/m^3)**
25th October'19	129.62	2
26th October'19	139.35	1
27th October'19 (Diwali Day)	173.45	1
28th October'19	148.15	2

***Source**: CO data taken from CPCB 2019*

By using the above mentioned equation 4.1, we have calculated the contribution of fireworks in $PM_{2.5}$ pollutant concentration in the burning of fireworks during the year of 2018 and 2019 with the help of secondary data from CPCB (Central Pollution Control Board). In the year 2018, the contribution of $PM_{2.5}$ comes out to be 29 µg/m^3 and in 2019 it comes out to be 89.7 µg/m^3. So, from these concentrations it can be said that the contribution of fireworks in $PM_{2.5}$ during the Diwali festival was more in the year of 2019 then 2018.

4.6 SHORT-TERM HEALTH IMPACTS DISCUSSION DUE TO FIREWORKS

People who are living in the environment of air pollution can be attributed to the different health effects. If we talk about fireworks emission, there are many distinct types of health effects related to air pollution which also includes physical injuries like skin burning, eye damage and loss of eye sight etc. Very less information or study is there on the health effects of the fireworks bursting. Sometimes we heard news that due to mishandling of firecrackers the shop has caught fire or the people who were transporting them got injury like body burning and hearing loss. If we talk about the festivals in which fireworks burning takes place, then the people who are more in danger are young age people and children. These people are more prone to the effects caused by fireworks burning (Billock et al., 2017). At the time of firecrackers burning, old people can catch the problems like loss of hearing, mental stress due to so much of noise, hearing dysfunction etc. Poor visibility can also be the cause of this fireworks bursting. Mainly, the Particulate Matter concentration which is emitted by the fireworks emission have some unique health effects like lung related problems which includes cardiovascular and respiratory problems as one of the dangerous diseases (Franklin ., et al., 2015). People who are already having respiratory problems are very much prone to serious diseases caused by it like asthmatic patients. While in manufacturing of fireworks, some heavy metals are also added in it like Pb, Mg, Cd, Mn, Al, Ba etc for the purpose to add colours, coating them etc. But some of the heavy metals have very serious effects to the human beings like Manganese, Barium and Cadmium. The most important thing is that the short or acute exposures of these firecrackers burning from hours to days are very much connected to the significant health impacts. The effect of fireworks on targeting the people depends upon person to person like how a person is burning the fireworks and in what way plus with existing regional meteorological conditions. These all things change the rates of pollution emitted by them. In India, we use fireworks mainly on Diwali festival but similarly in other countries they have also some main festivals in which they also burn crackers like Chinese New Year in China, New Year’s Eve globally, Christmas in maximum countries etc.

CHAPTER -5

CONCLUSIONS

The concentration of particulate matter (PM_{10}, $PM_{2.5}$ & PM_1) were monitored for 4 consecutive days of the study during the celebration of Diwali in Delhi, India for assessing the impacts on particulate matter levels deteriorating the air quality of the city. According to that observation, it can be concluded that high PM_1 concentration levels are unanimously high even with more than the concentration levels of air quality standards of $PM_{2.5}$. This shows that with sudden burning of fireworks there has been an adequate amount of increment of the levels of $PM_{2.5}$. Extreme bursting of fireworks has led to the high ratios of PM_1 to $PM_{2.5}$ which shows that in overall concentration of particulate matter, majority of particles concentrations falls under PM_1. All the mean concentration of PM_{10} & $PM_{2.5}$ was found to be more than the NAAQS which are found as 100 and 60 $\mu g/m^3$ respectively. The SCI ruling of bursting Anar and Phuljari like green crackers was not found much effective. Strong positive correlation was observed of PM_{10} & $PM_{2.5}$ with the trace gases CO and NO_2. $PM_{2.5}$ showed best strong correlation with CO and NO_2 than PM_{10}. During the study period of Diwali day, it was observed that both PM_{10} and O_3 had given a strong negative correlation coefficient of -0.88, which may be due to less heterogeneous reactions. SO_2 showed weak negative correlation coefficient with both the parameters of particulate matter i.e. PM_{10} ($r = -0.08$) and $PM_{2.5}$ ($r = -0.03$) respectively. Statically significant positive correlation was found between Particulate matter and RH on Diwali day, which shows that influence of humidity is playing an important role in increasing the concentration of particulate matter. Increased levels of particulate matter may be attributing towards the loopholes in the policy of usage of green crackers and its implementation. PM_{10} & $PM_{2.5}$ are very much toxic to the patients suffering from respiratory diseases and cardiovascular problems in most of the polluted urban cities in the world because of dense traffic transport network and extreme pollution episodic events (like Diwali) in India.

REFERENCES

Amato, F., Lucarelli, F., Nava, S., Calzolai, G., Karanasiou, A., Colombi, C., Gianelle, V., Alves, C., Custódio, D., Eleftheriadis, K., et al., (2016). Atmospheric processes and health. In: Case Studies of Source Apportionment and Suggested Measures at Southern European Cities. *42*, pp. 168.

Ambade, B., (2018). The air pollution during Diwali festival by the burning of fireworks in Jamshedpur city, India. *Urban climate*, *26*, pp.149-160.

Barman, S.C., Singh, R., Negi, M.P.S. and Bhargava, S.K., (2008). Ambient air quality of Lucknow City (India) during usage of fireworks on Diwali Festival. *Environmental monitoring and assessment*, 137(1-3), pp. 495-504.

Barman, S.C., Singh, R., Negi, M.P.S. and Bhargava, S.K., (2008). Ambient air quality of Lucknow City (India) during use of fireworks on Diwali Festival. *Environmental monitoring and assessment*, *137*(1-3), pp.495-504.

Beig, G., Chate, D.M., Ghude, S.D., Ali, K., Satpute, T., Sahu, S.K., Parkhi, N. and Trimbake, H.K., (2013). Evaluating population exposure to environmental pollutants during Deepavali fireworks displays using air quality measurements of the SAFAR network. *Chemosphere*, *92*(1), pp.116-124.

Betha, R. and Balasubramanian, R., (2012). Particulate emissions from commercial handheld sparklers: evaluation of physical characteristics and emission rates. *Aerosol and Air Quality Research*, *13*(1), pp.301-307.

Billock, R.M., Chounthirath, T. and Smith, G.A., (2017). Pediatric firework-related injuries presenting to United States Emergency Departments, 1990-2014. *Clinical pediatrics, 56*(6), pp.535-544.

Bonasoni, P., Cristofanelli, P., Calzolari, F., Bonafe, U., Evangelisti, F., Stohl, A., Sajani, S.Z., Van Dingenen, R., Colombo, T. and Balkanski, Y., (2004). Aerosol-ozone correlations during dust transport episodes.

Boubel, R.W., Vallero, D., Fox, D.L., Turner, B. and Stern, A.C., (2013). *Fundamentals of air pollution*. Elsevier.

Chatterjee, A., Sarkar, C., Adak, A., Mukherjee, U., Ghosh, S.K. and Raha, S., (2013). Ambient air quality during Diwali Festival over Kolkata-a mega-city in India. *Aerosol and Air Quality Research*, *13*(3), pp.1133-1144.

Chen, Y., Wild, O., Conibear, L., Ran, L., He, J., Wang, L. and Wang, Y. (2020). Local characteristics of and exposure to fine particulate matter (PM2. 5) in four indian megacities. *Atmospheric Environment: X*, *5*, p.100052.

CT, Resmi, Satheesh Kumar MK, and Valsaraj KT. "Temporal Changes in Air Quality during a Festival Season in Kannur, India." *Atmosphere* 10, no. 3 (2019): 137.

Dayan, U. and Levy, I., (2002). Relationship between synoptic-scale atmospheric circulation and ozone concentrations over Israel. *Journal of Geophysical Research: Atmospheres*, *107*(D24), pp.ACL-31.

Dentener, F.J. and Crutzen, P.J., (1993). Reaction of N2O5 on tropospheric aerosols: Impact on the global distributions of NO x, O3, and OH. *Journal of Geophysical Research: Atmospheres*, *98*(D4), pp.7149-7163.

Dey, P., (2016). Diwali: A smog-mare for the Indian capital. *South Asia@ LSE*.

Devara, P.C., Vijayakumar, K., Safai, P.D., Made, P.R. and Rao, P.S., (2015). Celebration-induced air quality over a tropical urban station, Pune, India. *Atmospheric Pollution Research*, *6*(3), pp.511-520.

Dickerson, R.R., Kondragunta, S., Stenchikov, G., Civerolo, K.L., Doddridge, B.G. and Holben, B.N., (1997). The impact of aerosols on solar ultraviolet radiation and photochemical smog. *science*, *278*(5339), pp.827-830.

Firdaus, G. and Ahmad, A., (2011). Indoor air pollution and self-reported diseases–a case study of NCT of Delhi. *Indoor Air*, *21*(5), pp.410-416.

Galea, A. and Powles, O., (2010). A review of firework legislation and acute health effects. *Chemical Hazards and Poisons Report*, pp.32-36.

Gautam, S., Yadav, A., Pillarisetti, A., Smith, K. and Arora, N., (2018), March. Short-Term Introduction of Air Pollutants from Fireworks During Diwali in Rural Palwal, Haryana, India: A Case Study. In *IOP Conference Series Earth and Environmental Science* (pp. 1755-1315).

Ghei, D. and Sane, R., (2018). Estimates of air pollution in Delhi from the burning of firecrackers during the festival of Diwali. *PloS one*, *13*(8), p.e0200371.

Habil, M., Massey, D.D. and Taneja, A., (2016). Personal and ambient PM2. 5 exposure assessment in the city of Agra. *Data in brief*, *6*, pp.495-502.

Hirai, K., Yamazaki, Y., Okada, K., FURUTA, S. and KUBO, K., (2000). Acute eosinophilic pneumonia associated with smoke from fireworks. *Internal medicine*, *39*(5), pp.401-403.

Hutton, G., Rehfuess, E. and Tediosi, F., (2007). Evaluation of the costs and benefits of interventions to reduce indoor air pollution. *Energy for Sustainable Development*, *11*(4), pp.34-43.

Instruments, S (2005). "FIREWORKS The Fireworks Regulations 2004," *Interpret. A J. Bible Theol.*, vol. 11, no. 1836, pp. 1–10.

Kong, S.F., Li, L., Li, X.X., Yin, Y., Chen, K., Liu, D.T., Yuan, L., Zhang, Y.J., Shan, Y.P. and Ji, Y.Q., (2015). The impacts of firework burning at the Chinese Spring Festival on air quality: insights of tracers, source evolution and aging processes. *Atmos. Chem. Phys*, *15*(4), pp.2167-2184.

Kumar, M., Singh, R.K., Murari, V., Singh, A.K., Singh, R.S. and Banerjee, T., (2016). Fireworks induced particle pollution: a spatio-temporal analysis. *Atmospheric research*, *180*, pp.78-91.

Kumar, N., Midday, A., Rao, S.P. and Kadu, S. (2017). festival of light comparative study of pollutants with meteorology on ambient air of a central urban site nagpur during two successsive years. *Journal of Earth and Environmental Sciences*.

Mandal, P., Prakash, M. and Bassin, J.K., (2012). Impact of Diwali celebrations on urban air and noise quality in Delhi City, India. *Environmental monitoring and assessment*, *184*(1), pp.209-215.

Mao, M., Zhang, X. and Yin, Y., (2018). Particulate matter and gaseous pollutions in three metropolises along the Chinese Yangtze River: Situation and Implications. *International journal of environmental research and public health*, *15*(6), p.1102.

Munir, S., (2016). Analysing temporal trends in the ratios of PM2. 5/PM10 in the UK. *Aerosol and Air Quality Research*, *17*(1), pp.34-48.

Nigam, S., Kumar, N., Mandal, N.K., Padma, B. and Rao, S., (2016). Real time ambient air quality status during diwali festival in central, India. *Journal of Geoscience and Environment Protection*, *4*(01), p.162.

Parkhi, N., Chate, D., Ghude, S.D., Peshin, S., Mahajan, A., Srinivas, R., Surendran, D., Ali, K., Singh, S., Trimbake, H. and Beig, G., (2016). Large inter annual variation in air quality during the annual festival 'Diwali'in an Indian megacity. *Journal of Environmental Sciences*, *43*, pp.265-272.

Pathak, B., Bharali, C., Biswas, J. and Bhuyan, P.K., (2013). Firework induced large increase in trace gases and black carbon at Dibrugarh, India. *Journal of Earth Science and Engineering*, *3*(8), p.540.

Pearce, J.L., Beringer, J., Nicholls, N., Hyndman, R.J., Uotila, P. and Tapper, N.J., (2011). Investigating the influence of synoptic-scale meteorology on air quality using self-organizing maps and generalized additive modelling. *Atmospheric Environment*, *45*(1), pp.128-136.

Perrino, C., Tiwari, S., Catrambone, M., Dalla Torre, S., Rantica, E. and Canepari, S., (2011). Chemical characterization of atmospheric PM in Delhi, India, during different periods of the year including Diwali festival. *Atmospheric Pollution Research*, *2*(4), pp.418-427.

Prospero, J.M., Schmitt, R., Cuevas, E., Savoie, D.L., Graustein, W.C., Turekian, K.K., Volz-Thomas, A., Diaz, A., Oltmans, S.J. and Levy, H., (1995). Temporal variability of summer-time ozone and aerosols in the free troposphere over the eastern North Atlantic. *Geophysical research letters, 22*(21), pp.2925-2928.

Ramalho, O., Mandin, C., Ribéron, J. and Wyart, G., (2013). Air stuffiness and air exchange rate in French schools and day-care centres. *International Journal of ventilation, 12*(2), pp.175-180.

Road, V.V and Four,E. "Cat . No . 500-100 Performance Pro fi le," no. 500, pp. 8–11.

Seidel, D.J. and Birnbaum, A.N., (2015). Effects of Independence Day fireworks on atmospheric concentrations of fine particulate matter in the United States. *Atmospheric Environment*, *115*, pp.192-198.

Service,M.P and Intervention, E,, *Fireworks Act 2003 Fireworks Act 2003*, vol. 22, no. 2. 2003.

Singh, A., Pant, P. and Pope, F.D., (2019). Air quality during and after festivals: Aerosol concentrations, composition and health effects. *Atmospheric Research*, *227*, pp.220-232

.

Singh, D.P., Gadi, R., Mandal, T.K., Dixit, C.K., Singh, K., Saud, T., Singh, N. and Gupta, P.K., (2010). Study of temporal variation in ambient air quality during Diwali festival in India. *Environmental monitoring and assessment*, *169*(1-4), pp.1-13.

Smith, K.R., (2000). National burden of disease in India from indoor air pollution. *Proceedings of the National Academy of Sciences*, *97*(24), pp.13286-13293.

Sokolik, I.N. and Toon, O.B., (1996). Direct radiative forcing by anthropogenic airborne mineral aerosols. *Nature*, *381*(6584), pp.681-683.

Statista, “India - share of Delhi’s annual household income 2015 | Statistic,” 2019.[Online].Available:https://www.statista.com/statistics/658909/share-of-annual-income-in-delhi-india/. [Accessed: 01-May-2019].

Tiwari, S., Chate, D.M., Srivastava, M.K., Safai, P.D., Srivastava, A.K., Bisht, D.S. and Padmanabhamurty, B., (2012). Statistical evaluation of PM 10 and distribution of PM 1, PM 2.5, and PM 10 in ambient air due to extreme fireworks episodes (Deepawali festivals) in megacity Delhi. *Natural hazards*, *61*(2), pp.521-531.

Tiwari, S., Bisht, D.S., Srivastava, A.K., Shivashankara, G.P. and Kumar, R., (2013). Interannual and intraseasonal variability in fine mode particles over Delhi: influence of meteorology. *Advances in Meteorology*, *2013*.

Thurston, G.D., Ito, K. and Lall, R., (2011). A source apportionment of US fine particulate matter air pollution. *Atmospheric environment*, *45*(24), pp.3924-3936

.

Verma, C. and Deshmukh, D.K., (2014). The ambient air and noise quality in India during Diwali festival: A review. *Recent Research in Science and Technology*.

Viana, M., Kuhlbusch, T.A., Querol, X., Alastuey, A., Harrison, R.M., Hopke, P.K., Winiwarter, W., Vallius, M., Szidat, S., Prévôt, A.S. and Hueglin, C., (2008). Source apportionment of particulate matter in Europe: a review of methods and results. *Journal of aerosol science*, *39*(10), pp.827-849.

Wen, P. and Thomas,S. (2018). “China’s millennium-old fireworks hub grapples with bans and shifting traditions - Reuters,” *Reuters*.

Worecasting, F., “Air Quality during Diwali-(2016) National Capital Territory of Delhi (NCT) Delhi University -HIGHEST Polluted NOIDA Mathura road Palam Pusa Loadhi road Aya Nagar – LEAST Polluted AIR QUALITY INDEX (AQI) – Overall DELHI-NCT,” pp. 1–4, (2016).

Xu, G., Jiao, L., Zhang, B., Zhao, S., Yuan, M., Gu, Y., Liu, J. and Tang, X., (2016). Spatial and temporal variability of the PM2. 5/PM10 ratio in Wuhan, Central China. *Aerosol and Air Quality Research*, *17*(3), pp.741-751.

You, M.L., Shu, C.M., Chen, W.T. and Shyu, M.L., (2017). Analysis of cardinal grey relational grade and grey entropy on achievement of air pollution reduction by evaluating air quality trend in Japan. *Journal of cleaner production*, *142*, pp.3883-3889.

Zalakeviciute, R., López-Villada, J. and Rybarczyk, Y., (2018). Contrasted effects of relative humidity and precipitation on urban PM2. 5 pollution in high elevation urban areas. *Sustainability*, *10*(6), p.2064.

Zhao, D., Chen, H., Yu, E. and Luo, T., (2019). PM2. 5/PM10 Ratios in Eight Economic Regions and Their Relationship with Meteorology in China. *Advances in Meteorology*.